PUBLIC VERSION

March 2017

US TRADE AND DEVELOPMENT AGENCY

South Africa Energy Storage Technology and Market Assessment

PARSONS

Order Number: TDA-IE201511210

USTDA Activity Number: 2015-11032A

Parsons Job Number: 640368

This report was funded by the U.S. Trade and Development Agency (USTDA), an agency of the U.S. Government. The opinions, findings, conclusions, or recommendations expressed in this document are those of the author(s) and do not necessarily represent the official position or policies of USTDA. USTDA makes no representation about, nor does it accept responsibility for, the accuracy or completeness of the information contained in this report.

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All reports referenced in this document are posted to a Parsons SharePoint site for review. The Due Diligence Matrix (DDM) is the index to this site. Please contact Paul Frink of Parsons at paul.frink@parsons.com for access to this site.

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1 Introduction

South Africa's existing electricity infrastructure is insufficient to meet demand, which has resulted at times in load shedding (planned rolling blackouts), excessive use of diesel to run peaking plants (as well as for baseload capacity), and billions of dollars in lost business. Significant further expenditure will be required in the years ahead to bring new generation sources online (coal, hydroelectric, and renewable), to upgrade the transmission grid, to address the electricity distribution maintenance backlog, to upgrade an aging fleet of coal-fired power stations for environmental compliance, and to replace those stations reaching end of life. It has been suggested that the adoption of energy storage technologies could provide a cost-effective way of improving South Africa's electric grid. Specifically, the adoption of energy storage could offset the need to use diesel and other fossil fuels for peaking and baseload power, provide backup power for commercial and industrial operations during blackouts, and increase the capacity of South Africa's electric grid to successfully integrate renewable electricity generation sources, especially intermittent power sources such as solar and wind.

As a state-owned development finance institution, the Industrial Development Corporation of South Africa Limited (IDC) is interested in evaluating the potential of energy storage technologies to increase access to reliable, affordable electricity in South Africa, encouraging policies to support the adoption of energy storage technologies, and exploring opportunities to invest in energy storage projects. IDC is currently leading a steering committee – which also includes the South African Photovoltaic Industry Association (SAPVIA), the South African Wind Energy Association (SAWEA), the South African National Energy Development Institute (SANEDI), Council for Scientific and Industrial Research (CSIR), Eskom Research, Independent Power Producer (IPP) Office, Energy Intensive Users Group (EIUG), South Africa Department of Science and Technology (DSI), and South Africa Department of Trade and Industry (dti) – to help guide and promote the adoption of energy storage technologies in South Africa. The steering committee is working closely with the South African Department of Energy (SADOE), Eskom (South Africa's national electricity utility), the National Energy Regulator of South Africa (NERSA), as well as other key stakeholders.

The objective of the South Africa Energy Storage Technology and Market Assessment was to provide advisory services to the IDC and Steering Committee that will help guide and promote the adoption of energy storage technologies in South Africa. This effort included market research; technical, economic and financing assessments; development, environmental, and legal/regulatory assessments; and a roadmap that recommended steps, milestones and timelines for the adoption of energy storage technologies in South Africa through 2030. Although the advisory services provide some information related to residential, commercial, and industrial energy storage technologies, the focus of the advisory services has been on utility-scale (over 1 megawatt) energy storage technologies.

This report documents the completion and results of the Suth Africa Energy Storage Technology and Market Assessment and consists of a compilation of the documents and deliverables submitted during the conduct of Objectives 1 through 7.

Kickoff, Market Research, & Needs Assessment

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ACRONYMS

BAU	business as usual
CAES	Compressed Air Energy Storage
COR	Contracting Officer’s Representative
CSIR	Council for Scientific and Industrial Research
CSP	Concentrating Solar Power
DST	South Africa Department of Science and Technology
dti	South Africa Department of Trade and Industry
EIUG	Energy Intensive Users Group
IDC	Industrial Development Corporation
IPP	Independent Power Producer
NDA	Non-Disclosure Agreement
NERSA	National Energy Regulator of South Africa
PHS	Pumped Hydro Storage
PSC	Project Steering Committee
REIPP	Renwable Energy Independent Power Producer
SADOE	South African Department of Energy
SANEDI	South African National Energy Development Institute
SAPVIA	South African Photovoltaic Industry Association
SAWEA	South African Wind Energy Association
TOU	time-of-use
UPS	Uninterrupted Power Supplies

2 Task 1.1 – Kick-off Meetings

2.1 USTDA Kick-off Meeting

Following notice of award in late September 2015, Parsons executed the USTDA's standard Non-Disclosure Agreement (NDA). Parsons also contacted Michael DeRenzo, USTDA Country Manager and Contracting Officer's Representative (COR) and scheduled a Kick-off Meeting in Pasadena at Parsons Corporate Offices on Tuesday, September 29, 2016. During that meeting Michael DeRenzo was present. Garth Hibbert, USTDA Contracting Officer; Jacob Flewelling, USTDA Africa Business Development Manager; and Kendra Kintzi, USTDA Program Evaluation Office participated concurrently in the meeting via teleconference. The kick-off meeting covered the following topics:

I. Welcome and Introductions
II. Contract Administration, Roles and Responsibilities
III. Overview of the Statement of Work
IV. Overview of the Scope of Work
V. USTDA Program Evaluations
VI. Proposed Schedule / Next Steps
    a. Introduction and Kick-off Meeting with IDC

2.2 IDC and Steering Committee Kick-off

Following USTDA kick-off, key members of the Parsons Team traveled to South Africa to hold a kick-off meeting with the project beneficiary, Industrial Development Corporation of South Africa (IDC) and the Steering Committee members. An initial kick-off meeting was held on Monday, October 26, 2015 to review, discuss, and refine the overall Assessment strategy, the scope and objectives, and deliverables to be provided. The Parsons Team made a formal presentation that introduced team members, their companies, and assigned roles and responsibilities on the Assessment. The presentation also introduced the proposed approach and methodology for each Assessment objective and task as directed by the USTDA Statement of Work and proposed in the Parsons proposal. The Parsons presentation is included as Appendix A. The Parsons Team also presented an initial schedule for completion of the Assessment (Appendix B). It was mentioned that Parsons had proposed an aggressive schedule that would complete the Assessment in approximately the first year of the two-year period of performance, with many of the deliverables being submitted in the first seven months. Satisfaction of this schedule would be dependent to a large degree on the availability and detail of data and information necessary to complete the Assessment. Additional meetings and consultations were held between the Parsons Team, Steering Committee Members, and Stakeholders through the remainder of the week. These meetings took place in Sandton, Pretoria, and Cape Town in South Africa and in Stellenbosch, South Africa at Stellenbosch University. A list of the individual meetings, attendees, and summary findings are included as Appendix C.

3 Task 1.2 – Market Research and Needs Assessment

3.1 Market Research

3.1.1 Available Information

During the course of this project, the Parsons Team has collected current and recent information and data relating generally to Energy Storage and specifically to South Africa's needs and requirements. Identification and collection of this data began at the initial kick-off meeting. Each data/information source has been assigned an index number and entered into the Project Reference Matrix maintained on the Parsons Project SharePoint site. A copy of each source is also maintained on the SharePoint Site. All Parsons Team members have access to the SharePoint Reference site so that these documents can be consistently referenced in Parsons deliverables. There are currently over 240 data sources in the Parsons Reference Matrix for this project. This list of documents is included as Appendix D.

3.1.2 Stakeholder Consultations

The Parsons Team's Market Research included a series of consultations with Steering Committee Members and other relevant Stakeholders. Some of these meetings occurred during the week following the IDC/Steering Committee Kick-off Meeting. Other meetings have been held as needed via teleconference. Finally, several additional face-to-face meetings have been held between Stakeholders and host country team members, and with other Parsons Team Members who have traveled back to South Africa since the Kick-off. Meeting summaries from the initial consultations are included in Appendix C. Additionally, during this period, the Parsons Team has contacted numerous U.S. and South African energy storage equipment and services suppliers as well as potential financiers for energy storage projects in South Africa. Parsons has consulted with relevant Stakeholders, including SAPVIA, SAWEA, SANEDI, SADOE, Eskom and NERSA as well as other U.S. and international energy storage companies and organizations.

3.2 Needs Assessment

South Africa has a number of challenges related to operation, maintenance, development, and expansion of its electric utility grid. The first step in this Assessment is to identify the uses and benefits that energy storage could provide in meeting the challenges faced by South Africa.

According to the Energy Storage Association, an application of energy storage to meet a given objective would be considered a "use", whereas a "benefit" would connote an associated value, especially quantifiable financial value. A benefit derived from an energy storage use might take the form of either an avoided cost or additional revenue received by the storage owner/operator. The gross benefit derived from an energy storage use would be the total amount saved/received. The net benefit – or value – would be the gross benefit minus cost to implement the use. This Assessment explores what energy storage technologies could be employed against specific uses, and in which times frames in order to generate net positive benefits more favorable than non-storage alternatives.

3.2.1 Energy Storage Use Cases

Energy storage is the capture of energy produced at one time for use at a later time. Energy storage involves converting energy from forms that are difficult to store to more convenient or economical storage forms. The number of services or "benefits" that energy storage can provide and the definitions of those services have been defined differently by various organizations. This study has chosen to align its definitions with that of CSIR [0016].

Accordingly, there are three main energy storage use cases that can be of interest to South Africa as defined by the Project Steering Committee (PSC):

- Power-to-Power
- Power-to-Gas/Liquid
- Power-to-Heat

In this study only the first case, power-to-power, will be considered. The relevant technologies are therefore the storage of available electrical energy, in the form of electricity, as mechanical, electro-mechanical or chemical energy, in a form that can later be efficiently converted back to electricity. Therefore only storage systems for use cases that provide for electricity-in then electricity-out are considered. In the following table the main use cases of such storage are defined. The study used the defined use cases to investigate the role of energy storage in the South African context.

Table 3-1 – Selected Relevant South Africa Use Cases

Area	Use / Main Purpose	Range
Bulk Energy Services	• Time-shifting of electric energy (arbitrage) • Schedulable capacity • Re-dispatch ("> 15-minute reserves")	100MW+ 600MWh+ Minutes & Hours
Ancillary Services	• Frequency support (reserves) • Voltage support (reactive power) • Bottleneck management (congestion relief / N-1) • Black-start capability	1 – 10 MW+ 3 – 50 MWh+ Seconds & Minutes
Grid Infrastructure Services	• Transmission upgrade deferral • Distribution upgrade deferral	10MW+ 60MWh+ Hours up to Days
Customer Energy Management Services	• Power quality • Power reliability (security of supply) • Energy-charge management (arbitrage) • Demand-charge management (peak shaving) • Island and off-grid	3kW – 100MW 10kWh – 500MWh Seconds, Minutes & Hours

There are specific benefits that energy storage can provide to facilitate the integration of variable renewable energy sources (PV and wind), however, each of these also fit into the more general definitions provided in Table 3-1.

The following use cases were explicitly excluded from the study because these are generally addressed through user/consumer products or are integrated into a system/component for a specific purpose.

- Uninterrupted Power Supplies (UPS) for a variety of applications
- Back-up power for a variety of grid support and protection systems

The following table briefly summarizes how energy storage can be used to serve each aspect of the Use Cases.

Table 3-2 – Descriptions of Selected Use Case Benefits

Role	Purpose / Benefit	Description
Bulk Energy Services	Time-shifting of electric energy (arbitrage)	Energy is stored at times of the day when electricity is in less demand and therefore less valuable (typically during nighttime hours) to allow the subsequent production and sale of electricity to the market at peak times when it is more valuable.
	Schedulable Capacity	Stored energy is used to meet generation requirements during peak electricity-consumption hours allowing grid operators and utilities to meet demand while incrementally deferring or reducing the need for new generation capacity.
	Re-dispatch (> 15 min reserves)	Stored energy is used to serve load immediately in response to an unexpected contingency event, such as an unplanned generation outage or increased demand for periods longer than 15 minutes.
Ancillary Services	Frequency Support	Provide immediate and automatic response of power to reconcile momentary differences caused by fluctuations in generation and loads to avoid system-level frequency spikes or dips.
	Voltage Support	Power conditioning (management of reactance caused by grid-connected equipment) to ensure system voltage is maintained within an acceptable range. Ensures that both real and reactive power production are matched with demand.
	Bottleneck Management / Congestion Relief	Energy storage is deployed downstream of congested transmission corridors to allow for discharge during periods of congestion and reduce congestion in the transmission system.
	Black-start Capability	Stored energy is used to reenergize power lines necessary to restore operation to power stations and to bring the regional grid back online in the event of an outage.
Grid Infrastructure Services	Transmission Upgrade Deferral	Energy storage is used to delay, reduce the size of, or entirely avoid, utility investments in transmission system upgrades which would otherwise be necessary to meet projected load growth on specific regions of the grid.
	Distribution Upgrade Deferral	Energy storage is used to delay, reduce the size of, or entirely avoid, utility investments in distribution system upgrades which would otherwise be necessary to meet projected load growth on specific regions of the grid.
Customer Energy Management Services	Power Quality	Energy storage allows power conditioning to ensure an acceptable quality of electrical power in the event of unstable or poor quality grid power including short-term voltage spikes or dips, frequency variations, low power factor, or momentary service interruption.
	Power Reliability	Energy storage provides a source of backup power when there is a total loss of power from the source utility. This requires islanding during the utility outage and resynchronization with the utility when power is restored.
	Energy Charge Management (arbitrage)	Use of energy storage to minimize electricity purchases during peak electricity consumption hours when time-of-use (TOU) rates are highest and shifting these purchases to periods of lower rates.
	Demand Charge Management (peak shaving)	Electricity storage used by end users (i.e., utility customers) to reduce overall costs for electric service by reducing their demand (and resultant demand charges for maximum load) during peak periods specified by the utility.

	Island and Off-Grid	Energy storage paired with a local generation or renewable energy sources provide power during extended grid outages or in areas outside of utility service.

3.2.2 Energy Storage Needs

Based on the "power-to-power" Use Cases developed earlier, a preliminary needs assessment was conducted for the short (1-5 years), medium (6-10 years) and long-term (11-15 years) for the various market sectors (residential, commercial, industrial, utility). This needs assessment included a business as usual (BAU) scenario as well as a high scenario for South Africa's energy storage needs based on different assumptions for growth in electricity demand, investments in various types of new electricity generation capacity, and investments in smart grid infrastructure.

This report is based on the assessment of a number of key experts in the field, and the outcome of this assessment will be compared to the outcomes of the modeling exercise.

3.3 Methodology

A questionnaire was developed in Excel and sent to selected South African energy experts. Participants were assured of anonymity and asked to complete the form in their individual capacity based on their experience and knowledge of the system, and not as an official view of their employer, should such a view exist.

The questionnaire listed the previously developed Use Cases, the market segments and short, medium and long time frames for a BAU (business as usual) and a growth scenario. The experts were asked to give a weighting of the need for each category (Not applicable = 1; Low need = 2; Medium need = 3; High need = 4).

3.4 Results

Completed forms were received from nine key individuals that included academics, researchers, consultants and engineers. Further comments from participants who did not complete the fillable forms are shown as follows:

Respondent 1: "Storage is important for all players, especially given the increasing unreliability of our grid, the fact that RE is the cheapest newbuild and that any baseload after Kusile is 10-12 years away (with lots of existing capacity falling off the cliff in that time). In my perception, the benefit is greatest at the common (grid level) and dissipates as it goes down the chain to smaller end users. In time, as costs decrease, the benefit will become greater to all players and probably in the same order as mentioned above."

Respondent 2: "I am afraid we do not have any information on any of this. This is the kind of information I would hope to be able to gain/work out based on the outcomes of the study. The only space we have considered energy storage is on the arbitrage front, and in our current case we have seen there is no need as the cost is too high. Hopefully, the outcomes of the study will be able to inform price trajectories, business cases and thus will lead to good understanding of what demand would be. From the utilities we have worked with, none of these cases have been investigated at all, and guidance on what makes sense to look at is what is being asked for. This list of use cases alone is probably more in-depth than much of the work that has been done."

Respondent 3: "I am unable to complete it but would provide the following thoughts:

- Energy storage in the context of a deep gold mine would primarily be to avoid peak period power costs, especially in winter tariff periods.
- A secondary function will be to minimize the impact of load curtailment."

The completed forms were then collated and the mode (the value that is most likely to be selected by all respondents) was calculated. The result of this is shown in the tables on the next pages, with the key as follows:

Key	
Not applicable	1
Low need	2
Medium need	3
High need	4

Table 3-3 -- BAU Scenario: Bulk Energy Services

	Bulk Energy Services								
	Time-shifting of Electric Energy (Arbitrage) 100MW+ 600MWh+ Minutes & Hours			Schedulable Capacity 100MW+ 600MWh+ Minutes & Hours			Re-dispatch (">15-Minute Reserves") 100MW+ 600MWh+ Minutes & Hours		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	1	1	1	1	1	1	1	1	1
Commercial	1	1	1	1	1	1	1	1	1
Industrial	2	3	1	2	1	1	1	1	1
Utility	3	3	4	2	3	4	2	3	3

Table 3-4 -- Growth Scenario: Bulk Energy Services

	Bulk Energy Services								
	Time-shifting of Electric Energy (Arbitrage) 100MW+ 600MWh+ Minutes & Hours			Schedulable Capacity 100MW+ 600MWh+ Minutes & Hours			Re-dispatch (">15-Minute Reserves") 100MW+ 600MWh+ Minutes & Hours		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	1	1	1	1	1	1	1	1	1
Commercial	1	1	1	1	1	1	1	1	1
Industrial	1	3	4	1	3	3	1	1	1
Utility	4	3	4	4	3	4	3	4	4

Table 3-5 -- BAU Scenario: Ancillary Services

	Ancillary Services											
	Frequency Support (Reserves)			Voltage Support (Reactive Power)			Bottleneck Management (Congestion Relief / N-1)			Black-Start Capability		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	1	1	1	1	3	1	1	1	1	2	1	1
Utility	3	3	2	2	2	2	2	2	3	2	2	2

Table 3-6 -- Growth Scenario: Ancillary Services

	Ancillary Services											
	Frequency Support (Reserves)			Voltage Support (Reactive Power)			Bottleneck Management (Congestion Relief / N-1)			Black-Start Capability		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	1	1	1	1	1	1	1	1	1	1	1	1
Commercial	1	1	1	1	1	1	1	1	1	1	1	1
Industrial	2	1	1	2	3	1	2	1	1	2	1	2
Utility	4	3	3	3	3	4	3	3	3	4	4	4

Table 3-7 -- BAU Scenario: Grid Infrastructure Services

	Grid Infrastructure Services					
	Transmission Upgrade Deferral			Distribution Upgrade Deferral		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	1	1	1	1	1	1
Commercial	1	1	1	1	1	1
Industrial	1	1	1	1	1	1
Utility	2	2	2	3	3	3

Table 3-8 -- Growth Scenario: Grid Infrastructure Services

	Grid Infrastructure Services					
	Transmission Upgrade Deferral			Distribution Upgrade Deferral		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	1	1	1	1	1	1
Commercial	1	1	1	1	1	1
Industrial	1	1	1	1	1	1
Utility	2	2	2	2	4	4

Table 3-9 -- BAU Scenario: Customer Energy Management Services

	Customer Energy Management Services														
	Power Quality			Power Reliability (Security of Supply)			Energy-charge Management (Arbitrage)			Demand-charge Management (Peak Shaving)			Island and Off-grid		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	2	2	2	2	3	2	1	2	1	1	1	1	3	3	4
Commercial	2	3	3	3	3	3	2	2	3	3	3	3	2	3	3
Industrial	2	3	2	3	3	3	2	2	2	3	3	3	2	2	4
Utility	2	3	3	2	2	2	1	1	1	1	1	1	1	1	1

Table 3-10 -- Growth Scenario: Customer Energy Management Services

	Customer Energy Management Services														
	Power Quality			Power Reliability (Security of Supply)			Energy-charge Management (Arbitrage)			Demand-charge Management (Peak Shaving)			Island and Off-grid		
	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)	Short-Term (1-5 Years)	Medium-Term (6-10 Years)	Long-Term (11-15 Years)
Residential	2	2	2	2	3	2	1	1	1	1	1	1	3	4	4
Commercial	2	3	2	3	4	4	2	3	3	3	3	3	3	3	4
Industrial	2	3	2	3	3	4	2	3	4	3	3	3	4	4	4
Utility	3	3	3	4	1	1	1	1	1	1	1	1	1	1	1

3.5 CONCLUSION

From the feedback of the specialists the following key Use Cases were identified as the most important at this time:

Short-Term (1-5 years):

- Time-shifting of energy, arbitrage, by the utility in the growth scenario
- Schedulable capacity by the utility in the growth scenario
- Reserves for frequency support by the utility in the growth scenario
- Black-start capability by the utility in the growth scenario
- Power reliability, security of supply, by the utility in the growth scenario

Medium-Term (6-10 years):

- Re-dispatch by the utility in the growth scenario
- Black-start capability by the utility in the growth scenario
- Distribution upgrade deferral by the utility in the growth scenario
- Power reliability, security of supply, by commercial customers in the growth scenario
- Island and off-grid by residential and industrial customers in the growth scenario

Long-Term (11-15 years):

- Time-shifting of energy, arbitrage, by the utility in both scenarios
- Time-shifting of energy, arbitrage, by industry in the growth scenario
- Schedulable capacity by the utility in both scenarios
- Re-dispatch by the utility in the growth scenario
- Reactive power for voltage support by the utility in the growth scenario
- Black-start capability by the utility in the growth scenario
- Distribution upgrade deferral by the utility in the growth scenario
- Power reliability, security of supply, by industrial and commercial customers in the growth scenario
- Energy charge management, arbitrage, by industrial customers in the growth scenario
- Island and off-grid by residential and industrial customers in both scenarios
- Island and off-grid by commercial customers in the growth scenario

3.5.1 SELECTED UTILITY-SCALE ENERGY STORAGE TECHNOLOGIES

In accordance with Task 1.2 “Market Research and Needs Assessment” of the South Africa Energy Storage Technology and Market Assessment, the Parsons Team evaluated the spectrum of potential utility-scale energy storage technologies that might be effectively applied in South Africa. These included existing commercially available technologies as well as technologies currently under development or in the demonstration or pilot phase. These technologies will be carried forward for detailed evaluation under Task 2.1 “Technology Assessment”. During this exercise, existing and developing energy storage technologies were considered and selected based on the following criteria:

1. Technologies suited for the performance requirements of the selected Use Cases, including cycle time (duration), response time, and range of power requirements.
2. Current maturity, commercial availability, or demonstrated potential to become a mature and economically viable technology within the time frame of this assessment (15 years).
3. Operating characteristics favorable to the South African environment (moderate to hot, relatively arid climate).
4. Technology-specific manufacturing or operational characteristics favorable to the RSA industries or economic growth (beneficiation of natural resources or existing industrial expertise).

With regard to the required performance necessary to support the selected Use Cases shown in Table 3.1, extremely long cycle durations supporting seasonal and inter-seasonal applications are not required. The selected Use Cases point to the need for daily cycles of up to about 12 hours for Bulk Energy Services such as arbitrage, schedulable capacity, and for Grid infrastructure Services such as transmission and distribution upgrade deferral. Use cycles in the order of seconds and minutes are required to support applications of Ancillary Services such as Congestion Management, Voltage Regulation, and Renewable Integration. Some of the short to medium duration Use Cases, like frequency and voltage regulation, also require a response time in the order of milliseconds. A selected technology is not required to support all Use Cases, however, its optimal operating range should cover as many as possible.

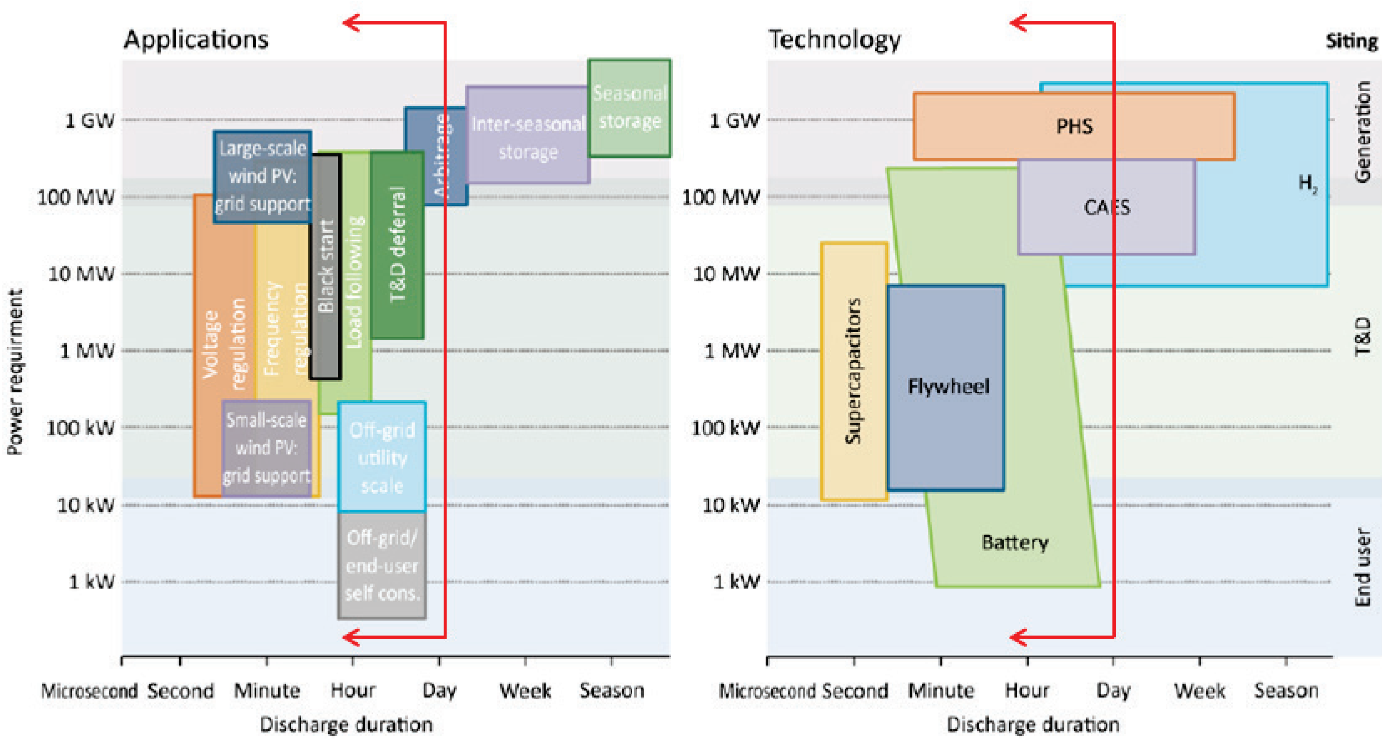

Figure 3-1 – Technologies and Uses Cases compared to Power and Discharge Duration (red line shows discharge duration applicable to this study)

Mechanical energy storage technologies typically include:

- Pumped Hydro Storage (PHS)
- Compressed Air Energy Storage (CAES)
- Flywheels

Pumped Hydro is specifically excluded from the scope of this study and this includes large-scale reservoir-type PHS. South Africa already has three large PHS systems (Steenbras, Palmiet and Drakensberg); one has been commissioned (Ingula) and another PHS project (Steelpoort) has been developed for implementation but has been put on hold due to budget constraints. The current PHS facilities and possible construction of the next PHS facility will be modeled under this study; however, large reservoir PHS technology will not be an evaluated technology under this study. The potential for high-head PHS to be installed in unused/abandoned mineshafts will be considered initially based on the availability and somewhat geographical diversity of mine shafts in South Africa.

The use of large reservoir CAES in underground caverns, caves, salt domes, and oil wells is not considered particularly relevant to this study because these types of geological features are relatively few in South Africa. However, this study will evaluate large reservoir CAES as well as the application of smaller micro-CAES based on tanks or smaller underground features. It will also look at advanced-CAES to determine the maturity and developmental timeframe for those applications.

Lastly, flywheels will be considered for fast response, short duration Use Case applications such as frequency and voltage regulation and renewable smoothing.

Electro-chemical energy storage technologies will consider battery-type applications including conventional, high-temperature, and flow batteries. Based on the low cost and demonstrated maturity of lead acid technology, this study will assess lead acid and in particular will consider advanced lead acid applications and their potential for increased performance and reduced cost. The study will also consider lithium battery technologies based on their demonstrated longevity, performance, and moderate cost. Advanced lithium applications are also expected to achieve increased performance and reduced costs within the time frame of this study. Other battery technologies such as NiCd and NiMh will be discussed and evaluated for relevancy.

This study will evaluate existing high-temperature molten salt battery technologies such as NaS and Na-NiCl2. Additionally, the study will evaluate liquid metal batteries such as Mg-Sb and Li-Sb/Pb, which are still in development but have strong potential.

This study will evaluate Redox Flow batteries based on their flexibility, long life, and promised future economic advantages. Of particular interest is the Vanadium Redox technology based on the beneficiation of Vanadium resources in the RSA. An additional promising technology is a Zinc-flow battery which, while still relatively early in development, offers potentially the lowest CAPEX and Life Cycle costs.

Electrical Energy Storage Technologies include technologies where electrical energy is stored without a chemical reaction. These typically include capacitors and superconductors. Capacitors (super-capacitors, ultra-capacitors) are reasonably mature, fast-response, and high-cycle devices that are promising for short-duration, fast-response applications such as frequency or voltage regulation. They could also be combined with slower response, medium duration technologies to provide a more robust hybrid application for Use Cases such as Ancillary Services or Renewable Integration. Superconductors are excluded based on the current costs and maturity of the technology.

Chemical Energy Storage Technologies are typically not Power-to-Power applications. The collection of methane gas for combustion or reaction in a fuel cell is a Fuel-to-Power application while the electrolysis of water to produce hydrogen and oxygen is a Power-to-Fuel/Gas process. The electrolysis of hydrogen as a fuel supply for vehicles or other engines is a viable technology for South Africa based on the beneficiation of platinum resources in the country. This study will evaluate regenerative fuel cells and the specific application of a hydrolysis unit combined with a hydrogen fuel cell since this would represent an “electricity in-electricity out” or Power-to-Power application.

Thermal Energy Storage Technologies such as Molten Salt and Chillers (cold-water reservoirs) will not be evaluated in this study because they generally represent Power-to-Thermal or Thermal-to-Power technologies which are not within the scope of this study. Modeling within this study will include projections of CSP facilities with molten salt storage to be constructed within the RSA, however, these will be considered dispatchable generation facilities rather than storage facilities.

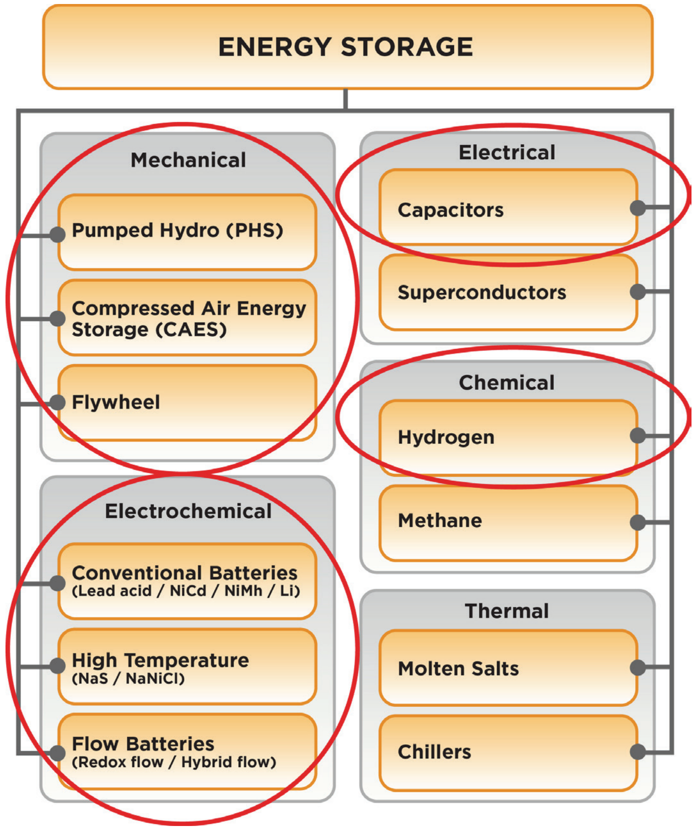

Figure 3-2 – General Technology Categories retained for Evaluation

The following is an initial short list of selected technologies to be forwarded to Task 2.1 for evaluation:

1. Pumped Hydro Storage (PHS) for High Heads
2. Compressed Air Energy Storage (CAES) large reservoir (although not preferred technology) and micro/tank and advanced applications
3. Electrochemical Batteries
    a. Lead Acid and Advanced Lead Acid
    b. Lithium ion, NiCd, NiMH-based Batteries
    c. High Temperature (NaS, Na-$NiCl_2$, Mg/PB-Sb)
    d. Flow Batteries (VRFB, Zn-Fe, Zn-Br)
4. Flywheels
5. Capacitors
6. Electrolysis and Fuel Cells

As these technologies are initially evaluated under that task, one or more may be dropped from further consideration. Additionally, a technology may also be added if additional information provides a basis for further evaluation and inclusion.

Technology Assessment

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ACRONYMS

AA-CAES	advanced adiabatic compressed energy storage
AC	alternating current
AEP	American Electric Power
AGM	Absorbant glass mat
AHI	aqueous hybrid ion
ALA	advanced lead acid
ALABC	Advanced Lead Acid Battery Consortium
ALC	advanced lead carbon
ARPA-E	Advanced Research Projects Agency-Energy
ARRA	American Recovery and Reinvestment Act
BAU	business as usual
BESS	Battery Energy Storage System
CAES	compressed air energy storage
CES	Community Energy System
CES	cryogenic energy storage
CHP	combined heat and power
CO_2	carbon dioxide
CoC	Center of Competence
COR	Contracting Officer's Representative
CSIR	Council for Scientific and Industrial Research
DC	direct current
DoD	depth of discharge
EC	electrochemical capacitor
emf	electromotive force
EPRI	Electric Power Research Institute
ESS	energy storage system
EV	electric vehicle
FeCr	iron chromium
FESS	flywheel energy storage system
GCAES	General Compression Advanced Energy System
GDP	gross domestic product
GE	General Electric
GVEA	Golden Valley Electric Association
GWh	gigawatt-hour
H_2	hydrogen
H_2SO_4	sulfuric acid
HEV	hybrid electric vehicle
HVAC	heating, ventilation, and air conditioning
HySA	Hydrogen South Africa
ICAES	isothermal compressed air energy storage
IDC	Industrial Development Corporation

IPP	independent power producer
kW	kilowatt
LAES	liquid air energy storage
LCO	lithium cobalt oxide
LFP	lithium iron phosphate
Li	lithium
Li-ion	lithium ion
LMO	lithium manganese oxide
LTO	lithium titanate oxide
MIT	Massachusetts Institute of Technology
MW	megawatt
MWh	megawatt-hour
NaS	sodium sulfur
NASA	National Aeronautics and Space Administration
NERSA	National Energy Regulator of South Africa
NCA	lithium cobalt aluminum oxide
NGK	NGK Insulators, Ltd.
NGO	non-government organization
Ni	nickel
NiCd	nickel cadmium
$NiCl_2$	nickel chloride
NMC	lithium nickel cobalt
O&M	operations and maintenance
Pb	lead
PbO_2	lead dioxide
$PbSO_4$	lead sulfate
PCC	power control and conditioning
PEM	proton exchange membrane
PEMFC	proton exchange membrane fuel cell
PHS	pumped hydro storage
PJM	Pennsylvania New Jersey Maryland Interconnection (Regional Transmission Organization in the Eastern United States)
PNNL	Pacific Northwest National Laboratory
PSC	project steering committee
P-V	pressure volume
PV	photovoltaic
PVC	polyvinyl chloride
R&D	research and development
RAES	regenerative air energy storage
REIPPPP	Renewable Energy Independent Power Producer Procurement Program

RFB	redox flow battery
RTE	round trip efficiency
SA	South Africa
SG	specific gravity
SoC	state of charge
SOFC	solid oxide fuel cell
T&D	transmission and distribution
TOU	time of use
UET	UniEnergy Technologies
UPS	uninterruptible power supply
URFC	unitized regenerative fuel cell
USDOE	United States Department of Energy
USTDA	U.S. Trade and Development Agency
V	volt
V_2O_5	vanadium pentoxide
VAR	Undefined in Appendix A.4, page A-13
VLA	vented lead acid
VRFB	vanadium redox flow battery
VRLA	valve regulated lead acid
ZEBRA	Zeolite Battery Research Africa
Zn-Br	zinc bromine

1 Introduction

This document provides the results of the Task 2.1 "Technology Assessment" of Objective 2 "Technology, Economic, and Financing Assessments" performed in support of the overall USTDA South Africa Energy Storage Technology and Market Assessment effort.

1.1 APPROACH

Section 2 of this report provides an overview and summary of the energy storage technologies selected for evaluation under Task 1.2 "Market Research and Needs Assessment." A more detailed evaluation of each considered technology is provided in Appendix A.

Section 3 of this report provides a summary of United States and South African (SA) Energy Storage equipment, systems, and service suppliers that responded to an initial survey and subsequently provided company information and product data for inclusion in this report. Detailed profiles on each company are included in Appendix B.

Section 4 of this report provides a summary of additional thoughts and comments contributed by more than 15 energy storage suppliers that expressed an interest in supplying goods and services to the energy storage market in SA.

2 Energy Storage Technology Assessment

This section provides a high-level summary for each energy storage technology identified under Task 1.2. These are believed to represent utility-scale energy storage technologies that may be suitable for the South African environment, particularly in conjunction with solar photovoltaic (PV) and wind power plants. A more detailed discussion for each technology is included in Appendix A.

2.1 PERFORMANCE

Table 2-1 summarizes the performance parameters for each technology; Table 2-2 provides a qualitative comparison. These values and opinions are taken from manufacturer's data, industry literature and reports [Ref. 0079, 0221, 0229, 0239, 0240, 0241, 0245, 0252, 0300, and 0370][1]. Values are provided as a range that in some cases are fairly broad. This spread of range is due to increased performance over time as a result of technology advances or differences in chemistry or manufacturing and should be taken as general. Products from companies with recent technology advances will tend to lie closer to the higher performance end of the spectrum. Although estimates are presented in this report, cost statistics in particular should be viewed with care because they are difficult to assess objectively. This is due to the current lack of defined standards and approaches by which companies provide cost and performance data including lack of reference duty cycles and the environmental conditions under which testing is performed [0079].

[1] References are provided in Appendix C.

Table 2-1: Comparison of Energy Storage Technologies

Technology	Self-Discharge (%/day)	Life (years)	Cycles	Max. Depth of Discharge	Power Density (kWm^3)	Energy Density (kWhm^3)	Round Trip Efficiency (1)	Typical Discharge Time	Response Time	Cost Power (2)($/kW)	Cost Energy (2) ($/kwh)
Lead-Acid Battery	0.1-0.3	3-15	500-1,800	50%	90-700	50-80	70-90%	sec-hours	ms	300-600	50-400
Advanced Lead Acid Battery	0.1-0.3	5-15	2,200-4,500	100%	90-700	50-80	75-90%	min-hours	ms	300-600	425-1,150
Nickel-Cadmium Battery	0.2-0.6	15-20	800-3,500	80%	80-600	60-150	60-80%	sec-hours	ms	500-1,500	800-1,500
Lithium Ion Battery	0.1-5	10-20	300-20,000	80%	1,500-10,000	250-620	92 -97%	sec-hours	ms	175-4,000	200-3,800
Sodium Sulfur Battery	20%	12-20	2,500-4,500	90%	140-180	150-300	75-90%	sec-hours	ms	1,000-3,000	300-500
Sodium Nickel Chloride	15%	12-20	>2,500	80%	220-300	150-200	85-90%	sec-hours	ms	150-300	100-200
Vanadium Redox Flow	small	10-20	>2x10^4	100%	<2	16-35	60-85%	sec-10hours	ms	500-1,500	150-1,000
Iron-Chromium Flow	small	10-20	1-1.5x10^4	100%	<25	30-65	70-80%	sec-10hours	ms	1,200-1,900	300-400
Zinc-Bromine Flow	small	10-20	1-1.5x10^4	100%	<25	30-65	65-80%	sec-10hours	ms	600-2,500	150-1,000
Flywheel	100%	15-20	10^6	100%	1,000-2,000	20-80	90-95%	sec-min	ms	850-2,000	1,000-14,000
Supercapacitors	20-40%	>20	5x10^5	75%	40,000-120,000	10-30	90-97%	ms-min	ms	100-300	300-2,000
CAES Adiabatic - cavern	small	25-40	1-3x10^4	80-100%	0.5-2	2-6	60-70%	hours-days	1-15min	400-1,000	2-50
CAES Tank Storage	very small	20+	>1x10^4	80-100%	> large CAES	> large CAES	~70%	min-hours	sec-min	1,000-1,5000	100-300
Hydrogen Fuel Cell	almost zero	5-15	2x10^4	100%	500-3,000	500+	30-45%	min-hours	ms	10,000+	>10,000
Liquid Metal	almost zero	10-20	2,700	100%	TBD	TBD	80%	min-hours	ms	TBD	TBD
Liquid Air	small	30+	2x10^4	80-100%	TBD	TBD	50-70%	hours	2-5 min	900-1,900	260-530

Notes:
(1) Round Trip Efficiency (RTE) is generally expressed for the DC-DC RTE of the underlying technology.
(2) Cost ($/kW or $/kWh) is generally expressed as the cost for the manufactured ESS units rather than installed project cost

Table 2-2: Comparison of Energy Storage Technologies

Technology	Maturity	Risks/Barriers	Disadvantages	Advantages	Best Applications **	Future potential for SA utility-scale energy storage
Lead-Acid Battery	mature	environmental consideration	• low cycle life and DoD • Deteriorates with microcycles • limited lifetime	• Very mature technology • Low capital cost	**CEMS**	none
Advanced Lead Acid Battery	mature	environmental consideration	Low cycle life and limited DoD	• Better performance than lead-acid • Capital cost relatively low	**AS, GIS, CEMS**	Moderate-, near-, to mid-term
Nickel-Cadmium Battery	mature	environmental - toxic cadmium	• Low cycle life • Exhibits memory effect • low energy-to-weight • Relatively expensive	• Few maintenance requirements • Can operate in low temperatures	CEMS	none
Lithium Ion Battery (chemistry dependent)	commercial	• Safety - thermal runaway • More expensive than Lead-Acid	• limited but improving cycle life • Deep discharge cycles lower lifetime • Requires monitoring / BMS	• high round trip efficiency • high energy-to-weight ratio • continuing performance improvements • continuing manufacturing cost reductions	**BES, AS,** GIS, **CEMS**	Significant near- to long-term
Sodium Sulfur Battery	mature	• Safety - containment issues • Competition from other technologies	• limited cycle life • requires external heat system • high temperature system • large daily self-discharge	• high power and energy density • Longer discharge times than Li-ion	**BES, AS, GIS**, CEMS	Moderate near-term
Sodium Nickel Chloride	commercial	Competition from other technologies	Large daily self-discharge	Able to operate in relatively harsh climates	CEMS	limited
Vanadium Redox Flow	demo	• Not proven at utility scale • Rx stack membrane degradation	• lower round trip efficiency • low energy density • requires mechanical systems • high cost of Vanadium	• Power and energy scale independently • Mature for a flow technology • Vanadium is a SA resource • high cycle life, full DoD	**BES, AS, GIS, CEMS**	Significant now & long term
Iron-Chromium Flow	demo	• Not proven at utility scale • Toxicity of Chromium • Less mature than other flow batteries	• lower round trip efficiency • low energy density • requires mechanical systems	• Power and energy scale independently • small daily self-discharge • high cycle life, full DoD	**BES, AS, GIS, CEMS**	Moderate mid- to possibly long-term

Technology	Maturity	Risks/Barriers	Disadvantages	Advantages	Best Applications **	Future potential for SA utility-scale energy storage
Zinc-Bromine Flow	demo	• not proven at utility scale • Potential bromine toxicity • Limited module capacities • Dendrite formation	• lower round trip efficiency • Requires mechanical systems • Power and energy not fully independent • Requires occasional full discharge for dendrite removal	• High cycle life, full DoD • Less expensive electrolyte than Vn • Small daily self-discharge	**BES, AS, GIS, CEMS**	Significant near- to long-term
Flywheel	demo	• Long-term reliability unproven • expensive to manufacture	• Complex design /moving parts • short discharge duration • Very high daily self-discharge	• High cycle life / high peak power • Very fast charge / discharge and response • High round trip efficiency	**AS, CEMS**	Moderate mid- to long-term
Supercapacitors	commercial	High capital cost	• Low energy density • Short discharge time • High daily self-discharge	• High cycle life • Very fast charge / discharge and response	**AS, CEMS**	Significant now and future (hybrid apps)
CAES Adiabatic - cavern	demo	• system efficiency • environmental / permitting	• complex mechanical systems • limited geological sites • Relatively slow response time	• Eliminates need for fossil fuel • long system life, low LCOS • Small daily self-discharge	**BES, AS**	Moderate possibly long-term
CAES Tank Storage	demo	Expensive storage (tanks)	Complex mechanical systems	• increased siting flexibility • small daily self-discharge • high cycle life, full DoD	**BES, AS, GIS, CEMS**	Significant mid- to long-term
Hydrogen Fuel Cell	commercial	Low round trip efficiency	Complex mechanical systems	• Platinum is a SA resource • Small self discharge	not as a power-to-power app	none as power-to-power application
Liquid Metal	R&D	• Design challenges: battery seal • Lacking manufacturing processes	• Stationary applications, Liquid layers sensitive to motion • High temperature - requires active heating	• Long electrode life • Components self-segregate - no membrane • Low cost potential • Rapid charge/discharge	**AS, GIS, CEMS**	Significant in the future
Liquid Air	demo	Requires waste heat source to be competitive	• Slow ramping times / response • Complex mechanical systems	• Increased siting flexibility • Higher energy density than CAES • Small daily self-discharge • High cycle life, full DoD	**BES,** AS, **GIS, CEMS**	Significant mid- to long-term

** BES = Bulk Energy Services, AS = Ancillary Services, GIS = Grid Infrastructure Services, CEMS = Customer Energy Management Services

Figure 2-1 summarizes the potential of competing energy storage technologies to be mature and competitive over the near, middle, and long term time frames.

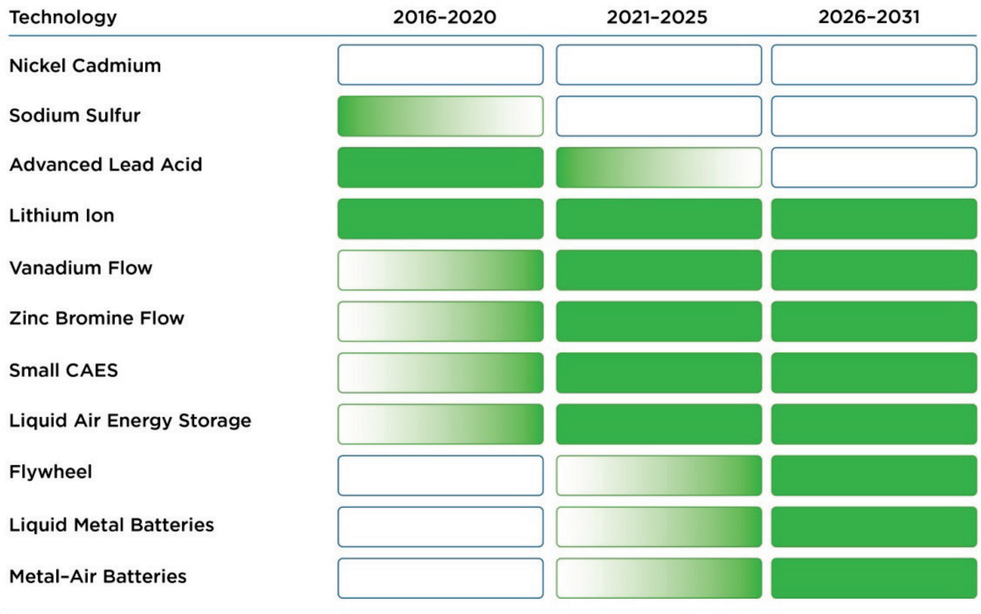


Figure 2-1: Time Frames for Technology Relevance in SA

2.2 Advanced Lead Acid (Lead-Carbon) Batteries

Several companies offer advanced lead-acid or lead-carbon batteries. Each developer has a different method of integrating carbon into the traditional lead-acid battery negative plate (cathode). The addition of carbon to the negative plate avoids sulfate accumulation and turns the battery into a quasi-asymmetric supercapacitor. These batteries exhibit higher rates of both charge and discharge without the detrimental effects experienced by traditional lead-acid batteries.

Although larger and heavier than lithium ion (Li-ion) batteries, the advanced lead-carbon (ALC) battery is low cost, operates at subfreezing temperatures, and does not need active cooling. Unlike regular lead acid, lead carbon can operate at between 30 percent and 70 percent state-of-charge without becoming sulfated. The ALC is said to outlive the regular lead acid battery, but the negative is a rapid voltage drop on discharge, resembling that of a supercapacitor [0235].

With a lower initial cost and better temperature performance, advanced lead-acid batteries are expected to retain market share in niche areas of utility-scale energy storage market unless challenged by lowering the cost of Li-ion.

2.3 Lithium-Ion Batteries

Lithium-ion-based energy storage systems (ESSs) are expected to be the dominant energy storage technology for utility-scale applications with cycle durations up to 4 hours. Li-ion will also be dominant in commercial, industrial, and home consumer applications. Although some concern still exists regarding the potential safety issues related to thermal runaway and fire, cell monitoring, battery management, fire detection, and suppression systems typically address these concerns. Over time, consumers will become more comfortable with Li-ion as additional large-scale systems demonstrate long-term reliability, performance, and safety.

High round-trip efficiency, high power, and energy density of Li-ion provide a significant advantage where footprint and available real estate are an issue. A significant disadvantage to Li-ion has been the high initial cost and limited cycle lives represented by early chemistries and manufacturers. Recent advances in technology and large-scale manufacturing will continue to drive down prices and provide increased performance. Li-ion is expected to be an important energy storage technology in the near, middle, and long term through 2030.

2.4 Sodium Sulfur

Although sodium sulfur (NaS) has been the dominant storage technology for utility-scale energy storage applications with cycle durations of 4 to 6 hours over the last decade, NaS is expected to be challenged by flow batteries for applications requiring more than 4-hour discharge cycles and by Li-ion for shorter discharge cycles. As a mature technology, significant near-term performance or cost improvements are not expected. Few commercial companies are active in this technology. In the future, NaS may experience a resurgence as existing patents expire, thereby leading to increased competition and development for lower temperature designs. Without significant improvements, NaS is not expected to be an important energy storage technology beyond the near term through 2020.

2.5 Flow Batteries

Many manufacturers have invested significant capital in the development of commercial flow battery designs. Flow batteries require mechanical systems (pumps, pipes, and tanks) and are inherently more complex than a solid-state battery. The most expensive components within the flow battery are generally the reaction stacks. The greatest advantage of the flow battery is the potential to scale up to longer duration discharge cycles more cost efficiently than solid-state batteries. The most successful and prevalent of these batteries use vanadium and zinc-bromine chemistries. Several flow battery systems have been sold or have gone bankrupt before they achieved a market competitive commercial offering. Flow battery manufacturers across all chemistries are expected to continue to refine product offerings while reducing the initial costs of their products, and demonstrating long-term reliability. Manufacturers that provide reliable systems at competitive prices through efficient manufacturing practices will achieve increased market share and improved bankability

2.5.1 Vanadium Redox Flow Battery

Several companies have demonstrated the potential for significant scale-up of vanadium modules to the megawatt (MW) scale and discharge durations of 4 to 12+ hours. Scale-up provides the potential for significant cost reduction because it avoids multiple redundant smaller systems. Vanadium is a significant resource in South Africa; however, it is also expensive: the vanadium itself accounts for about 35% of the ESS costs [0372, 0239]. The newer mixed acid electrolyte formulation offers the advantage of a higher concentration of vanadium and increased temperature performance. Companies employing a mixed acid electrolyte are expected to have an advantage over the earlier sulfuric acid-based electrolyte. Vanadium is a nontoxic chemical; however, the electrolyte is caustic and poses corrosive and environmental hazards similar to lead-acid batteries. Vanadium flow batteries will likely be a dominant long-duration discharge application in the coming 5 years, and they could dominate the long-duration market (>4 hours) over the middle to long term through 2030.

2.5.2 Zinc Bromine Flow Battery

As a hybrid flow battery, zinc-bromine (Zn-Br) systems deposit or "plate out" zinc on the anode of the reaction stack during charging. Zn-Br has been successfully developed in smaller 10- to 25-kW modules that have been demonstrated as power backup devices for telecommunications and cell tower applications. Zn-Br has experienced difficulties in scale-up of module size and thus has generally scaled to MW-capacity systems by combining or " ganging" a large number of smaller modules. An increasing number of smaller modules potentially reduces the cost competitiveness of Zn-Br systems. Zn-Br poses additional environmental and safety concerns relating to the use of bromine and the potential for release or exposure. Zn-Br has an advantage over vanadium in that both zinc and bromine are relatively inexpensive and account for less than 10% of the total flow battery costs. Bromine creates a harsh and corrosive environment that requires more robust mechanical systems and materials.

2.5.3 Iron-Chromium Flow Battery

As a true redox flow battery, iron-chromium (FeCr) demonstrates full power and energy independence. The use of chromium presents additional environmental and toxicity issues. This technology has not been proven on a utility scale and no current manufacturers are offering demonstration or production systems.

2.5.4 Zinc-Iron Redox Flow Battery

Although not discussed in detail, a zinc-iron (ZnFe) RFB uses a zinc oxide anolyte in a proprietary alkaline solution and an iron complex catholyte. This chemistry offers many of the same advantages as a vanadium or FeCr flow battery, such as full discharge, long calendar, and high cycle life. It is being developed by a limited number of companies and is currently offered in demonstration applications.

2.6 COMPRESSED AIR

Although capable of high power, compressed air systems are most competitive on longer duration applications in which a larger storage volume increases energy capacity while holding the more expensive compression and expansion "power capacity" systems constant. There are only a couple utility-scale CAES facilities world-wide however, and large-scale CAES has not received much market acceptance over the past several decades. The potential for the development of smaller sized compressed air ESSs is potentially more significant. The development of standardized specialty mechanical compression and expansion components that could be manufactured cost effectively and low-cost high-pressure storage tanks could result in cost effective ESSs on par with pumped hydro storage (PHS) and large system compressed air energy storage (CAES) costs, but on a smaller scale. The smaller size would allow them to be favorably located at the point of use. Small-scale CAES might become competative with other technologies in the middle and long term through 2030.

2.7 LIQUID AIR

With long system life, high cycle life, and deep depth of discharge, liquid air energy storage (LAES) provides performance characteristics similar to CAES but with an increased energy density. This technology is being demonstrated on a near utility scale and is expected to be competitive in the future when sited with a source of waste heat, such as a gas turbine peaking power plant. LAES could be a competitive technology in the middle to long term through 2030.

2.8 LIQUID METAL BATTERIES

High-temperature liquid metal batteries have the potential provide high power and energy capacities, long system life, and high cycle life with the potential for low initial material and manufacturing cost. Still in the research and development (R&D) stage, liquid metal must overcome several remaining challenges, including a metal-to-ceramic seal and the development of efficient manufacturing practices. Commercial applications are expected to be at least 5 years out. Liquid metal batteries could be a competitive technology in the middle to long term through 2030.

2.9 METAL-AIR BATTERIES

Metal-air batteries use an electropositive metal in an electrochemical couple with oxygen from ambient air to generate electricity. Metal-air batteries have up to three times the energy density of Li-ion; however, unlike lithium-ion, metal-air batteries do not produce potentially toxic or explosive gases, nor do they contain toxic or environmentally dangerous components.

Because such batteries only require one electrode within the product, they could have very high energy densities. In addition, the metals used or proposed in most metal-air designs are relatively low cost. Developed for electric vehicles (EVs) and power electronics applications, this technology could evolve into a competitive low-cost stationary storage system for grid services in the middle to long term through 2030. Zinc-air is the most promising metal-air chemistry.

2.10 Supercapacitors

Supercapacitors, ultracapacitors, or electrochemical capacitors (EC) store direct electrical charge in the material rather than converting the charge to another form. This provides a reversible, efficient, and fast storage device. Electrocapacitors are best suited for applications requiring high cycle life and charge or discharge times of one second or less. A relatively simple technology with a high round trip efficiency (RTE) and extremely long calendar and cycle life, supercapacitors are still relatively expensive and suited primarily for very short and highly responsive power applications. These devices are increasingly coupled with longer duration energy storage (battery) technologies as part of a hybrid system in which the fast response and high-power ultracapacitor complements a slower but high-energy-density battery system such as a Li-ion or flow battery. Deployment of hybrid systems is expected to increase in the near to middle term as these systems gain maturity and acceptance.

2.11 Flywheels

Although some flywheel designs are intended for longer discharge duration, most utility scale applications are on the order of seconds to a minute. Flywheel energy storage systems (FESSs) respond very quickly to changes in demand and thus are well suited for short duration and rapidly changing control applications such as frequency, voltage control, or smoothing applications. High-performance flywheels are relatively expensive to manufacture and require close tolerance parts and machining. There are only a few utility scale FESS facilities and these have only been in operation for a limited time. Flywheels will become commercially viable where there is high value for ancillary fast response services. A successful manufacturer will have to reduce manufacturing costs and develop a history of reliable operation. This is not likely to occur in the short term.

2.12 Technologies Not Evaluated in This Report

Pumped Hydro Storage was not evaluated because it was specifically excluded from the scope of the study. South Africa already has significant pump hydro resources/facilities. Underground or high-head PHS in abandoned mines was considered but was not evaluated based on limited interest and high environmental concerns.

Thermal Energy Storage, particularly molten salt thermal energy storage systems when integrated with a concentrating solar power facility, represent good thermal-to-power applications but do not meet the power-to-power requirements specified for this study.

Superconducting Magnet Energy Storage, while promising in terms of efficiency and response time, is a technology still in the research and development stage. Short discharge duration, high system cost, and environmental concerns related to strong magnetic fields are major challenges of this technology [0229]. No manufacturer is producing or developing a commercial utility scale system.

Gravity-Potential Energy Storage has been proposed in several different formulations. It consists of using excess electrical power to raise a weight to a higher elevation, thus storing potential energy. A generator is subsequently driven by the lowering weight to produce electrical power when needed. Proposed systems include rail-based, pullies that raise and lower weights (e.g. “mine winders” in abandoned mines), and an underground hydro-piston arrangement. See ARES company profile for typical description

Aqueous Ion Battery formulations are offered by several companies. These batteries use proprietary low-cost electrochemical couples that can sustain a high number of deep discharge cycles over extended periods. The low environmental footprint of these batteries is a significant discriminator. The aqueous electrolyte significantly reduces the risk of fire of combustion. See Aquion Energy company profile for additional description.

3 US and SA Sources of Supply for Energy Storage

As part of this effort, the Parsons Team sent surveys to more than 110 companies or sources of supply for ESSs, equipment, or services. The survey requested information on each company's product or service offerings and details of its current deployments or plans for market introduction. Parsons subsequently also contacted companies that did not respond to the survey but were considered to have a significant product offering or experience that could be beneficial to South Africa. Table 3-1 lists the companies and their technologies for which company profiles have been prepared; these profiles are included in Appendix B.

Table 3-1: US and SA Energy Storage Equipment, Systems, and Service Providers

Company	Service	Technology	Location
1Energy	Software / Control	Power Controls Systems	Seattle, WA
Adara power	ESS / Integrator	Lithium Ion	Milpitas, CA
AES	ESS / Integrator	Lithium Ion	Arlington, VA
Alevo	ESS / Service Provider	Lithium Ion	Concord, NC
Ambri	Storage	Molten Metal Battery	Cambridge, MA
Aquion	Storage	Aqueous Hybrid Ion	Pittsburgh, PA
ARES	ESS	Rail based – gravity	Sata Clara, CA
Axion Power	storage / ESS	Advanced Lead Acid	New Castle, PA
Bushveld	Manf. / Service Provider	Vanadium Flow Battery	Johannesburg, SA
Dresser-Rand	Equipment	Compressed Air Energy Storage	Houston, TX
Dynapower	PCC / Integrator	Power Conversion	South Burlington, VT
Ecoult	Storage / ESS	Advanced Lead Acid	Lyon Station, PA
ElectronVault	ESS / Integrator	Lithium Ion	Woodside, CA
EnSync	ESS / PCC	Zinc-Bromine Flow Battery	Menomonee Falls, WI
Eos Energy Storage	ESS	Zn-air Battery	Edison, NJ
Fluidic Energy	ESS / Integrator	Zn-air Battery	Scottsdale, AZ
Freedom Won	ESS	Lithium Ion	Ruimsig, SA
GreenSmith Energy	Software / Control	Power Controls Systems	Rockville, MD
Imergy	ESS / Integrator	Vanadium Flow Battery	Fremont, CA
Ingeteam	Equipment / PCC	Power Control Systems	Milwaukee, WI
Johnson Controls	Storage / ESS	Lithium Ion	Milwaukee, WI
LG Chem	Storage / ESS	Lithium Ion	Troy, MI
LightSail	ESS	ICAES	Berkley, CA
Lockheed Martin	ESS / integrator	Li-ion and Flow battery	Bethesda, MD
Maxwell Technologies	Storage	Ultracapacitor	San Diego, CA
NEC	ESS	Lithium Ion	Westborough, MA
Powertech System Integrator	System Integrator	ESS	Pretoria, SA
PowerStormESS	ESS	Li-ion and generator	Los Angeles, CA
Powin Power	ESS / Integrator	Lithium Ion	Tualatin, OR
Primus Power	ESS	Zinc-Bromine Flow Battery	Hayward, CA

Company	Service	Technology	Location
PV Hardware	ESS / Integrator	Vanadium Flow Battery	San Francisco, CA
Redflow	ESS	Zinc-Bromine Flow Battery	Austin, TX
S&C Electric	PCC / Integrator	Power Controls Systems	Chicago, IL
Simpliphi	ESS	Lithium Ion	Ojai, CA
Tesla	ESS	Lithium Ion	Palo Alto, CA
UET	ESS / Integrator	Vanadium Flow Battery	Mukilteo, WA
Vionx	ESS / Integrator	Vanadium Flow Battery	Woburn, MA
ViZn	ESS / Integrator	Zinc-Iron Flow Battery	Austin, TX
WattJoule	ESS	Vanadium Flow Battery	Devens, MA

4 US Supplier Interest in SA Energy Storage Market

The Parsons team contacted 15 US equipment and service suppliers that expressed an interest in the South Africa market to understand their thoughts and concerns. See a general summary across several lines of discussion below. Where possible, the specific language used by responders has been retained.

- In general, most of the larger companies with mature product lines expressed an immediate interest in developing relationships and potential marketing leads in South Africa. As identified in the individual company profiles, several of these companies have a formal presence (or legal entity) in South Africa; others have established distributors or teaming relationships.
- Several of the less mature and smaller behind-the-meter storage companies, while interested in expanding their markets, expressed a concern that they needed to develop their business and supply chains, and to demonstrate reliable products in the US before expanding into South Africa.
- Many of the flow battery companies and newer battery technologies are very interested in gaining a first (or pilot) deployment in South Africa on which they can establish a reputation and leverage additional projects.

Overall, the majority of companies indicated that their analysis shows that South Africa offers a strong market for ESSs and that they were excited to expand into South Africa. The following sections curate their responses to survey questions posed by the Parsons team. These reflect the perceptions held by these companies on the challenges and opportunities in South Africa for their products.

4.1 Perceived Barriers and Challenges to Project or Business Development in South Africa

One perceived barrier for companies and suppliers without international resources or distribution networks is the distance between the United States and South Africa and the difficulty of bringing new technologies to distant areas, difficulty in communications (time differences), and the long and expensive travel to get to South Africa to find competent project partners, identify sites, create proposals, and develop projects.

Many companies identified a lack of experienced regional partners with established relationships with subcontractors and equipment vendors. Local partners must have the right skills and knowledge to fill the gaps of an overseas company. Of especial importance are local partners that can provide for in-country deployment, engineering, and operations and maintenance (O&M) support.

Another perceived barrier is the old model of centralized generation, transmission and distribution (T&D), and consumption that is held by many stakeholders in South Africa. Several companies suggested that this concept should be advanced to plan for a more decentralized microgrid-based system that can take advantage of South Africa's abundant solar capacity while providing needed resiliency to the grid. It was also pointed out that ESKOM is the main customer and that the monopolistic structures for existing producers seem to have stronger incentives for conventional energy than clean energy. A perceived lack of financial stability and creditworthiness of the utilities was also mentioned as a weakness.

A significant barrier to attracting investment in development of ESSs in South Africa was unclear and inconsistent energy policies. Companies indicated a desire to better understand the use case for energy storage in South Africa and the total opportunity size. Suppliers noted that the regulatory or market framework has no specific mechanisms to motivate companies to invest in such projects and give them a consistent and reasonable return on investment. Without adequate compensation for ancillary services, energy storage projects lack the revenue opportunity to make the project viable. Energy storage projects must be able to acquire long-term contracts for providing energy storage services (e.g., balancing services, ancillary services, and peaking capacity) at a sufficient price point that allows traditional project financing to enter into the deal.

A repeated concern was the availability of project financing and the fact (expressed by newer technology providers) that the domestic financial sector was not experienced in new energy storage technologies. Many energy storage opportunities are based on government or nongovernment organization-funded projects, and although this business model will prime the market, a robust commercial market must emerge, and energy policy is central to making this happen. High interest rates (linked to country/client risk profiles) are a huge barrier for renewables and storage projects due to the capital expense-heavy nature of the projects. Project financing is necessary to allow businesses to grow beyond their first project.

An additional concern was the potential that high local content requirements on energy storage procurements might limit or preclude reasonable competition. Any significant requirement for local content could limit proposal response and could shift awards away from established, reliable, and cost-competitive companies and technologies to smaller and less reliable startups with a lower performance and higher failure rate. Although companies appreciated the goal to develop the local industry, they suggested that, due to the complexity of energy storage solutions, very high local content requirements may limit the South African market's timely access to the benefits of the technology. It was suggested that procurements should initially require minimal or moderate levels of local content or "value add" as a criterion for award (see Section 4.2).

Several responders expressed a concern over import customs issues and foreign exchange issues related to the volatility and strength of the Rand.

A high crime rate and the need for increased levels of facility and equipment security was cited by two companies.

It was generally felt that all of the above, compounded by a perceived low probability of success due to limited funding and a highly unstable atmosphere with regard to energy, make any strategic decisions risky.

4.2 Where US Technology/Systems Might Contribute to Economic Development in South Africa Economy

Based on the size of the energy storage opportunities in South Africa, many companies professed that systemic deployment of their ESSs could have a significant impact across the entire value chain (e.g., materials, manufacturing, systems installation, O&M, and employment). US companies indicated an interest in exploring ways in which they could leverage local resources (labor, materials, technical expertise) to reduce the cost of their products and accelerate introduction into South Africa.

Several companies were quick to point out that their technology would benefit commodities abundant in South Africa (e.g., vanadium, platinum, and iron). One manufacturer maintained that well over 50% of system costs of a vanadium flow battery could be spent on materials and manufacturing originating in South Africa.

Several companies expressed the opinion that South Africa could support a local battery manufacturer, or that South Africa could fabricate major system components (including electrolyte) for flow batteries. Along those lines, several companies indicated that South Africa has a sophisticated manufacturing base that could manufacture batteries and key battery components, or could provide final system or module assembly in South Africa. One supplier noted “The nature of our technology allows a large portion of the value added to be locally assembled and tested locally using locally source materials, creating cost savings on labor and shipping and opportunities to export to other African nations.”

Almost all US providers indicated that adoption of their energy storage technology would provide opportunities for engineering, procurement, and construction companies and craft labor and supervision associated with installation of the initial systems in South Africa.

Lastly, a majority of the companies expressed a desire to turn over routine integration, installation, and O&M of their system to in-country local partners that were trained by the original equipment manufacturer. Although O&M represents a smaller effort (in terms of full-time equivalents) than initial installation, O&M provides for significant long-term job creation.

Beyond the direct impact associated with the manufacturing, installation and operation of ESSs, several companies opined that the introduction of ESSs would benefit economic development through increased reliability and reduced cost of energy. That ESSs could free some fraction of existing power generation capacity, currently held in reserve for balancing purposes, to reduce or possibly eliminate “power cuts” (power outage events), and that energy storage could be used to defer infrastructure upgrades.

This was thought to be especially relevant to large-capacity users (mining and manufacturing), especially if those users were remotely located. Energy storage providers indicated their ability to support remote mining, commercial, and industrial power, as well as village power via microgrids. It was noted that energy storage can deploy power to small villages or large remote mines at very high quality without the expensive diesel fuel or supply chain issues that arise when trying to truck it long distances.

One supplier noted “The systemic deployment of energy storage systems will help reduce overall cost of electricity which will have a positive impact on the country’s GDP of attracting macroeconomic activity and foreign investment in South Africa”.

4.3 Best use of Regulation, Legislation, Policies, Incentives, and Tariff Structure to Encourage adoption of Energy Storage Systems in South Africa

In general, responding companies felt that the successful adoption of ESSs in South Africa will be highly dependent on the country establishing policies, regulations, tariff structures, and market conditions that provide a favorable and predictable investment environment to invest in, adopt, operate, and maintain ESSs and technologies.

Incentivizing the installation of renewables, storage, and microgrids through grants or tax breaks would be useful, as would structuring tariffs to reflect the real costs of operating the grids at certain times of the day. The key would be to incentivize renewables to about 30% of generation capacity and make the grid resilient by incentivizing microgrids, which can offer more affordable rates. Simply raising electricity prices would not be practical in a country that already has many people who cannot afford grid electricity.

Behind the meter: Creating time of use billing structures and an enabling regulatory system for embedded generation will by itself result in an accelerated uptake of distributed storage to the benefit of the system as a whole (e.g., in shifting loads out of peak). It was also suggested that South Africa could develop a rebate or tax credit system to drive the development of energy storage. It was suggested that the Smart Grid Interoperability Panel (SGIP) in the United States is a good example of a public/private funded, non-profit organization that supports power grid modernization through the harmonization of technical interoperability standards to advance grid modernization. SGIP stakeholders include utilities, manufacturers, consumers and regulators.

Front of Meter, T&D/Generation: A number of companies strongly agreed that the best use of regulations would be to allow energy storage to be included in, and compensated for, under the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) (similar to what is currently done for concentrating solar power). The upfront integration of storage with generation would allow additional penetration of variable renewable generation without creating system impacts. A similar thought was that the REIPPPP should require solar and wind to guarantee a fixed megawatt-hour capacity by providing local integrated storage or being an off-taker of large grid scale storage supplied by a third party. The REIPPPP should be opened up to solutions that could deliver a specific outcome (e.g., peak time dispatchable power) rather than being technology specific; this approach would create room for innovative storage applications that would result in the lowest cost solutions for the system as a whole.

An additional suggestion was that South Africa should fund some medium-scale, 1- to 10-MW storage projects to learn/demonstrate how to effectively incorporate energy storage to enable large penetrations of wind and solar power, the provision of ancillary services, and T&D deferral. Lastly, it was suggested that the existing ESKOM battery test site should receive additional funding to allow for the evaluation of additional energy storage technologies including flow batteries.

4.4 Preference on Teaming Arrangement / Project Structure for Work in South Africa

This question had no uniform or dominant response; most companies had a preference for a strategy/project structure consistent with their own business model and unique capabilities.

Several smaller companies offering direct current (DC) battery systems are generally looking to sell their systems to an integrator/developer because they specialize in the DC ESS and they do not have the resources to provide for full systems design and integration. This integrator/developer could be a South African entity, an international integrator/developer, or a combination international integrator/South Africa developer.

Several companies were very firm in their intent to work on projects for which they would be the main integrator of the system and therefore could guarantee the system performance at the end of the project. Several of these companies have significant international experience in ESSs and stressed that "we have found that our involvement as integrator to be extremely critical for the success of any project in this area and we have many field proven success stories that could be replicated in the South African market."

About one-third of the companies indicated that they were capable and flexible in the selection of strategies/project structures in which they could provide ESSs or power control and conversion systems to an integrator/developer or alternately could act in either capacity as the integrator or, potentially, as the developer.

Lastly, two manufacturers indicated that they would be willing to pursue arrangements in which they would provide energy storage services by acting as a service provider that builds and operates its own equipment/facility and provides services to the utility/grid operator based on a contractual price.

Appendix A Specific Technology Assessments

For additional information on energy storage technologies, the reader is directed to the EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications [0242] and the DOE/EPRI 2013 Electricity Storage Handbook [0235].

A.1 Layout for Each Technology Assessment

The following information is provided for each energy storage technology evaluated under this assessment:

Summary: Brief overview of technology summarizing significant issues and areas.

Technology: Basic description of the technology and an explanation of how it operates. This description assumes that the reader has a basic technical background, including some knowledge of science, electricity, and materials. This discussion does not provide detailed descriptions or specifics of vendor proprietary technologies.

Performance: Anticipated averages or ranges for power ratings, power discharge time, self-discharge per day, storage duration, energy and power density, cycle life (charge/discharge cycles), and lifetime (in years). This information is based on manufacturer literature and industry studies.

Applications: Details and information related to installation, integration, operation and maintenance (O&M) requirements, preferred applications (plant side or grid side), network connection characteristics, and grid compliance issues. This information is derived from manufacturer literature and industry studies.

Maturity: Assessment of the maturity and commercial readiness for each technology. Includes information related to market penetration, existing commercial applications, and examples of demonstration/pilot projects and other proof-of-concept or testing conducted to date).

Case Study(ies): Identifies and describes representative case studies of commercial applications or demonstration/pilot projects that highlight best practices and lessons learned and are indicative of technological maturity and commercial readiness.

Risks/Barriers: Key technological risks and barriers for each technology and recommendations or approaches for mitigation.

Applicability for South Africa: Assessment of the overall technical suitability of the technology for the South African environment.

A.2 Lead Acid / Advanced lead Acid

Lead-acid batteries are one of the oldest and most mature energy storage technologies. Lead-acid is inexpensive compared to newer technologies, and lead-acid batteries are still widely used.

They typically have lower cycle lifetimes and depths of discharge than other battery types and contain toxic materials that have negative environmental impacts.

Advanced lead-acid batteries introduce a carbon anode that reduces maintenance requirements, extends life expectancy, and improves cell uniformity, which increases both battery life expectancy and cost [0239]. In many applications, lead-acid is being replaced by advanced lead-acid.

Technology

In the charged state, the battery consists of lead (Pb) and lead oxide (PbO_2) in dilute sulfuric acid (H_2SO_4); in the discharged state, lead sulfate ($PbSO_4$) is produced both at the anode and at the cathode, while the electrolyte changes to water. A "porous separator" is placed between the electrodes to prevent contact. An advantage of lead-acid is that the state of charge (SoC) of the battery can be determined by measuring the concentration of the electrolyte through the specific gravity (SG) method.

At the positive electrode

$$PbO_2 + 3H^+ + HSO_4^- + 2e^- \underset{Charge}{\overset{Discharge}{\rightleftarrows}} PbSO_4 + 2H_2O \quad (1.685\ V).$$

At the negative electrode

$$Pb + HSO_4^- \underset{Charge}{\overset{Discharge}{\rightleftarrows}} PbSO_4 + H^+ + 2e^- \quad (0.356\ V).$$

For the overall cell

$$PbO_2 + Pb + 2H_2SO_4 \underset{Charge}{\overset{Discharge}{\rightleftarrows}} 2PbSO_4 + 2H_2O \quad (2.041\ V).$$

The negative electrode supplies electrons to the external circuit (or load) during discharge. In a fully charged lead-acid storage battery, the negative electrode is composed of sponge lead (Pb). The positive electrode accepts electrons from the load during discharge. The positive electrode is composed of lead dioxide (PbO_2). The electrolyte completes the internal circuit in the battery by supplying ions to the positive and negative electrodes.

Electrolyte

Dilute sulfuric acid (H_2SO_4) is the electrolyte in lead-acid batteries. In a fully charged lead-acid battery, the electrolyte is approximately 25% sulfuric acid and 75% water.

Separator

A separator is used to electrically isolate the positive and negative electrodes to prevent an electrical short circuit while allowing ion transfer between the electrolyte and electrodes. Many separators are made of a porous plastic or glass fiber material.

In the absorbent glass mat (AGM) design, the space between the cells is replaced by a glass fiber mat soaked in electrolyte. The mat has only enough electrolyte to keep it wet; if the battery is punctured, the electrolyte will not flow out of the mat. Likewise, the mat greatly reduces evaporation so that the batteries do not require periodic refilling of the water. This combination of features allows the battery to be completely sealed.

Flooded / Vented Lead-Acid Batteries

Flooded cells are those in which the electrodes/plates are immersed in electrolyte. Because the gases created during charging are vented to the atmosphere, distilled water must be added occasionally to bring the electrolyte back to its required level. The most familiar example of a flooded lead-acid cell is the 12-V automobile battery. Flooded batteries will not expected to be used for new large-scale energy storage because of the increased maintenance and are not discussed in further detail.

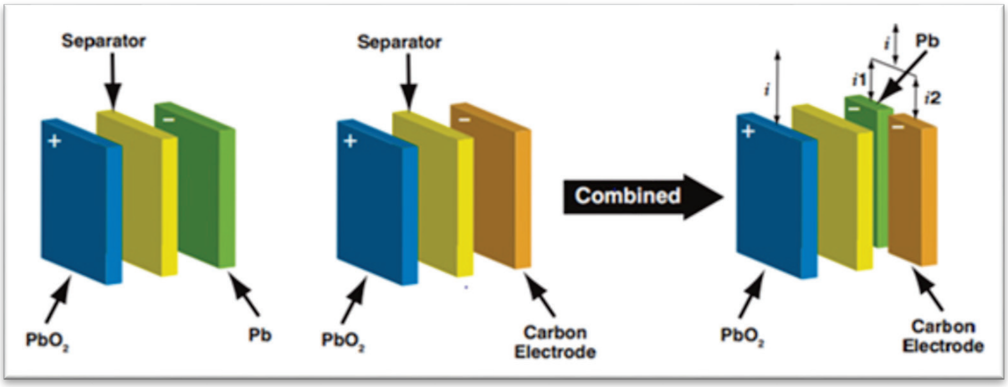
Sealed or Valve Regulated Lead-Acid Batteries

These types of batteries confine the electrolyte, but they have a vent or valve to allow gases to escape if internal pressure exceeds a certain threshold. During charging, a lead-acid battery generates oxygen gas at the positive electrode. Sealed lead-acid batteries are designed so that the oxygen generated during charging is captured and recombined in the battery. This is called an oxygen recombination cycle, and it works well as long as the charge rate is not too high. Too high of a rate of charge may result in case rupture, thermal runaway, or internal mechanical damage. The valve-regulated battery is the most common type of sealed battery. It was developed for stationary and telecommunication battery applications. Sealed batteries were developed to reduce the maintenance required for batteries in active service. Because electrolyte levels are preserved by trapping and recombining offgases, the addition of distilled water should not be needed over the life of the battery.

Advanced Lead-Acid (lead-acid carbon) Battery

Advanced lead-carbon batteries combine lead and carbon in the cathode. This allows them to exhibit a high-rate characteristic in both charge and discharge with no apparent detrimental effects as are typically experienced in traditional vented lead-acid (VLA) and valve-regulated lead acid (VRLA) batteries. This characteristic allows the lead-acid carbon batteries to deliver and accept high current rates that are only available with higher-cost Li-ion batteries [0235].

One significant drawback to classic lead-acid batteries is that sulfate accumulation can rapidly degrade performance; partial charge and aging are the main causes because the negative lead plate is not sufficiently scrubbed. The advanced lead-carbon (ALC) battery avoids sulfate accumulation experienced in a standard lead-acid battery by adding carbon to the negative plate (cathode). This turns the battery into a quasi-asymmetric supercapacitor to improve charge and discharge performance [0251]. Several companies offer lead-acid carbon technologies. Each developer has a different implementation of carbon integrated with the traditional lead-acid battery negative plate.



The UltraBattery combines lead and carbon in a twin negative electrode (courtesy ALABC)

Although larger and heavier than Li-ion, the ALC is low cost, operates at subfreezing temperatures, and does not need active cooling — advantages that Li-ion cannot claim. Unlike regular lead acid, lead carbon can operate at between 30% and 70% state-of-charge without becoming sulfated. The ALC is said to outlive the regular lead acid battery; however, the negative is a rapid voltage drop on discharge, resembling that of a supercapacitor [0235].

PERFORMANCE

The depth of discharge also affects the life of a battery; discharges beyond about 50% will shorten battery life. Colder operating temperatures will yield a little extra life, but they will also lower the capacity of lead acid cells. High temperatures yield higher capacity, but they have a detrimental effect on life.

Typical Performance for Lead Acid and Advanced Lead-Acid Batteries

Parameter	Lead Acid	Advanced Lead-Acid
Power Rating	Fully scalable	Up to 100 MW
Discharge at Rated Power	generally < 1 hour	15 minutes to 4 hours
Round Trip Efficiency	70% – 80%	75% – 90%
Response Time	milliseconds	milliseconds
Self Discharge per day	0.1% – 0.3% per day	0.1% – 0.3% per day
Power Density	50 – 80 kWm³	50 – 80 kWm³
Energy Density	10 – 400 kWhm³	10 – 400 kWhm³
Cycle Life	200 to 1,800 cycles	2,200 – 4,500 cycles
Depth of Discharge	~50%	~50%
System Lifetime	3 – 15 years	3 – 15 years

Parameter	Lead Acid	Advanced Lead-Acid
Cost, power	200 – 600 $/kW	300 – 600 $/kW
Cost, energy	50 – 400 $/kWh	500 – 1,150 $/kWh
Actual cost/performance varies by construction and manufacturer.		

Applications

Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, lead-acid batteries can supply high surge currents, which means that the cells have a relatively large power-to-weight ratio. Lead-acid is inexpensive compared to newer technologies, and lead-acid batteries are still widely used. Large-format lead-acid designs are widely used for storage in backup power supplies in cell phone towers, high-availability settings such as hospitals, and stand-alone power systems. Applications for a stationary ESS will favor advanced lead-acid.

Lead-acid storage batteries have numerous applications. Advanced lead-acid batteries are being considered for transportation applications and have been installed for frequency regulation in utility-scale grid connected applications.

Operation and Maintenance

Maintenance requirements for lead acid batteries include float charging, equalization charging, water replacement, and cell post maintenance. To prevent self-discharge, voltage is continuously applied to the already-charged battery to generate a small current. Equalization charging corrects the inconsistency in state of charge between individual battery cells by charging the battery at a high voltage for an extended period. Water replacement is only necessary for flooded lead-acid batteries (not for valve-regulated lead-acid) to compensate for water lost through evaporation and electrolysis [0239].

Corrosion of the external metal parts of the lead–acid battery results from a chemical reaction of the battery terminals, lugs, and connectors. Acid fumes that vaporize through the vent caps (often caused by overcharging) and insufficient battery box ventilation can allow the sulfuric acid fumes to build up and react with the exposed metals.

Decommissioning and Disposal

Some lead compounds are extremely toxic. Long-term exposure to even tiny amounts of these compounds can cause brain and kidney damage, hearing impairment, and learning problems in children.

Lead–acid battery recycling is effectively practiced in most parts of the world. In the United States, almost all battery lead is recycled, although a small percentage still shows up in landfills. During the recycling, an effective pollution control system is a necessity to control lead emission. Continuous improvement in battery recycling plants and furnace designs is required to keep pace with emission standards for lead smelters.

MATURITY

Lead-acid battery technology is very mature, and its performance and limitations are well understood. Several manufacturers have introduced advanced lead-acid batteries over the past several years, and a number of initial or demonstration utility-scale projects will determine the long-term performance of these promising but still evolving technologies.

CASE STUDIES

Axion PowerCube for Pennsylvania New Jersey Maryland Interconnection (PJM). Axion Power has had one of its PowerCube 500-kW (30-minute) advanced lead-carbon PbC® ESSs in service in New Castle, Pennsylvania, since November 2011. The system is used as a power resource for the PJM Regulation Market. This is the first time an external ESS was integrated into a major power grid [0365].

Axion Power International-Sharon, 12.5 MW. – In March 2016, Axion Power filed an interconnection application with PJM for a site in Sharon, Pennsylvania. Axion is proposing a 12.5-MW (1-hour) battery ESS to participate in the PJM regulation market. The application is currently moving through the PJM interconnection review process, and Axion is evaluating project financing options for this major commercial project [0365].

RISKS/BARRIERS

The risks and barriers associated with lead-acid batteries are well understood.

OVERCHARGING

Overcharging with high charging voltages generates oxygen and hydrogen gas by electrolysis of water, which is lost to the cell in a flooded or vented battery. Periodic maintenance therefore requires inspection of the electrolyte level and replacement of lost water.

A VRLA cell normally recombines any hydrogen and oxygen produced inside the cell, but malfunction or overheating may cause gas to build up. If this happens (for example, on overcharging), the valve vents the gas and normalizes the pressure, producing a characteristic acid smell. However, valves can fail (if dirt and debris accumulate), allowing pressure to build.

SULFATION

Lead-acid batteries can lose the ability to accept a charge when discharged for too long due to sulfation. During normal discharge, the battery's active materials, lead and lead dioxide, react with sulfuric acid in the electrolyte to form lead sulfate. The lead sulfate first forms in a finely divided, amorphous state, and it easily reverts to lead, lead dioxide, and sulfuric acid when the battery recharges. As batteries cycle through numerous discharges and charges, some lead sulfate is not recombined into electrolyte and slowly converts to a stable crystalline form that no longer dissolves on recharging. Thus, not all the lead is returned to the battery plates, and the amount of usable active material necessary for electricity generation declines over time. Advanced lead acid (ALA) technologies have largely resolved issues related to sulfation.

500-kW/360-kWh lead-carbon battery system in 40-foot container (courtesy Axion Power)

Suitability for South Africa

Lead-acid batteries are considered attractive alternatives because of technological maturity and availability as well as low relative cost [0239]; however, newer lead-acid applications will likely use an ALA design. Depending on the application, other battery technologies may outperform or provide lower life-cycle costs; however, ALA acid will likely retain niche applications for some time. There are numerous lead-acid battery manufacturers internationally, including several in South Africa.

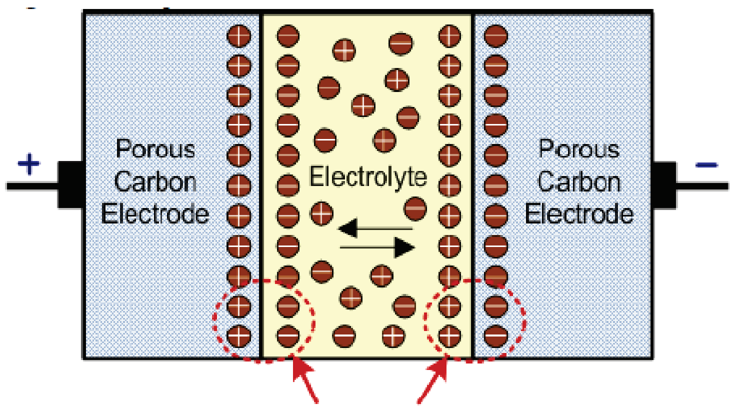
A.3 Electrochemical Capacitors

Electrochemical capacitor (EC) technology stores direct electrical charge in the material rather than converting the charge to another form, such as chemical energy in batteries or magnetic field energy in superconducting magnetic energy storage; this makes the storage process reversible, efficient, and fast [0064].

Technology

Sometimes referred to as “electric double-layer” capacitors, these devices also appear under trade names such as “Supercapacitor” or “Ultracapacitor.” The phrase “double-layer” refers to ECs physically storing electrical charge at a surface-electrolyte interface of high-surface-area carbon electrodes.

When the two electrodes of an EC are connected in an external current path, current flows until complete charge balance is achieved. The capacitor can then be returned to its charged state by applying voltage. Because the charge is stored physically with no chemical or phase changes taking place, the process is fast and highly reversible, and the discharge-charge cycle can be repeated virtually without limit. Because of the large surface area and the thin double layer, these devices can have very high specific and volumetric capacitances. This enables them to combine a previously unattainable capacitance density with an essentially unlimited charge-discharge cycle life. Thus, cells are connected in series for higher voltage operation, exactly like battery cells [0310].



Electrochemical "double layer" capacitor [0239]

There are two types of ECs: those with 1) symmetric designs, where both positive and negative electrodes are made of the same high-surface-area carbon and 2) asymmetric designs with different materials for the two electrodes, one high-surface-area carbon and the other a higher capacity battery-like electrode. There are other differences in the characteristics and performance of these two types leading to use in different applications [0310].

An EC may also have an aqueous or organic electrolyte. Aqueous are usually high-concentration sulfuric acid or potassium hydroxide. Organic electrolytes typically use an ammonium salt dissolved in an organic solvent. Organic electrolytes are the most common type in use today [0242].

There are different requirements for energy storage in different electricity grid-related applications from voltage support and load following to integration of wind generation and time-shifting. Symmetric ECs have response times on the order of 1 second and are well-suited for short duration high-power applications related to both grid regulation and frequency regulation. Asymmetric ECs are better suited for grid energy storage applications that have long duration, for instance, charge-at-night/use-during-the-day storage (i.e., bulk energy storage). Some asymmetric EC products have been optimized for ~5 hour charge with ~5 hour discharge. Advantages of ECs in these applications include long cycle life, good efficiency, low life-cycle costs, and adequate energy density.

PERFORMANCE

Typical Performance for Electrochemical Capacitor Technology

Parameter	Range
Power Rating	scalable
Discharge at Rated Power	seconds-– minutes
Round Trip Efficiency	90% – 97%
Response Time	milliseconds
Self Discharge per day	20% – 40% per day
Power Density	10 – 30 kWm^3
Energy Density	100,000+ kWhm^3
Cycle Life	5 × 10^5 cycles
Depth of Discharge	75%
System Lifetime	> 20 years
Cost, power	100 – 300 $/kW
Cost, energy	300 – 2,000 $/MWh

Applications

ECs are better suited than batteries for applications requiring high cycle life and charge or discharge times of 1 second or less. The greatest barrier to market growth has been the lack of understanding of the technology and the applications for which it is best suited [0310]. These devices are increasingly coupled with longer duration energy storage technologies as part of a hybrid system in which the fast response and high power ultracapacitor complements a slower but higher energy density battery system such as a Li-ion or a flow battery.

The lack of recycling programs for electrochemical capacitors pose environmental implications, which could contribute to siting, permitting, and disposal costs [0239].

Maturity

The technology is comparatively young, but it has been evolving at a remarkable pace and is regarded as an excellent solution for voltage regulation [0299]. Because of their high power, long cycle life, good reliability, and other characteristics, the market and applications for ECs have been steadily increasing. Dozens of manufacturers produce ECs and more are entering the market because of market growth.

Case Studies

Duke Energy Rankin Substation. Operational in 2016 at Mount Holly, North Carolina, this hybrid project combines ultracapacitors (Maxwell Technologies) that provide a fast response and high power density with a low-cost performance and high energy density battery technology (Aquion Energy's aqueous hybrid ion [AHI] batteries). This combination provides for simultaneous solar smoothing, price arbitrage, and load following, as well as peak shaving. While rated at 250 kW and 2 hours of duration, the Ultracapacitors are only responsible for fast response (solar smoothing) services [0365].

Regenerative Breaking Systems. Several applications use ultracapacitor-based ESSs for braking energy recuperation systems for electric rail and high-speed rail applications. The recuperation systems, ranging from 750 V to 1,500 V, absorb energy during rail vehicle braking and deliver the stored energy to the vehicles' electric motors for propulsion and to stabilize voltage throughout the system. Typical systems include seven 525-kW (0.33-minute) systems for in Seoul, Korea, and 300-kW (0.63-minute) systems in Cerro Negro, Spain [0365]. Some systems have been in service since 2009.

1-MW electrochemical capacitor regenerative breaking system provides 20-second charge and discharge cycles [0365]

RISKS/BARRIERS

Voltage Imbalance. Double layer capacitor cells are interdependent and sensitive to voltage imbalances between cells. If one cell in the string fails (short circuits), it may lead to the failure of the entire string, in a "domino effect," or it may lead to a voltage and stress increase on other cells. The cells life expectancies are directly tied to strict maximum voltages requirements [0242].

Safety Issues. The safety issues associated with ECs include electrical, chemical, fire, and explosion hazards. Electrical and chemical hazards are similar to those common to batteries. The voltages of double layer capacitors are often lethal and should be treated with the same precautions as other high-voltage devices. Some capacitors have aqueous electrolyte, which eliminates the possibility of hazardous fires but allows for the possibility of chemical burns similar to those from other electrochemical storage devices. Some capacitors with an organic electrolyte pose a fire threat and health threats if the electrolyte is inhaled, ingested, or contacts skin [0242].

Cost. A significant barrier to further deployment and adoption of ultracapacitors is their high initial cost [0299].

Suitability for South Africa

ECs will have important applications for smoothing variable renewable sources and for fast response DC voltage regulation. These systems are increasingly incorporated into hybrid ESSs that seek to enhance overall system performance by matching complementary characteristics of differing technologies. Additionally, there may be applications for braking energy recuperation systems for electric rail. All of these applications will be important in South Africa.

A.4 Nickel-Cadmium (NiCd) Batteries

Each NiCd cell contains a pair of electrodes: a positive nickel electrode and a negative cadmium electrode. Nickel electrode batteries are known as dry cell batteries [0299]. Several materials have been matched with nickel to produce a variety of battery technologies; however, NiCd batteries are most commonly proposed for use in utility applications [0242].

Technology

The NiCd (or NiCad) battery is a rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes. NiCd batteries have an alkaline potassium hydroxide electrolyte. As with any other rechargeable battery systems, NiCd batteries operate on the principle that electrochemical reactions at each electrode are reversible; this enables energy to be stored during charging and released during discharging. The overall reaction schematically depicts a simple transfer of OH-ion between $Ni(OH)_2$ and Cd, depending on whether the cell is being charged or discharged.

$$2Ni(OH)_2 + Cd(OH)_2 \underset{\text{discharging}}{\overset{\text{charging}}{\Longleftrightarrow}} 2NiOOH + Cd + 2H_2O$$

Early NiCd cells used pocket-plate technology, a design that is still in production today. Sintered plates entered production in the mid-20th century, to be followed later by fiber plates, plastic-bonded electrodes and foam plates. Cells with pocket and fiber plates generally use the same electrode design for both the nickel positive and cadmium negative; sintered and foam positives are now more commonly used with plastic-bonded negatives [0310].

NiCd batteries usually have a metal case with a sealing plate equipped with a self-sealing safety valve. The positive and negative electrode plates, isolated from each other by the separator, are rolled in a spiral shape inside the case. This is known as the jelly-roll design and allows an NiCd cell to deliver a much higher maximum current than an equivalent size alkaline cell.

Performance

Recently, nickel–metal hydride and Li-ion batteries have become commercially available and less expensive, the former type now rivaling NiCd batteries in cost. Where energy density is important, NiCd batteries are now at a disadvantage compared with nickel–metal hydride and lithium-ion batteries.

Vented cell NiCd batteries have long lives (up to 20 years or more, depending on type) and operate at extreme temperatures (from −40° to +70°C). The NiCd battery is still very useful in applications requiring very high discharge rates because it can endure such discharge with no damage or loss of capacity.

Typical Performance for Nickel-Cadmium Battery Technology

Parameter	Range
Power Rating	Fully scalable
Discharge at Rated Power	Minutes to hours
Round Trip Efficiency	60% – 80%
Response Time	milliseconds
Self Discharge per day	0.2% – 0.6 % per day
Power Density	80 – 600 kWm^3
Energy Density	60 – 150 $kWhm^3$
Cycle Life	800 – 3,500 cycles
Depth of Discharge	80%
System Lifetime	15 – 20 years
Cost, power	500 – 1,500 $/kW
Cost, energy	800 – 1,500 $/MWh

Applications

While not excelling in typical measures such as energy density or first cost, NiCd batteries remain relevant by providing simple implementation without complex management systems while providing long life and reliable service. The relative low cost, high energy density, high power delivery capabilities, hardiness, reliability, and life expectancy of NiCd batteries made them a popular choice for substation batteries and bulk storage [0239]. However, increased performance and lowering costs of Li-ion batteries will largely displace NiCd for utility applications.

Maturity

Nickel-cadmium batteries have been in commercial production since the early twentieth century. Used mostly as rechargeable power supply for small appliances, they have seen periodic advances in electrode technology and packaging. Some previous technology applications included telecom or off-grid renewable energy applications. The current technology is considered relatively mature with limited potential to expand beyond its current applications. NiCd batteries are unlikely to compete with Li-ion batteries as a storage medium for utility scale BESS.

Case Studies

Golden Valley Electric Association

The Golden Valley Electric Association (GVEA) Battery Energy Storage System (BESS) was completed in December 2003 and is located in Fairbanks, Alaska. The GVEA BESS was still in operation in 2015. Rated at 27 MW for 15 minutes, the system provides sufficient time to start up local generation in the event of a generation- or transmission-related outage. NiCd technology was selected based on the extreme range of operating temperatures required [0337]. This system also provides voltage regulation, spinning reserve, frequency regulation, power system stabilization, load following, load leveling, and black start applications [0299].

Risks/Barriers

Memory

NiCd batteries can suffer from a “memory effect” if they are discharged and recharged to the same state of charge hundreds of times. The apparent symptom is that the battery “remembers” the point in its charge cycle where recharging began and during subsequent use suffers a sudden drop in voltage at that point, as if the battery had been discharged. The capacity of the battery is not actually reduced substantially. Some electronics designed to be powered by NiCd batteries are able to withstand this reduced voltage long enough for the voltage to return to normal. However, if the device is unable to operate through this period of decreased voltage, it will be unable to get enough energy out of the battery, and for all practical purposes, the battery appears “dead” earlier than normal.

Toxicity

NiCd batteries contain cadmium, which is a toxic heavy metal and therefore requires special care during battery disposal. In the United States, part of the battery price is a fee for its proper disposal at the end of its service lifetime. In the European Union, used industrial NiCd batteries must be collected by their producers to be recycled in dedicated facilities. Because cadmium is a heavy metal, it can cause substantial pollution when discarded in a landfill or incinerated. Because of this, many countries now operate recycling programs to capture and reprocess old batteries.

Applicability for South Africa

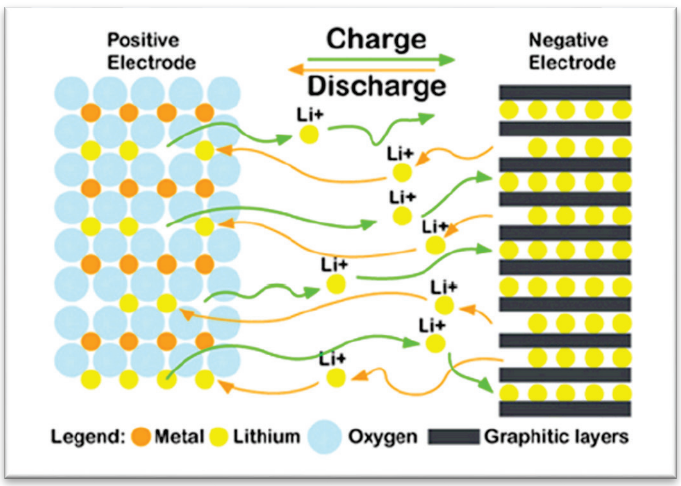
NiCd batteries cannot compete with recent improvements in Li-ion batteries. Better performance and lower cost will make Li-ion a more attractive technology in the future for utility-scale applications in South Africa.

A.5 LITHIUM ION (LI-ION) BATTERIES

A lithium-ion (Li-ion) battery is a rechargeable electrochemical battery. Rather than a single electrochemical couple like NiCd, "lithium-ion" refers to a wide array of chemistries in which lithium ions are transferred between the electrodes during the charge and discharge reactions.

TECHNOLOGY

A Li-ion cell consists of three main components: cathode and anode electrodes and an electrolyte that allows lithium ions to move from the negative electrode to the positive electrode during discharge and back when during charge. When the battery is charging, lithium ions flow from the positive metal oxide electrode to the negative graphite electrode. When the battery is discharging, the ions flow in reverse.



Li-ion battery function and components [0239]

Li-ion technology has been improved significantly through the evaluation and optimization of various combinations of chemistries, each of which presents slightly different performance characteristics. These chemistries can be confusing. Cathode materials can generally be grouped into two categories, namely iron phosphate and mixed metal (combinations of cobalt and manganese oxide). Anode material is generally graphite/carbon or titanate. The following discussion of popular cathode/anode chemistries relevant to stationary energy storage are taken from Bloomberg New Energy Finance [0244] and Berenberg [0277].

NEGATIVE ELECTRODE (CATHODE DURING CHARGING)

The cathode is a key area of focus for research and development into Li-ion batteries because it accounts for a large percentage of total cell costs. Therefore, improvements in the cathode, more than in any other part of the cell, have the potential to reduce cell costs and improve the performance of the battery. Lithium in its pure form is not an effective cathode because it does not favor reversible reactions and because its energy density is reduced significantly when inserted into the cell.

Lithium cobalt oxide (LCO) materials are typically used in Li-ion batteries for consumer electronic applications. Although LCO cathodes have high capacity, they have a lower cycle life, and in a large format LCO battery, they can represent a high potential fire risk and are therefore not generally used for transport applications.

Lithium manganese oxide (LMO) forms a cubic crystalline structure that makes the battery very safe, and it has a high temperature tolerance. Because manganese is cheaper than cobalt, LMO is also lower cost. LMO provides a higher voltage than LCO but has about 20% less energy density. One disadvantage is that, at temperatures above 50°C, manganese can dissolve in the electrolyte, causing a shortened life unless significant thermal management systems are installed in the battery.

Lithium nickel cobalt aluminum oxide (NCA) replaces cobalt with nickel in the cathode, resulting a higher specific energy, higher power density, longer life span, and lower cost. This is further improved by additional cobalt and aluminum, which results in high capacity and voltage with improved stability. NCA currently has a poor temperature tolerance. Finding the optimum ratio of the metals is a continuing area of research and could provide further improvements in power and energy capabilities.

Lithium iron phosphate (LFP) uses phosphorus to bind the oxygen atoms rather than a lithium metal oxide, which results in increased safety even when the battery is hot or overcharged. It also produces a longer cycle life, which is a significant advantage. An LFP cathode has a lower energy density, but it can accept higher currents and therefore has a higher power density. Although LFP materials are lower in cost, these cathodes are more expensive to manufacture. Several companies are developing LFP battery chemistries for stationary applications in which the lower energy density is less important than it would be for a mobile application.

Lithium nickel cobalt manganese (NMC) is a blend of nickel, manganese and cobalt that has a high energy density profile and has the potential to be low cost. The three metals can be combined in various ways to display various properties. Reducing the cobalt content reduces price, but it compromises the electrochemical performance. The high energy density performance of NMC cathodes make it a popular technology for consumer electronics, electric vehicle applications, and ESSs that need frequent cycling.

General Technical Comparison of several Li-ion Cathode Chemistries [0244]

	Commercial			Pre-Commercial		
Cathode Type and Abbreviation	Lithium-Manganese (LMO)	Lithium-Nickel Cobalt Aluminum (NCA)	Lithium-Iron Phosphate (LFP)	Lithium-Nickel Manganese Cobalt (NMC)	Lithium-Air (Commercial Goals)	Lithium-Sulfur (Commercial Goals)
Chemistry	$LiMn_2O_4$	$LiNiCoAlO_2$	$LiFePO_4$	$LiNiMnCoO_2$	LiO_2	LiS
Voltage (V vs Li/Li+)	3.8	3.6	3.4	3.7	3.2	2.2
Specific capacity (mAh/g)	100–120	180–200	170	160–170	1,700 (3,350)	1,000 (1,670)
Volumetric energy density: practical (and theoretical) (Wh/L)	280	250 (730)	130–300	350 (700)	700–1,000 (3,400)	300–800 (2,800)
Gravimetric energy density: practical (and theoretical) (Wh/kg)	110 (280)	210 (280)	120 (219)	190 (290)	500–1,000 (3,500)	400–550 (2,500)
Cycle life	500–1,000	500	2,000–3000	1,000–2,000	1,000	<1,000

Positive Electrode (anode during charging)

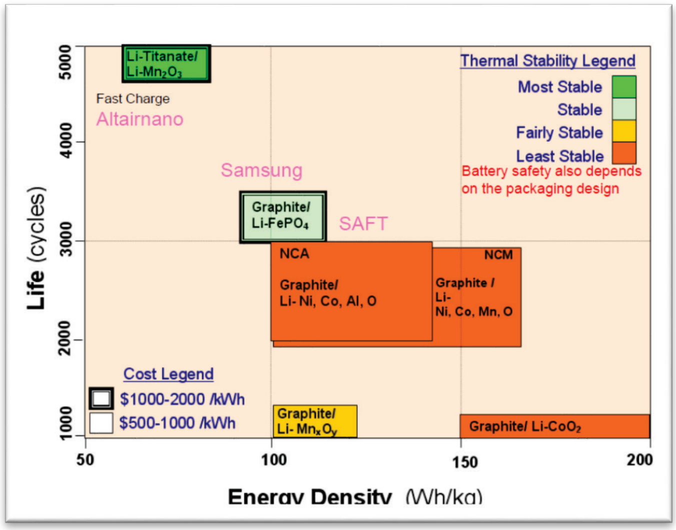
The role of the anode is to accept lithium ions and release them when required without disrupting the structure of the material. Lithium metal would normally be the first choice for anode material; during charging, however, the lithium swells considerably, causing fissures on the surface and allowing lithium ions to escape. In addition, metallic lithium and current electrolytes are highly reactive, which cause safety issues. Some anodes are being developed that are a composite or combination of types of chemistries.

Carbon (or graphite) is used for most lithium-ion anodes. Carbon has an "intercalating" property: lithium ions sit between the layers of bonded carbon atoms and can be released without interfering with the material structure. This provides for a very high capacity and excellent cycle life. Synthetic graphite (rather than natural graphite) has an increased cycle life, a higher capacity, and less swelling; however, synthetic graphite is more expensive. Some companies use a combination of natural and synthetic graphite. Hard carbon and soft carbon have been used as alternatives to graphite to improve the performance due to their high discharge capacity and higher voltage; however, this can cause issues with voltage variability.

Lithium titanate oxide (LTO) is a cubic crystalline structure that produces a higher voltage (1.5 V), enabling it to overcome safety problems that graphite anodes have at low temperatures and high currents. Electrolytes are more stable at the higher voltages of LTO than the low voltage of graphite; LTO does not swell during operation, and lithium does not plate onto the anode at this high voltage. The LTO anode can exhibit a lifetime of up to 20 years. However, an LTO anode is significantly more expensive than graphite.

Silicon anodes are actually made of carbon with a silicon additive. Rather than providing for intercalation (like graphite), silicon reversibly reacts with lithium to form a silicon-lithium alloy.

Theoretically, silicon has a capacity 10 times that of graphite, making it a much more powerful anode. However, during alloying, the silicon swells significantly and thus offers a very poor cycle life that must be addressed before it can be an effective anode.



Performance of various Li-ion chemistries [0337]

Electrolyte

Li-ion cell electrolytes are typically fluorine-based lithium salts in an organic solvent. This combination can withstand typical cell voltages, has a cycle life of about 5,000 cycles, and has a high coulometric efficiency (it carries all the ions between the anode and cathode). Many electrolyte research and development (R&D) activities are dedicated to researching additives for the electrolyte to further improve the cell life, safety or the maximum voltage of cell. One of the main roles of the additives is to reduce the side reactions within the cell, thereby increasing cell life. Several companies have introduced inorganic electrolytes which are nonflammable and inherently safer than the combustible organic solvents. Alevo uses an inorganic electrolyte and claims over 50,000 cycles to date on its aqueous LFP cells [0315].

Electronics

Electronic battery management subsystems are an important feature for Li-ion batteries, which lack the capability of aqueous technologies (e.g., lead-acid batteries) to dissipate overcharge energy. Safety characteristics of Li-ion batteries are ultimately determined by the attributes of system design, including mechanical and thermal characteristics, electronics and communications, and control algorithms, regardless of electrochemistry.

Packaging and Construction

Li-ion cells may be produced in cylindrical or prismatic (rectangular) format. These cells are then typically built into multicell modules in series/parallel arrays, and the modules are connected together to form a battery string at the required voltage, with each string being controlled by a battery management system.

PERFORMANCE

As discussed in the technology section above, Li-ion performance depends on the electrode and electrolyte materials (chemistries); however, the following generalizations apply.

Typical performance for Li-ion battery technology

Parameter	Range
Power Rating	Fully scalable
Discharge at Rated Power	generally < 4 hours
Round Trip Efficiency	92% – 96%
Response Time	milliseconds
Self Discharge per day	0.1 – 0.3% per day
Power Density	200 – 500 kWm^3
Energy Density	1,500 – 10,000kWhm^3
Cycle Life	2,000 – 20,000 cycles
Depth of Discharge	~80%
System Lifetime	10 – 20 years
Cost , Energy	200 – 3,800 $/kWh
Cost, Power	175 – 4,000 $/kW
Actual cost/performance is highly dependent on chemistry and manufacturer	

One disadvantage of Li-ion batteries is that the expected lifetime is related to the cycling depth of discharge. Although they perform better than lead-acid batteries, which perform better at less than <50% depth of discharge [DoD]), Li-ion batteries' lives are generally limited to <80% DoD to ensure an adequate life.

APPLICATIONS

Li-ion batteries have been deployed in a wide range of energy-storage applications, ranging from energy-type batteries of a few kilowatt-hours in residential systems with rooftop PV arrays to multimegawatt containerized batteries to provide grid ancillary services. Li-ion batteries can meet all the identified use cases for South Africa.

CONSTRUCTION AND INSTALLATION

The modularity of the Li-ion cells allows them to be constructed as modules and scaled. Battery packs can then be combined with inverters and controls systems and packaged into BESS at manufacturing facilities. When packaged into standard shipping container sizes, shipping the BESS around the world via truck, rail, or ship is greatly facilitated. Containerized BESS can be sited on pads or simple foundations and electrically connected to switchgear. Containerization significantly reduced the costs for local labor and on-site construction.

Operation and Maintenance

Small ESS for residential and light industrial or office buildings are essentially maintenance free and require little on-site monitoring. This is particularly true for systems that are monitored remotely and maintenance staff can be dispatched as needed. The greatest maintenance issue for Li-ion batteries is generally the monitoring and replacement of individual cells/modules later in life as replacement is required.

Decommissioning and Disposal

Modularized and packaged systems offer ease of system removal from site for disposal at end of life. Site contamination is unlikely, and site restoration would include infrastructure removal and revegetation. The materials used in Li-ion batteries are typically considered nonhazardous waste. The metals in the system can be recycled, but they do not represent a high salvage value.

Maturity

Li-ion batteries are a relatively mature commercial technology and are now the dominant electrical storage technology in automotive applications for both electric vehicles and hybrids. Although manufacturers are still experimenting with formulations and fabrication techniques to improve performance, reliability and reduce costs, the overall performance of this technology is reasonably well developed and understood. Most MW and MWh scale utility applications have been operating for less than 5 years of a presumed 10-year lifetime and some of the newer formulations have been operating for significantly less than that. Long-term performance reliability data is therefore still being confirmed. The recent construction of several gigawatt factories in the United States, Japan, and China is indication of confidence in the maturity and bankability of the Li-ion technology.

Case Studies

Demonstrations have shown Li-ion batteries' ability to support the use cases identified for South Africa.

Pacific Northwest Smart Grid Demonstration. A 5-MW/1.25-MWh (15-minute) system was installed in Salem, Oregon, in 2013. It provides renewables time shifting, renewables capacity firming, electric energy time shifting, and electric supply capacity [0365].

AES Elkins. One of the largest Li-ion installations in the United States is in Elkins, West Virginia. This facility installed by AES connects 98 MW of wind generation with 32 MW/8 MWh (15 minutes) of storage for reserve capacity and renewables integration and has been in service since 2011 [0365].

Tehachapi. A final demonstration worth mentioning is the Tehachapi energy storage project in Tehachapi, California. This project is funded by the American Recovery and Reinvestment Act (ARRA) and uses an 8-MW/32-MWh (4-hour) Li-ion battery to demonstrate voltage support (grid stabilization), avoid transmission curtailment, system reliability, transmission investment deferral, renewable energy transmission effectiveness, system capacity credit, renewable energy smoothing, time shift of wind generation, frequency regulation, spin/non-spin replacement reserves, load following, and energy price arbitrage [0365].

Risks/Barriers

The risks and barriers associated with Li-ion technologies are well understood and have been substantially overcome.

Overheating and Runaway

One of the greatest challenges facing lithium-ion is safety. The energy density of the cells and the combustibility of the organic-based electrolyte make these batteries a fire hazard. Excessive charging, discharging, high current, or imbalances between cells can cause overheating in a cell and result in thermal runaway as neighboring cells also overheat. Extreme high temperatures lead to leaks, smoke, gas venting, and/or combustion of the cell pack. Manufacturers of large systems have employed sophisticated battery management systems to monitor cell performance and limit operation to safe and acceptable performance ranges [0079].

Cost

Manufacturing costs associated with Li-ion batteries and a relatively short cycle life have limited their early implementation for large utility-scale ESSs. Recently, Li-ion has been able to compete with NaS batteries based on improved performance and cost. Li-ion battery development is following a similar learning curve: electronics and solar PVs with manufactured battery cell costs having fallen by 50% in the last 5 years from $440/kWh to $200/kWh in 2015. Li-ion battery costs are predicted to fill by 40% to 45% by 2020, resulting from a 30% to 35% cost reduction from economies of scale at the cell level economies of scale and a 20% cost reduction from economies of scale at the pack level [0227]. When combined with the potential increases in performance (particularly the longer life cycles offered by LFP batteries), lithium may continue to be a dominant technology.

Suitability for South Africa

Li-ion technology is a commercial and proven electrochemical battery technology. It exhibits a high energy density and moderate cost that can be scaled for a wide variety of energy storage applications. A variety of chemistries and formulations yield slightly different performance characteristics. Li-ion is and will likely continue to be the dominant energy storage technology for the next 10 to 15 years and will be the yardstick by which other technologies are compared.

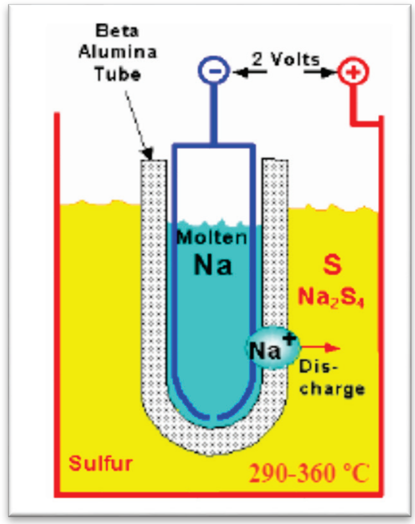
Li-ion systems are the basis for many current residential and industrial-commercial BESS being installed and will be increasingly used for grid connected utility-scale applications globally and in South Africa as prices fall. Beyond the prospect for local cell manufacture, these systems will require local resources for final system assembly, installation, operation, and maintenance.

A.6 Sodium Sulfur (NaS) Batteries

Sodium-sulfur batteries are high-temperature devices that operate between 300° and 350°C. There have been significant installations of NaS for energy storage to facilitate distribution line construction deferral.

Technology

The active materials in a NaS battery are molten sulfur as the positive electrode and molten sodium as the negative. The electrodes are separated by a solid ceramic, sodium alumina, which also serves as the electrolyte. This ceramic allows only positively charged sodium ions to pass through. During discharge, electrons are stripped off the sodium metal (one negatively charged electron for every sodium atom), leading to formation of the sodium ions that then move through the electrolyte to the positive electrode compartment. The electrons that are stripped off the sodium metal move through the circuit and then back into the battery at the positive electrode, where they are taken up by the molten sulfur to form polysulfide. The positively charged sodium ions moving into the positive electrode compartment balance the electron charge flow. During charge, this process is reversed [0310].



Schematic of sodium sulfur cell [0239]

Packaging and Construction

NaS batteries use hazardous materials, including metallic sodium, which is combustible if exposed to water. Therefore, NaS batteries have airtight, double-walled stainless-steel enclosures that contain the series-parallel arrays of NaS cells. Each cell is hermetically sealed and surrounded with sand both to anchor the cells and to mitigate fire. Other safety features include fused electrical isolation and a battery management system that monitors cell block voltages and temperature.

Performance

The round-trip AC-to-AC efficiency of sodium-sulfur systems is approximately 80%. The estimated life of a sodium-sulfur battery is approximately 15 years after 4,500 cycles at 90% depth of discharge [0240].

Typical Performance for Sodium-Sulfur Battery Technology

Parameter	Range
Power Rating	Fully scalable
Discharge at Rated Power	6 – 8 hours
Round Trip Efficiency	75% – 90%
Response Time	milliseconds
Self Discharge per day	20% per day
Power Density	140 – 180 kWm^3
Energy Density	150 – 300 kWhm^3
Cycle Life	2,500 – 4,500 cycles
Depth of Discharge	90%
System Lifetime	12 – 20 years
Cost, power	1,000 – 3,000 $/kW
Cost, energy	300 – 500 $/MWh

Applications

NaS batteries are appropriate for both energy and power applications. They can also serve power and energy applications simultaneously, making them particularly useful. Current installations and demonstrations have showed their suitability for peak shaving, load shifting, power quality control, uninterruptable power systems, "islanding," and storage of intermittent renewables [0239].

Decommissioning and Disposal

The sodium, sulfur, beta-alumina ceramic electrolyte, and sulfur polysulfide components of the battery are disposed of by routine industrial processes or recycled at the end of the NaS battery life.

Maturity

NaS batteries were originally developed by Ford Motor Company in the 1960s; the technology was subsequently sold to the Japanese company NGK. NGK now manufactures the battery systems for stationary applications [0310]. NaS batteries are a relatively mature composition in the power market. They were demonstrated and used in Japan by the Tokyo Electric Power Company and NGK Insulators in the late 1990s. They have been commercially available since 2002 [0242].

Case Study

NaS battery technology has been demonstrated at over 190 sites in Japan. More than 270 MW of stored energy suitable for 6 hours of daily peak shaving have been installed. The largest NaS installation is a 34-MW, 245-MWh unit for wind stabilization in northern Japan [0310].

American Electric Power (AEP) Company was an early adopter of NaS batteries in the United States. Between 2006 and 2008, AEP installed four systems totaling 7.2 MW at substations in the midwestern United States to provide load leveling and alleviate transformer loading during summer peaks, defer capital upgrades, and offer emergency backup power to several hundred customers during electrical system outages. The units provide the utility time to decide whether to redesign a substation, build generation, or keep the storage units in place permanently. All of the NaS systems are capable of being relocated for an estimated $85,000 to $115,000 if and when the company's storage needs change [0365].

1-MW / 7.2-MWh sodium-sulfur BESS at substation for T&D deferral

RISKS/BARRIERS

The risks and barriers associated with sodium sulfur are well understood.

FIRE

NaS batteries must operate at extremely high temperatures and can explode if they come into contact with water, making them a safety hazard if not handled properly. Like any battery, toxicity concerns, especially those related to decommissioning and disposal, are still major obstacles to widespread installation. Consumers dislike the prospect of batteries located close to residential or highly populated areas [0239].

In September 2011, an NaS Battery manufactured by NGK Insulators caught fire at a Mitsubishi Plant in Japan The fire was a result of breach in a battery cell that leaked hot molten material. This caused a short circuit that emitted additional heat and destroyed a number of other battery cells, which in turn caught fire. Following this fire and investigation, NGK added additional fuses, insulation, fire barriers, and fire suppression systems to improve safety, and retrofitted the NaS systems already deployed [0367].

Reliability

If not maintained near operating temperature, thermal expansion from freeze-thaw cycles could lead to mechanical stresses, damaging seals and other cell components. In the event of damage to the solid electrolyte, a breach could allow the two liquid electrolytes to mix, possibly causing an explosion and fire. Thus, the battery must have insulation and active heating, which increases system costs and reduces round trip efficiency.

Cost

Cost reductions in other technologies (Li-ion and flow batteries) may allow them to compete favorably with NaS.

Suitability for South Africa

NaS-based ESS is a suitable technology for South Africa for applications with longer energy-intensive (6- to 8-hour) cycles. Flow batteries, however, may prove to be a safer and more economical solution.

A.7 Sodium-Nickel-Chloride Batteries

The sodium nickel chloride battery is a high-temperature, molten sodium-based battery. Sometimes referred as a ZEBRA battery, the technology was developed in 1985 by the Zeolite Battery Research Africa (ZEBRA) project at the Council for Scientific and Industrial Research (CSIR) in Pretoria, South Africa.

Technology

Sodium-nickel-chloride batteries contain a molten sodium negative electrode and a nickel chloride positive electrode. To facilitate ion transfer, the battery operates around 270°C [239]. When charging a sodium-nickel-chloride battery at normal operating temperatures, salt (NaCl) and nickel (Ni) are transformed into nickel-chloride ($NiCl_2$) and molten sodium (Na). The chemical reactions are reversed during discharge, and there are no chemical side reactions. The electrodes are separated by a ceramic wall (electrolyte) that is conductive for sodium ions but an isolator for electrons. Therefore, the cell reaction can only occur if an external circuit allows electron flow equal to the sodium ion current. The porous solid $NiCl_2$ cathode is impregnated with a sodium ion-conductive salt ($NaAlCl_4$) that provides a conductive path between the inside wall of the separator and the reaction zone. Cells are hermetically sealed and packaged into modules of about 20 kWh each [0235].

An internal normal operating temperature of 270° to 350°C is required to achieve acceptable cell resistance and must be thermally managed by design features. The ZEBRA battery uses molten sodium aluminum chloride as its electrolyte. Sodium nickel batteries are produced by FIAMM SONICK and General Electric (GE).

Each cell is hermetically sealed within its own metal case and is strung together with other cells in a thermally insulated battery module, which ensures that the battery's external surfaces remain within 10° to 15°C of the surrounding ambient temperature. GE's Durathon batteries are managed by the Durathon Battery Management System, which controls and protects the battery and relays information for monitoring the battery's condition.

PERFORMANCE

Sodium-nickel-chloride batteries have been produced with power ratings between 5 and 500 kW with up to 100 kWh of energy. ZEBRA units have 85% to 90% round trip efficiency, 20-ms response times, and expected cycle lives of up to 3,000 cycles at 80% DoC [0239].

Some advantages over NaS chemistry include tolerance of overcharge and discharge, higher cell voltage, and potentially better safety characteristics. In addition to its high tolerance of short circuits, the failure of one cell in a ZEBRA battery does not cause complete failure of the battery [0239].

Typical performance for sodium-nickel-chloride battery technology

Parameter	Range
Power Rating	Fully scalable
Discharge at Rated Power	generally < 4 hours
Round Trip Efficiency	85% – 90%
Response Time	milliseconds
Self Discharge per day	15% per day
Power Density	220 – 300 kWm^3
Energy Density	150 – 200 kWhm^3
Cycle Life	>2,500 cycles
Depth of Discharge	80%
System Lifetime	12 – 20 years
Cost, power	150 – 300 $/kW
Cost, energy	100 – 200 $/MWh

APPLICATIONS

Developed in the 1970s and commercialized since the mid-1990s, sodium-nickel-chloride batteries have found application in electric vehicles and hybrid electric buses, trucks, and vans. The implementation of sodium-nickel-chloride batteries in stationary applications is relatively new. Demonstration systems combined with distributed renewable generators (large PV plants and micro wind turbine) as well as for grid support have been designed and are in field test phase.

Maturity

Much of the early research has been with electric vehicles in mind; however, sodium-nickel-chloride battery systems are in development for renewable integration and load leveling applications [0239]. In 2010, GE introduced a Na-$NiCl_2$ battery under the Durathon brand name. It also referred to the technology as sodium-metal halide battery. Originally developed for train locomotives, the Durathon product was advertised as having a 20-year lifetime and at least 3,500 charge cycles. Although Na-$NiCl_2$ is a relatively mature technology, only a few manufacturers have products in commercial production. Other sodium-metal halide chemistries allow substantially lower operating temperature and lower discharge rates.

Case Study

The GE Durathon battery has deployed a significant quantity of smaller scale units to back up cellphone towers and other telecom sites, with about $63 million in orders placed as of 2012. GE has also put 50-kWh versions of its Durathon batteries to use in some of its wind power deployments, and in 2013 it had announced a 500-kWh demonstration system to back up the nonprofit Discovery Science Center in Santa Anna, California [0365].

Risks/Barriers

If the battery is not required for an extended period, the heater can be switched off and the battery allowed to solidify. This freezes in the state of charge; no charge is lost while the battery is frozen. Unlike the earlier sodium-sulfur battery, an unlimited number of freeze-thaw cycles can be performed without damage or loss of capacity [0335]. Once solid, it can take up to 12 hours to reheat and charge, depending on the battery pack temperature and power available for reheating. After shutdown, a fully charged battery pack loses enough energy to cool and solidify in 3 to 4 days.

Cost/Performance

Recent technology improvements and cost reductions in Li-ion batteries have yielded a room temperature battery with higher performance at a lower cost than sodium-nickel-chloride batteries. In January 2015, GE announced a significant scale-back at its Durathon (sodium-nikel-chloride) manufacturing facility in Schenectady, New York.

Suitability for South Africa

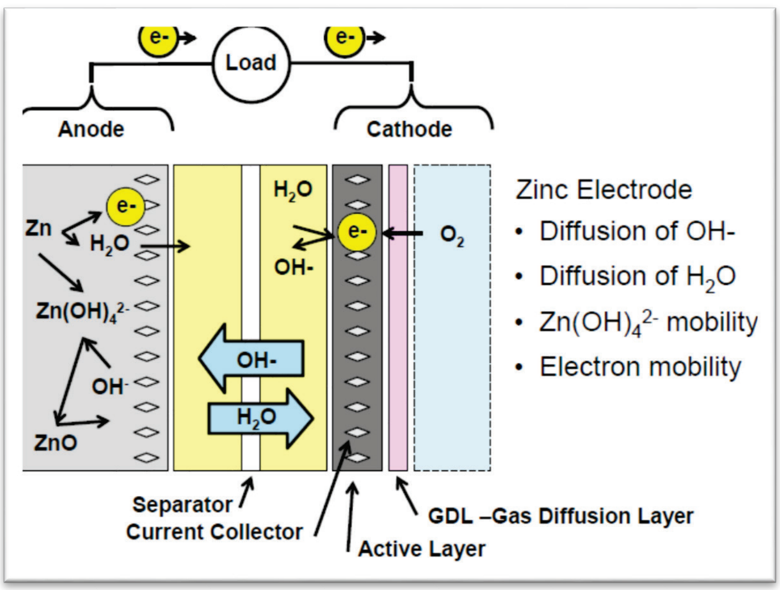
Although able to operate in relatively harsh climates, the cost and performance of the current sodium-nickel-chloride battery is not currently competitive for stationary utility-scale energy storage applications.

A.8 Zinc-Air Batteries

A metal-air electrochemical cell consists of the anode made from pure metal and the cathode connected to an inexhaustible supply of air. For the electrochemical reaction, only the oxygen in the air is used [0252]. Zinc–air is one of these metal-air electrochemical technologies. These batteries use the oxygen in ambient air to oxidize zinc. These batteries have the potential for high energy densities and low production costs.

TECHNOLOGY

Zinc-air batteries are a metal-air electrochemical cell technology. Metal-air batteries use an electropositive metal, such as zinc, aluminum, magnesium, or lithium, in an electrochemical couple with oxygen from the air to generate electricity. Because such batteries only require one electrode within the product, they can have very high energy densities. In addition, the metals used or proposed in most metal-air designs are relatively low cost. This has made metal-air batteries potentially attractive for electric vehicle and power electronics applications in the past, as well as raising hopes for a low-cost stationary storage system for grid services. Zinc-air batteries take oxygen from the surrounding air to generate electric current. The oxygen serves as an electrode, while the battery construction includes an electrolyte and a zinc electrode that channels air inside the battery as shown below [0235].



Schematic for zinc-air battery cell [0235] (courtesy ReVolt)

The zinc-air battery produces current when the air electrode is discharged with the help of catalysts that produce hydroxyl ions in the liquid electrolyte. The zinc electrode is then oxidized and releases electrons to form an electric current. When the battery is recharged, the process is reversed, and oxygen is released into the air electrode [0235].

Anode: $Zn + 4OH^- \rightarrow Zn(OH)_4^{2-} + 2e^-$ (E_0 = - 1.25 V)

Fluid: $Zn(OH)_4^{2-} \rightarrow ZnO + H_2O + 2OH^-$

Cathode: $1/2\ O_2 + H_2O + 2e^- \rightarrow 2OH^-$ (E_0 = 0.34 V pH = 11)

Overall: $2Zn + O_2 \rightarrow 2ZnO$ (E_0 = 1.59 V)

Cell reactions for zinc-air battery

PERFORMANCE

Zinc-air batteries have up to three times the energy density of Li-ion, its most competitive battery technology. Unlike lithium-ion, however, zinc-air batteries neither produce potentially toxic or explosive gases, nor do they contain toxic or environmentally dangerous components. Zinc-oxide, which is the main material in a zinc-air battery, is 100% recyclable [0235].

One early developer, Eos Energy Storage, has indicated that it intends to sell its initial rechargeable zinc-air battery products for $1000 per kilowatt for a 6-hour battery, or $160/kWh. Eos' stated goal is over 10,000 cycles at "a full-duty cycle and at full depth of discharge." The first battery pack will be capable of storing 6 MWh of power, and the system will fit in a 40-ft storage container [0368].

Typical performance for zinc-air battery technology

Parameter	Range
Power Rating	Fully scalable
Discharge at Rated Power	hours
Round Trip Efficiency	50% – 70%
Response Time	< second
Self Discharge per day	% per day
Power Density	50 – 100 kWm3
Energy Density	130 – 200 kWhm3
Cycle Life	>1,000 cycles
Depth of Discharge	100%
System Lifetime	>1 year
Cost, power	1,750 – 1,900 $/kW
Cost, energy	325 – 350 $/kWh

APPLICATIONS

In addition to EV applications, zinc-air batteries are expected to have strong potential for longer energy intensive applications including off-grid and microgrid. For utility-scale applications Zinc-Air can support T&D deferral, energy arbitrage, and renewable integration.

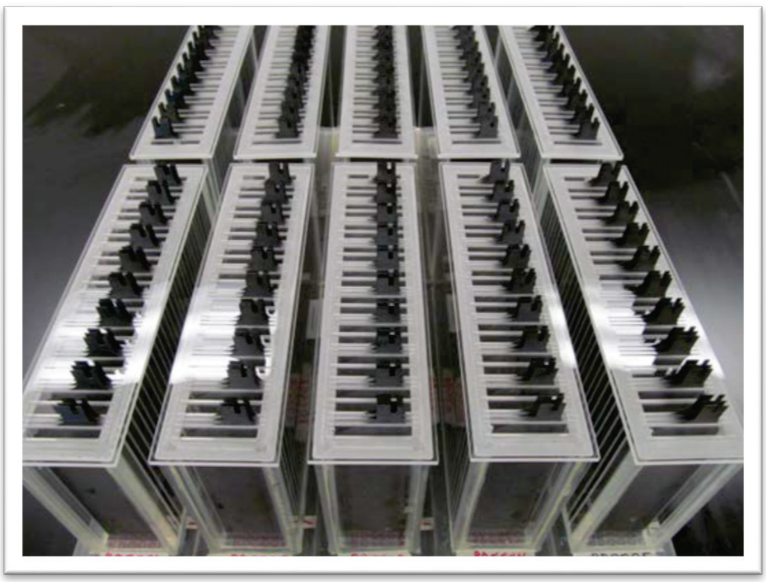
Maturity

Zinc-air technology is still in the early R&D phase for stationary storage systems for grid service markets. Despite substantial technical obstacles faced in the past, this technology holds a great deal of potential because of its low capital cost for grid support and potentially for electric transportation applications.

A few early-stage companies are attempting to bring energy-dense, high-operating-efficiency, better DoC stationary systems to the market, particularly for utility T&D grid support and renewable energy integration. R&D is under way by several companies, with some research still in the university laboratory stage [0235].

Case Study

The Eos Energy System battery is about half the size of a shipping container and provides 1 MWh of storage. Con Edison, National Grid, Enel, and GDF Suez began testing the battery for grid storage. Con Edison and City University of New York are testing a zinc-based battery from Urban Electric Power as part of a New York State Energy Research and Development Authority program.



1-kW zinc-air prototype [0368]

Pacific Gas and Electric Company (PG&E) announced on December 2, 2015, that it had awarded to Convergent Energy + Power, a 10-MW, 40-MWh energy storage project that will use the zinc-hybrid cathode (ZnythTM) battery technology developed by Eos Energy Storage [0368].

Risks/Barriers

Developmental Challenges

The challenge for researchers has been to address issues such as electrolyte management, avoiding carbon dioxide (CO2) impacts from the air on the electrolyte and cathode, thermal management, and avoiding Zn dentrite formation. Methods are also being investigated to address issues with the air electrolyte not deactivating in the recharging cycle and slowing or stopping the oxidation reaction. The cessation of the oxidation reaction reduces the number of times that a zinc-air battery can be recharged [0235].

Despite the many advantages, metal-air batteries also pose several historical disadvantages. The batteries are susceptible to changes in ambient air conditions, including humidity and airborne contaminants.

Cost

The air electrode – a sophisticated technology that requires a three-way catalytic interface between the gaseous oxygen, the liquid electrolyte, and the solid current collector – has been difficult and expensive to make. However, the technology is far more stable and less dangerous than other battery technologies.

Combustion

Zinc corrosion can produce potentially explosive hydrogen. Vent holes prevent pressure buildup within the cell. Manufacturers caution against hydrogen build-up in enclosed areas. A short-circuited cell gives relatively low current.

Suitability for South Africa

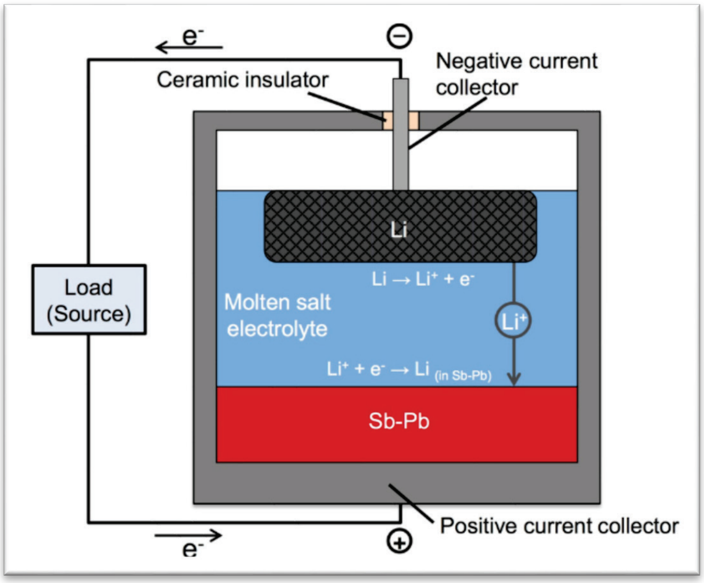
Zinc-air is an emerging technology and is still in the R&D phase. It has very high potential, but it must first be proven and demonstrated at smaller scales [0240].

A.9 Liquid Metal Battery

An early-phase developmental high-temperature liquid metal battery comprises two liquid metal electrodes separated by a molten salt electrolyte that self-segregate into three layers based on density and immiscibility [0369].

Technology

Similar to a conventional battery, a liquid metal battery has two electrodes with an electrolyte between them. During discharging and recharging, positively charged metallic ions travel from one electrode to the other through the electrolyte, and electrons make the same trip through an external circuit. In a liquid metal battery, however, all three layers are liquid. The negative electrode—the top layer in the battery—is a low-density liquid metal that readily donates electrons. The positive electrode—the bottom layer—is a high-density liquid metal that readily accepts those electrons. The electrolyte—the middle layer—is a molten salt that transfers charged particles but will not mix with the materials above or below. Because of the differences in density and the immiscibility of the three materials, they naturally settle into three distinct layers and remain separate as the battery operates.



Molten metal battery [0304]

This approach provides a number of benefits. Because the components are liquid, the transfer of electrical charges and chemical constituents within each component and from one to another is ultrafast, permitting the rapid flow of large currents into and out of the battery. When the battery discharges, the top layer of molten metal gets thinner and the bottom one gets thicker. When it charges, the thicknesses reverse. No stresses are involved; the entire system is very pliable and assumes the shape of the container. While solid electrodes are prone to cracking and other forms of mechanical failure over time, liquid electrodes do not degrade with use.

When the battery is charged, ions from the top metal that have been deposited into the bottom layer are returned to the top layer, purifying the electrolyte in the process. All three components are reconstituted. In addition, because the components naturally self-segregate, membranes or separators, which are subject to wear, are not necessary. A liquid battery could perform many charges and discharges without losing capacity or requiring maintenance or service. The self-segregating nature of the liquid components could also facilitate simpler, less-expensive manufacturing compared to conventional batteries [0304].

Performance

This technology is still in the R&D phase, but Ambri scientists claim to have built more than 2,500 liquid metal battery cells and have achieved thousands of charge-discharge cycles with negligible reduction in the amount of energy stored.

A significant advantage to the proposed technology will be the cost. A recent paper written by Massachusetts Institute of Technology (MIT) scientists concluded liquid metal batteries currently produced at the laboratory-scale generally have cell electrode materials energy costs of $50/kWh to $100/kWh and power costs of $50/kW to $400/kW. When allowing for battery balance of system costs (typically on the order of four times the material costs), liquid metal batteries have the potential to outperform lead-acid, NaS, NiCd, Li-ion, and various flow cell devices on both a cost per energy and cost per power basis, all before accounting for unknown economies of scale [0369].

In addition, due to the unique design of the three-liquid-layer system, which enables rapid charge−discharge and long life imparted by robust liquid electrodes, continuous operational lifetimes in excess of 20 years might be possible [0369].

Potential performance for liquid metal battery technology

Parameter	Range
Power Rating	Currently bench scale
Discharge at Rated Power	Minutes – hours
Round Trip Efficiency	80%
Response Time	milliseconds
Self Discharge per day	almost zero
Power Density	—
Energy Density	—
Cycle Life	2,700 cycles
Depth of Discharge	100%
System Lifetime	20 years*
Cost, power	200 – 1,600 $/kW*
Cost, energy	200-400 $/kWh*
*Speculative estimates of future performance.	

Applications

Specific applications for this technology cannot be fully evaluated until the final cost and performance metrics are understood for commercial product. A liquid battery should be inexpensive and exhibit a long cycle life without performance degradation. The technology will be able to respond quickly to charge/discharge and its electrodes can operate at electrical currents tens of times higher than any previous battery, making it capable of quickly absorbing large amounts of electricity.

Maturity

Initial development of a liquid metal battery started in 2006 at MIT in Boston, where initial success with bench scale prototypes led to more than $11 million from funders including the US DOE's ARPA–E program [0304].

A spinoff from MIT, Ambri was founded in 2011 and is an early-stage company. Ambri is headquartered in Cambridge, Massachusetts, and recently opened a manufacturing facility in Marlborough. In 2014, Ambri had hoped to deploy five prototype systems for testing around the United States in the next year. In September 2015, however, Ambri announced that it had not met the technology challenges necessary to deliver commercial prototypes and that a reduction in staff and slowed commercialization path would allow more time to solve the remaining engineering challenges. Thus liquid metal battery technology is a relatively immature and its commercial entry may be five or more years away.

Case Study

No case studies are available; this technology is in R&D and early development.

Risks/Barriers

This is a relatively immature technology that requires refinement and improvement to reach commercial maturity.

Battery Seal

A mechanical seal is necessary to stop air from leaking into each individual cell. An effective, low-cost seal that can be designed into the final battery manufacturing has not yet been achieved and is necessary to achieve extended multiyear high-temperature battery operation [0303].

High Temperature

High operating temperatures require the battery to have active heating systems that increase costs and reduce round trip efficiency. Improvements to liquid metal chemistry are necessary to increase performance while allowing reduced operating temperatures.

Suitability for South Africa

This is a promising technology, but it is still in the R&D phase. When commercially mature in 5 to 10 years, this technology has the potential for application internationally and in South Africa.

A.10 Redox Flow Batteries

A redox flow battery (RFB) is a rechargeable battery in which the energy is stored in one or more electrolyte species dissolved into liquid electrolytes. The electrolytes are stored externally in tanks and pumped through electrochemical cells that convert chemical energy directly into electrical energy and vice versa, on demand. The power density is defined by the size and design of the electrochemical cell; the energy density or output depends on the size of the electrolyte tanks [0241].

TECHNOLOGY

Flow batteries are reaction stacks separated from one or more of the electrolytes held in external storage tanks. Either one or both active materials are in solution in the electrolyte at all times. Flow batteries have unique characteristics in terms of the power (rate at which energy changes) and energy (volume of energy) they provide. Power (in kW) is a function of the number of cells that are stacked; energy (kWh) is a function of the electrolyte volume, which is circulated by pumps. Flow batteries are generally less affected by overcharge or discharge. This means they can be used without significant degradation of performance. This is even the case when using the majority of energy capacity (deep discharge) uncommon for most battery types and a distinct advantage for this type of battery. On the other hand, tanks, piping, and pumps associated with electrolyte storage and flow add costs and maintenance to the plumbing and pipe work ads to the cost, and the electrolyte may be prone to leaks and must be contained [242].

Until now, membrane materials have been susceptible to premature degradation and contamination and/or are expensive. Flow batteries are often used for storing and discharging long durations of energy supply (typically between 2 and 10 hours). Leading chemistries at the moment include vanadium redox and zinc bromine redox flow batteries.

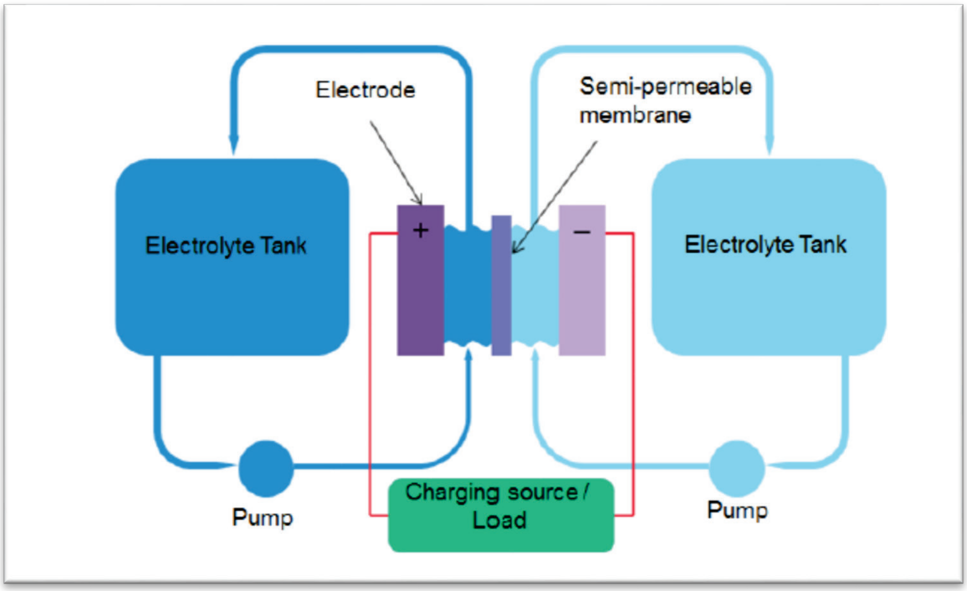
Redox flow batteries (RFB) can be divided into two categories. In a true redox flow battery, the active chemical species used to store energy remain dissolved in solution. This allows for the separation of power and energy capacity during battery design as the power is determined by the reaction cell and the energy is determined by the volumes of electrolyte available. Examples of true RFBs include the vanadium-vanadium and iron-chromium systems.

In a hybrid redox flow battery, at least one chemical specie is deposited as a solid in the electrochemical cells during charge. This prevents the complete separation of power and energy characteristics. Examples of hybrid RFBs include the zinc-bromine and zinc-chlorine systems.

Redox flow batteries represent one class of electrochemical energy storage devices. The term “redox” refers to chemical reduction and oxidation reactions employed in the RFB to store energy in liquid electrolyte solutions that flow through a battery of electrochemical cells during charge and discharge.

During discharge, an electron is released via an oxidation reaction from a high chemical potential state on the negative or anode side of the battery. The electron moves through an external circuit to do useful work. Finally, the electron is accepted via a reduction reaction at a lower chemical potential state on the positive or cathode side of the battery. The direction of the current and the chemical reactions are reversed during charging.

The total difference in chemical potential between the chemical states of the active elements on the two sides of the battery determines the electromotive force (emf or voltage) generated in each cell of the battery. The voltage developed by the RFB is specific to the chemical species involved in the reactions and the number of cells that are connected in series. The current generated by the battery is determined by the number of atoms or molecules of the active chemical species that are reacted within the cells as a function of time. The power delivered by the RFB is the product of the total current and total voltage developed in the electrochemical cells. The amount of energy stored in the RFB is determined by the total amount of active chemical species available in the volume of electrolyte solution present in the system.



Schematic for typical of flow battery [0245]

The separation of power and energy also provides design flexibility in the application of RFBs. The power capability (stack size) can be directly tailored to the associated load or generating asset. The storage capability (size of storage tanks) can be independently tailored to the energy storage need of the specific application. In this way, RFBs can economically provide an optimized storage system for each application. In contrast, the ratio of power to energy is fixed for integrated cells at the time of design and manufacture of the cells. Economies of scale in cell production limit the practical number of different cell designs that are available. Hence, storage applications with integrated cells will usually have an excess of power or energy capability.

An additional advantage of flow batteries is that flow can easily be stopped during a fault condition. As a result, system vulnerability to uncontrolled energy release in the case of RFBs is limited by system architecture to a few percent of the total energy stored. This feature is in contrast with packaged, integrated cell storage architectures (lead-acid, NaS, Li-ion) in which the full energy of the system is connected at all times and available for discharge.

One of the primary barriers to the deployment of flow battery systems has been the reluctance of the utilities to allow the interconnection of untried/unproven storage devices on the utility grid. Much of this reluctance is based on the early failures of flow battery systems that were introduced before they were fully ready to perform a successful demonstration. The rush to bring poorly designed and untried flow battery systems to market has contributed heavily to this reluctance. Another barrier to the wide deployment of flow battery systems is the issue of bringing large quantities of potentially dangerous liquid electrolytes to locations that could expose the public to these chemicals in the event of a spill. The public perception of the danger in having bromine chemicals nearby is somewhat widespread. This "not-in-my-backyard" issue has been a major obstacle in the deployment of large flow battery systems [0373].

A.11 Vanadium Redox Flow Battery (VRFB)

Technology

The vanadium redox flow battery (VRFB) is based on redox reactions of different ionic forms of vanadium. During battery charge, V3+ ions are converted to V2+ ions at the negative electrode through the acceptance of electrons. Meanwhile, at the positive electrode, V4+ ions are converted to V5+ ions through the release of electrons. Both of these reactions absorb the electrical energy put into the system and store it chemically. During discharge, the reactions run in the opposite direction, resulting in the release of the chemical energy as electrical energy [0235].

Positive electrode: $$V^{4+} \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} V^{5+} + e^{-}$$

Negative electrode: $$V^{3+} \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} V^{2+} + e^{-}$$

VRFB cell electrochemistry [0242]

As a true RFB, the active chemical species (vanadium) are fully dissolved at all times in electrolyte solutions and the power and energy ratings of a VRFB are independent of each other and each may be optimized separately for a specific application.

Electrolyte

Both electrolytes in the VRFB are composed of vanadium ions in an aqueous sulfuric acid solution at very low pH. The acidity of the sulfuric acid is comparable to that of the electrolyte found in lead-acid batteries, with a pH of between 0.1 and 0.5 [0242]. The acidity of the electrolyte serves two purposes in the battery: to increase the ionic conductivity of the electrolyte, and to provide hydrogen ions to the reaction at the positive electrode. In 2011, Pacific Northwest National Laboratory (PNNL) patented a new electrolyte formulation that contains a mixture of hydrochloric and sulfuric acid. PNNL discovered that this increased the batteries' energy storage capacity by 70% and allowed the battery to work in both colder and warmer temperatures, between –5° and +50°C, greatly reducing the need for costly cooling systems [249].

ELECTRODES

The electrodes used in VRFB are composed of high-surface area carbon materials. These materials operate across a wide range of voltage potentials with minimal hydrogen and oxygen evolution, are chemically stable with respect to the acidic electrolytes at both the anode and cathode of a cell, and are available at reasonable costs. Carbon materials have a very wide range of characteristics depending on the methods of manufacturing and preparation.

MEMBRANE

The two half-cells in each cell are separated by a proton exchange membrane (PEM). The membrane physically separates the two vanadium-based electrolyte solutions, preventing self discharge while allowing for the flow of ions to complete the circuit. Several membranes can be used in vanadium redox batteries.

CELL STACKS

In practice, vanadium redox batteries are constructed by stacking several cells together in series to form a battery stack. Electrodes are placed on either side of a bipolar plate, which separates each cell from the next cell. The bipolar plate acts as the current conducting mechanism between the negative electrode of one cell and the positive electrode of the next. The positive electrode of the most positive cell in the stack and the negative electrode of the cell at the other end of the stack form the positive and negative ends of the battery, and are connected to the power conditioning system. The cells in the battery are electrically connected in series, but in most designs the electrolyte flows through the cells in parallel. The number of cells used in the complete battery depends on the desired voltage level of the final battery.

ELECTROLYTE TANKS

The vanadium electrolytes are stored in separate large electrolyte tanks outside the cell stack. The tanks must be composed of materials that are resistant to corrosion in the very low pH environment. In the past, off-the-shelf plastic or fiberglass tanks, such as those used to store gasoline, have been used to store electrolyte.

PUMPS, PIPING, AND AUXILIARY

Pumps, valves, pipes, and other piping components must be corrosion resistant and stable in low pH environments. For this reason, pumps using plastic impellers are used in most installations.

Similarly, valves must be rated for low pH environments. For piping, most developers use standard polyvinyl chloride (PVC) piping, which is inexpensive and readily available. Laying out pipe can be a labor intensive process, however. At least one major developer has made an effort to cut down on the amount of piping used, using prefabricated piping wherever possible and minimizing placement of valves.

Performance

Typical Performance for Vanadium REDOX Battery Technology

Parameter	Range
Power Rating	Fully scalable
Discharge at Rated Power	4 – 12 hours
Round Trip Efficiency	60% – 85%
Response Time	milliseconds
Self Discharge per day	Small
Power Density	<2 kWm^3
Energy Density	16 – 35 $kWhm^3$
Cycle Life	>20,000 cycles
Depth of Discharge	100%
System Lifetime	10 – 20 years
Cost, power	500 – 1,500 $/kW
Cost, energy	150 – 1,000 $/kWh

Applications

Due to its relative mechanical complexity and economies of scale, the vanadium redox battery is most suited for utility-scale power systems in the 100-kW to 10-MW size range in applications having low power/energy ratios (long discharge durations). Transmission and distribution applications with these characteristics include load shifting (peak shaving), renewables time shifting, fluctuation suppression, forecast hedging, mitigating transmission curtailment, spinning reserve, power quality (especially long duration), voltage support, and frequency excursion suppression [0239].

Construction and Installation

Newer systems being produced are based on standardized design of modular or containerized construction. Both approaches reduce shipping and installations costs.

Operation and Maintenance

The normal operating temperature of a VRB ranges from about 10° to 40°C. Active cooling subsystems are employed if ambient temperatures exceed 40° to 45°C.

For new installations, monthly visual inspections of piping and tanks are required, with detailed inspection at 6-month intervals. Pumps and HVAC systems require inspection every 6 months. Pump bearings and seals may require replacement at 5-year intervals. Electronic parts such as boards, sensors, relays, and fuses, may require replacement as necessary.

Without extended field experience, the system maintenance requirements have not been thoroughly established. However, a typical system has only two moving parts — pumps on the positive and negative sides. Thus, maintenance costs are relatively low. Further, the VRB system operates at atmospheric pressure and the temperature never exceeds 40°C. Primary maintenance items are annual inspections and replacement of pump bearings and impeller seals at intervals of about every 5 years. As necessary, smaller parts, such as electronic boards, sensors, relays, and fuses are replaced [0242].

Decommissioning and Disposal

The cell stack is generally environmentally benign. The only material in the stack that might be considered toxic is the ion exchange membrane, which is composed of highly acidic (or alkaline) material. During decommissioning, users can dispose of the membranes using the same processes used to handle highly corrosive substances. In fact, membranes are somewhat simpler to handle because they are solid and do not require containment.

In considering vanadium electrolyte toxicity, it should be noted that the electrolyte does not require change over the lifetime of the battery because it does not degrade or otherwise require replacement. At the end of life for the battery system, the electrolyte will almost certainly be recycled to recover its valuable vanadium content. For these reasons, electrolyte disposal is not likely to be a significant obstacle to the adoption of VRFBs.

Maturity

The VRFB is the most technically mature of the flow-type battery chemistries. The first operational VRFB was successfully demonstrated in the late 1980s, and early commercial systems were deployed by SEI in the early 2000s. Several manufacturers (Vionx, and UniEnergy Technologies [UET]) are employing advanced designs are at an early stage of field deployment for larger scale systems (500 kW to 1 MW with 6 hours of storage).

Case Study

One of the longest operating VRB facilities is the Castle Valley, Utah facility. Built by VRB Power Systems, it was sized to provide 250 kW for 8 hours. The battery system was commissioned in November 2003, operational in May 2004, and decommissioned in March 2008. The system successfully demonstrated both peak shaving and voltage support functions [0365].

UET's Uni.System: 500 kWac and 4- to 12-hour discharge (up to 6 MWhac) (courtesy UET)

A 1-MW/3.2-MWh UniEnergy Technologies (UET) vanadium flow battery was installed in Pullman, Washington, at Washington State University in June 2015 to support WSU's smart campus operations. The system will be used for load shifting, frequency regulation, and conservation voltage regulation [0365].

RISKS/BARRIERS

The VRFB presents several challenges that have been adequately addressed by experienced manufacturers.

MEMBRANE PERFORMANCE

The VRFB offers a relatively high cell voltage, which is favorable for higher power and energy density; however, the higher voltage and highly oxidative V^{5+} electrolyte puts more chemical stress on the materials used in the cell electrodes, membranes, and fluid handling components. Cross-transport of vanadium ions across the membrane is also reported as a challenge, and expensive ion-exchange membranes must be used to minimize losses due to cross-membrane transport. These membranes can be vulnerable to fouling, wherein vanadium ions become irreversibly trapped in the membrane and increase resistive losses in the cell. On the other hand, lower cost membranes are under development and will soon be available for use.

ELECTROLYTE COST

Vanadium is a readily available material, used in steel manufacturing and as a chemical catalyst, which is found naturally and can also be recovered from various waste streams. Although somewhat volatile, the market price of vanadium as V_2O_5 has generally fallen over the past 5 years from a recent high of around $7.50/lb in November 2009 to under $5.00/lb in April 2015 due to Chinese overproduction, although the price is predicted to increase to about $6.00/lb over the next few years [0371].

Reliability

For the VRFB to be successful, it must demonstrate a level of reliability that is comparable to substation transformers and other T&D equipment. Given that the VRFB incorporates equipment (e.g., pumps and power electronics) for which there is little or no experience with failure modes and effects in the substation environment, this may be difficult to verify in the near term. Extended field experience will be required to validate the reliability of the newer system designs.

Suitability for South Africa

VRFB represents a mature and well understood energy storage technology that is well suited for energy intensive energy storage applications. Advanced vanadium flow battery designs with higher energy capacity and wide operating temperature ranges are expected to further improve cost and performance. The relative ease of vanadium electrolyte production and the availability of vanadium in South Africa further enhances the attractiveness of this specific flow technology.

A.12 Iron-Chromium Flow Batteries

The iron-chromium (Fe-Cr) flow battery is a redox flow battery (RFB). The active chemical species are fully dissolved in the aqueous electrolyte at all times. Like other true RFBs, the power and energy ratings of the Fe-Cr system are independent of each other, and each may be optimized separately for each application [0310].

Technology

During the discharge cycle, Cr^{2+} is oxidized to Cr^{3+} in the negative half-cell and an electron is released to do work in the external circuit through the negative and positive terminals of the AC/DC converter. In the positive half-cell during discharge, Fe^{3+} accepts an electron from the external circuit and is reduced to Fe^{2+}. These reactions are reversed during charge, when current is supplied from the external circuit through the AC/DC converter. Hydrogen (H^+) ions are exchanged between the two half-cells to maintain charge neutrality as electrons leave one side of the cell and return to the other side. The hydrogen ions diffuse through the separator, which electronically separates the half cells. In early implementations of the Fe-Cr RFB, diffusion of the iron and chrome ions across the separator created an imbalance between the positive and negative electrolytes, resulting in an irreversible system capacity loss. Modern electrolyte formulations using mixed iron and chromium on both sides of the separator have eliminated the irreversible loss and have enabled the use of low-cost, porous separator materials. These porous separators have also eliminated the “membrane fouling” failure mode that occurs with ion exchange membranes used in early Fe-Cr and some other current RFB technologies [0310].

Discharging:	$Fe^{3+} + e^- \Leftrightarrow Fe^{2+}$ (reduction)
	$Cr^{2+} \Leftrightarrow Cr^{3+} + e^-$ (oxidation)
Charging:	$Fe^{3+} \Leftrightarrow Fe^{2+} + e^-$ (oxidation)
	$Cr^{3+} + e^- \Leftrightarrow Cr^{2+}$ (reduction)

Fe-Cr cell electrochemistry [366]

PERFORMANCE

The standard cell voltage is 1.18 V and cell power densities are typically 70 to 100 mW/cm^2. The comparatively low cell voltage results in a low energy density, but developers can still meet the EPRI footprint target of 500 ft^2 per MWh of storage. The DC/DC efficiency of this battery has been reported in the range of 70% to 80%.

One notable attribute that system performance is enhanced at higher operating temperatures in the range of 40° to 60°C (105° to 140°F), which makes Fe-Cr RFB very suitable for warm climates and practical in all climates where electrochemical energy storage is feasible.

Typical Performance for Iron-Chromium Battery Technology

Parameter	Range
Power Rating	Fully scalable
Discharge at Rated Power	generally > 4 hours
Round Trip Efficiency	70% – 80 %
Response Time	milliseconds
Self Discharge per day	Small % per day
Power Density**	kWm^3
Energy Density**	kWhm^3
Cycle Life**	cycles
Depth of Discharge	100%
System Lifetime	10 – 20 years
Cost, power	1,200 – 1,900 $/kW
Cost, energy	300 – 400 $/kWh
**Not reported but similar to other flow battery technologies.	

APPLICATIONS

Iron-chromium flow batteries like other flow batteries are suited for longer duration, energy-intensive applications.

MATURITY

Fe-Cr flow batteries were pioneered and studied extensively by NASA in the 1970s–1980s and by Mitsui in Japan. Fe-Cr flow batteries have been used successfully for telecom backup at the 5-kW – 3-hour scale. For utility scale applications however, this technology is still considered to be in the R&D demonstration phase.

CASE STUDY

ENERVAULT TURLOCK

EnerVault's 250-kW/1-MWh (4-hour) Fe-Cr RFB system was used to reduce demand use charge. The system was operated in combination with a 150-kW PV system to power a large 260-kW irrigation pump. The project was funded under a DOE ARRA Storage Demonstration grant. Located in Denair, California, the project was commissioned in May 2014 and operational for approximately 1 year [0365].

RISKS/BARRIERS

HYDROGEN EVOLUTION

The standard potential of the Cr^{2+} – Cr^{3+} couple is near the hydrogen evolution potential. Care must be taken in the design of Fe-Cr RFBs to minimize parasitic side reactions and then to reverse the associated capacity loss and electrolyte imbalance. Current developers of Fe-Cr RFBs appear to have mitigated this side reaction and implemented effective rebalancing subsystems with minimal system efficiency loss [0310].

SUITABILITY FOR SOUTH AFRICA

Like other flow batteries, Fe-Cr RFB systems have good potential for longer duration, energy-

EnerVault 250kW/1MWh Iron-Chromium Flow Battery System

intensive grid applications; however, Fe-Cr has not advanced significantly since R&D efforts and an initial demonstration 2014. In the near future, the flow battery market globally and in South Africa will likely be dominated by VRFB or Zn-Br technologies that are currently being deployed by multiple companies.

A.13 Zinc-Bromine (Zn-Br) Flow Batteries

Zinc-bromine is a type of RFB that uses zinc and bromine in solution to store energy as charged ions in tanks of electrolytes. The Zn-Br battery is charged and discharged in a reversible process as the electrolytes are pumped through a reactor vessel [0240].

Technology

The Zn-Br flow batteries are the most developed example of hybrid RFBs. A Zn-Br battery consists of a zinc negative electrode and bromide positive electrode. An aqueous solution of zinc bromide is circulated through the two compartments of the cell from two separate reservoirs. During charge, zinc metal is plated as a thick film on the anode side of the electrode. Meanwhile, bromide ions are oxidized to bromine on the other side of the electrode. During discharge, the zinc metal (plated on the anode during charge) releases two electrons and dissolves into the aqueous electrolyte. These two electrons return to the cathode and reduce bromine molecules to bromide ions [0245].

Positive: $$Br_2(aq) + 2e^- \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} 2Br^-(aq)$$

Negative: $$Zn \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} Zn^{2+}(aq) + 2e^-$$

Zn-Br cell electrochemistry [0242]

Electrodes

The cell electrodes are generally composed of carbon plastic and are designed to be bipolar. Thus a given electrode serves both as the cathode for one cell and the anode for the next cell in series. Carbon plastic must be used because of the highly corrosive nature of bromine. The positive electrode surface is coated with a high-surface-area carbon to increase surface area [235].

Electrolyte

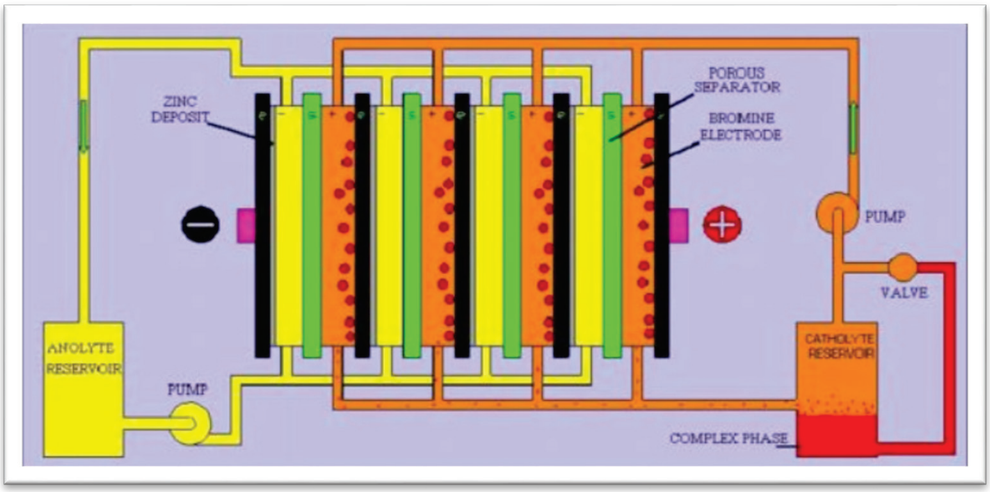
The two electrolytes (anolyte and catholyte) will have the same zinc and bromine ion concentrations at any given time during the charge/discharge cycle and differ only in the concentration of elemental bromine. Because of the limited solubility of elemental bromine, the catholyte will contain organic amine, which reacts with the bromine to form dense, viscous bromine-adduct oil that tends to settle to the bottom of the catholyte tank. Adequate mixing of the catholyte solution is therefore necessary to enable discharge [0235].

SEPARATOR

A membrane provides a porous separator between the electrolyte streams in the cells. This membrane can be either selective or non-selective. A selective membrane allows the passage of zinc and bromine ions while preventing the transfer of elemental bromine. Selective membranes, however, can be more costly and less durable so nonselective membranes are generally used. Nonselective micro-porous membranes allow the passage of elemental bromine however, the flow of the catholyte sweeps the bromine (in the form of polybromine) from the positive electrode quickly, freeing up the surface area for further reaction. It also allows the polybromine to be stored in a separate tank to minimize self-discharge.

PACKAGING

Zn-Br flow batteries are generally constructed as module ranging from 5 kW to 1,000 kW, with



Zinc-bromine flow battery cell configuration [0245]

variable energy storage duration from 2 to 6 hours, depending on the service requirements and need.

PERFORMANCE

The Zn-Br redox battery offers one of the highest cell voltages and releases two electrons per atom of zinc. These attributes combine to offer the highest energy density among flow batteries. The zinc-bromine cell has a nominal voltage of 1.8 V.

Self-discharge arises largely from bromine crossover to the anode side. Testing has shown the effect to be about 1% per hour on a watt-hour basis. Self discharge can be minimized by stopping electrolyte circulation during stand periods, limiting the degree of crossover to bromine that is in the cell when circulation ceases [0242].

Typical Performance for Zinc-Bromine Battery Technology

Parameter	Range

Power Rating	Fully scalable
Discharge at Rated Power	4 – 12 hours
Round Trip Efficiency	65% – 80%
Response Time	milliseconds
Self Discharge per day	Small
Power Density	<25 kWm^3
Energy Density	30 – 65 $kWhm^3$
Cycle Life	10,000-15,000cycles
Depth of Discharge	100%
System Lifetime	10 – 20 years
Cost, power	600 – 2,500 $/kW
Cost, energy	150 – 1,000 $/kWh

Applications

Zn-Br flow batteries exhibit the dual advantages of low cost and high energy density and are best suited for applications requiring high energy density (such as load shifting), as opposed to high power density.

Construction and Installation

Integrated Zn/Br ESSs have been tested on transportable trailers (up to 1 MW/3 MWh) for utility-scale applications. Multiple systems of this size could be connected in parallel for use in much larger applications. Smaller Zn-Br systems are also being supplied at the 5-kW/20-kWh community energy storage (CES) scale and are now being tested by utilities, primarily in Australia.

Operation and Maintenance

Zn-Br flow battery operations are typically fully automated. Maintenance is similar to any piece of mechanical/process equipment. Most systems require scheduled conditioning for morphology control and dendrite removal (stripping) about once a week. Annual preventive maintenance, testing, and reconditioning of electrolytes may be required approximately every 5 years.

Decommissioning and Disposal

Bromine is a toxic material and should be recovered in the event of a spill or if the unit is decommissioned. Zinc-bromine is corrosive and should be handled appropriately. Zinc is considered a transition-metal contaminant in some locales and thus should be properly recovered when the unit is decommissioned.

Maturity

Although initially patented in 1885, the zinc-bromine flow battery was not developed as a hybrid flow battery system until the early 1970s. Since 2009, small projects comprising 5-kW/2-hour systems have been deployed in rural Australia as an alternative to installing new power lines. Larger scale Zn-Br flow batteries are generally in an early stage of field deployment and demonstration trials, although several companies (e.g., Redflow, Primus Power, and EnSync) are introducing commercial products.

CASE STUDY

A Primus 250-kW/1-MWh EnergyPod Zn-Br flow battery was installed at Marine Corps Air Station Miramar in May 2015 and is integrated with an existing 230-kW PV system. The combined microgrid system will demonstrate several capabilities, including reducing the peak electrical demand typically experienced in weekday afternoons and providing power to critical military systems when grid power is not available.

The National Grid Distributed Energy Storage Systems Demonstration will use two 500-kW / 6 hour Zn-Br energy storage systemESSs manufactured by Vionx to lower peak energy demand and reduce the costs of power interruptions. One ESS will be installed next to a 605-kW PV array in Everett, Massachusetts. A second ESS will be installed next to a 600-kW wind turbine on a customer site in Worcester, Massachusetts. These systems are schedule to be operational in 2016 and are intended to demonstrate competitively priced, grid-scale, long-duration advanced flow batteries for utility grid applications [0365].

Concept for Primus Power 1.5-MW / 7.5-MWh EnergyPod system (courtesy Primus)

RISKS/BARRIERS

Historically, Zn-Br flow battery technology has faced several challenges; however, several companies are introducing commercial products that appear to address these issues.

CORROSIVE

The relatively high cell voltage and the highly corrosive nature of elemental bromine in the electrolyte produce a harsh chemical environment; therefore, higher cost cell electrodes, membranes, and fluid handling components are necessary to withstand the tough operating conditions. In general, the life of a Zn-Br system is limited not by the number of operating cycles or the cycle duty, but by the number of hours that the storage system has been in operation. The expected lifetime of Zn-Br is about 6,000 hours, which is approximately equivalent to 2,000 cycles at continuous operation and 100 percent depth of discharge [0239]. Manufacturers indicate that improved materials and designs have resulted in extended lives for newer products.

Dendrite Formation

An important factor affecting efficiency is the uneven buildup of zinc across electrodes and cells during charging. To remedy this problem, the battery is fully discharged, a process called stripping, which dissolves all zinc in the electrolyte before it is redeposited during charging. This must be done every 5 to 10 charge-discharge cycles [0239].

Toxicity

Bromine is a highly toxic material through inhalation and absorption; as a result, the possibility of a hazardous environmental event or personnel exposure must be addressed through adequate design features and operational practices. Maintaining a stable amine complex with the bromine is key to system safety. Active cooling systems are provided by system manufacturers to maintain stability of the bromine-amine complex if ambient temperatures exceed 95°F.

Scale-up

Manufacturers have experienced difficulty in 10-kW to 25-kW modules up to the two-tank/two-pump systems in the range 500 kW to 1 MW. Zn-Br scale-up has generally been combining many smaller modules, which leads to systems with a multitude of pumps and tanks at the megawatt system scale. This approach somewhat defeats the economy of scale produced by flow batteries.

Reliability

Although smaller Zn-Br flow batteries have been in service for up to 6 years, several larger systems are coming on the market for which long-term reliability and performance have yet to be fully evaluated.

Suitability for South Africa

Zn-Br flow batteries offer an economical, low-vulnerability means for grid scale electrical energy storage. These batteries also offer greater flexibility to independently tailor power rating and energy rating for a given application than other electrochemical means for storing electrical energy. Zn-Br flow batteries are suitable for energy storage applications with power ratings from kilowatts up to multiple megawatts and are most efficient for storage durations of 4 to 12 hours. This technology shows strong potential for energy storage application in South Africa.

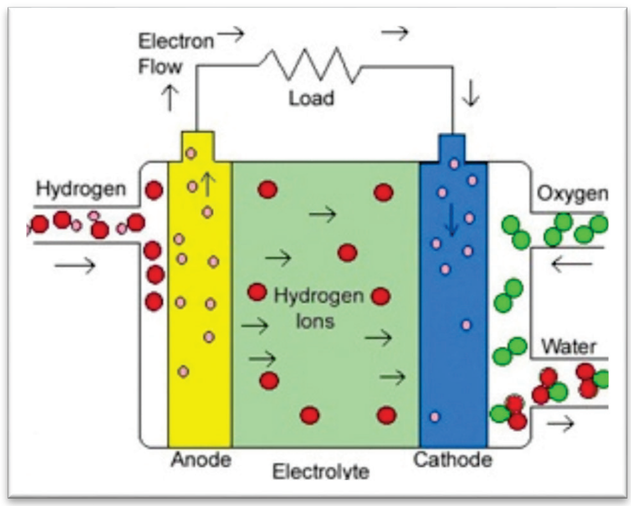
A.14 Fuel Cells

Fuel cells are similar to flow cells. Most fuels cells are fuel-to-power applications with no “charge cycle” that re-creates the fuel state. However, several regenerative fuel cell technologies could provide a power-to-power application.

Technology

A fuel cell converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent. Fuel cells differ from batteries in that they require a continuous source of fuel and oxygen or air to sustain the chemical reaction, whereas in a battery the chemicals present in the battery react with each other to generate an electromotive force (emf). Similar to flow batteries, fuel cells can produce electricity continuously for as long as these inputs are supplied.

Many types of fuel cells are available, but they all consist of an anode, a cathode, and an electrolyte that allows positively charged hydrogen ions (or protons) to move between the two sides of the fuel cell. The anode and cathode contain catalysts that cause the fuel to undergo oxidation reactions that generate positively charged hydrogen ions and electrons. The hydrogen ions are drawn through the electrolyte after the reaction. At the same time, electrons are drawn from the anode to the cathode through an external circuit, producing direct current electricity. At the cathode, hydrogen ions, electrons, and oxygen react to form water.



Simplified schematic for alkaline and PEM fuel cell [0356]

Anode: The negative post of the fuel cell conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit. It has channels etched into it that disperse the hydrogen gas equally over the surface of the catalyst.

Cathode: The positive post of the fuel cell has channels etched into it that distribute the oxygen to the surface of the catalyst. It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.

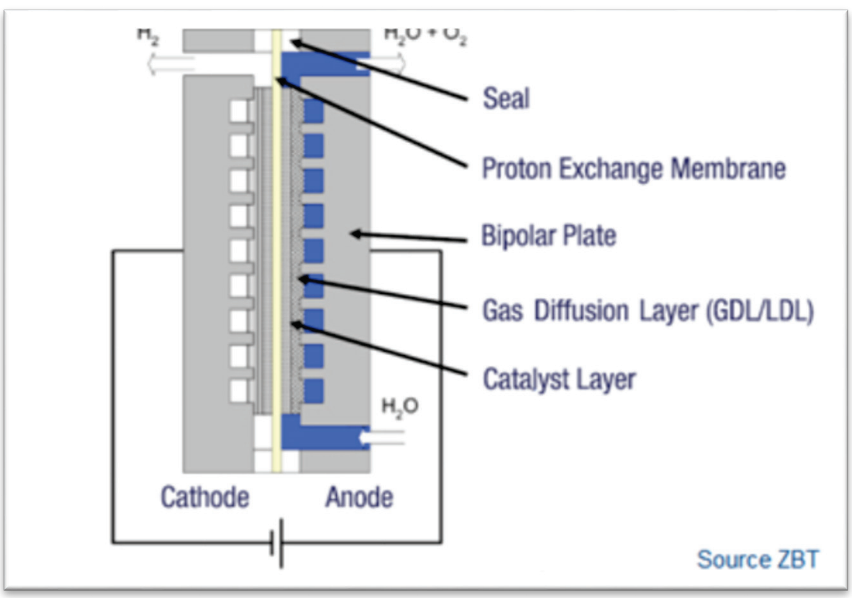
Electrolyte: A proton exchange membrane. This specially treated material, which looks something like ordinary kitchen plastic wrap, only conducts positively charged ions. The membrane blocks electrons. For a proton exchange membrane fuel cell (PEMFC), the membrane must be hydrated in order to function and remain stable.

Catalyst: In a PEM fuel cell, hydrogen is oxidized at the anode and electrocatalyzed by platinum or platinum alloys; at the cathode, oxygen is reduced, again with platinum or platinum alloys as electrocatalysts a special material that facilitates the reaction of oxygen and hydrogen. It is usually made of platinum nanoparticles very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces the proton exchange membrane (PEM).

Reaction Stack: A single fuel cell generates a tiny amount of direct current. In practice, many fuel cells are usually assembled into a stack.

Electrolyser: Electrolysis cells are characterized by their electrolyte type. Two types of low temperature electrolysis are commercially available: alkaline and proton exchange membrane (PEM).

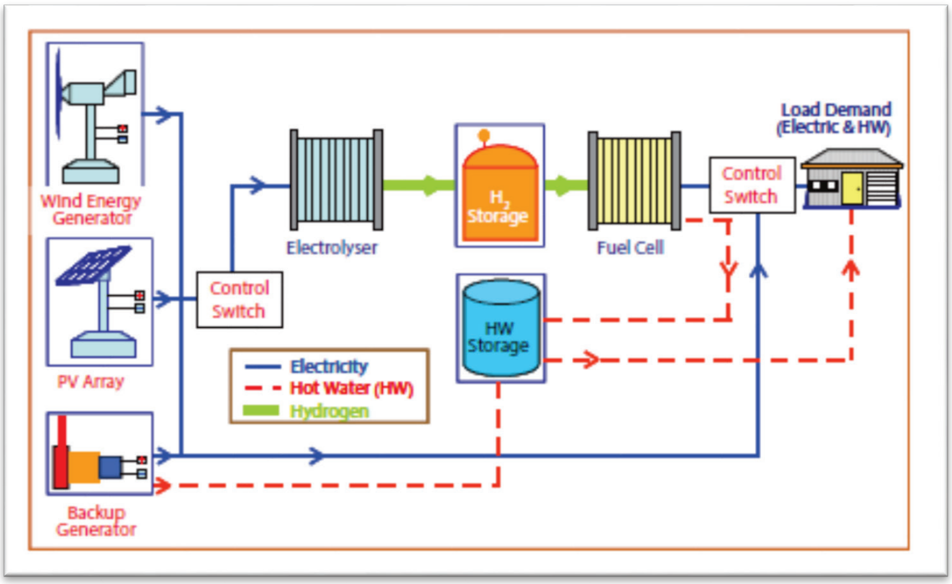
A PEM electrolyser uses an ionically conductive solid polymer. When potential difference (voltage) is applied between the two electrodes, negatively charged oxygen in the water molecules give up their electron at the anode to make protons, electrons, and O_2 at the anode. The H+ ions travel through the proton-conducting polymer toward the cathode, where they take up an electron and become neutral H atoms that combine to make H_2 at the cathode. The electrolyte and two electrodes are sandwiched between two bipolar plates. The role of bipolar plate is to transport water to the plates, transport product gases away from the cell, conduct electricity, and circulate a coolant fluid to cool down the process [0359].



Schematic of PEM electrolyser [0360]

As with fuel cells, many electrolyser single cells may be connected in series to make the core component of an electrolyser system, the cell stack, in which both hydrogen and oxygen are produced.

Most basically, a PEMB fuel cell could be part of a power-to-power application if paired with an electrolyser system to generate hydrogen and oxygen through the electrolysis of water. Two sets of reaction stacks (fuel cell and electrolysis) are required due to the different operating conditions and optimized design.



Concept for a hydrogen renewable energy system [0241]

South Africa's National Hydrogen and Fuel Cell Technologies Research, Development and Innovation strategy, branded as Hydrogen South Africa (HySA) was formed in 2008 and includes three Centers of Competence (CoC) [0357]:

- HySA Systems: CoC on hydrogen systems integration and technology validation, hosted by the University of the Western Cape.
- HySA Catalysis: CoC on hydrogen catalysis, co-hosted by the University of Cape Town and MINTEK.
- HySA Infrastructure: CoC on hydrogen generation, storage and distribution, co-hosted by the North West University and the Council for Scientific and Industrial Research (CSIR).

These centers are working on three potential products:

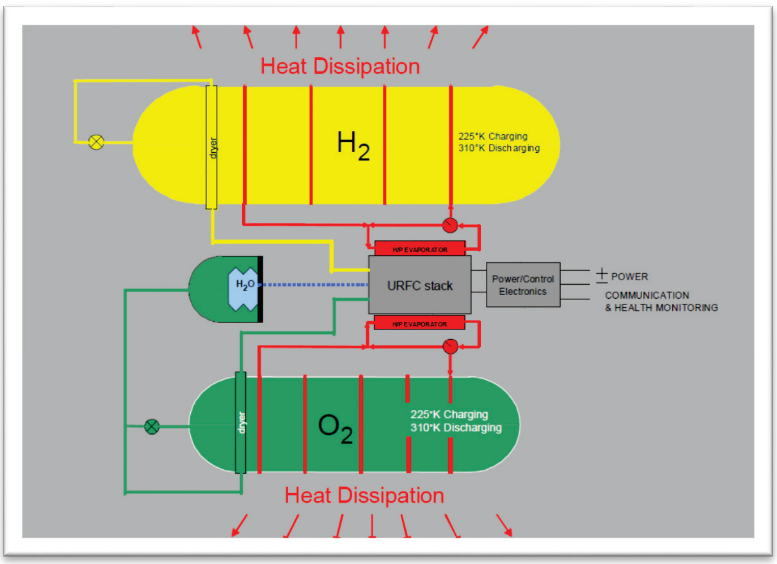
- A portable power source for use as a back-up power source as a quieter and cleaner alternative to generators.
- A combined heat and power (CHP) source based on fuel cells, to supply decentralized power and heating for buildings and industries.

- Fuel cell powered vehicles that could provide an alternative to hybrid and pure electric vehicles.

UNITIZED REGENERATIVE FUEL CELL

As an ESS, the unitized regenerative fuel cell (URFC) system “charges” and “discharges” like a rechargeable battery. While charging, the URFC operates the electrolysis process, which splits water into hydrogen and oxygen. While discharging, the URFC operates the fuel cell process, which combines hydrogen and oxygen and produces electricity [0358].

The gases produced during electrolysis are expelled from the cell stack by the production of still more gas inside the cell stack. The continued production of gases by the cell stack pushes the gases into the reactant storage tanks, gradually pumping the gases to higher and higher pressure where they are stored. In addition to the oxygen and hydrogen, a certain level of water vapor also accompanies these gases when they are expelled from the cell stack.



Concept for unitized regenerative fuel cell [0358]

The URFC system is generally based on the hydrogen PEMFC. Both the fuel cell and electrolyser stacks can be said to consist of the same major parts: membrane, catalyst, bipolar plates, and end plates. The objective is to use bifunctional electrodes that can switch roles during charge and discharge without losing efficiency (similar to a rechargeable battery).

PERFORMANCE

Because the main difference among fuel cell types is the electrolyte, fuel cells are classified by the type of electrolyte they use and by the difference in startup time ranging from 1 second for proton exchange membrane fuel cells (PEM fuel cells, or PEMFC) to 10 minutes for solid oxide fuel cells (SOFC). Individual fuel cells produce relatively small electrical potentials, about 0.7 V, so cells are “stacked,” or placed in series, to create sufficient voltage to meet an application’s requirements. In addition to electricity, fuel cells produce water, heat and (depending on the fuel source) very small amounts of nitrogen dioxide and other emissions. The energy efficiency of a fuel cell is generally between 40% and 60%, or up to 85% efficient in cogeneration if waste heat is captured for use. Because this study is concerned with power-to-power applications, the fuel cell technologies of interest are those that can be reversed to regenerate the fuel during a charge cycle that was consumed during discharge. Although any fuel cell can theoretically be reversed, a limited number cell designs can be operated efficiently in both directions.

Typical Performance for Hydrogen Fuel cell (fuel to power)

Parameter	Range
Power Rating	Multi-MW
Discharge at Rated Power	hours – days
Discharge Efficiency	40% – 60%
Response Time	milliseconds
Self Discharge per day	almost zero
Power Density	500 – 3000 kWm^3
Energy Density	500+ $kWhm^3$
Cycle Life	20,000 cycles
Depth of Discharge	100%
System Lifetime	5 – 15 years
Cost, power	10,000+ $/kW

APPLICATIONS

A cost-efficient regenerative fuel cell (power to power) system is unlikely to be commercially available within the next 5 to 10 years. A number of electrolysis systems generate and store hydrogen for shipment or injection into the local natural gas grid. Numerous fuel cells systems are available that can be used for enhanced power reliability and black start capability. These are especially applicable for remote locations and the protection of critical loads such as data centers.

A utility scale H_2 electrolysis/fuel cell system would have to store large quantities of high-pressure hydrogen. This creates some significant safety requirements that might restrict deployment locations.

CASE STUDY

Grapzow Power to Gas System. A 1 MW electrolysis system from Hydrogenics is co-located with a 140-MW wind farm in Germany. The unit produces 210 nm^3 of H_2 per hour. The owners have the option to use the hydrogen in an internal combustion engine to produce electricity or inject it directly into the local natural gas grid depending on operational needs. The hydrogen compression and storage system stores up to 27 MWh of energy and dramatically increases the overall efficiency of the wind park by tapping into wind energy that would otherwise be wasted. System has been in operation since 2013 [0365]. The storage project is funded by the Germany Federal Government with funds from the National Innovation Programme for Hydrogen and Fuel Cell Technology.

Energiepark Mainz. The world's first multi-megawatt PEM electrolysis-based power-to-gas (hydrogen storage) project can produce about 6 MW of peak capacity and 4 MW continuous capacity. The produced hydrogen is compressed by an ionic compressor, stored on site, filled in trailers, and injected into the natural gas grid. The project is located in Mainz, Germany, and started operation in 2015 [0365]. This is a power-to-gas project.

Risks/Barriers

Cost and Round Trip Efficiency

The greatest barrier to a power-to-power system is the high cost of the equipment combined with the very low round trip efficiencies at which such a power-to-power system could currently operate.

Water Management

The greatest challenge for a URFC is the management of liquid water. Water formed in the cathode chamber during the fuel cell mode must be circulated out of the system, but at the same time must allow water to be fed back into the electrode chamber to perform electrolysis during the regenerative mode.

Some research has been conducted related to a URFC that avoids the liquid phase altogether. In this system, a hydrogen gas tank, oxygen tank, and water reservoir are connected to the URFC stack. The design is simplified by incorporating static feeds of water, oxygen, and hydrogen in their vapor phases by operating under a vacuum and using the storage tanks as heat sinks and sources.

Suitability for South Africa

Power-to-power hydrogen storage technology is not sufficiently mature or economical to be a viable power-to-power technology. The catalyst in hydrogen fuel cells is typically platinum, which is a significant natural resource in South Africa. There are many applications for independent fuel cell and electrolyser systems in South Africa and globally.

A.15 Flywheels

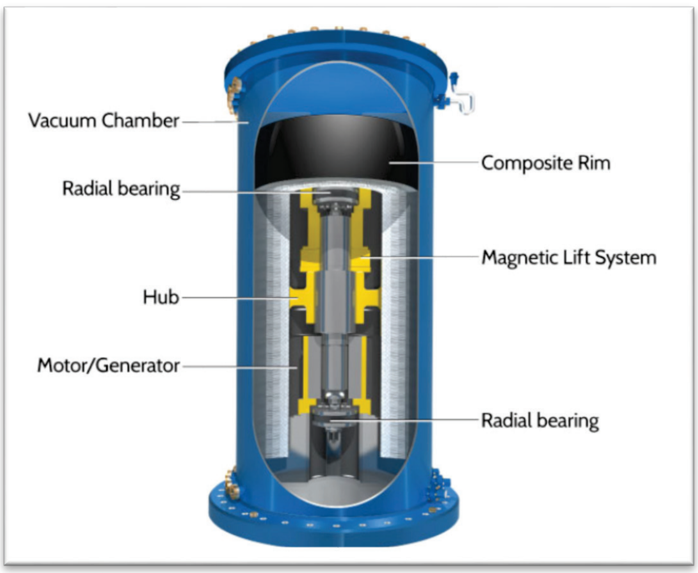
Flywheel energy storage systems (FESS) store energy in the form of the angular momentum of a spinning mass, called a rotor. The work performed to spin the mass is stored in the form of kinetic energy. A flywheel system converts kinetic energy to AC power through the use of controls and power conversion systems [0235]. Electric energy input accelerates the mass to speed via an integrated motor-generator. The energy is discharged by drawing down the kinetic energy using the same motor-generator.

Technology

The amount of energy that can be stored is proportional to the object’s moment of inertia times the square of its angular velocity. Flywheels are characterized as having low-speed or high-speed rotors. Although these categories are somewhat arbitrary, and some designs do not fit neatly into one category or the other, they are useful to draw some general distinctions. Both types of rotors have advantages and disadvantages, and the two find uses in different applications [0242].

Low-speed flywheels typically have steel rotors and conventional mechanical bearings. Higher speed flywheels may have a composite carbon or fiberglass rotor and more often have magnetic bearing to reduce friction and allow for higher rotational speeds. High speed flywheels may also operate in an evacuated container where the vacuum further reduces friction. The flywheel is connected to a motor-generator that interacts with the utility grid through advanced power electronics.

Most flywheel systems include a containment or enclosure for safety and increased performance. The containment is usually a thick steel vessel surrounding the rotor, motor-generator, and other rotational components of the flywheel. The containment is intended to stop or slow parts and fragments should the rotational components fail catastrophically, preventing personnel injury and damage to surrounding equipment.



Cross section of 100-kW Beacon flywheel (courtesy Beacon Power)

PERFORMANCE

Advanced FESSs have several advantages over chemical energy storage. They have high energy density and substantial durability that allows them to be cycled frequently with no impact to performance. They also have very fast response and ramp rates. In fact, they can go from full discharge to full charge within a few seconds. FESSs are increasingly important to high-power, relatively low-energy applications. They are especially attractive for applications requiring frequent cycling given that they incur limited life reduction if used extensively (i.e., they can undergo many partial and full charge-discharge cycles with trivial wear per cycle).

Today's flywheel systems are shorter energy duration systems and are not generally attractive for large-scale grid support services that require many kilowatt-hours or megawatt-hours of energy storage. They have a very fast response time (4 ms or less), can be sized between 100 and 1,650 kW, and may be used for durations of up to 1 hour. They have very high efficiencies (over 90%), with lifetimes estimated at 20 years [0240].

Although flywheels have power densities 5 to 10 times that of batteries—meaning they require much less space to store a comparable amount of power—there are practical limitations to the amount of energy (kWh) that can be stored. A flywheel energy storage plant can be scaled up by adding more flywheel system modules. Typical flywheel applications include power quality and uninterruptible power supply (UPS) uses, as seen in commercial products. Research is under way to develop more advanced flywheel systems that can store large quantities of energy.

Most power flywheel products presently available can provide from 100 to 2,000 kW_{ac} for a period ranging from 5 to 50 seconds. It should be noted that power systems rated below 500 kW, particularly those using high-speed rotors, are usually rated in kW_{dc}. Larger systems, particularly those using low speed steel flywheels, are usually sold as integrated AC-output systems and are rated in kVA [0242].

Typical Performance for FESS

Parameter	Range
Power Rating	Fully scalable
Typical Discharge at Rated Power	seconds to minutes
Round Trip Efficiency	90% – 95%
Response Time	milliseconds
Self Discharge per day	100%
Rotor Speed, low/high	Up to 10,000 / up to 100,000 RPM
Power Density	1,000 – 2,000 kWm^3
Energy Density	20 – 80 $kWhm^3$
Cycle Life	> 100,000 cycles
Depth of Discharge	100%
System Lifetime	15 – 20 years
Cost , Energy	1,000 – 14,000 $/kWh
Cost, Power	850 – 2,000 $/kW

Applications

Because flywheel systems are fast responding and efficient, they are being positioned to provide ISO frequency-regulation services. Analysis of such flywheel services have been shown to offer system benefits, including avoiding the cycling of large fossil power systems and lower CO2 emissions [0235].

A number of applications now propose using flywheels as an energy storage medium. These include inrush control, voltage regulation, and stabilization in substations for light rail, trolley, and wind-generation stabilization. The majority of products currently being marketed by national and international-based companies are targeted for power quality applications. Another high value application in power quality is short-term bridging through power disturbances or from one power source to an alternate source [0242].

Construction and Installation

Flywheel systems are generally modular and scalable. Units are generally housed and require suitable structural rigidity.

Operation and Maintenance

As with any energy storage technology, hazardous conditions may exist around operating flywheels. Considerable effort has gone into making flywheels safe for use under a variety of conditions. The most prominent safety issue in flywheel design is failure of the flywheel rotor while it is rotating. In large, massive rotors, such as those made of steel, failure typically results from the propagation of cracks through the rotor, causing large pieces of the flywheel to break off during rotation. Unless the wheel is properly contained, this type of failure can cause damage to surrounding equipment and injury to people in the vicinity. Large steel containment systems are employed to prevent high-speed fragments from causing damage in the event of failure.

In contrast to many other ESSs, flywheel systems have few adverse environmental effects, both in normal operation and in failure conditions. Neither low-speed nor high-speed flywheel systems use hazardous materials, and the machines produce no emissions.

Maturity

Several companies have installed pilot, demonstration, or initial deployments for utility scale applications. Most commercially available systems are intended for smaller/lighter industrial applications. The largest commercially available systems of this type are in the 2- to 6-kWh range, with plans for up to 25 kWh [235].

Case Study

The Beacon Power facility in Stephentown, New York, is a 20-MW plant consisting of 200 Beacon Power Series 400 flywheels that provide frequency regulation services to the New York Independent System Operator. This system was placed in service in June 2011 and can provide 15 minutes of response at rated power [0365].

A second Beacon Power facility, Hazle Spindle in Pennsylvania, is also a 20-MW plant consisting of 200 Beacon Power Series 400 flywheels that provide frequency regulation services to grid operator PJM Interconnection. This facility was place in service in July 2014; it also provides 15 minutes of response at rated power [0365].

Amber Kinetics installed a 10-kW flywheel storage demonstration project in Fremont, California (California Independent Systems Operator), capable of delivering 1 hour of stored energy at full power. It was connected to the transmission system to maintain voltage and frequency as well as to provide spinning reserve. The system was operational for about 6 months in 2015 [0365].

The ABB PowerStore system, which includes both flywheels and power conversion, has been installed at several locations in Australia to provide grid stabilization. These applications have generally been 500 kW with a duration of less than 1 minute [0365].

20-MW (15-minute) flywheel energy storage facility (courtesy Beacon Power)

Risks/Barriers

Equipment Cost

An advanced FESS is a complex mechanical device involving many subsystems, high-performance materials, and close manufacturing tolerances. Continued improvement and refinements in design, materials, and manufacturing processes will gradually reduce the capital costs for these systems.

Long-term Performance

Few utility-scale FESSs have been in operation for more than a few years. There will continue to be some uncertainty with regard to maturity and bankability of this 20-year technology until more commercial facilities perform suitably into at least mid-life.

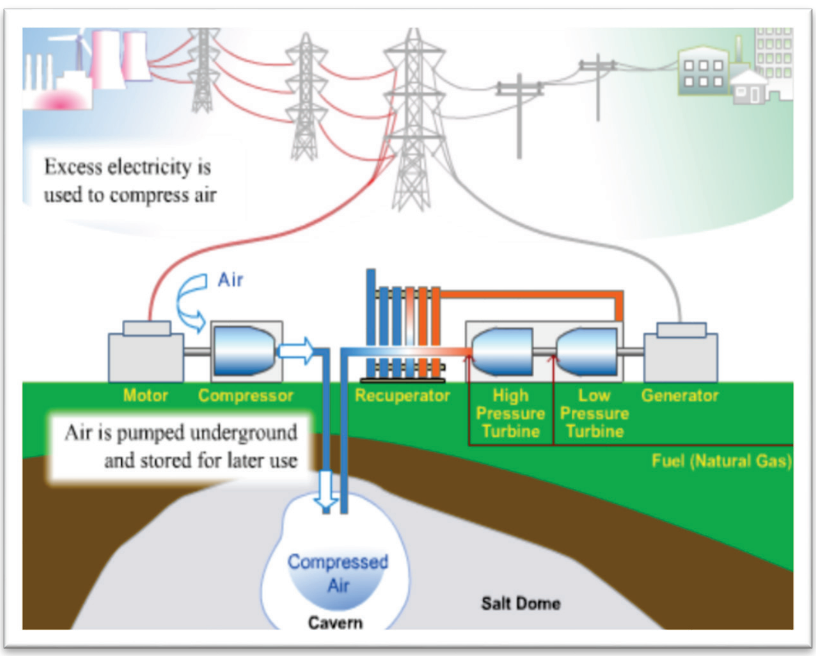
Suitability for South Africa

An FESS system might be appropriate for a narrow range of high power, ancillary service, utility-scale type applications in South Africa. However, the current commercial product offerings are likely more expensive, less mature, and less bankable than competing technologies. This situation may change in the next 5 to 10 years as the technology evolves, installed cost comes down, and system reliability and performance are demonstrated.

A.16 Compressed Air Energy Storage

Compressed air energy storage (CAES) systems use off-peak electricity to compress air and store it in a reservoir — either an underground cavern or aboveground pipes or vessels. When electricity is needed, the compressed air is heated, expanded, and directed through an expander or conventional turbine-generator to produce electricity [0235].

A significant aspect of CAES is that air heats up significantly when compressed from atmospheric pressure to a storage pressure of around 70 bar (1,000 psia). In addition, compressed air must be heated in order to compensate for cooling effect during expansion. There are many methods of managing the heating and cooling. This section discusses diabatic and adiabatic CAES, as well as newer isothermal CAES technology.



CAES with underground storage (Energy Storage News [0235])

Diabatic CAES Technology

Compression and Expansion

In the first-generation applications of CAES, air was compressed to around 70 bar in successive stages of compression and heat-exchange to achieve a lower final temperature (close to ambient). Inter and after coolers were used to remove heat from the compressed air and to maintain the discharge temperature at approximately 160°C and cavern injection air temperature at approximately 45°C. The removed heat of compression was discharged to the environment. During the generation cycle, prior to being expanded through a turbine generator, the high-pressure air was heated in combustors using natural gas fuel, or alternatively using the heat of a combustion gas turbine exhaust in a recuperator.

Storage

Independent of the selected method, very large storages are required because of the low storage density. Preferable locations are in artificially constructed salt caverns in deep salt formations. Salt caverns are characterized by several positive properties: high flexibility, no pressure losses within the storage, no reaction with the oxygen in the air, and the salt host rock. If no suitable salt formations are present, it is also possible to use natural aquifers; however, tests must be carried out first to determine whether the oxygen reacts with the rock and with any microorganisms in the aquifer rock formation, which could lead to oxygen depletion or the blockage of the pore spaces in the reservoir. Depleted natural gas fields are also being investigated for compressed air storage; in addition to the depletion and blockage issues mentioned above, the mixing of residual hydrocarbons with compressed air will have to be considered.

A concept for small CAES uses compressed air stored in smaller pressurized vessels located near the compressor. One arrangement envisions compressed air stored in steel pipes buried underground. When combined with higher pressure, isothermal compression this could provide for smaller cost efficient CAES units.

Advanced Adiabatic CAES Technology

Advanced adiabatic compressed air energy storage (AA-CAES) is an evolution of traditional CAES that is designed to deliver higher efficiencies via a zero-carbon process. Operation is similar to traditional CAES in that energy is stored by compressing air with turbomachinery and storing in an underground cavern.

In AA-CAES, a thermal ESS is used to capture the heat removed during the compression cycle. This heat is then stored and used to heat the compressed air prior to expansion, thus eliminating the need for natural gas. Recovery and reuse of the heat from compression allows a higher efficiency of up to 70% because there is no longer any need to burn extra natural gas to warm the decompressed air. An international consortium headed by the German energy company RWE is developing the necessary components and the heat storage. The pilot plant is scheduled to start operations in 2018. Thermal oil and molten salt storage is being investigated in the United States.

One method (LightSail) is to spray fine droplets of water inside the piston during compression. The high surface area of the water droplets coupled with the high heat capacity of water relative to air means that the temperature stays approximately constant within the piston: the water is removed and either discarded or stored and the cycle repeats. A similar process occurs during expansion.

Isothermal CAES Technology

Controlling the pressure-volume (P-V) curve during compression and expansion is the key to efficient CAES. Roughly speaking, the closer the P-V curve resembles an isotherm, the less energy is wasted in the process.

Rather than employing numerous stages to compress cool, heat, and expand the air, isothermal CAES technologies attempt to achieve true isothermal compression and expansion in situ, yielding improved round-trip efficiency and lower capital costs. In principle, it also obviates the need to store the heat of compression by some secondary means (e.g., oil).

The technology compresses and expands gas near isothermally over a wide pressure range, namely from atmospheric pressure (0 psig) to a maximum of about 170 bar. This large operating pressure range, along with the isothermal gas expansion (allowing for recovery of heat not achieved with adiabatic expansion), achieves a ~7× reduction in storage cost as compared to classical CAES in vessels.

Isothermal CAES is technologically challenging because it requires heat to be removed continuously from the air during the compression cycle and added continuously during expansion to maintain an isothermal process. Heat transfer occurs at a rate proportional to the temperature gradient multiplied by surface area of contact; therefore, to transfer heat at a high rate with a minimal temperature difference, a very large surface area of contact is required.

Although no commercial isothermal CAES are currently implemented, several possible solutions have been proposed based up reciprocating machinery.

Other CAES Variations

One CAES variation that has been proposed is to modify the design of wind turbines to compress air directly via a mechanical link. In theory, skipping the conversion to and from electricity should improve efficiency and lower costs. A further variation is to store the compressed air in inflatable underwater bags. This could provide an alternative to the requirement for a storage cavern and would allow air to be stored and retrieved at constant pressure, which could improve operating characteristics.

CAES Performance

CAES power plants are a realistic alternative to pumped-hydro power plants. The capital and operating expenses for the already operating diabatic plants are competitive, however there have been few large-scale deployments. First generation systems produce a round trip efficiency (RTE) of approximately 42%; those with waste heat utilization can be approximately 55%. In the future, an advanced adiabatic system could provide 70% RTE. When the technology is refined and commercialized, isothermal CAES could provide an RTE as high as 70%.

Underground CAES storage systems are most cost-effective with storage capacities up to 400 MW and discharge times of 8 to 26 hours.

Typical Performance for CAES

Parameter	Adiabatic Cavern	Aboveground Storage
Power Rating	Up to 400 MW	Up to 3 – 50 MW
Discharge at Rated Power	Hours – days	Hours
Round Trip Efficiency	up to 70%	up to 70%
Response Time	1 – 15 min	seconds – minutes
Self Discharge per day	Small	very small
Power Density	0.5 – 2 kWm^3	higher than large CAES
Energy Density	2 – 6 kWhm^3	higher than large CAES
Cycle Life	10,000 – 30,000 cycles	>10,000 cycles
Depth of Discharge	80 – 100%	80% – 100%
System Lifetime	25 – 40 years	20+ years
Cost, power	400 – 1,000 $/kW	1,000 – 1,500 $/kW
Cost, energy	2 – 50 $/kWh	100 – 300 $/kWh

CAES plants employing aboveground air storage would typically be smaller than plants with underground storage, with capacities up to 3 MW and discharge times of 2 to 6 hours. Aboveground CAES plants are easier to site but more expensive to build (on a $/kW basis) than CAES plants using underground air storage systems, primarily due to the incremental additional cost associated with above ground storage [0235].

Applications

Large underground systems are most applicable to high-energy storage requirements such as bulk energy management, backup and seasonal reserves, and renewable integration. These systems might be hundreds of megawatts with discharge times of 8 to 26 hours [0235]. Isothermal systems or smaller aboveground CAES systems might have capacities up to tens of megawatts and shorter discharge times of 2 to 6 hours and could support a variety of other benefits, including an alternative to the battery for industrial applications, such as UPSs and backup power systems [0307].

MATURITY

CAES using cavern storage is a commercial and mature technology, however there have only been a couple deployments; aboveground storage systems are in the demonstration phase. A commercial isothermal CAES is still in the early stages of R&D and pilot demonstration by several companies. It will likely be 2 to 5 years however, before standard compression-expansion equipment and cost-effective tank storage systems are available on the market to support commercial deployment.

CASE STUDIES

KRAFTWERK HUNTORF CAES

In operation since 1978, the Kraftwerk Huntorf CAES plant in Germany was the first commercial CAES plant. The 321-MW plant uses nuclear-sourced nighttime power for compression and produces peak power during the day via a natural gas turbine. The facility stores the compressed air in two “solution-mined” salt caverns that encompass 310,000 m^3. (Water was pumped into and out of a salt deposit to dissolve the salt and form the cavern.) The depth of the caverns is more than 600 m, which ensures the stability of the air for several months’ storage, and guarantees the specified maximum pressure of 100 bar. One cavern is cycled on a diurnal basis. The second cavern serves as a black start asset if the nearby nuclear power plant unexpectedly goes down [0365].

MCINTOSH ALABAMA CAES

The McIntosh Alabama CAES plant has been in operation since 1991 and uses nuclear-sourced nighttime power to compress air into a solution mined salt cavern. The pressurized air (~75 bar) feeds a 110-MW natural gas combustion turbine and is used primarily for peak shaving. The capital cost of the facility was $65 million (~$600/kW) [0365].

Aboveground facilities for 110-MW McIntosh Alabama CAES plant

Gaines Dispatchable Wind Project

The Gaines project is a 2.0-MW wind generation project in west Texas. Commissioned in 2012, the project consists of a wind turbine, a General Compression Advanced Energy Storage (GCAES™) system that relies on a series of near-isothermal compressor/expanders, a storage cavern, and other electrical and ancillary facilities. During periods of low demand, the system can store portions of the energy generated by the wind turbine and later, during periods of increased demand, release the stored energy [0365].

Liverpool Wind and Energy Storage Project

Construction was scheduled to start in April 2016 for the Liverpool Wind Energy Storage Project, which will demonstrate a 500-kW/3-MWh regenerative air energy storage (RAES) system (near isothermal) designed by LightSail. The storage will be interconnected to the local distribution grid and will act as a buffer to the output of a 4.7-MW wind farm consisting of two Enercon E-92 wind energy converters. Waste heat from a nearby industrial facility will be used to boost the efficiency of RAES. This project is the first wind + RAES system ever developed, as well as the first RAES system integrated with an industrial waste heat source.

Risks/Barriers

Siting, Permitting, Project Development

The greatest barrier to CAES is the availability of suitable underground geologic features. This is compounded by the facility size and resultant project cost, as well as the extended project time frame necessary for siting, permitting, and construction. Use of existing hard rock mines would significantly reduce the time for preparation of the storage facility.

Affordable Aboveground Storage

Aboveground CAES systems require the use of high-pressure air storage systems. Ongoing R&D for advanced storage technologies such as carbon-fiber composite tanks will likely reduce these costs in the future.

Suitability for South Africa

CAES is a cost-effective technology for large-scale bulk facilities using underground storage, however suitable locations are very limited and significant geological studies and EIAs will have to be conducted.

Smaller scale aboveground systems are increasingly cost effective for specific applications and sites. Aboveground equipment, including compressors and turbine-expander equipment, is likely manufactured by large international equipment manufacturers in Europe, United States, or Asia. Small CAES facilities using aboveground storage in tanks would be an attractive option for South Africa in that they could be easily sited. South Africa could easily provide for local manufacture of aboveground storage tanks based on an economically competitive design/technology.

A.17 Liquid Air Energy Storage

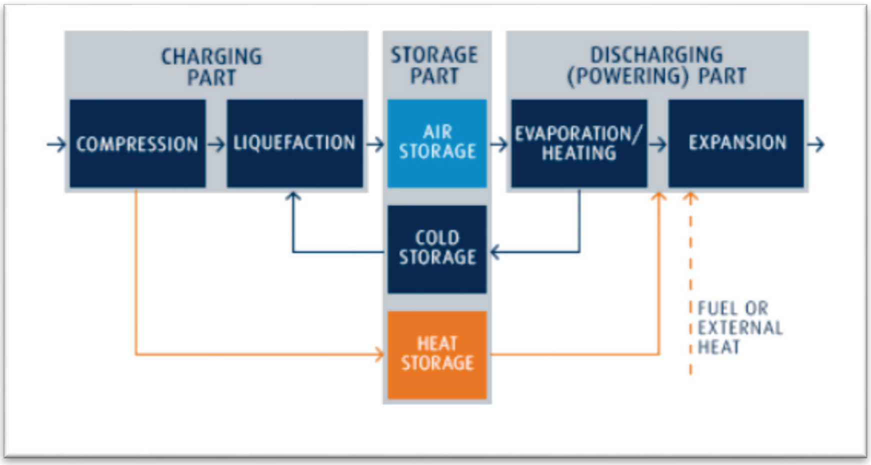
Liquid air energy storage (LAES) uses excess or off-peak electricity to power an air liquefier to produce liquid air. The liquid air is then stored in insulated tanks at low pressure. When the energy is needed, the liquid air is pumped into a heat exchanger and is heated to a gaseous state at high pressure. The gas is then used to drive a turbine.

Technology

LAES, also referred to as cryogenic energy storage (CES), is a long-duration, large-scale energy storage technology that can be located at the point of demand. The working fluid is liquefied air or liquid nitrogen (~78% of air is nitrogen). LAES systems share performance characteristics with pumped hydro and can harness industrial low-grade waste heat/waste cold from co-located processes. Size extends from about 5 MW to >100 MW and, with the ability to decouple power and energy capacity, the systems are very well suited to long-duration applications.

Although novel at a system level, the LAES process uses components and subsystems that are mature technologies available from major original equipment manufacturers. The technology draws heavily on established processes from the power generation and industrial gas sectors, with known costs, performance and life cycles all ensuring a low technology risk. LAES involves three core processes [0310]:

- **Charging the system.** The charging system is an air liquefier, which uses electrical energy to draw air from the surrounding environment, clean it, and then cool the air to subzero (–190°C) temperatures until the air liquefies. In this process, 700 liters of ambient air become 1 liter of liquid air.
- **Energy Storage.** Liquid air is stored in an insulated tank at low pressure, which functions as the energy store. This equipment is already globally deployed for bulk storage of liquid nitrogen, oxygen, and liquefied natural gas. The tanks used within industry could store gigawatt-hours of energy.
- **Power Recovery.** When power is required, liquid air is drawn from the tank(s) and pumped to high pressure. The air is evaporated and superheated to ambient temperature. This produces a high-pressure gas, which is then used to drive a turbine.



Liquid air energy storage (courtesy Linde Group)

Performance

This technology is geared toward larger and longer duration applications. LAES will not have the fast ramping times of some other forms of energy storage, however, LAES can be ready in about 2 to 5 minutes, compared to about 10 minutes for conventional gas peaker plants [0245]. LAES can have a very high energy density. Like pumped hydro, power density for LAES varies significantly by application.

Typical Performance for LAES Technology

Parameter	Range
Power Rating	10 – 200MW
Discharge at Rated Power	2 – 10 hours
Round Trip Efficiency***	20% – 70%
Response Time	2 – 5 min
Self Discharge per day	Small
Power Density**	**kWm3
Energy Density	4 times > CAES
Cycle Life	20,000 cycles
Depth of Discharge	80 – 100%
System Lifetime	30+ years
Cost, power	900 – 1,900$/kW
Cost. energy	260 – 530 $/kWh
**Not determined or N/A, ***with waste heat/cold	

Applications

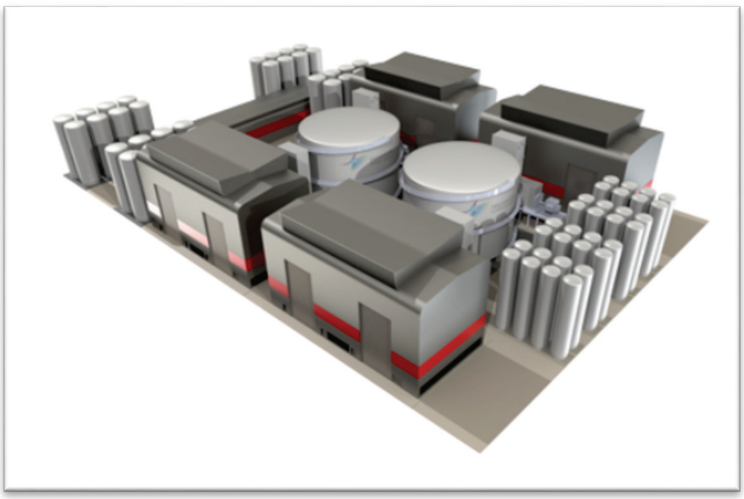
LAES has the potential for large-scale, long-duration energy storage and is expected to be a competitive storage alternative in applications above 50 MW and for storage durations from 2 to 20 hours. The system can be built either as a pure power-to-power storage or combined with usage of industrial waste heat or fuel; in the latter case, it can also be run as a gas turbine peaker (even when the storage is empty).

The main advantage in comparison with classic large-scale alternatives (pumped hydro/ compressed air energy storage) is that no geology is involved. This advantage, combined with the high energy density afforded by liquid air, offers more flexibility in siting LAES, erection time is short, and it is much less prone to public resistance and geological risks.

General Electric is evaluating the integration of utility-scale liquid air ESSs into the design of its gas peaker plant offerings [0305].

Maturity

This technology has been successfully demonstrated and, following refinements, may start initial commercial deployment at scale in the next 5 years.



Concept for 200-MW/1.2-GWh LAES gigaplant (courtesy Highview Power)

Case Study

For 3 years, Highview Power Storage operated a grid-connected 350-kW/2.5-MWh pilot plant with Scottish & Southern Energy next to the utility's 80-MW Slough Heat and Power Biomass Plant just outside London and subjected it to a full testing regime, including performance testing for the US PJM electricity market. The plant was recommissioned at the end of 2015 and has now been relocated to a new site at the University of Birmingham, where it will be used for further testing and research.

350-kW/2.5-MWh LAES Pilot Plant (courtesy Highview Power)

Risks/Barriers

Heat Input

In order to be competitive from a return trip efficiency standpoint, LAES requires some form of waste heat input. Heating liquid air by itself has an RTE of less than 50%; when combined with waste heat from a power plant or industrial process, efficiencies can approach 80% [0305]. Therefore, future applications will have to be sited next to existing facilities or built in conjunction with new facilities that have sizable quantities of waste heat (e.g., thermal plants, steel mills, liquefied natural gas terminals, and other industrial processes).

Suitability for South Africa

This emerging technology could have useful applications in South Africa where high capacity and long discharge energy storage is desired at specific points of demand. Fabrication and assembly of the large air storage tanks and piping necessary for utility-scale facilities could be locally supplied to reduce transportation costs.

Appendix B US and South Africa Company Profiles

1Energy Systems Inc.

Point of Contact

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Company Description

Located in Seattle, Washington, 1Energy Systems (1Energy) is a small software company that provides software for grid-connected energy storage systems (ESSs) and other electric energy assets. 1Energy provides upfront design services, a software control and optimization platform, and system integration services for its utility customers. Founded in 2011, it currently has more than 20 employees and brings in approximately $10 million in annual revenue.

Technology

1Energy provides control system software and power system engineering services that assist electric utilities in the integration of distributed energy resources into the grid. It is a founding member of the Modular Energy Storage Architecture (MESA) effort to create open standards around energy storage communications and control. 1Energy's expertise is derived from extensive distribution and power systems engineering experience and a long track record developing innovative technology for business and energy customers. 1Energy does not make hardware (battery modules or power conversion systems [PCSs]), instead choosing to partner with leading suppliers in these areas.

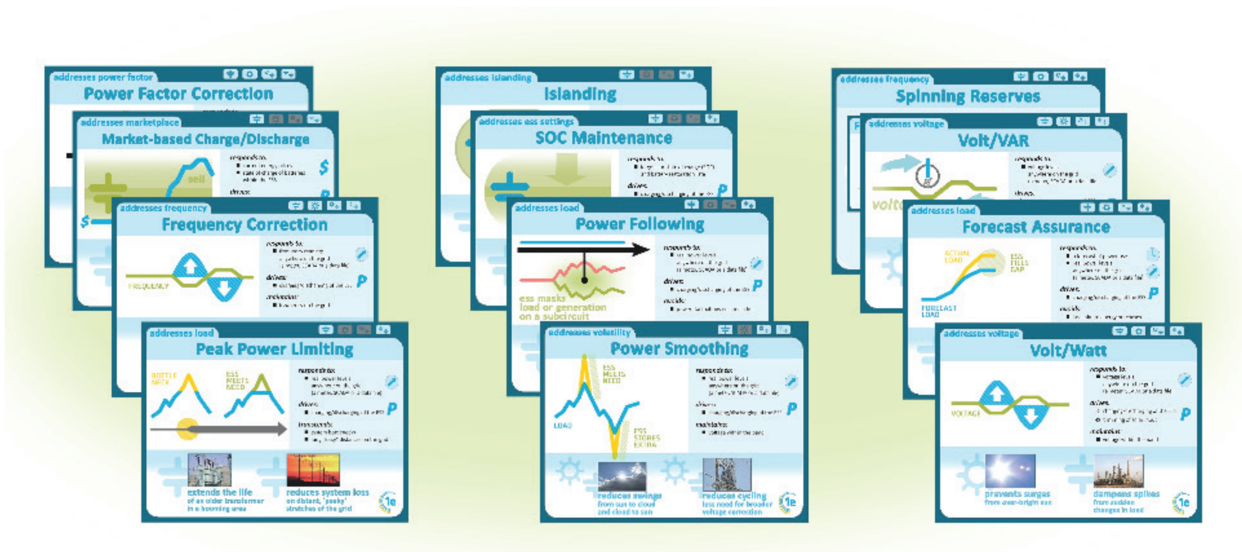
Energy Storage Products/Services

1Energy provides control software based on upfront design services to help customers accurately specify the system they need based on the technical requirements of the circuit where the ESS will be installed. It also provides integration services to ensure that the system gets properly installed, configured, tested, and commissioned. 1Energy does not provide turnkey ESS services, but rather works with a variety of battery and PCS vendors. This approach gives the customer the opportunity to procure these expensive components directly. One way to characterize 1Energy's role is that of a software provider and an owner's rep for the utility customer.

1Energy has two software products:

Intelligent Controller (1E-IC)™

The 1Energy Intelligent Controller (1E-IC) is a Windows-embedded-based system that installs on a hardened PC that is located on site with the ESS. The product is based on the MESA open standard and includes more than a dozen operating modes (peak shaving, spinning reserves, frequency regulation, etc.) with the capability to extend to new, customer-driven ones if desired. The software interacts with the power conversion hardware and the battery modules themselves to direct the operation of the system and to integrate it with the utility's supervisory control and data acquisition (SCADA) or other grid management software. The 1E-IC currently controls a variety of battery chemistry types and power/energy ratios ranging from 1MW/500kWh to 20MW/20MWh. The software is capable of controlling even larger systems.



1E-IC provides a suite of operating modes to address a wide variety of utility needs.

DISTRIBUTED ENERGY RESOURCE OPTIMIZER™ (1E-DERO™)

The 1Energy Distributed Energy Resource Optimizer (1E-DERO) is a Windows-server-based system that installs in a utility's data center. It optimizes a fleet of ESSs as well as other distributed energy resources such as solar and demand response. 1E-DERO takes in information about energy prices in the wholesale market, weather, the state of charge of ESSs on the grid, and other information, and generates a schedule for the fleet of resources, which optimizes the fleet's technical and economic value to the customer. This "fleet schedule" is then intelligently allocated to the individual resources in the system. The product is in an emerging category called Distributed Energy Resource Management Systems (DERMSs).

When combined, the 1E-IC™ offers a powerful suite of local operating modes that complement 1E-DERO™'s bulk power applications for distributed fleet optimization. This combination provides a safe, reliable, and effective platform for utility control of energy storage fleets and other distributed resources.

O&M REQUIREMENTS

All ESSs need to be regularly maintained to support their warranties. 1Energy's software has a 1-year warranty at purchase and then support and maintenance can be purchased at 10 to 20 percent of the software's original purchase price per year thereafter. Support and maintenance keep the software updated and secure as well as help to troubleshoot and fix any problems that arise after commissioning.

1Energy systems are substation-hardened, rack-mounted computers with preinstalled software based on a Windows Embedded Standard 7 operating system, configured using the Industrial Automation configuration as a base and then customized for secure ESS operation. The controller software, including the graphical human-machine interface (HMI), is consistent with control room standards and designed for touch or keyboard/mouse interface.

Deployment

1Energy systems do not have specific deployment requirements. The 1E-IC is generally located at the ESS site and provides a standard MESA interface to all ESSs regardless of battery type.

The 1E-DERO is installed in a utility data center and works with any DNP3-enabled ESS control system.

Field-deployed 1Energy 1E-IC system.

1Energy has been fielding megawatt scale ESSs since 2012. It has worked with five different utilities and an independent power producer to deploy a total of seven projects to date.

Project	Utility	Power	Energy
MESA-1a	Snohomish PUD	1 MW	0.5 MWh Li-ion
MESA-1b	Snohomish PUD	1 MW	0.5 MWh Li-ion
Rankin	Duke Energy	1.25 MVA	0.3 MWh NaNiCl
Cochrane	AES (Chile)	20 MW	5 MWh Li-ion
MESA-2	Snohomish PUD	2 MW	7 MWh VRFB
Glacier	Puget Sound Energy	2 MW	4.4 MWh Li-ion
Bainbridge	Puget Sound Energy	0.5 MW	1 MWh Zinc Flow
AM-1	Austin Energy	1.5 MW	3.0 MWh
TOTALS		**+28 MW**	**+ 20 MWh**

1Energy 1E-IC system deployments.

South African Presence/Experience

1Energy's international project experience to date is limited to a project for AES in Chile, but it is in talks with an international industrial company about partnering for wider distribution and support.

Adara Power

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Company Description

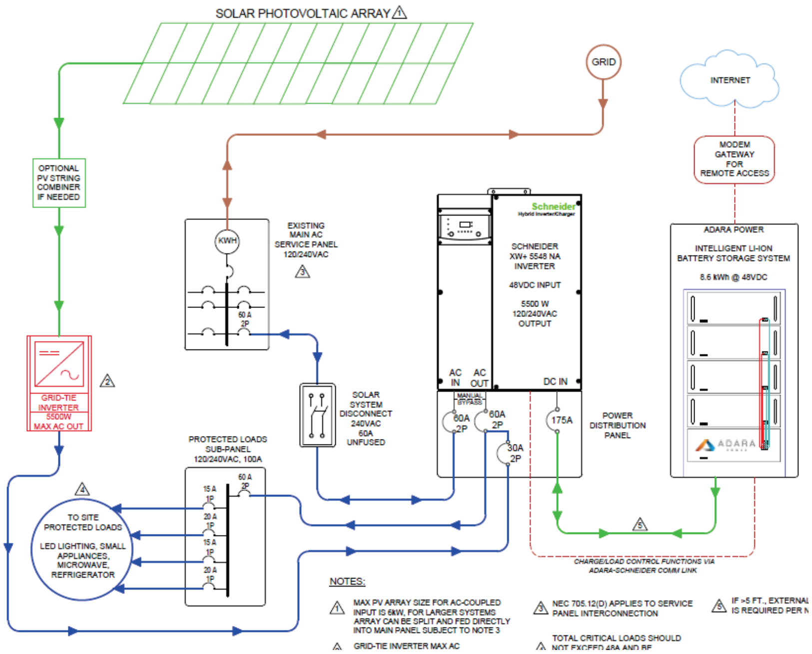
Founded in 2013, Adara Power (formerly JuiceBox Energy) is a Silicon Valley–based company that develops advanced energy storage and management systems to meet the growing demand for renewable energy storage. Located in Milpitas, California, Adara is a privately owned startup with six direct employees and a network of 100 certified installers. The company has its roots in automotive electric vehicle (EV) and battery management controls.

Technology

Adara's expertise involved the development of a state-of-the-art power control system specifically designed to operate in conjunction with an off-the-shelf power inverter. Adara packages its control system in a custom cabinet along with third-party lithium-ion nickel manganese cobalt (NMC) battery modules in an indoor/outdoor UL-rated enclosure. It distributes system "kits" for installation by qualified installers. The Adara system is simple and yet extremely flexible in configuration. A significant advantage to the Adara systems are that they can be AC- or DC-coupled to photovoltaic (PV) solar arrays and on loss of power can switch to discharge in 8 milliseconds (quick enough to prevent dropping electrical loads). The lithium ion battery allows for 98% RTE_{DC} and overall 84% RTE_{AC}. The systems are warranted for 4,000 cycles at 70%-75% depth of discharge (DOD).

The Adara Power controller is the brains of the system. Adara has developed a system controller that integrates a full-featured, commercially available inverter/charger and can be deployed in parallel for higher power and energy needs. The system is designed to operate grid-tied, grid-isolated, and off-grid configurations. Each configuration delivers years of dedicated peak shifting, backup power, and energy efficiency, and enables participation in emerging transactive energy exchanges. It constantly monitors the state of the battery, the PV output, and the building load from the inverter, and it determines the mode of operation based on customer bill rates and other priorities. A balance between rates of charge and discharge, operating temperature, DOD, and number of cycles must be achieved to ensure long life.

The power control system is mounted in the Adara custom enclosure along with the battery modules. Adara has selected a lithium-ion NMC battery chemistry based on its long life, high-energy density, and safety. NMC is the leading automotive cell chemistry. Although the NMC is capable of high rates of discharge, Adara Power controls the discharge and charge current depending on the cell temperatures and other conditions to ensure long life.



Example of typical Adara wiring schematic.

Adara ESSs are connected to the cloud through a robust and secure cellular connection. Installers and homeowners do not have to deal with fire walls or router issues. The data is securely managed and used to provide the homeowner with status, reporting, and control via our mobile app. The connectivity enables Adara Power to roll out firmware updates and provide monitoring services for customers.

Energy Storage Products/Services

Adara's current residential product can be installed separately, with a rooftop PV system, or retroactively in a residence that already has a rooftop system, but is looking to maximize self use of the solar-generated power. Adara currently manufactures a stackable 5.5kW/8.6 kWh lithium-ion ESS for residential and small-scale commercial buildings.

The Adara ESS contains an array of lithium-ion batteries with a battery management system for safe, reliable, long-lasting control of the lithium-ion cells. It also contains a system controller to manage the inverter/charger interface to ensure control of charge and has redundant protection mechanisms to prevent over-voltage, over-current, under-voltage, and over-temperature conditions. To provide optimal performance, Adara builds its control system around a commercially available inverter; in this case, a Schneider Conext XW+ 5548/6848 NA also known as the XW+ 7048/8548E for overseas markets. The inverter is mounted along with a wiring connection box next to the Adara cabinet. A cellular gateway to a secure cloud-based repository enables remote monitoring, updates, and control.

Adara has plans to expand to a larger commercial system for commercial/light industrial applications, which will require the refinement of its power control system around a large commercial inverter.

Adara Power's battery/controller cabinet (left) with inverter/wiring box (center) and solar controller (right).

O&M Requirements

Adara provides training for installation and basic maintenance of its systems to each authorized, qualified installer. No routine or periodic maintenance is required for Adara systems, and each system is monitored remotely. Different operating schemes and algorithms can be remotely "pushed" to an individual system as needed by the customer's specific situation. A local qualified technician is dispatched to address any situations that cannot be corrected remotely.

Deployment

Adara builds "kits" that contain the battery/control cabinet, inverter, wiring box, cellular modem, and other necessary components. These components are palletized and shipped to commercial installers. Adara systems are typically installed in a garage, outdoor wall, or storage area, and can be wall- or floor-mounted. These systems can be installed by a two-person crew in 2 days or less.

As of April 2016, Adara had 27 systems installed in eight states across the United States. Its goal is to install a demonstration system in conjunction with large installers in many areas across the country and to allow the installers to generate additional sales.

South African Presence/Experience:

Distribution and installation of Adara systems is currently limited to the United States. However, Adara intends that its business model will be expanded in the near future to include other countries through existing solar/wind system installers. It seeks local partners that can source the local manufacture of the sheet metal enclosure, receive battery modules directly from its Asian supplier, and put together "kits" with its control system from California.

AES

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COMPANY DESCRIPTION

Associated Energy Services (AES) is a significant player in the Energy Storage Market and has been a pioneer in energy storage, having installed its first utility-scale facility of 12 interconnected megawatts (MW) in 2009 in the Atacama desert of Northern Chile. Since then, AES Storage has installed an additional 74 MW in Chile and the United States, with an additional 80 MW under construction globally, with projects in the United States, Northern Ireland, the Netherlands, Chile, and the Philippines. Another 218 MW are in the late stages of development [0375-Forbes].

TECHNOLOGY

AES provides its Advancion integrated platform, which combines physical architecture, a controls system, and software that sits on top of an array of lithium ion batteries. AES also tests and certifies batteries at its battery testing center, working with various manufacturers to create modules to the company's specifications. Depending on the manufacturer, the process can take from weeks to months.

To date, AES has exclusively used Li-ion batteries in its storage deployments because these batteries have been in the field for decades, with literally millions of hours in applications ranging from power tools to laptop computers, as well as hybrid buses [0375-Forbes].

ENERGY STORAGE PRODUCTS/SERVICES

AES specializes in utility-scale lithium ion energy storage systems built around the Advancion platform. These systems as generally housed in a purpose-built building.

DEPLOYMENT

AES has been focused almost exclusively on providing storage in front of the meter to the utilities. The following are some of the significant utility-scale projects completed by AES.

INDIANAPOLIS, INDIANA – INDIANAPOLIS POWER & LIGHT COMPANY (IPL)

Size: 20 MW (40 MW Resource)   Online date: May 2016

Service: IPL, a subsidiary of AES Corporation, developed a grid-scale, battery-based energy storage system to improve reliability and lower costs for its customers. The facility will deliver enhanced grid reliability and ancillary services, focused on primary frequency response, with possible other services as conditions and markets allow.

CARRICKFERGUS, NORTHERN IRELAND – AES KILROOT

Size: 10 MW (20 MW Resource) Online date: January 2016

Service: The 10 MW array is a crucial first step towards a planned 100-MW energy storage array adjacent to Kilroot Power Station, which would be among the largest in the world. The array provides harmonized ancillary service to the System Operator of Northern Ireland (SONI) and represents a significant investment in the future of Northern Ireland's energy infrastructure.

THE NETHERLANDS – AES ZEELAND

Size: 10 MW (20 MW Resource) Online date: December 2015

Service: The AES Zeeland array, which is AES's first installation on the European continent, will provide Primary Control Reserve (PCR), matching supply and demand for an integrated market. Using Advancion® 4, AES Zeeland is supporting the European transmission grid via regional distribution system operator DELTA Netwerkgroep and transmission system operator, TenneT.

CUMBERLAND, MARYLAND – AES WARRIOR RUN

Size: 10 MW (20 MW Resource) Online date: November 2015

Service: Provides frequency regulation in the PJM market. It is the first deployment of Advancion 4 and features a new, industry-leading compact footprint and optimized design that is five times denser than prior installations; smaller, more manageable building blocks for Advancion Arrays; and a digital control system that provides owners with unprecedented control to maximize revenue and reduce operating costs.

MORAINE, OHIO – DAYTON POWER & LIGHT

Size: 20 MW (40 MW Resource) Online date: September 2013

Service: The Tait Energy Storage Array provides frequency regulation in the PJM market, operated by AES' fast-response architecture that applies patented performance algorithms to optimize performance, increase efficiency for customers and extend the life of the battery. The facility put AES' US energy storage fleet over 100 MW in commercial operation.

NORTHERN CHILE – AES GENER ANGAMOS POWER PLANT

Size: 20 MW (40 MW Resource) Online date: May 2012

Service: The AES Angamos Storage Array integrates 40 MW of energy storage with a 544-MW thermal power plant to provide advanced reserve capacity. The storage enables AES Gener's Angamos plant to increases power generation by 4% to serve an important mining region in the country.

Elkins, West Virginia – AES Laurel Mountain

Size: 32 MW (64 MW Resource) Online date: October 2011

Service: The AES Laurel Mountain Storage Array enables a 98-MW windfarm to be among the first wind generation facilities to supply critical grid stability services. For more than 2 years, it has consistently been selected for regulation service from among competitively bid offerings in PJM, serving as a lower cost, better performing, zero-emissions, renewable energy alternative to traditional power generation.

Atacama Desert, Chile – AES Gener Los Andes Substation

Size: 12 MW (24 MW Resource) Online date: December 2009

Service: The Los Andes Storage Array provides critical contingency services to maintain the stability of the electric grid in Northern Chile. It is one of the best-performing reserve units in the region, according to CDEC-SING, the grid operator. The only unit that has responded to all generator assisted fault restorations, supporting energy-intensive and economically important mining operations in the region.

South African Presence/Experience

As evidenced by the projects listed above, AES has extensive international experience. In South Africa, AES has a country-specific organization, AES South Africa, which operates and manages energy and utility plants on behalf of industrial users across various industries throughout the country. AES's outsourced operations include the takeover of existing energy and utility operations, as well as upgrades to or new-build energy plant operations. AES South Africa headquarters are in Cape Town with regional operations in the Eastern Cape (Port Elizabeth), Gauteng (Johannesburg), Kwa-Zulu Natal (Pinetown) and the Western Cape (Cape Town). More than 300 staff are currently employed, including numerous technical personnel befitting the nature of its business activities, as well as engineers and engineering technicians of varying disciplines.

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Alevo

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Company Description

Alevo is a vertically-integrated global manufacturer and provider of energy storage systems (ESSs). Alevo Group was founded in 2009 and is headquartered in Martigny, Switzerland. Alevo launched its first battery manufacturing and Gridbank™ assembly facility at its Alevo campus in Concord, North Carolina, where it started production in 2015. Alevo has also opened an electrolyte-manufacturing facility in Martigny that will produce batteries on a smaller scale than at the Concord facility. In addition to battery ESSs, Alevo Analytics also provides analytics and services, as well as energy management system (EMS), battery management system (BMS), and supervisory control and data acquisition (SCADA) software solutions.

Currently, Alevo has more than 230 global employees. It is budgeted to grow to more than 2,500 employees by 2017. Alevo intends to deploy more than 1 gigawatt worth of batteries in the United States in 2016. Although a relatively new company, Alevo has positioned itself with standardized initial product offering based on an improved competitive technology. Manufacturing a relatively standardized product in a large-capacity facility, Alevo intends to offer a low-cost, high-performance utility scale energy storage solution.

Technology

Alevo manufactures a large prismatic lithium-ion (Li-ion) battery cell that uses a patented sulfur-based inorganic electrolyte referred to as "Alevolyte," which Alevo believes to be 10 times more conductive than the organic chemistry in conventional Li-ion batteries. This allows for a much higher power output and shorter charge times. Alevo notes a number of significant performance improvements based on its design including faster charging time, higher efficiency, long cycle life, and increased safety.

Alevo battery tray (four modules, each containing eight cells).

ENERGY STORAGE PRODUCTS/SERVICES

Alevo's main product is Gridbank, a packaged ESS. Each Gridbank is housed in a 40-foot container and contains 22 Li-ion battery strings. Li-ion battery cells are packaged eight to a module, four modules to a tray, and 20 trays to a string. The Gridbank container includes a BMS, DC electrical controls and disconnects, and a chiller and air-handling unit for environmental control. The Gridbank is connected via underground cabling to an external inverter which is manufactured by Alevo's partner, Parker-Hannifin. GridBank containers and/or facilities are designed by third-party partners.

Gridbank is intended to be source-agnostic in that it can be used across a wide variety of transmission & distribution, and generation applications and use cases.

Concept of Alevo Gridbank system with external inverter.

Performance

The standard Alevo Gridbank is a 2MW/1MWh storage system. Although only starting full-scale production in 2015, Alevo claims several strong performance metrics for its batteries including a cycle life of more than 10 times that of its competition. Alevo has currently tested its battery technology to 55,000 cycles with testing still continuing. The batteries have greater than 94 percent roundtrip efficiency, and can charge/discharge at the megawatt nameplate rating in 20 milliseconds. The system can be fully charged and discharged in 30 minutes while simultaneously providing reactive output. A nonflammable inorganic electrolyte is inherently safer and unlike other Li-ion technology, Alevo's GridBanks will not catch fire or explode. Alevo's chemistry also avoids calendric aging (no loss or reduction in energy storage over time).

O&M Requirements

GridBanks are designed as utility-scale ESSs and, as such, they are designed to be very low maintenance. They are designed to operate in an ambient temperature range of –20 C to +55 C.

Alevo GridBanks do not produce emissions, require no water use, are fully containerized, are noncombustible and nonflammable, and are designed to be robust, safe, and reliable.

Deployment

Alevo has a demonstration GridBank unit installed in Concord, North Carolina. It has also closed several commercial contracts for GridBanks (for both US and international locations). The Alevo factory in Concord is currently mass producing batteries, and the initial deployment of GridBanks for several clients in the United States and other international locations is scheduled for March 2016.

South African Presence/Experience

Alevo is pursuing energy storage and analytics opportunities worldwide. Although GridBanks are not currently deployed in South Africa, the country is a primary target region. Alevo has been in conversation with various power providers, solar companies, and potential mining and other commercial customers in South Africa. Alevo Analytics has also performed a preliminary assessment of the potential benefits of distributed energy storage to the South African power system. Alevo does not have an office in South Africa, but several of its partners have a presence.

Ambri, Inc.

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COMPANY DESCRIPTION

Ambri (formerly Liquid Metal Battery Corporation [LMBC]) was founded in 2011 and is an early-stage company focused on developing a transformative energy storage technology based on the research of Donald Sadoway, MIT professor of materials chemistry. Ambri is headquartered in Cambridge, Massachussetts, and recently opened a manufacturing facility in Marlborough, Massachusetts. Ambri technology was considered to have very high commercial potential and the company was reported to have raised more than $50 million in venture capital from several high-profile technology venture capitalists and investors.

Ambri reports a strong intellectual property position and claims to have filed or have licensing rights to more than 35 domestic and international patents and patent applications, and continues to pursue broad coverage. Ambri declined to participate directly in the United States Trade and Development Agency (USTDA). Information herein is taken from public sources.

TECHNOLOGY

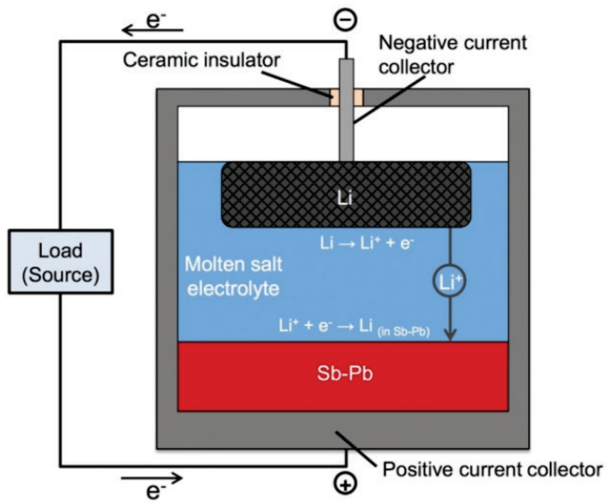
Ambri is developing a unique liquid metal battery technology where all three active components are in liquid form when the battery operates. The two liquid electrodes are separated by a molten salt electrolyte, and these liquid layers float on top of each other based on density differences and immiscibility. The system operates at an elevated temperature maintained by self-heating during charging and discharging. The result is a low-cost and long-life storage system. The system is intended to be low cost through the use of inexpensive, earth-abundant materials and an elegant design that takes advantage of the economies of scale inherent to electro-metallurgy and conventional manufacturing.

Ambri claims that the technology can respond to grid signals in milliseconds and that it can store up to 12 hours of energy and discharge it slowly over time.

Liquid electrodes offer a robust alternative to solid electrodes, avoiding common failure mechanisms of conventional batteries, such as electrode particle cracking. The all-liquid design avoids cycle-to-cycle capacity fade because the electrodes are reconstituted with each charge. The idea behind the battery is to use ultra-low-cost materials that can make cheap, long-lasting batteries that can be used in power-grid applications. Ambri's batteries are targeted to cost a third of what lithium-ion (Li-ion) batteries cost.

The materials used in the original design were magnesium and antimony separated by a salt but in order to obtain a higher voltage and lower operating temperature, Ambri has announced that it is evaluating a new, undisclosed chemistry with the help of ARPA-E funding.

A recent paper in Nature (Sept 2014, #514, pp. 348-350) identified a lithium-antimony-lead formulation that Ambri may be considering where the battery consists of a liquid lithium negative electrode, a molten salt electrolyte, and a liquid antimony–lead alloy positive electrode. These materials self-segregate by density into three distinct layers owing to the immiscibility of the contiguous salt and metal phases. The all-liquid construction confers the advantages of higher current density, longer cycle life and simpler manufacturing of large-scale storage systems (because no membranes or separators are involved) relative to those of conventional batteries.



Ambri's potential Li/Sb/Pb chemistry (source: *Nature*).

According to the company, "Cells have cycled thousands of times in in-house tests with negligible fade on full depth of discharge cycling, extrapolating that after 10,000 charge/discharge cycles the batteries will retain 98 percent capacity availability." Ambri CEO Phil Giudice said a battery seal, which can withstand the liquid metal battery's high temperatures, had shown disappointing results in tests. Ambri is now working on testing out new types of seals that could hold up under the high operational temperatures.

In September 2015, Giudice announced that Ambri had "not made the technology progress we had anticipated. As a result, we will not be delivering commercial prototype systems later this year or early next, as we had originally planned. Consequently, we have reduced our team by 14 colleagues." That reduction is approximately 25 percent of Ambri staff. Giudice indicated that the "reduction in staff and slowed commercialization path will provide us more time to solve the engineering challenges ahead of us before we re-engage in committing to commercial deployment schedules. Specifically, we are acutely focused on developing a robust high-temperature seal for our liquid metal battery. Our primary design of this component demonstrated promising results last fall and this spring, but did not perform sufficiently well under rigorous verification testing protocols which we ran this summer. We are now pursuing other seal designs that show initial promise, but it will take more time to confirm their viability."

ENERGY STORAGE PRODUCTS/SERVICES

Ambri prototype units started as the "shot glass," followed by the 3-in, 20-Wh "hockey puck," and then by the 6-in, 200-Wh "saucer." The commercialized product will use a 6-in square.

Ambri will have to develop all manufacturing processes and robotic cell assembly. However, Ambri claims the technology has a lower manufacturing cost and lower employee-per-square-foot-of-factory ratio than that of Li-ion battery technology. Ambri's CTO also suggested that Ambri's pricing will fall between that of pumped hydro and compressed-air energy storage.

The base unit for Ambri's system is a fully-sealed liquid metal battery cell. Ambri's cells are strung together in a thermal enclosure to form an Ambri Core. The Ambri Core is 'self-heating' when operated every couple of days, requiring no external heating to keep the batteries at operating temperature. The Ambri system comprises multiple Ambri Cores that are strung together and connected to the grid with power electronics. The configuration of the Ambri System is modular and can be customized to meet specific customer needs.

Concept for Ambri 500 kW/1 MWh system (consisting of five Ambri Cores).

O&M REQUIREMENTS

O&M requirements for the Ambri System are not well documented and likely pending the development of a first commercial unit. It is speculated that the complexity of O&M requirements may lie between the range of Li-ion and VRFB technologies.

DEPLOYMENT

Ambri had originally planned on commercial deployment in 2016 but that timeframe has been extended indefinitely as it continues to refine the technical design. Ambri is reported to be working on prototype storage systems in Massachusetts, Hawaii, New York, and Alaska, with project partners such as First Wind, Hawaiian Electric, and Con Edison.

SOUTH AFRICAN PRESENCE/EXPERIENCE

Ambri does not appear to have a presence in South Africa nor specific South Africa experience.

Aquion Energy

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Company Description

In 2007, with support from Carnegie Mellon University, Dr. Jay Whitacre began researching low-cost electrochemical approaches to bulk energy storage. Dr. Whitacre was looking for a way to create inexpensive and easy to manufacture batteries to meet the challenges of the world's growing energy needs and increase the use of renewable power. In 2008, he produced the first functioning Aqueous Hybrid Ion (AHI) battery. The result was promising enough to attract the attention of VC firm Kleiner Perkins Caufield and Byers and, by 2009, the technology was developed enough to spin out of Carnegie Mellon's labs. The operations moved from Carnegie Mellon to the Lawrenceville neighborhood of Pittsburgh, where Aquion is currently headquartered. Aquion has manufacturing facilities in nearby Mount Pleasant, Pennsylvania. The following information is taken from the Aquion website and from publically available Aquion sales and technical brochures.

Technology

Aquion Energy manufactures batteries that are safe, reliable, sustainable, and cost-effective. The Aspen batteries are based on Aquion's proprietary Aqueous Hybrid Ion (AHI™) chemistry, which has a environmentally friendly electrochemical design, and they are the first and only batteries in the world to be Cradle to Cradle Certified™. Aspen batteries contain no heavy metals or toxic chemicals and are nonflammable and nonexplosive.

The Aqueous Hybrid Ion Batteries use a low-cost electrochemical couple that combines a high-capacity activated carbon anode with a sodium intercalation cathode capable of thousands of deep discharge cycles over extended periods. The carbon anode provides an electrochemical double layer capacitor effect. The MnO_2 alkali ion intercalation material provides a cathode that is very stable in neutral pH aqueous electrolyte. The Aspen battery uses an electrolyte comprising Na_2SO4 in water (~1 M). The functional ions are Na, Li, and protons.

In June 2012, Aquion Energy, Inc. completed the testing and demonstration requirements for the U.S. Department of Energy's program with its low-cost, grid-scale, ambient temperature AHI energy storage device. During the 3-year project, Aquion manufactured hundreds of batteries and assemble them into high-voltage, grid-scale systems. This project helped Aquion move its aqueous electrochemical energy storage device from bench-scale testing to pilot-scale manufacturing.

Aqueous Hybrid Ion (AHI™) chemistry is made from abundant, nontoxic materials

Energy Storage Products/Services

Aspen produces three basic battery modules, all of which use its proprietary AHI™ chemistry. The Aspen 48S is a basic battery module; the Aspen 48M is a parallel string of twelve Aspen 48S batteries configured as a single, palletized battery unit. Aspen 48Ms can be connected in series up to 1,000 Vdc. Batteries are provided with a 5-year full warranty plus a 3-year prorated warranty.

Aquion Aspen Standard Battery Modules

Parameter	Aspen 48S	Aspen 48M	Aspen 24S
Energy (at 20-hr discharge)	2.2 kWh	25.9 kWh	
Cycle life	3,000 (with 70% retained capacity)		
Operating Temperature	–5 to +40°C ambient		
Nominal Voltage	48 V	48 V	24 V
Usable DoD	100%		
Round Trip Efficiency	>90%		
Dimensions	935 × 330 × 310 mm	1,159 × 1,321 × 1,504 mm	935 × 330 × 310 mm
Weight	118 kg	1,504 kg	118 kg

Aquion Aspen 48M: a parallel string of 12 Aspen 48S batteries configured as a single, palletized battery unit

DEPLOYMENT

Under CEO Scott Pearson, Aquion began low-volume production in the summer of 2011 and broke ground on full-scale manufacturing facility in nearby Mt. Pleasant in 2012. Aquion has been shipping commercially since mid-2014.

The DOE Global Energy Storage Data Base [0365] lists ten projects using Aquion batteries that range from a 20-kW/2-hour system at Natural Energy Laboratory of Hawaii Authority (NELHA) in Kailua-Kona, Hawaii, to a 450-kW/2-hour system on the Bakken Hale Microgrid at Kiholo Bay, Hawaii.

SOUTH AFRICAN PRESENCE/EXPERIENCE:

South Africa distribution is supported through Aquions's European offices. Aquion has two distributors in South Africa, Mulilo Renewable Energy and Solarworld South Africa, both of which are located in Cape Town.

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ARES

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ares
the power of gravity

Company Description

Advanced Rail Energy Storage (ARES) based in Santa Barbara, California, provides a deployable solution for grid-scale energy storage. ARES facilities are designed to provide grid security and reliability, support the increased use of renewable technologies, and to provide an energy storage solution that does not rely on water. Founded in February 2010, ARES has developed and filed both domestic and international patents for an advanced method of utility-scale electrical storage.

Technology

ARES is developing a gravity-based potential energy storage technology that leverages the high efficiencies of rail transport to provide a significant improvement in performance characteristics, efficiency, and cost relative to other large-scale energy storage technologies.

ARES energy storage technology employs a fleet of electric traction drive shuttle-trains operating on a closed low-friction automated steel rail network to transport a field of heavy masses between two storage yards at different elevations. During periods in which excess energy is available on the grid, ARES shuttle-trains draw electricity from the grid, which powers their individual axle-drive motors as they transport a continuous flow of masses uphill against the force of gravity to an upper storage yard. When the grid requires energy to meet periods of high demand, this process is reversed. The shuttle-trains provide a continuous flow of masses returning to the lower storage yard with their motors operating as generators, converting the potential energy of the masses elevation back into electricity in a highly efficient process.

Like pumped hydro storage (PHS), the ARES system requires specific topography, but ARES claims its system delivers more power for the same height differential. It is also more efficient, with a round-trip efficiency of more than 85%, compared with 70% to 75% for PHS. An ARES facility will provide the full range of energy storage capabilities generally associated with pumped-storage hydro at approximately 60% of the capital cost and at a significantly higher efficiency. Facility life is expected to span 40 years or more with only routine maintenance.

The components of an ARES Energy Storage System can be deployed to create a robust ancillary services system that functions as a limited energy storage resource. These high-power short-duration energy storage systems are designed to provide grid-scale regulation-up, regulation-down, spinning reserves, VAR support, and grid inertia. The ARES Fast Response Ancillary Service technology bridges the power gap between large-scale battery and flywheel installations and far larger pumped-storage hydro — at a lower life-cycle cost than batteries, a higher energy-to-power ratio than flywheels, and a greater efficiency and far faster ramp rate than pumped-storage hydro.

ARES facilities do not require the use of water, which is a significant mitigating factor in the deployment of new pumped-storage hydro facilities. ARES technology can be deployed with minimal environmental implications in many locations throughout the United States and around the world.

Energy Storage Products/Services

ARES envisions that its facilities may be configured to three primary storage functions:

- Smaller ARES facility in the power range of 20 to 50 MW can provide ancillary services only. This type of facility is called an Ancillary Service Facility.
- Intermediate-scale ARES facilities ranging from 50 to 200 MW can provide ancillary services and short-duration (4- to 8-hour capacity) storage necessary for renewables integration.
- Grid-scale ARES Energy Storage Facilities range in from 200-MW transmission storage systems up to 3-GW regional energy storage hubs. Energy capacity may range from 4 to 16 hours duration at full power output.

Deployment

Demonstration Project

ARES successfully built and operated a ¼-scale rail-based energy storage project in Tehachapi, California in 2013. In the midst of one of the most active wind farm areas in the world, the demonstration project operates on 850 feet of electrified railroad with an average grade of 6.5%. The system stores and releases electrical energy by shuttling the 6-ton rail vehicle along the railroad. The testing has successfully demonstrated ARES' ability to rapidly input or withdraw power from the electrical grid in response to fluctuating electrical loads while operating under various environmental conditions. The ARES Tehachapi facility remains an active test bed and research facility as ARES continues to develop green energy storage.

ARES demonstration project provided proof of concept

PILOT PROJECT

ARES has proposed to locate a grid-scale ancillary services facility in the Carpenter Canyon area east of Pahrump, in Nye and Clark Counties, Nevada. ARES proposes to partner with Valley Electric Association, an electric cooperative based in Pahrump, which will provide interconnection with California, where ARES plans to sell ancillary services such as frequency regulation to the California ISO (CAISO).

The ARES REM project will provide 50 MW/12.5 MWh of fast response energy to assist the balancing of intermittent renewable energy (solar and wind) connected to the regional transmission grid, thus increasing renewable energy penetration while maintaining grid reliability.

The system is envisioned to use a nearly 5.5-mile track up an 8-degree slope, gaining about 2,000 feet from top to bottom. It will have up to seven 8,600-ton trains on the track with each train comprising two locomotives and four rail cars. The entire system, including substation and control systems, would occupy about 43 acres of public land near Pahrump in Clark and Nye Counties. ARES expects to begin construction in late 2017 or early 2018, with operations starting early in 2019.

Artists concept for a 50-MW/12.5-MWh gravity-based potential energy storage system

SOUTH AFRICAN PRESENCE/EXPERIENCE

ARES is focusing its initial development and deployment in California and the southwestern United States. Concurrently, ARES is in discussion with several utilities in the United States to develop its technology in different locations, expanded capacity, various applications of its technology and different terrains. ARES has also been contacted by many other countries as more and more renewable energy comes on line and the need for energy storage becomes more apparent. As ARES deploys additional systems, it will look to expand globally including the emerging South Africa Energy Storage market.

Axion Power

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COMPANY DESCRIPTION

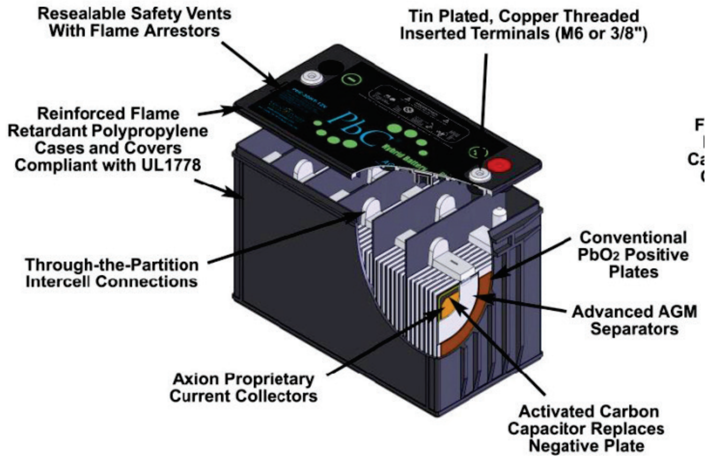
Axion Power's headquarters and manufacturing facilities are located in New Castle, Pennsylvania, and currently include a 75,000-ft^2 lead-carbon battery-manufacturing plant plus a 50,000-ft^2 carbon electrode manufacturing plant. Axion currently has fewer than 50 employees and is transitioning from R&D to commercial operations.

Axion Power is the developer and manufacturer of the PbC® battery and energy management system. Axion can also provide complete, packaged energy systems using inverters and other components that have been selected and proven compatible with the PbC technology. Axion also offers custom system design services to develop energy storage for specific applications.

TECHNOLOGY

Axion Power has developed a lead carbon battery called the PbC battery. Based on absorbent glass mat (AGM) lead acid technology, the lead negative plate is replaced with a layered activated carbon electrode. The resulting product shares characteristics of both a battery and a super capacitor. Compared to lead acid, the PbC battery provides a longer cycle life, ability to work in a partial state of charge, faster recharge, greater charge acceptance, and self-equalization in strings. The carbon electrode can operate consistently in a partial state of charge (PSOC) without negative plate sulfation experienced by lead-acid batteries. The PbC battery will provide in excess of 2,500 cycles at 83% depth of discharge (DOD) and cycle life increases dramatically as DOD decreases. The PbC batteries are produced as a six-cell, 12-Vdc module and an eight-cell, 16-Vdc module. The battery modules are manufactured in standard module sizes to allow for drop-in replacement of standard lead-acid batteries.

Axion has developed an energy management system (EMS) and complete energy storage systems (ESSs) based around the PbC technology. Systems are scalable from a few kW up to multiple MW and can be packaged in a container or assembled in an existing building.

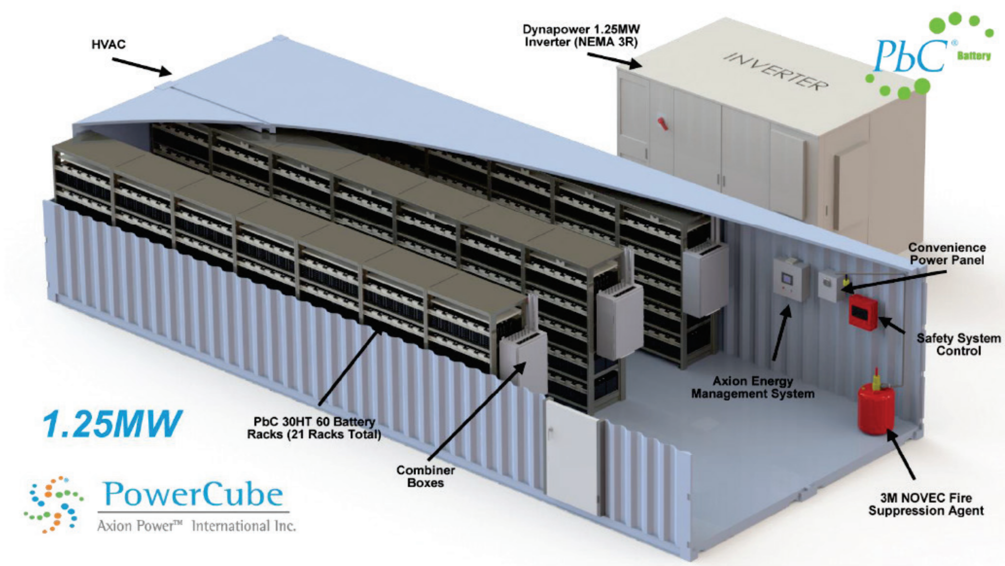


Axion Power 12-V PbC battery module.

ENERGY STORAGE PRODUCTS/SERVICES

Axion Power is currently offering a number of residential and commercial energy storage products built around their PbC battery modules. It manufactures the PbC batteries, and assembles /programs the battery management system (BMS) and EMS.

The commercial product is called the PowerCube and manufactured in three sizes: 100 kW, 500 kW, and 1.25 MW. The 1.25 MW/800 kWh version consists of 1260 Axion PbC 12-V battery modules, arranged in 21 strings of 60. The system includes a BMS, an EMS, heating, ventilating, and air conditioning (HVAC), and a safety control/fire suppression system housed in two NEMA 3R 40-ft ISO shipping containers that are mated together. The battery housing is connected to an external Dynapower 1.25MW bidirectional inverter.



Axion 1.25-MW/800-kWh PowerCube ESS.

A smaller ESS provides 500 kW/400 kWh using 600 PbC 12-V modules and five Princeton Power Systems GTIB-100 bidirectional inverters housed in a single 40-ft ISO container. Axion also makes a 100-kW commercial system. Axion manufactures residential ESSs in 4-kW, 5.5-kW, 6.8-kW, and 10-kW sizes with scalable battery modules for varying energy sizes.

O&M Requirements

The PbC batteries are AGM maintenance-free construction and share the same operational and safety requirements as standard AGM lead acid batteries. Periodic maintenance checks differ based on system use, system size, and geographical location. The PbC batteries share the same safety record and concerns as AGM lead acid and can be recycled through the same existing channels. The use of carbon for the negative electrode reduces the quantity of lead in the battery. However, the battery has the normal environmental concerns associated with lead toxicity and requires recycling for disposal.

Deployment

Axion Power is a recent company and has limited commercial deployments. Axion operated a 500-kW PowerCube at its manufacturing facility and participated in the frequency regulation market from 2011 to 2013 as a behind-the-meter asset.

Axion Power currently has a small number of systems deployed and the batteries are commercially available. Axion has deployed five systems totaling just over 1 MW/800 kWh.

South African Presence/Experience

Axion is currently pursuing projects in North and South America and evaluating opportunities in Europe and China. While not currently pursuing energy storage in South Africa, Axion would be interested in evaluating any potential opportunities.

Bushveld Energy

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Company Description

Bushveld Energy Company (Pty) Limited is a South African energy storage solutions company headquartered in Illovo, Johannesburg. It uses vanadium redox flow battery (VRFB) technology to provide energy storage solutions for commercial, industrial, and utility customers across Africa. It is principally owned by London-listed Bushveld Minerals Resources, which has significant low-cost vanadium assets in South Africa. This group of companies envisions an integrated value chain strategy to manufacture vanadium electrolyte and eventually VRFBs in South Africa.

Currently, Bushveld Energy both develops its own energy storage projects and provides systems and solutions to developers across Africa, including ongoing projects in Sao Tome, South Africa, Tunisia, and Uganda.

Bushveld Energy has a core team combining technical expertise, business acumen, and beneficiation experience. Bushveld's team understands that mass adoption in African electricity markets will not be driven by price and hardware sales but rather by business models that address customer pain points, such as cash flow, reliability of energy supply, and total cost of ownership. The team includes the following:

- Executive-level experience in the mining and power industry, including managing Eskom power stations and pumped storage schemes
- Nearly 10 years of senior strategy and policy experience in power sectors across Africa
- More than 15 years of experience in vanadium beneficiation, including involvement in vanadium electrolyte production and the VRFB development process (and authoring multiple patents on the process)
- More than 15 years of experience in renewable generation and energy storage in South Africa, including installation and testing of scale battery applications of 1 MWh and larger
- Board-level experience at multiple European and African companies, with a track record in investment, policy development, and local empowerment

Technology

Bushveld Energy exclusively uses the VRFB, a unique electrochemical device that stores electrical energy in liquid vanadium electrolytes, instead of in electrodes as many other "solid state" batteries do. The VRFB then releases the stored energy according to the demands of the customer, at levels up to multi-megawatt and megawatt-hours (MWh). The battery lasts for more than 20 years, offers more than 10,000 cycles with 100 percent depth of discharge, while using safe, nontoxic, and nonflammable chemistry. As a result of its performance superiority, when used daily, it provides a cheaper means of storing energy than any other battery technology (including lithium-ion). Furthermore, 70 percent of the VRFB's chemistry is water and 100 percent of the vanadium is reusable after the battery achieves its lifetime, making VRFBs the most sustainable battery technology on the market.

Bushveld Energy has executed a Memorandum of Understanding (MoU) with US-based UniEnergy Technologies (UET) as its technical partner on medium- and large-sized VRFBs (100 kW to 100 MW), both for immediate deployment in Africa and medium-term manufacturing in South Africa. Founded in 2012 as part of a larger company group dating to 2006, UET manufactures and installs megawatt-scale energy storage solutions for utility, commercial/industrial, and microgrid applications.

Energy Storage Products/Services

Bushveld Energy can provide energy storage systems or complete solutions of various sizes, as small as 5 kW in power to up to 100 MW. Systems can range from 3 hours up to 16 hours in energy supply, depending on customer needs. VRFBs come in standard shipping containers, allowing for extremely flexible, modular, and scalable configurations. In addition to providing the systems to African customers, Bushveld Energy tailors the VRFB size, application, and supporting equipment to a specific customer's load profile and needs, while also integrating the VRFBs into the existing electricity supply configuration. Bushveld can either sell the systems and solutions outright or offer independent power producer (IPP)-type Build, Own, Operate, Transfer configuration to a customer, as it is doing with its Tunisia project. In the future, Bushveld Energy is looking into offering other innovative solutions, including leasing of the vanadium electrolyte and short-term (3- to 5-year) rental or leasing of the VRFBs. This is part of Bushveld Energy's strategy to provide African customers cash flow solutions that decrease their energy costs from day one, thus removing a key hurdle to the adoption of energy storage.

Smaller systems (5 kW up to 500 kW) are ideal for grid-connected commercial and industrial customers looking to reduce their demand charges and peak-time electricity costs by using VRFBs to "time shift" energy between off-peak to peak times, while also receiving the benefit of uninterruptible power supply (UPS) in case of grid failures or load shedding. Such customers can also combine the VRFB to better use their rooftop solar installations, further reducing their energy costs. Similarly, off-grid customers can combine VRFBs with either solar or wind generation to enable a 100 percent renewable energy solution, while achieving electricity costs that are below those of diesel or heavy fuel oil (HFO) generation.

Large systems (over 500 kW and up to 100 MW) are ideal for utilities to support their electric power grids, either in transmission and distribution networks or to address the intermittency, cyclicality, and frequency challenges posed by increased numbers of grid-connected renewable energy generators. Large, remote industrial customers currently relying on thermal generation, such as mines, can also use VRFBs with solar or wind generation to reduce and stabilize their energy costs.

The company is not considering residential energy storage applications at this time.

O&M Requirements

The containerized configuration of VRFBs allows for quick installation and commissioning, ranging from 2 days for small systems to 4 weeks for 10 MW and larger configurations. Performance of every cell is monitored remotely by the manufacturer to allow for instant response to any issues. Furthermore, a 20-year manufacturer performance guarantee and full maintenance warranty are available for Bushveld Energy's solutions (with 25-year options also possible).

Deployment

Bushveld's partner, UET, already has 10-MW and 40-MWh systems deployed or ordered. UET's patented technology is an advanced vanadium flow battery, with a new-generation electrolyte first developed at the Pacific Northwest National Laboratory with the support of the US Department of Energy's Office of Electricity, and then improved, patented, and commercialized by UET.

Bushveld Energy expects to install a small VRFB (approximately 30 kW) during 2016, which will nonetheless be the largest in the country to date. It also plans to start procurement of a 500-kW/1-MW sized system for demonstration in South Africa later in 2016, with commissioning in early 2017. It is also working to deploy a 200-kW/1.2-MWh VRFB to the Eskom Research and Innovation Center for testing and use.

South African Presence/Experience

All of Bushveld Energy's full-time and part-time personnel are located in South Africa. Similarly, its group company, Bushveld Minerals, has most of its employees based in South Africa, with large vanadium assets located near Mokopane and Brits. Bushveld expects to start manufacturing vanadium electrolyte as early as Q4 2016 (with 2017 more likely) and VRFBs as early as Q4 2017 (with 2018 more likely), all of which is subject to market growth. The objective is to supply both electrolyte and VRFBs to South Africa and export to the rest of the African continent.

Dresser-Rand

DRESSER-RAND
A Siemens Business

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Company Description

Dresser-Rand (D-R), a Siemens business, is headquartered in Houston, Texas, and has manufacturing facilities worldwide. Compressed Air Energy Storage (CAES) components are primarily produced in Wellsville and Olean, New York. D-R has supported CAES since the mid 1980s. D-R's involvement with compressed air energy storage dates back to 1991 at the PowerSouth Plant in McIntosh, Alabama — the first CAES facility ever commissioned in North America and only the second in the world.

Technology

Drawing on its experience with PowerSouth in Alabama, D-R has developed an integrated solution it refers to as SMARTCAES®. SMARTCAES is a "one-stop" power island that includes all rotating equipment and auxiliary equipment necessary for a grid-scale application. The D-R machinery train also includes all auxiliary subsystems including heat exchange equipment, pollution abatement systems, plant controls, electrification equipment, integration with the grid dispatch interface, performance guarantees, equipment warranties, system operating diagnostics, and emissions controls. This vital integration of multiple components ensures plant uptime and operational flexibility to meet client needs.

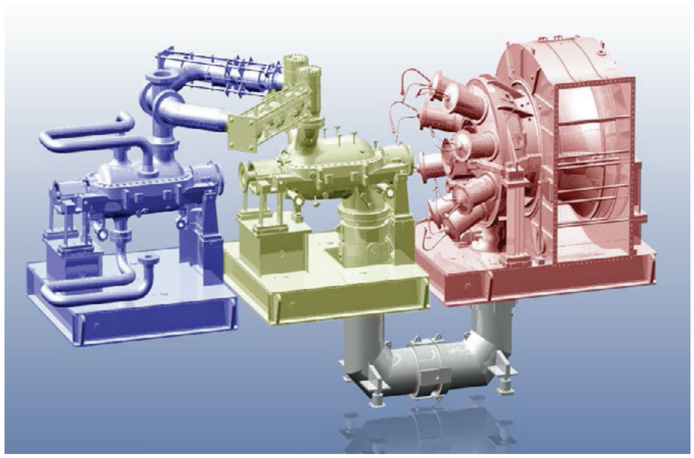
Energy Storage Products/Services

D-R provides at minimum the SMARTCAES power island system, but can also provide an above-ground turnkey installation (EPC). D-R manufactures the CAES compression and turbo-expander trains including gear, motor, generator, and variable frequency drives, digital control systems, recuperators, transformers and switchgear; and associated auxiliary systems.

Expander (Generation) Train

Currently, D-R offers both a 135-MW generation train and a 160-MW generation train. The 135-MW variant uses two fired expanders and the 160MW adds an additional unfired expander. Trains are modular so that multiple generation trains can be used to achieve an overall desired megawatt output. The fired expanders use one third the amount of fuel compared to a conventional simple-cycle gas turbine and operate well below 2,000°F (1,093°C). The

SMARTCAES cycle is extremely flexible. The generation train can ramp up/down at 20 percent per minute and can go from offline to full generation in less than 10 minutes. The generation train can operate between 10 and 100 percent of rated capacity with a rather flat heat rate across the entire operating range.

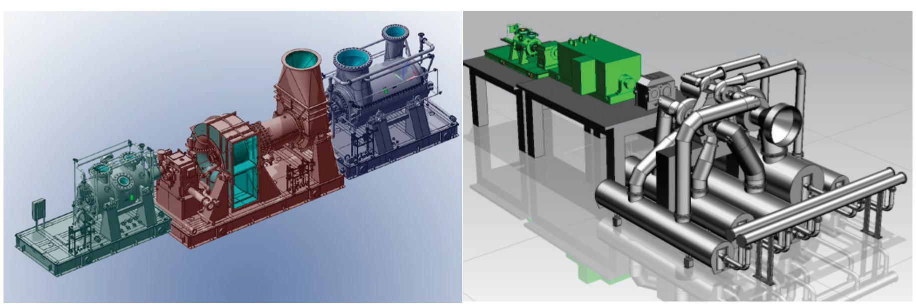


Conventional three-stage expander train.

COMPRESSION TRAIN

The compression train rating/sizing depends on the desired reservoir charging rate. Compressors are intercooled between sections by air, water, or a hybrid of both.

The compression train can ramp up/down at a minimum of 30 percent per minute and can go from offline to full compression load in less than 5 minutes. The compression train can operate between
65 and 110 percent of motor rating.



Four axial + centrifugal (left) and integrally-geared + centrifugal (right) arrangement.

RESERVOIR

Maximum reservoir pressure is typically 800 to 3,000 psi. Typically, a maximum pressure rating of above 2,200 psi at the wellhead will justify the 160-MW offering. Operating pressure range depends on geotechnical limits – typically 400 to 1,000 psi. Reservoir can be salt cavern, depleted gas field, aquifer, or hard rock mine.

O&M Requirements

O&M depends on equivalent operating hours (EOHs). The compression train requires minimal maintenance and inspection and is condition-based monitoring. The turbo-expander train operates at relatively low temperature, so it also requires minimum maintenance and inspection. Plant life for a CAES system is in excess of 30 years.

Deployment

The PowerSouth CAES Plant that was commissioned in 1991 uses D-R's CAES equipment and was the first CAES facility ever commissioned in North America (and only the second in the world). It is still able to meet intermediate and peak electrical production demands after more than two decades. D-R supplied the 140-ft machinery train, including the centrifugal and axial compressors, motor, generator, and multistage turboexpanders, as well as the reciprocating fuel gas booster compressors.

Power South McIntosh AL, CAES plant has been online since 1991

In 2013, D-R received a project award from Apex Compressed Air Energy Storage, LLC to supply SMARTCAES equipment for a 317MW CAES facility (expansion up to 476 MW) in the Electric Reliability Council of Texas (ERCOT) power market. It will be the first CAES facility built in the United States since the PowerSouth McIntosh facility was commissioned in 1991.

D-R has active North American opportunities in California, Texas, and Utah, and also has several in Canada.

South African Presence/Experience

D-R is pursuing international energy storage projects in Europe (Northern Ireland, Holland, Denmark, Germany, and the UK), Australia, and Asia. D-R has several opportunities in early development in South Africa. Both D-R and Siemens have offices in South Africa.

Dynapower Company

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Company Description

Formed in 1963, the Dynapower Company is a leading independent manufacturer of custom power conversion equipment. Dynapower products are designed and manufactured in its 150,000 ft^2 vertically integrated facility in South Burlington, Vermont. Dynapower joined the energy storage market in 2007 and has installed 230 MW of storage projects throughout the world with another 100 MW in backlog.

Technology

Dynapower manufacturers inverters and control systems, and provides integration services.

Energy Storage Products/Services

Related to energy storage applications, Dynapower manufactures single-port and multi-port ultrafast, bidirectional inverters for use with energy storage systems (ESSs). These are available in several general product lines:

- Micro Power Systems (MPS): 30 kVA to 100 kVA
- Compact Power Systems: 600 V, 100 kVA to 2.0 MVA
- PowerSkid™: Medium voltage, 1 to 6 MVA
- IPS Solar Storage System: 500 kW of solar inversion and 500 kW and 250 kWh of battery storage

PowerSkid: Dynapower's larger power conversion systems are most applicable to utility scale ESSs and provide for direct interconnection of battery storage systems to 5 kVac, 15 kVac, and 34.5 kVac class grid. The integrated package combines a medium-voltage step-up transformer, bidirectional inverter modules, system cooling, controls, and a full complement of switchgear and protection into a single heavy-duty industrial enclosure. This includes an AC circuit breaker, AC contactors, AC and DC fusing, DC load break contactors, and a DC manual isolation switch. The PowerSkid provides power conditioning (voltage and frequency support) for intermittent loads and renewable generation.

The PowerSkid provides two modes of operation: grid-tied and stand-alone . In the grid-tied mode, the system controls the AC output real power (P) and reactive power (Q). In stand-alone mode, the system controls the AC output voltage (U) and frequency (f). The system can be started in either mode and the transfer between modes is done dynamically. Advanced control schemes for multi-unit autonomous and micro-grid applications are available.

The IPS-500 Solar Storage System: This integrated power system is for grid-tied and micro-grid applications and provides 500 kW of solar inversion and 500 kW and 250 kWh of battery storage housed in a 23-ft container. The integrated, advanced lithium ion battery storage system provides flexibility to manage photovoltaic (PV) ramp rate, shift peak loads, and generate revenue in frequency regulation markets.

The IPS-500 includes an optional solar recombiner and offers maximum power point tracking (MPPT) for 600V and 1,000V class solar arrays. Integrated storage allows high DC-to-AC power ratios while minimizing lost PV production due to clipping or site interconnection limits. The IPS-500 features seamless dynamic transfer functionality, which allows the host site to maintain uninterrupted power to a set of critical loads during grid outages. The IPS-500 provides reliable power even when the grid is down and solar generation is variable.

Cut-away view of the Dynapower IPS-500 solar storage system.

Turnkey Services: DynaPower also has the capability to provide turnkey services with the customer's preferred battery provider/battery chemistry. It has provided support or integration services on nearly 40 projects since 2010, with a significant number of projects in Hawaii involving renewable integration. Dynapower has worked with a large number of storage system providers and technologies including lithium-ion, lead-acid, lead-carbon, advanced acid, compressed air, and ultracapacitor storage systems. These systems provide for a variety of use cases including wind grid smoothing; ramp rate control of renewable assets; integration of hydro, diesel, wind, and solar; frequency and voltage regulation; peak shaving; and demand response.

O&M Requirements

Dynapower maintenance requirements are typical for power conversion and control equipment and include annual inspections and periodic replacement of components/refurbishment of inverters.

Deployment

Dynapower currently has 230 MW of installed projects throughout the world and an additional 100 MW in backlog. Its largest single installation is the 36-MW battery storage project in Notrees, Texas. Completed and shipped in 2012, the installation consists of twenty-four 1.5-MW inverters and associated lead-acid batteries which support intermittency and service regulation for the 125-MW Notrees Wind Power project. The current lead-acid storage system is currently being upgraded to lithium-ion with no change in the Dynapower equipment.

Dynapower maintains a demonstration system at its facility in South Burlington, featuring its 1.5-MW PowerSkid. The facility is attached to Dynapower's factory and provides power to that facility during peak energy demand times, preventing facility shutdown during curtailment periods. The storage system is coupled to Dynapower's 100-kW wind turbine and 100-kW roof-mounted solar system. The system provides a development environment for Dynapower and its partners.

South African Presence/Experience

Dynapower has deployed equipment internationally in parts of Asia, Croatia, Italy, Spain, Africa, Tasmania, Australia, and North America, and has ongoing projects throughout Europe including Germany. Although Dynapower has not deployed equipment in South Africa, it has expressed interest in pursuing projects and has established a legal entity and relationships with local developers.

Ecoult

Point of Contact

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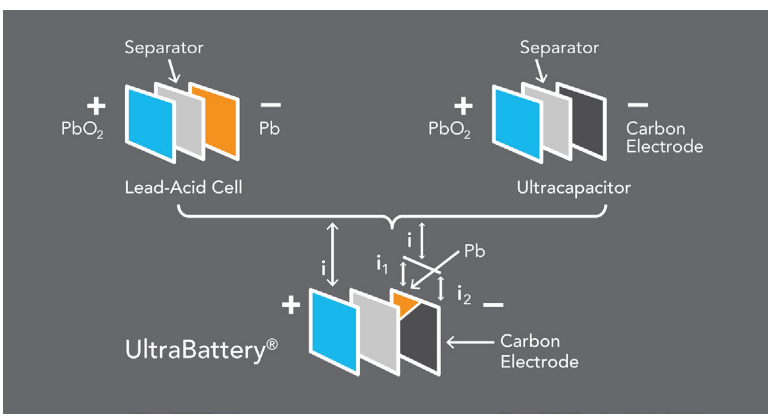
Company Description

Ecoult (Smart Storage Pty Ltd) is an Australian subsidiary of East Penn Manufacturing. East Penn is based in Lyons, Pennsylvania, where the Ecoult battery is manufactured. Ecoult is a supplier of energy storage systems and holds the license to distribute the UltraBattery® to the world market (with the exception of Japan and Thailand). Ecoult has installed megawatt-scale projects for frequency regulation and solar variability management in the PJM and PNM grids in the United States. It has also installed megawatt- and kilowatt-scale installations in Australia, performing diesel optimization (saving over 50 percent diesel on off-grid sites), renewable smoothing and storage, island micro-grid variability management and small industrial grid-connected photovoltaic (PV) power management.

Technology

The UltraBattery represents a breakthrough lead-acid technology that brings all the safety and fully closed-loop sustainability of lead acid into applications requiring high-rate partial state of charge operation. UltraBattery is unique in that it combines lead-acid battery and ultracapacitor technology in a single electrolyte. This single electrolyte achieves a hybrid chemistry that overcomes the problems lead acid has typically faced with partial state of charge operation, while achieving significant improvements in cycle life, power handling, efficiency, and usability.



Schematic of Ecoult UltraBattery technology.

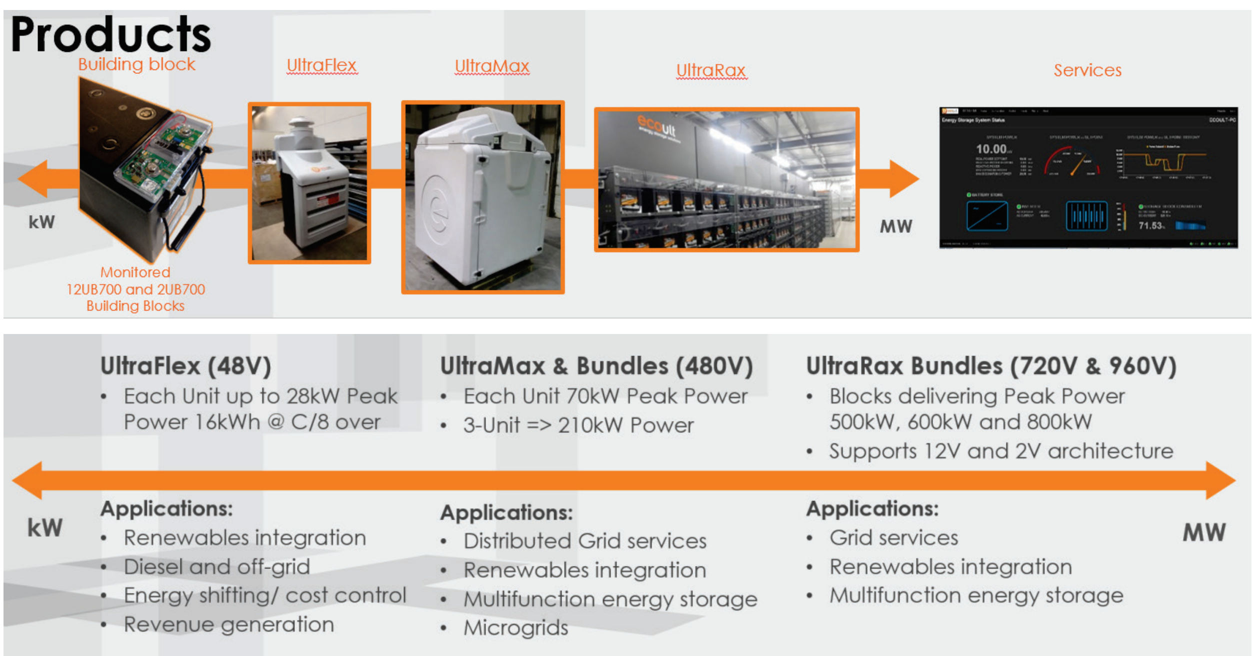
The UltraBattery retains the temperature, stability, energy, and power advantages of a traditional lead-acid battery, but also has a number of significant advantages. Because of its high-power capabilities and extended range of charge, the effective size of power-focused installations can be reduced up to 50 percent compared with other lead-acid technologies.

Cycling in partial state of charge has been a differentiator for chemistries like lithium ion (Li-ion) and nickel metal hydride (NiMH) cells. Lead acid adoption has been held back due to sulfation, which occurs when lead sulphate crystals eventually grow to inhibit the cell's performance. The UltraBattery is very resistant to the formation of these large crystals and thus can stay under 80 percent charge for very long periods without going to full charge.

Ecoult maintains that the UltraBattery provides a safe and robust chemistry while achieving performance standards (high charge/discharge rates, constant partial state of charge use, high efficiency) equal to or better than Li-ion batteries and at a lower price in large-scale storage applications (i.e., multiple kilowatt or megawatt installations). Two of the sixteen USDOE American Recovery and Reinvestment Act of 2009 (ARRA) energy storage grants that were very successful used UltraBattery with the storage solution being integrated by Ecoult/East Penn.

Energy Storage Products/Services

Ecoult (or its parent company, East Penn Manufacturing) designs most aspects of Ecoult energy storage products (batteries, cabinets, hardware, printed circuit boards, firmware, software, human machine interface). The batteries are manufactured on site, and other manufacturing is provided by contractors (e.g., fabrication being contracted to a fabricator near the installation in the case of large items like cabinets).



Ecoult UltraBattery storage products.

Ecoult provides bespoke engineered systems or off-the-shelf energy storage products in various sizes from 25 kW to 800 kW (which can be combined to create larger systems). While Ecoult has not previously provided unbranded or co-branded batteries to OEM manufacturers for installation in their systems (ESSs, diesel generators, etc.), it is currently engaged in discussions with various manufacturers.

O&M Requirements

Ecoult kilowatt-scale systems are essentially maintenance-free, even in systems where the cells are involved in complex power control for a PV/diesel/load site. Refresh and other maintenance functions are automated. Annual inspection is recommended. A visual inspection of the batteries is required, and a check that all venting and airflow passages are free. All other inspections, if necessary, can be done remotely over the internet using the site's monitoring, because every battery has an on-board monitor.

For megawatt-scale installations, the sites are relatively maintenance-free, but more frequent inspections would usually be carried out due to the nature of such sites.

Deployment

Ecoult has deployed around 8 MW (14 MWh) at six separate megawatt-scale sites. It has also deployed 10 kilowatt-scale UltraFlex units to date and expects to have around 50 sites installed by mid-2016.

UltraBattery has similar safety characteristics to other valve-regulated lead-acid batteries (i.e., nonflammable, very low levels of electrolyte, extremely high resistance to catastrophic failure). UltraBattery installations should follow the same standards around ventilation (for hydrogen) as regular lead-acid battery installations.

Lead-acid batteries have high end-of-life economic value and are the most thoroughly recycled product on the planet – 98 percent of lead-acid batteries are returned. Almost all of the other 2 percent goes to industrial and agricultural use.

South African Presence/Experience

Ecoult systems are installed in the United States, Australia, and (soon-to-be-announced) Ireland. Ecoult has had discussions with many potential customers and is looking closely at India, southeast Asia, and Europe. Although Ecoult is not actively pursuing any South Africa projects, it believes it has a very good product for the temperature ranges seen in South Africa.

EnSync Energy Systems

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Company Description

Founded in 1986, EnSync Energy Systems (EnSync) is located in Menomonee Falls, Wisconsin, and currently employs approximately 70 skilled workers, some of whom are key team members with up to 30 years of experience providing quality-control testing and commissioning of power generation, substations, and communications stations. Originally known as ZBB Energy Corporation, the company name was changed to EnSync in 2015.

EnSync occupies a wide area of the energy storage value chain from the design and manufacture of various components such as batteries and power conditioning system (PCS) to the design, deployment, and commissioning of integrated systems. EnSync's key markets include commercial and industrial building energy management systems, remote micro-grids, and utility-scale energy storage systems (ESSs).

Technology

EnSync energy storage products include both zinc-bromide flow batteries and lithium-ion (Li-ion) based storage solutions. EnSync provides hybrid offerings that combine battery technologies. In addition, it manufactures advanced energy management and control systems. Experienced team members work closely with customers to develop and provide custom-designed, fully-integrated energy storage solutions.

Energy Storage Products/Services

The EnSync flow battery technology provides the bulk energy storage needed in many applications from support and micro-grids, to smoothing and shifting renewable energy generation, to providing the necessary energy storage for off-grid or on-grid controllable power plants using renewable energy.

Agile Flow Batteries. EnSync is currently manufacturing its fourth-generation zinc-bromide (Zn-Br) flow battery. The Zn-Br technology offers high availability, 100 percent depth of discharge capability, high-energy density, a small footprint, long life, and 70 percent RTE. EnSync's standard offering is a 12.5kW/50kWh modular system. Multiple units can be interconnected and configured with EnSync's inverter technology to deliver a utility-scale end-to-end system for quick and simple installation.

EnSync flow batteries are often deployed with high-power (but more shallow discharge) Li-ion batteries at the same installation. This unique industry-leading hybrid approach provides the end user with greater flexibility and uses the strengths of each battery type.

EnSync agile flow battery Zn-Br; 12.5kW/50 kWh.

Matrix Energy Management ™ platform. EnSync's patented power integration platform creates a customized ESS. The Matrix and associated equipment offer a modular, expandable, and flexible power electronics architecture that allows integration of various types of renewable energy-generating sources and conventional energy-generating sources, and various types of energy storage. The Matrix automatically manages, in real time, AC- and DC-generating assets along with energy storage assets and provides single or multiple outputs to meet customer application needs.

The EnSync Energy Management platform features a fully integrated PCS and battery management system (BMS) to provide full control, protection, and reporting functions. EnSync's patented "AutoSync" modular controls enable simple integration of all the system inputs, and autonomously manages and optimizes individual resources. In addition, EnSync has a common data acquisition and communication point for remote control.

EnSync's Matrix Energy Management system.

Local control functionality: Local autonomous functions are achieved in part by the EnSync "AutoSync" control with the addition of end-user-specific requirements. Individual units use parameters received from the local or remote control, and input from the common DC bus using EnSync's patented AutoSync technology to quickly, autonomously, and proactively react as needed. Individual power units are interconnected to the EnSync central control that enables secure commands to and from the outside world through standard communication protocols including distribution network protocol 3 (DNP3).

EnSync's proprietary topology and control concept eliminates the need for complex software algorithms typically used in hybrid systems with multiple generating sources, including the capability of multiple outputs to customer loads through a single device, and use in on-grid and/or off-grid applications. The EnSync Matrix Energy Management platform can provide the active power (kVa) required for applications, in addition to the reactive power (kVar) for power factor correction, regulation, and voltage stability.

Agile Hybrid 600. For larger scale commercial systems, EnSync offers an Agile Hybrid 600-kWh system that is housed in a completely self-contained, 480 VAC interconnected container, designed for drop and deploy where at least 400 kW of PV-generated power is used.

The system is capable of managing high-frequency, intermittent power input while simultaneously performing bulk energy storage, all off the same point of connection and without a complex control scheme. This expands the system's ability to support fast response and longer bulk energy use cases. The Agile Hybrid 600 includes 450 kWh of flow battery, 160 kWh of Li-ion battery, and all supporting BMS, PCS, and other electronics. Multiple Agile Hybrid 600 units can be connected to create a larger hybrid storage system.

O&M Requirements

EnSync's deployed equipment is designed to require minimal maintenance. Service and equipment replacement intervals are highly project dependent, based on technology selection, location, temperature, and duty cycle. EnSync deploys both Zn-Br and Li-ion batteries. Each technology comes with its own set of safety parameters that must be managed. However, these technologies are both mature and well understood. EnSync uses lithium iron phosphate (LFP) battery chemistry due to its favorable thermal profile. These systems are supplied with BMSs such that the batteries are not exercised beyond limits.

Through EnSync's remote monitoring process, key parameters are monitored continuously. EnSync recommends that the end user perform periodic visual observations of the module to inspect for wear and tear, abnormalities, etc. It also recommends conducting an annual system inspection consisting of a variety of tasks including visual inspection, filter inspection and/or change out, mechanical connections inspection and adjustment, and software parameters update, if needed. Depending on usage, a system refurbishment process, which includes the introduction of new stack elements, may be desired every 3 to 10 years. The electrolyte for Zn-Br flow batteries is acidic and has bromine vapors. Personal protection equipment (rubber gloves, safety glasses, etc.) and neutralizing agents such as baking soda and water are used to mitigate such risks.

Deployment

EnSync has deployed approximately 20 MWh of energy storage across the globe and is an experienced system integrator and partner. It assembles and ships ESSs as modular or containerized systems for ease of installation.

EnSync also manufactures a range of power electronic equipment designed for integration of various energy sources (e.g., PV, wind, generators) to energy storage and AC loads. These products have been commercially available since 2010. All of EnSync's products have been deployed in a number of applications, ranging from grid connection of renewables to off-grid power supply systems and UPS backups.

South African Presence/Experience

EnSync currently has projects in North America, the Caribbean, French Polynesia, Australia, China, and Japan.

Eos Energy Storage

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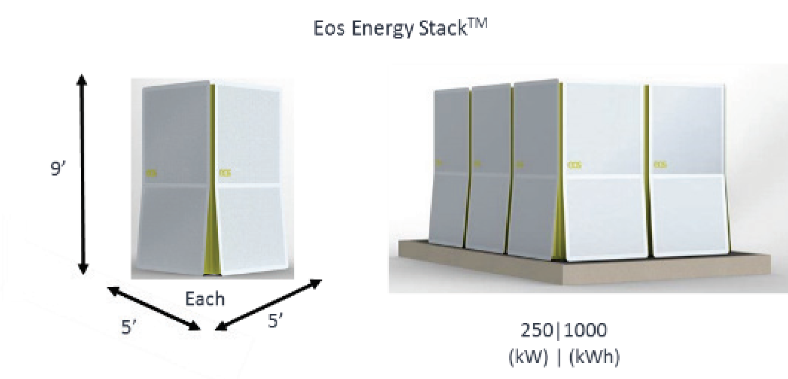
Company Description

Founded in 2008 after the issuance of the patent for its core technology, Eos Energy Storage (Eos) has worked to develop a technology that meets the fundamental requirements of grid-connected energy storage. The company specializes in manufacturing low-cost, long-life DC battery systems for electric utilities, with additional applications in commercial and industrial, telecom, and residential markets. Eos' mission is to produce safe, robust, and market-leading energy storage solutions that are less expensive than incumbent alternatives. Eos is located in Edison, New Jersey, and in New York, New York.

Eos is a DC battery manufacturer and does not provide turnkey installation services. However, it is able to recommend one of its Aegis integration partners to provide a turnkey solution. Eos' Aegis partners include Siemens, NEC, Toshiba, and Alstom/GE.

Technology



Eos' Znyth™ technology contains an inherently safe zinc-based aqueous electrolyte located and sealed in each individual cell of the battery. The technology allows the use of inexpensive, widely available materials and commoditized manufacturing equipment and processes to deliver safe, low-cost energy storage. Eos does not use flow designs or pumps as parts of its technology, which is specifically not a zinc-air system. Sealed, static cell submodules that are roughly the size of a shoe box comprise the basic unit of production and aggregation. Using Znyth, systems are capable of 75 percent RTE at 100 percent depth of discharge and of approximately 5,000 cycles for a system life of about 15 years with daily cycling.

Eos' rechargeable zinc hybrid cathode (Znyth) technology has a nonflammable electrolyte, is nonhazardous when fully discharged and is long lasting with low cost. Eos' battery system consists of sealed, static batteries containing an aqueous, near-neutral pH electrolyte.

The Znyth technology employs a bipolar electrode design that optimizes internal battery connections; the chemistry and design eliminate the need for a membrane separator, cutting out significant cost and a common source of cell failure. Hybridization of multiple cathode reactions improves roundtrip efficiency and enables flexible performance such that the battery can provide short surges of power with immediate response time in addition to multi-hour discharge at nominal power levels.

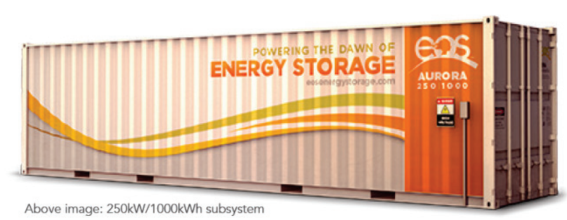
After 10 years of development, Eos' Znyth technology is built on 21 patents and patent applications with more than 600 claims covering cell configuration and architecture, cathode design and materials, electrolyte and electrolyte additives, battery management systems (BMSs), and low-cost manufacturing processes. End of life results in a nonhazardous battery that can be recycled and or disposed of in nonhazardous waste, further reducing the total cost of ownership throughout the installation lifetime.

Energy Storage Products/Services

Eos's base product is the Aurora 1000 | 4000, a DC battery system consisting of four 250-kW DC subsystems aggregated into a 1-MW system specifically designed to meet the requirements of grid-scale energy storage including bulk energy services, ancillary services, grid infrastructure support, energy security, peak shaving, and energy access.

Eos' systems are designed for a C/4 discharge and have flexibility to surge to C/3 for limited duration. Eos sells systems for $160/kWh at volume purchasing of 40 MWh or more; orders less than 40 MWh are priced at $200/kWh.

The Eos Aurora system includes battery modules, a BMS, a containerized solution, and ventilation equipment per local code. With 4 hours of discharge capability, immediate response time, and modular construction, the Aurora system can be scaled and configured to reduce cost and maximize profitability for utilities, project developers, and industrial end-users.



Eos Energy Storage 250-kW/1,000-kWh containerized system.

Battery Technology	Znyth™ (Zinc hybrid cathode)
Power	1MW
Energy	4MWh
System Voltage	320-960 min/max Vdc; 768 nominal Vdc
Response Time	Millisecond response
Round-Trip Efficiency	>75% at 100% Depth of Discharge
Lifetime	≈5,000 cycles or ≈15 calendar years
Operating Temperature	10 to 45°C
Dimensions	4 containers (40 ft. x. 9.5 ft. x 8 ft.)

Low Price	**$160/kWh** (>10MW) **$200/kWh** (<10MW)
Long Life	**5,000 cycles** at 100% DOD
Energy Dense	18 kWh/m^3 (DC system level)
Efficiency	**75%** at 100% DOD
Safety	Non-flammable electrolyte; non-hazardous and non-corrosive when shipped

Eos Energy Storage Aurora
500-kW/2,000-kWh subsystems.

O&M Requirements

Eos offers preventative maintenance options that accompany their 5- and 10-year warranties. Annual scheduled preventive maintenance performed by Eos for the DC system includes the following:

- Thermistor/current/voltage sensor verification
- Inspection of the following DC system components: batteries, safety lighting, BMS hardware, insect/vermin infiltration, fans, wires/cables
- Verification of operation of contactors and E-Stop
- BMS self-test and initiation
- Replacement of filters, as needed
- Report providing status of key equipment components as part of maintenance checks

Deployment

The Eos Aurora system is containerized and can be deployed under ambient temperatures of 10°C to 45°C. Using a novel Energy Stack^{TM} approach, Eos enables flexible installation options where the system can be installed outside in the elements on gravel or a concrete pad with or without a shade structure and can be arranged according to site-specific needs.

Eos has contracted 20 MWh of demonstration projects and commercial deployments with commercial operating dates in 2016 and anticipates upwards of 200 MWh commercial deployments in 2017.

South African Presence/Experience

Although it does not have a formal presence in South Africa, Eos is currently working with project developers internationally, including in South Africa.

Fluidic Energy

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Company Description

Formed in 2006, Fluidic, Inc. (dba Fluidic Energy) has been selling and deploying its intelligent energy storage solutions since 2011. Fluidic has more than 250 employees worldwide. The company is headquartered in Scottsdale, Arizona, and has manufacturing facilities in the United States and Indonesia. Fluidic's rechargeable zinc-air technology replaces lead-acid batteries and diesel gen-sets for long-duration applications such as critical backup power and micro- mini-grids. Fluidic now has more than 75,000 batteries deployed at more than 1,200 locations, with the majority of those locations in some of the toughest environments in the world.

Technology

Metal air technology is considered the least expensive way to store energy, but until Fluidic's breakthrough innovation, metal-air energy storage was only commercially viable in small, single-use applications such as button cells for hearing aids.

Fluidic's successful innovation in metal air technology fills a void in the energy storage market that might just be the catalyst needed for the clean, smart, and accessible energy revolution—long-duration capabilities. Comparing the Fluidic energy storage technology with other commercially available technologies such as lithium and lead-acid based batteries is like comparing a "marathoner" battery with a "sprinter" battery. Fluidic's technology is the "marathoner" capable of storing large amounts of energy and discharging that energy over several days, providing energy autonomy in a variety of applications through its runtimes of up to 72 hours. The technology is the perfect solution for integration with a renewable and intermittent power source such as photovoltaic (PV).

Fluidic modules have integrated intelligence and are self-governing to autonomously balance the Ah discharge of the contributing energy and power cells. This self-governing is central to Fluidics' reliable architecture. Each module behaves similar to a large capacity 50-V battery and can therefore be arranged in parallel to each other, and added or removed from the system based on the power and capacity needs and changing load profiles.

The Fluidic solution comes with integrated proprietary smart controls that monitor load profile to selectively dispatch the high-peak-power, high-cycle-life power technology component to optimize total performance (cycle life, RTE percentage, nominal power, peak power, runtime), total cost of ownership and life-cycle cost to the customer. The result is an advanced and cost-effective energy storage solution.

Fluidic's intelligent, fully integrated, and internet-connected software controls are continuously capturing, self-optimizing, self-remediating, learning, and transmitting information to the Fluidic control centers, enabling exceptional performance management, lower energy costs, and higher reliability, which far exceeds any other battery technology company.

Fluidic received two separate US Department of Energy grants under its Advanced Research Program – Energy (ARPA-E) for metal-air battery development, and has filed more than 95 unique patents and hundreds of intellectual property claims around its core rechargeable zinc air and smart-battery controls technology.

Energy Storage Products/Services

Fluidic Energy designs, manufactures, and markets its energy storage solutions. Depending on the market and customer, Fluidic installs and provides ongoing support through 24/7 network operating centers. It offers a fully vertically integrated solution, which is often a drop-in replacement for incumbents.

Fluidic Energy DC Energy Storage System

The Fluidic systems have a range of voltage capabilities from 48V up to megawatt high-voltage systems. In smaller systems, Fluidic can interface directly with existing 48V DC bus configurations and its systems are directly compatible with existing 48V rectifier/inverter for their output conversion and charging needs.

Fluidic's smallest modules are currently 500 W, 4 kWh. Fluidics' unique "LEGO" type platform architecture makes it possible to customize and scale the systems to meet changing power and/or energy requirements, allowing capacities up to MW/MWh solutions.

Fluidic systems have up to 85 percent RTE_{DC} and a design life of more than 10 years and in some micro- and mini-grid settings up to 25 years. Fluidic systems can operate at any state of charge and are designed for 100% DoD with no capacity fade.

Turnkey Solutions for Mini- and Micro-grids

Over the years, Fluidic has also established its own turnkey project development team. The team, in partnership with local EPC partners across Southeast Asia and Southeastern Africa, identifies, develops, operates, and provides financing of large-scale deployment of PV- and energy-storage-powered mini-grids in Southeast Asia and Africa, including the "500 Island" project in Indonesia, which provides electricity to more than 1.5 million people, and the "100 Community" project on Madagascar, which is expected to provide electricity to more than 400,000 people who currently have no such access.

O&M Requirements

Maintenance needs for the Fluidic system are minimal and depend on the siting of the unit. Typically, light maintenance is required on an annual basis and can be performed by local maintenance personnel. Fluidic's intelligence, "FluidicIQ," offers transparent site visibility 24/7, allowing for remote monitoring, maintenance, and preventative attention. Operating data is constantly fed back to the Fluidic Network Operating Centers (NOCs) located in the United States, Indonesia, and (soon) Africa.

Deployment

Commercialized since 2011, Fluidic now has more than 75,000 batteries deployed at 1,200 customer sites across three continents. Fluidic technology excels in applications requiring more than 4 hours of continuous runtime. This spans a range of use cases in South Africa energy access, including energy security, peak shaving, mini- and micro-grids, telecom towers, and critical power applications. The longer the runtime, the lower the $/Wh delivered.

Furthermore, Fluidic's modular architecture allows for the power plant to be scaled at any time from kilowatt to megawatt solutions. The Fluidic systems can be installed outdoors, require no cooling, and can operate over the temperature range of 0°C to 50°C.

Environmental Sustainability: Fluidic's zinc-air technology uses earth-abundant materials in the construction of the cell and ancillary equipment. These raw materials (such as zinc, carbon, water, potassium, and consumer-grade ABS plastics) are readily available; for the most part they are easily reclaimable and recyclable at the cell's end of life.

Societal Health and Safety: The Fluidic zinc-air cell architecture is fundamentally safe with respect to thermal runaway or fire hazards due to its fail-safe discharge dynamics. All reacting oxidant is stored "outside the cell" until the reaction is desired and the system discharges using ambient air (unlike solid-state batteries). In addition, Fluidic's aqueous alkaline electrolyte is environmentally benign and does not contaminate groundwater or other sensitive natural resources.

South African Presence/Experience

Fluidic Energy has largely focused on developing areas in Southeast Asia and Latin America but has significant traction in the southern part of Africa as a key market development metric in 2016. It has performed preliminary research with a top energy solution provider to validate its value proposition in the South African market and is currently deploying resources to support these efforts, including an assessment of establishing local manufacturing. Fluidic plans to have a formal presence in South Africa in 2016.

Freedom Won

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Company Description

Freedom Won, a South African company, was founded in 2011. With company headquarters and manufacturing facilities in Roodepoort, Gauteng, South Africa, the company started developing electric vehicle concepts in 2009 and produced the first prototype in 2011. Energy storage using advanced lithium batteries became the leading revenue stream in 2015. The company has approximately 10 employees and about US $2 million in annual revenue.

Technology

Freedom Lite uses lithium iron phosphate ($LiFePO_4$) technology that requires no cooling and its large-format cells can sustain continuous high charge and discharge currents. These cells were developed in the nineties for use in electric vehicles and they became affordable and available from around 2010 for this purpose. Freedom Won has been using these cells in its electric vehicles since 2011. It believes they have proven themselves according to expectations and product specifications for longevity and reliability. It also offers a second-life refurbishment for the Lite range, which involves replacing the cells only, and hence providing a reduced life-extension cost. The Freedom Lite is guaranteed for 10 years to produce at least 70 percent of its original capacity based on 1 cycle every day.

Freedom Won 10/7 home battery (10 kW/7 kWh).

Energy Storage Products/Services

Freedom Won offers a range of Freedom Lite energy storage modules, all based on $LiFePO_4$ batteries. The Freedom Lite contains a number of large format $LiFePO_4$ cells configured to 51 Vdc nominal output as well as a sophisticated battery management system (BMS) that looks after the cells and is able to shut down the battery if the operating parameters are exceeded. The

Freedom Lite DC output is connected to an external inverter of the client's choosing (as to brand and size). This DC output is also connected to a solar charge controller if one is used for the photovoltaic (PV) connection, or alternatively a grid tie inverter can be connected to the output of the inverter to incorporate the PV. In some cases, a hybrid inverter may be used that incorporates the PV control and battery inverter systems all in one.

Load Shedding	Hybrid	Off Grid	Custom
Eliminate load shedding from your home or business by installing a super efficient and long life Lithium battery and inverter system from Freedom Won.	Eliminate Load Shedding AND reduce your Utility/Eskom consumption with a long life Lithium battery and Solar Power and save bundles of money	Say goodbye to Eskom troubles for ever and run your own Lithium battery based solar power plant on renewable energy with massive long term cost savings	Freedom Won provides energy storage solutions for any application from 5kWh to 4000kWh or more using long life high performance Lithium batteries.There is nothing else on the market that can come close to competing on life cycle cost and warranty.
Starting From (incl VAT) **R 86 292.30** **Financed over 60 months:** **R 2183.83 per month**	**Starting From (incl VAT)** **R 145 914.34** **Financed over 60 months:** **R 3707.44 per month**	**Starting From (incl VAT)** **R 313 065.66** **Financed over 60 months:** **Deposit R 63 065.66** **R 6373.75 per month**	**Our Custom Solutions Service Includes:** Assessment of Energy and Power Requirements Inspection of Site or Premises Complete Solution Recommendations including PV Array, Inverter design and overall integration Detailed Design and Cost Estimating Turnkey Project Delivery
Package Includes: Freedom Lite Home 5/4 3kVA Inverter Installation and Delivery incl materials 10 Year Warranty	**Package Includes:** Freedom Lite Home 5/4 Premium Brand 3kVA Inverter PV Panels 3kWp Premium Brand Solar Charge Controller Installation and Delivery incl materials	**Package Includes:** Freedom Lite Home 20/14 Premium Brand 5kVA Inverter PV Panels 6kWp Premium Brand Solar Charge Controller Installation and Delivery incl materials	

Freedom Won provides several configurations for specific applications

O&M Requirements

No routine maintenance is required. The system will report any concerns that should be investigated or resolved. The energy modules are designed for a service life of 15 to 20 years.

Deployment

Freedom Won has approximately 100 installations in operation up to 40 kWh. Total installed capacity is approximately 2 MWh. Larger systems have reached design concept and proposal stages for various projects awaiting approval. Systems are zero emissions and fully sealed, and are not sensitive to ambient temperatures. Standard models are for indoor use; outdoor models are also available. Ambient temperature is –20ºC to +60ºC .

South African Presence/Experience:

Freedom Won is a registered company in South Africa and has offices and a workshop near Johannesburg.

Greensmith Energy Management Systems Inc.

POINT OF CONTACT

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COMPANY DESCRIPTION

Established in 2008, Greensmith specializes in software and control solutions to operate and manage distributed energy storage systems (DESSs) for utility-scale, commercial & industrial or micro-grid deployments often tied to renewable generation. Greensmith has delivered more than 45 energy storage projects to its clients, including nine major North American utilities. Greensmith's core team has more than 100 collective years of relevant experience, specializing in battery management, power systems, electrical engineering, software development, utilities, and customer energy management. Since 2011, Greensmith has been awarded dozens of projects via competitive request for proposal (RFP) processes and deployed energy storage systems employing PJM frequency regulation, frequency response/droop control, and solar photovoltaic (PV) ramp rate control.

Greensmith is located in Herndon, Virginia, and Emeryville, California. It currently has more than 30 employees and generated $16 million in revenue in 2014.

TECHNOLOGY

The Greensmith Energy Management System (GEMS5) is Greensmith's fifth-generation energy storage control system and is built on a foundation of "connectors" to physical assets. These connectors enable the system to control and acquire data from batteries, inverters, and numerous other sources such as building load, solar output, and supervisory control and data acquisition (SCADA) signals from an independent system operator. On top of these connectors sits a computational platform, which enables Greensmith to control physical assets based on a rules-based engine and provide additional functionality such as fleet control. Finally, an ever-growing library of grid applications are built on top of the GEMS computational platform to provide hardware-agnostic applications such as frequency regulation, capacity shifting, and demand charge management.

Greensmith develops and delivers its GEMS control software, and provides engineering/design support and the technical integration, project management, and logistics support for the delivery of its energy storage systems. Components such as batteries, power conversion systems (PCSs), heating, ventilation, and air conditioning (HVAC), fire suppression, and enclosures are purchased from other suppliers through established industry relationships.

Greensmith's primary focus is on the development of advanced software control solutions and it has delivered stationary energy storage systems with a battery-agnostic and inverter-agnostic design framework. Its software has integrated systems with eight different inverter OEMs and twelve different battery OEMs, including integration at the cell-level and at the rack-level. Its installed systems have been located on both the customer and utility side of the meter, providing operational data on a wide variety of use cases.

Following are lists of Greensmith's valued industry OEM partners (companies whose products the GEMS software has been successfully integrated to support):

Batteries	Power Electronics
LG Chem	Parker Hannifin
Johnson Controls	Eaton
Samsung	Ingeteam
Aquion Energy	SunGrow
ViZn	Energy Princeton Power Systems
Winston Battery	Siemens
BYD	Ideal Power
Saft Groupe S.A.	Powerhub Systems
Boston Power	Selectronic

Energy Storage Products/Services

Greensmith designs all system components in-house, and works with local suppliers to manufacture custom items. Greensmith has successfully employed this design and contract model in many prior installations. Greensmith will typically source all of the components and source the container construction based on its own proprietary designs. Greensmith looks to the EPC for the majority of installation on-site, however, Greensmith advises on project logistics, safety, and other trouble shooting based on its experience with installations. During commissioning, Greensmith supports the EPC with all aspects of final implementation, SCADA integration and software installation.

Greensmith also offers a StorageCheck service for utilities, independent power producers, storage developers, and owners. This is an audit service that evaluates the design of energy storage systems and recommends changes to improve performance and return on investment.

O&M Requirements

Specific O&M requirements are driven by the selected storage technology and the storage and power conversion equipment manufacturers.

Deployment

Greensmith has demonstrated the ability to control/manage capacity shifting, PJM frequency regulation, frequency response/droop control, and PV solar ramp rate control applications. Key projects (all of which will be commissioned by end of 2015) are detailed below.

Site	System Power	Controls Algortihms
FR Project 1	20 MW	PJM Regulation D
FR Project 2	1 MW	PJM Regulation D
FR Project 3	18 MW	PJM Regulation D
FR Project 4	2 MW	PJM Regulation D
PRANG Deployment (PR)	1 MW	PREPA MTR (RRC and frequency response)
SDG&E Carport	85 kW	RRC, Capacity Shifting
SDG&E CES System	90 kW	RRC, Capacity Shifting
Southern Company	5 kW	RRC
Distribution Scale System (Quest)	1 MW	Capacity Shifting, load RRC
SDG&E Pala Substation	500 kW	Capacity Shifting, load RRC

Key Greensmith projects through 2015.

South African Presence/Experience:

Greensmith has active projects in Canada and Puerto Rico and has open bids and projected projects for 2016 throughout Europe, Canada, Africa, South America, and Asia. It additionally has long-standing relationships with numerous international partners providing energy storage in Africa. Mr. Ken Kim is Greensmith's international business development contact and CTO.

South Africa Point of Contact

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Imergy Power Systems Inc.

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Company Description

Established in 2005, Imergy Power Systems is a US company with headquarters and manufacturing facilities in Fremont, California. Some of Imergy's manufacturing is outsourced to several sites, including the Republic of South Africa (RSA) for various components. Imergy has approximately 100 employees. It had $3 million in revenue in 2015 and projects $28 million in revenue in 2016. It manufactures its electrolyte and cell stacks and procures the balance of plant components and power control systems.

Imergy entered into an Assignment for the Benefit of Creditors ("ABC"), a form of insolvency under California state law, on Monday, July 18, 2016. Imergy has terminated its employees and ceased operations [0380]. Under the ABC, Imergy intellectual property and its related assets may be sold and subsequently developed/offered by another offeror.

Technology

Energy Storage Platform (ESP) is based on a redox flow battery using a proprietary vanadium electrolyte formulation that includes a catalyst and additives. Flow batteries consist of two key elements: cell stacks where energy is electrochemically created, and electrolytes where energy is stored. These two elements are supplemented with two pumps and control systems. A flow battery is charged and discharged by a reversible reduction-oxidation reaction between the battery's two liquid electrolytes. During discharge these electrolytes are pumped through a stack of power cells, and an electrochemical reaction takes place, producing electricity.

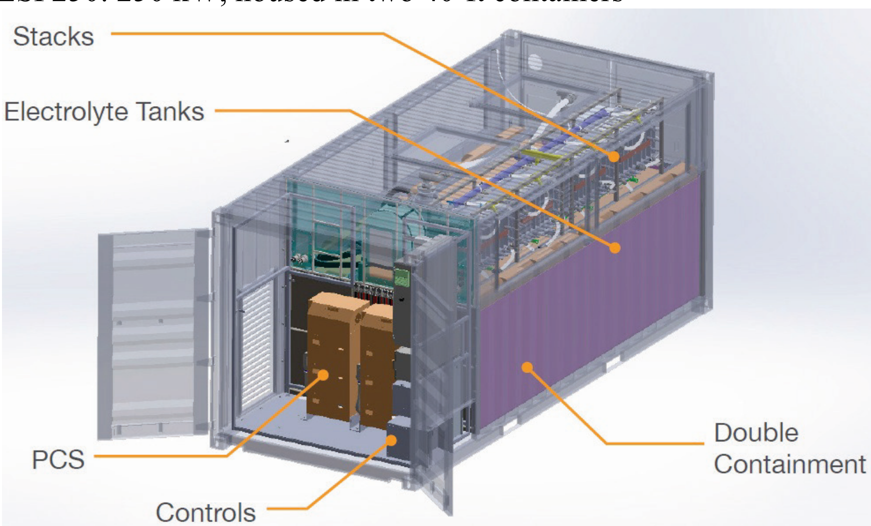
The power and energy (output duration) of Imergy's battery systems are independent. Output power is determined by the size and number of cell stacks, while energy is determined by the volume of liquid. This enables the increase in output duration by many hours – from 2 to 10 hours – just by adding more liquid electrolyte, which is about one-third of the system cost. The electrolyte is never consumed or used up and can be totally reused. This flexibility enables power providers to scale energy storage systems as their sites grow, at a fraction of the cost of conventional batteries.

Imergy has developed an exclusive process for producing high-performance flow batteries with recycled vanadium from mining slag, oil field sludge, fly ash, and other forms of environmental waste. Other manufacturers of vanadium flow batteries build their devices with virgin vanadium extracted from mining. The virgin vanadium must then be processed to a greater than 99 percent level of purity. Through an extensive R&D program, Imergy has developed a way to produce flow batteries with vanadium at a 98 percent purity level that can be harvested from environmental waste sites. This lowers the cost of obtaining and processing vanadium – the principal active ingredient in many flow battery electrolytes – by 40 percent relative to competitors. As a result of this technology and other developments, Imergy maintains it will be able to lower the cost of its flow batteries from $500/kWh, already an industry benchmark, to under $300/kWh.

Energy Storage Products/Services

Imergy generally provides a total packaged solution but also works with Engineer, Procurement, and Construction contractors in local countries and for larger projects. It offers three standard containerized solutions with up to 8 hours of storage. These products offer an AC response time < 70 ms, a DC-DC efficiency of 70 to 75 percent, and a projected life of 100,000 cycles. Systems can be paralleled to 10MW scale.

- IMERGY ESP5: 5 kW and 15 to 30 kWh housed in a 2.15 m x 1.33 m x 2.08 m cabinet
- IMERGY ESP30: 15 to 45kW and 120 to 200 kWh, housed in a single 20-ft container
- IMERGY ESP250: 250 kW, housed in two 40-ft containers



Anatomy of an Imergy EPS 30 in a single 20-ft container.

Because Vanadium redox flow Battery (VRFB) systems are most economical as a high-energy system, Imergy systems are most appropriate for longer duration applications and can service use cases such as peak shaving, demand response, energy shifting, utility grid ancillary services, renewable energy firming, micro-grid, and backup power.

O&M Requirements

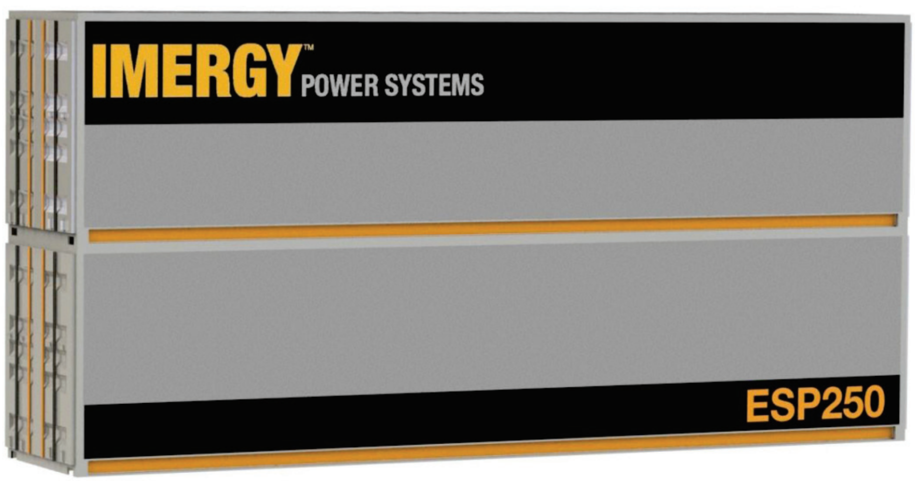
O&M includes an annual system inspection. Replacement of electronics capacitors in the power conversions system (PCS) is required every 3 years. Electrolyte rebalance requires removing some electrolyte and replacing it with an appropriate concentration to rebalance if needed every 7 years. Stacks are replaced once every 10 years. Balance of plant and electrolyte is expected to last more than 25 years.

Imergy's Energy Storage Platform (ESP) system stores energy in nonflammable aqueous-based liquid electrolyte using a simple exchange of electrons among different ions of the common metal vanadium. A small volume of liquid electrolyte is continuously pumped through a stack of cells, where it is either charged or discharged, by adding or removing electrons, and then stored in tanks. By eliminating the phase state reactions that limit the lifetime of conventional batteries, Imergy's flow batteries provide an unlimited number of charge/discharge cycles over the full capacity range with more than 10 years of consistent performance.

Over the –20°C to 55°C operating range, no power is consumed to either provide active cooling, as needed for most other batteries, or heating of the chemistry, as needed in molten metal batteries. The significant volume of liquid in the electrolyte tanks provides thermal inertia to naturally moderate the battery temperature. Unlike all other batteries, there is no charge or discharge derating as temperature increases above 40°C.

DEPLOYMENT

Imergy has participated in pilot projects with the CEC, US Navy, colleges, and end-use customers like Honda and Bosch. Imergy has 3 years of system operation in India, totaling nearly 100 of its smaller ESP5 units. Systems are also installed and have been operating for a year in Slovenia with sales in China, Czech Republic, Nigeria, California, and with customers such as Duke Energy. The majority of systems are ESP5 units with eight ESP30 systems in India and the United States. Sales of an additional 16 units are due for installation in Q1 2016. Imergy has also sold one ESP250 unit in India. Imergy has started implementing micro-grid and electrification projects in Africa and India with Sun Edison.



The Imergy ESP250 is a 250-kW system packaged in two 40-ft containers.

SOUTH AFRICAN PRESENCE/EXPERIENCE

Imergy is active in the RSA and plans to have more than 60 units installed by December 2015, primarily with telecom operators. It manufactures electrolyte in South Africa but does not have a legal entity or local contact. The US point of contact (above) is also registered professional engineer in the RSA who has extensive experience as a senior manager at ESKOM.

Ingeteam

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Company Description

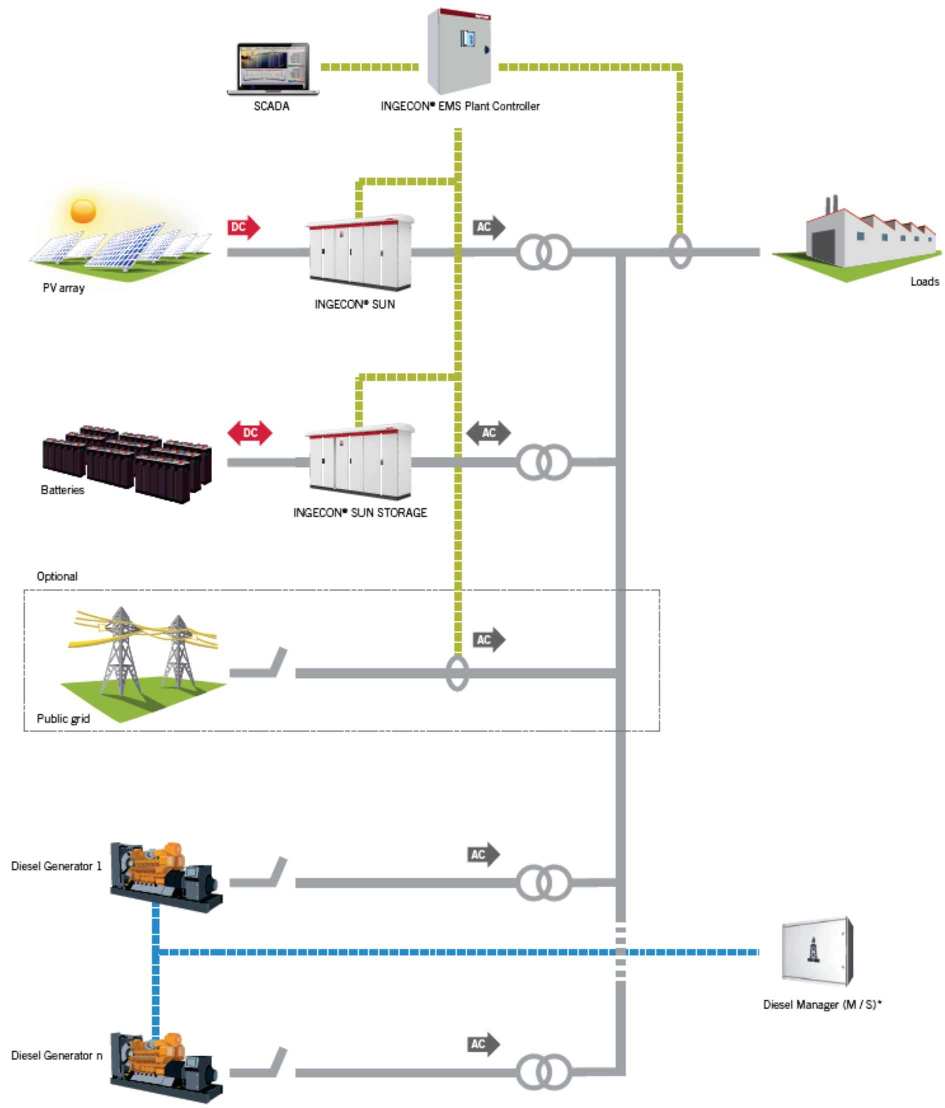
Founded in 1972, Ingeteam is a corporation with more than 3,500 employees and offices in 39 countries around the world. Ingeteam brings its products and services to four primary markets: energy, marine, industrial, and rail traction. Headquartered in Bilbao, Spain, it specializes in highly engineered electrical and electronic equipment and services. It has manufacturing facilities globally, including multiple ones in Europe, Brazil, and the United States. In the United States, Ingeteam has a 138,000-ft^2 combined production facility and office in Milwaukee, Wisconsin, that manufactures wind generators, wind power converters, solar photovoltaic (PV) inverters, Low and medium voltage industrial drives. More than 150 employees currently work at Ingeteam's Milwaukee facility. Ingeteam Energy has been supplying energy solutions for more than 25 years. It is currently active in energy storage installations and has projects installed since 2010. In the energy storage market, Ingeteam "sells" its power conversion system (PCS) inverters and energy management system (EMS) controller to the integrators, developers, and/or EPC of the plant(s) who are designing the entire plant solution, or the whole battery energy storage system (BESS).

Technology

Ingeteam provides plant controller (EMS) and supplies PV and storage inverters (PCS) for renewable energy and energy storage projects. The plant controller is a critical component within a plant that commands the various inverters (PV and/or battery) and connects to the BMS for battery management while communicating to the utility supervisory control and data acquisition (SCADA) and running the various algorithms to connect to the utility. Of particular note is Ingeteam's experience and products, which provide for integration of diesel-PV solutions and diesel-PV storage solutions for both grid-connected and off-grid applications.

Plant Controller

The INGECON® EMS plant controller helps the grid operator to predict the PV plant performance and to guarantee the quality and stability of the electricity supply. It offers maximum PV plant control. An advanced control algorithm combined with a fast and efficient communications system (with response times of less than 1 s) permits precise control of the active and reactive power delivered by the plant to the grid. The INGECON EMS plant controller controls the PV inverters, ensuring compliance with the grid operator's requirements at the PV plant connection point. Measured at the point of interconnect (POI), the total plant is capable of time responses of less than 3 s.



Example of how Ingeteam products are used to integrate multisource generation systems.

Energy Storage Products/Services

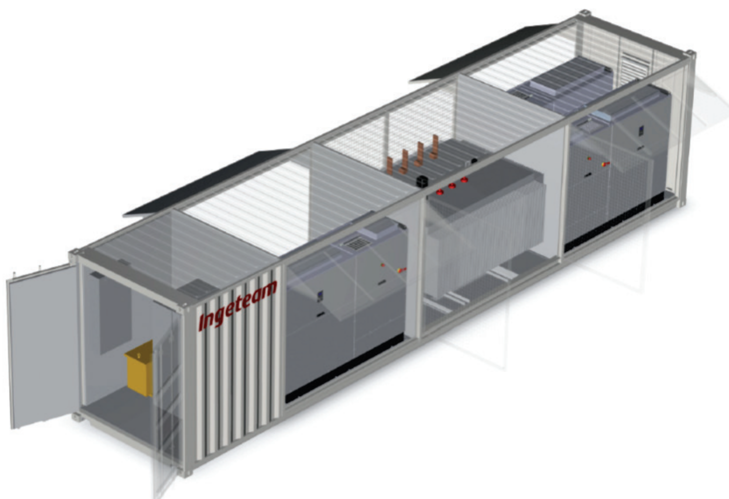
Photovoltaic Inverters

The INGECON SUN PowerStation products come fully equipped with everything necessary: high- efficiency PV inverters, LV AC panels, MV panel, auxiliary services, and an LV/MV transformer. Different solutions are available to suit the needs of each and every project.

Managing energy storage systems and other devices such as diesel generators is also possible through the use of INGECON SUN STORAGE PowerMax inverters.

Battery Inverters

Ingeteam manufactures battery inverters that range in size from 375 kW to 1070 kW, with multi-inverter configurations that can increase the power to more than 4 MW. Ingeteam has storage technology experience with lead-acid batteries, lithium-ion (Li-ion) batteries, high-temperature batteries, and ultracaps.



The CON40 PowerStation provides a 2,500 to 3,500 kVA capacity substation, including LV/MV transformer, PV inverters, and MV switchgear in a 40-foot container.

O&M Requirements

Ingeteam has O&M service contracts for large wind and PV installations worldwide, accounting for more than 4 GW of service contracts for power generation plant maintenance.

Deployment

Since 2010, Ingeteam has approximately 12 significant demonstration, pilot, and commercial installations in Spain and France ranging up to 4 MW and 9 MWh. It has worked with companies including Acciona Energy and Abengoa/Abensia, and has partnered with energy storage providers including SAFT. Four of these installations were being constructed and started up in 2015.

South African Presence/Experience:

Ingeteam has had over 2.3 GW of systems installed in Africa and has experience connecting to the South African grid, including inverters installed in the largest PV plants in South Africa. It has also been involved with diesel-PV storage integration solutions.

South Africa Point of Contact

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Johnson Controls, Inc.

Point of Contact

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Company Description

Johnson Controls, Inc. (JCI) is a multinational company headquartered in Milwaukee, Wisconsin, and has manufacturing facilities located in the United States and around the world. JCI has three main divisions including building efficiency, power solutions, and automotive. In 2014, the power solutions division, which designs and manufactures batteries for various applications, generated $6.6 billion in sales and accounted for 18 percent of JCI's consolidated net sales while employing more than 15,000 employees.

JCI has more than 100 years of experience in delivering quality batteries that meet customers' evolving needs for improved performance, emissions reductions, and fuel economy. JCI is the world's largest manufacturer of automotive batteries, supplying approximately 146 million of them in FY 2015 to automakers and aftermarket retailers. JCI's full range of lead-acid and lithium-ion (Li-ion) battery technology powers nearly every type of vehicle for its customers, including conventional, start-stop, advanced start-stop, micro-hybrid, hybrid, and electric. Combining advanced building efficiency technology with the leading batteries of the power solutions division, the distributed energy storage business is focused on the stationary energy storage market.

Technology

Li-ion technology is a safe and proven technology provided that it is managed appropriately. JCI uses the VL41M cell which is manufactured by JCI and they therefore have a deep understanding of its performance characteristics.

JCI has developed system controls to ensure that the Li-ion cells never experience conditions that exceed their safe operating range. From a safety perspective, JCI provides a number of levels of safety. Safety starts with proper control of the batteries. This includes the software controlling the applications down to the battery management systems (BMSs). Second, the modules that house JCI cells are designed in such a way to significantly limit thermal propagation from cell to cell. Finally, the cells and module are designed in such a way that if all else fails they can vent safety to avoid any safety risk.

Energy Storage Products/Services

JCI has designed a battery container that will increase flexibility of applications in front of and behind the meter, and ultimately increase energy cost savings. This battery container is implemented into two scalable form factors: in-building (L1000) and containerized (L2000) solutions.

The basic components of an energy storage system are the batteries, BMS, battery controls, and power conversion system. JCI provides all of these with the exception of power conversion, where it has a number of companies that it partners with to provide those services. JCI also integrates batteries into building systems to provide an advanced level of control and value.

VL41M (per cell)	Performance
Capactity (C rate, 25oC)	41 Ah
Total Energy (C rate, 25oC)	150 Wh
Max. Discharge Power (10s, 50%SOC, 2.5V)	805 W
Max. Charge Power (Current limited, 10s, 50%SOC, 4.1V)	695 W
Low Temperature Power (10s, 50%SOC, 2.0V min, -25C)	140 W
Mass	1070 g
Dimensions (Length x Diameter)	217mm x 54 mm

Johnson Controls VL41M Li-ion cell.

JCI form factors (containerized and in-building) provide scalability to fit customer needs. These systems may be partnered with a variety of inverter sizes to ensure compatibility.

Johnson Controls L2000 system in Puerto Rico.

L1000 In-Building Distributed Energy Storage System

Power from 50 kW up to 250 kW. Energy capacity in 43 kWh, 65 kWh, or 85 kWh increments.

L2000 Modular Container Distributed Energy Storage System

Power from 500 kW up to 2 MW. Energy capacity in 500-kWh increments.

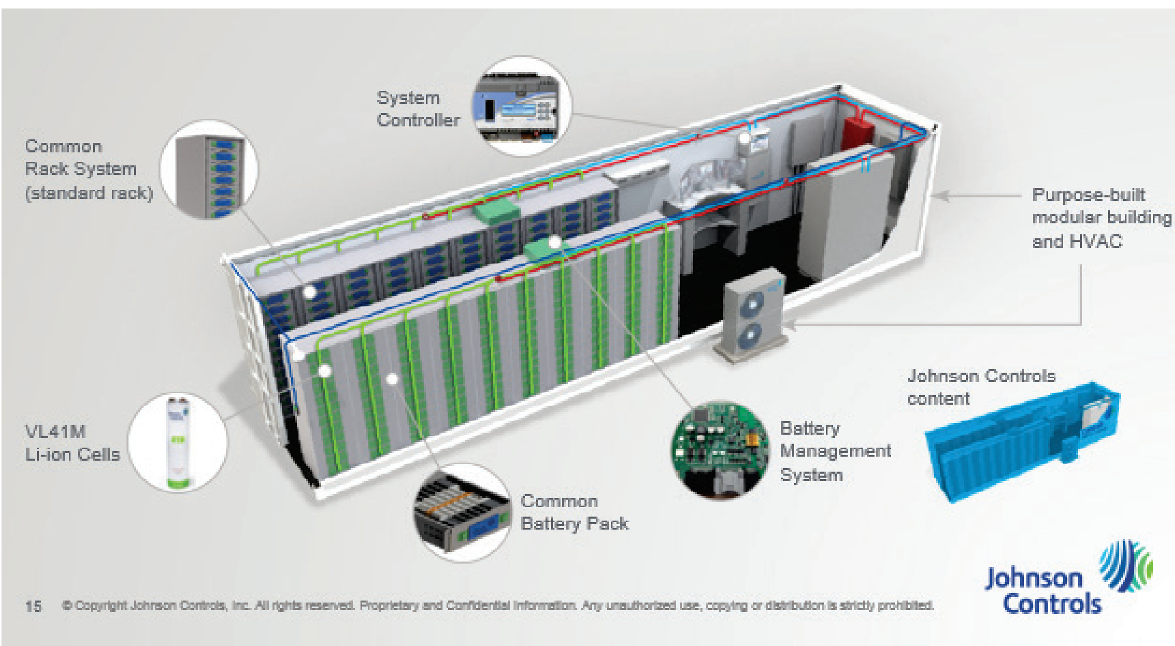
O&M Requirements

JCI systems are designed to run up to 6,000 cycles, depending on the application, C-rates, and depth of discharge. Li-ion batteries do not require routine maintenance or service. Typical O&M tasks include the cooling system, care and maintenance of the containers, fire suppression, and other support systems.

Deployment

JCI has performed several pilot projects of our energy storage solutions. Specific site dates or visits are available upon request. While JCI is not new to batteries or the energy business, stationary energy storage is a relatively new business unit. As of December 2015, it had four systems installed and many more in development. These installed systems include:

- Commercial Office (Wisconsin, United States): 125 kW, L1000
- Manufacturing Facility (Illinois, United States): 1 MW, L2000
- Federal Government Facility (Puerto Rico): 1 MW, L2000
- Commercial Office (Illinois, United States): 125 kW, L1000



South African Presence/Experience:

JCI does business in more than 150 countries. It has done extensive market segmentation activities and has identified the high-value geographies that it will be pursuing – including South Africa. South Africa has been identified as a market that is attractive because of JCI's existing footprint in the region as well as because of what it believes to be favorable market conditions for energy storage. JCI has facilities in six cities across South Africa. These facilities include manufacturing, management, sales, and service activities. JCI currently employs around 1,000 people in South Africa.

LG Chem

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Company Description

LG Chem is headquartered in Seoul, South Korea, and had revenues of $22 billion in 2014. The energy solutions business unit, which includes batteries for consumer, automotive, and stationary energy storage system (ESS) applications, accounted for $3.1 billion of these revenues and employs a total of 12,000 associates.

LG Chem Michigan is a wholly owned subsidiary of LG Chem based in Holland, Michigan, which operates a plant to manufacture advanced battery cells for electric vehicles. Additional cell manufacturing facilities are located in Ochang, South Korea; Nanjing, China; and (a future plant not yet operational) Wroclaw, Poland. Current aggregate annual capacity for automotive and ESS cells is approximately 7 GWh, with plans to increase capacity to 30 GWh by 2019. LG Chem's stationary ESS business has 260 employees dedicated to product management, project management, QA, and sales and marketing. Other functions including production, R&D, and central QA/QC functions are provided by central functions that service automotive, ESS, and consumer battery businesses.

In 2015, Navigant ranked LG Chem as the #1 lithium-ion (Li-ion) battery supplier for both stationary grid-scale and automotive applications.

Technology

LG Chem's advanced Li-ion battery technology is the product of 20 years of experience in development and production, including mobile batteries and large-format batteries for automotive and energy storage applications. LG Chem completed development and began mass production of Li-ion batteries in the early 1990s.

Batteries used for LG Chem stationary ESSs are 100 percent nickel manganese cobalt (NMC) chemistry. Although it also manufactures a small number of cells with LMO, LFP, LTO chemistries for specific auto applications, LG Chem believes that NMC provides the best solution when considering all relevant factors including the following: performance; degradation; C-rate flexibility (for power and energy solutions); durability; inherent safety; energy density; cycle life; ease of manufacture; cost; and potential for future cost reduction.

For stationary storage systems, LG Chem uses the same pouch-type cells that have been tested and selected by the world's leading automotive OEMs (the only exception being Toyota). These cells are manufactured on the same production lines and with the same high levels of QA/QC.

LG Chem is the leading supplier of batteries for all-electric, plug-in hybrid, and hybrid automobiles in terms of current market share.

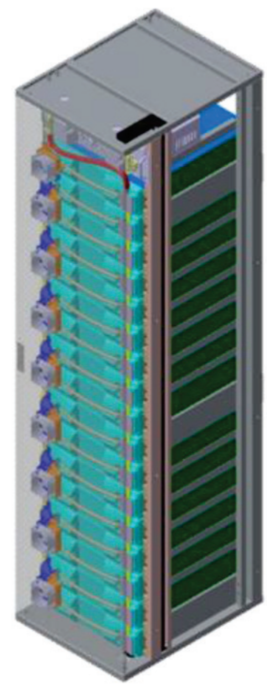
ENERGY STORAGE PRODUCTS/SERVICES

LG Chem's advanced Li-ion energy storage products are designed to meet the needs of three distinct market segments.

Residential: Wall-mounted battery enclosures with ratings from 6.4 kWh to 10 kWh suitable for either AC- or DC-coupled architectures.

Commercial and Industrial (behind the meter): Rack-mounted module systems that can be installed in an equipment room or an outdoor rated enclosure, with DC output voltage options in the range of 400 to 800 Vdc to match with the most commonly used inverters for these applications. Rack systems are fully certified to UL.

Grid-scale (in front of meter): Rack-mounted module systems that can be installed in a building or a container/modular building, with C-rates that support either power applications (15 to 60 min discharge) or energy applications (discharge periods of 4 or more hrs). For grid-scale energy storage applications, LG Chem uses standard rack systems that can be paralleled to deliver an optimum storage solution. Integrated systems are therefore nonstandard and (to optimize both cost and performance) are essentially configured on a project-by-project basis.



Typical LG Chem battery rack.

Round trip efficiencies really depend on the system duty cycle and anticipated C-rates for the batteries. Total life can be as long as 20 years for energy applications, backed up by long-term performance and capacity guarantees.

LG Chem works closely with its customers during the system design phase so that the battery capacity is optimized for the required duty cycle. LG Chem personnel also provide project management and technical operations support specialists to ensure successful installation, commissioning, and commercial operations.

O&M REQUIREMENTS

Battery racks require a minimal amount of O&M support. They are usually installed at unmanned sites, and operations are monitored remotely. For larger grid-scale systems, LG Chem recommends annual site visits that include a visual inspection of the battery racks and associated cabling. This typically requires the unit to be off-line for 36 to 48 hrs. Depending on the application, LG Chem battery modules can operate for up to 20 years without replacement. Extended warranties can also be provided.

DEPLOYMENT

LG Chem has supported many early-stage pilot deployments for storage systems intended for grid-scale, commercial and industrial, and residential applications. LG Chem stationary ESSs have been deployed since 2009. To date, we have approx 400 MW/580 MWh of stationary energy storage capacity installed or on firm order worldwide. ESS applications containing LG Chem batteries can be containerized and located on a concrete foundation as with other integrated Li-ion ESSs. Alternately, they can be located indoors.

Inside the Tehachapi Energy Storage project.

The Tehachapi Energy Storage project is currently the largest (by megawatt-hour) battery energy storage project in North America. The 32-MWh battery ESS entered service in 2014 and uses LG Chem Li-ion batteries located in a 6,300-ft^2 building at Southern California Edison’s Monolith substation in Tehachapi, California.

SOUTH AFRICAN PRESENCE/EXPERIENCE

LG Chem has deployed and is currently pursuing energy storage projects globally. The company recognizes the potential benefits of energy storage in South Africa and can use the experience gained over several years of deploying systems in Asia, Europe, and North America to the benefit of its future customers in South Africa.

At this time, LG Chem has only provided smaller battery systems for telecom applications in Nigeria, and it has no installations in South Africa. However, with the increasing penetration of renewables in South Africa, the country will be able to realize significant benefits from the deployment of energy storage to both aid the integration of renewables and to enhance T&D system operations.

SOUTH AFRICA POINT OF CONTACT

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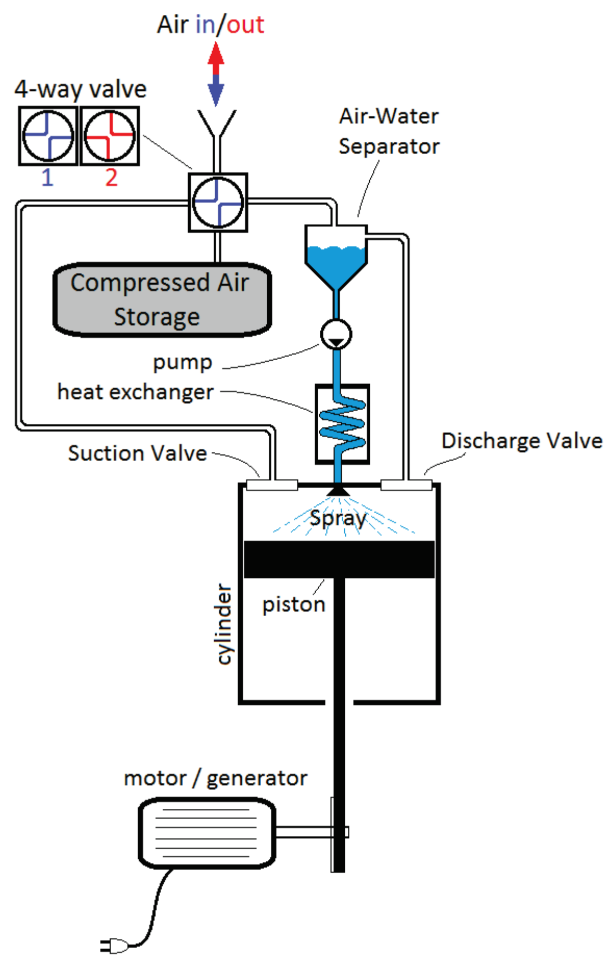
Company Description

LightSail Energy is developing a high-efficiency energy storage system (ESS) using compressed air, which it refers to as regenerative air energy storage (RAES). Founded in 2009 and based in Berkeley, California, LightSail has raised $70 million from several high-profile investors. LightSail is in technology development.

Technology

In most previous compressed air energy storage (CAES) designs, the compression of air creates heat energy, which was wasted or underutilized, thus reducing overall system efficiency. LightSail is proposing an isothermal CAES system in which a water mist is infused into two reciprocating compression stages as the air is compressed. This heated water is removed and stored. During discharge when the air is expanded, the stored heated water is reinjected into the expansion chambers to warm the expanding air. The theoretical RTE for this system is about 70 percent. LightSail is continuing to refine its design to maximize the actual system efficiency towards this limit.



LightSail has also developed a storage tank for high-pressure air. A composite carbon fiber shell is spun around an internal plastic liner to create a large, inexpensive pressure vessel. The basic tank design is 25 ft in length with a volume of about 5.7 m^3. The tanks have been extensively tested and are American Society of Mechanical Engineers (AMSE) certified as pressure vessels. They can be connected in groups of eight and packaged in a 40-

ft shipping container to provide around 1 MWh of storage.

25-ft composite carbon fiber tank for high-pressure air storage.

ENERGY STORAGE PRODUCTS/SERVICES

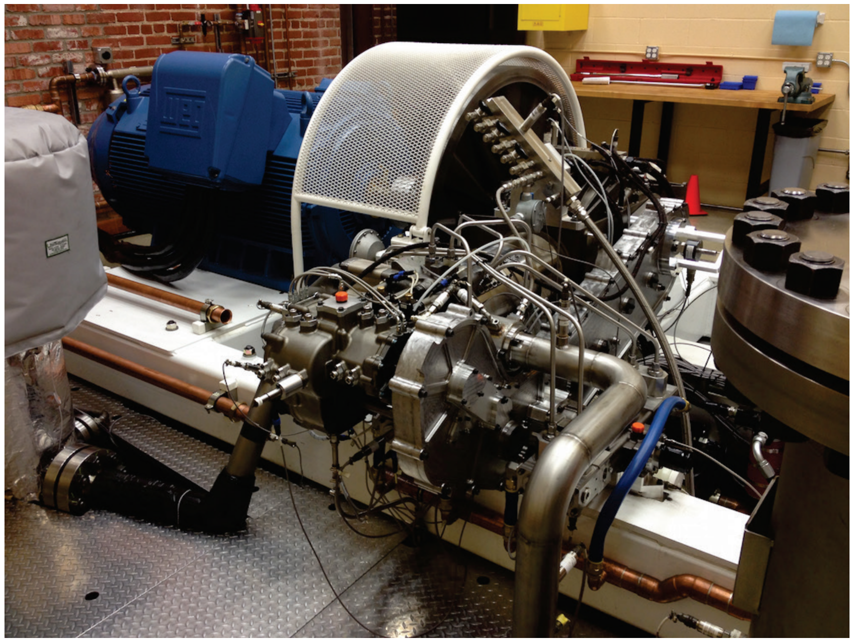
The proposed LightSail system includes a compressor/expander (power) unit and one or more storage tank units. The storage tanks are mounted in a steel frame with a shipping container form factor using industry-standard fittings and complying with ASME and ISO safety standards. This approach allows development of standard products that can be configured to meet any required power and energy capacity similar to a flow battery. LightSail's basic product is a 500-kW power module supplemented with 1-MWh storage units. For large energy-intensive applications, air can be stored in underground caverns – a standard approach for large-scale natural gas storage.

O&M REQUIREMENTS

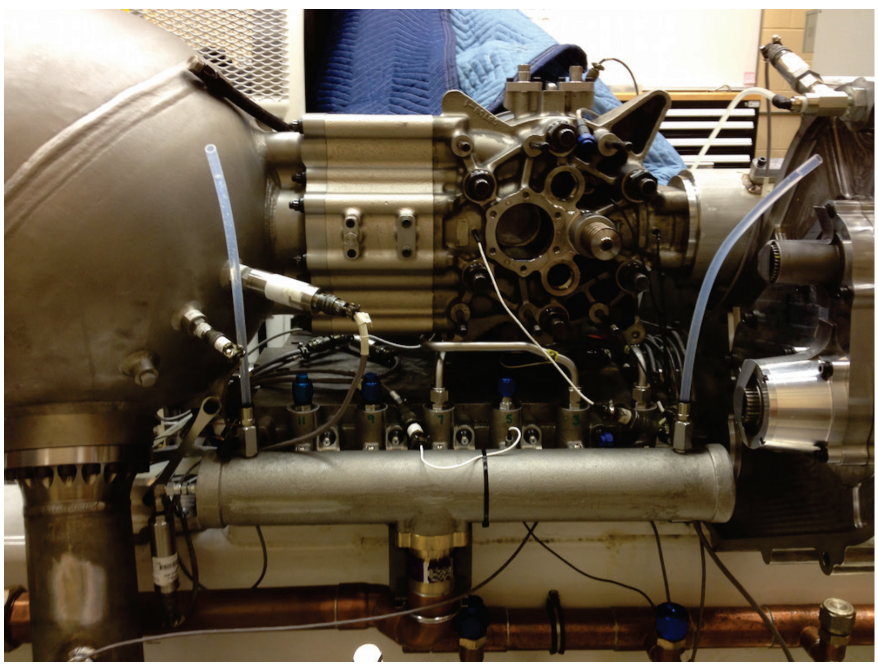
Because CAES systems are more mechanically complex than battery storage systems, O&M requirements are more extensive. The power unit has the same components as an industrial reciprocating air compressor and has similar O&M requirements.

DEPLOYMENT

LightSail is involved in technology development and has not deployed ESSs to date. It is currently evaluating and refining a 500-kW system in its Berkley laboratory and is ready to deploy it in a pilot installation, pending availability of sufficient funding to support that effort.



500-kW system test/demonstration unit at LightSail facility in Berkley.



High-pressure cylinder head (upper center) with the valve actuation mechanism removed and water pump (lower center).

South African Presence/Experience

As a small startup developing its first commercial products, LightSail does not have either an international or South Africa presence.

Lockheed Martin

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Company Description

Headquartered in Bethesda, Maryland, Lockheed Martin is a global security and aerospace company that employs approximately 125,000 people worldwide and is principally engaged in the research, design, development, manufacture, integration, and sustainment of advanced technology systems, products, and services. Lockheed Martin is leveraging its global network of talent and resources to develop the next generation of energy storage systems (ESSs) and batteries. Locations include Dallas, Texas; Cambridge, Massachusetts; and Palo Alto, California.

Technology

Lockheed Martin has two separate energy storage technology offerings. The first technology is lithium-ion (Li-ion) storage built into an integrated turnkey system, which is intended to help commercial and industrial customers reduce their electric bills, help utilities defer costly transmission and distribution infrastructure upgrades, and enable the integration of behind-the-meter customer renewable electricity production.

The second technology Lockheed Martin Energy is offering is an innovative flow battery system. The technology behind Lockheed Martin's GridStar™ Flow system is the coordination chemistry flow battery (CCFB). The CCFB technology is built on a fundamentally new electrochemistry consisting of engineered electrolytes with characteristics that enable lower cost balance of plant components, higher efficiency, and longer useful life than currently available flow battery solutions.

In contrast to chemistries typically employed in flow batteries, which often involve highly acidic or caustic solutions, the GridStar Flow battery electrolyte framework of proprietary combinations of transition metals and ligands results in a low-cost, mildly alkaline aqueous electrolyte solution that is both stable and safe. The resulting electrolyte performance characteristics, such as cell voltage, current density, and solution properties, enable low-cost, durable, and high-efficiency cell stack and balance of plant components.

Energy Storage Products/Services

Lockheed Martin provides turnkey energy storage solutions for commercial, industrial, and utility applications. Backed by a full Lockheed Martin warranty, the company's modular ESSs are designed for performance, reliability, and low total cost of ownership.

Lockheed Martin's energy storage portfolio includes both behind-the-meter and front-of-the meter solutions, that range in size (from 125 kW to multi-megawatt) and duration, and use different battery technologies (Li-ion and flow).

Lockheed Martin is uniquely positioned to offer energy storage solutions due to its key strengths in technology innovation and world-class systems integration capability, leveraging decades of delivering mission-critical systems. Its energy storage portfolio of products includes both medium- and long-duration ESSs. Lockheed Martin has the following two technology offerings.

GridStar Li-ion

For short- and medium-duration applications, Lockheed Martin offers a GridStar Li-ion product that it believes addresses a gap in the market for turnkey AC-AC compact, modular, easy-to-install Li-ion energy storage units. GridStar Li-ion is a turnkey, outdoor-rated ESS that includes AC/DC protection, power conversion, energy storage, thermal management, and controls. These systems are offered with a 3-year standard warranty and extended warranties.

GridStar Li-ion systems are available in 125-kW and 250-kW configurations and have a capacity of 270 to 540 kWh DC at beginning of life. These systems have a 480-Vac, 3-phase 3-wire standard (4-wire optional) power interface and RS-485/Modbus, Ethernet/Modbus TCP control interface. They are compatible with Lockheed Martin or third-party-provided control software/hardware. GridStar Li-ion systems have a roundtrip efficiency of 96 percent and are rated for ambient operating temperatures of
–20° to +50°C.

Lockheed Martin GridStar™ Li-ion 250-kW/540-kWh system in Grand Prairie, Texas.

GRIDSTAR FLOW

For longer-duration applications, Lockheed Martin is pioneering an innovative long-duration proprietary flow battery technology. GridStar Flow is a multi-megawatt CCFB ESS.

DEPLOYMENT

Lockheed Martin has been involved in ESSs for a number of years.

In partnership with Convergent and C&D Technologies, Lockheed Martin has deployed a 500-kW/3-MWh (6-hr) ESS in Boothbay, Maine. Commissioned in May 2015, this system provides transmission and distribution capacity deferral as a third-party-owned asset under a long-term pay-for-performance contract with Central Maine Power.

Lockheed Martin 500-kW/3-MWh energy storage system in Boothbay, Maine.

Lockheed Martin also has a 300-kW/60-KWh Li-ion storage system integrated into a grid-tied micro-grid at the US Army Fort Bliss in El Paso, Texas. This system integrates energy storage, solar PV, on-site generation, and load control.

SOUTH AFRICAN PRESENCE/EXPERIENCE

Lockheed Martin is currently formulating its international energy storage strategy.

Maxwell Technologies

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COMPANY DESCRIPTION

Maxwell's headquarters and principal operations are located in San Diego, California. It has a manufacturing facility in Peoria, Arizona, a European base of operations in Rossens, Switzerland, and sales offices in Munich, Germany; Seoul, South Korea; and Shanghai, China. Maxwell employs more than 450 people worldwide.

Founded in 1965 as Maxwell Laboratories, the company was originally a government contractor, providing advanced physics, pulsed-power, and space-effects analysis, as well as other research and development services to the US military and other government agencies. In the early 1990s, Maxwell began focusing on commercial applications for its technologies and products, and it now generates all of its revenue from commercial sources.

TECHNOLOGY

Maxwell's primary focus is on ultracapacitors, energy storage devices that are characterized by high power density, long operational life, the ability to charge and discharge in a fraction of a second, reliable performance at an extreme temperature range (–40°C to 65°C), and an operational lifetime of 1 million or more charge/discharge cycles.

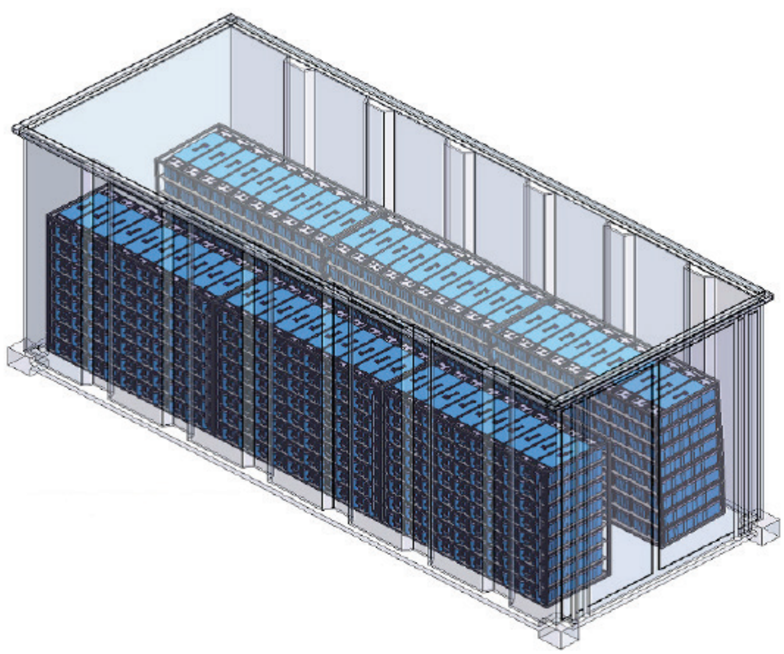
Ultracapacitor energy storage provides multiple benefits to independent energy generators and utilities alike, including renewable generation such as solar and wind as well as traditional fuel energy generation. Within the context of a hybrid ultracapacitor plus battery energy storage solution, ultracapacitors perform fast response functions and extend battery lifetime. Generation applications may include frequency regulation, voltage control and power quality, renewables capacity firming/ramping, peak shaving and load leveling, and spinning reserve.

ENERGY STORAGE PRODUCTS/SERVICES

Maxwell produces a variety of ultracapacitor cells and modules. One example is Maxwell's BMOD0130 56-V energy storage module, which is a self-contained energy storage device consisting of 23 individual ultracapacitor cells. This module includes bus bar connections and integrated cell voltage management circuitry. Modules can be connected in series to obtain higher operating voltage, in parallel to provide higher current or longer discharge time, or a combination of series/parallel arrangements as needed. The module is intended for installation in a standard 19-inch equipment rack or a 23-inch UPS rack. When configured in an array of modules of 10 series by 50 parallel (500 total modules), the module results in 1-MW/60-s ultracapacitor bank.

Maxwell Technologies 56-V ultracapacitor module.

Maxwell ultracapacitors provide cost-effective and reliable instantaneous power. With over 11 GW of power installed worldwide, the long life, high power, and superior charge/discharge cycling of ultracapacitors make them the ideal energy storage solution for utility-scale, micro-grid, or commercial applications. Ultracapacitors can be used as a standalone solution or in combination with other energy storage technologies such as batteries. By combining two complementary technologies, ultracapacitors can extend battery life and reduce overall operating cost, providing fast response as well as backup capacity. With Maxwell ultracapacitors, it is easy to design scalable systems with lifetimes of up to 1 million charge/discharge cycles at 100 percent depth of discharge.



Concept for 1-MW/60-s ultracapacitor bank housed in a 20-ft container.

O&M Requirements

Unlike batteries, ultracapacitors require minimal to no maintenance over their lifetime. Prior to removal from the system, cable removal, or any other handling, the energy storage module must be completely discharged in a safe manner. The stored energy and the voltage levels may be lethal if mishandling occurs. Maintenance should only be conducted by trained personnel on discharged modules.

Annual maintenance includes cleaning the exterior surface of the modules and checking the module housing, fasteners, and ground connections for signs of damage. At the end of life, ultracapacitors can be disposed of according to local regulations for general electronics waste.

Deployment

With respect to grid energy storage, ultracapacitors are best suited for high-power, short-duration applications (sub-seconds up to 1 to 2 minutes).

Maxwell ultracapacitors can be deployed in a wide variety of configurations for high-power and short-duration use cases. As an example, Maxwell ultracapacitors were employed for a power stabilization application at the Yangshan Deep-Water Port near Shanghai, China. The Port's 23 quay cranes have enough power draw to cause significant voltage fluctuations on the local grid for 10 to 15 s at a time. The Port is located at the end of a 20-mi bridge, and increasing the transmission line capacity was deemed too costly. The system design included a 3-MW/17.2-kWh energy storage system (ESS) with 20 s of reserve power that mitigates voltage sag caused by crane operation. The solution made it possible to avoid the costs associated with installing a larger transmission line. The ultracapacitor ESS has been fully operational for 2 years, has demonstrated a 38 percent reduction in peak demand grid energy, and will result in an estimated $2.9 million in energy savings over the expected system lifetime of 10 years.

Maxwell ultracapacitors can be used in a hybrid system configuration with batteries (e.g., Li-ion, lead-acid, low-cost aqueous) to deliver multiple-grid or micro-grid services. Working with a major US utility, Maxwell hybridized the ultracapacitors with low-cost batteries to perform solar intermittency smoothing and load shifting. Because the ultracapacitors are able to remove high peak loads from the batteries, the batteries did not need to be oversized and the system was approximately 15 percent lower in cost versus the battery-only solution.

South African Presence/Experience

Maxwell has sold a small amount of product in South Africa to date, via the distributors Digikey, Mouser, and Richardson.

NEC Energy Solutions, Inc.

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Company Description

NEC Energy Solutions is a wholly-owned subsidiary of NEC Corporation. It is headquartered in Westborough, Massachusetts, and has about 175 employees.

Technology

NEC Energy Solutions (NEC) develops and manufactures smart energy storage solutions for electric grid, backup power, and lead-acid replacement applications with system integration expertise focusing on high performance, efficiency, safety, and reliability. NEC's products range from compact advanced industrial batteries to grid-scale ESSs, all based on lithium-ion (Li-ion) battery technology. Its turnkey GSS® (Grid Storage Solution) products have successfully operated in commercial revenue service since 2009; its commercial and specialty batteries provide solutions to fit the needs for telecom, IT backup, datacenter, medical, lead-acid replacement, and other industrial applications.

Energy Storage Products/Services

NEC's GSS is an integrated ESS that is available in a variety of standard configurations to meet specific performance requirements. The GSS consists of the following:

- NEC's GBS® (Grid Battery System), which is configurable in total storage capacity (MWh) and is typically housed in various standard-sized, international Standards Organization (ISO)-compliant battery containers. The GBS consists of either long-duration (LD) energy storage racks for high-energy applications (1+ hr) or high-rate (HR) energy storage racks for high-power-output applications (15+ min).
- NEC's AEROS® is a comprehensive monitoring and control system that manages GBS® and power conversion systems, and interfaces with the customer facility's control system (supervisory control and data acquisition [SCADA]) through standard control connections.
- A prequalified power conversion system (PCS).
- A thermal management system (heating, ventilation, and air conditioning [HVAC]).

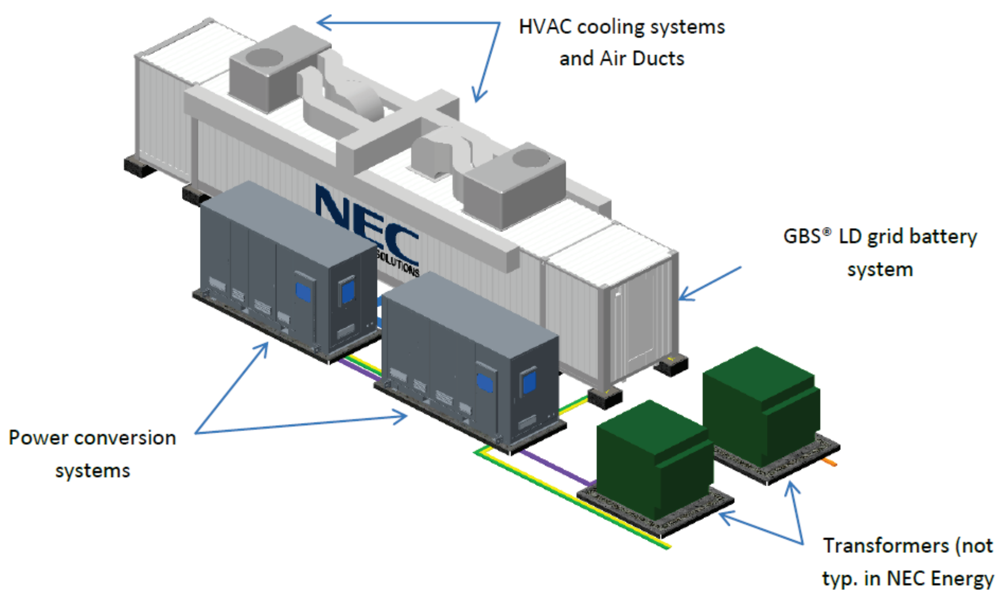
The GSS will interface with customer systems at the following points:

- 480-Vac terminals of the PCS enclosures

- Ethernet connections on the AEROS control and monitoring system in the battery container (alternatively, AEROS can be installed in the customer's control building)
- Auxiliary power at each piece of NEC–supplied equipment

The GSS can be set to operate autonomously, with high-level control available to a remote operator, or it can be interconnected to the owner's SCADA systems for continuous monitoring and remote management or dispatch.

The figure below shows one possible GSS site layout using NEC's LD energy storage technology, in this case a 4-MW/4-MWh Li-ion battery optimized for 1 hr of energy storage. Many other sizes and configurations are possible, up to hundreds of megawatts and megawatt-hours in a single site. There are also many combinations of power capability (megawatts) and energy storage capacity (megawatt-hours) ranging from high-power to high-energy combinations. The dimensions of this layout are 25 m (82 ft) by 7.4 m (24 ft). This example site consumes 185 m^2 (1,968 ft^2) of area inclusive of standard working clearances. The layout can additionally be optimized according to the application and final site location.



Representative 4 MW, 4 MWh GSS® Site Layout

The GSS product can support all identified South Africa power-to-power energy-storage use cases. NEC designs and manufactures the battery systems and controls systems, and it purchases power conversion equipment from third-party vendors. It sources component battery cells and modules to assemble the GBS product and it is not a manufacturer of Li-ion cells. GSS grid energy storage platforms have successfully operated in commercial revenue service since 2009.

O&M Requirements

Typical O&M requirements include semiannual inspections to check over thermal management (air conditioning or water chiller systems) and power connections. Depending on application/usage/duty cycles, batteries can have a service life of 10 years or longer. At end of life, only battery modules are replaced. Replacement does not require the entire site to be replaced – only the individual battery modules need be replaced and the physical rack structure, battery management system, and controls hardware can remain. Additional batteries can also be added to the site to augment the energy storage capabilities if the conditions of the site change.

Deployment

NEC deployment requirements are relatively standard for a Li-ion ESS and include a stable base or foundation, and ethernet, main power, and auxiliary power connections. The containerized system facilitates shipping and reduces the extent of on-site installation.

NEC has an extensive list of Li-ion grid energy storage projects in the United States and internationally. NEC GSS systems account for 11 of the 50 largest Li-ion grid storage systems in the world (118 MW of a total of 311 MW) according to Navigant Research (data from Q1 2015).

An NEC 32-MW/8-MWh GSS grid energy storage solution provides frequency regulation in Laurel Mountain, West Virginia.

South African Presence/Experience

NEC has already installed megawatt-scale energy storage projects globally and actively pursues projects outside the United States. In Africa, NEC has registered companies in Kenya, Zambia, Nigeria, and Namibia. It also has sales and project offices in Tanzania, Ethiopia, Congo, Madagascar, Angola, Ghana, Niger, and the Ivory Coast. In South Africa, NEC Energy Solutions, with NEC Africa, has partnered with XON Alternative Energy, and they are busy with various engagements on energy storage across the African continent, including with multiple engagements and proposals in the mining and manufacturing sectors. The NEC Africa head office is in Midrand (Johannesburg) and NEC Africa has offices in all nine provinces in South Africa.

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Powerstorm ESS

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COMPANY DESCRIPTION

Powerstorm ESS (Powerstorm) is a Los Angeles–based company that specializes in renewable energy technology and is dedicated to understanding and developing optimal energy solutions for underserved communities without electricity. Powerstorm offers sustainable, green, plug-and-play, and hybrid solutions that provide reliable energy to communities in off-grid locations. Its products have diverse applications across the world, including emergency preparedness, powering community institutions, and services and use by telecom tower operators in remote areas.

Powerstorm supports rural communities in off-grid areas that need reliable, clean, and safe electricity. To meet these communities' demand for power and interconnectivity, Powerstorm addresses every segment of energy storage solutions such as lithium battery chemistry, power conversion, voltage transformation, grid communications, algorithmic prediction, and operating logic.

Powerstorm technology is protected with several patents pending. In December 2015, it secured a strategic alliance with C4V, which will exclusively supply breakthrough lithium-ion (Li-ion) cells. Powerstorm believes that ongoing negotiations with key players in the industry with which it can partner and collaborate financially will establish the company as the industry leader.

TECHNOLOGY

Powerstorm is a differentiator in the industry with Li-ion batteries in all products, and it promotes an alternative to lead acid. Also, its products feature a modular design that allows scalability and customization without compromising price. Sleek design sets its products apart from conventional off-grid powering systems that are bulky and industrial. Its products also offer performance, capacity, footprint, cost, and environmental benefits.

Powerstorm products introduce the patent-pending digital brain, a management system that collects data to enable real-time energy and data management, with the ability to monitor/control remotely. This innovative technology will optimize energy generation, storage, and distribution, and optimize system efficiency at the macro level. In addition, it will provide a range of functional applications in one smart platform.

ENERGY STORAGE PRODUCTS/SERVICES

MODULAR ENERGY STORAGE SOLUTION (MESS™)

Powerstorm's main product is the MESS. The MESS is an outdoor-rated cabinet that contains a DC generator and modular Li-ion batteries. The Li-ion batteries can be connected to wind turbines, solar panels, fuel cells, and hydrocarbon generators, either individually or in combination via smart controller. Powerstorm's patent-pending control systems deliver a steady and efficient stream of reliable power. The MESS is easily transportable with "plug-and-play" features for rapid installation and startup. Its advanced interconnectivity and monitoring capabilities make it ideal for operation in even the most remote locations.

The MESS hybrid technology has the capacity to power telecom operators for off-grid or unreliable grid sites. The emerging markets have great need for plug-and-play systems such as the MESS with its comparatively small footprint. Powerstorm supports rural communities in off-grid areas that need reliable, clean, and safe electricity.

MESS performance and capacity data (in addition to brochure data):

- Energy range: 1 kWh to 1.5 MWh
- Power range: up to 1 MWh
- Duration: 24 hr
- Roundtrip efficiency: ≥ 90 percent
- Total lifetime: 4,000 cycles
- Operating life: 10 years
- Energy: 125 Wh/kg (system level)
- Power densities: 275 Wh/l (system level)

Powerstorm's MESS combines a diesel generator and modular Li-ion batteries.

Powerstorm creates safe and environmentally friendly access to power and networks. For example, the MESS uses Li-ion, solar, and/or wind turbine technology to reduce emission of pollutants between 20 to 45 percent compared to traditional diesel system. It also saves more than 70 percent in operational expenses and reduces greenhouse emissions by 40 percent. Although initially marketed for telecommunications (cell towers), Powerstorm intends to adapt the MESS product line and market it for use as an off-grid power application.

O&M Requirements

Ease of use is Powerstorm's top priority for energy storage solutions. Thus, the company's products require little maintenance, inspection, service, and replacement. Remote management of cell towers' power and fuel monitoring enables the monitoring of MESS performance. MESS requires preventive maintenance every 6 months.

Deployment

Powerstorm intends to have its pilot and first production unit for the African market by the end of 2016. To date, Powerstorm has deployed three systems. In 2014, a containerized MESS unit was deployed in the Republic of Uzbekistan. Additional MESS units have been deployed in Tanzania and New Delhi, India. Powerstorm expects to produce 500 MESS units in 2017.

Powerstorm intends to design each system and match selected components for each installation. It will build the main MESS unit (which includes an outdoor-rated cabinet, Li-ion batteries, and installation of a third-party generator) in their US facility for shipment to the deployment site. It will perform the engineering for integration of other options such as power inverters or photovoltaic (PV) panels at its
US facility, but the components may be procured by a local installer and shipped directly to the point of installation.

An early diesel generator unit for the Powerstorm MESS.

South African Presence/Experience

Powerstorm aims to provide energy storage internationally and intends to address energy poverty in Nigeria, Cameroon, Tanzania, El Salvador, and the United States. It is currently pursuing work and projects in South Africa.

Powertech Systems Integrators

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Company Description

Powertech System Integrators (PTSI) is a South African multidisciplinary engineering business with a core capability in systems engineering and integration. PTSI is a subsidiary of Powertech Technologies Limited, whose home office is in Menlyn, Pretoria, Gauteng, South Africa, and which does manufacturing/assembly in Midrand Gauteng and has approximately 320 employees. PTSI's customers are typically in the power utilities, renewable energy, mining and industrial, building and construction, and transport and rail market segments. PTSI works with leading ESS OEMs (and related power conversion systems [PCSs] and micro-grid control systems) for potential use of their ESS products in projects as a value-added reseller in South Africa and the rest of Africa. In addition to the value-added services and balance of plant equipment, PTSI, in conjunction with South African technology partners, could potentially provide local PCSs to an OEM's DC ESS to increase local content for the South African market and South Africa export into the African market.

PTSI has provided DC standby systems for utilities and telcoms. Additionally, PTSI designed, provided, installed, commissioned, and currently supports the ESKOM ESS test facility's site supervisory control and data acquisition (SCADA) control system. PTSI also supplies most of ESKOM's protection and control equipment (GE) and have supplied the ESKOM grid-compliance control systems for many of the REIPP plants in South Africa.

PTSI intends to extend into ESS applications in South Africa and the rest of Africa for applications involving distributed power generation, renewables, utility scale, mining, industrial, and behind the meter.

Technology

PTSI is technology- and manufacturer-agnostic. Because different ESS technologies are each well suited for different applications and use cases, the best technology in any given case is dependent on the specific requirements of the project at hand. PTSI will select the best technologies, often keeping in mind customer-specific preferences for specific OEMs/technologies.

PTSI uses the Homer energy modeling software package for high-level studies and trade-offs, but has also developed its own models for further optimization/benefit refinement related to parameters that are not fixed over the expected project life (e.g., electricity tariff escalations).

PTSI provides solutions for behind-the-meter micro-grid control including energy storage, energy management, load control, and standby generation control to ensure uninterrupted power for critical loads during grid failures, as well as using energy storage for peak clipping and load shifting.

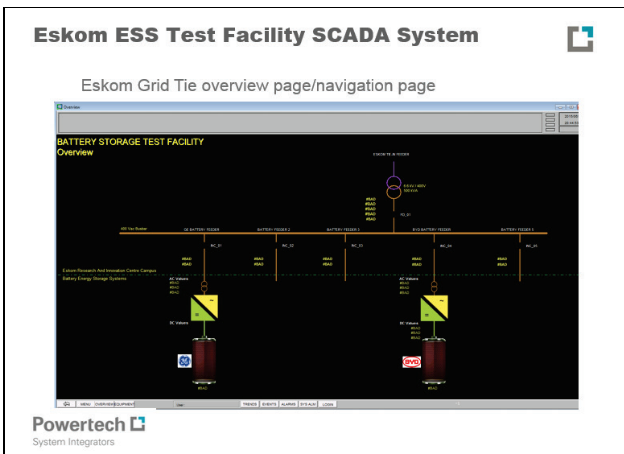
Energy Storage Products/Services

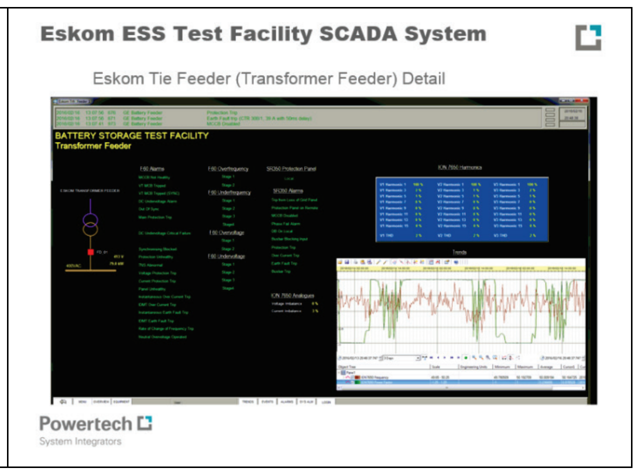
PTSI doesn't offer a unique product but instead uses standard storage/power schemes to develop unique integrated solutions. PTSI can function in several different roles but primarily functions as systems integrator for integrated system or EPC/M for turnkey projects, and as value-added reseller of products used in the systems and for replacements (e.g., new batteries). PTSI has provided standby power market solutions for existing installations from 1 kW/(4 kWh to 30 kWh) to 50 kW/(200 kWh to 1,000 kWh) and plans to support ESS business with systems in the range of 50 kW/50 kWh to 50 MW/200 MWh or more.

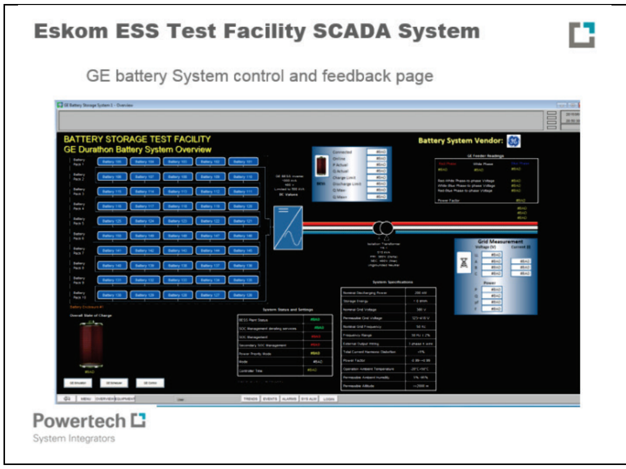
PTSI is working with Primus Power and the United States Trade and Development Agency (USTDA) to make a Primus Power zinc-bromide (Zn-Br) flow battery available to the Eskom ESS test site for 2 years; and thereafter install it at an end-customer yet to be determined.

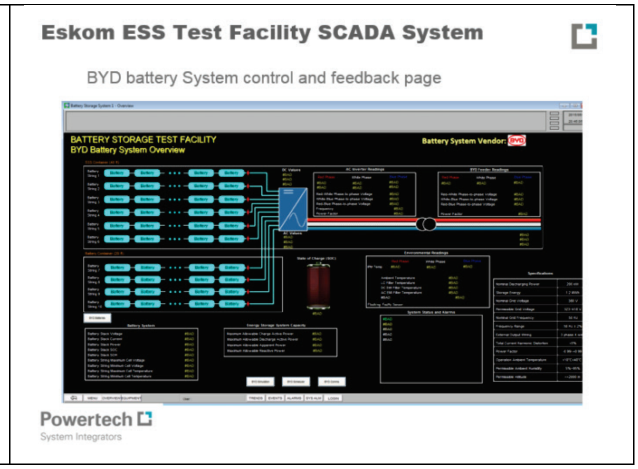
PTSI works or is pursuing a relationship with a number of companies and technologies including the following:

- Lead-acid batteries, flooded and sealed: Hoppecke and Enersys
- Rectifiers/Converters: mainly from Alpha Power Group; power control and protection equipment: mainly General Electric
- Aqueous batteries: Aquion Energy
- Li-ion: General Electric/Alstom and others in Europe, South Korea, and China
- Zn-Br flow batteries: Primus Power and Redflow
- Vanadium flow batteries: Imergy Power, Gildemeister (American Vanadium), UET (through General Electric)
- Zinc-Air: Fluidic Energy









Eskom ESS Test Facility SCADA System Provided by PTSI

High-Temperature Sodium Battery Provided by GE Lithium Iron Phosphate Battery Provided by BYD

O&M Requirements

Specific O&M requirements depend upon the technology and specifics of each application.

Deployment

Deployment requirements also depend upon the technology and specifics of each application.

South African Presence/Experience

PTSI is a South African company with extensive experience in the energy sector in South Africa and Africa and has specific experience with ESKOM and large municipalities.

Powin Energy

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Company Description

Powin Energy (Powin) is a design and integration company that provides scalable energy storage technologies in grid-level applications for electric utilities and their commercial, industrial, and institutional customers. Powin has been around since late 2011. It started as a branch of the Powin Corporation (an OEM manufacturer), building wind turbines for the commercial and industrial market for a few wind turbine companies. Since then it has shifted its business model to become an energy storage system integrator and a battery management system (BMS) developer. Powin headquarters, including the company's management team and sales and marketing and O&M operations, are located in Tualatin, Oregon. Powin's engineering leadership, responsible for developing hardware and software architecture/framework for its BMS and battery system, is also in Tualatin. Currently, 20 people work for Powin in Tualatin.

Technology

Although Powin designs and manufactures a turnkey battery energy storage system (BESS), the main product differentiator is Powin's proprietary BMS software. Powin's BMS includes the following features:

- Automatic active and reactive battery balancing (reduces downtime for maintenance)
- Ability to be scaled up to multi-megawatt configurations at a lower cost (all hardware and intelligence is built in at the low level [i.e., battery modules and battery packs])
- Detailed remote monitoring, including the ability to see battery data at the module, pack, array, string, and system levels
- Warranty tracker function: Powin's system keeps a historical log of every single charge and discharge cycle that the system performs during its lifetime; Powin will track the duration, power, and current of every single discharge/charge cycle; Powin will help its customers claim manufacturers defects and warranties with the battery manufacturers by generating reports to prove defects

Powin currently uses lithium iron phosphate ($LiFePO_4$) cells in prismatic modules in its BESS. It believes that $LiFePO_4$ chemistry is both a stable and proven battery chemistry because of the decades of test data accumulated from the use of $LiFePO_4$ in consumer electronics such as laptops and cell phones.

Powin products were ready for market in the first quarter of 2016 and plans to have commercial deployments starting in March 2016.

Energy Storage Products/Services

Powin is currently focused on a modular 20-ft containerized BESS where each 20-ft container has a useful storage capacity of up to 400 kWh. Powin offers a turnkey, fully integrated BESS including batteries, battery management, inverter/converters, and balance of system. The system operation is fully automated if connected with an energy management software (EMS)/supervisory control and data acquisition (SCADA) system. It can be remotely monitored and manually controlled over a web-based interface.

Powin manufactures its own battery packs, which use its proprietary BMS. It sources cells, inverters/converters, power control system, heating, ventilation, and air conditioning (HVAC), other balance of system (cables, transformers, etc.), and the container from qualified suppliers.

The Powin proprietary BMS software can be paired with a third-party EMS or SCADA system.

Powin Li-ion BESS in 20-ft container.

Name	Description
C250-125-000T	125-kW/250-kWh BESS container w/converter – 20-ft G container
C370-250-000T	250-kW/370-kWh BESS container w/converter – 20-ft G container

In addition to the standard specifications above, Powin can meet power and capacity requirements by adjusting the amount of battery "strings" or the number of containers and by selecting smaller or larger converters/inverters. Powin is capable of delivering solutions with capacity ranging from 400 kWh all the way to solutions with multicontainer configurations of more than 100 MWh. Powin systems can be configured into short duration solutions (as fast as 30 min to 1 hr) and long duration systems (from 2 hr or more). During testing at the Bonneville Power Administration (BPA), Powin achieved a roundtrip efficiency of 85 to 90 percent. Powin systems are designed to last more than 2,500 cycles, and their performance is warranted for 10 years.

The battery packs and BMS will be assembled in Powin's factory in China, where the container housing will be rack-outfitted and prewired for installation of the battery packs (with BMS), inverter/converter, power conversion system (PCS), HVAC, and fire protection systems. Final assembly/integration with HVAC, fire protection system, EMS, and balance of system will take place in Tualatin.

O&M Requirements

Typical O&M requirements are similar to other Li-ion BESS systems and include system monitoring, preventative maintenance, software and hardware upgrades, component or equipment change-out, general housekeeping, and warranty coordination.

Battery racks inside a Powin containerized BESS.

Deployment

Similar to other containerized systems, Powin equipment is relatively easy to ship. It requires a level and structurally sound surface for placement and an electrical connection with a fused disconnect switch and a circuit breaker installed in an existing switchboard.

Powin participated in a 2-year pilot program with the BPA, Energy Northwest (EN), and Pacific Northwest National Laboratory (PNNL). The project's objective was to "mission-prove" a modular, dispatchable battery-based energy storage system (ESS) for deployment by the BPA and its utility customers to help meet the region's energy challenges. Four separate tests were performed during the project including: (1) basic evaluation and qualification at the BPA's Ross Complex Medium Power Lab; (2) support for wind generation at the Energy Northwest Nine Canyon Wind Farm; (3) support for solar generation at the PNNL solar facility; and (4) support for demand reduction for the city of Richland, Washington.

A second pilot with EN tested the demand response integration and management of resources between Powin's BESS unit and EN/BPA. The intent of this project is for EN and BPA to use the experience gained and data collected to help determine the applicability of using load flexibility to manage a variety of transmission and utility-scale conditions via aggregated demand response. The project is 1 year (ongoing), commencing in February 2015.

South African Presence/Experience

Powin is currently pursuing international deployments of its ESS, including in the United Kingdom, China, Japan, Philippines, Australia, Mexico, Morocco, and Saudi Arabia. It has no current pursuits in South Africa, but would like to identify and explore all opportunities.

Primus Power

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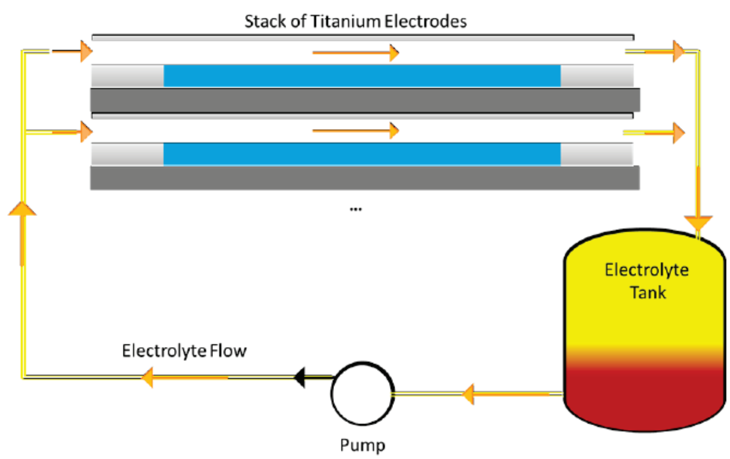
Company Description

Founded in 2009, Primus Power is located in Hayward, California, and has approximately 35 employees. Primus Power is a manufacturer of long-duration energy storage systems (ESSs). The company's main product is the EnergyPod®, which is based on a unique zinc-bromide (Zn-Br) flow battery.

Technology

Primus Power's integrated DC EnergyPods are based on Zn-Br flow battery technology. During charging, Zn ions from a $ZnBr_2$ solution are reduced to metallic Zn, releasing two electrons, which are deposited on the titanium electrode in each cell, oxidizing bromide ions to bromine. The bromine passes through the porous titanium electrode and is returned to the electrolyte tank. This process continues until the Zn in the electrolyte is fully consumed and plated to the electrode or the load is reversed for charging. The size of the plates sets the amount of current per cell, and the number of cells determines the voltage. In contrast, instead of flowing through a porous metal, conventional ZnBr flow batteries use a membrane where free ions are exchanged, requiring two separate tanks and two separate flow loops. To discharge, the process is reversed by a load, with the plated zinc going into the solution and bromine going back to bromide ions.



Primus Power EnergyPods use a single-loop Zn-Br configuration.

ENERGY STORAGE PRODUCTS/SERVICES

Primus EnergyPods are integrated, DC ESSs based on Zn-Br flow battery technology. The system includes a fully self-contained unit, with enclosure and framing, electrochemical stack, electrolyte, pumps and flow subsystems, and the battery management system (BMS). Primus is energy management system (EMS)- and inverter-agnostic; it offers its system without them but also has multiple options available for them, depending on the needs of the application and customer.

Primus' standard product is a 25-kW_{AC}/150-kWh_{AC} contained modular system. Both system and cell stack life are rated at 15,000 cycles at a 100 percent depth of discharge (DOD) and a 20-year life based on the use of titanium plates that avoid conventional flow battery issues (e.g., membrane degradation, failure due to dendrite damage, impedance changes due to graphite components, graphite felt clogging, and catastrophic failure due to high-temperature precipitation). The system allows for full DOD and provides for an RTE_{DC} of 65 to 70 percent. It has a distributed glycol loop with a radiator and fan that allows an ambient environment of 0°C to 40°C (–25°C to 40°C with the cold package option and 0°C to 50°C with the extreme heat option).

**EnergyPod
25-kW/125-kWh Zn-Br**

O&M REQUIREMENTS

Operations are normally fully automated, controlled by an EMS remotely or on site. Maintenance is similar to any piece of industrial equipment. Periodic scheduled conditioning, included in automatic control system, for stripping (morphology control and dendrite removal) and other steps to ensure system performance take less than 1 hour per week; monthly visual inspections take less than 1 hour; annual preventative maintenance with test and replacement of system parts such as pumps, flow meters, valves, and electronic components is also required. Primus recommends periodic test and reconditioning of electrolytes every 5 years consisting of adding small amounts of spiking elements to electrolyte to ensure full performance.

Low fire hazard: Primus Power's system is designed with smoke detection and has optional fire suppression for fires originating in electronics, pumps, or outside the system. Primus Power's Zn-Br chemistry is aqueous base and does not have thermal runaway issues.

Low chemical hazard: The system is safe enough for conventional shipping by common carrier. It is designed with leak detection and provides full containment of the electrolyte. To optimize the performance, complexing agents are used that significantly dilute the total elemental bromine found in the electrolyte, such that for systems under 10 MWh, no reporting would be required for worst-case full spills (per US Environmental Protection Agency requirements).

Low air pollution hazard: Gas release is not a significant issue because the vapor pressure of Primus Power's proprietary electrolyte is low (less than 0.75 mm Hg). This is the result of complexing agents used to make the Zn-Br electrolyte suitable for Primus Power's unique single-flow path system, and compares to 25 mm Hg for conventional Zn-Br flow battery systems, and 400 mm Hg for pure bromine.

Reuse and Recycle: Because the systems have been designed for decades of use, they are inherently low impact on the environment and landfill. At the end of life, the electrolytes are reclaimed and recycled, the steel framing and copper wire are recycled, and less than 1 percent by weight is disposed of in landfill.

DEPLOYMENT

Shipments of systems began in May 2015. As of March 2016, a total of 17 EnergyPods have been deployed at four sites totaling more than 1,200 kWh. In May 2015, Primus installed a large EnergyPod 280-kW/1-MWh system.

Primus Power 280-kW/1-MWh EnergyPod system installed at Miramar Marine Corps Air Station.

South African Presence/Experience

Primus Power is pursuing energy storage globally, shipping its first exported system in February 2016. It is pursuing early demonstration systems in South Africa in 2016. It also had early shipments in California and other areas on the US West Coast in 2015. Projects under discussion currently are a 120-kW/600-kWh system for demonstration, which will be followed up in early 2018 with larger, full-scale systems over 10 MWh. In formulating a demonstration project in South Africa, Primus Power has been in contact with Eskom, the US Trade and Development Agency (USTDA), and potential South African integrators (including Powertech System Integrators [Pretoria] and other partners).

Primus Power 1,500-kW/7.5-MWh EnergyPod system planned for export in early 2017.

PV Hardware

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Company Description

PV Hardware (PVH) is a company operated by experts in solar energy technology, product engineering, and construction. Founded in 2011 in California, USA, PVH currently forms part of the Spanish group GRS, a firm with a significant experience in the photovoltaic (PV) industry. PVH is headquartered in San Francisco, California. The firm has logistics, operations, and R&D centers in Sacramento, California, and maintains offices in Madrid, Spain, as well as its principal manufacturing facility center in Cheste, near the international port of Valencia, Spain. In 2015, PVH accounted for 81 staff, which generated a turnover of $24.5 million.

PVH is a provider of state-of-the-art balance-of-system (BOS) solutions for utility-scale solar power plants worldwide, and it has the same goal for energy storage. The firm's large–scale storage solutions are robust, proven and bankable, cost effective, easy to build, and have a long lifespan.

Technology

PVH energy storage began at the end of 2014 when it leveraged its engineering strengths and industrial capabilities. Using fast track product development, PVH developed a vanadium redox flow battery (VRFB) technology. During 2015, the firm's knowledge and experience grew as a result of its intensive work with pilot laboratory systems, cells, and engineering. Closing the year, PVH tested the A2_v2 battery cell that opens PVH's systems for large-scale solutions.

PVH batteries' strong record and the firm's proven experience in vanadium redox flow chemistry with an industrial optimization provide reliability at the lowest cost. In addition to having a lower environmental impact compared to other technologies, the vanadium electrolyte could be provided by any supplier that has the same electrolyte chemistry, because it meets a standard range, thus making the technology even more accessible. The electrolyte used in PVH's systems is within the standard ranges of concentration, i.e., a vanadium ion solution of 1.6 M, with an H_2SO_4 2M solvent. Therefore, a standard electrolyte can be guaranteed to ensure the correct development of the electrochemical reactions.

Due to the increasing amount of energy being produced from fluctuating renewable energy sources, the role of energy storage in decoupling energy demand and supply is becoming even more pronounced. Redox flow batteries demonstrate unique advantages over other technologies. Their high efficiency, long lifetime, and the flexible scalability of power and capacity make them an attractive alternative to conventional batteries. This is especially true for decentralized applications in the form of autonomous systems and stand-alone grids. In addition to a long lifetime, vanadium redox flow batteries (VRBs) exhibit a particularly high cyclic stability. For large storage capacity, PVH proposes the vanadium flow battery, which has the following advantages:

- Full range of power (kW) and energy (kWh) applications all in the same battery
- From short to long duration, simultaneous ramping and frequency regulation
- No state-of-charge or duty cycle limitations
- Operational from –40°C to +50°C
- Power and energy are decoupled, enabling maximum system flexibility and security
- 20-year system life; unlimited cycles
- Aqueous electrolyte is safe: moderate pH, zero reactivity and flammability
- No thermal runaway mechanisms, unlike other chemistries containment systems
- Lowest leveled costs, lowest cost installation, commissioning, low O&M costs.
- Full capacity access over lifetime
- Efficiency exceeding 75%

The flow battery captures multiple value streams, especially for quick response, 100 percent depth of discharge (DOD), and unlimited cycles of operation. The flow battery is the best solution for large storage with high flexibility and peak demand supply (large number of cycles at different depths of discharge). VRFBs have the following advantages over flow batteries:

- Operating temperature: The ideal operating temperature of traditional VFBs is limited to slightly above ambient temperature.
- Minimal fire hazard: The aqueous electrolyte is completely nonflammable and noncombustible, effectively minimizing the fire hazard of the entire system, including hazards from external heat and fire sources.
- Environmental impact: Studies examining the life-cycle environmental impact of vanadium redox batteries show that they have less impact than lead-acid batteries.

Energy Storage Products/Services

PVH Energy Storage offers these products for the large-scale storage market:

- 100-kW and 8- to 12-hour containerized solutions. Turnkey solutions for commercial, industrial, and renewables integration and other demands, especially off-grid applications. Advanced power electronics (grid-maker function included) will be used to allow an easy integration for PV and diesel backup, if necessary.
- Scalable energy storage systems from kW to MW. Modular solutions optimize project costs (CAPEX and OPEX) with a turnkey bankable system.

Using proven vanadium redox chemistry, advanced power electronics, and sophisticated control systems, PVH vanadium ESS can provide all electrical services: bulk energy services, ancillary services, grid infrastructure support, and peak shaving. PVH also has strong expertise in integrating renewable sources. PVH’s has control platforms on more than 300 MW of storage systems, enabling the integration of renewable and conventional energy sources. Our tailor-made advanced power electronics solution can work as:

- Tie-grid solution: Power scheduling, power-frequency regulation, peak shaving, and ramp control
- Off-grid solution: Integrated hybrid battery-PV solution-diesel, micro-grid controller and grid-maker

Deployment

In addition to PVH's experience in the diverse fields detailed above and its access to VRFB technology, PVH's 100-kW containers will be running in late winter 2016, and its first multi-power system is expected to pass standard international certifications in the summer of 2016.

South African Presence/Experience

In 2014, the PVH parent company GRS was awarded the construction of two 64-MWac (75-MWdc) solar facilities, Lesedi and Letsatsi, under the REIPPP Program. PVH contributed to these projects through the design, manufacturing, supply, and installation of all structural module support structures. PVH was also in charge of the design, supply, and installation of the supervisory control and data acquisition (SCADA) system for both projects. Both projects were successfully completed, and both were commissioned under Round 1 of the REIPPP Program. This experience provided the company first-hand experience in the challenges of operating in the South African PV and energy space. Both facilities are currently in operation. As senior partner (78% control) in the in the O&M Consortium parent company, GRS has developed the capacity to meet the full turnkey O&M requirements of these two solar plants, including managerial and technical capacity; personnel recruitment, training, and development; key subcontract relationships; and compliance with all technical (NERSA, Eskom, DoE) and social (economic development obligations) aspects of the work.

RedFlow LLC

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Company Description

RedFlow was founded in 2005 to commercialize its proprietary zinc-bromide flow battery technology and has been installing its core product, the 10-kWh ZBM (zinc-bromide battery module) in the field since 2009. RedFlow is a battery manufacturer and supplier to systems integrators and end customers. RedFlow will be releasing a residential plug and play product (complete with inverter) in 2016. RedFlow Limited is headquartered in Brisbane, Australia, and has manufacturing facilities in Juarez, Mexico (co-located with Flextronics). In 2014, RedFlow partnered with global manufacturer Flextronics, one of the world's largest end-to-end supply chain solutions companies to produce RedFlow modules in Mexico. RedFlow recently announced that Flextronics will start assembling RedFlow containerized systems from a factory in South Carolina in the United States. RedFlow and Flextronics have collaborated to produce commercial ZBMs, making RedFlow the first flow battery globally to enter large-scale production.

Technology

RedFlow's ZBM DC batteries are based on zinc-bromide flow battery technology. These batteries are best suited to multi-hour applications, such as renewables support, peak shifting, and frequent backup. The ZBM products constitute a complete battery system: electrolyte in tanks, electrode stacks, pumps and battery management system (BMS) with MODBUS communications. The ZBM2 product is rated at 3 kW/10 kWh; the ZBM3 product is rated at 5 kW/11 kWh. As a hybrid flow battery, the ZBM stores energy through different states in its electrolyte and through plating zinc onto its electrodes. The ZBM has a regular 100 percent depth-of-discharge capability that does not degrade the life of the battery. In addition, the ZBM operates without degradation at higher ambient temperatures (up to 50°C). All of RedFlow's products can be connected to make larger battery systems. The ZBMs can be connected in series or parallel, depending on the voltage required.

Energy Storage Products/Services

RedFlow's LSB (Large Scale Battery) product is a containerized DC battery system, based on up to 60 ZBMs in each ISO container. The LSB has been designed for compatibility with off-the-shelf inverters with MODBUS communications and an operating voltage range of 500 to 800 Vdc. The LSB architecture is based on strings of seven or eight ZBMs in series. Each string is connected to the 500- to 800-Vdc common bus through a DC-DC converter. Unlike other flow batteries of this size, this configuration allows the LSB to always maintain a 500- to 800-Vdc voltage range for the inverter, even on initial system startup. The temperature and depth of discharge characteristics are similar to the ZBM.

Characteristics of RedFlow Standard Products

	ZBM2	ZBM3	LSB
Energy	10 kWh	11 kWh	Up to 660 kWh
Power	3 kW continuous, 5 kW peak	5 kW continuous, 5.5 kW peak	Up to 300 kW
Duration	3+ hours	2+ hours	2+ hours
Round trip efficiency-DC	Up to 80%	Up to 80%	Up to 75%
Total lifetime cycles	Warranted: Equivalent of 30 MWh delivered Expected: Equivalent of 40 MWh delivered	Warranted: Equivalent of 33 MWh delivered Expected: Equivalent of 44 MWh delivered	Equivalent for the number of ZBMs in LSB
Operating life (yrs)	Based on energy throughput as above	Based on energy throughput as above	Based on energy throughput as above

RedFlow LSB (Large Scale Battery)

In April 2016, RedFlow introduced a ZCell residential system that can store 10 kWh of energy, allowing people to 'timeshift' solar power from day to night, store off-peak power for peak demand periods, and support off-grid systems. ZCell uses the RedFlow ZBM2 in a custom-designed outdoor-rated enclosure that sits on the ground and connects to a battery inverter/charger unit that delivers stored energy to the home. ZCell comprises a smart battery, managed and protected by an on-board computer control system, with an integrated ZCell BMS that enables on-site battery commissioning, monitoring, and control using a smartphone-compatible WiFi interface.

O&M Requirements

RedFlow batteries do not require any specific manual maintenance, although visual checks are encouraged. The batteries also undergo an automatic self-maintenance cycle that is entirely internally managed. The electrolyte within the batteries is classified as a type of Dangerous Goods Class 8 (as is the electrolyte in standard lead-acid batteries) and should therefore be handled as such when not sealed in batteries.

Deployment

RedFlow has participated in a number of demonstration or pilot projects in a number of applications in the Philippines, the Dominican Republic, New Zealand, and larger system demonstrations in Australia.

Since 2009, RedFlow has deployed approximately 200 batteries. Most of these systems have been in smaller applications, such as for powering wireless sites, integration with renewables, and other smaller behind-the-meter applications.

South African Presence/Experience

RedFlow has ongoing projects in Asia Pacific, Europe, North and Central America, and Africa. In South Africa, RedFlow has established two system integrators: Probe Group based in Johannesburg and Specialized Solar Systems based in George. RedFlow has deployed two systems to South Africa and a third is in commissioning:

- !Kheis Pumping Station, Northern Cape: 2 x ZBM supporting a grid connected to a local municipal water pumping station. The system includes 7 kW of solar PV, 2 x ZBM (20 kWh) and 3-phase Victron inverter power electronics.
- Residential installation in George, Western Cape: two ZBMs (20 kWh) supporting an off-grid residential house with 5 kW of Solar PV and a 5-kW single-phase Victron inverter.
- Detailed design – Johannesburg Manufacturing plant: 12 ZBMs (120 kWh), 60-kW, 3-phase Victron inverters.

  The !Kheis project is an evaluation project in a remote community with a following five municipalities to install a similar solution. Further upgrades are being undertaken to expand the installation from 20 kWh to 60 kWh, which will be the total system configuration.

South Africa Point of Contact

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S&C Electric Company

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Company Description

Founded in 1911 and headquartered in Chicago, S&C has a 100+ year history in the power transmission and distribution industry. S&C began deploying MW-scale power conversion equipment in UPS systems in 1999 and installed its first megawatt-scale energy storage project in 2006. Since then, S&C has completed dozens of grid-connected energy storage systems, integrating a wide array of battery technologies, including lithium-ion, sodium-sulfur (NAS), sodium-nickel-chloride (NaNiCl), and lead acid (both traditional and advanced). To date, S&C has performed technical study work and supplied power electronics equipment and/or grid integration for 20 percent of the world's battery energy storage capacity with 177 MWh in service. S&C has integrated a wide variety of use cases, including peak shaving, T&D deferral, frequency regulation, islanding, micro-grid, wind and solar leveling and smoothing, load following and balancing, voltage support, and power factor correction.

Technology

S&C's PureWave Storage Management System (SMS) products are robust utility-grade power conversion systems (PCS). The PureWave SMS provides four-quadrant control, acting as either a voltage or current source (adjustable on the fly) with the ability to absorb or provide real and reactive power. Whether responding to commanded volts-amps-reactive (VAR) requests or regulating voltage to a set point using VARs, the PureWave four-quadrant design allows the PureWave SMS to manage a wide range of real and reactive power requirements

Smart Grid Storage Management System, 2.0 MW/2.5 MVA.

Energy Storage Products/Services

The PureWave SMS provides an interface between a stored power source and the utility grid. It consists of a master control system and a 2-MW/2.5-MVA power conversion system (PCS). The PCS consists of two inverters, each rated 1 MW/1.25 MVA. When coupled with stored energy, the PureWave SMS can charge the storage device from a utility source, or discharge the storage device to the utility source. When connected to a feeder, the PureWave SMS can supply VARs in response to an external command or hold the feeder voltage at a preset level. The PureWave SMS can also operate independently, supplying power to a load that is not connected to the utility.

Individual PureWave SMS units can be operated in parallel up to 20.0 MW/25 MVA, with the outputs of the units connected to a common bus at medium voltage. Two or four PureWave SMSs are housed in a single ISO container for outdoor installation. Each 2-MW block contains two dc circuit breakers, two AC circuit breakers, and two PCSs and controls.

Although S&C manufactures and provides power conversion systems, its capabilities extend beyond that of an equipment vendor and integrator. S&C's Power Systems Services (PSS) organization provides project design, power system studies and analysis, EPC, project management, and after-sale monitoring and support services for renewable energy and energy storage projects. S&C's suite of distribution automation hardware and controls can facilitate interconnection to the grid and transfer to and from a micro-grid, intelligently prioritizing load control to ensure the stability of an islanded electrical network.

O&M Requirements

The PureWave SMS requires an annual maintenance visit to inspect, service, and replace certain components. Different components have different replacement cycles, which are taken into account when planning each maintenance visit. Servicing is typically performed by two technicians who are either S&C employees or trained and certified subcontractors. Remote monitoring via S&C's Global Service and Monitoring Center is suggested to improve system performance and reduce the requirements for field maintenance. Remote monitoring and annual maintenance are required for any extended warranty contracts. S&C power conversion and control system are designed in accordance with standard safety precautions related to voltage and current levels of the system.

Deployment

S&C's manufacturing facility for energy storage products is in Franklin, Wisconsin, USA. Systems are air-cooled and packaged in enclosures. The systems are designed for ambient cooling air between –40°C and +40°C and can be installed in outdoor applications in system configurations of 2.0 MW/2.5 MVA per ISO container or 4.0 MW/5.0 MVA, and can be pad mounted inside or outside in a wide variety of environments.

S&C has been involved in the design, integration, installation and operation of more than 20 multi-MW/MWh energy storage systems. As one of the earliest implementers of utility scale energy storage systems, S&C's first installation was at the Chemical Substation site in West Virginia, USA, in June 2006. This system consisted of ±1.25 MVA SMS on a 1-MW/7-hour sodium-sulfur battery that has been in successful operation since June 2006.

First S&C SMS Project ±1.25 MVA SMS on a 1-MW/7-hour NaS Battery

Another application is the installation of a ±2.5-MVA SMS supporting a 2-MW NaS battery. This project was installed to successfully design, manufacture, and demonstrate the ability of the S&C SMS to create and maintain an independent electrical energy island during outages on the utility system.

S&C 2 MW SMS provides for Islanding.

South African Presence/Experience

S&C is pursuing Energy Storage opportunities internationally and specifically in South Africa. S&C has a local sales representative, EBM (www.ebm.co.za), which can stock spare parts and provide local first response.

South Africa Point of Contact

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SimpliPhi Power Inc.

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Company Description

Founded in 2002 and located in Ojai California, SimpliPhi Power (formerly LibertyPak/Optimized Energy Storage) designs, manufactures and distributes lithium ferrous phosphate batteries primarily for residential, commercial, military, and portable/mobile markets.

Technology

SimpliPhi's uses a lithium ferrous phosphate (LFP) battery chemistry that offers the following features:

- Nontoxic and noncorrosive; no off-gassing
- Environmentally benign lithium ion chemistry, nonhazardous manufacture and disposal
- No risk of thermal runaway or fire
- Operates from –20°C to 60°F
- Does not require ventilation or toxic liquid cooling to prevent heat buildup or thermal runaway, a characteristic of other lithium ion cobalt-based batteries
- Operates at 98% efficiency with 5,000+ cycles, delivering multiple cycles a day, 100 percent depth of discharge
- Warranty: 10 years with a product life expectancy of 15 to 20 years

Energy Storage Products/Services

SimpliPhi Power provides turnkey power storage solutions that integrate with existing inverters and come equipped with an internal BMS. SimpliPhi produces a variety of small, lightweight, plug-and-play portable, rechargeable storage and delivery systems.

Because SimpliPhi batteries emit no heat and require no ventilation, they are ideal for remote, rugged environments. The US Military and the California Utility use these batteries in such conditions.

SimpliPhi OES3
3.4-kWh Battery Module

SimpliPhi has a full range of scalable portable/mobile battery units that are ideal for emergency relief, expedition, outdoor adventure, and/or travel. Larger systems can be used for renewable power integration or power reliability/backup applications.

O&M Requirements

O&M requirements are typical of lithium-ion installations. Using an integrated battery management system, SimpliPhi modules are maintenance free over their intended lifetime.

Deployment

SimpliPhi has been deploying battery systems for over 5 years and has deployed more than 400 individual battery units constituting over 5,000 kWh of storage. SimpliPhi systems have no special requirements for delivery and installation. They can be used as drop-in replacements for traditional batteries within existing electrical infrastructure for small and large residential or commercial installations.

Example: SimpliPhi of drop-in replacement capability.

SimpliPhi systems provide clean and efficient energy storage, intelligent management, and reliable, uninterrupted power solutions for on-grid and off-grid applications. Systems can protect against the intermittency of renewable energy sources and support power stability interfacing with the grid — from peak shaving to net-zero and backup power — while ensuring access to emergency power during outages.

Example: SimpliPhi systems providing renewable energy integration.

One such application for Whole Foods in Folsom, California, includes a 22-solar-panel array that collects and stores enough energy in 6 hours to power the entire store's sign load for this 1+ acre store for more than 36 hours while operating within the site's rooftop temperatures of more than 60°C. Applications such as this are scalable and could be used as off-grid or micro-grid systems.

South African Presence/Experience

SimpliPhi has deployed projects worldwide and, although the firm is in discussion with South Africa developers, it has not deployed product and does not have a formal presence in South Africa.

Tesla Energy
(part of Tesla Motors, Inc.)

Point of Contact

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Company Description

Tesla Headquarters is in Palo Alto, California. It has a factory in Fremont, California, and the Tesla Gigafactory is being constructed in Sparks, Nevada. Tesla was founded in 2003 with the mission *To accelerate the world's transition to sustainable energy*. Over this time, Tesla has developed the Roadster, Model S, and Model X fully electric cars to critical market acclaim. Key to the development of these high-performance electric vehicles has been Tesla's world-leading battery and drive train technology. By the end of 2015, Tesla had sold over 100,000 vehicles around the world, each representing a remotely monitored battery system. In 2015, Tesla also announced the launch of Tesla Energy which is focused on stationary storage products. The fundamental architecture and design is shared between cars and stationary storage products.

The company has unparalleled battery system expertise. Tesla is currently on its eighth generation battery and has more than 7.5 GWh of vehicle batteries deployed with over 1.5 billion miles driven. Furthermore, more than 95 MWh of grid batteries have been deployed to date. Tesla has over 14,000 employees.

Technology

Tesla Energy's storage solution is based on the powertrain architecture and components of Tesla electric vehicles, with optimizations in design and cell chemistry for grid connected stationary energy storage applications.

Energy Storage Products/Services

Tesla Energy has two energy storage products.

Powerwall – a 3.3-kW/6.4-kWh DC home battery that maximizes the usefulness of a home's solar panels and offers backup electricity supply solutions. The Powerwall is a rechargeable lithium-ion battery designed to store energy at a residential level for self-consumption of solar power generation, emergency backup power, load shifting and other applications. Powerwall consists of the battery pack, liquid thermal management control system, and software that receives dispatch commands from a solar inverter. The unit mounts seamlessly on a wall and is integrated with the local grid to harness excess power and give customers the flexibility to draw energy from their own reserve. Multiple batteries may be installed together for homes with greater energy needs. Powerwalls are a component and require a third-party inverter to connect to a home system and solar panels. The battery can provide a number of benefits to the customer:

- Increasing self-consumption of solar power generation: The Powerwall can store surplus solar energy not used at the time it is generated and use that energy later when the sun is not shining. This functionality can extend the environmental and cost benefits of solar.
- Load shifting: The battery can provide financial savings to its owner by charging during low rate periods when demand for electricity is lower and discharging during more expensive rate periods when electricity demand is higher.
- Back-up power: Ensures power availability in the event of an outage.

Powerpack – a commercial/industrial/utility solution that can provide a variety of functions to end customers and grid operators. It is a fully integrated AC solution with a power control system that comes in configurations of 250 kW, coupled with 2 to 7 hours of energy storage (i.e., 500 kWh to 1,750 kWh). It is modular and scalable to meet any size requirement above that. The Powerpack can be configured to fulfill all the use cases identified for South Africa. Tesla Powerpack is a fully integrated solution that includes the following components:

- DC battery pack "Powerpack" that consists of the following:
  - Several battery "pods" connected in parallel to a common internal DC bus
  - Each pod consists of battery modules with an isolated DC-DC converter
  - Integrated liquid thermal management system
  - Battery management system (BMS)
  - Single DC and communication interface
- 250-kVA bi-directional inverter
- DC combiner panel
- DC cable harnesses between battery packs and DC combiner panel (to be installed at site)
- Communication cable harnesses between battery packs and DC combiner panel (installed at site)
- Site master controller (SMC)
- Control and monitoring software

The modular 250-kVA inverter blocks can be grouped together to scale from 500 kWh to large-scale arrays for utility scale operations. Tesla Energy's grid-tied inverter provides a high-efficiency and economic solution, using high-frequency PWM architecture and closed loop control algorithms to ensure reliable operation. The fully integrated AC connected design allows for streamlined installation and significantly reduced integration complexity.

O&M Requirements

All Tesla Energy products are designed to be internet connected — a technology Tesla developed for its vehicles. This connectivity allows the products to be remotely monitored, faults to be detected, software to be updated, and utilization to be altered remotely. Furthermore, on-site maintenance is minimal by design. For example, Powerwall requires no maintenance for the 10-year warranty lifetime.

Deployment

Tesla Energy products are outdoor rated, extremely safe, and are fully recycled at the end of life. Tesla Energy already has more than 95 MWh deployed around the world. Public projects include systems at wineries, commercial buildings, manufacturing, retail, microgrids, and utilities.

South African Presence/Experience

Tesla Energy is already active in a number of markets globally across four continents. The firm has a formal presence in and will begin supplying its products to South Africa in early 2016. Its first installations will be Powerwalls followed by Powerpacks.

South Africa Point of Contact

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UniEnergy Technologies (UET)

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Company Description

Based near Seattle, Washington, UniEnergy Technologies (UET) produces large-scale energy storage systems for utility, microgrid, commercial, and industrial applications. With 50 employees, UET operates a 60,000-ft^2 engineering and manufacturing facility and is scaling to produce 100 MW annually. Founded in 2012, UET produced its first full system in 2014, and as of December 2015, UET had sold 9.35 MW/37.4 MWh of systems.

Technology

UET's core technology is a vanadium redox flow battery (VRFB) using advanced electrolytes, a containerized design, mature large-scale power stacks, and state-of-the-art controls.

UET's proprietary vanadium-based mixed acid electrolyte was invented by UET's founders while serving as leading scientists and program managers at the US DOE's Pacific Northwest National Laboratory. The new-generation electrolytes double the energy density of traditional vanadium sulfate electrolytes and tolerate a much greater operating temperature range, among other benefits, while retaining the inherent safety of vanadium-based flow batteries. Benefits include the ability to physically separate active materials for safety, operational flexibility for the full range of power and energy applications, and unlimited fade-free cycles over a 20-year life, all at reduced cost and high system reliability.

Another unique feature of the UET systems is that each system contains its own power conversion equipment and thus acts essentially as an alternating current (AC) coupled module. UET believes this to be a more elegant solution over a DC battery module because it simplifies the balance of power and allows the sharing and balance of power between coupled AC sources. It also eliminates the combination of DC/DC converters and inverter as a single point of failure, which occurs when a battery module is coupled directly with DC power sources such as wind or PV behind a single inverter system, albeit with a slight loss in efficiency.

Energy Storage Products/Services

UET offers two families of commercially ready, factory-integrated VRFB energy storage systems. These product lines are fully AC integrated, modular, scalable, and tailorable to the specific needs of each project. They can be deployed both at the distribution or transmission level and/or behind the meter (BTM) or off grid. UET leverages a mature and large-scale international supply chain to produce the Uni.System™ product.

The Uni.System™ is deployable in single or multiple parallel strings of AC-coupled energy storage systems. Each string is rated for 500 kWac and from 2 MWh up to 6 MWh (4- to 12-hour discharge). Each string is housed in four 20-ft shipping containers with a fifth container on each string that contains the 600-kWac power conditioning system (PCS). The Uni.System power density allows efficient use of real estate with up to 20 MW/acre behind-the-fence deployed footprint (60 MW/acre with a three-layer high stacked container configuration). The technology provides a 0.8-ms battery response time and less than 100-ms total AC system response time from full charge to full discharge power or reverse. The system provides an overall AC/AC efficiency of 65% to 70%, depending the mix of stacked uses. The Uni.System uses Siemens SCADA software SIMATIC WinCC Open Architecture to integrate key components from the Siemens Totally integrated Automation (TIA) portfolio and work together with other key suppliers to ensure optimum efficiency, reliability, and cost effectiveness.

The modular system configuration allows for rapid, incremental deployment. UET's system exhibits no capacity fade and can be fully discharged without losing capacity any number of times over its 20-year lifecycle design. The systems have no flammable components and no risk of thermal runaway, which can ignite surroundings and cause explosions in some environments. In June 2015, a Uni.System successfully passed third-party witness testing performed by Sandia National Laboratories.

Uni.System – 500kWac and 4 to 12 hour discharge (up to 6MWhac)

UET's second product is ReFlex™ which is a scaled-down version of the Uni.System configured in a single 20-ft ISO container. The Reflex system is also an AC-coupled modular system rated at 100 kWac/500 kWh.

O&M Requirements

Very basic Level 1 items are performed by locally trained personnel. Specific details and procedures are provided in the Uni.System Maintenance Manual, along with training requirements for service activities. UET offers its systems under an Unlimited Capacity Program (UCP) that significantly reduces the O&M responsibilities placed on the owner. The UCP program is offered at an extra fee and includes the following four features:

- Full system maintenance (customer field training for basic mandatory maintenance activities is included at no-cost)
- No-fade performance warranty up to year 20
- Monitoring and operating analysis with 24-hour monitoring and event notifications
- Full system recycling at project conclusion at year 20

Deployment

Factory integration of the UET systems and modular ISO container packaging facilitate shipping and rapid installation. Infrastructure for the Uni.System and ReFlex systems is thus limited to a concrete pad, connection to WiFi, and connection to an appropriate AC switchgear. The UET VRFB systems can operate within a broad temperature range with the electrolyte volume reacting very slowly to peak temperatures. The UET electrolyte is totally stable over a temperature range of –40°C to +50°C (–40°F to +120°F), and the UET VRBF systems can operate anywhere in South Africa, requiring only minimal active cooling during periods of high peak ambient temperature, with typical ambient 24-hr daily average temperatures ranging from -20°C to +35°C.

UET uses a benign chemistry: it uses no chemicals or materials hazardous to human health under normal operating conditions. The electrolytes are nonreactive with water and contain about 30 wt% vanadium salt and low concentrations of hydrochloric acid and sulfuric acid (<10%), which are acidic and corrosive (for comparison, a traditional lead-acid battery uses 30 to 50 wt% of sulfuric acid water solution). Other materials used in constructing the system such as plastics, carbon, and copper plate, pose no health concerns.

The core UET technology is intrinsically safe and is further reinforced by the UET system architecture to mitigate unexpected or emergency situations.

South African Presence/Experience

UET is pursuing international Energy Storage in North America, Canada, the Caribbean, Europe, Africa, Australia, and Oceania. UET does not yet have a formal presence in South Africa, but it has established a partnership with Bushveld Minerals. UET is currently developing bids for various projects in South Africa in the utility, microgrids (including off grid), and commercial and industrial segments.

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Vionx Energy

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Company Description

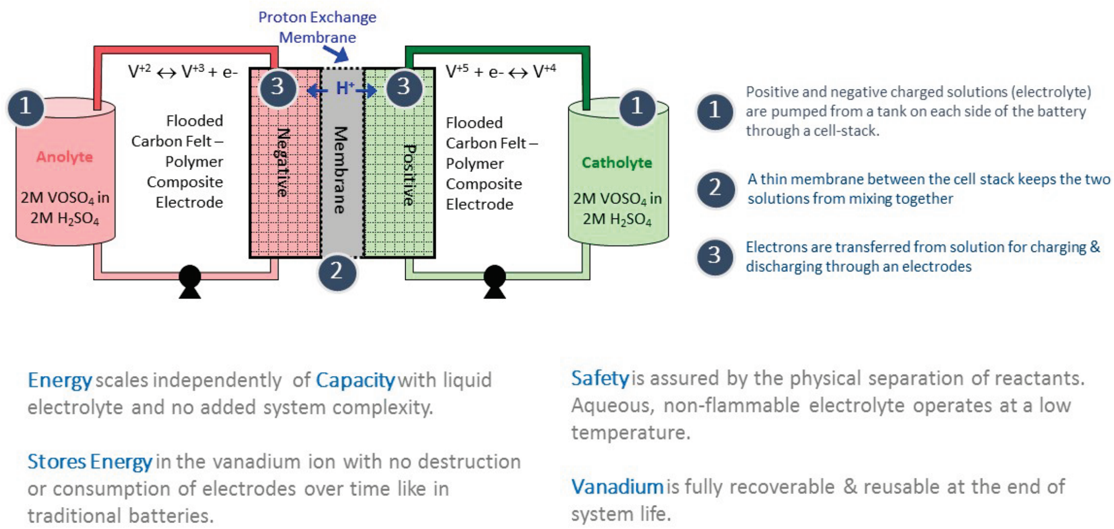
Vionx Energy Corporation (Vionx) manufactures and delivers vanadium flow battery systems. Its energy storage solutions meet the needs of the power industry that include T&D asset deferral, renewables firming and shifting, peak shaving, energy arbitrage, voltage support (static VAR compensation), local grid management, and others. Vionx Energy Corporation was formerly known as Premium Power Corporation; it was founded in 2002 and is based in Woburn, Massachusetts.

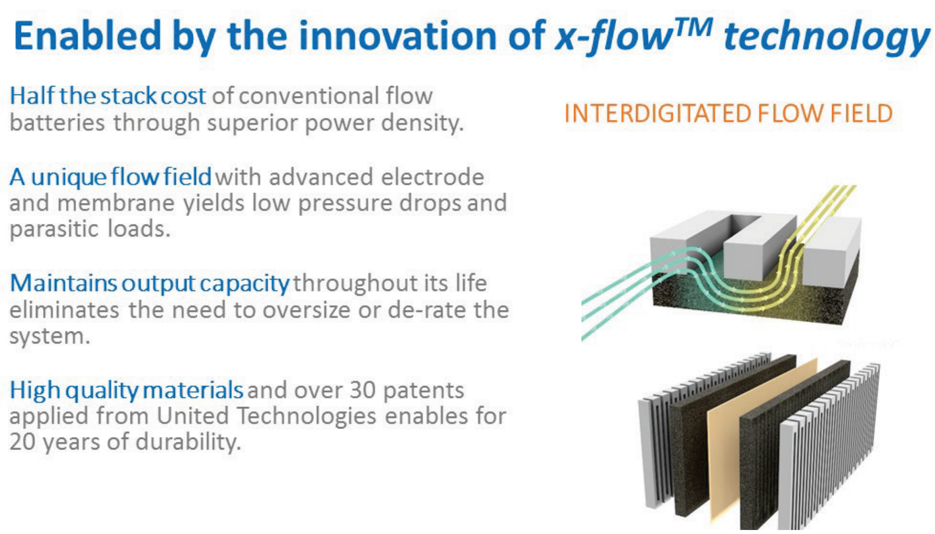
The technology behind the Vionx vanadium flow storage system was originally developed by researchers at United Technologies Corporation. Vionx designs, engineers, and manufactures a DC battery system including the battery controls; the AC portion and balance of plant is completed by others under Vionx's supervision or, for larger systems, Vionx supplies its systems to EPC contractors that complete the entire project.

Vionx is currently ramping up to commercial production. Jabil Circuit Inc., a Florida company with operations in Massachusetts, is building a factory in St. Petersburg to manufacture the batteries, which are about the size of a shipping container. The 3M Co. of St. Paul, Minnesota, is also making components. Siemens AG, the German technology company, having previously installed the pilot located at the Army Reserve facility at Fort Devens, can serve as EPC in the US and internationally.

Technology

Manufacturer of vanadium redox flow battery based on exclusive use of the patented United Technologies Corporation (UTC) battery stack design. Traditional vanadium redox flow batteries employ a range of components that include tanks of anolyte and catholyte fluids and a power cell at the center of the system. How these fluids "flow through" or "flow by" the power cell is at the heart of system performance—and this is the area in which UTC focused its efforts. The breakthrough was a new process improvement within the cell called the "Interdigitated Flow Field," by which the most efficient flow-through and flow-by processes are integrated to generate a much higher power density (2×) at lower pressure. Vionx claims that this increased power output combined with lower material costs makes its vanadium redox flow batteries extremely competitive when compared with other long-term grid battery options.





Energy Storage Products/Services

Vionx manufacturers all DC components in one integral system to include the battery stacks, electrolyte storage tanks, electrolyte piping, pumps, and battery control system. This DC system is fully containerized with all battery stacks, or capacity, located in one container while the electrolyte, or energy, is held in separate containers. All AC and balance of plant equipment and systems are provided by others, whether via contract to Vionx or via an EPC contractor to the ultimate customer.

Vionx commercial system will have a capacity of 1 MW and may have up to 10-hr duration (10 MWh) at a round trip AC efficiency of 68%. The Vionx system provides for a full depth of discharge with no limitations on cycle life. Multiple systems can be deployed for increased total capacity without limit.

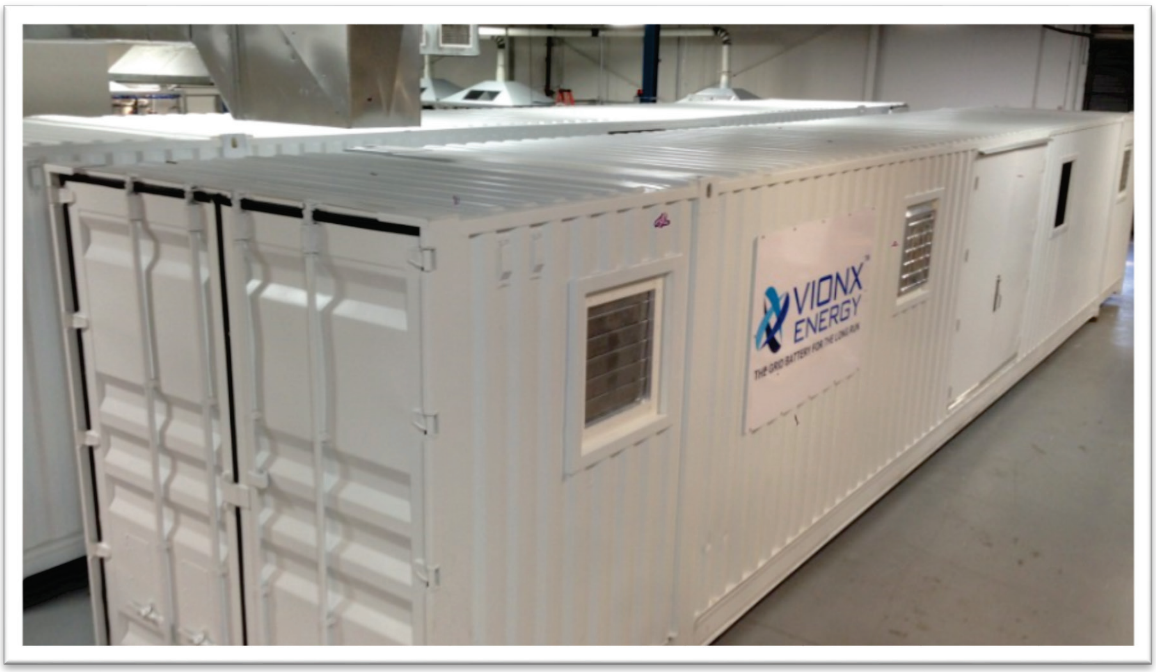
O&M Requirements

Vionx provides a long-term service agreement under which the battery's performance is warrantied based on a comprehensive preventive maintenance program. The battery has a 20-year life with no intermediate capital expenditures required and by the nature of a VRB system the output does not change over the life of the battery.

Deployment

Vionx's initial pilot system was placed in commercial operation in the fall of 2015. The pilot is a 160-kW, 4-hour battery system located on the US Army base at Fort Devens, Massachusetts. It has performed to specification and with a 96% availability to date.

In addition to the pilot system, Vionx is currently constructing two 500-kW, 6-hour systems to be put into commercial operation in early 2016. Both will be located on National Grid's utility distribution system in Massachusetts and will serve to better integrate a wind and a solar energy facility, respectively.



Vionx's Pilot VRB containerized energy storage system at Ft. Devens, Massachusetts

South African Presence/Experience

Vionx is pursuing opportunities in Africa, South Asia, and Southeast Asia. As it approaches commercial deployment of its 1-MW systems, Vionx is seeking to obtain information about South African partners and business opportunities.

ViZn Energy Systems

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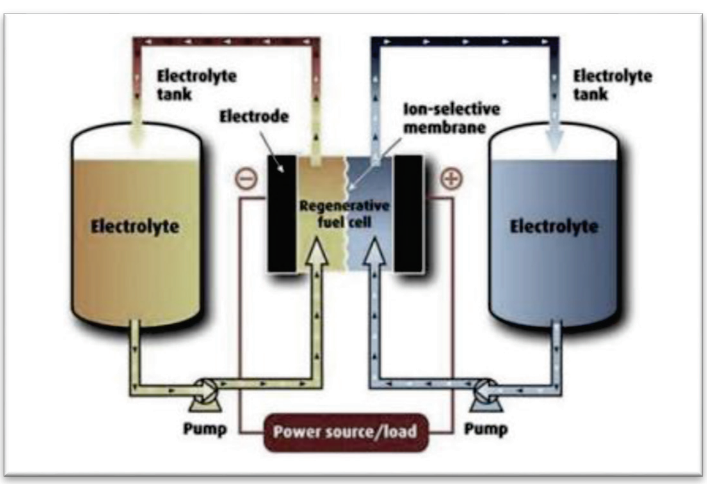
Company Description

ViZn Energy Systems (ViZn) was founded in 2009 and currently employees more than 60 staff, primarily consisting of technology experts in engineering, chemistry, and equipment manufacturing, as well as lean manufacturing expertise. ViZn is headquartered in Austin, Texas, with additional facilities in Columbia Falls, Montana. ViZn products are manufactured by its strategic partner, Jabil Circuit Inc., in state-of-the-art manufacturing facilities in St. Petersburg, Florida. The company had revenues of $891,000 in 2015 and is projecting $37 million in2016.

Technology

ViZn acquired its zinc-iron redox flow battery technology from a DOE project at Lockheed Martin; it has been refined by redox experts at Semitool (a leading redox company in the semiconductor industry) and by ViZn engineers and scientists. The results offer superior safety, cycle life, duty cycle, power delivery, and energy capacity.

The ViZn battery uses a zinc oxide anolyte in a proprietary alkaline solution to make a zincate complex designed for conductivity and solubility under normal operation. The catholyte is yellow prussiate of potash (YPP) and/or yellow prussiate of soda (YPS) in a proprietary alkaline solution to make an iron complex also designed for conductivity and solubility under normal operation.



ViZn batteries are capable of switching charge/discharge states within 30 ms, making them useful in frequency regulation markets. They can also deliver energy for 9 hours or more, enabling applications such as T&D upgrade deferral. The ViZn system has demonstrated its reliability in a grid connected setting since the first quarter of 2014 and has documented accelerated lifecycle testing covering 10,000 complete charge/discharge cycles and over 1.1 million partial discharge cycles at maximum power.

Typical parameters for ViZn systems include:

- Lifetime 10,000 cycles @ 100% DoD: 20 years
- External operating temperature: 10°C to 45°C (14°F to 113°F)
- Duration at maximum power: 2.4 hr and up to 8.8 hr at nominal power
- ESU efficiency: AC/AC 74% at nominal power

In association with a German contract, ViZn has undergone technical diligence by TUV, the leading inspection company in Europe; it has passed all technological and manufacturing categories. In addition, ViZn is in the final process of completing a technology evaluation by Black & Veatch, which is targeted for release to select customers and investors in May 2016.

Energy Storage Products/Services

ViZn offer three separate product lines based on size and application:

The Z20 Energy Storage System is self-contained in a 20-ft shipping container. On-board chemistry tanks and battery stacks enable stress-free expansion and unmatched reliability. Three to five battery stacks per Z20 provide 48 kW to 80 kW power with 160 kWh energy. Automated ventilation is the only temperature control needed. Systems are easily interconnected for higher power and energy requirements.

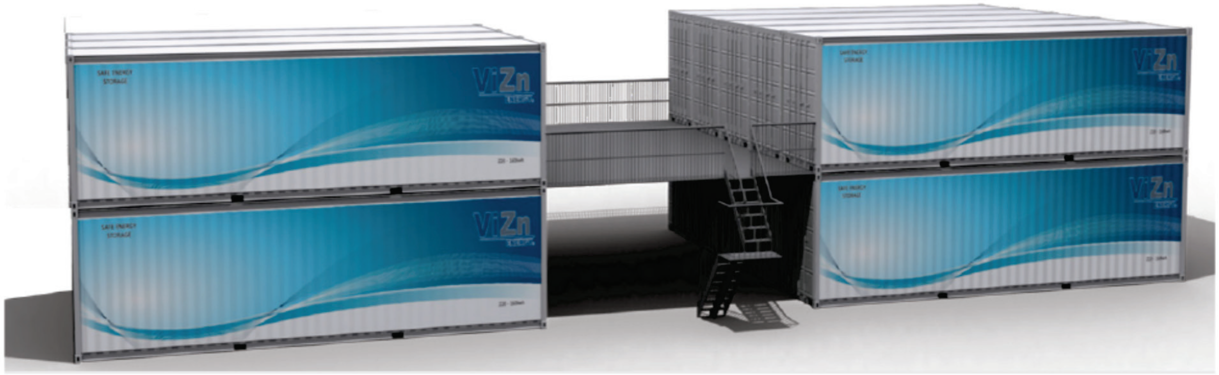
Z20 Options	Power (kW)	Energy (kWh)
Z20-3	48	160
Z20-4	64	160
Z20-5	80	160

ZAC is a fully integrated energy storage system intended for microgrid or Commercial and industrial applications. ZAV includes ViZn Battery, Princeton Power Systems' 100 kW grid-tied inverter, PCS and basic software package for ease of deployment. The ZAC has three configurations: 70 kW/320 kWh, 152 kW/640 kWh, and 288 kW/960 kWh.

ZAC Options	Power (kW)	Energy (kWh)
ZAC – 2	70	320
ZAC – 4	152	640
ZAC – 6	288	960

The GS200 Energy Storage System is designed for utility-scale, megawatt-sized storage solutions. GS200s are self-contained, modular storage systems. The flexible GS200 modules can be interconnected for higher power and energy requirements.

GS200 Options	Power (kW)	Energy (kWh)
1.0 MW	1,000	3,000
1.2 MW	1,200	3,600
1.4 MW	1,600	4,200



GS200 1.4 MW (7 units)1.4 MW/4.2 MWh

O&M Requirements

ViZn systems require minimal maintenance over their 20-year life and they are designed to be easily recycled at the end of their life. ViZn offers a 20-year warranty that places zero limitations on duty cycle, depth of charge/discharge, or ambient cell temperature.

Other than the high pH of the alkaline system, the ViZn Energy electrolytes pose little to no environmental hazard in the event of a spill. Once neutralized, the electrolytes are not even classified as hazardous waste, and no toxic liquid or gas by-products are produced either by accidental spill or in neutralization process.

Deployment

ViZn has deployed seven Z20 systems to date and plans to ship 100 MWh over next 12 months. ViZn indicates that, as of April 2016, it has been formally notified by customers that its products have been selected for procurements of over $43 million in the next 12 months. ViZn reports the following current deployments:

- Z20 system at Flathead Electric Cooperative
- Z20 system at Randolph-Macon College as Part of Dominion Solar Project

South African Presence/Experience

ViZn is currently pursuing Energy Storage in Germany, Spain, Côte d'Ivoire, India, Colombia, Samoa, USA, and Canada. ViZn is currently completing contractual agreement for installation in the Africa Ivory Coast for a 384-kW system consisting of six Z20 systems. Although it does not have a formal presence, ViZn will be actively pursuing project development and energy storage deployments in South Africa.

WattJoule

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Company Description

WattJoule was founded in 2012 and has multiple strategic investors. It currently has 6 fulltime employees and another 18 through R&D contractual relationships. WattJoule is a pre-revenue company that is in development of a proprietary advanced vanadium redox flow energy storage technology exclusively licensed from University of Tennessee at Knoxville, Oak Ridge, and Pacific Northwest National Laboratories. Early development work was funded by the US DOE, US Office of Naval Research, and the US National Science Foundation. The company has developed and acquired additional unique IP and has multiple patents pending.

Technology

The WattJoule advanced vanadium flow battery stores electrical energy in a liquid with no self-discharge. As a true flow battery, it can store as much energy as desired based on the liquid volume, independent of power. Unlike lithium ion batteries, its electrolyte does not wear out or degrade over time. It does not require any refrigerated cooling or air conditioning, and the system will have a compact footprint. All of these benefits translate to much lower overall cost.

Energy Storage Products/Services

WattJoule is currently developing a modular energy storage platform for OEMs that provides the core DC battery function. The intent is that OEMs will build their full energy storage systems using the WattJoule flow battery module. Standard storage modules are planned for 100 kWh and 500 kWh. Full specifications are not yet available for public distribution, however, energy range is 100 kWh to 500 MWh, power range is 10 kW to 500 MW. Typical cycle duration would be 4 to 6 hours but can be any amount of time and is purely based on the volume of liquid. Efficiency is in the range of 80% to 90%, and the lifetime is greater than 20,000 cycles over a 20-year life. WattJoule initially plans to develop standard storage modules at both 100 kWh and 500kWh.

WattJoule does not have any pilot demonstrations installed but has identified more than 20 early sites, dispersed globally, that have expressed interest in purchasing early systems for testing and demonstrations. WattJoule intends to ship its first product in early 2017.

O&M Requirements

It is expected that O&M consideration would be typical of other VRFB storage systems.

Deployment

Unlike lithium ion systems, the WattJoule liquid electrolyte consists of more than 60% water, so it can never burn or explode. It is inherently safer than solid batteries regarding the risk of fire and explosion. These are two critical siting concerns.

South African Presence/Experience

WattJoule has ongoing discussions with potential strategic partners throughout the world. Although it is not currently pursuing energy storage in South Africa, it plans to identify a suitable partner for South Africa.

Appendix C Glossary

The following terms and acronyms are introduced and defined in simple terms to assist readers that may be unfamiliar with their definition or use.

Absorbent glass mat (AGM): Used for sealed lead acid batteries, the acid is absorbed by a very fine fiberglass mat, making the battery spill-proof.

Active material: Chemicals within a cell that participate in the electrochemical charge/discharge reaction.

Alkaline electrolyte: An aqueous alkaline solution (such as potassium hydroxide) that provides a medium for the ionic conduction between the positive and negative electrodes of a cell.

Ampere-hour: Unit of capacity of a cell/battery. Capacity is defined as the product of the discharge rate and the discharge time.

Anode: The electrode that releases electrons on discharge, the negative side.

Battery: One or more connected electrical cells. In common usage, the term *battery* is also applied to a single cell, such as a household battery.

Battery: Two or more cells electrically connected to form a unit. In common usage, the term *battery* also applies to a single cell.

Black start: The ability of a generating unit to start without an outside electrical supply. Black start service is necessary to help ensure the reliable restoration of the grid following a blackout.

Capacity: Number of ampere-hours (Ah) a fully charged cell or battery can deliver under specified conditions of discharge.

Cathode: The electrode that receives electrons through the discharge process, the negative side.

Cell: An electrochemical unit constituting positive and negative electrodes, separator, and electrolyte to provide electrical energy.

Cell reversal: In reversal, the normal terminal polarities of a cell in a multiple cell battery are switched. Cell reversal normally occurs only if three of more unit cells are connected, and the battery is deeply discharged. Cell reversal is detrimental to performance and should be avoided by proper selection of cutoff voltages during discharge.

Charge: The operation which inputs electrical energy to a cell/battery.

Charge efficiency: A measurement of accumulated efficiency during the charging operation.

Charge rate: The rate of current supplied to a cell/battery.

Charge retention: The percentage of capacity remaining after a charged cell/battery has been stored for a period of time.

Closed-circuit voltage: The voltage of the cell/battery with loading.

Constant current charging: Charging with a fixed current value.

C-Rate: Relative rate used in cell/battery, defined as the quotient of current (mA)/nominal capacity (mAh). Charge rate that, under ideal conditions, is equal to the energy storage capacity divided by 1 hour. The charge rate necessary to charge a battery in 1 hour is 1 C.

Current: Flow of electrons equal to 1 coulomb of charge per second, usually expressed in amperes (A).

Cutoff voltage: Cell or battery voltage at which the discharge is terminated. The cutoff voltage is specified by the manufacturer and is a function of discharge rate and temperature.

Cycle: The discharge and subsequent charge of a secondary battery so that it is restored to its fully charged state.

Cycle life: The number of charge/discharge cycles a cell/battery can run under specific conditions while still delivering specified minimum capacity.

Demand: The rate at which electric energy is delivered to or by a system or part of a system, generally expressed in kilowatts or megawatts, at a given instant or averaged over any designated interval. Alternately, the rate at which energy is being used by the customer (NERC).

Demand charge reduction: Use of distributed or onsite generation or storage and/or use of demand response or energy efficiency to reduce the maximum power draw by electric load.

Demand charges: The price paid by a retail electricity user for each unit of power draw on the electric grid. Demand charges are typically applied to the maximum demand during a given month, hence units are $/kW-month.

Demand response (DR): Reduction of retail electricity end-users' electric load (power draw) in response to control or price signals. DR resources are deployed and used in lieu of installing/operating peaking generation capacity.

Depth of discharge: The percentage of the available capacity from a cell/battery during discharge.

Discharge: The operation that releases stored electrical energy from a cell/battery.

Discharge duration: The amount of time that a storage device can be discharged at the nominal power rating.

Discharge rate: The rate of current drained from a cell/battery.

Duty cycle: Operating parameters of a cell or battery including factors such as charge and discharge rates, depth of discharge, cycle length, and length of time in the standby mode.

Electrode: Electrical conductor and the associated active materials in which an electrochemical reaction occurs. Also referred to as the positive and negative plates in a secondary cell.

Electrolysis: Chemical dissociation of water into hydrogen and oxygen gas caused by passage of an electrical current.

Electrolyte: Medium that provides the ion transport function between the positive and negative electrodes of a cell.

Energy density: The amount of energy (Wh) that a battery can deliver per unit of volume, similar to specific energy.

Equalizing charge: Charge applied to a battery that is greater than the normal float charge and is used to completely restore the active materials in the cell, bringing the cell float voltage and the specific gravity of the individual cells back to "equal" values.

Exothermic reaction: A chemical reaction that results in the release of heat energy as it proceeds.

Float charge: Method of charging in which a secondary cell is continuously connected to a constant-voltage supply that maintains the cell in a fully charged condition.

Gassing: Evolution of gas from one or more electrodes resulting from electrolysis of water during charge or from self-discharge. Significant gassing occurs when the battery is nearing the fully charged state while recharging or when the battery is on equalizing charge.

Levelized cost of energy (LCOE): the discounted cost of operation over a lifetime divided by the total power generated by a source ($/kWh).

Levelized cost of storage (LCOS): the discounted cost of operation over a lifetime divided by total power discharged by a source ($/kWh).

Memory effect: The phenomenon whereby the capacity of a cell may be temporarily decreased when it is repeatedly used in a shallow discharge pattern. Memory effects are erased when the cell is discharged to the normal cutoff voltage (e.g., 1.0 V at the 0.2 C discharge rate).

Negative electrode: The electrode with negative potential. Current flows through the external circuit to this electrode during discharge.

Nominal voltage: A general value to indicate the voltage of a battery in application.

Open-circuit voltage: The voltage of the cell/battery without loading.

Overcharge: The continued charging of a cell/battery after it is fully charged.

Peaker plant: Also known as peaking power plants, or occasionally "peakers"; power plants that are generally run only when there is a high demand, known as peak demand, for electricity.

Positive Electrode: The electrode with positive potential from which current flows through the external circuit to the negative electrode during discharge.

Potential difference: Work that must be done against electrical forces to move a unit charge from one point to the other, also known as electromotive force (emf).

Primary cell or battery: Cell or battery that is not intended to be recharged and is discarded when the cell or battery has delivered its useful capacity.

Overcharge current: The charge current supplied during overcharge. Cells/batteries can accept continuous overcharging at recommended rates and temperatures specified by the manufacturer.

Rated capacity: A nominal capacity available from a cell at specific discharge conditions.

Safety vent: A device to release the gas when the internal pressure of the battery exceeds the preset value.

Round trip efficiency (RTE): The ratio of the output of an electricity storage system to the input required to restore it to the initial state of charge under specified conditions. Can be expressed as AC-to-AC (RTE_{AC}) or DC-to-DC (RTE_{DC})

Self-discharge: The loss of useful capacity of a storage system due to internal losses such as internal chemical action in a battery, frictional losses in a flywheel, or air lost from the storage reservoir in a CAES system.

Secondary battery: A battery that after discharge may be restored to its charged state by passage of an electrical current through the cell in the opposite direction to that of discharge. (Also called storage or rechargeable.)

Separator: Electrically insulating layer of material that physically separates electrodes of opposite polarity. Separators must be permeable to ions in the electrolyte and may also store or immobilize the electrolyte.

Short Circuit: The direct connection of the positive electrode/terminal to the negative electrode/ terminal of the battery.

Specific energy: The amount of energy (Wh) that a battery can deliver per unit of mass.

Specific power: The measure of power (W) per unit of mass.

Specific gravity: Ratio of the weight of a solution to an equal volume of water at a specified temperature. Used as an indicator of the state of charge of a cell or battery.

Standard Charge: The normal charge rate used to charge a cell/battery in 16 hours. Normally 0.1 C.

Sulfation: Occurs in a lead-acid battery when the active materials of the electrodes convert to large lead sulfate crystals that have the effect of insulating the particles of the active material either from each other or the grid. Occurs during storage and self discharge.

Terminal: External electric connections of a cell or battery; also referred to as "terminal post" or "post."

Thermal Fuse: A component assembled into batteries, which breaks the current when the temperature reaches a predetermined value.

Thermistor: A component with a negative temperature coefficient that is built into batteries and/or used to detect the ambient and battery temperature.

Thermal runaway: A situation in which an increase in temperature changes the conditions in a way that causes a further increase in temperature, often leading to a destructive result.

Time-of-use (TOU): An electricity bill structure that charges customers a different rate for electricity depending on the time of day.

Trickle charge: Method of charging in which a secondary cell is either continuously or intermittently connected to a constant current supply in order to maintain the cell in fully or nearly fully charged condition.

Voltage: Electromotive force or potential difference, expressed in volts (V).

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Economic Assessment

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ACRONYMS

BOP	balance of plant
BTM	behind the meter
CAES	compressed air energy storage
CAPEX	capital expenditure
CPP	critical peak pricing
CSIR	Council for Scientific and Industrial Research
CSP	concentrating solar power
DER	distributed energy resource
DOE	Department of Energy
EIA	environmental impact assessment
EPC	engineering, procurement, and construction
EPRI	Electric Power Research Institute
ESS	energy storage system
EV	electric vehicle
FVT	full value tariff
GHG	greenhouse gas
HVAC	heating, ventilating, and air conditioning
IRENA	International Renewable Energy Agency
IRP	Integrated Resource Plan
LCOE	levelized cost of energy
LCOS	levelized cost of storage
Li-ion	lithium ion
LTSA	long-term service agreement
MW	megawatt
NaS	sodium-sulfur
NiCad	nickel-cadmium
NRECA	National Rural Electric Cooperative Association
O&M	operations and maintenance
OPEX	operational expenditure
PCCS	power conversion and control system
PCS	power conversion system
PHS	pumped hydroelectric storage
PV	photovoltaic
R	South African Rand
R&D	research and development
REDZ	Renewable Energy Development Zone
RESOLVE	Renewable Energy Solutions model
REV	Reforming the Energy Vision
RPS	renewable portfolio standard

SA	South Africa
SMUD	Sacramento Municipal Utility District
T&D	transmission and distribution
TOU	time of use pricing
TRC	total resource cost
USD	US dollar
USTDA	US Trade and Development Agency
VAR	Volt-Ampere Reactive
WACC	weighted average cost of capital
WECC	Western Electric Coordinating Council
Zn-Br	zinc-bromine

1 Introduction

This report presents the results of an economic assessment of the potential for storage in South Africa in the short, medium and long term. It presents the findings of the study that was designed to assess the benefits and costs of energy storage in South Africa through 2030 and includes the following components:

- Relevant historical cost reduction/learning curves and anticipated cost reduction forecasts over the short term (0–5 years), medium term (5–10 years), and long term (10–15 years). These are discussed in Section 2.1.1. These values are developed in detail for lithium ion (Li-ion) and flow batteries as inputs to the economic modeling.
- Anticipated averages or ranges for capital, installation, operating, maintenance, and decommissioning costs. These are also discussed in Section 2.1.2 as components of the total storage costs modeled in the economic analysis.
- Marginal levelized cost of energy (including potential impact on existing electricity tariffs). These have been presented as annualized costs for storage capacity and power conversion for the battery options studied in the economic analysis to avoid the confusion of levelized cost of storage (LCOS) comparisons for batteries across the various use cases. The estimated tariff impacts of the various battery scenarios are presented in Section 2.4.1.
- Cost-recovery tariffs and/or subsidies required to make the technology economically viable for commercial deployment. The cost recovery tariffs or subsidies are calculated through the economic analysis and are presented in Section 2.4.1. We show this as a funding gap between the price at which storage is adopted in South Africa based on bulk system use cases, and the projected price based on storage market forecasts.
- Economic risks and barriers, and recommendations for their mitigation, including costs associated with those recommendations. The key findings of the study are provided in Section 1.3 and the recommendations in Section 1.4. The recommendations are for changes in system planning processes and valuation methodologies so that storage can be recognized and compensated for the full value it can offer. Therefore, no direct costs are involved other than the costs associated with study and reform of existing processes. Beyond these enabling steps, costs could include new communications infrastructure, and this is discussed in the Objective 6 Roadmap section of the project.
- Anticipated revenues, cost savings, and other benefits associated with utilization of the technology, such as ability to offset the use of diesel and other fossil fuels for peaking power, continuity of operations, increased ability to sell electricity during peak hours, and increased capacity to successfully integrate renewable electricity generation sources, especially intermittent power sources such as solar and wind, into South Africa’s electric grid. All are assessed through the cost benefit analysis performed for storage offering grid services. These grid services include the bulk energy services and ancillary service use case categories previously identified under Objective 1. The results of the analysis are presented in a cost

benefit curve that shows the megawatts of economic build of storage at various price points, and the comparison of those prices with the expected cost of Li-ion and flow batteries in 2030. Local storage benefits are also discussed qualitatively, and how optimal placement of storage devices on the electricity grid can increase the viability of storage as an economic resource.

The remainder of this section introduces the future South African energy plans, discusses the role that storage can play in serving the needs of the system, and summarizes the findings and recommendations of the economic analysis. Section 2 describes the work done to determine storage pricing over time, and the economic analysis of bulk system storage benefits and costs, including presentation of the funding gap, and cost benefit curves for storage. Section 3 discusses qualitatively the potential local and customer benefits of storage that are not captured in the bulk system modeling and that could contribute to closing the funding gap. Section 4 introduces the challenges of aligning the operations of customer-controlled storage with grid needs through compensation and incentive structures.

1.1 South African Energy System and Future Plans

The value of energy storage depends significantly on other electric generation resources on the grid and on how energy storage is integrated into grid operations. The USTDA Storage Evaluation Steering Committee identified the following three resource cases developed through the South African Integrated Resource Plan (IRP) process for which the Committee would like to determine whether storage is needed:

- **2010 IRP:** The official 2010 IRP with 9.6 GW of new nuclear, 6.25 GW of new coal, 9.2 GW of new wind, 8.4 GW of new photovoltaic (PV), and 1.2 GW of new concentrating solar power (CSP) over current generation relative to the system at the time of the IRP [0004].
- **Updated IRP:** A public but unofficial update of the 2010 IRP with nuclear additions reduced to 3.6 GW and load growth significantly reduced [0005].
- **Rooftop PV:** A high distributed solar case that adds approximately 21.6 GW of rooftop PV to the previous case – a scenario tested in the update of the 2010 IRP.

The resource procurement for these cases is already identified through 2030. We are therefore testing whether storage has enough operational benefits to justify building it. Storage can also have benefits in avoiding building capacity however, and running the IRP cases with their fixed resource procurement trajectories does not allow storage to realize this benefit. We therefore add an additional case where we re-optimize the IRP in the high distributed solar case above, allowing the model to select the least cost portfolio of resources out to 2030 where storage is one of the resource options:

- **Modified Rooftop PV:** The Rooftop PV case described above in which the resources between 2016 and 2030 are optimally selected to serve system needs.

We conduct the study using the RESOLVE optimal investment model to determine whether at different price points storage would be an economic investment for least-cost system operations relative to other conventional generation operations, or, in the case of the Modified Rooftop PV, relative to other capital investments as well. RESOLVE is an optimization tool designed to find the least-cost portfolio solution of resources to meet long-term energy policy targets such as high renewable penetrations. The costs are modeled for both generic Li-ion and flow batteries.

1.2 STORAGE BENEFITS

Our analysis is restricted to evaluating the benefits of storage at the bulk system level. These are only a subset of the total potential benefits that storage can realize, depending on where the storage is located on the system. Figure 1-1 shows the full spectrum of geographies on the electrical system that determines the types of service that storage can offer. These include bulk transmission, local congestion zones, subtransmission, distribution, and behind-the-meter storage. The benefits that we capture in the bulk system analysis presented in this report are the benefits that would be attributed to storage in an IRP planning process where least cost system operations are being solved. These benefits include the bulk energy service and ancillary service use case categories previously identified under Objective 1.

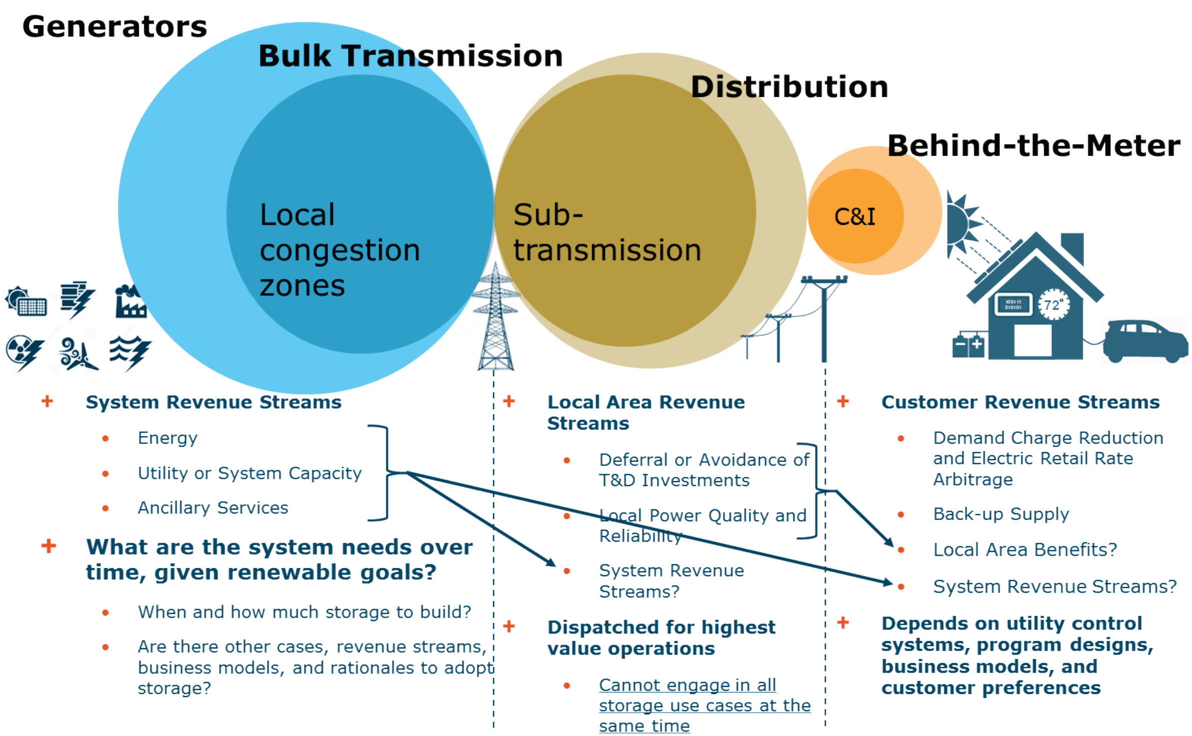

Figure 1-1: Potential Revenue Streams for Storage

From a bulk system level planning perspective, the question is when and how much storage to build as part of a least cost portfolio of resources, given the energy, capacity, and ancillary service needs of the system as loads grow, the existing generator fleet changes, and new renewables are installed. However, other use cases and storage revenue streams are potentially realizable, depending on the available storage business models, available market products, and regulations.

In local congestion zones, storage can realize the benefits of congestion price arbitrage or local resource adequacy value in the form of avoided local generation. At the distribution level, these benefits include deferral of capital investments and improvements in reliability and power quality. Behind the meter, customers can benefit from additional back-up power. Although it is true that storage cannot engage in all use cases at the same time, storage can often realize a close to single use case application value for several use cases over the course of the year, thereby stacking the benefits.

In our quantitative analysis of the bulk system benefits of storage, we identify the 'funding gap' necessary to incentivize storage build. The funding gap is the difference between the expected cost of storage and the cost at which different levels of bulk system level storage adoption occur according to our model. However, we are capturing only the funding gap for storage systems installed at the bulk system level. Storage installed further down the system may be able to fill the funding gap with additional benefits. This depends on the specific location of the resource, the markets or programs available to realize the value the device offers to the grid, the control systems available to the utility, and the ownership or business model of the installed storage device. Section 3 of this report qualitatively discusses these additional benefits to storage, the opportunities available for storage to realize those benefits, and recommendations to facilitate the full value of storage being realized.

One benefit for the storage owner that is not mentioned above is the potential retail rate savings from demand charge reduction and arbitrage. These savings could be high enough for some customers to invest in storage. However, unless the customer tariff incentivizes usage of the storage device that aligns with valuable grid scale uses of the battery, this type of storage investment can lead to a more expensive electricity system. In Section 3 of this report, we discuss the various business models for storage ownership and operations, as well as the steps that the utility can take to align behind-the-meter storage operations with valuable grid services.

1.3 Key Findings

Energy storage on a system level provides value in combination with other resources deployed in the system, and the best use of system storage and its value depend on storage's highest value use cases in that context. Therefore, our study evaluates several different resource futures agreed upon by the study steering committee, examining the value of storage and the funding gap that might persist between its value in that future and the cost of the storage. We then discuss the additional values that storage can receive beyond the bulk system that, depending on where the storage is located, could cover the funding gap.

- In a conventional least-cost planning regime, reflected by the 2010 IRP scenario that meets growth through additional coal and nuclear capacity, the dominant initial use of energy storage is to improve the efficiency of providing instantaneous reserves, combined with some energy arbitrage. Even so, we find a funding gap of approximately R1,100/kWh in the 2010 IRP scenario before storage is built, relative to the low-cost storage cost projections for Li-ion in 2030. The requirement for instantaneous reserves amounts to 800 MW off peak and 500 MW on peak according to Eskom estimates of reserves through 2021. Depending on the ability of pumped hydro resources to provide this service, the actual instantaneous reserve opportunity for other types of storage will be far less than the Eskom requirements. If pumped storage can provide all instantaneous reserves, other forms of storage are not economically justifiable at a R1100/kWh funding gap based on bulk system benefits.
- The value of storage under IRP resource procurement scenarios is restricted to operating benefits on the bulk system if the IRP resource capacity plan is not modified downward to accommodate storage. We therefore analyze an alternative to the Rooftop PV scenario that allows storage to avoid capital investment. In this case, the funding gap is significantly reduced R297/kWh relative to the low cost storage cost projections for Li-ion in 2030. Although this does not justify storage investment on the merits of bulk system use cases alone, additional benefits realized by storage at the distribution level may be enough in some circumstances to trigger cost-effective storage.
- At the bulk system level, storage competes against traditional generating resources and curtailment of renewables in the determination of cost-effective procurement and operations. The renewable penetration is low in the 2010 IRP case at approximately 11.5% of load in 2030, and only about 25% of load in the Rooftop PV case. This is significantly lower than renewable penetrations on other systems where models predict economic storage procurement on the bulk system. One planning benefit for storage that is currently not available in South Africa is the avoidance of renewable overbuild caused by curtailment under renewable portfolio standard (RPS) policies. The requirement of delivering renewable energy as sales under an RPS makes curtailment of renewables more expensive because for every megawatt-hour curtailed, another megawatt-hour from another renewable resource must take its place. If in the future South Africa transitions to an RPS policy and greater levels of renewable penetration, bulk system storage benefits will increase.
- To investigate whether, despite realizing no capacity benefits in the IRP scenarios, feasible system or policy conditions could trigger cost-effective storage procurement based on bulk system benefits, we look at several sensitivities. These include reduced renewable diversity, an RPS constraint, uncurtailable renewables, a more inflexible coal fleet, and a greater efficiency loss related to the coal fleet offering instantaneous reserves. We find that economic storage is selected in none of these cases. However, these conditions would

increase the bulk system benefits for storage, lowering the funding gap and the benefits that storage requires from other nonbulk system use cases to fill it.

- In areas with local capacity constraints, the capacity value for energy storage can be significantly higher and can be sufficient to make storage cost effective in select cases. In other words, the funding gap for storage, based on system benefits alone, may be covered by the benefits of avoiding having to invest in grid transmission and distribution infrastructure.
- The funding gap can also be reduced by stacking customer-sided and utility-sided benefits with behind-the-meter storage allowing for some utility dispatch. Bill savings for the customer are not a total resource cost (TRC) benefit. Nevertheless, customers are willing to pay for reliability benefits and bill savings provided by storage, thus reducing the cost that must be paid by the utility. If sufficient system and transmission and distribution (T&D) capacity benefits are realized with utility dispatch of behind-the-meter (BTM) storage, net benefits for the utility and its ratepayers can be achieved.

In all future scenarios, we quantify the funding gap as the difference between the projected cost of storage in the future and the cost at which the various levels of storage would be economically deployed. The funding gap can be closed through a combination of lower storage costs and increased value. The primary approach to increasing value is the use of distributed energy storage technology to capture additional local benefits. In certain situations, the higher value of distributed energy storage systems can outweigh the somewhat higher cost of these technologies. Capturing the value streams of system renewable integration and local benefits does face some barriers. Some local benefits require the storage to be used in such a way that it is not available to provide system benefits. These incompatibilities are identified. In addition, capturing local benefits requires reforming the distribution utility planning and operations to reduce capital investment to account for capabilities of storage and then dispatch storage appropriately. Finally, customer-located storage will also require development of a business model for storage that aligns the operations of customer-owned storage with the value to the grid.

1.4 Key Recommendations

Key recommendations are as follows:

- Reform the IRP planning process to consider storage as an alternative resource to thermal generation. The IRP should factor in the additional benefits of storage from distribution and customer levels of the system and consider the customer-level adoption of storage if bulk system-level and distribution-level benefits were available to customers. Consider all grid resources on a level playing field to ensure least cost procurement.
- Develop market products for bulk system services that storage can provide. By developing markets to procure grid services such as energy, capacity, and ancillary services, third-party storage owners can participate efficiently in optimal system dispatch. This is important for

local and distributed resources with additional use cases that may be stackable, and whose participation depends on the tradeoffs between use case value in each moment.

- Study the locations on the grid where storage can realize the highest value stacked benefits. These include locations on the distribution system where storage can defer expensive capital upgrades.
- Develop business cases for distributed storage so that the grid can realize the highest value from customers that install storage.

2 Bulk System Value of Energy Storage

2.1 Energy Storage Technologies

The energy storage technologies considered in the overall study were presented in Objective 2.1. Costs for mature energy storage technologies currently being deployed for commercial utility-scale energy storage systems can be reasonably determined through industry studies and reports. Significantly less data is available for younger, less mature, developing technologies that are not yet being manufactured commercially. Costs for energy technologies will tend to follow a general learning curve with a slope specific to that technology. In addition, typical cost breakdowns can be assumed for different portions of the energy storage system (ESS) as discussed in Section 2.1.2.

For the purposes of the economic assessment, the technologies considered were limited to generic Li-ion and flow battery technologies priced using the storage resources listed below. This section presents the model performance parameters and costs. The battery technology costs are presented in dollars in this section but are converted to rand for the study results using an exchange rate of R15 per dollar.

2.1.1 Learning Curve

The cost for a product will decrease over time with accumulated experience in its design and production. This can be expressed as a learning curve in which each time the cumulative production doubles, cost declines by a fixed percentage. When expressed on a logarithmic scale, this slope appears to be linear. The slope of the curve is specific to a manufacturer and is determined by many factors [0396]:

- Management styles and actions
- Corporate culture
- Organization structure
- Technology
- Capital investment
- Engineering

The learning curve is extremely important to emerging storage technology providers. An emerging technology or product that is still immature with regard to design and/or production will experience a large degree of cost reduction early in life (a low number of cumulative units produced) because the doubling phenomena occurs more frequently. Later in life when a product is more mature, it takes a significantly larger number of production units to double the cumulative number and therefore learning occurs more slowly. This means that over time, with a constant production rate, the opportunity for additional cost savings is gradually reduced. This has several important ramifications:

- Through aggressive marketing, an early innovator may capture a larger market share earlier and can therefore produce more units than a competitor with a small market share. This allows the innovator to achieve lower costs and introduce product improvements by advancing faster down the learning curve.
- A mature product will have to produce more units to achieve the same cost reductions as a less mature product because much of the available learning has been achieved.
- A producer with a low production rate (mature or less-mature product) will achieve cost reductions more slowly.

New products in any industry may experience a rapid expansion as decreasing costs increase the number of economically competitive applications which, in turn, increases sales, generates higher production, and thus allows for further cost reduction. This cyclical trend is illustrated in Figure 2-1 and explains the current trends in the energy storage industry: increasing rechargeable battery production driven by the small appliance and electric vehicle markets has resulted in lowering battery pack costs and opened up the stationary residential, industry and utility-scale energy storage markets to the battery manufacturers.

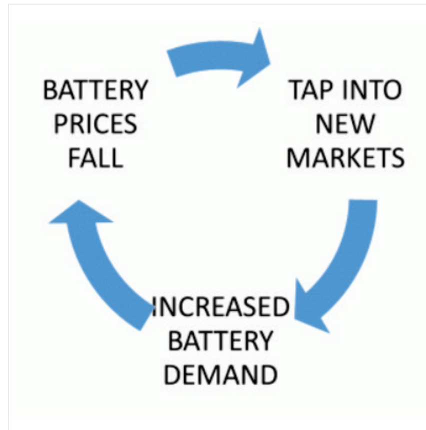

Figure 2-1: Lowering Cost Accelerates Market Expansion [0394]

This effect is most visible in the Li-ion industry: manufacturers have built significant manufacturing facilities, giving them considerable advantages in the ability to meet large-volume orders and use economies of scale in order to reduce prices [0397]. Figure 2-2, which is based on data from a recent International Renewable Energy Agency (IRENA) study [0079], shows that Li-ion and flow batteries have shown a steeper learning curve through cost reductions achieved through increased production rates and increasingly more efficient manufacturing processes. Advanced lead acid and sodium sulfur, which are more mature technologies with more limited opportunities for market growth, are predicted to have more modest cost reductions over the next 5 years. The IRENA data has been manually extrapolated to 2030.

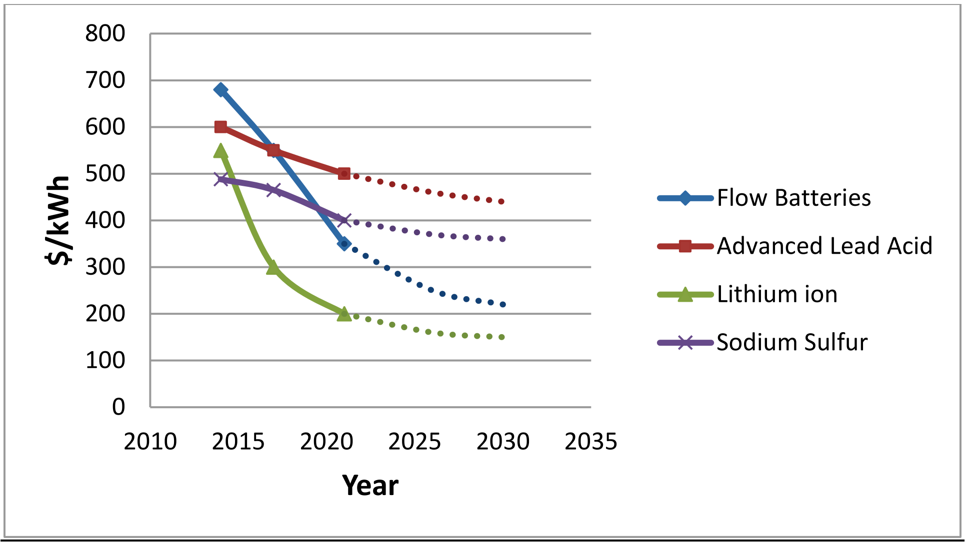

Figure 2-2: Generalized Future Storage Costs by Technology (original data from [0079])

Although it is clear that both Li-ion and flow battery costs will likely soon drop below the more mature technologies, it is uncertain whether flow batteries will be able to achieve mature initial costs as low as Li-ion. In a levelized cost of storage comparison, however, flow batteries may compensate for this difference based on higher cycle life of the system.

2.1.1.1 Lithium Ion

Li-ion battery system experts report that the installed costs of Li-ion battery systems are now in the $350–$700/kWh range for energy applications (or nominally $1,000–$2,000/kW), while one system supplier claims $250/kWh [0231]. Li-ion battery manufacturers have benefitted from research and development (R&D) and innovation driven by the rapidly emerging electric vehicle market and have significantly improved performance and cost over the last decade. Cost reductions have been evaluated over the past decade and predicted with increasing accuracy over the next 15 years. Figure 2-3 [0395] shows a consolidated summary of recent cost reduction predictions for electric vehicle battery packs from more than 80 sources reported between 2007 and 2014 and includes future cost estimates through 2030. This study concluded that cost reductions following a cumulative doubling of production was found to be between 6% and 9%.

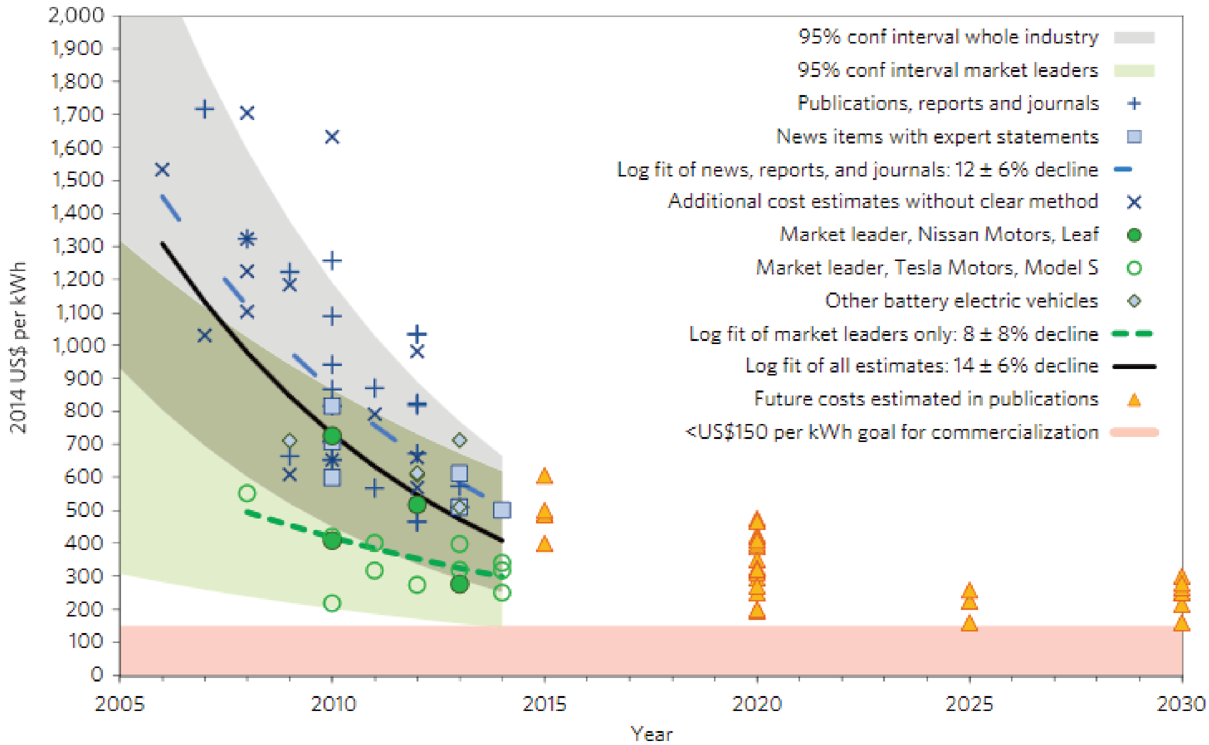

Figure 2-3: Cost of Li-ion Battery Packs in Electric Vehicles [0395]

2.1.1.2 Flow Batteries

Flow batteries are at the cusp of substantial market penetration similar to what Li-ion has enjoyed for the past 10 years. Flow Batteries can operate for 10,000 cycles or more. In addition, the electrolyte in a flow battery is a liquid that can be replaced, refurbishing the battery at a fraction of the cost of installing a new one [0394]. Many flow battery companies have invested significant equity into R&D and the development of high capacity production technologies necessary to produce high performing and cost competitive products. Several manufacturers are bringing products to the market that may challenge both Li-ion and NaS batteries in the longer duration (high-energy) applications. There are many competing flow battery technologies and while the characteristics of a specific technology may contribute to its overall success, an equal and perhaps greater factor may be the degree to which an innovator can get its product to market, generate sales, and advance along the learning curve. The future of flow batteries will be determined based on the success of their initial product deployments and their ability to stimulate sufficient sales to support cost effective (and improving) manufacturing processes. Because flow batteries last for so many more cycles, the levelized cost of storage is likely to overcome their generally slightly smaller round trip efficiencies.

2.1.1.3 NiCad, Nickel Metal Hydride, NaS

Performance and manufacturing limitations associated with NiCad, nickel metal hydride, and sodium sulfur (NaS) technologies may preclude their ability to compete in the large-scale stationary energy storage market. The Li-ion battery has already overcome NiCad in the large scale stationary or vehicle market; NiCad can no longer compete with Li-ion's lower weight, high performance, and lowering costs. This is similarly true for nickel metal hydride (Zebra) batteries for which sales have stalled and the market has collapsed except for specialized niche applications. NaS batteries are also increasingly challenged by Li-ion systems and by the potentially emerging flow battery technologies, although advancements in lower temperature NaS designs have been predicted. These generally mature technologies will have difficulty reducing costs particularly with declining market share.

2.1.1.4 Mechanical Flywheel

Mechanical flywheel technology provides a very fast and efficient energy storage medium for shorter duration (high power/lower energy) applications. Leading flywheel manufacturer Beacon Power achieved market penetration with the deployment of two utility-scale commercial systems. Higher manufacturing costs and questions concerning long-term reliability have prevented these flywheels from generating continued sales which, in turn, has stalled production and the innovation necessary to achieve further performance improvements and additional costs reductions. Many of the applications previously attractive for flywheels may be more efficiently addressed with advanced lead-acid, Li-ion, supercapacitors, or hybrid systems that combine several of these technologies. As a result, a learning curve or future pricing cannot be predicted for flywheels. It is uncertain whether flywheels have a strong future in utility-scale energy storage, but if so, it is likely 5 to 10 years in the future and only with substantial investment.

2.1.1.5 Compressed Air and Liquid Air

Like flow batteries, compressed air energy storage (CAES) and liquid air energy storage (LAES) use physical components that are rated for 10,000+ cycles of compression and decompression. A utility-scale cavern-type CAES facility has not been built for several decades; however, R&D for advanced compression and expansion equipment has continued. Several companies are developing and offering smaller systems with tank storage. Costs for these technologies are likely competitive with Li-ion costs over the long term and at similar scale, although system costs or potential cost reductions over time are difficult to predict until more projects have been completed.

2.1.1.6 Metal Air and Liquid Metal

Metal air and liquid metal technologies could offer high performance and long service life at significant cost reductions; however, both are insufficiently mature to predict future costs or the degree of a learning curve.

2.1.2 Components of Total Cost

As discussed in Objective 2, Task 2.1, the best criteria for selection of a storage technology for a given application is the levelized cost of storage (LCOS). As seen in Larard's analysis [0152], LCOE must be calculated for each specific project considering the specific technology and use case.

2.1.2.1 Energy Storage System Costs

Initial capital costs for energy storage systems (ESSs) can generally be divided into four general categories:

- Storage system
- Power conversion system
- Power control system
- Balance of plant (BOP)

Although not all technologies fit neatly into these categories, Figure 2-4 shows a generalized cost breakdown for a Li-ion ESS.

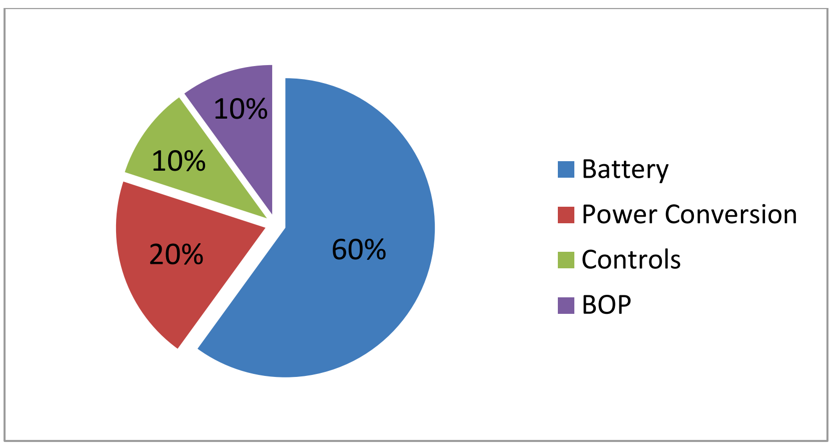

Figure 2-4: Li-ion ESS Costs by Component [0231]

2.1.2.1.1 Storage System

The storage system is the 'energy reservoir' that retains the potential energy within a storage device. It includes chemical potential energy (batteries), electrical potential energy (supercapacitors) and mechanical potential energy (CAES or PHS). Generally, the storage system includes the equipment to convert from direct current (DC) electrical power to potential energy, including battery a management system that monitors and controls the storage system and integrates with power conversion and control (PCCS) and BOP systems. A Li-ion battery storage system might represent 60% of the ESS cost; for a flow battery, this percentage would be higher [0231].

2.1.2.1.2 Power Conversion and Control System

A power conversion system consists primarily of an inverter that converts alternating current (AC) electrical power to DC power during system charging and then back to AC power when the system is discharged (except for systems such as PHS or CAES that can convert directly from AC to potential energy). The power control system monitors both the power conversion and battery management systems and coordinates with the grid or electrical system to which it is attached. Control systems supplying multiple stacked services can require significantly more complex architectures and algorithms. The PCCS may represent 30% to 50% of the ESS cost; the more complex control systems push the cost to the higher end of the range.

2.1.2.1.3 Balance of Plant

Balance of plant (BOP) includes the equipment necessary to house the storage and PCCS equipment, any HVAC or battery cooling systems necessary to control the storage facility environment, and the electrical connection between the basic connection between the PCCS and the power grid.

2.1.2.2 Overall Capital Expenditure Costs

The installed battery system capital costs for a straightforward Li-ion ESS can account for 70 to 80% of total capital expenditure (CAPEX); however, this can vary widely based on the specifics of the project. The following can add significantly to the overall CAPEX:

- **Land:** If the project is not sited on the owners' existing property, costs to purchase or lease property can be significant.
- **Structures**: Is the ESS containerized in factory-constructed units or will purpose-built structures be required, involving more field integration, field testing, and civil costs which will increased CAPEX cost.
- **Permitting and engineering costs:** The larger and more complex the system, the greater the costs for facility permitting, facility engineering, engineering oversight, and environmental impact analysis. A simple modular battery system may account for 4% or less of CAPEX; field-erected power equipment could account for as much as 8% [0231].
- **Grid Intertie:** The ESS may be installed either behind or in front of the meter. It may be installed into transmission or distribution lines. Finally, the intertie may require a substantial power line extension, the installation or expansion of a substation, and necessary grid protection equipment. Recent evaluations show that the intertie costs could be 5% to 50% of the overall system CAPEX.

2.1.2.3 Operational Expenditure Cost Factors

In evaluating the LCOS for a proposed ESS, consideration should be given to major operational expenditure (OPEX) costs that can significantly influence the long-term storage costs based on the selected storage technology.

- **Component replacement** includes cell replacement for advanced lead acid or Li-ion batteries. The life of these cells depends on the number of cycles and the depth to which the cell is discharged. For flow batteries, it may include replacement of the reaction cell membrane, replacement of the reaction stack, or adjustment of the electrolyte chemical concentrations. Mechanical systems such as compressors, turbines, refrigeration, and pumps may also require replacement or overhaul within the useful life of the ESS.

  For many of the technologies coming on the market, there is insufficient data to reliably predict replacement cycles. Although bench scale or pilot systems may indicate long-term performance results, it cannot be assumed that these results will be replicated in full-scale production systems operating under actual field conditions. Some projects build replacement costs into the capital structure with a warranty or long-term service agreement (LTSA) with the vendor. Another approach is to oversize the battery capacity in the original design so that it still meets the design capacity at the end of life. In general, however, it is more expensive to purchase an oversized battery than to purchase the battery supplier's warranty.
- **Inverter replacement rate.** The life of an inverter depends on both on-off cycling and thermal management issues. Depending on how often the battery is cycled, experience from the solar PV business suggests that a 10% annual replacement rate following year 10 is appropriate [0231]. Some inverters can be purchased with extended warranties.
- **Controls upgrade and replacement.** Control equipment (including digital software and automation hardware and software) generally requires replacement within the life of a 20-year facility. When considering technological advances, software and hardware may require two replacements within the life of the facility. Historically, the instrumentation, controls, and automation equipment have been responsible for a large share of unreliability and unavailability at peaking gas-fired plants, which must also respond quickly to electricity grid disturbances.
- **Annual operating costs.** Because battery facilities are designed for remote, unattended operation, the fixed and variable operating costs are relatively low. However, initial systems for utilities will likely include some labor and staff until an appropriate comfort level is established.

2.1.2.4 Decommissioning and Disposal

Although not part of initial facility cost, decommissioning and disposal (D&D) costs at end of life should be considered and factored into any facility financial model. These cost also vary by technology and chemical/materials involved. Some materials (acids, lead, bromine, chromium) may pose environmental hazards; others (lead, vanadium) may have economic value. Unlike lead acid, Li-ion batteries suffer from a weak recycling and repurposing infrastructure. Disposal costs tend increase with system size. California utilities evaluating storage have used figures ranging from 8% to 15% of original CAPEX costs for D&D [0231]. D&D costs should be understood and should be included in the total cost to own and to operate the facility.

2.1.2.5 Power vs. Energy Capacity

Many energy storage systems allow the power (MW) capacity of an ESS to be sized independently from the energy (MWh) capacity. In these cases, the costs related to each component may vary considerably. Table 2-1 compares the likely differences across major storage technologies and shows that some favor power applications (e.g., flywheels and supercapacitors) while others favor energy applications (PHS, CAES).

Table 2-1: Energy Storage Cost Assumptions by Technology [0079] (current as of 2010)

Technology	Power Subsystem ($/kW)	Energy Storage Subsystem ($/kWh)
Advanced lead acid	400	330
Sodium sulfur	350	350
Flow battery, Zn-Br	400	400
Flow battery, vanadium	400	600
Li-ion	400	600
Flywheels	600	1,600
Supercapacitors	500	10,000
Compressed air energy storage (CAES), cavern	700	5
Pumped hydroelectric storage (PHS	1,200	75

2.1.3 Storage Cost Projections

The costs presented in this section are derived from a survey of the literature and define the mid-price case in this study. As shown in the following subsection, both a high and low price case were also developed, but neither scenario was low enough to trigger investment in storage in our three cases based on bulk system benefits alone. We show the funding gap that would have to be covered between the storage cost that produces economic selection at the various levels of storage adoption and the mid-price scenario cost of storage.

Energy storage cost and performance inputs are based on a review of the literature and projections from the following manufacturers and developers:

- Lazard's Levelized Cost of Storage Analysis – version 1.0 (Lazard, 2015) [0152].
- DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA (Sandia National Laboratories, 2013) [0235].

- Electrical energy storage systems: A comparative life cycle cost analysis (Zakery and Syri, Renewable and Sustainable Energy Reviews 2015) [0361].
- Rapidly falling costs of battery packs and electric vehicles (Nykvist and Nilsson, Nature Climate Change 2015) [0362]
- Tesla Powerwall webpage (Last visited March 2016) [0363].
- Capital Cost Review of Power Generation Technologies; Recommendations for WECC's 10- and 20-year studies (E3, 2014); only used for pumped hydro [0388].

Capital investment and operations and maintenance (O&M) costs are annualized using E3's Pro Forma tool. Table 2-2 lists the battery performance inputs going into the Pro Forma tool; Table 2-3 shows the battery cost inputs.

For Li-ion and flow batteries, an additional 15% is added to the capital costs shown in Table 2-3 to take into account the engineering, procurement, and construction (EPC) costs and the interconnection. The final costs with this additional 15% represent the total costs for an installed system. E3 modeled replacement of the Li-ion battery pack in Year 8 and replacement of the flow battery and Li-ion battery power conversion system in Year 10. Replacement costs are assumed to be equal to the capital costs of the replacement item in the year of replacement (not including the 15% adder).

Table 2-2: Energy Storage Performance Characteristics by Technology

Technology	Charging & Discharging Efficiency	Financing Lifetime (yr)	Replacement (yr)	Minimum Duration (hr)
Li-ion Battery	92%	16	8	0
Flow Battery	84%	20	N/A	0
Note: An inverter replacement at year 10 is also assumed for Li-ion batteries and flow batteries.				

Table 2-3: Energy Storage Cost Assumptions by Technology

Type	Cost Metric	2015	2030
Li-ion Battery	Storage Cost ($/kWh)	375	183
	Power Conversion System Cost ($/kW)	300	204
	Fixed O&M Battery/Reservoir ($/kWh-yr)	7.5	3.7
	Fixed O&M PCS ($/kW-yr)	6.0	4.1
Flow Battery	Storage Cost ($/kWh)	700	315
	Power Conversion System Cost ($/kW)	300	204
	Fixed O&M Battery/Reservoir ($/kWh-yr)	14.0	6.3
	Fixed O&M PCS ($/kW-yr)	6.0	4.1

The E3 Pro Forma tool converts these inputs into an annualized cost shown in Table 2-4. The RESOLVE model can select both the size and duration of economic storage. To approximate the pricing of storage technologies in the model, the power and energy components of the price are separated. Table 2-3 shows both the annualized cost of the power conversion system ($/kW-yr) of the device and the annualized cost of the energy storage capacity or reservoir size ($/kWh-yr). Both numbers are additive. This annualized cost is the full cost of owning and operating the system, including O&M and replacement costs.

Table 2-4: Energy Storage Annualized Cost (USD) by Power and Energy Component

Technology	2015 Annualized Cost		2030 Annualized Cost	
	Capacity/Reservoir ($/kWh-yr)	Power Conversion System ($/kW-yr)	Capacity/Reservoir ($/kWh-yr)	Power Conversion System ($/kW-yr)
Li-ion Battery	85	69	40	46
Flow Battery	118	58	53	39

The cost and performance assumptions above represent the base case ('Mid') scenario. Because storage costs are uncertain and are changing rapidly, E3 developed a low and high scenario to encompass the wide range of possible storage costs. These were developed from the ranges of costs for the battery technologies presented in the storage cost sources listed at the beginning of this section. In addition to lower/higher costs, the replacement time for the Li-ion battery pack was changed to 6 years and 10 years in the low and high scenario, respectively, while replacement of the power conversion system was kept constant in all scenarios and for all technologies.[1] Table 2-5 shows the final RESOLVE inputs for these scenarios in rand. To determine the range of costs at which storage would become cost effective in the funding gap analysis, E3 progressively lowered the costs of the 'Li-ion Battery – Low' scenario.

Table 2-5: Annualized cost (Rand) Inputs for All Modeled Scenarios

Technology	2015 Annualized Cost		2030 Annualized Cost	
	Capacity/Reservoir (R/kWh-yr)	Power Conversion System (R/kW-yr)	Capacity/Reservoir (R/kWh-yr)	Power Conversion System (R/kW-yr)
Li-ion Battery - Low	817	618	346	356
Flow Battery - Low	1,123	572	491	328
Li-ion Battery – Mid	1,277	1,034	596	687
Flow Battery – Mid	1,765	873	795	580
Li-ion Battery – High	2,640	1,603	1,451	1,435
Flow Battery – High	2,780	1,189	1,590	1,064

[1] E3 assumed that the flow battery's energy component has a 20-year lifetime and does not require replacement in any scenario.

2.2 Resolve Optimal Investment Model

Planning the development of a high renewable penetration electric energy system presents a number of challenges. The plan must choose a portfolio of varied resources that work in concert to reliably meet consumer electricity demand while accommodating the variability of renewable energy resources. For every hour of the planning horizon, the system must satisfy several operational constraints including reliability needs, e.g., minimum generating levels, ramping constraints, contractual obligations, and reserve requirements. Figure 2-5 shows a hypothetical day when generating resources must operate to meet the following constraints (circled numbers):

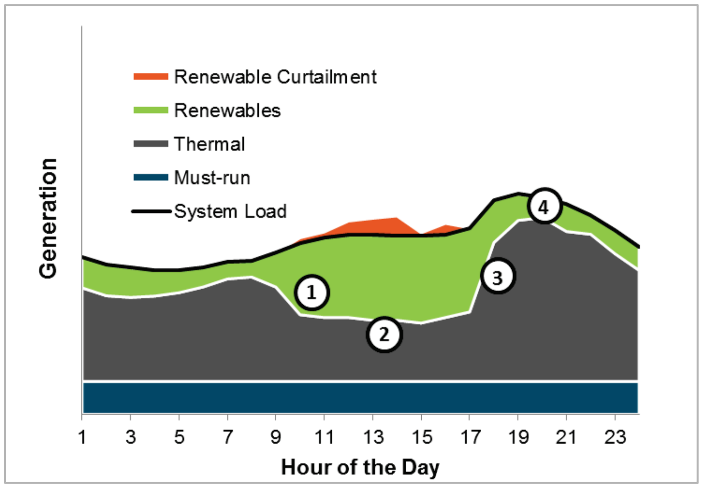

Figure 2-5: Power System Flexibility Constraints

1. **Downward ramping capability.** Ramp capability must be available to meet morning ramps as solar production increases and the net load drops.
2. **Minimum generation.** Resources must be capable of lowering their output sufficiently, either by turning off generation or ramping down output, so that low mid-day net loads are balanced while reliability requirements are still met.
3. **Upward ramping capability.** Ramp capability must be available to meet capacity needs as solar production falls in the evening.
4. **Peaking capability.** Peak loads must be met, often after solar generation has dropped off.
5. **Reserves.** A fifth category not shown on the chart is the need to hold reserves to cover forecast error and contingencies.

As renewable generation increases on the system, the types of integration solution that can be used to integrate them expands. These include conventional generation, flexible loads, storage, renewable diversity, expanded transmission, and new market products and energy policy. Many combinations of resources can be included in the resource portfolio to meet reliability needs; therefore, the least cost portfolio is best determined through an optimization framework.

The lowest cost portfolio of renewables and integration solutions at any point in time will be a mix of resources that minimizes both operating costs and capacity expenditures over the planning horizon. The value of each integration solution will change over time depending on the evolving needs of the system. Those selected in an optimal resource portfolio will offer the greatest net value over their lifetime in combination with the other resources selected. Some technologies may be stepping stones to longer term portfolios. Figure 2-6 depicts an optimal tradeoff between renewable overbuilding and other integration solutions in meeting a renewable sales target. The optimal point for each resource will be where the benefit of the marginal unit of any resource to the system is equal to its marginal cost. In reality, each type of resource adds a dimension to the optimization and each combination of resources will have complex operational interactions. Finding the least cost solution requires a sophisticated optimization model that treats operational and investment costs while satisfying operational and reliability constraints.

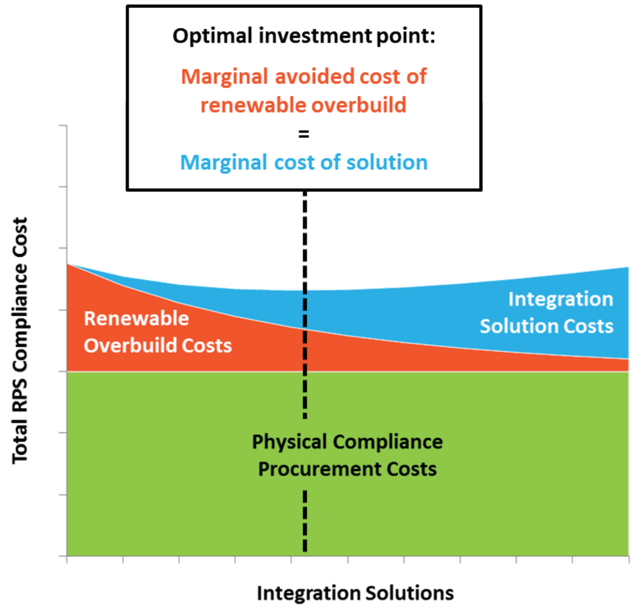

Figure 2-6: Tradeoff between Integration Solutions – How to Find the Least Cost Portfolio

E3's Renewable Energy Solutions model (RESOLVE) is an optimal investment and operational model designed to inform long-term planning questions around renewables integration in systems with growing penetration levels of renewable energy. RESOLVE co-optimizes investment and dispatch over a multiyear horizon with 1-hour dispatch resolution for a study area — in this case, the South African electricity grid. RESOLVE solves for the optimal investments in renewable resources; various energy storage technologies; and new coal, gas, and nuclear plants subject to various different constraints on the system. These can include annual constraints on delivered renewable energy that reflects a renewable portfolio standard (RPS) policy, a capacity adequacy constraint to maintain reliability, constraints on operations that are based on a linearized version of the classic zonal unit commitment problem, and customized constraints by scenario or sensitivity, such as modeling the efficiency loss of the coal fleet when offering instantaneous reserves.

We use the RESOLVE model in this study to investigate sets of potential future conditions in the South African system and their favorability for storage as an economic resource in offering grid services. The grid services that storage can offer are discussed in the use case section Object 2, Task 2.1 . RESOLVE finds the optimal deployment of storage depending on its price point against other resources that can offer the same services. The grid services considered within the RESOLVE framework are listed in Table 2-6.

Table 2-6: Grid Services That Storage Can Offer in RESOLVE

Use Case	Description
• Bulk Energy Services	• Energy arbitrage • Peaking capability
• Ancillary Services	• Instantaneous reserves • Regulating • 10-minute

Appendix A presents a detailed description of the RESOLVE model and the assumptions used.

2.3 CASES

Our analysis looks at three potential future IRP cases agreed upon by the study steering committee:

- 2010 IRP base case [0004]
- Updated 2010 IRP base case [0005]
- Updated 2010 IRP Rooftop PV case [0005].

The assumptions for each case are listed in Table 2-7.

Table 2-7: Cases Modeled in the Analysis

Input	2010 IRP Base Case	Updated 2010 IRP Base Case	Updated 2010 IRP Rooftop PV
Load	2010 hourly IRP base case load forecasted out to 2030	Hourly adjusted greenshoots load forecasted out to 2030	Hourly adjusted greenshoots load forecasted out to 2030
Renewable generation data	CSIR REDZ and EIA scenario wind and solar production shapes	CSIR REDZ and EIA scenario wind and solar production shapes	CSIR REDZ and EIA scenario wind and solar production shapes
Forecasted renewable generation capacity	2010 IRP build out of renewables by 2030	2013 IRP update build out of renewables by 2030	2013 IRP update Rooftop PV case – additional 21,600 MW of rooftop PV by 2030
Generator fleet characteristics	2010 IRP generator fleet, including additions and retirements, out to 2030. Generic operating characteristics by technology	2013 IRP update generator fleet, including additions and retirements, out to 2030. Generic operating characteristics by technology	2013 IRP update generator fleet, including additions and retirements, out to 2030. Generic operating characteristics by technology
New generator characteristics	New generator operating constraints and costs from EPRI IRP report from 2012.	New generator operating constraints and costs from EPRI IRP report from 2012.	New generator operating constraints and costs from EPRI IRP report from 2012.

Input	2010 IRP Base Case	Updated 2010 IRP Base Case	Updated 2010 IRP Rooftop PV
Intertie characteristics	No interchange with surrounding countries is assumed; SA is treated as an island.	No interchange with surrounding countries is assumed; SA is treated as an island.	No interchange with surrounding countries is assumed; SA is treated as an island.
System ancillary service requirements	Using 2016/17–2020/21 Eskom projected ancillary services in 2021. Holding 2021 reserves constant through 2030.	Using 2016/17–2020/21 Eskom projected ancillary services in 2021. Holding 2021 reserves constant through 2030.	Using 2016/17-2020/21 Eskom projected ancillary services in 2021. Holding 2021 reserves constant through 2030.
Instantaneous reserves value	Assumes a 0.2% efficiency loss on coal generation offering instantaneous reserves. Assumed coal plants offer 3% capacity towards instantaneous reserves.	Assumes a 0.2% efficiency loss on coal generation offering instantaneous reserves. Assumed coal plants offer 3% capacity towards instantaneous reserves.	Assumes a 0.2% efficiency loss on coal generation offering instantaneous reserves. Assumed coal plants offer 3% capacity towards instantaneous reserves.
Fuel prices	Fuel prices from 2016 CSIR LCOE model.	Fuel prices from 2016 CSIR LCOE model.	Fuel prices from 2016 CSIR LCOE model.

CSIR = Council for Scientific and Industrial Research
EIA = environmental impact assessment
EPRI = Electric Power Research Institute
LCOE = levelized cost of energy
REDZ = Renewable Energy Development Zone
SA = South Africa

The RESOLVE model will select storage as an economic investment if the total cost of storage, including capital and operating losses, is less than the alternatives for offering the same services. The resources selected in the IRP and IRP Update are sufficient to operate the system reliably in accordance with the criteria defined in the IRP process. If all IRP planned resources are built through 2030, the benefits that storage can offer through different grid services are purely operational –investment in capital infrastructure cannot be avoided unless the IRP were re-evaluated with storage as a selectable resource.

To investigate the potentially higher benefits of storage when capital investment in other technologies can be avoided, we ran a fourth case in which the RESOLVE model can optimally select resources through 2030 to meet load while also building out the same renewable portfolio as the updated IRP Rooftop PV case. In this case, the selection of storage can displace the services offered by other new resources and potentially avoid investment in them.

2.4 RESULTS

The results show that regardless of which price evolution we assume for storage, no storage is built in any of the cases above with the base case assumptions. This is to be expected, given the relatively low penetration of renewable energy in each case, and the assumption that all IRP resources are constructed. The construction of the IRP resources ensures that the system can generate enough to meet the needs of the grid in each period investigated. Storage can therefore only reduce operating costs; it cannot avoid capital investment. Reduction of operating costs alone is not enough to justify storage investment when evaluating system use cases only. Storage selection in the RESOLVE model is based on bulk system benefits and does not factor in the potential local level benefits described in the introduction.

Even in the high Rooftop PV case, the total energy produced by renewables equates to about 25% of energy sales. This is roughly equivalent to current renewable energy sales in California — far lower than the penetrations of renewables where storage is forecasted to become an economic integration resource for the state [0391].

This is not to say that storage has no value to the South African grid. As shown in the funding gap analysis in the next section, storage becomes part of an optimal portfolio when the costs are reduced further, indicating that the benefits of storage are at least as high as the costs in those cases. We show the funding gap as the difference between the cost in each case and the mid-case Li-ion price or flow battery price at different levels of installed storage.

In the next section, we evaluate sensitivities that can increase the value of storage:

- Renewable generation as a must-take resource in the Rooftop PV case. In this scenario, renewables cannot be curtailed. This may be somewhat realistic from a controls perspective if the installed rooftop PV is outside the system operator's control.
- An RPS target is put in place in which a percentage of electricity sales must be from renewables. California starts to see costs that justify storage adoption when the RPS exceeds 50% in some scenarios [0391]. Hawaii starts to see meaningful economic storage adoption above 40% RPS [0389]. The South African system is significantly less flexible than California, so we investigate the effect of an RPS on storage adoption.
- The coal fleet is currently modeled using a minimum generation level of 60% and startup and shutdown times of 12 hours. The actual flexibility of the fleet is uncertain. We investigate increasing the minimum generation constraint on the coal fleet to 70% on storage adoption.
- A significant driver of storage value is increasing the efficiency of the coal fleet by displacing coal from offering instantaneous reserves. The base case assumption is that coal generators offering instantaneous reserves incur a 0.2% energy conversion efficiency loss. However, much of this opportunity is likely to be taken by pumped hydro. In the results, we present two bracketing cases: the first where battery storage receives all instantaneous reserve benefits, and the second where pumped hydro receives all of the benefits. We also investigate the value of storage when the instantaneous reserve efficiency loss of coal is increased to 0.5%.

For computational efficiency, we show the results of these sensitivities for Li-ion only. The similar pricing of flow batteries in our mid-price scenario means that we would see economic flow battery adoption at similar levels if adoption is triggered. None of our sensitivities generated economic adoption of storage.

The funding gap to reach economic storage adoption can be closed in three ways:

- The price of storage drops to levels at which adoption is economic at a system benefits level. This is unlikely given that the prices triggering storage in our analysis are lower than the low price scenario.
- System conditions are different from our base assumptions, or policy changes in the future to favor storage. We present an investigation of a limited set of these changes in the sensitivities results, however, none of them gave enough value to storage for economic adoption.
- Storage can realize other benefits not captured at the system level. These include local use cases that can only be realized with careful placement of the devices in high value areas.

Section 3 discusses the additional benefits that storage can realize when placed on the distribution system.

2.4.1 FUNDING GAP

The funding gap is the difference between the forecasted price in 2030 and the price at which storage adoption is triggered. We drop the price of storage until adoption of storage is triggered. The analysis is performed for the periods 2016, 2020, 2025, and 2030; however, we focus here on 2030 given that system conditions are most favorable for storage in 2030 and forecasted storage prices are lowest.

One significant driver of storage value was instantaneous reserves. The need for instantaneous reserves in South Africa varies by time of day between 500 MW and 800 MW. We have modeled the median 650 MW for simplicity. The recent addition of the Ingula pumped hydro facility brings total pumped hydro capacity to nearly 3,000 MW. It is unclear how much pumped hydro can contribute to instantaneous reserve, but it will displace some or all of the instantaneous reserve opportunity that other forms of storage could take advantage of. In the following funding gap results, we have bracketed this opportunity — first, by presenting results in which pumped hydro does not offer any instantaneous reserve, and second, by presenting the funding gap where the entire instantaneous reserve need is covered by pumped storage.

2.4.1.1 Funding Gap with Full Instantaneous Reserve Opportunity

Figure 2-7 shows the levels of adoption in three cases:

- The 2010 IRP case with distribution of renewable resources by REDZ
- The Rooftop PV using the REDZ distribution
- The Modified Rooftop PV case, i.e., the Rooftop PV case in which future resources do not adhere to the IRP but instead are selected by RESOLVE , allowing storage to defer capacity investments if economical.

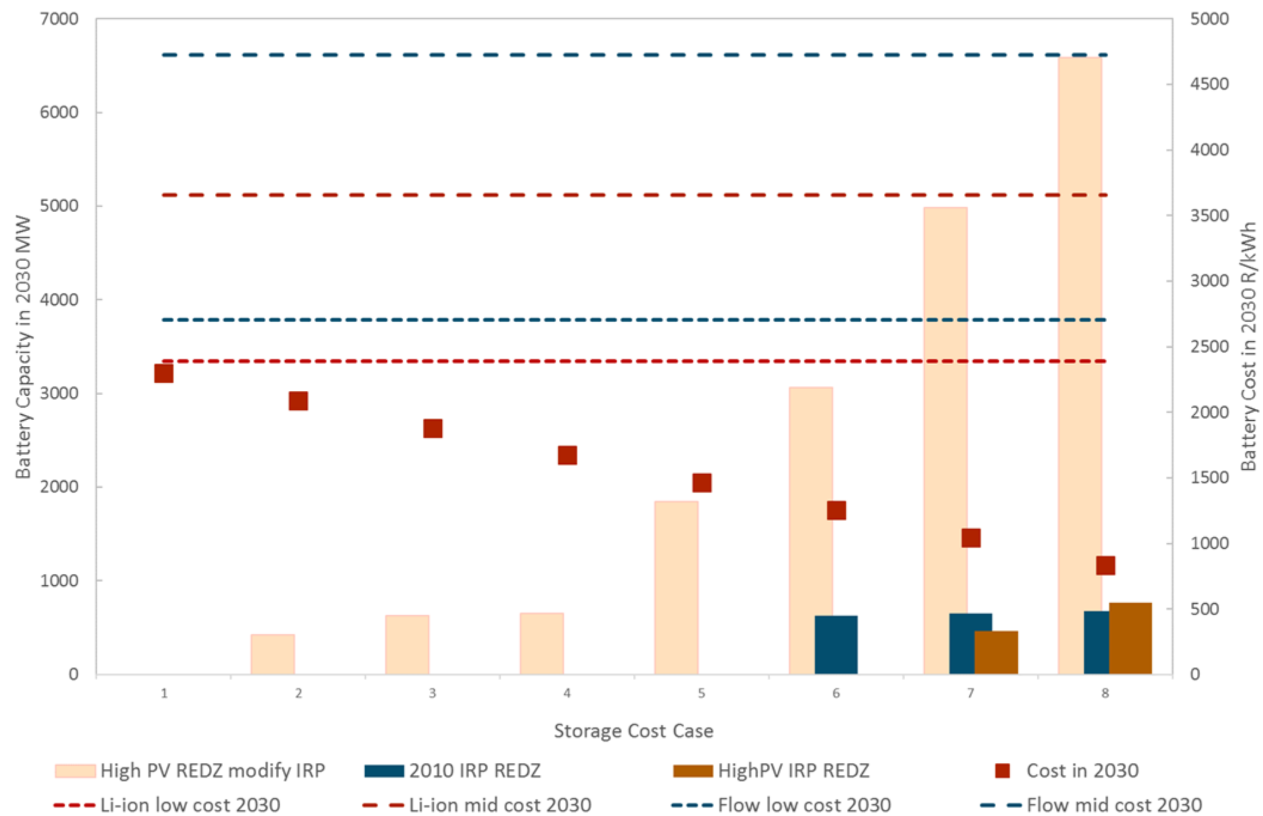

Figure 2-7: Funding Gap at Various Levels of Storage Penetration by Case

For each case, eight price points are investigated. For each level of storage adoption found by RESOLVE , these prices estimate the total value the storage developer can extract from system level use cases with the marginal megawatts of storage installed. The difference between the expected 2030 prices for storage and the modeled price is how much a developer would need beyond the bulk system benefits to invest, assuming they are paid for bulk system services. This value could come from incentives or from additional local value streams from use cases not captured in the system level analysis.

Table 2-8 summarizes the storage costs in Figure 2-7, translating the storage costs into a dollar cost per kilowatt-hour for reference. It also shows the funding gap. The payment required to cover the funding gap spread over the kWh sales results in the rate increases shown in the last column for each case, assuming that the amount of storage in each case above is installed and the funding gap is paid for by rate payers. The average rate increase is calculated assuming that the storage developer has a real Rand levelized power purchase agreement (PPA) over the lifetime of the storage device.

Table 2-8 shows a significant gap between the economic price of storage and the projected cost of storage for South Africa in 2030. From a system integration perspective, storage is not economical in the three cases studied at mid- or low-price storage projections. The case when storage is installed at the highest price point is the modified IRP where storage has the opportunity to avoid capital investments.

Table 2-8: Funding Gap in 2030

	Storage Cost in 2030		Funding Gap in 2030		Average Rate Increase R cents/kWh in 2030		
Case	R/kWh	$/kWh @15R/$	Mid Case R/kWh	Low Case R/kWh	2010 IRP	Rooftop PV	Modified IRP
1	2299	153	1,359	88	0.00	0.00	0.00
2	2090	139	1,568	297	0.00	0.00	0.22
3	1881	125	1,777	506	0.00	0.00	0.36
4	1672	111	1,986	715	0.00	0.00	0.40
5	1463	98	2,195	924	0.00	0.00	1.24
6	1254	84	2,404	1,133	0.45	0.00	2.25
7	1045	70	2,613	1,342	0.50	0.36	4.11
8	836	56	2,822	1,551	0.56	0.19	6.06

In all cases, optimal storage sizing for system level benefits is between 6 and 7 hours, when storage participates in system level use cases only. However, as described in Section 3, several potential local use cases of storage stack well with system level use cases when the storage device is located at the distribution system level. The potential benefits of the local use cases may be high enough in some locations to cover the funding gap. When sizing the battery for optimal operations across both system level and local level use cases, the battery sizing may be different. For example, local storage that can defer investment in distribution infrastructure may only be needed for that use case over a maximum 2-hour period. A battery optimized for both local and system level benefits may be sized smaller for this example.

The funding gap chart shows a few notable transitions as storage becomes cheaper. These are discussed below for the price points at which the storage changes use case.

2.4.1.1.1 Case 2 – Displacement of Coal in Offering Instantaneous Reserves

Case 2 is the first case in which storage adoption is seen in the model when RESOLVE is allowed to optimally pick resources. The amount of renewables and pumped storage in the rooftop PV case is maintained at the same level of additions as the updated IRP rooftop PV case. The RESOLVE model selects to build gas instead of coal or nuclear. This is subject to the pricing used in the model and other constraints on gas availability not captured here. However, storage is part of the optimal portfolio, with approximately 400 MW of storage being built. Battery additions are made in 2030. The case's resource selection is shown in Figure 2-8.

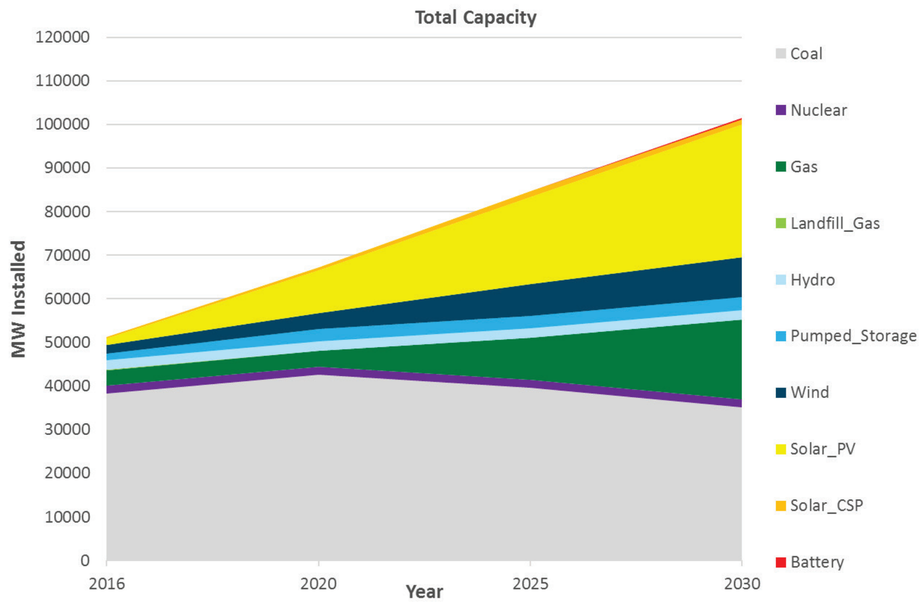

Figure 2-8: Funding Gap Case 2 Total Capacity 2016 to 2030

In Figure 2-9, retirements are shown on the negative axis in the textured areas. Figure 2-10 shows an example day's dispatch. Pumped hydro is used for energy arbitrage, pumping during high solar production in the middle of the day and discharging in the evening. However, pumped hydro is prevented from offering instantaneous reserves in these model runs. The cheap capital gas generation is used in the evenings to meet peak loads, thus reducing commitment and cycling of the coal fleet.

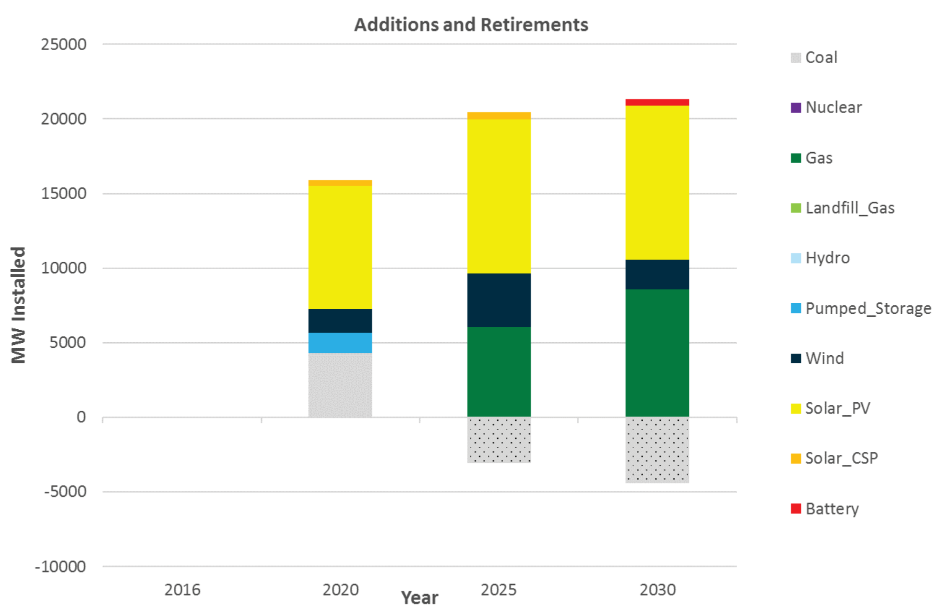

Figure 2-9: Additions and Retirements 2016 to 2030

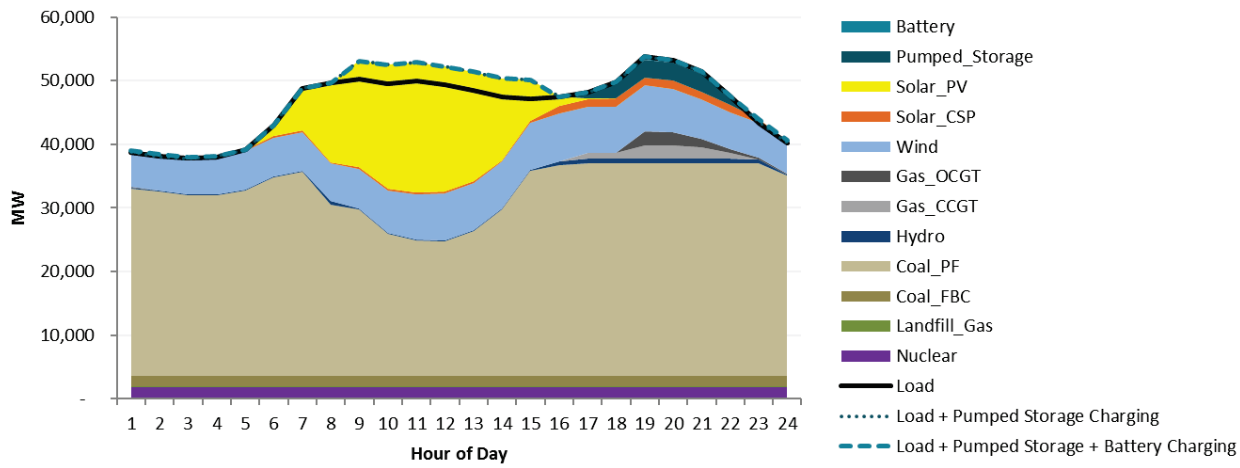

Figure 2-10: Case 2 Example Daily Dispatch

In Figure 2-10, the battery is so small that the charge and discharge cycle is not visible. Figure 2-11 shows the average battery behavior over all modeled days. Clearly, the predominant use case of the battery is to displace the coal fleet offering instantaneous reserves. In addition to offering reserves, the batteries are used to displace peak capacity in the morning and evening. Because this case allows resource selection, the battery realizes the value of avoided capital expenditure, thus batteries are built at a higher price point than in the IRP cases.

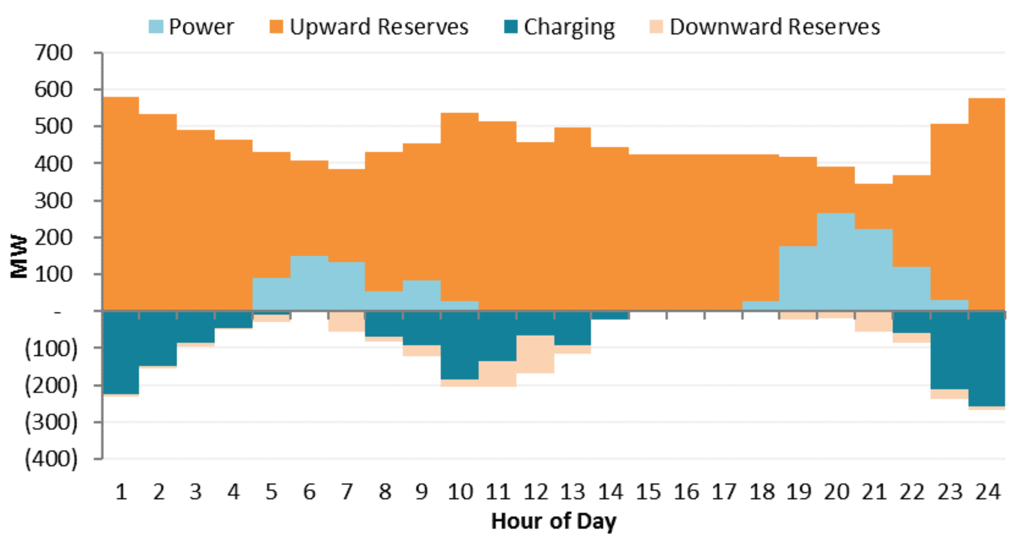

Figure 2-11: Case 2 Battery Storage Average Applications

In price point Cases 3 and 4, batteries offer a similar service to Case 2 in the modified IRP case. This is evident from the funding gap chart showin in Figure 2-7 in which the batteries built in these two cases are capped at 650 MW, which is the total market size for instantaneous reserves.

2.4.1.1.2 Case 6 – Storage Selection in IRP Case and Energy Arbitrage in Modified IRP

Similar to the Case 2 discussion above, Case 6 is the first time that storage is economically selected in the 2010 IRP case. It builds up to 650 MW in 2030 to displace coal offering instantaneous reserves, combined with energy arbitrage. Selection of storage for instantaneous reserves is at a lower price point for the 2010 IRP case because storage does not have the opportunity to displace capital investments; instead, benefits come from operating cost reductions of the thermal fleet only.

In the Modified IRP, the price point drops low enough that storage can compete with the costs of curtailing renewable resources. Curtailment in 2030 drops from 4.1% to 3.3% as economic energy arbitrage becomes a cost effective use case. The example daily dispatch (Figure 2-12) shows battery storage operating with pumped hydro to provide energy arbitrage and avoiding additional peak capacity.

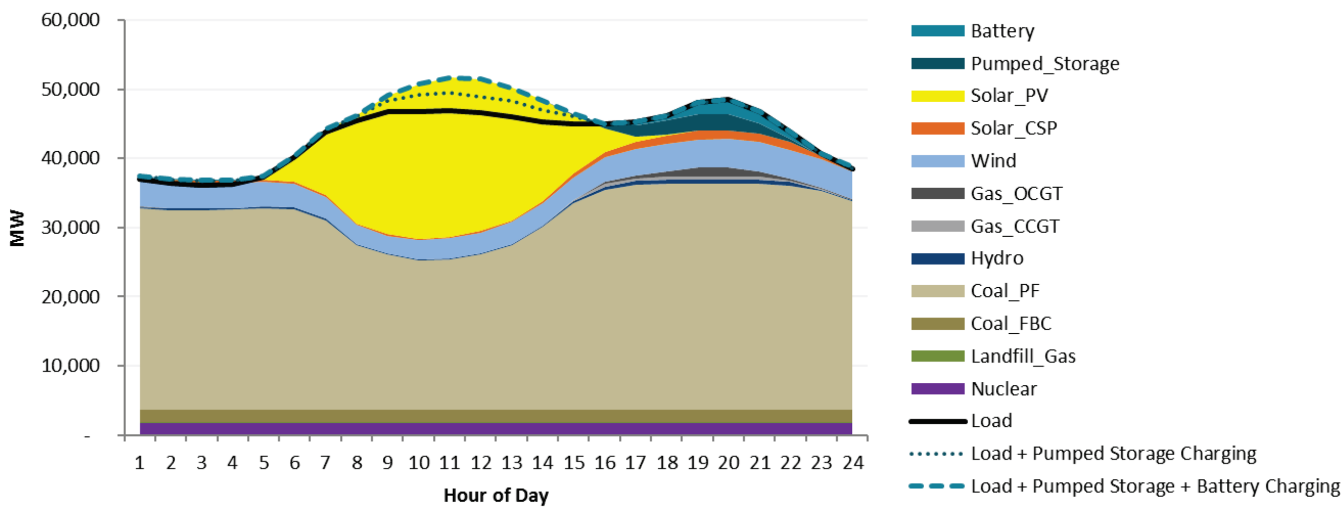

Figure 2-12: Case 6 Example Daily Dispatch

The storage average dispatch chart (Figure 2-13) shows that batteries are being used for both upward reserves and energy arbitrage. The higher amount of upward reserves, above the 650 MW of instantaneous reserves, shows that storage is also being used for regulating reserves.

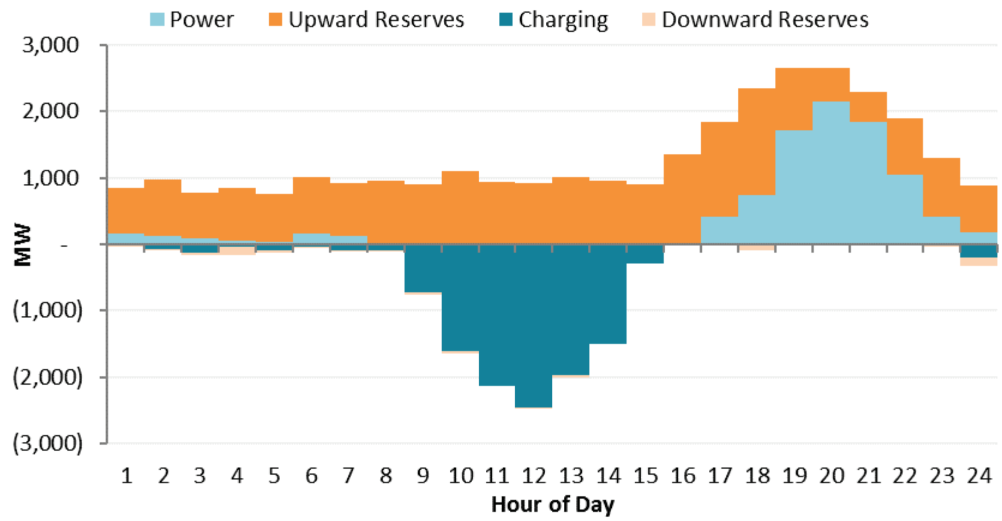

Figure 2-13: Case 6 Battery Storage Average Applications

2.4.1.2 Funding Gap without Instantaneous Reserve Opportunity

The same analysis as above is presented here for the case in which pumped hydro is assumed to be flexible enough to offer the entire instantaneous reserve need of the system. In this case, storage that was previously found to be economical at relatively small funding gaps is no longer selected by the model. The instantaneous reserve service that storage provides as its primary use case in the example in Section 2.4.1.1.1 is instead provided by pumped storage. Economic storage is not constructed until the price is dropped sufficiently to make the behavior described in Section 2.4.1.1.2 economical. Given the number of megawatts of pumped storage in South Africa, the opportunity to realize instantaneous reserve benefits for other forms of storage is likely to be significantly diminished, as shown in Figure 2-14.

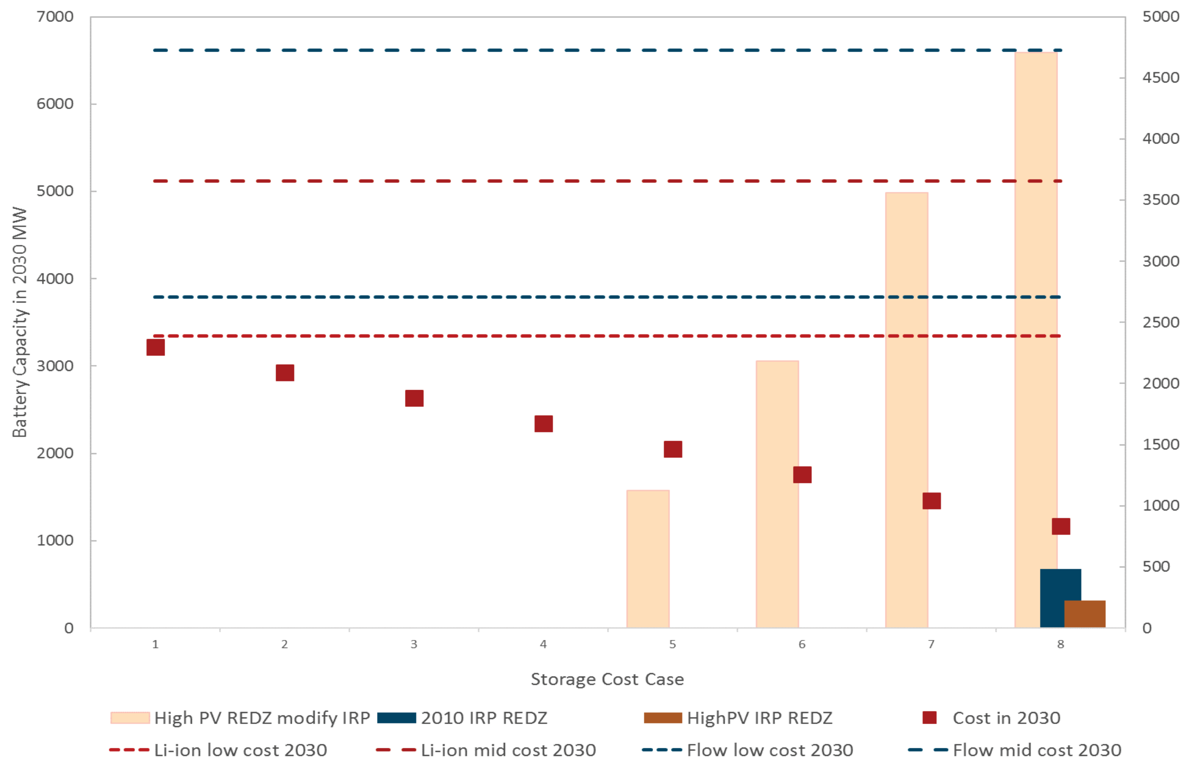

Figure 2-14: Funding Gap at Various levels of Storage Penetration by Case

Table 2-9 summarizes the storage costs in Figure 2-14, translating the storage costs into a dollar cost per kilowatt-hour for reference. It also shows the funding gap. The first price point at which storage becomes economical in the Modified IRP case is 5: storage can now competitively displace energy and capacity services. Again, the other two cases see very limited adoption of storage, showing that the cost effectiveness of storage depends on the ability to displace capacity investments in other types of generation. Economic storage is therefore best identified during the IRP process as a candidate for a least cost portfolio resource solution.

Table 2-9: Funding Gap in 2030

	Storage Cost in 2030		Funding Gap in 2030		Average Rate Increase R Cents/kWh in 2030		
Case	R/kWh	$/kWh @15R/$	Mid Case R/kWh	Low Case R/kWh	2010 IRP	Rooftop PV	Modified IRP
1	2,299	153	1,359	88	0.00	0.00	0.00
2	2,090	139	1,568	297	0.00	0.00	0.00
3	1,881	125	1,777	506	0.00	0.00	0.00
4	1,672	111	1,986	715	0.00	0.00	0.00
5	1,463	98	2,195	924	0.00	0.00	1.05
6	1,254	84	2,404	1,133	0.00	0.00	2.25
7	1,045	70	2,613	1,342	0.00	0.00	4.11
8	836	56	2,822	1,551	0.56	0.07	6.00

2.4.2 Sensitivities

As the above funding gap analysis shows, storage in the IRP scenarios has little bulk system energy value compared to its cost. This is in part due to the inability of storage to displace capital investment in the IRP scenarios. In the following set of sensitivities, we investigate renewable or policy conditions in 2030 that could result in cost-effective bulk storage adoption. The following results were found to be true in both instantaneous reserve sensitivity cases.

2.4.2.1 Less Geographically Diverse Renewable Resources

In addition to REDZ distribution of renewables, we investigated whether renewables clustered by existing environmental impact assessments (EIAs) would affect the need for storage. The reduced geographic diversity increases the intermittency in the hourly renewable production time series. The result is greater forecast error and potentially larger system ramps. The former is captured through increased reserve requirements; however, data was not available to estimate the impact of less diversity on reserves. We modeled the potentially larger ramps by using the EIA shape in each IRP case and again found no storage adoption at the high, medium, or low price projections.

2.4.2.2 RPS Constraint

Adding an RPS constraint makes curtailment more expensive because the model will invest in replacement renewables to satisfy the RPS requirement. To set the RPS constraint, we assume that the level of energy produced by the renewable resources built in the Modified Rooftop PV scenario has to be delivered as a percentage of sales. The RPS requirement in 2030 in that case is roughly 25% of sales. However, the 4% curtailment encountered is not high enough to justify investment in storage.

2.4.2.3 Must-Take Renewables

Enforcing all renewables as must-take is a stricter version of the RPS constraint sensitivity above. We modeled all renewables on the system as uncurtailable in the updated IRP rooftop PV case to investigate whether lack of controls systems as an integration hurdle would justify need for storage. In this case we found that the coal generation fleet combined with midday pumping from pumped hydro were flexible enough to avoid curtailment of renewables, although the operating costs to do so were higher than with curtailment. This is a result of the fleet taking an efficiency reduction through operating at a lower setpoint with more generation online to accommodate the renewables. The operating cost penalty was not enough to justify storage in the high, mid, or low pricing scenarios.

2.4.2.4 Higher Inflexibility in the Coal Fleet with Must-Take Renewables

The flexibility of the coal fleet in a higher renewable world is uncertain. We investigated whether storage adoption in the must-take renewables scenario above would be driven by greater coal fleet flexibility. We increased the minimum generation level for coal generators to 70% of load and maintained 12-hour up and down times. Again, the system was capable of adapting to deliver all renewable generation without triggering economic storage beyond pumped hydro. Even in the rooftop PV case, the renewable penetration is too low to drive integration with storage.

2.4.2.5 Higher Inefficiency from Instantaneous Reserves

The 0.2% efficiency loss for coal generators offering instantaneous reserves is also highly uncertain. We investigated a higher efficiency loss of 0.5% to determine whether more storage would be built for reserves. Across the high, mid, and low pricing scenarios, the increase in the inefficiency was not enough to trigger economic storage adoption.

2.4.3 System Level Storage Analysis Conclusions

The above sensitivities show that the system currently, and projected through 2030, has enough flexibility to integrate renewables to the levels projected in the Rooftop PV case. Additional benefits from storage come from offering instantaneous reserves; however, the value of offering these reserves is not enough to justify the investment in storage until well below the lowest price projection, as shown in the funding gap analysis. The size of the opportunity for instantaneous reserves is also limited by the significant amount of pumped storage South Africa has online.

Changes to the South African policy and regulatory landscape that influence carbon or renewable targets beyond 2030 may drive storage investment for renewable integration. Currently, the value of system level use cases are not high enough to justify storage investment on their own. However, storage does offer system level value as shown in the funding gap analysis. Additional value streams from well-placed local storage applications may be able to cover the funding gap. Section 3 describes the additional benefits that storage can produce locally on the system. We qualitatively discuss the benefits that storage can receive, the opportunities to realize local storage value, provide case study examples of local storage valuation in California, discuss the value of next generation utility business models for storage, and describe a potential business model developed recently for New York.

3 Local and Customer Benefits

Section 2 presented the analysis of the system benefits of storage and any remaining funding gap under several South African resource futures. The quantification of these benefits is based on E3's RESOLVE model, which combines a simulation of system operations with a least-cost system expansion.

In this section, we qualitatively address local and customer benefits that are not included in the system benefits analysis and that may close the funding gap. We also provide an assessment of the barriers to realizing these benefits and approaches to address them.

3.1 OVERVIEW OF LOCAL AND CUSTOMER STORAGE BENEFITS

To describe the potential local and customer storage benefits, we start with the generalized distribution system schematic in Figure 3-1. The distribution system depicted is served by a high-voltage transmission system, a medium-voltage subtransmission system that serves multiple distribution substations, and distribution feeders serving loads. The distribution system is typically radial (as opposed to networked) and uses switching to provide for contingencies and maintenance.

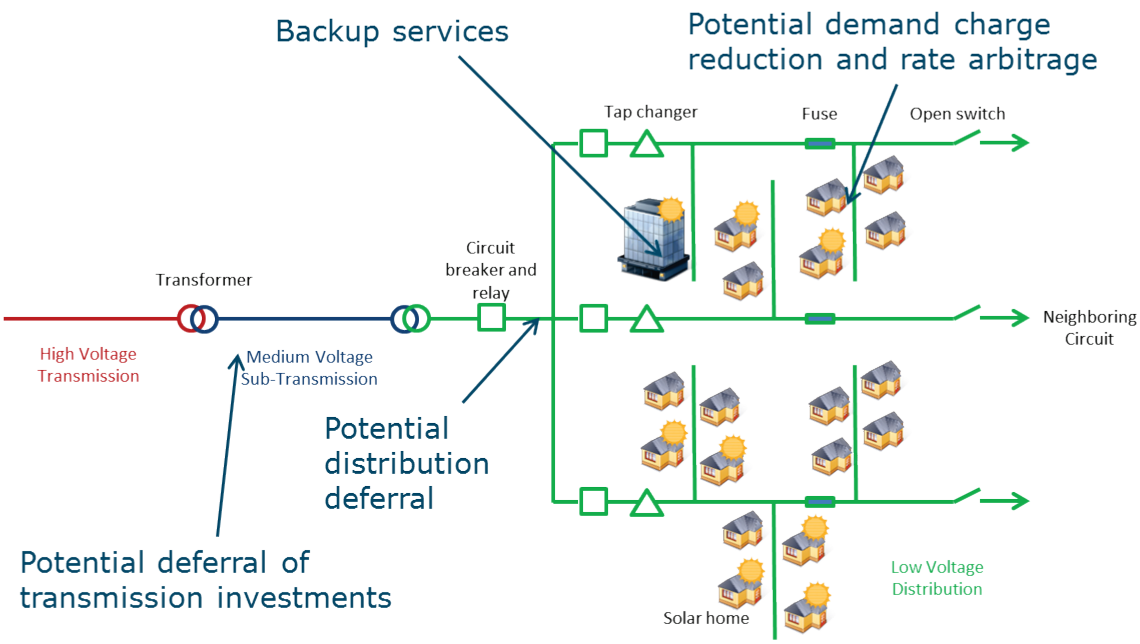

Figure 3-1: Distribution System Schematic with Local Benefits

Within this framework, distributed energy storage systems could provide local and customer benefits if the appropriate telemetry and controls are in place. The local and customer benefits are defined in our use cases as grid infrastructure services and customer energy management services. We have defined these categories somewhat broadly for both clarity and to reduce the potential to 'double count' benefits:

- Potential Grid Infrastructure Services Benefits
  - Local capacity investment savings (transmission, subtransmission, and distribution);
  - Distribution voltage / volt-ampere reactive (VAR) regulation savings
- Potential Customer Energy Management Services Benefits
  - Customer retail rate savings, including arbitrage and demand charge peak shaving
  - Customer backup services

In all cases, the benefits are described as 'potential' benefits because they cannot necessarily all be captured by the same storage system. In addition, conflicts may arise between the needs to operate storage for each value stream (system, local, and customer) that would result in value reductions for one or more of the value streams. The 'use case' for each storage system, that is, how the battery is used, will therefore determine the total benefits that the storage can provide.

Table 3-1 lists the benefits that are potentially compatible, or mostly compatible within the same storage system, for the various storage system owners and operators and storage interconnection locations. The owner and operators fall into four cases: (1) Eskom as an owner and operator for distribution system interconnected storage, (2) a public distribution utility that purchases wholesale energy and capacity, (3) customer-owned storage under existing retail rates, and (4) customer owned storage under reformed rates. In each case, the primary use of the storage system is identified along with an indication of whether additional benefits might be provided by storage.

Table 3-1: List of Compatible Benefits by Owner & Operator/Location

Storage System Owner & Operator	Eskom Vertical Utility	Public Distribution Utility	Customer owned (existing rates)	Customer owned (reformed rates)
Location	Distribution	Distribution	Customer	Customer
Production costs	Primary			Yes
Generation capacity	Primary			Yes
Ancillary services	Yes, with limits			Yes, with limits
Transmission capacity	Yes			Yes
Distribution utility wholesale		Primary		Yes
Sub-transmission capacity	Yes	Yes		Yes
Distribution capacity	Yes	Yes		Yes
Voltage / VAR regulation	Yes	Yes	Yes, with limits	Yes
Customer retail savings			Primary	Primary
Customer back-up			No	No

As the results in Section 2 show, the primary *system* benefit for Eskom from storage would be the efficiency gains from taking coal generation off instantaneous reserve duty, combined with energy arbitrage. The potential for this service is capped at the requirements for instantaneous reserves. Storage is also physically limited in offering reserves depending on the state of charge.

In the future at higher renewable penetrations, renewable integration may be the primary system value.

At the local level, the same system can also provide transmission, subtransmission, and distribution capacity because these services generally require less than 100 hours per year, freeing the battery to provide reserves and renewable integration benefits for the remaining 8,660 hours of the year. To the extent that the peak loads are not coincident, additional hours may have to be reserved for local capacity. In some situations, it may be necessary to choose between providing distribution capacity and subtransmission or transmission capacity, which will make it impossible to capture all of the capacity benefits, but these instances should be rare. Finally, if equipped with the proper inverter and controls, this storage system can help regulate local voltage and power factor, which can reduce losses and save energy.

Public distribution utility owned and operated battery storage can provide the local utility the same local capacity benefits as well as voltage and VAR regulation as a vertical utility. The difference between the value of storage for this structure and a vertically integrated utility is that, to the extent that the wholesale pricing or utility tariffs do not align with the system renewable integration needs or regulation, then there is no way to capture these values.

The primary benefit of customer-owned and -operated energy storage is reducing the utility bills by arbitraging the retail rate. For storage on existing retail rates, which are only somewhat aligned with system and local needs, the operation of the storage system is unlikely to provide much system benefit. Under reformed rates that reflect system and local capacity benefits and time-dependent marginal costs of system operation, the customer optimal storage dispatch pattern and the utility value can be more closely aligned and can thereby provide additional benefits. Rate reforms to align customer and utility benefits are discussed in Section 4.

3.2 Grid Infrastructure Benefits

Integrating storage and the necessary enabling technologies and systems into the set of options available to planners to address their local area needs offers the potential to lower total utility costs. Using the distribution system schematic in Figure 3-2, we show three possible upgrades to the capacity of a local distribution system in response to load growth. At [A] the distribution planner can select from one or more capital investments in transmission and distribution (T&D) infrastructure, which is the standard industry practice. At [B], the utility could install a utility-owned distributed energy resource (DER) interconnected to the distribution system, such as fixed or mobile storage. At [C], the utility could encourage customer-side energy storage through incentives, demand response style capacity programs and/or time-varying retail pricing.

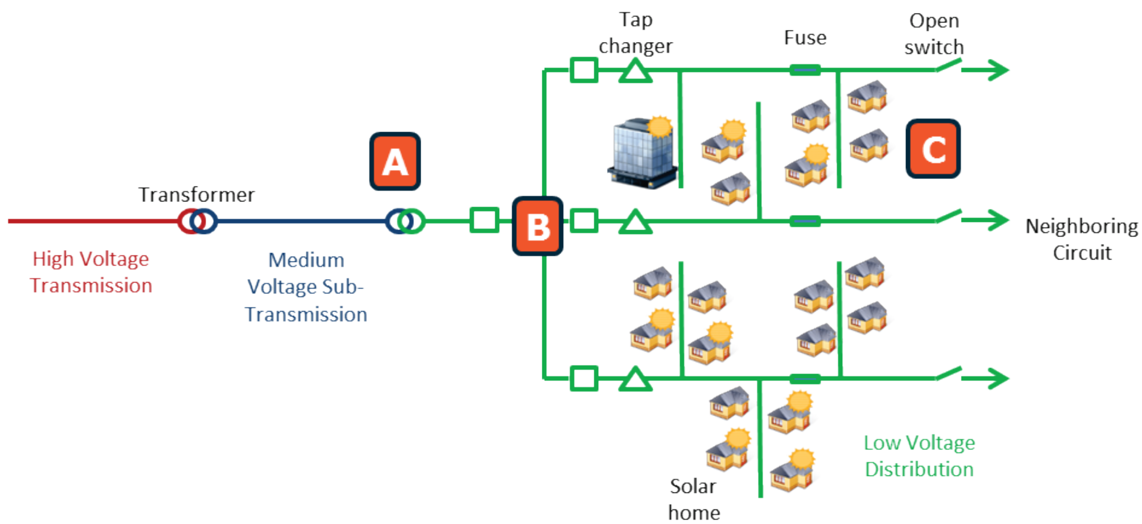

Figure 3-2: Distribution System Schematic with Various Storage Locations

3.2.1 Value of Deferral

The value of avoiding or delaying the traditional T&D infrastructure investment can be calculated accurately using the present worth method, which is calculating the difference in net present value between the revenue requirement of the local area investments before and after DER is installed. By lowering peak load, DER can defer investments in T&D infrastructure that would have otherwise been needed to serve load growth. Because the cost of borrowing is generally lower than inflation, a delayed investment will result in a lower net present value cost to ratepayers, which results in savings.

The first two charts in Figure 3-3 show a network T&D investment of $10 million. The project is needed to prevent the load growth from exceeding the area load carrying capability. In the second two charts, the load growth is reduced from the red line to the blue line, which allows the investment to be deferred by 2 years. The deferral results in a savings of about $1 million if inflation is 2% and the utility weighted average cost of capital (WACC) is 7.5% ($10M – $10M*$[1.02/1.075]^2$). Once the net present value customer savings are calculated, this can be converted to a marginal cost by dividing by the amount of load reduction required to achieve the deferral. If we further assume that 5 MW of load reduction is needed to achieve that deferral, the avoided cost is $200/kW ($1M/5MW).

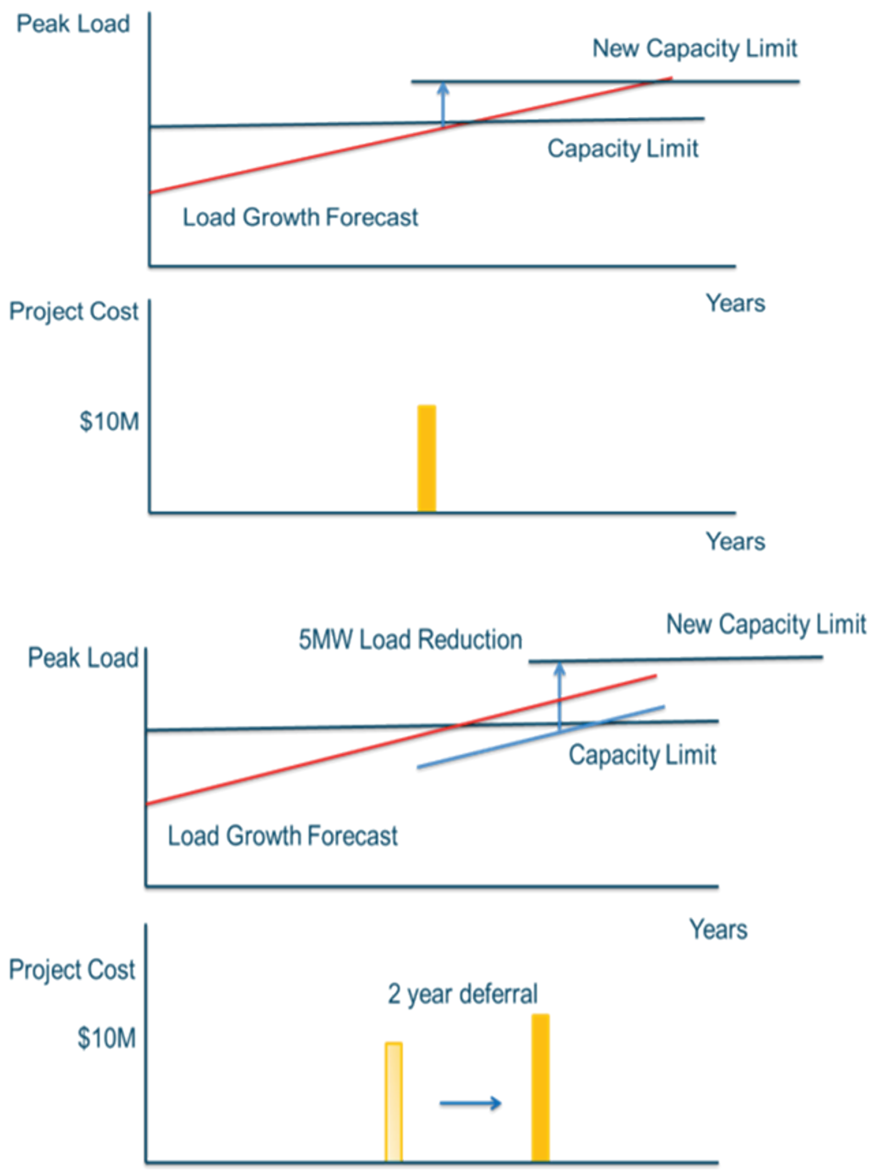

Figure 3-3: Present Worth Method for Storage Deferral Value

Storage devices sited in local load pockets where load growth is expected to cause significant investment costs in new infrastructure can realize high benefits from being dispatched for local load reduction. Dispatch of storage for local deferral value can often be added as a use case without significantly reducing the bulk system level benefits of storage operated for energy, capacity and reserves. An example local load shape from California shown in Figure 3-4 shows why this can be the case. Peak load conditions occur in relatively few hours over the course of the year. In this particular area, peak loads can be reduced 10% by action in only 30 hours over the course of the year.

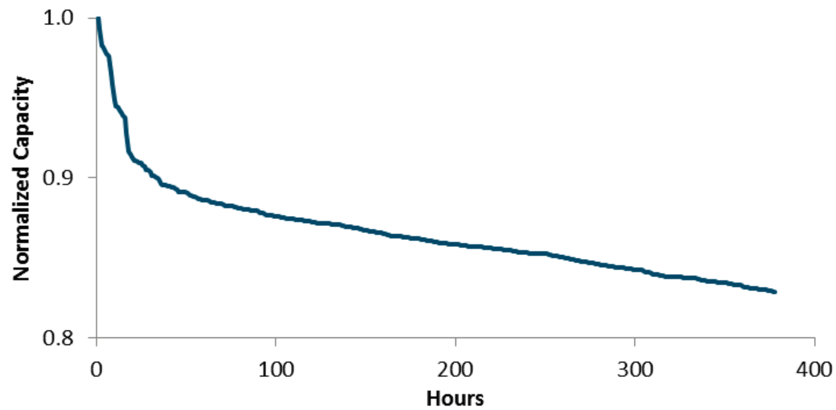

Figure 3-4: Present Worth Method for Storage Deferral Value

When storage is used for local load reductions and capacity deferrals, it is possible that the same device can realize almost all bulk system level benefits over the year as well.

3.2.2 Case Study of Potential Deferral value

Numerous studies have been conducted in the United States and abroad that have characterized the distribution marginal cost using this approach for the purposes of local integrated resource planning. These are done by using the distribution capacity investment plans, and associated local load growth, to compute the value using the present worth method. Figure 3-5 shows the result of a 2012 study in California for the three largest investor-owned utilities (PG&E, SCE, and SDG&E) [0362]. The marginal costs of investment deferral by distribution substation in California are sorted from highest to lowest. Other similar studies show similar patterns. In this case, a few areas show very high distribution marginal costs, a fair number are moderate, and many are very low. The highest cost distribution areas tend to be those that require near-term expensive upgrades but have relatively low levels of load growth. The moderate areas are those that have necessary upgrades but also have significant planned growth. The low areas are those without capacity constraints in the near future.

Depending on the combination of projected load growth and required capital investments by local area in South Africa, there may be a number of high distribution avoided cost opportunities for storage. A 2-hour duration mid-case Li-ion battery is priced at $240/kW-yr in our study for 2015. Even at this high value, two T&D constrained areas in California have been identified in which the deferral value is high enough to justify investment, assuming that the battery can continue to receive the same deferral value over its lifetime. If the battery can recover an additional $100/kW-yr from bulk energy services, several more areas in Figure 3-5 would become potentially economic storage investment locations. Searching for these high-value storage locations where storage can offer both bulk energy services and local value is the key to developing economic storage.

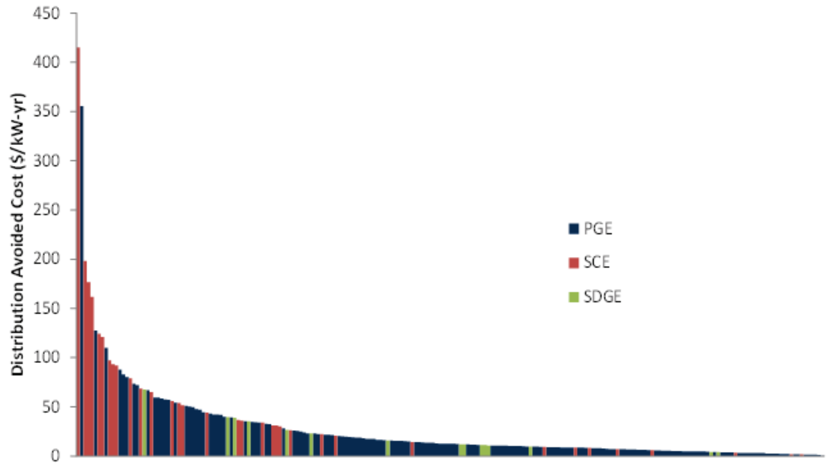

Figure 3-5: Range of Distribution Marginal Capacity Costs in California

One caveat is analogous to the bulk system level analysis presented in the first half of this report. Although storage may offer large benefits to the grid in the local T&D constrained areas above, it competes against many other technologies, just as on the bulk system, to offer the same services. For example, the most expensive local capacity investments in Figure 3-5 could be deferred far more cheaply using demand response programs than storage investments used for the single use case of local deferral. Economic storage is therefore best identified through integrated resource planning that incorporates both bulk energy and local level resource selection. In the demand response example above, for instance, storage may be competitive because it can defer capacity, avoiding the investment in demand response programs, while also realizing bulk energy system benefits.

3.2.3 Considerations for Screening High Value Areas

To capture the distribution capacity value, the distribution planning process must be reformed to screen for the potential to defer and save distribution capital budget. For those areas of consideration, four screening steps must be considered:

- **Engineering solution**. Does the energy storage device solve the problem that is driving the need for capital expenditure? Many distribution capital projects are designed to replace aging equipment, improve safety, improve reliability, or accomplish other goals. A good test is to ask if peak load reduction would eliminate the need for the investment. If it would, then the area is a positive candidate for deferral.
- **Timeline available for deployment.** Is there enough time to deploy sufficient numbers of energy storage devices and enough storage capacity before the investment must be

committed to in order to construct or order transformers or other equipment? Often, there is a very short period to deploy storage, which presents a significant challenge.

- **Capital expenditures.** What are the costs of the capital expenditures that can be deferred? The level of costs drive the value of deferral; therefore, areas with inexpensive upgrades do not provide significant benefits.
- **Cost-effectiveness.** Is the value of distribution deferral, when combined with other benefits that can be captured, enough to justify the costs of the system?

3.2.4 Lower Risk of Integrated Plans

An additional consideration in the use of energy storage or other distributed energy resources for local capacity expansion is that the resulting plans may have lower risk. The lower risk stems from the ability to purchase capacity in smaller increments and then observe the future load growth. For example, if a new residential development is expected to grow significantly, it may be possible to add mobile energy storage to the system, wait and see if the development occurs, and then invest in the traditional utility investment if the growth materializes.

Figure 3-6 shows an example substation from California where the load is growing, shown by the solid lines and the left-hand vertical axis. The peak load limit of the infrastructure available to serve the area is shown by the dotted lines and the same axis. When the load crosses these limits, additional capacity is needed and an investment is made. Investments are identified through the utility capital expansion planning process. When an investment is made, the cost of that investment is shown by the bar chart and the right vertical axis.

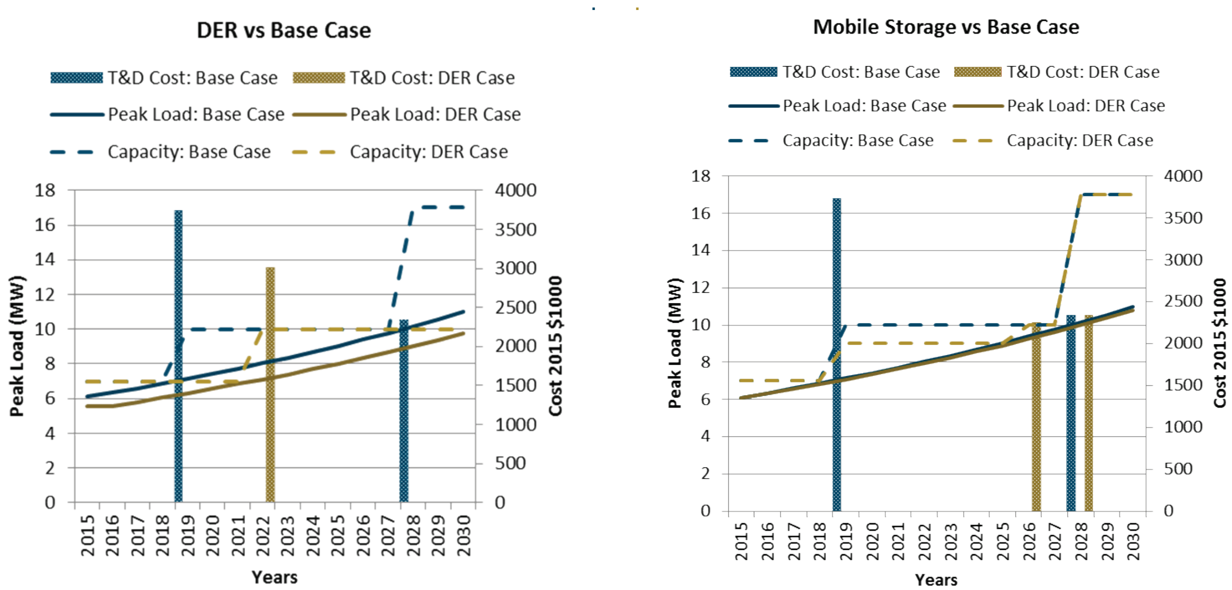

Figure 3-6: Deferral Value Example Case Study

The base case, shown in blue, corresponds to the typically business-as-usual utility case — invest in new infrastructure. The gold cases show two alternatives. In the chart on the left, the utility incentivizes distributed generation for customers to install. This option reduces loads through energy efficiency and demand response programs, but costs the utility in payments to the customers and lost sales. The initial upgrade is shifted from 2019 in the base case to 2022 in the DER case, resulting in deferral benefits. In the chart on the right, the utility adopts a wait-and-see approach by installing mobile storage. Because load growth is uncertain, the utility may want to gain more information about development patterns before committing to large capital investments. An example of this is in development zones: new development is expected or being incentivized, but load growth is contingent on business being attracted to the area. The option of mobile storage pushes the capital investment decision into the future by deferring an upgrade until more is known about load growth. In this case, mobile storage defers the investment from 2019 to 2026, at which point the battery is removed and the capacity limit returns to the base case trajectory. Using a wait-and-see approach with mobile storage can be particularly valuable when very large capacity upgrades have to be committed to 1 to 3 years ahead of when they are needed for load growth. If load growth does not materialize as expected during construction, there is a risk these investments can be very large unnecessary expenditures. Load growth uncertainty can factor into which decision is made. In the same example as presented in Figure 3-6, we use Monte Carlo analysis and Markov Chain transitions to model uncertainty in the load growth. Figure 3-7 shows the distribution of costs around the mean cumulative discounted cash flow to the utility in 2030.

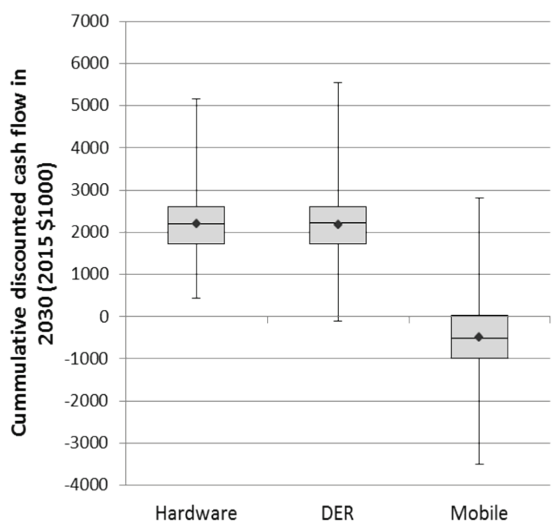

Figure 3-7: Capital Budgeting Risk vs. Return

In this case, mobile storage was not as cost effective as the other two investments. However, the relative cost of the various solutions is highly dependent on the local area characteristics.

4 Customer-Controlled Energy Storage

So far, we have considered utility-owned and operated distributed energy storage systems. In this section, we consider customer-controlled storage. Although integrating energy storage into the distribution planning process for utility-owned systems is somewhat complex, the control and operations of the storage are internal processes and can be integrated with standard utility operations. For customer-controlled energy storage, the integrated distribution planning process must be accompanied with retail incentives to encourage or require the energy storage system to operate in concert with the needs of the distribution and bulk energy systems. Without an incentive to storage owning or controlling customers to respond to the needs of the local T&D system, grid infrastructure benefits are unlikely to be realized from the customer-controlled storage. The remainder of this section describes rate design options for providing those incentives to customers.

4.1 Current Business Model: Time of Use Pricing

The minimum level of complexity in retail pricing to encourage storage operations that align with utility value is time of use (TOU) pricing. Rate designs with flat tariffs discourage storage because there is no way to reduce bills by operating the storage in any particular hour. Rate designs with noncoincident demand charges can encourage customers to use storage to reduce their bills, but to the extent that the customer's peak loads do not coincide with system peaks, demand charges do not align customer and utility value propositions.

Even TOU pricing, however, tends to have pricing periods that are too aggregate to be highly effective for addressing local capacity needs. A more effective option is to pair critical peak pricing (CPP) with the TOU rate. The CPP rate is an even higher price that the utility can dispatch when needed. The intent is to encourage customer load reduction during the CPP period, and better align customer behavior with grid needs.

Figures 4-1 and 4-2 show the impact of using a CPP rate with a customer energy storage system at Sacramento Municipal Utility District (SMUD) in California. Figure 4-1 shows the energy use for a participant in SMUDs solar plus energy storage pilot program (TOU rate with CPP); Figure 4-2 shows the energy usage for a customer on the regular TOU rate.

The customer on the TOU CPP rate, shown in Figure 4-1, responds to the CPP pricing in the evening by discharging the battery. The utility calls the CPP event a day in advance, allowing the customer to prepare for the CPP event, charging the battery from PV produced at the customer's site during the day. The SMUD TOU-CPP program is designed to be called based on system peak load conditions, as is the case with most utility CPP programs. This provides bulk system capacity value to the utility when the customer dispatches storage in response to CPP pricing.

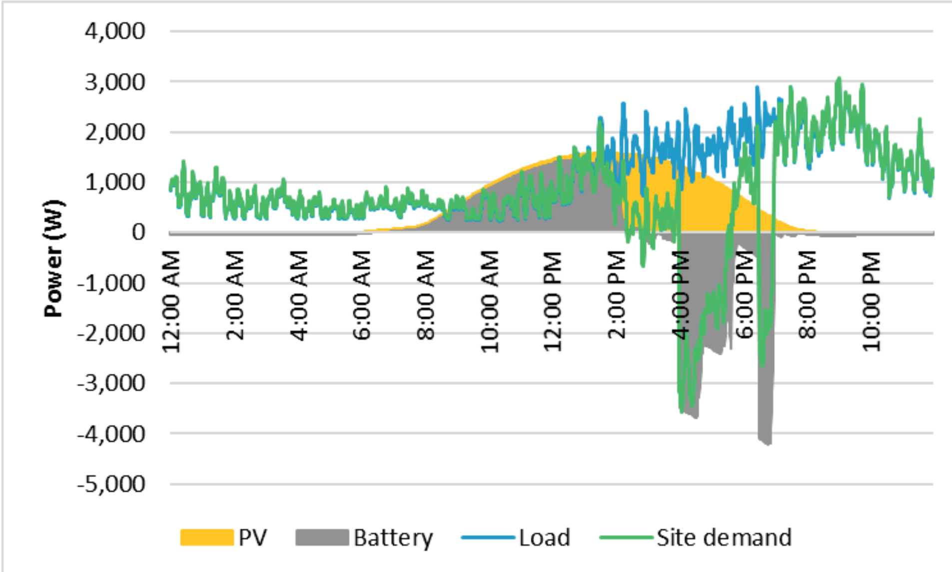

Figure 4-1: Average TOU CPP Program Participant Power Flows on 26 June 2015

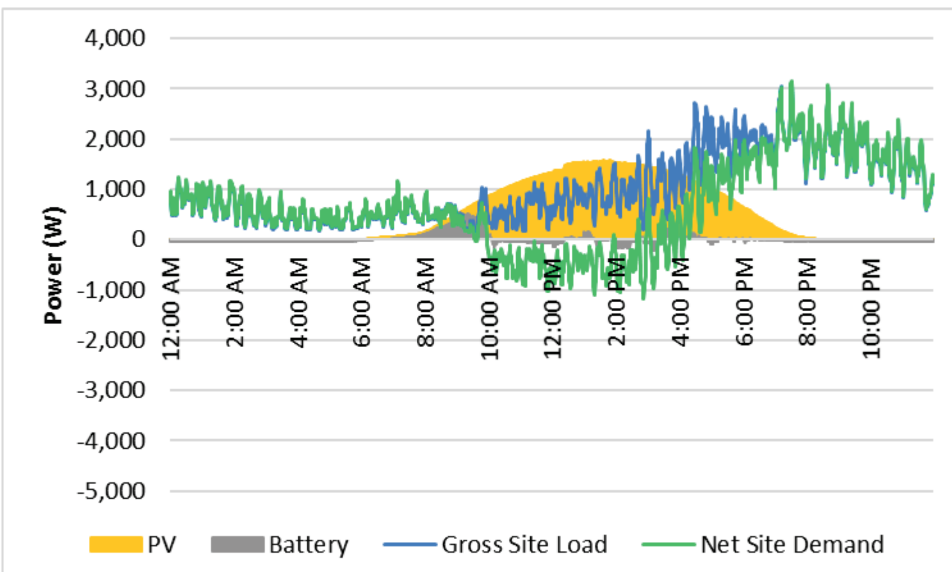

Figure 4-2: Average Non-Participant Power Flows on 26 June 2015

In Figure 4-2, the customer not participating in the TOU CPP rate has no incentive to discharge the battery in hours that are valuable to the utility. Instead, the battery charges at a low rate prior to the TOU period and then stops during the peak period.

Figure 4-1 also shows that on this date the participant's discharge to the grid ceases at 6 pm before returning to discharge during the following hour. This is the result of a software problem that has since been corrected. This highlights the need for software and controls system development on both the utility and customer side to ensure effective operation of the system. This interfacing is key to realizing greatest value from behind-the-meter systems.

The TOU CPP program goes some way to aligning customer behavior with grid needs by compensating customers at a higher rate during high value periods. However, significant storage benefits are still not being realized because of the lack of incentive for optimal operations. In effect, the above program uses storage as a demand response product that can be used for capacity and deferral value. Behind-the-meter storage can offer the full suite of storage benefits to the system including bulk system, distribution, and customer benefits, depending on which are highest value in each hour. Some of these use cases can stack with little degradation in value over a single use case application.

To demonstrate the difference in benefits, Section 4.2 shows a comparison between full utility control and customer control of a storage device for two example regions of the SMUD service territory.

4.2 Utility vs. Customer Control

In the same solar and storage pilot at SMUD, the utility modeled the benefits of utility-controlled and customer-controlled storage. The utility-controlled storage used AutoDR protocols to operate the customer storage as part of distribution operations. In this case, the control systems do not provide ancillary service functionality. The customer-controlled storage used the TOU CPP rate to incentivize customer behavior. Figure 4-3 compares the costs and benefits for both control schemes in two distribution planning areas; one with relatively higher distribution avoided capacity costs (Jackson-Sunrise) and one with relatively lower distribution marginal capacity costs

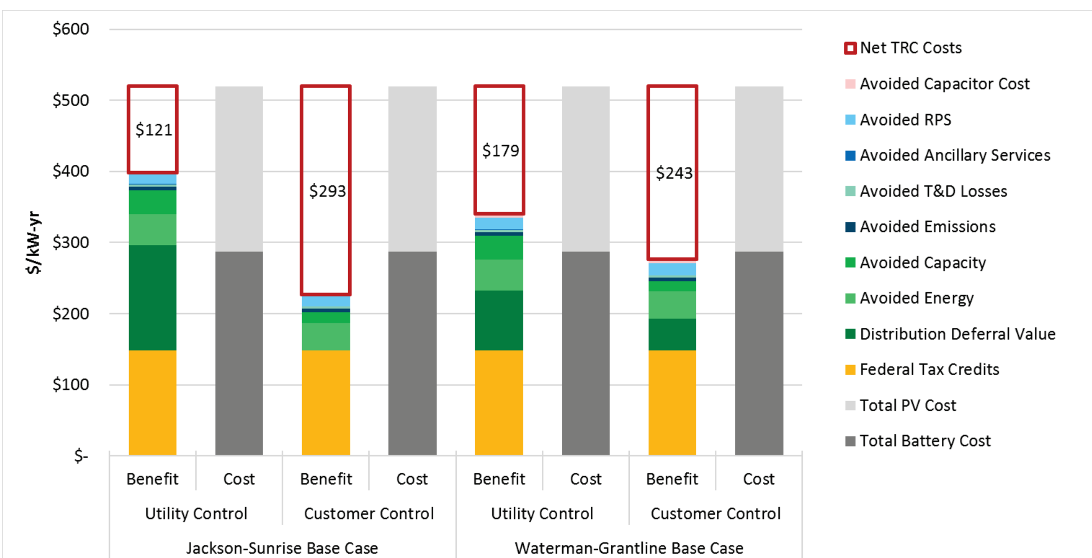

Figure 4-3: Base Case SMUD Results, Utility Control vs. Customer Control

(Waterman-Grantline). In both cases, the utility control system provides significantly more value because the system operates when needed in each instance of capacity shortfall.

In the Jackson-Sunrise area, utility-controlled solar plus storage can realize very high distribution deferral values of $150/kW-yr that the storage device cannot capture under customer control. The utility-controlled system can also realize significant capacity and energy benefits at a greater level than under customer control from the TOU CPP rate incentive. Although utility control can provide significantly higher benefits, the value of those benefits, even when factoring in federal tax credits, is still short of meeting costs of the total system by $121/kW-yr. These costs are at current PV and storage prices, however, and as costs decline this funding gap will also decline.

For a case in which we assume that ancillary services are an additional use case that storage can offer, the funding gap in the utility control case declines from $121/kW-yr to $95/kW-yr. The comparison of value offered from storage for each use case between Figure 4-3 and Figure 4-4 shows that storage can offer additional use cases with little degradation in value of the other services it offers. This is true to a greater or lesser extent depending on the use case. The results in these charts show the optimal behavior of the device for utility benefits in the case of utility control.

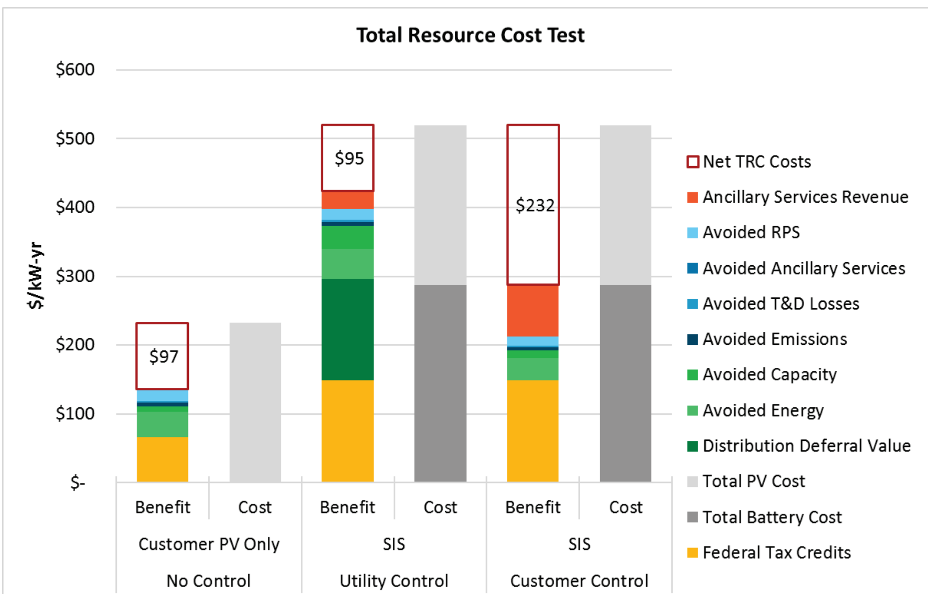

Figure 4-4: Base Case SMUD Results, Utility Control vs. Customer Control

The second interesting comparison in the chart above is between the customer control case and the utility control case. Customer control is no longer TOU CPP; rather, it is the participation of individual customers in existing electricity markets through an aggregator. The aggregator can bid the aggregated storage product into California markets for maximum storage value. However, currently there are a limited number of market products that storage can participate in and they do not represent the full value that storage can provide to the energy system as a whole.

To realize the full value of customer-owned storage a more complete set of markets and tariffs that represent the full value of storage would have to be available to the customer. In South Africa, similar market products would have to be developed to align customer behavior with the highest value storage applications to the grid. Section 4.3 describes next-generation business models that can align utility and customer benefits, providing incentives and price signals for the customer to dispatch storage to provide maximum value to the utility grid.

4.3 Next Generation Business Models

A number of next generation business models are being developed throughout the world to monetize the various services that energy storage can provide. The most advanced evolution of these business models is occurring in the United States due to a combination of domestic technology innovation and the fragmented domestic wholesale and retail energy markets and policies, which leads to a diversity of enabled business models.

These emerging next-generation business models revolve around capturing, monetizing, and potentially stacking various sources of value for providing specific energy storage services. These services can be wholesale or bulk system services such as frequency regulation, as well as retail services or distributed system services such as electricity rate arbitrage or even a hybrid model with utility or system operator control over some services with the remaining services controlled by the customer or a third-party owner/aggregator.

The most robust and highest value proposition next generation business models will be those that can maximize revenues from the services that energy storage could provide at both the distributed and bulk system levels of the electrical grid. This means that one way to resolve the funding gap to encourage greater adoption of energy storage would be to leverage next generation business models. These can increase the value proposition of storage by monetizing and stacking multiple services rather than relying on a limited subset of services provided at the bulk system.

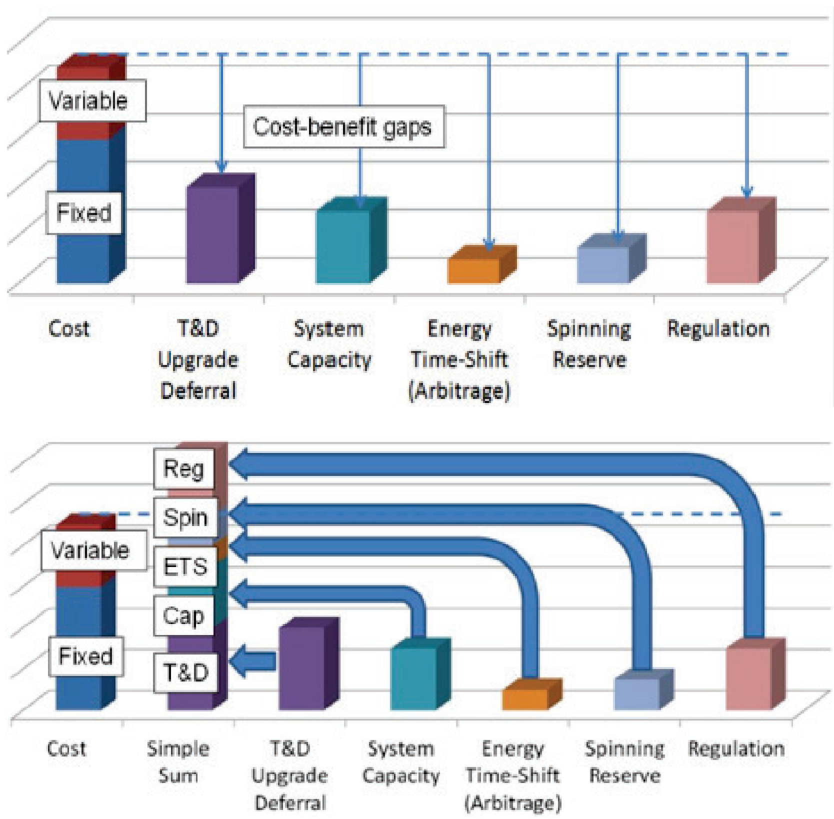

Figure 4-5: Increased value proposition of storage by monetizing and stacking multiple services

Bulk system services alone may not result in enough value or revenues to trigger adoption. For example, energy storage could be located at a host customer site to provide electricity bill savings along with backup power services, while simultaneously being able to provide more bulk system services like voltage support, capacity, or deferral of transmission and distribution capital expenditures.

The following section illustrates a next generation business model that monetizes several storage use cases to realize revenues that could resolve the funding gap for storage technologies leading to increased levels of adoption.

4.4 FULL VALUE TARIFF

E3 recently authored a report [0361] as part of New York's Reforming the Energy Vision (REV) proceeding[2], one of the more innovative regulatory initiatives occurring in the United States regarding the future of utility business models, retail rates, and new technologies including storage. We proposed moving retail rate design and compensation for distributed energy resources such as storage and customer-sited solar PV to a full value tariff (FVT) that sends true marginal cost signals differentiated by time and geographic location to customers or technology to encourage more economically efficient outcomes, while simultaneously recovering the fixed costs of the local utility. Figure 4-5 shows the FVT proposal in more detail.

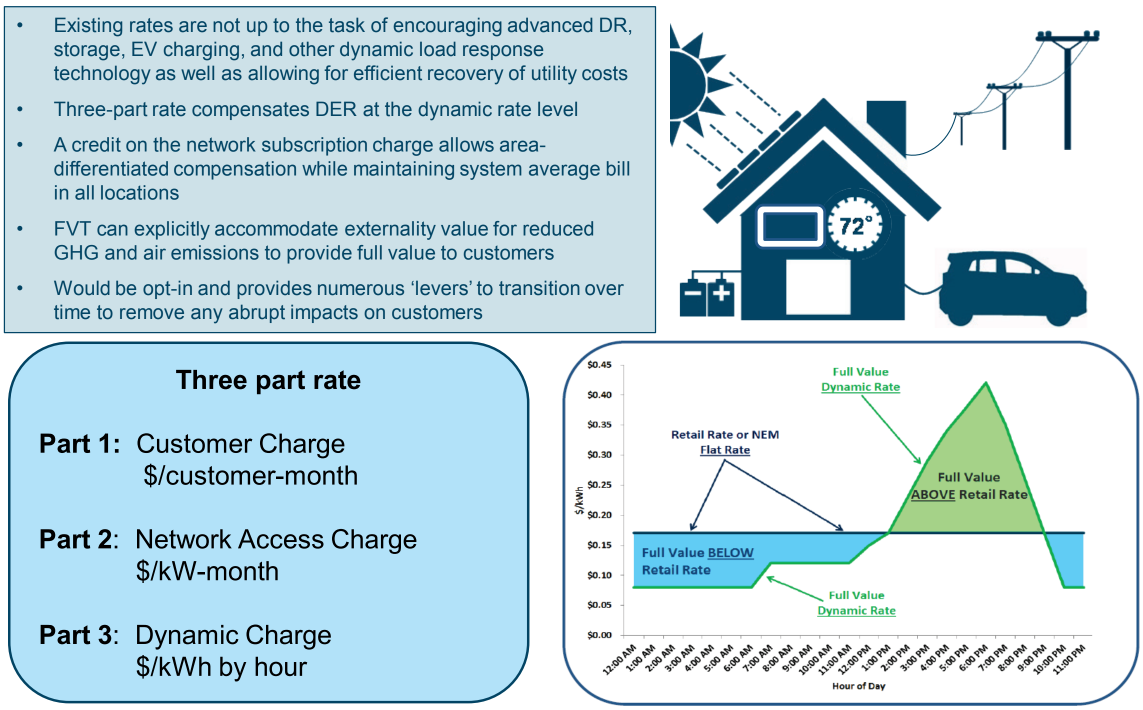

Figure 4-6: Proposed Full Value Tariff is a 3-Part Retail Electricity Rate that Varies by Time (Hourly) and Location (Distribution Planning Area) vs. Today's Flat Retail Rates

The key innovations of E3's FVT proposal are as follows:

1. **Enables Smart Grid Technologies**
   a. The FVT's dynamic prices send technology agnostic signals to enable a whole host of DERs like storage, smart EV charging, more efficient appliances, etc.
2. **Translates Utility Costs into Prices in Innovative and Novel Ways**
   a. "D" value of utility distribution and sub-transmission translated to customers as "prices to beat" to enable DER participation, including customer behavioral changes in managing the costs of the grid.

[2] http://www3.dps.ny.gov/W/PSCWeb.nsf/All/CC4F2EFA3A23551585257DEA007DCFE2?OpenDocument.

   b. Encourages more economically efficient electricity consumption and use of the electrical grid.

3. **Utility Rate Design and Business Model Rationalization**
   a. Utility costs have better and more transparent fixed cost recovery through the FVT's network subscription charge, potentially forestalling future issues with retail rates.
   b. Encourages creating various business models that lead to customer adoption of high-value DERs rather than DERs that have low, zero, or negative value.

This type of retail rate structure may be particularly effective in South Africa, where customers may be inclined to respond to marginal price signals to avoid noncompensated curtailment of electric service. Customers can respond to the true marginal costs of electrical service to either reduce consumption in peak, constrained times or simply pay the marginal cost-based price. This creates a true economic loading order as compared to the current practice of curtailing electrical service equally among all customers, who may have very different values associated with that curtailed electricity service. Further, there are very real questions regarding equity with retail electricity pricing and the current practice of curtailing electricity service for all customers equally. Under an FVT, the equity questions would be forestalled as all customers would be exposed to the same FVT pricing and those customers with a low value of curtailment would shift or reduce consumption in peak periods with high prices reducing their energy bills versus customers that have a high value of curtailment who would simply pay the price.

This is one example of how more innovative pricing structures could lead to more economically efficient outcomes as well as next generation business models. Figure 4-6 shows that the customer value proposition could be quite high under a FVT, which could enable a host of new business models.

E3's Smart Home Model

E3's Smart Home model simulates the customer and utility system benefits of controllable flexible loads under any user defined retail rate price scheme like the FVT including TOU, tiers, subscription charges, and real-time pricing

A 2,500 square foot, 3-bedroom New York specific home is modeled with a generic home energy control device that:

- Sends and receives data signals to/from the electricity grid
- Learns customer preferences and behavior
- Controls electricity use and generation of home appliances

Bill savings (high local T&D value) $/year
Bill savings (zero local T&D value) $/year

	Rate Option	Solar Roof (75% Usage Offset)	A/C EE 25% Savings	Price Induced Load Shifting	Smart HVAC	Battery Storage	Smart Electric Vehicle
ConEd	Existing Rates	$1,253 / $1,253	$112 / $112	No Savings	No Savings	No Savings	No Savings
ConEd	Current Optional TOU	$1,467 / $1,467	$136 / $136	$50 / $50	$98 / $98	$357 / $357	$202 / $202
ConEd	Full Value/Smart Rate	$1,179 / $742	$146 / $93	$274 / $(74)*	$236 / $151	$430 / $305	$141 / $133
ConEd	Full Value/Smart Rate + Societal Signal	$1,300 / $863	$142 / $89	$260 / $(74)*	$229 / $144	$404 / $280	$123 / $122
National Grid	Existing Rates	$664 / $664	$51 / $51	No Savings	No Savings	No Savings	No Savings
National Grid	Current Optional TOU	$582 / $582	$44 / $44	$10 / $10	$8 / $8	$31 / $31	$7 / $7
National Grid	Full Value/Smart Rate	$587 / $425	$51 / $33	$48 / $12	$156 / $50	$350 / $144	$192 / $48
National Grid	Full Value/Smart Rate + Societal Signal	$723 / $562	$61 / $43	$37 / $24	$149 / $43	$328/ $122	$184 / $39

Figure 4-7: Proposed FVT can Enable a Variety of Next-Generation Business Models based on Core Function of Customer Electricity Bill Savings

Appendix A – Resolve Methodology

A.1 INTRODUCTION

One economic lens that can be used to evaluate various integration solutions is to consider the consequences of failing to procure adequate resources to meet grid needs. This is similar to an avoided cost framework, which has been applied broadly to cost-effectiveness questions in the electricity sector and other areas. In a flexibility-constrained system, the default consequence of failing to secure enough operational flexibility to deliver all of the available renewable energy is to curtail some amount of production during the periods in which the system becomes constrained. The direct cost of this is increased fuel burn by conventional units on top of the investment costs of renewables. The frequency of curtailment and the dispatch of conventional units dictates whether investments like storage are cost-effective solutions to integration. If binding renewable energy targets are set in South Africa in the future, these costs may increase further since curtailment of renewables may jeopardize the utility's ability to comply with the renewable energy target. In such a system, a utility may have to procure enough renewables to produce more than the energy target in anticipation of curtailment events to ensure compliance. This "renewable overbuild" carries with it additional costs to the system. In these systems, the value of an integration solution, like energy storage, can be conceptualized as the renewable overbuild cost that can be avoided by using the solution to deliver a larger share of the available renewable energy. Cost effectiveness for an integration solution under these conditions may be established when the avoided renewable overbuild cost exceeds the cost of the integration solution.

These benefits of storage and other investments on the system are in addition to the other grid services that they can offer. For example, we use the RESOLVE model to calculate the potential savings storage can make by displacing coal generation in offering instantaneous reserves in South Africa. The combined operations across all grid services defines the value of storage and whether it would be selected in optimal resource procurement.

Beyond cost effectiveness, the RESOLVE framework also allows for the determination of an optimal solution by examining the costs and benefits of increasing levels of investment in integration solutions. If a single integration solution is available to the system, the optimal investment in that solution is the investment level at which the marginal cost of the solution is equal to the marginal benefit in terms of avoided renewable overbuild of the solution. However, as described above, many strategies can be pursued and the value of each solution will depend on its individual performance characteristics as well as the rest of the solution portfolio. RESOLVE provides a single optimization model to explicitly treat the cost and behavior of specific solutions as well as the interactions between solutions.

The RESOLVE model co-optimizes investment and operational decisions over several years in order to identify least-cost portfolios for meeting renewable energy targets. This appendix describes the RESOLVE model in terms of its temporal and geographical resolution, characterization of system operations, and investment decisions. Particular attention is placed on topics that are unique to an investment model that seeks to examine renewable integration challenges, including renewables selection; reserve requirements; energy storage; flexible loads; and day selection and weighting for operational modeling.

A.2 Temporal Scope and Resolution

In this analysis, investment decisions are made with 5-year resolution between 2016 and 2030. Operational decisions are made with hourly resolution on a subset of independent days modeled within each investment year. Modeled days are selected to best reflect the long-run distributions of key variables such as load, wind, and solar. The day selection and weighting methodology is described in more detail below.

For each year, the user defines the portfolio of resources (including conventional, renewable, and storage) that are available to the system without incurring additional fixed costs – these include existing resources, resources that have already been approved, and contracted resources, net of planned retirements. The South African IRP cases have resources scheduled through 2030. When analyzing the value of storage, we assume that these IRP resources are unavoidable and are therefore included in the user-defined portfolio of resources. In addition to these resources, the model may be given the option to select additional resources or retrofit existing resources in each year in order to meet policy goals, fulfill a resource adequacy need, or to reduce the total cost. Fixed costs for selected resources are annualized using technology-specific financing assumptions and costs are incurred for new investments over the remaining duration of the simulation. In the case presented in the results showing a remodeled IRP resource build, additional resources beyond those in place today or under construction are treated as investment options with an annualized investment cost.

The objective function reflects the net present value of all fixed and operating costs over the simulation horizon, plus an additional N years, where the N years following the last year in the simulation are assumed to have the same annual costs as the last simulated year, T. When the investment decision resolution is coarser than 1 year, the weights applied to each modeled year in the objective function are determined by approximating the fixed and operating costs in unmodeled years using linear interpolations of the costs in the surrounding modeled years.

A.2.1 Operating Day Selection and Weighting

To reduce the problem size, subset of days must be selected for which operations can be modeled. To accurately characterize economic relationships between operational and investment decisions, the selected days and the weights applied to their cost terms in the objective function must reflect the distributions of key variables. In the analysis described here, distributions of the following parameters were specifically of interest: hourly load, hourly wind, hourly solar, and hourly net load. In addition, the selection of the modeled days seeks to accurately characterize the number of days per month and site-specific annual capacity factors for key renewable resources. To select and weight the days according to these criteria or target parameters, an optimization problem was constructed. To construct the problem, a vector, b, was created that contained all of the target parameter values and described each target parameter distribution with a set of elements, each of which represents the probability that the parameter falls within a discrete bin. The target values can be constructed from the full set of days that the problem may select or from an even longer historical record if data is available.

For each day that can be selected, a vector, a, is produced to represent the contribution of the conditions on that day to each of the target parameters. For example, if b_i represents the number of hours in a year in which the load is anticipated to fall within a specified range, a_{ij} will represent the number of hours in day j that the load falls within that range. The target parameters vector, b, may therefore be represented by a linear combination of the day-specific vectors, a_j, and the day weights can be determined with an optimization problem that minimizes the sum of the square errors of this linear combination. An additional term is included in the objective function to reduce the number of days selected with very small weights and a coefficient, c, was applied to this term to tune the number of days for which the selected weight exceeded a threshold. The optimization problem was formulated as follows:

$$\begin{aligned} &\mathit{minimize} \quad && \sum_i \left[\left(\sum_j a_{ij} w_j \right) - b_i \right]^2 - c \sum_j w_j^2 \\ &\mathit{subject\ to} \quad && \sum_j w_j = 365 \end{aligned}$$

The resulting weights can then be filtered based on the chosen threshold to yield a representative subset of days. This method can be modified based on the specific needs of the problem. For example, in this analysis, while the hourly net load distribution was included in the target parameter vector, cross-correlations between variables were not explicitly treated. These could be incorporated into future studies, as could several other parameters of interest in characterizing the likelihood of various system states.

A.3 Geographic Scope and Resolution

Although RESOLVE selects investment decisions only for the region of interest (in this case South Africa), operations in an interconnected region are influenced by circumstances outside the region. South Africa is treated as an island in this study due to the relatively small flows between regions. However, these interactions can be captured in RESOLVE using a zonal dispatch topology with interactions between the zones characterized by a linear transport model. Both the magnitudes of the flows and the ramps in flows over various durations can be constrained based on the scenario. Hurdle rates can also be applied to represent friction between balancing areas.

Simultaneous flow constraints can also be applied over collections of interties to constrain interactions with neighboring regions.

A.4 Investment Decisions

A.4.1 Renewable Resources

The RESOLVE model was designed primarily to investigate investment driven by renewable energy policy goals. This constraint is flexible and can include renewable sales targets, procurement targets, carbon targets or carbon prices. For South Africa, we have modeled different levels of renewables depending on the case that each represent varying levels of renewable procurement, carbon, and renewable sales. Our goal has been to preserve the renewable build in each case as the only policy constraint. RESOLVE allows the user to specify a set of resources that must be built in each modeled year, as well as additional renewable resources that may be selected by the optimization. These options allow for the design of portfolios that consider factors such as environmental or institutional barriers to development.

While a traditional capacity-expansion model might take into consideration the technology cost, transmission cost, capacity factor of candidate renewable resources, RESOLVE also considers (1) the energy value through avoided operational costs, (2) capacity value through avoided resource adequacy build, and (3) the integration value through avoided renewable resource overbuild. These three factors depend on the timing and variability of the renewable resource availability as well as the operational capabilities of the rest of the system. To account for all of these factors, each candidate resource is characterized by its hourly capacity factor over the subset of modeled days, installed cost on a per kW basis, location within a set of transmission development zones, and maximum resource potential in MW.

A.4.2 Integration Solutions

RESOLVE is given the option to invest in various renewables integration solutions, such as different types of energy storage or gas resources. Renewable curtailment occurs when the system cannot accommodate all of the procured renewable energy in hourly operations. Although no explicit cost penalty is applied to the curtailment observed in the system dispatch, the implicit cost is the cost of additional fuel burn and, in the case of a renewable energy sales constraint, overbuilding renewable resources to replace the curtailed energy and ensure compliance with the renewable energy target. This renewable overbuild cost is the primary renewable integration cost experienced by the system and may be reduced by investment in integration solutions.

A.5 System Operational Constraints

RESOLVE requires that sufficient generation be dispatched to meet load in each hour in each modeled zone. In addition, dispatch in each zone is subject to a number of constraints related to the technical capabilities of the fleets of generators within the zone, which are described in detail below. In general, dispatch in each zone must satisfy

$$\sum_{i\in I_z} x_h^{it} + w_h^{zt} + \sum_{\omega\in Z}\sum_{j\in J_{z\omega}} (R_{jt}^{tot} r_h^j - q_h^{jt}) + \sum_{k\in K_z^{in}} f_h^{kt} - \sum_{k\in K_z^{out}} f_h^{kt}$$

$$+ x_h^{dzt} - x_h^{czt} + u_h^{zt} - o_h^{zt} = l_h^{zt}$$

Where:

l_h^{zt} is the load in zone *z*, year *t*, and hour *h*;

x_h^{it} is the generation from thermal resource *i*;

I_z is the set of all thermal resources in zone *z*;

R_{jt}^{tot} is the total installed capacity of renewable resource *j*;

q_h^{jt} is the curtailment of renewable resource j;

$J_{z\omega}$ is the set of all renewable resources located in zone *z* and contracted to zone *ω*;

w_h^{zt} is hydro generation in zone *z*;

x_h^{dzt} and x_h^{czt} are the energy discharged from energy storage and energy extracted from the grid to charge energy storage respectively;

u_h^{zt} is the undergeneration and o_h^{zt} is othe overgeneration in zone *z*;

f_h^{kt} is the flow over line k, and

K_z^{in} and K_z^{out} are the sets of all transmission lines flowing into and out of zone *z*, respectively.

A.5.1 Reserve Requirements and Provision

RESOLVE requires upward and downward load following reserves to be held in each hour in order to ensure that the system has adequate flexibility to meet subhourly fluctuations and to accommodate forecast errors. In real systems, reserve requirements depend nonlinearly on the composition of the renewable portfolio and the renewable output in each hour. To avoid additional computational complexity, RESOLVE requires the user to specify the hourly reserve requirements for each scenario. The reserves used in this study come from the ESKOM Ancillary Service Technical Requirements for 2016/17 – 2020/21 [0215]. Reserves are held constant from 2021 through 2030.

The user specifies whether each technology is capable of providing flexibility reserves, and the reserve provisions available from each technology are described above. Flexibility reserve violations are penalized at a very high cost to ensure adequate commitment of resources to meet flexibility challenges within the hour. In South Africa, we model a generic upward and downward reserve requirement with an additional requirement for instantaneous reserves. The offering of instantaneous reserves with the coal fleet is assumed to have an efficiency penalty on the heat rate of the units. Our base case assumption is an energy conversion efficiency drop of 0.2% for coal generators. Each generator is assumed to offer up to 3% of capacity toward instantaneous reserves to provide the required amount in each hour. For a 600-MW generic unit size, this corresponds to 18 MW. RESOLVE models the storage benefit by realizing the efficiency gains in coal operations for every 18 MW of instantaneous reserves it can displace. We also assume conservatively that pumped hydro cannot offer instantaneous reserve. If pumped hydro is capable of offering instantaneous reserve, the potential for battery storage to offer this service would be significantly diminished.

RESOLVE allows the user to constrain the absolute amount of observed subhourly curtailment in each hour to reflect potential limits in the participation of renewable resources in real-time markets or real-time dispatch decisions. These limits are typically set as a fixed fraction of the available energy from curtailable renewable resources in each hour. Finally, RESOLVE allows the user to apply a minimum constraint on the fraction of the downward reserve requirement held with conventional units. This constraint reflects a level of conservativism on the part of the system operator. Although full participation of renewable resources in real-time markets may be the lowest cost approach to managing downward flexibility challenges, a system operator may seek to keep some downward flexibility across the conventional fleet as a backstop if the full response from renewable resources does not materialize in real time. Operating knowledge on this subject is limited; however, it is anticipated that with improved participation of renewable resources in markets over the next several years, additional data can be brought to bear on this question of renewable responsiveness at the subhourly level and the extent to which system operators can rely on it when scheduling conventional resources. In this study, we assume that all reserves are provided by nonrenewable technologies.

A.6 RESOURCE OPERATIONAL CONSTRAINTS

A.6.1 THERMAL RESOURCES

For large systems such as those of South Africa, thermal resources are aggregated into a homogenous fleet of units that share a common unit size, heat rate curve, minimum stable level, minimum up and down time, maximum ramp rate, and ability to provide reserves. In each hour, dispatch decisions are made for both the number of committed units and the aggregate setpoint of the committed units in the fleet. For sufficiently large systems such as South Africa, commitment decisions are represented as continuous variables. For smaller systems, specific units may be modeled with integer commitment variables. For the continuous commitment problem, reserve requirements ensure differentiation between the committed capacity of each fleet and its aggregated set point. The ability of each fleet to provide upward reserves, $\overline{x}_h^{it}$, is:

$$x_h^{it} + \overline{x}_h^{it} \leq n_h^{it} x_{max}^i \; \forall i, t, h$$

where n_h^{it} is the number of committed units and x_{max}^i is the unit size. Downward reserve provision is limited by:

$$x_h^{it} - \underline{x}_h^{it} \geq n_h^{it} x_{min}^i \; \forall i, t, h$$

where x_{min}^i is the minimum stable level of each unit.

Upward reserve requirements are imposed as firm constraints to maintain reliable operations but downward reserve shortages may be experienced by the system with implications for renewable curtailment. The primary impact of holding generators at setpoints that accommodate reserve provisions is the increased fuel burn associated with operating at less efficient setpoints. This impact is approximated in RESOLVE through a linear fuel burn function that depends on both the number of committed units and the aggregate setpoint of the fleet:

$$g_h^{it} = e_i^1 x_h^{it} + e_i^0 n_h^{it}$$

where g_h^{it} is the fuel burn and e_i^1 and e_i^0 are technology-specific parameters.

Minimum up and down time constraints are approximated for fleets of resources. In addition, startup and shutdown costs are incurred as the number of committed units changes from hour to hour, and constraints to approximate minimum up and down times for thermal generator types are imposed.

Must-run resources are modeled with flat hourly output based on the installed capacity and a derate factor applied to each modeled day based on user-defined maintenance schedules. Maintenance schedules for must-run units are designed to overlap with periods of the highest anticipated oversupply conditions so that must-run resources may avoid further exacerbating oversupply conditions in these times of year. Maintenance and forced outages may be treated for any fleet through the daily derate factor. However, in the analysis presented here, maintenance schedules for dispatchable resources were not explicitly modeled – it was instead assumed that maintenance on these systems could be scheduled around the utilization patterns identified by the dispatch solution.

A.6.2 HYDRO RESOURCES

Hydro resources are dispatched in the model at no variable cost, subject to an equality constraint on the daily hydro energy; daily minimum and maximum outputs constraints and multihour ramping constraints. These constraints are intended to reflect seasonal environmental and other constraints placed on the hydro system that are unrelated to power generation. The daily energy, minimum, and maximum constraints are derived from historical data from the specific modeled days taken from California to approximate this small resource contribution. Ramping constraints, if imposed, can be derived based on a percentile of ramping events observed over a long historical record. Hydro resources may contribute to both upward and downward flexibility reserve requirements, but not to instantaneous reserves in this study.

A.6.3 Energy Storage

Each storage technology is characterized by a round-trip efficiency, per unit discharging capacity cost ($/kW), per unit energy storage reservoir or maximum state of charge cost ($/kWh) and, for some resources, maximum available capacity. Energy storage investment decisions are made separately for discharging capacity and reservoir capacity or maximum state of charge. Dispatch from each energy storage resource is modeled by explicitly tracking the hourly charging rate, discharging rate, and state-of-charge of energy storage systems based on technology-specific parameters and constraints. Reserves can be provided from storage devices over the full range of maximum charging to maximum discharging. This assumption is consistent with the capabilities of battery systems, but may overstate the flexibility of pumped storage systems. Pumped storage can only provide reserves in pumping mode if variable speed pumps are installed, may not be able to switch between pumping and generating on the time scales required for reserve products, and are subject to minimum pumping and minimum generating constraints. The instanteous reserve offering possible from pumped hydro will depend on the constraints of their operations.

An adjustment to the state of charge is assumed that represents the cumulative impact of providing flexibility reserves with the device over the course of the hour. For example, if a storage device provides upward reserves throughout the hour, it is anticipated that over the course of the hour the storage device will be called upon to increase its discharge rate and/or decrease its charge rate to help balance the grid. These subhourly dispatch adjustments will decrease the state of charge at the end of the hour. Similarly, providing downward reserves will lead to an increase in the state of charge at the end of the hour. Little is known about how energy storage resources will be dispatched on subhourly timescales in highly renewable systems – this behavior will depend on storage device bidding strategies and technical considerations like degradation. Rather than model these factors explicitly, RESOLVE approximates the impact of subhourly dispatch with a tuning parameter, which represents the average deviation from hourly schedules experienced as a fraction of the energy storage reserve provision.

Appendix B – References

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ACRONYMS

ARPA-E	Advanced Research Projects Agency—Energy)
BMS	battery management system
CAES	compressed air energy storage
CAFD	cash available for distribution
CRL	commercial readiness level
DDM	Due Diligence Matrix
DFI	development finance institution
DOE	Department of Energy
EPC	engineering, procurement, and construction
EPCM	engineering, procurement, and construction management
ESA	energy storage agreement
ESS	energy storage system
IP	intellectual property
IPO	initial public offering
IPP	independent power producer
IRP	Integrated Resource Plan
IRS	Internal Revenue Service
ISO	independent system operator
Li-ion	lithium ion
LLC	limited liability company
MLP	master limited partnership
NaS	sodium-sulfur
NASA	National Aeronautics and Space Administration
NYSE	New York Stock Exchange
O&M	operations and maintenance
PACE	property assessed clean energy
PCS	power conversion system
PG&E	Pacific Power and Gas
PPA	Power Purchase Agreement
PTP	partnership for tax purposes
PV	photovoltaic
R	South African Rand
R&D	research and development
REC	renewable energy credit
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
REIT	Real Estate Investment Trust
SC	supercapacitor
SCE	Southern California Edison

SPC	special purpose company
SPE	special purpose entity
SSA	Storage Services Agreement
TRA	Technology Readiness Assessment
TRL	technology readiness level
UK	United Kingdom
USD	US dollar
USDOE	US Department of Energy
USTDA	US Trade and Development Agency
Zn-Br	zinc-bromine

1 Introduction

This document provides the results of the Task 2.3 "Financial Assessment" of Objective 2, "Technology, Economic, and Financial Assessments" performed in support of the overall United States Trade and Development Agency (USTDA) South Africa Energy Storage Technology and Market Assessment effort.

1.1 Synopsis

Section 2 provides an overview of the bankability and key financial risks associated with the energy storage technologies and concludes that lithium-ion (Li-ion) is currently the battery of choice and arguably the most bankable technology for grid-scale energy storage.

Section 3 provides an overview of typical financing structures used in energy storage projects elsewhere around the world and recommendations for proposed financing structures for energy storage projects in South Africa.

Section 4 identifies international best practices for key contracting arrangements (e.g., off-take agreements and guarantee packages) and key technical loan terms and conditions, as well as innovative financial products and structures that can support the adoption of energy storage technologies in South Africa.

Section 5 presents financial products or structures in use or being adopted by the renewable energy industry in the United States and internationally. These structures could all be adopted for use with energy storage projects and for use in South Africa.

Section 6 identifies the perceived key risks, barriers, challenges, and opportunities for financing energy storage projects in South Africa that were identified through discussion with potential financiers.

2 Bankability of Technologies

This section provides an overview of the bankability and key financial risks associated with each energy storage technology identified under Task 1.2, Technology Assessment. It also describes the difference between technology bankability and project bankability, as well as the necessity for adequately mature and sophisticated monitoring and control systems in the development of storage projects.

2.1 Technology Bankability

Energy storage is viewed as the next enabling technology that will be required to cost-effectively facilitate grid modernization while allowing for the full potential of renewable energy power generation and distribution to be realized. The rapid pace of development of new storage technologies and project deployments is widely viewed as following the same path as solar and wind with respect to the need for mainstream financing. However, unlike solar and wind — which rely on debt, equity, and power purchase agreement (PPA) financing structures with predictable fixed revenues and built-in cost escalators — energy storage projects have the potential for multiple-use applications within a given project to enable variable revenue streams. This increased flexibility serves as both an opportunity for creative project development and a risk to realizing full revenue projections [Ref. 373].

For this study, a bankable technology would be one that is sufficiently mature so that, when properly applied, the resulting performance and reliability can be adequately predicted to ensure the overall technological success of the project. Bankability is determined through an assessment of the likely risks associated with a technology and evaluates whether the risks are sufficiently low and adequately controlled, or bounded, so that an informed lender can be reasonably confident in the technical success and profitability of the project.

The US Department of Energy (USDOE) uses a tailored version of a proven National Aeronautics and Space Administration (NASA) Technology Readiness Assessment (TRA) model that addresses the maturity of an evolving technology. As shown in Table 2-1, Technology readiness levels (TRLs) are expressed as a numerical value between TRL 1 and TRL 9 [Ref. 387]. For an energy storage technology to be considered “bankable,” it should be developed to an equivalent TRA-9 level, i.e., it has been deployed using similar equipment and systems and operated in a full-scale application under all expected operational conditions for an extended period.

Table 2-1: Technical Readiness Level (TRL) Definitions [Ref. 387]

TRL	Description
1	Scientific research begins translation to applied R&D – Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2	Invention begins – Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Active R&D is initiated – Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Basic technological components are integrated – Basic technological components are integrated to establish that the pieces will work together.
5	Fidelity of breadboard technology improves significantly – The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include “high fidelity” laboratory integration of components.
6	Model/prototype is tested in relevant environment – Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
7	Prototype near or at planned operational system – Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.
8	Technology is proven to work – Actual technology completed and qualified through test and demonstration.
9	Actual application of technology is in its final form – Technology proven through successful operations.

The USDOE’s Advanced Research Projects Agency—Energy (ARPA-E) has developed a similar system for assessing a commercial readiness level (CRL) that provides a means for all parties to discuss the commercial development of a technology. Like the TRL, the CRL is important because the rating implies adherence to a set of standardized commercial milestones, assuring the users of continual progress toward a commercially ready solution [Ref. 438].

Because the TRL and CRL scales describe two different attributes of the system, they are not directly comparable, and they typically overlap. As with the TRL, the CRL scale ranges from 1 to 9, as shown in Table 2-2.

Table 2-2: Commercial Readiness Level (CRL) Definitions [Ref. 438]

CRL	Description
1	Knowledge of applications, use cases, and market constraints is limited and incidental, or has yet to be obtained.
2	A cursory familiarity with potential applications, markets, and existing competitive technologies/products exists. Market research is derived primarily from secondary sources. Product ideas based on the new technology may exist, but they are speculative and unvalidated.
3	A more developed understanding of potential applications, technology use cases, market requirements/constraints, and a familiarity with competitive technologies and products allows for initial consideration of the technology as product. One or more "strawman" product hypotheses are created and may be iteratively refined based on data from further technology and market analysis. Commercialization analysis incorporates a stronger dependence on primary research and considers not only current market realities but also expected future requirements.
4	A primary product hypothesis is identified and refined through additional technology-product-market analysis and discussions with potential customers and/or users. Mapping technology/product attributes against market needs highlights a clear value proposition. A basic cost-performance model is created to support the value proposition and provide initial insight into design trade-offs. Basic competitive analysis is carried out to illustrate unique features and advantages of technology. Potential suppliers, partners, and customers are identified and mapped in an initial value-chain analysis. Any certification or regulatory requirements for product or process are identified.
5	A deep understanding of the target application and market is achieved, and the product is defined. A comprehensive cost-performance model is created to further validate the value proposition and provide a detailed understanding of product design tradeoffs. Relationships are established with potential suppliers, partners, and customers, all of which are engaged in providing input on market requirements and product definition. A comprehensive competitive analysis is performed. A basic financial model is built with initial projections for near- and long-term sales, costs, revenue, margins, etc.
6	Market/customer needs and how those translate to product needs are defined and documented (e.g., in market and product requirements documents). Product design is optimized by considering detailed market and product requirements, cost/performance tradeoffs, manufacturing tradeoffs, etc. Partnerships are formed with key stakeholders across the value chain (e.g., suppliers, partners, customers). All certification and regulatory requirements for the product are well understood and appropriate steps for compliance are under way. Financial models continue to be refined.
7	Product design is complete. Supply and customer agreements are in place, and all stakeholders are engaged in product/process qualifications. All necessary certifications and/or regulatory compliance for product and production operations are accommodated. Comprehensive financial models and projections have been built and validated for early stage and late stage production.
8	Customer qualifications are complete, and initial products are manufactured and sold. Commercialization readiness continues to mature to support larger scale production and sales. Assumptions are continually and iteratively validated to accommodate market dynamics.
9	Widespread deployment is achieved.

Pilot or prototype applications of early-stage technologies (at CRL-6 or CRL-7) might be funded through cash or owner-operator sources until both the technology and projects are deemed "bankable." A technology might be considered initially bankable at CRL-8. The transition from an initial demonstration or proof-of-concept project to full-scale commercial application can be difficult because full-scale application may be beyond the financial resources of a young research and development (R&D) company or its equity investors. Programs such as the USDOE Loan Guarantee Program in the United States or the Industrial Development Corporation in South Africa play a key role in providing funding or loan guarantee for loans of an initial full-scale commercial application.

Table 2-2 shows a high level assessment of the maturity and developmental status of each general technology identified in Task 2.1. This table includes the technologies evaluated to have relevance in the South Africa Energy Storage Market currently or in the future. Technologies not meeting the relevance criteria have been screened out.

Table 2-3: Assessment of Technology Bankability and Associated Risks

Technology	Overall Technical Bankability	Key Risks
Advanced lead acid battery	Strong	
Li-ion battery	Strong	Thermal runaway resulting in fire or system damage
Sodium sulfur (NaS) battery	Strong	Loss of containment or short circuiting resulting in fire or damage
Supercapacitor	Strong	Demonstrated ability to effectively integrate SC into hybrid ESS
Flywheel	Moderate	No current vendors in production Long-term reliability of flywheels and components
Vanadium redox flow	Moderate	Manufacturing processes Cost volatility of vanadium Long-term reliability of system components
Zinc-bromine (Zn-Br) flow	Moderate	Potential environmental and personnel hazards associated with bromine Leaks or spills of highly corrosive electrolyte Long-term reliability of membrane and resultant need for replacement
CAES tank storage	Moderate	Lack of commercial production of compression and expansion components Lack of inexpensive tank with proven long-term performance
Liquid air	Moderate	Lack of commercial manufacturing processes Lack of utility-scale commercial facility Long-term reliability of system components
CAES adiabatic cavern	Weak	Technology not mature at scale Lack of pilot or commercial facilities Long-term reliability of system components
Iron-chromium flow	Weak	Lack of mature design and manufacturing processes Lack of successful pilot or commercial facilities Long-term reliability of system components
Liquid metal	Weak	Technology not mature Lack of a final cell design and manufacturing process Lack of demonstration, pilot, or commercial facilities Long-term reliability of system components
Metal air	Weak	Technology not mature at scale Lack of a large-scale cell design and manufacturing process Lack of pilot or commercial facilities Long-term reliability of system components

Li-ion is currently the battery of choice and arguably the most bankable technology for grid-scale energy storage. Individual projects based on Li-ion are scaling up to the tens — and soon hundreds — of megawatts. These battery cells have proven themselves in laptops, cell phones, and electric vehicles; however, for large-scale grid energy storage, the required battery system architecture is quite different. Large grid batteries typically have long battery strings each containing hundreds of cells. The performance of the system often hinges on the weakest link, which introduces new challenges and some risks. With grid energy storage projects that contain thousands of cells, the controls and data acquisition systems are critical [Ref. 376]. Advanced lead acid is a scalable mature technology with few identified weaknesses.

Several other technologies, including lead acid, sodium sulfur (NaS), and supercapacitors, are sufficiently mature and are considered bankable. Technical bankability is a reflection of the maturity of the technology and the relative certainty of performance and reliability; however, it does not necessarily mean that these are the most competitive technologies for any given application.

A number of evolving energy storage technologies have achieve technical bankability and are nearing commercial bankability. Several companies have deployed flow batteries on a smaller industrial or commercial scale and are now expanding to deploy demonstration and pilot projects at a utility scale. Reliable, long-term operation and performance of the initial utility scale systems will be the precursor to full bankability of these technologies. Other technologies such as compressed air energy storage (CAES) small reservoir, liquid air, gravity storage are slightly further behind and are in the process of showcasing demonstration projects.

Other technologies, such as metal air or liquid metal, are still in basic R&D and have a still longer path to eventual technical bankability. Further innovation and pilot and demonstration projects are still needed; one of these technologies is likely to be able to compete with Li-ion at some point in the future, but the grid-scale systems being deployed today must operate with high reliability and safety for a number of years. Utilities have high standards, and all new technologies will need a substantial period of vetting before they can be deployed on a broad scale.

2.2 Project Bankability

Bankability of an underlying technology should not be confused with bankability of an overall specific project, which goes well beyond the demonstrated maturity of an underlying technology. A project with a bankable technology may not represent a bankable project if it has weaknesses in areas other than technology.

Bankability for a project is achieved when (1) a lender is satisfied that a given project will be successful so that the borrower will profit from the project and be able to repay the loan plus interest; and (2) when a lender is satisfied that the contractual allocation of risk between the project parties is such that, even if difficulties are encountered, the debt will be protected so far as reasonably possible. A bankable project will be able to compete for non-recourse lending.

The project development team or project sponsors must provide sufficient design, manufacturing, and performance data to demonstrate a record that will enable a lender and its technical advisors to determine project bankability. Other alternatives for a project/technology that fall short of full bankability are to seek recourse financing, to offer parent company guaranties, or to provide technology insurance.

For a project to be considered bankable by a lending institution, it must demonstrate the adequacy and viability of all aspects of the proposed project:

- Proposed Technologies
- Integrated Project Design
- Site Selection, Environmental, and Permitting
- Project Schedule
- Project Budget
- Financial Pro Forma
- Experience and Qualifications of Project Staff
- Project and Supplier Quality Programs
- Adequacy of Supply Chain
- Adequacy and risk allocation within all major contracts
- Supporting company balance sheets
- Past performance by participants

2.3 CONTROL SYSTEM BANKABILITY

Although this section addresses the perceived bankability of the energy storage technologies identified in Task 2.1, it is important to understand that a complete energy storage system (ESS) requires more than batteries and an inverter. As shown in Figure 2-1, numerous components and subsystems must be integrated. The industry has not arrived at a point where storage system components can be considered “plug and play.” The careful selection and evaluation of a project integrator and control system software developer can be essential to the ultimate success of a project from design and engineering through to long-term operations and maintenance (O&M) [Ref. 373].

Control software and the algorithms necessary to control the battery system and power conversion system (PCS) and to communicate with the utility or integrated systems operator are complex and require a thorough understanding of all underlying systems and components. This includes the batteries, system configuration, power conversion hardware, and battery management system (BMS), as well as a review of the monitoring, communications, and control systems, and balance of plant.

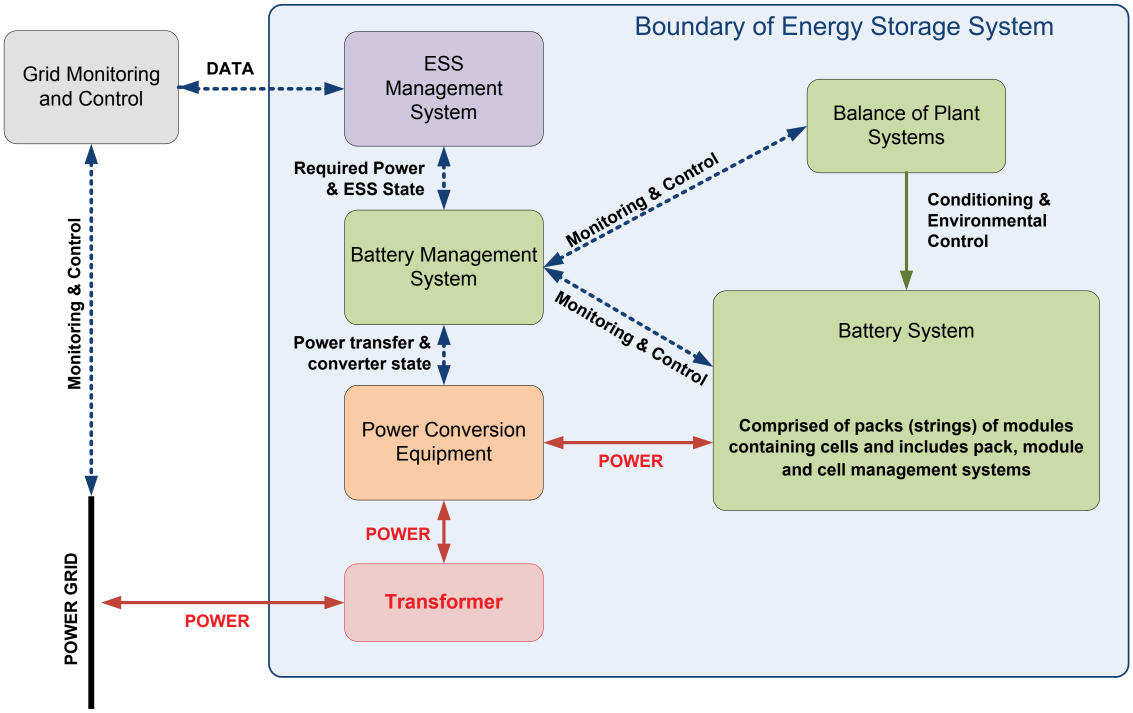

Figure 2-1: Interrelation of Subsystems within an Energy Storage System [modified from Ref. 376]

A unique aspect of an integrated ESS is the operational and advanced storage dispatch control software and the BMS, which are layered over the battery technology. This software is essential in generating the revenue streams and cash flows upon which the project financial model is based. The maturity of energy storage control software for peak shifting, energy firming, and grid resiliency applications, along with the underlying storage technology, are essential to the success of the project. As more opportunities arise for aggregated storage to participate in utility and independent system operator (ISO) capacity and regulation markets, aggregator control layers will require further layers of validation. Without independent validation of this key component, the reliability and robustness of the other aspects of energy storage projects could be meaningless or could impede adoption and market growth [Ref. 373].

3 Energy Storage Financing Structures

Project finance is the current leading method of financing large infrastructure projects that might otherwise be too expensive or risky to be carried on a corporate balance sheet. The basic tenet of project finance is that lenders loan money for the development of a project based on the specific project's risks and future cash flows. In project finance, the lenders generally have either no recourse or limited recourse to the parent company that owns, develops, or "sponsors" the project. The accurate assessment and control of project risks, and a high degree of confidence in the projected revenue flow then become essential factors in the development of a project to be financed. This is equally important for energy storage projects.

Project financing has become particularly important to project development in emerging markets, with participants often relying on guarantees, long-term off-take or purchase agreements, or other contractual relationships with the host sovereign or its commercial appendages to ensure the long-term viability of individual projects. These were typically backstopped by multilateral lending agencies that mitigated some of the "political" risks to which the project lenders were exposed [Ref. 433].

As the energy storage industry accelerates into sustained commercial growth, project financing is emerging as the linchpin for the future health, direction, and momentum of the industry. For many years, the energy storage industry has made great progress in developing the technology, standards, public policy, and market rules that have formed the basis of today's market. These elements have led to the expanding opportunities for energy storage that now seem almost limitless, but in reality those opportunities are severely inhibited by the lack of available and cost-effective capital. The low level of understanding and discomfort of lenders on these issues is preventing many from making an informed and timely decision regarding which project to fund [Ref. 434].

Figure 3-1 shows a typical project finance structure for a renewable energy project. The roles of the key participants and agreements are as follows:

- **Project Sponsor** or project developer is an individual or company in charge of creating/acquiring and managing the project. The sponsor conceptualizes the project and develops it sufficiently to attract equity and loans capital necessary to finance the project.
- **Special Purpose Company** (SPC), or Project Company, is an entity formed to hold all of the project's assets, including all of its contractual rights and obligations. The SPC is usually a single-member limited liability company (LLC), although in some cases it may be a limited partnership.
- **Equity Investors** provide capital in exchange for an ownership interest in the SPC. This interest can be in the form of ownership of common or preferred stock or instruments that convert into stock. In addition to taking an ownership interest in the SPC, equity investors

may also participate as a member of the SPC's board of directors and take an active role in managing the company.

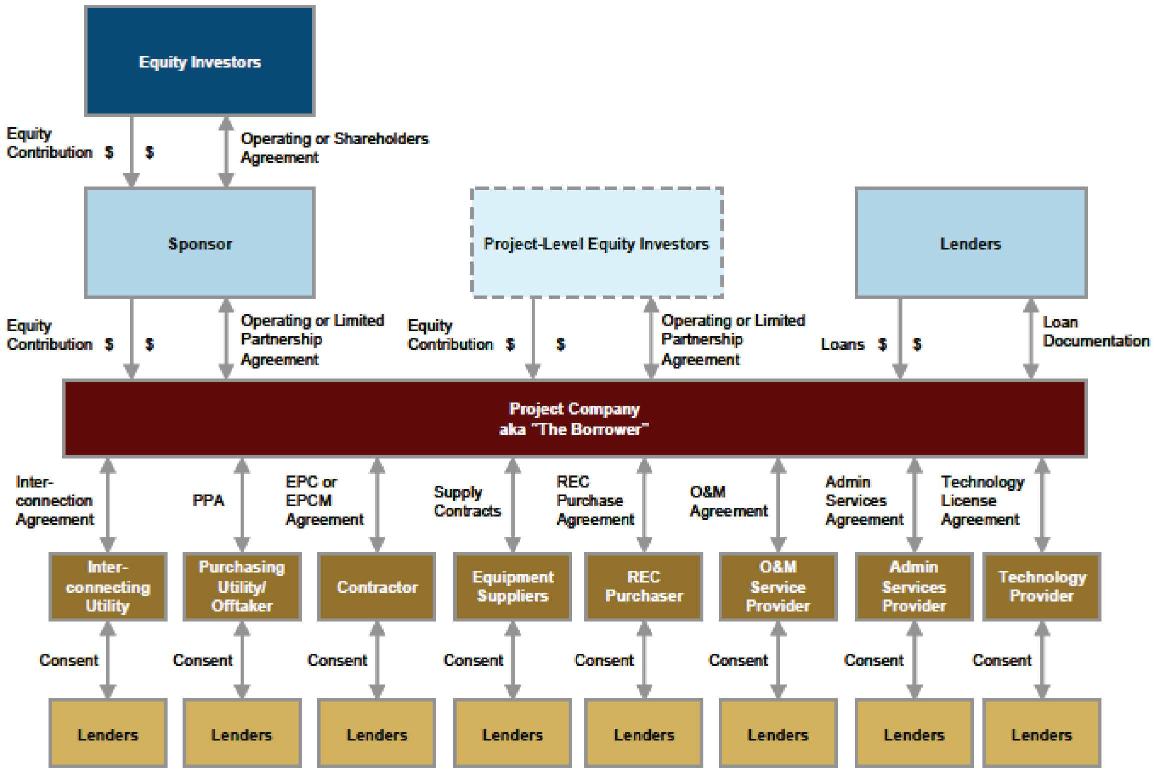

Figure 3-1: Typical Project Finance Structure [Ref. 434]

- **Project level Equity Investors** represent additional equity brought into the project after it is initially developed.
- **Lenders** are the entities that loan money to the SPC at a specific interest rate to be repaid over a period. The lender may be a single institution of a consortium of several lending institutions (alternately an international loan syndication) that group together to jointly finance a single borrower. A loan syndication is led a managing bank that is generally responsible for negotiating conditions and arranging the syndicate. Lenders can be commercial investment bank or development finance institutions (DFIs) that provide credit in the form of higher risk loans developing countries.
- **Project Agreements** are contracts related to the development, construction, ownership, and operation of the project that are entered into by the SPC. It is important that the development-stage contract executed by the Sponsor or one of its affiliates can be assigned to the SPC once it has been established for the purposes of pursuing project financing. Typically, the lender will have the right of consent (approval) for each agreement and may also have a direct agreement that allows the lender to step-in in place of the SPC in case of default. Project agreements typically include the following:

- **Interconnection Agreement** between the SPC and an electrical utility that governs the requirements for connection of the ESS to the utilities electrical grid.
- **Power Purchase Agreemen**t (PPA) between an off taker and the SPC for the purchase/sale of energy. Some US utilities (e.g., PG&E, SCE) have entered into what they have called energy storage agreements (ESAs) for ESS, which address the sale of capacity, energy, and ancillary services associated with both capacity and energy provided by the ESS facility. Alternately, the term Storage Services Agreement (SSA) has been use by some providers.
- **Engineering, Procurement, and Construction (EPC) Contract** between the SPC and a construction firm to perform the detailed engineering design of the project, procure all necessary equipment and materials, and then construct to deliver a functioning facility or asset. Alternately, this could be an engineering, procurement, and construction management (EPCM) contract in which the contractor is not directly involved in performing the construction but is responsible for administering the construction contracts.
- **Supply Contracts** are between the SPC and major suppliers of major equipment, components, or materials necessary or specific to the technology.
- **Renewable Energy Credit (REC) Purchase Agreement** provides for the sale of RECs generated by the project. This would more likely related to renewable energy generation project with co-located energy storage.
- **Operations and Maintenance (O&M) Contract** provides for the continued operation of the facility after construction and turnover, as well as ongoing and periodic maintenance and upkeep. For energy storage facilities, this can include a long-term maintenance contract with the technology provider or a third-party operator.
- **Administrative Services Agreement** (or Asset Management Services) consists of the financial, commercial, and administrative activities necessary to ensure that a plant's energy production translates into the appropriate revenue stream. Separate from O&M services, these activities typically include billing and collections and sometimes distributions to investors, management of incentives, accounting and financial reporting, administrative interface with regulations, local authorities, and grid operators and insurance paperwork and processing.
- **Technology License Agreement** grants license to, and specifies the conditions under which, the facility owner can use and operate the technology provider's equipment and intellectual property. This often includes provision for continued technical support, maintenance, and upgrade of the equipment/technology and includes compensation provisions.

In determining whether to support, invest, or become involved in a project, it is essential to examine the project structure and finances to determine its soundness. The following questions should be useful in determining if project financing is a realistic opportunity [modified from Ref. 434]:

- Is an individual project or group of projects of a sufficient size to make either a stand-alone or portfolio project financing worthwhile? Lenders are typically reluctant to provide project financing if the total amount of debt is less than US$50 million and, preferably, US$100 million. Residential, commercial, and light industrial behind-the-meter energy storage projects may have to be bundled.
- Will a revenue stream from the project be large enough to support highly leveraged debt financing? Recent studies have shown that ESSs may be profitable using "stacked benefits" and accessing multiple revenue streams. Not all these revenue streams have been fully established for energy storage in South Africa; some regulatory changes may be required to establish these markets.
- Will the receipt of revenue be enforceable under contractual rights against a creditworthy party? This is not necessarily a prerequisite for all project financings, but the absence of a contract, or questionable creditworthiness of the purchaser, will prompt lender skepticism and necessitate thorough due diligence regarding future revenue projections.
- Will physical assets be sufficient to ensure lender repayment in case of foreclosure? Lenders will want to know that, even if the Project Company's projected revenue stream does not materialize, they will be able to foreclose on the project's assets sufficient in value to "make themselves whole," either by selling the project outright or operating it until the debt is repaid. The greatest risk is with failed technologies, components, or bankrupt technology companies that may render the energy storage capital assets essentially worthless.
- Is a significant level of technology risk involved? Project finance lenders almost never want to be the first to finance an untested technology. Demonstrated successful use in some context is often necessary to secure project financing.
- Does the project have contractual relationships with reputable companies for services key to the success of the project or the technology it employs? Lenders will be less likely to lend to a project the success of which depends solely on a few talented individuals who may depart, leaving the project unable to meet its potential.
- Is the Sponsor ultimately willing to "risk the project"? In other words, once project financing is completed, the Sponsor loses the ability to determine how the vast majority of the project's revenue is spent. If a project becomes uneconomic and is unable to service its debt, the only option other than refinancing the debt may be to turn over the project to the lenders (voluntarily or involuntarily), with the corresponding loss of the Sponsor's investment in the project.
- Is the Sponsor looking for a quick exit? Once project-financed, divestiture opportunities are complicated by the requirement of lender consent, and potential purchasers will be

thoroughly examined by lenders for development and operational expertise, as well as creditworthiness.

- Are sponsors willing to grant rights of high-level oversight regarding the project's development and operation to project finance lenders? In many cases, the interests of the sponsor and the lenders will be aligned, and lenders will tend to defer to the sponsor's developmental expertise. On the other hand, lenders must be viewed as additional project partners with veto rights over many significant decisions.

4 International Best Practices for Energy Storage Financing

As mentioned in Section 3, two critical factors in the development of projects with limited or no recourse financing are the accurate assessment and control of project risks and a high degree of confidence in the projected revenue flows. These two factors are particularly important for energy storage, where evolving technologies are being introduced into new markets. The following general practices are presented for consideration as international best practices for clean energy projects and specifically energy storage projects and are categorized by their general objective:

- **Ensure that the project is constructed within the budget and schedule.**
  - The owner should contract with a reliable, well established EPC/ESS Integrator under a total turnkey, design-build, firm fixed price, date certain contract. For energy storage projects there are many extremely experience system integrators such as AES Energy Storage, NEC Energy Solutions, RES Americas, S&C Electric, Greensmith Energy Management Systems, Green Charge Networks.
  - The EPC or integrator should offer a “full wrap” in which it assumes responsibility for all warranties and guarantees for the entire project. This means that the owner has recourse to the EPC/integrator for many issues. As appropriate, the SPC should consider obtaining technology insurance.
  - When possible, the EPC should be required to execute on a “back-to-back” basis. Back-to-back language has the EPC assuming responsible for fulfilling as many of the owner's obligations as possible with other SPC agreement parties such as interconnection, permitting, technology provider, and suppliers. This tends to shift risk for change orders driven by changing requirements from the owner’s control to the EPC.
  - The owner should consider contractor’s/builder’s “all risk” insurance, which insures the principal/employer and covers the contract works undertaken by the contractor and subcontractors on the project. This insurance can be purchased by either the owner or by the contractor.
  - The EPC contract should include liquidated damages in an amount that shield the owner from additional finance charges, continuing management and carrying costs, and any resultant penalties from the PPA/ESA. It is also advised to include a shared benefits clause that provides a bonus to the contractor for early completion.
- **Ensure that the project can generate the predicted revenues.**
  - The owners and lenders must fully understand the assumptions underlying the financial model and ensure that the model is conservative in estimating revenue and any impacts associated with future loads/demands, and capacities that could affect those assumptions. This may require hiring a third party with specific experience in this area.

- The EPC contract should require rigorous performance testing prior to acceptance of the completed facility. This testing should thoroughly demonstrate facility performance in all modes of operation, addressing all benefits and circumstances envisioned in the revenue assumptions of the financial model. The control system software should be fully validated to be capable of generating the revenue streams and cash flows upon which the project financial model is based. As discussed in Section 2.3, the maturity of energy storage control software for peak shifting, energy firming, and grid resiliency applications, along with the underlying storage technology, are essential to the success of the project.
- Beyond acceptance testing, the EPC or technology contractor should include a reliability period for the monitoring of actual operating conditions and actual revenue generation over an initial period (1 to 3 years) to ensure that the integrated system operates in the manner necessary to generate the revenues predicted in the performance model. The contract should include compensation from either the technology provider or the contractor for any underperformance prorated over the expected life of the project.
- The technology contract should specify intellectual property (IP) rights specific to licenses necessary to use, and maintain any technology incorporated into the overall system over the life of the project. As appropriate, this should include access to escrowed technical information (e.g., software source codes) if the technology supplier goes bankrupt.

▶ **Ensure that the revenues will be paid.**

- The PPA/ESA must be carefully developed to consider and provide for all forms and combinations of services and revenues contemplated by the financial model and allowed under operating limitations of the system. If the customer is to be given control of the ESS, the owner must ensure that appropriate operating limitations are placed on system so that long-term performance and system life expectancy are maintained within the assumed limits of the financial model. Because there is limited industry experience in the development of ESS PPAs and there is a deficit of existing standardized agreements to work from, the owner should consider hiring a consultant with specialized experience to be involved in the development and negotiation of the PPA/ESA.
- The PPA should be with a known and reliable entity. In some cases, it may be necessary to obtain third-party guarantees from the sovereign country or other reliable entity. In some cases, political risk insurance may be appropriate.

▶ **Ensure the long-term performance of the system over the term of the loan.**

- The owner should seek to obtain long-term performance guaranties and extended equipment warranties similar to the photovoltaic (PV) industry. Some companies alternately address this issue through the mandatory purchase of a long-term maintenance plan as a basis for a long-term performance guaranty. This ensures that the system is operated within the manufacturer’s limits and that necessary periodic maintenance is performed. Many manufacturers will use this maintenance plan to recoup costs for the replacement of cells or the regeneration or freshening of electrolyte or other systems. In any case, the owner must understand the system sufficiently to ensure that refurbishment or refreshment costs are adequate provided for by the O&M agreement, maintenance agreement, or reserve accounts.

5 Innovative Financial Products

Project financing is document-intensive, time-consuming, and expensive to consummate. It is not unusual that administrative and closing costs, including lenders, consultants, and attorneys' fees for all parties, can equal several percentage points of the amount of the loan commitment.

The following subsections present several financial products or structures in use or being adopted by the renewable energy industry in the United States and internationally. These structures could all be adopted for use with energy storage projects and for use in South Africa, although some would require regulatory changes. Each provides an alternative to project financing.

5.1 Leasing

A leasing agreement provides a method for a customer to gain the use and benefits of an ESS while avoiding a large initial capital outlay or taking direct ownership and responsibility for the asset. The lease funds a special purpose entity (SPE) that is not capitalized and is accounted for as a monthly rental expense by the customer. During the operating lease period, the ESS remains the property of the lessor, which carries and depreciates the asset.

For a number of reasons, this type of financing structure can be very useful to customers behind the meter. A lease is favored by customers that may not be familiar with the technology. This is an attractive option for a technology that is anticipated to experience significant future price reductions.

This arrangement has been a key financing tool in the significant development of the commercial and residential solar PV market. That market uses a variety of operating leasing business models, including models in which the customer paid no upfront cost, paid some of the system cost, or purchased the system prior to end of the lease term. Due in part to its success in developing a mature market, third-party ownership of solar is expected to start declining as a percentage of the overall market because the cost of the PV system has dropped to the point at which people can afford a loan for the system and alternative financing options such as Property Assessed Clean Energy (PACE) and allows the choice to finance the purchase of the system.

Leasing programs in the commercial energy storage market have accelerated over the last few years as companies such as STEM, CODA Energy, ViZn Energy Systems, and Green Charge Networks, etc., have been able to partner with financial groups to provide a funding facility for the energy storage company to finance the energy storage asset and execute an operating lease with the customer. The length of the lease varies among the companies, spanning 3 to 10 years [Ref. 434].

5.2 Green Bonds

Green bonds are debt instruments in which proceeds are used to fund qualifying green investments. Green bonds are essentially the same as traditional bonds in terms of deal structure, but they have different requirements for reporting, auditing, and proceed allocations. These additional requirements also provide marketing and branding value absent from traditional bonds. Any organization with bonding authority may issue green bonds.

Green bonds are intended to enable developers raise capital for projects with environmental benefits. Some of the largest banks and market players (13 major banks, led by Citibank, and the World Bank, European Bank for Reconstruction and Development, Organization of Economic Development and Cooperation, International Finance Corporation, and European Investment Bank) participated in developing the Green Bond Principles, which were released in January 2014 [Ref. 425]. The Green Bond Principles are intended to further a discussion on transparency and disclosure recommended for the financing of environmentally beneficial projects.

Green bonds are anticipated to provide financing for renewable energy, energy efficiency, sustainable waste management, sustainable land use, biodiversity conservation, clean transportation, and clean water projects. Some financial institutions predict a $1 trillion to $2 trillion market for green bonds, which will be used to scale up clean energy projects. In 2015, experts believe that the green bond market will grow by $100 billion; Currently, it is approximately $53.2 billion according to the United Kingdom's (UK's) Climate Bond Initiative [Ref. 424].

The City of Johannesburg, South Africa, was an early entrant into the use of green bonds: in June 2014, it successfully auctioned a green bond listed under the Johannesburg Stock Exchange. The bond (COJGO1) was R1.46 billion and was priced at 185 basis points (1.85%) above the R2023 government bond. The bond auction was a success in that it was 150 percent oversubscribed. The bond provided a funding source to improve and expedite the implementation of its climate change mitigation strategy and move the city toward a low carbon infrastructure, minimal resource reliance, and increased preservation of natural resources. Projects financed by this bond include green initiatives such as the Bio Gas to Energy Project and a Solar Geyser Initiative [Ref. 423].

5.3 Master Limited Partnership

A master limited partnership (MLP) is a publicly traded partnership that combines the benefits of corporations and partnerships. Like corporations, MLPs issue publicly traded interests ("units") that are accessible to investors with a brokerage account. However, MLPs are unincorporated entities under state law, like LLCs or limited partnerships, and are treated as partnerships for tax purposes (PTPs). As partnerships, PTPs can pass through all income, gains, deductions, losses, and credits to investors, and they generally pay no entity-level taxes. MLPs are simply PTPs that operate active businesses, as opposed to PTPs that operate passive businesses (e.g., certain types of exchange-traded funds) [Ref. 427].

An MLP generally has a two-tiered structure. The MLP is the traded limited partnership whose only asset is generally a wholly owned LLC operating company. The ownership of the MLP is split between two primary groups: the public and the sponsor, which is the overall organization/entity/person responsible for forming the MLP. The public will own some percentage of the MLP, which will vary at the time of the initial public offering (IPO) based on the optimal size of the offering and overall capital structure of the MLP. The sponsor will retain the portion of the MLP not sold to the public [Ref. 426]. In addition, the operating company can raise debt through standard finance structures. Figure 5-1 shows the general structure of an MLP.

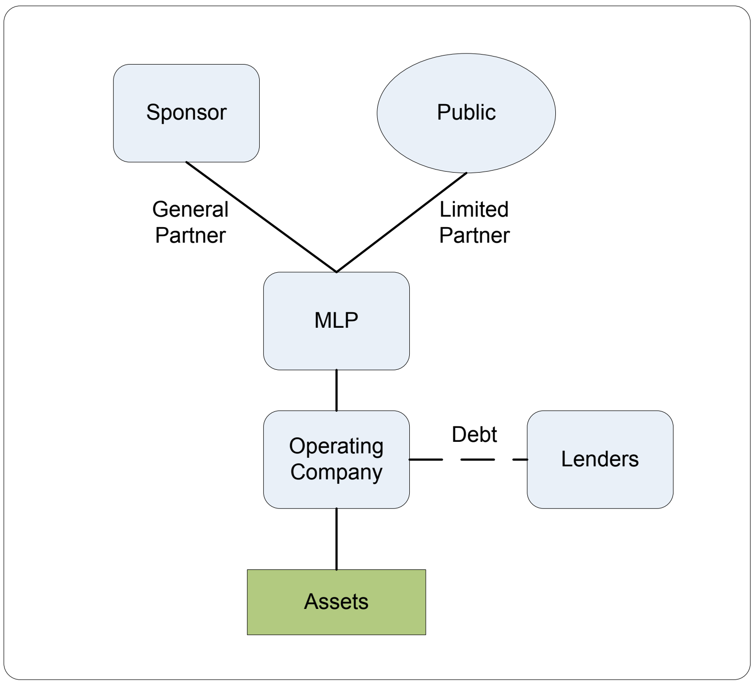

Figure 5-1: Typical MLP Structure [Ref. 426]

MLPs are most commonly present in the energy industry, providing and managing resources such as oil and gas pipelines. These types of business endeavors are conducive to producing regular income, thus enabling MLPs to offer attractive income yields because they earn stable income that is often based on long-term service contracts [Ref. 428].

In 2014, approximately 110 energy-related businesses constituted 82% of all existing publicly traded MLPs, representing a market capitalization exceeding $650 billion with average dividends at approximately 7.3%. At present, MLPs must derive 90% of their income from depletable natural reserves such as oil, gas, and coal and would thus require a statutory amendment to include clean energy or renewable power generation [Ref. 424].

5.4 Real Estate Investment Trust

A Real Estate Investment Trust (REIT) is an investment vehicle for real estate that is comparable to a mutual fund, allowing both small and large investors to acquire ownership in real estate ventures and own (and in some cases operate) commercial properties such as apartment complexes, hospitals, office buildings, timber land, warehouses, hotels, and shopping malls. A REIT is a type of security that invests in real estate through property or mortgages and often trades on major exchanges like a stock. REITs provide investors with an extremely liquid stake in real estate. They receive special tax considerations and typically offer high dividend yields. REITs, REITs raise low cost funds through IPOs or private placements with one level of taxation as a pass through entity [Ref. 431]. Although REITs originated in the United States, more than 40 countries have REIT legislation, including Australia, Canadian, Japan, France, Germany, and the UK.

The Internal Revenue Service's (IRS) current definition of *real property* inherently requires no moving parts, which is problematic for most renewable energy applications. The transmission industry received a private letter ruling from the IRS; certain solar and energy efficiency technologies have obtained a similar private letter ruling [Ref. 424]. Several REITs in the United States currently own energy industry assets. These include InfraREIT (New York Stock Exchange [NYSE]: HIFR), which owns transmission and distribution assets, and Corenergy Infrastructure Trust (NYSE: CORR), which owns oil and natural gas pipelines [Ref. 430]. In October 2014, Hannon Armstrong, a REIT, invested $144 million in a portfolio of 10 wind farms, following a $107 million acquisition of a solar and wind portfolio in May 2014. These transactions were the first of their kind in wind acquisitions by a REIT. However, energy storage units/projects are assets that may not yet, without legislative qualification, be qualified for standalone REIT treatment [Ref. 424].

The final story has yet to be written in the United States. On August 31, 2016, the IRS and US Department of the Treasury issued final regulations to clarify the definition of *real property* relating to REITs. The final regulations provide a safe harbor list of assets and establish the facts and circumstance tests to analyze other assets. Smaller scale renewable energy systems that primarily serve buildings are generally REIT-eligible assets; larger, utility-scale assets are effectively not eligible. The final regulations also clarified that until additional guidance is issued, the REIT-eligibility of renewable energy assets will not be affected if such assets generate excess electricity sold to utilities under net metering programs. The final regulations also addressed transmission systems: although a transmission system may serve an active function (e.g., transporting natural gas), distinct assets within the system (e.g., pipelines, isolation valves and vents) may nevertheless be REIT-eligible assets [Ref. 429].

5.5 YIELDCO

A yieldco is a dividend growth-oriented public company created by a parent company (e.g., SunEdison, NRG Energy, Abengoa), that bundles renewable and/or conventional long-term contracted operating assets in order to generate predictable cash flows. Yieldcos allocate cash available for distribution (CAFD) each year or quarter to shareholders in the form of dividends. This investment can be attractive to shareholders because they can expect low-risk returns (or yields) that are projected to increase over time. The capital raised can be used to pay off expensive debt or finance new projects at rates lower than those available through tax equity finance, which can exceed 8%.

The case for yieldcos can be compelling, especially as an alternative to MLPs and REITs. Yieldcos, sometimes referred to as *synthetic MLPs*, are structured to simulate the avoided double-taxation benefit of MLPs and REITs (Figure 5-2). This means that rather than taxation taking place twice (once at the corporate level and again at the shareholder level), the yieldco is able to pass its untaxed earnings through to investors [Ref. 432].

A yieldco can acquire projects in the development phase after it has reached a solid platform from which to invest in development rather than in new acquisitions. Yieldcos are particularly favorable for financing renewable power, energy storage, biofuel, renewable chemical, bio-based products, and other bioenergy projects because these assets are generally large and, unless structured under a yieldco, earn less revenue individually on the books of the parent company [Ref. 424].

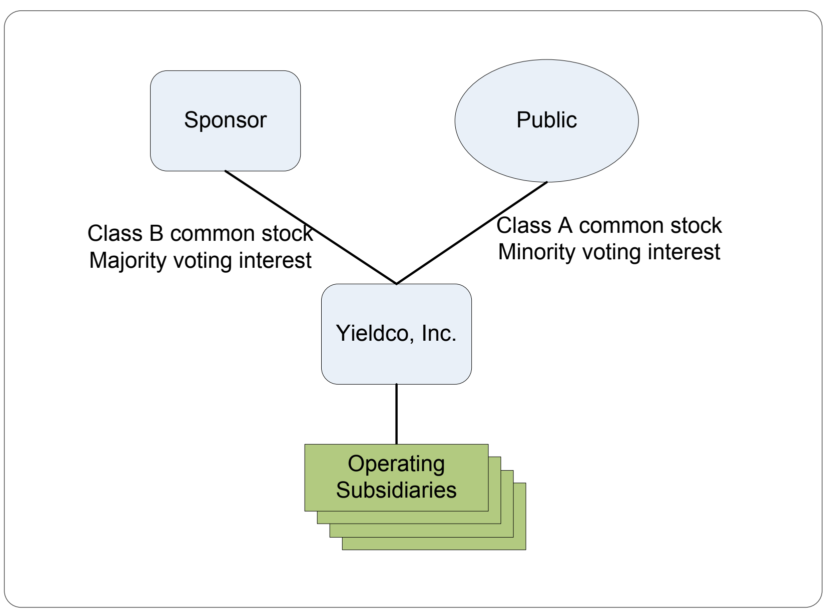

Figure 5-2: Typical Yieldco Structure [Ref. 432]

To date, yieldcos have been spinoffs of large industry players with the capital necessary to purchase third-party assets or build projects themselves. They can be created by unregulated arms of large utilities that own a mix of renewable and traditional generating assets (e.g., NextEra), independent power producers (IPPs), and pure-play solar or wind developers. As of June 2014, six renewable energy yieldcos were operating in the US market: NRG Yield Inc., Pattern Energy Group, Inc., TransAlta Renewables, Inc., Abengoa Yield Plc, Next Era Energy Partners, LP, and TerraForm Power, Inc. [Ref. 432].

6 Perceived Key Risks, Barriers, and Challenges for Financing

The Parsons team solicited input from 14 potential financiers, including the commercial and developmental finance institutions. This input was solicited through the distribution of surveys; a finance workshop in USTDA offices in Arlington, Virginia; and numerous teleconferences and face-to-face meetings. In general, these entities had limited experience in financing international renewable power generation systems that included energy storage, and demonstrated even less knowledge or opinion regarding the challenges facing a pure energy storage project located in South Africa. Some of the significant risks, barriers, and challenges for financing energy storage projects in South Africa and sub-Saharan Africa are described below.

The first challenge was to identify an energy storage project that was sufficiently robust financially to be bankable. It was thought that South Africa does not have the necessary regulatory/tariff structure to support utility-scale energy storage projects, specifically with regard to sufficient time-of-use tariffs or demand charge reduction programs for individual consumers, and the lack of a market for the types of ancillary services that energy storage can provide to the grid. Without these, financiers considered it difficult or impossible to find energy storage projects with a positive business case. This is also an area that would benefit from regulatory modifications and adjustments to the existing tariff structure.

The second challenge was the ability of projects to enter into a PPA or ESA that could provide adequate confidence in the ability to generate and collect revenues over the life of the project. Several financiers pointed to Eskom’s current resistance to signing PPAs for new renewable energy projects previously awarded under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). It was also mentioned that South Africa is undergoing some internal debate over its Integrated Resource Plan (IRP) and that the role that energy storage might have is uncertain until the 2016 IRP is finalized. Many of these concerns regarding South Africa’s intended future with energy storage would be alleviated if South Africa were to establish goals for energy storage adoption and enact legislation that encourages and incentivizes further energy storage development.

With regard to technology, most financiers felt that the first ESS to receive financing would likely be based on a proven solid state battery technology such as Li-ion, lead-carbon, or NaS. They expressed significantly less confidence in some of the newer energy storage technologies, including flow batteries. Several financiers expressed doubt that a significant flow battery project could be financed until a manufacturer could point to a commercially produced system operating in the field for a reasonable period.

The financial community was aware (at least at the technical level) of the ability of an ESS to provide multiple revenue streams through the stacking of benefits to one of more customers. However, there was some concern whether there was adequate experience in developing and demonstrating the control systems capable of implementing these potentially complex algorithms. There was also some concern about the lack of experience in developing ESA/PPAs to provide for multiple revenue streams.

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ACRONYMS

BTM	behind the meter
CAES	compressed air energy storage
CCS	carbon capture and storage
DER	distributed energy resource
DOE	Department of Energy
EC	electrochemical capacitors
EES	Electrical Energy Storage
ESS	energy storage system
EV	electric vehicle
FVT	full value tariff
GHG	greenhouse gas
IPPPP	Independent Power Producer Procurement Program
Li-ion	lithium ion
LMB	liquid metal battery
Munics	Municipalities
MW	megawatt
NaS	sodium-sulfur
NiCad	nickel-cadmium
O&M	operations and maintenance
PHS	pumped hydroelectric storage
PV	photovoltaic
R	South African Rand
R&D	research and development
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
SA	South Africa
SSA	Sub-Saharan Africa
T&D	Transmission and Distribution
USD	US dollar
USTDA	US Trade and Development Agency
VRE	Variable Renewable Energy
VRFB	Vanadium Redox Flow Battery
Zn-Br	zinc-bromine

1 Introduction

The USTDA uses Development Impact Measures to help quantify the impact of its support for infrastructure development in emerging economies. The assessment of development impacts helps USTDA set clear goals and measure the results of its programs relative to the Agency's core objective of promoting United States private sector participation in development projects around the globe. Understanding the local impacts of USTDA's program supports the Agency's ability to design projects with a higher likelihood of implementation and a higher likelihood of U.S. export generation, thus supporting the Agency's mission.

1.1 CONTEXT

Manufacturing remains an important sector within the South African economy given its potential to generate positive and significant spillover effects on the economy. A 2011 Pan-African Investment & Research Services study [0408] concluded that a growth rate of at least 10 percent in manufacturing production in South Africa would be needed to place the sector back on a sustainable track that would also help promote other sectors in the economy. The report recommended six strategies that can be considered to generate favorable conditions for the Manufacturing sector to grow and initiate the re-industrialization of the country. Many of these strategies are consistent with the adoption of energy storage and development of an SA energy storage industry through the activities recommended in the Objective 6 "Roadmap".

1. Adopting a favourable exchange rate policy for the Rand and a trade regime policy to promote Manufacturing (not substantially addressed by energy storage);
2. Differentiated electricity pricing policy to help energy intensive industries to manage costs and competitiveness (addressed through tariff setting and transformative policy related to energy storage);
3. Manufacturing industries in which South Africa has comparative advantage e.g. ferro-alloys need to be supported so as to enhance their global competitiveness as well as to expand exports and production both in terms of volume and scale (addressed through the Identification of SA Industrial Development Priorities);
4. Accelerating beneficiation of the Mining sector to promote downstream and upstream Manufacturing industries (addresses by Matching Supply Chain Value to SA Capabilities);
5. Encouraging skills generation in line with Manufacturing needs; encouraging Manufacturing development programs for artisans, technicians, etc. (follows from the Identification of SA Industrial Development Priorities)
6. Fast tracking infrastructural backlogs: a key source of re-industrialization of the country is an appropriate and urgent implementation of infrastructural backlogs, both national and municipal infrastructure (Energy Storage aids in accelerated strengthening of electrical

Transmission and Distribution (T&D) grid through added flexibility in the prioritization of improvements).

1.2 Purpose

The purpose of this assessment is to understand the potential developmental impacts on the society and economy of South Africa potentially resulting from implementing the recommendations in the South Africa Energy Storage Assessment.

This assessment was performed according to the Development Impact guidance issued by USTDA. The assessment was performed by:

- Identifying relevant and appropriate development measures and indicators from the list provided in USTDA's guidance. Measures include categories such as Human Capacity Building and Infrastructure Improvement. Development impact indicators should be quantifiable, meaning we can determine a value for the indicator. Development impact indicators must also be relevant and appropriate to the project being evaluated, meaning the implementation of the project produces a corresponding change in the value of the indicator.
- Determining baseline values for the selected indicators in close cooperation with the project sponsor.
- Projecting changes to the baseline values expected to be caused by implementation of the recommended program.

1.3 Limitations

Because the assessment of development impacts involves projection and interpretation of future conditions, the changes in impact indicators can be difficult to quantify with precision. For this reason impacts are often evaluated qualitatively, that is, a positive or negative change in the value of the indicator, rather than projection of a specific quantity. Thus, we can project that implementation of the program will result in the creation or increase in the number of jobs available in a certain sector without being able to quantify what that number will be.

2 Selected Development Impact Measures and Indicators

The USTDA provides guidance on assessing development impact to enable uniformity in evaluation of the success of different projects [0412]. This guidance provides indicators for measuring impacts under six general categories:

- Promoting Effective Markets and Governance
- Promoting Commercial Development
- Infrastructure Development and Efficiency Gains
- Human Capacity Building
- Promoting Safety and Security
- Promoting Environmental Benefit

2.1 How the Indicators Were Selected

Each category is subdivided into quantitative and qualitative indicators which can be used to determine the development impact of the activity if performed according to the recommendations of the study. We selected the development impact measures from the USTDA guidance according to the following criteria:

- Is the indicator relevant to the electrical power sector in South Africa? Many of the indicators pertain to specific industries, such as agribusiness, aviation, or oil and gas. Only indicators relevant to the electrical power sector were considered further.
- Is the indicator appropriate to the South African economy? The South African economy, and in particular the power sector, is in a mature and advanced state of development, especially when compared to the developing nations in sub-Saharan Africa. Only indicators relevant to an advanced economy were considered further.
- Does the indicator help differentiate between competing technologies or approaches? Because this study recommends a number of candidate energy storage technologies rather than a single approach, indicators that could help differentiate between the candidate technologies by indicating those with more beneficial impacts were given additional consideration.

Having selected the indicators based on the above criteria, we further refined the categories to relate more specifically to the selected indicators as follows (note that the category Promoting Safety and Security is not relevant to energy storage):

1. Support for Ability to Secure Financing for Energy Storage Projects in South Africa
2. Supporting Regulations that Promote Effective Governance
3. Improving Power Delivery and Continuity of Service
4. Reducing/Avoiding Greenhouse Gas Emissions
5. Creating Temporary and Permanent Jobs in South Africa

These categories are described in more detail in section 3 below. The selected development impact indicators and measures are given in Table 3-1 along with the measures used for determining the potential impacts.

2.2 DETERMINING THE POTENTIAL IMPACTS

Determine Baselines. The first step in determing the potential impacts of the proposed energy storage program is to assess the baseline value or current condition of each indicator. For quanititative indicators such as number of jobs created, this means determining the number of existing jobs in that sector. This can be done by reviewing employment reports from the relevant industry or government agency. For qualitative indicators such as support for regulations that promote effective governance, this is done by assessing the current regulatory regime and in particular noting if there are existing policies or regulations that can restrict the growth or implementation of energy storage.

Determine Projected Changes to Baselines from Program Implementation. The next step in determining the potential impacts is to project the changes to the baseline values that could result if the recommended projects are implemented. This is also done quantitatively or qualitatively depending on the indicator. An example of a quantitiave indicator is permanent jobs created by the mining of raw meterials for the manufacture of storage batteries. The number of new jobs created would be projected by determining the following parameters:

1. Amount of the materials currently extracted in the South African mining industry
2. Number of workers employed in mining those materials
3. Amount of battery capacity required to implement the energy storage program
4. Additional amount of materials required to manufacture those batteries
5. Additional number of workers required to support the additional material extraction based on the unit production per worker determined from items 1 and 2

For qualitative indicators, such as supporting regulations that promote effective governance, the project tream will use their experience with and knowledge of the situation in the South African economy and regulatory environment to project the effect the implementation of the project recommendations are likely to have on the indicator. The following sections present the results of this process for the selected indicators.

3 Potential Development Impact Statement

Qualitative and quantitative (when possible) estimates of development impact are given for each relevant indicator in Table 3-1. However, we feel that breaking down the assessment into detailed indicators as in Table 3-1 could restrict the discussion of the collective impact of each category as a whole. Accordingly, we present a more in-depth discussion of potential impacts of implementation of energy storage in South Africa according to the five general categories in the USTDA guidance:

3.1 Supporting Ability to Secure Financing for Energy Storage Projects in South Africa

This category includes impacts related to promoting commercial development; providing access to new financial services; and establishing new business relationships.

The activities recommended by this study will result in project sponsors having better access and availability to financing. This will be driven by several issues. First, the development of procurement targets for energy storage systems will confirm the government and Eskom's intention to proactively add storage. Additionally, standardization of requirements for energy storage systems in SA will provide assurance to lenders and financiers in the adequacy and acceptability of proposed systems. Most importantly, the deployment of utility scale pilot or demonstration projects will demonstrate the benefits of energy storage in operation. It will also establish the performance and reliability of specific manufacturers and their technologies thereby increasing their bankability.

As suggested by several proposed Roadmap activities and Objective 3 recommendations, the lack of an existing market for ancillary services and a program for procurement of energy storage capabilities (similar to Independent Power Producer Procurement Program [IPPPP]) places significant limitations on the manner in which energy storage can be added cost effectively. It is impossible to bill services and to generate sufficient revenue to support a viable business case without this market. Valuation of ancillary services and creation of a market will allow the development of additional finance, project ownership, and revenue structures that will increase the number and types of financial products available to fund energy storage projects and facilities.

Lastly, the activities proposed by the roadmap and recommendations made in other deliverables will stimulate additional meetings, working groups, and interactions between manufacturers, project sponsors and developers including Eskom, municipalities, and SA government agencies that will facilitate new connections and relationships between stakeholders in the energy storage industry.

3.2 Supporting Regulations that Promote Effective Governance

This category includes impacts related to supporting regulations that promote effective governance; support clear, transparent, open tender processes; promote an improved investment climate; and promote competition

The current REIPPPP provides very limited ability for project sponsors to offer energy storage in South Africa and to be compensated for it. Although a provision is made for the inclusion of thermal storage for Concentrating Solar Power (CSP) plants, there is no corresponding allowance for PV or wind sources. A long term approach and sustainable new tender process for either the inclusion of energy storage in Variable Renewable Energy (VRE) projects or as a separate procurement program will significantly increase the opportunity for project sponsors to offer cost effective energy storage to Eskom, and municipalities to support the electrical grid.

The recommendations made in this study will promote direct investment in South Africa. This will occur as manufacturers and vendors recognize that SA is committed to the long-term development and incorporation of energy storage systems. This will encourage manufacturers and vendors to support this growth through direct investment either by putting equity into projects or by owning them directly. In addition, this demonstrated commitment will encourage the opening of regional offices and the training of existing technicians in energy storage system installation and maintenance. Additionally, the government can incentivize established manufacturers to bring manufacturing or assembly activities to SA to support developments in SA and Sub-Saharan Africa (SSA). South Africa may also incentivize the internal organic development and growth of the energy storage technologies and services in SA to support development in SA and SSA.

Establishing a set of policies, programs, and regulations designed to fully incorporate energy storage into the SA electrical grid consistent with other international best practices and standards will significantly increase the confidence of foreign companies to do businesses in SA, which will further open the energy storage market to greater competition.

3.3 Creating Temporary and Permanent Jobs in South Africa

This category includes human capacity building through increased access to employment and training and skill development.

The most significant long-term impact is the increased number of permanent positions necessary to operate and maintain energy storage facilities and fabrication and manufacturing positions necessary to support the increase in industry necessary to support the manufacture of domestically produced materials and equipment. This has a significant long-term impact in that the direct jobs will also result in the creation of additional indirect positions necessary to support the direct growth.

A second impact is the addition of temporary jobs necessary to construct or install energy storage facilities or to build energy storage manufacturing facilities or subordinate facilities necessary to support mining, refinement, or production of materials and equipment necessary to the energy storage value chain. Although temporary in nature, a construction of a facility can result in a significant short-term employment over the six to eighteen months necessary for construction.

Finally, there will be a significant amount of training and skills development created by the introduction of energy storage systems and services. This includes the technical knowledge to operate and maintain electrical, mechanical, or chemical energy storage systems along with an increase in control systems, software development, and programming necessary to support installation.

3.4 IMPROVING POWER DELIVERY AND CONTINUITY OF SERVICE.

This category includes impacts related to improved output resulting from implementation of storage technology; improved power delivery and continuity of service; and new renewable energy capacity.

The use of energy storage systems to allow for deferment of Transmission and Distribution (T&D) upgrades means that rather than upgrading all existing T&D systems to address congestion or under capacity, some potential T&D upgrades can be deferred through the use of energy storage systems. This allows utility resources and funding to be prioritized to critical upgrades or the expansion of transmission and distribution infrastructure. This is less of an impact in South Africa than other SSA countries because of the maturity of the extensive electrical transmission grid operated by Eskom and the distribution provided by Eskom and municipalities; however, Eskom currently has extensive plans for upgrading transmission lines to support an improved and more robust transmission system, thereby supporting increased population, industrial growth, and additional renewable energy generation. The efficient application of energy storage for T&D deferment will allow the planned T&D improvement program to occur faster.

The recommendation may provide for small increases in or the extension of the availability of electricity, however, this is not a major impact as relates to this report's recommendations. More importantly, the effective adoption of energy storage will allow for increased efficiency in the operation of the electrical grid and reduce losses due to outage or power quality issues.

Energy storage has the ability to increase overall system efficiency and to reduce losses as the storage systems provide additional flexibility and allow generation sources to be used more optimally.

One of the largest impacts of energy storage is the ability to incorporate significant amounts of variable renewable energy onto the SA electrical grid thus leveraging SA's significant natural resources (wind and sunlight). The current level of VRE penetration in South Africa is not sufficient to produce the level of instability or curtailment issues that are being currently experienced in Hawaii or beginning to be seen in California. Although the need for stabilization and smoothing of VRE sources is not significant today, the use and availability of energy storage will provide increasing benefit as SA continues to build a clean and robust electrical infrastructure while distancing itself from the need for dirty and expensive fossil fuel generation (diesel generation and/or gas peaking power plants).

The adoption of energy storage, particularly the adoption of the newer technologies, will expand commodity diversification as there will be more companies and technologies utilizing a different set of resources and material to produce storage systems that achieve benefits against identified use cases. The more variability in the companies and technologies that can address these needs will result in increased commodity diversity.

Increased access to electrical power is not seen as a major benefit in the adoption of energy storage, however, the use of energy storage behind, and in front of, the meter will increase the reliability and quality of electrical power. Some expansion in the availability of the electrical power will occur as energy storage is used in conjunction with VRE generation sources to build microgrids in remote areas of the country in advance of T&D systems.

3.5 Reducing/Avoiding Greenhouse Gas Emissions

This category relates to the ability of energy storage to displace fossil fuel-generated electricity with power from renewable sources during times when renewable power would otherwise be unavailable, such as at night or periods of low wind. Electrical Energy Storage (EES) enables Greenhouse Gas (GHG) emission reductions by two main mechanisms:

- EES can be used instead of natural gas generators to smooth out the variable output and availability of renewable generation sources such as wind or solar power over long periods, and allow these resources to be scheduled according to daily fluctuations of electricity demand (increasing dispatchability of VRE).
- EES charged with electricity from low-carbon sources can also be used to displace fossil fuel generation to provide regulation services by smoothing out the fluctuations between supply and demand over short periods of less than 15 minutes. This use of EES could reduce the amount of fossil fuels burned by generators, leading to GHG and conventional emission reductions.

However, the use of energy storage can also increase GHG emissions if charged with cheap electricity from high-carbon base load coal power plants to displace more expensive peaking power from lower-carbon natural gas generators. Thus GHG emission reduction potential from EES depends on its use with renewable or low-carbon (i.e., nuclear or coal with carbon capture and storage (CCS)) resources [0400].

Table 3-1 - Relevant Development Impact Indicators for Energy Storage Assessment

Indicator	Measure
1. Supporting Ability to Secure Financing for Energy Storage Projects in South Africa	**Promoting Commercial Development; access to new financial services; establishing new business relationships**
How will implementation/utilization of USTDA recommendations enable project sponsor and/or participants to secure financing (private or public) to implement storage technologies?	The amount of total value of funding obtained to further develop or implement storage technologies. The number of energy storage projects, or renewable energy generation projects with accompanying energy storage features, that reach financial close. Energy storage technologies and applications demonstrations through demos or pilot projects will increase the perceived bankability of energy storage and facilitate future project financing and at lower rates of finance.
What financial products will be made available to fund storage technologies that were not previously available to the industry?	The number of new or innovative financial product offered related to energy storage or projects that include energy storage. Transformative legislation will provide a means to value energy storage benefits and in turn provide individual energy storage service providers the ability to sell energy storage services to utilities through long-term contracts or by bidding into a national market. As evidenced through the advent of renewable energy, a variety of new and innovative finance structures (Task 2.3) will create alternate means to develop and fund energy storage projects.
How many new connections have been established between emerging companies, universities, IPPs and Eskom?	The number of working groups formed to address Roadmap activities. Number of new projects developed or proposed related to, or including, energy storage. Suggested Roadmap activities (Objective 6) include 21 different activities to facilitate the development and adoption of energy storage. Each of these activities will require leadership and participation by multiple SA organizations and entities. Each new energy storage project proposed, developed, and commissioned will involve the establishment of five to fifteen new relationships or connections between companies, universities, IPPs, and Eskom/municipalities.
2. Supporting Regulations that Promote Effective Governance	**Supporting Regulation that Promotes Effective Governance; Supporting Clear, Transparent, Open Tender Processes; Improved Investment Climate; Promoting Competition**
What new policies, regulations or laws have been adopted that promotes effective governance of the energy storage sector? (including compliance with a bilateral or multilateral policy or trade agreement)	The number of new policies or regulations enacted with regard to energy storage. New policies and regulations at national and regional levels will be generated through the Road maps activities surrounding transformative policies, including procurement goals, incentives, and tax credits.
What new tender processes were adopted or developed to implement storage technologies that were not previously available and provide greater transparency and openness?	The number of new tender processes used to adopt energy storage. Objective 6, Roadmap activities suggest introducing alternative procurement processes to the current REIPPPP for energy storage. These could be developed at the national level or by Eskom and municipalities, or through private industry.
Will Implementation/utilization of storage lead to direct investment in the South African economy (including	The number of additional energy storage projects built (or total MW/MWh storage installed).

Indicator	Measure
companies opening or expanding offices/operations)?	The number of new energy storage manufacturing or service providers created in SA. The adoption of energy storage will lead to investment in South Africa on a number of levels: Investment from international finance organizations for the development of utility-scale energy storage projects. Investment of US and international companies into the development of facilities and resources inside SA to provide for SA domestic needs as well as a platform for marketing and supplying SSA countries. Investment by US and international companies in joint ventures or supply contracts for the mining and refinement of natural resources to support energy storage manufacturing in SA or at other international locations.
Will implementation/utilization of storage in South Africa lead to opening of markets to greater competition or introduction of standards (elimination or reduction of threat to foreign business interests and competitiveness)?	The number of new markets developed related to energy storage. The number of new energy storage standards adopted in SA. Objective 6 Roadmap activities provide for standardization of energy storage requirements. This allows for equal and open competition in the procurement of energy storage within South Africa. Provide an effective means for South Africa to provide energy storage products specified and developed against accepted international industry standards.
3. Improving Power Delivery and Continuity of Service	**Improved output resulting from implementation of technology; Improved power delivery and continuity of service; Resulting new renewable energy capacity**
What is the value and impact to the economy of increased or extended availability of electricity resulting from introduction of storage technology? New technologies introduced to a host country resulting in an increase of efficiency, capacity, or output/process improvement	This measure may be meaningful for expanding access to rural off-grid customers but not for industrial or utility-scale storage which is more directly the scope of this study. Energy storage in conjunction with renewable energy generation allows for the development of micro-grids to remote areas in developing SSA countries ahead of the advent of formal and permanent utility T&D services
What efficiency gains and reductions in losses will result from implementation of storage (includes outages reduced and time reduced for energy redistribution throughout grid)? Will more power be available in underserved time periods?	The number and duration of unplanned local or regional electrical outages. The number and duration of rolling blackouts (rotational load shedding) instituted by electrical utility. Energy Storage behind the meter will allow for demand charge reduction and will reduce high demand during peak periods. Energy storage in front of the meter will lessen the strain on utility T&D infrastructure and avoid the procurement of peak electrical generation sources that are only required during a small fraction of the year.
Will implementation of storage lead to increased utilization of renewable energy capacity or increase in capacity?	The number of VRE projects that include energy storage and the use of energy storage for microgrid applications. Energy storage will allow independent power producers operational flexibility and the ability to dispatch their VRE sources (PV and wind).
Will implementation of storage create commodity diversification, leading to greater economic stability?	The number of new companies involved in energy storage (resource extraction, manufacturing, construction, and service providers). Adoption of energy storage, and in particular, the development and deployment of alternate energy storage technologies will increase commodity diversitification to the extent that SA participates in the energy storage value chain.

Indicator	Measure
Will implementation of storage provide more people access to power through new or expanded generation or improved transmission or distribution systems?	The number of off-grid or microgrid applications or projects developed. Most likely to occur in remote areas in SA
4. Reducing or avoiding GHG emissions	
Amount of GHG pollution reduced or avoided by implementation of storage by displacing fossil fuel-generated electricity by application of energy storage systems	GWh of fossil fuel-generated electricity displaced and tons per year of CO_2 equivalent saved by application of energy storage systems. Amount of fossil fuel-generated electricity displaced and tons of CO_2 The actual quantities under this category will depend on the amount of energy storage capacity installed and the use cases and applications, and operating schedule employed by each major facility.
5. Human Capacity Building	**Temporary and permanent jobs created; Training and skill development delivered by project implementation**
Temporary jobs created by project implementation	The number of temporary jobs created by implementation of energy storage in: • Constructing manufacturing facilities • Installing energy storage systems • Training workers
Permanent jobs created by project implementation	The number of permanent jobs created by implementation of energy storage in: • Mining or developing raw materials • Manufacturing equipment • Operating storage systems
Training and Skill Development delivered during project implementation	The number of individuals trained in development, manufacturing, and operation of energy storage systems. The number of new train or technical programs introduced or developed relating to energy storage.

4 Suitability Analysis

The suitability of various technologies was previously examined and reported in the Objective 2.1 "Technology Assessment" Report. This section provides a summary of the previous findings and addresses directly the suitability of the evaluated technologies in comparison with each other to determine the more advantageous technologies from a development perspective.

As shown previously in Objective 2.1, Figure 2-1 summarizes the potential of competing energy storage technologies to be mature and competitive over the near, middle, and long-term timeframes. This suggests that SA should concentrate on technologies that will be mature and competitive through 2030 and those that are expected to be mature and competitive as early 2020.

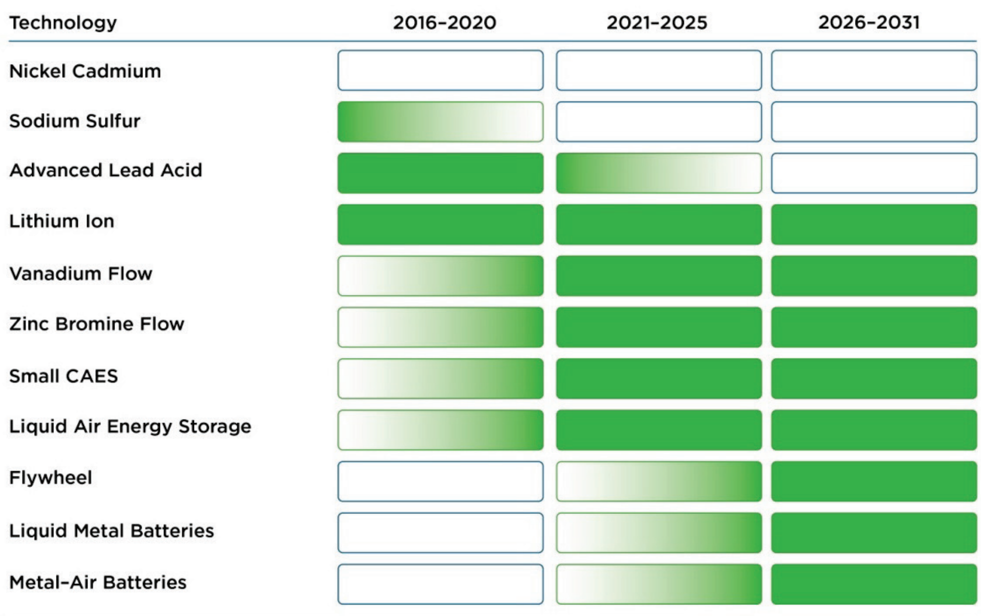

Figure 4-1: Time Frames for Technology Relevance in South Africa

4.1 Lithium-Ion Batteries

It is commonly understood that Lithium-ion-based energy storage systems (ESSs) will be the dominant energy storage technology for utility-scale applications with cycle durations up to 4 hours. Li-ion will also be dominant in commercial, industrial, and home consumer applications. Although some concern still exists regarding the potential safety issues related to thermal runaway and fire, cell monitoring, battery management, fire detection, and suppression systems typically address these concerns. Over time, consumers will become more comfortable with Li-ion as additional large-scale systems demonstrate long-term reliability, performance, and safety.

It is expected that Li-ion battery systems will account for well over 60% and potentially could exceed 90% of the total energy storage systems deployed in SA over the next 15 years. Li-ion battery cell manufacturing is highly competitive and favors the economics of scale. Large industrial factories will be able to achieve higher production efficiency and lower costs than smaller facilities. There are currently several large production facilities (Giga-factories) soon to begin production. Over the near-term, it is expected that there will be a winnowing of the Li-ion cell manufacturers with survival going to those companies that can generate the best performing battery at the lowest unit cost. With decades of experience in some cases, this will be a difficult market to penetrate.

Since Li-ion will be deployed extensively, SA should consider the areas of the value chain where it can play a competitive role outside of cell (and likely outside of module) manufacturing. Three areas of potential are the assembly of standardized commercial and industrial DC battery storage systems from cells and modules supplied by others; the development and assembly of standardized packaged AC BESS that include power conversion, power control, and ancillary systems; and installation and maintenance companies that would install and maintain Li-ion based systems.

4.2 Flow Batteries

Many manufacturers have invested significant capital in the development of commercial flow battery designs. Flow batteries require mechanical systems (pumps, pipes, and tanks) and are inherently more complex than a solid-state battery. The most expensive components within the flow battery are generally the reaction stacks. The greatest advantage of the flow battery is the potential to scale up to longer duration discharge cycles more cost-efficiently than solid-state batteries. The most successful and prevalent of these batteries use vanadium and zinc-bromine chemistries. It can take five years or longer to develop a sufficiently mature and proven technology to support commercialization. Several flow battery systems have been sold or have gone bankrupt before they achieved a market competitive commercial offering. Flow battery manufacturers across all chemistries are expected to continue to refine product offerings while reducing the initial costs of their products and demonstrating long-term reliability. Manufacturers that provide reliable systems at competitive prices through efficient manufacturing practices will achieve increased market share and improved bankability.

4.2.1 Vanadium Redox Flow Battery

Several companies have demonstrated the potential for significant scale-up of vanadium modules to the megawatt (MW) scale and discharge durations of 4 to 12+ hours. Scale-up provides the potential for significant cost reduction because it avoids multiple redundant smaller systems. Vanadium is a significant resource in South Africa; however, it is also expensive: the vanadium itself accounts for about 35% of the ESS costs [0372, 0239]. The newer mixed acid electrolyte formulation offers the advantage of a higher concentration of vanadium and increased temperature performance. Companies employing a mixed acid electrolyte are expected to have an advantage over the earlier sulfuric acid-based electrolyte. Vanadium is a nontoxic chemical, however, the electrolyte is caustic and poses corrosive and environmental hazards similar to lead-acid batteries. Vanadium flow batteries may become a dominant long-duration discharge application in the next 5 years, and they could dominate the long-duration market (>4 hours) over the middle- to long-term through 2030.

What would make Vanadium flow batteries most advantageous from a development perspective would be the promotion of mining of Vanadium combined with the processing and manufacture of Vanadium pentaoxide and the subsequent manufacture of electrolyte for Vanadium Redox Flow batteries (VRFB). There are a number of existing VRFB manufacturing companies that are beginning commercial production and deployment of utility-scale systems. These systems may be used in SA for longer duration applications and would likely be used in developing SSA countries where a lack of an established and mature electric grid may favour the development of microgrids based on a combination of renewable energy sources and longer duration energy storage such as VRFB.

Alternately, with the expiration of VRFB intellectual property, and the ability to license mixed electrolyte technology, it may be possible for a new company to rapidly develop and take to market a VRFB system based on currently available technology.

4.2.2 Zinc Bromine Flow Battery

Zinc-Bromine is likely the second most mature flow battery technology and has been offered commercially in smaller 10- to 25-kW modules for communication and cell tower application for nearly a decade. As mentioned in Objective 2.1, zinc-bromine (Zn-Br) systems are a hybrid flow battery technology that deposits or "plates out" zinc on the anode of the reaction stack during charging. Bromine creates a harsh and corrosive environment that requires more robust mechanical systems and materials. Zn-Br also poses additional environmental and safety concerns relating to the use of bromine and the potential for release or exposure. Based on the hazards of bromine, some companies may consider shipping systems without electrolyte and then loading it at a location near, or at, its point of installation. This approach might be advantageous to a company that could manufacture Zn-Br electrolyte. Additionally, such a company could receive pump and tank assemblies from a far east contract source and install reaction stacks manufactured by the technology vendor. The SA entity could assemble, fill, and test the final systems prior to installation. This would most likely involve building a strategic relationship with an existing Zn-BR manufacturer for responsibility in the distribution of its Zn-BR flow batteries on the African continent.

4.2.3 Iron-Chromium or Zinc-Iron Flow Battery

As a true redox flow batteries, these technologies represent full power and energy independence. The use of chromium for Iron-Chromium presents additional environmental and toxicity issues while the active materials in Zn-Fe are fairly benign. This technology has not been proven on a utility scale and no current manufacturers are offering demonstration or production systems, however, with the right technology provider a similar relationship to that proposed for Zn-Br might be achieved if a manufacturer with a mature and proven system could be identified. There is at least one company working towards utility scale applications.

4.3 Liquid or Compressed Air Energy Storage

Liquid or Compressed air systems are most competitive on longer duration applications in which increasing the storage volume expands energy capacity while holding the more expensive compression and expansion “power capacity” systems constant. The potential for the development of smaller-sized compressed or liquid air ESSs is significant. It is envisioned that the development of standardized specialty mechanical compression/expansion or cryogenic components that can be manufactured cost effectively and low-cost high-pressure storage tanks could result in cost-effective ESSs on par with pumped hydro storage (PHS) but on a smaller scale that could be located at the point of use.

As this technology gains acceptance, it could be advantageous for SA to enter the supply chain as a tank manufacturer, as a manufacturer of industrial expansion and compression equipment, or cryogenic equipment. There may be room for an SA entity working in concert with a larger technology vendor to take responsibility for installation or long-term operation of these systems.

4.4 Sodium Sulfur

Although sodium sulfur (NaS) has been the dominant storage technology for utility-scale energy storage applications with cycle durations of 4 to 6 hours over the last decade, NaS is expected to be challenged by flow batteries for applications requiring more than 4-hour discharge cycles and by Li-ion for shorter discharge cycles. As a mature technology, significant near-term performance or cost improvements are not expected. Few commercial companies are active in this technology. In the future, NaS may experience a resurgence as existing patents expire, thereby leading to increased competition and development for lower temperature designs. Without significant improvements, NaS is not expected to be an important energy storage technology beyond the near-term through 2020.

Based on existing literature, it seems that for this technology to be advantageous to SA from a development perspective it would require significant investment in the development of a new, advanced, low-temperature NaS technology during the time when existing intellectual property rights are expiring. This could be encouraged through the funding of studies and demonstrations through grants to individuals or direct funding to universities where the developed technologies could then be spun-off into new SA companies. This approach would require sufficient study and due diligence to assure its likelihood of success and eventual payoff.

4.5 Liquid Metal Batteries

High-temperature liquid metal batteries (LMB) have the potential to provide high power and energy capacities, long system life, and high-cycle life while enjoying low initial material and manufacturing costs. Still in the research and development (R&D) stage, liquid metal must overcome several remaining challenges, including a metal-to-ceramic seal and the development of efficient manufacturing practices. Commercial applications are expected to be at least 5 years out.

It is expected that LMB would rely on precise and complex manufacturing processes implemented on a large scale. Additionally, LMB would be a highly proprietary technology which could not likely be developed by a new or organic company. For this technology to be advantageous in the future, SA should pursue strategies similar to those proposed for Li-ion.

4.6 Metal-Air Batteries

Metal-air batteries have up to three times the energy density of Li-ion, however, unlike lithium-ion, metal-air batteries do not produce potentially toxic or explosive gases, nor do they contain toxic or environmentally dangerous components. In addition, the metals used or proposed in most metal-air designs are relatively low-cost. Developed for electric vehicles (EVs) and power electronics applications, this technology could evolve into a competitive low-cost stationary storage system for grid services in the middle- to long-term through 2030. Zinc-air is the most promising metal-air chemistry.

4.7 Supercapacitors

Similar to other small cell technologies, supercapacitors, ultracapacitors, or electrochemical capacitors (EC) will be most competitively produced by precise and complex manufacturing processes implemented on a large scale. South Africa's best option for participation in this value chain would be to play a competitive role in the packaging of supercapacitors supplied by others or in the incorporation of supercapacitors into hybrid energy storage systems.

4.8 Flywheels

As discussed in Objective 2.1, flywheel energy storage is not expected to become competitive until the energy storage market evolves to the point where ancillary services are routinely purchased and traded on a scale where short-duration and rapidly changing control applications such as frequency, voltage control, or smoothing applications could be valued sufficiently to justify the higher capital cost. A successful flywheel manufacturer will need to invest significant capital to achieve the required high performance and reliability while reducing manufacturing costs. This is not likely to occur in the short-term.

Appendix A – References

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Environmental Impact Assessment

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ACRONYMS

BASE	Beta-alumina solid electrolyte
CAES	Compressed Air Energy Storage
EIA	Environmental Impact Assessment
ESS	Energy Storage System
GHG	Greenhouse Gas
GN	Government Notice
GNR	Government Notice Regulations
HSA	Hazardous Substances Act
Li-ion	Lithium ion
MSDS	Material safety data sheet
NEMA	National Environmental Management Act
NEM:BA	National Environmental Management: Biodiversity Act
NEM:AQA	National Environmental Management: Air Quality Act
NEM:WA	National Environmental Management: Waste Act
NHRA	National Heritage Resources Act
NWA	National Water Act
PHS	Pumped-hydroelectric storage
RE	Renewable energy
RFB	Redox Flow Battery

1 Introduction

This report provides background on the potential environmental impact of the different types of energy storage systems (ESS) available for large-scale adoption. Electricity is not always produced at the exact time that it is needed. This problem can be seen with base load power generation sources that are most efficiently running continuously and thus produce power at night when electricity demand is low. Additioanlly, non-dispatchable variable renewable energy (RE) generators can only provide power when that resource (sun or wind) is available. The general purpose of an ESS is to save and store excess electrical output as it is generated and then to release this stored energy at a later time when it is needed. This can happen over the course of several hours or within a few seconds. ESS provides flexibility in the efficient operation of the electric grid by decoupling of energy supply and demand.

Each considered energy storage technology has environmental impacts in terms of the type of materials used, production, its integration, operation, use and recyclability or re-use as well as disposal. The ways in which energy storage is integrated into the electrical grid (regardless of technology) also has implications as to it's overall envirornmantl impact.

The South African Constitution gives effect to environmental provisions, which are included in the Bill of Rights in Chapter 2 of the Constitution (Act No. 108 of 1996). In terms of Section 24, everyone has the right:

- to an environment that is not harmful to their health or well-being; and
- to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:
  - prevent pollution and ecological degradation;
  - promote conservation; and
  - secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

"Electrical energy storage technology in sub-Saharan Africa is almost exclusively by chemical batteries, particularly the automotive lead acid. The batteries have low initial prices but this is deceptive, as their short life spans imply routine replacement expenses. **This increases the burden on the environment due to the frequent disposal of toxic materials**."[0276]

However:

"Battery storage would also help to improve household self-sufficiency of energy supply, an important motivation for installing microgeneration technologies [0255], **by allowing them to use electricity when needed rather than when generated**." Additionally, there are emerging ESS technologies.

As the protection of environmental rights are deeply entrenched in the constitution of South Africa, it is vital to comprehensively understand the effects that the introduction of an energy storage technology will have on the biophysical environment. These technologies must be adopted in compliance with the existing regulatory framework which has been established to protect these rights.

1.1 Purpose of Study

The purpose of this research is to understand the potential impacts that energy storage plays within the South African context. It is also important to understand how the benefits of a technology compare to the potential environmental risks. Moreover, understanding the environmental risks associated with each of the technologies provides insight on which technologies, from an environmental perspective, are more viable through reduced associated risks.

1.2 Approach to Study

This report provides an assessment of the anticipated environmental impacts of each energy storage technology with reference to local South African requirements which will include the following:

- Anticipated environmental impacts, both positive and negative, associated with each energy storage technology;
- Recommendations for maximizing positive environmental impacts and minimizing negative environmental impacts;
- Key considerations and steps that relevant stakeholders will need to take to comply with local environmental requirements.

This report also provides an overview of the anticipated environmental impacts of overall adoption of energy storage technologies in South Africa through 2030.

1.2.1 Regulatory Assessment

A description of the South African regulatory framework is provided as it relates to environmental impacts. This provides contextual understanding of the legislative requirements which may govern energy storage technologies. An analysis of the regulatory requirements for energy storage as well as a gap analysis is undertaken for energy storage systems.

1.2.2 Potential Impact Assessment

This study identifies potential environmental impacts, both positive and negative, associated with each energy storage technology. It is important to first contextualise each technology so that it can be related to potential environmental impacts at each stage of the life cycle (Figure 1). In order to determine the true environmental impact of each energy storage technology, a high-level cradle to the grave approach was taken. This study however, does not include the an evaluation of the overall net impact that the introduction of an ESS might have on the whole energy system.

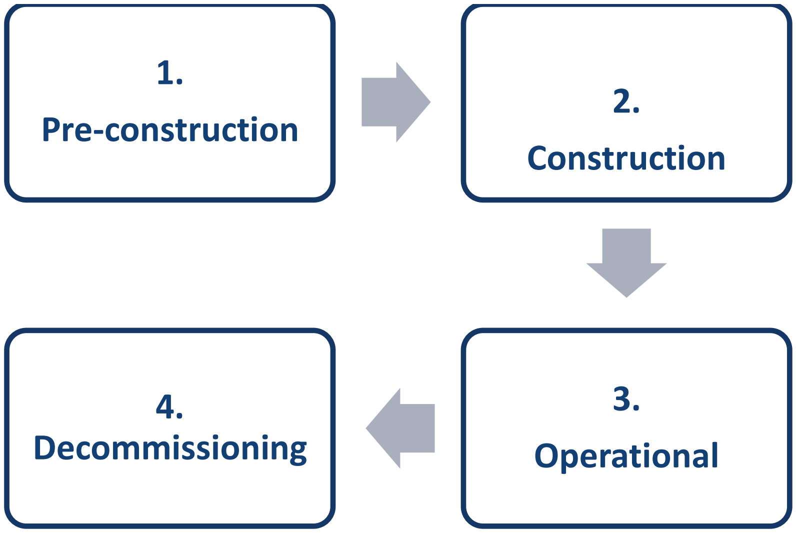

Figure 1-1 – Phases of Technological Implementation

The primary environmental impacts associated with each energy storage technology are identified according to the appropriate pre-construction, construction, operation and decommissioning phases. The **'pre-construction'** phase refers to the period of time leading up to and prior to commencement of construction activities. The bulk of environmental impacts will have immediate effect during the **'construction'** phase (e.g., noise, dust, and water pollution). The '**operational'** phase refers to the period after construction. The **'decommissioning'** phase refers to the period after the end of the operational phase. However, as this is a study assessing the potential environmental impacts from a conceptual technology approach, site specific impacts are not considered.

The impacts that are common among the technologies (such as production of steel etc., and general construction impacts) are not discussed. These are associative processes that will be common among all of the energy storage technologies as well as any alternative energy technology and does not give a realistic indication of the specific risks that the energy storage technologies pose to the environment.

Additionally, in order to effectively compare the various technologies, it was assumed that each technology would aim to achieve the same energy storage capacity to determine the differences in land requirements, material usage etc.

1.2.3 Suitability Analysis

Once the potential impacts are understood, the most feasible ESS from an environmentally sound perspective can be determined. An impact matrix weighting system is utilised to provide a rating for each technology. This rating system provides the cumulative score for each technology in order for a comparative analysis to be conducted for each technology to determine suitability.

2 Regulatory Framework

This section includes legislation and policy guidelines identified as pertinent environmental legislation in South Africa that will affect energy storage technologies and provide context in which these technologies will operate. The research has been assessed against the requirements of the following legislation:

- The Constitution, 1996 (Act No. 108 of 1996);
- National Environmental Management Act, 1998 (Act No. 107 of 1998) as amended; including associated published guidelines;
- Environmental Impact Assessment Regulations, 2010 (Government Notice No. R982, 983, 984 and 985 of 2014), promulgated in terms of Section 24(5), 24M and 44 of the National Environmental Management Act, 1998 (Act No. 107 of 1998);
- National Environmental Management: Waste Act (NEM:WA), 2008 (Act No. 59 of 2008);
- National Environmental Management: Air Quality Act (NEM:AQA), 2004 (Act No. 39 of 2004);
- National Forests Act, 1998 (Act No. 84 of 1998);
- National Water Act (NWA), 1998 (Act No. 36 of 1998);
- National Heritage Resources Act (NHRA), 1999 (Act No. 25 of 1999);
- National Environment Management: Biodiversity Act (NEM:BA), 2004 (Act No. 10 of 2004); and
- Hazardous Substances Act (HAS), 1973 (Act No. 15 of 1973).

2.1 The Constitution of South Africa

The legal reference source for environmental law in South Africa is found in the Constitution of the Republic of South Africa, Act No. 108 of 1996. All environmental aspects should be interpreted within the context of the Constitution. The Constitution has enhanced the status of the environment by virtue of the fact that environmental rights have been established (Section 24) and, as other rights created in the Bill of Rights, may impact environmental management.

> The Constitution ensures that "*everyone has the right to an environment that is not harmful to their health or well-being*". This section prevents the introduction of any technology that may have devastating effects to both the social and biophysical environment. Therefore, significant threats posed by a technology should be seriously considered prior to its development.

2.2 National Environmental Management Act Regulations

The National Environmental Management Act (NEMA), 1998 (Act No. 107 of 1998) is South Africa's overarching framework for environmental legislation. The objective of NEMA is to provide for operative environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote cooperative governance, and procedures for coordinating environmental functions exercised by organs of state.

NEMA sets out a number of principles that aim to implement the environmental policy of South Africa. These principles are designed, amongst other purposes, to serve as a general framework for environmental planning, as guidelines by reference to which organs of state must exercise their functions and to guide other law concerned with the protection or management of the environment.

The principles include a number of internationally recognized environmental law norms and some principles specific to South Africa, namely, the:

- Preventive principle;
- Precautionary principle;
- Polluter pays principle; and
- Equitable access for the previously disadvantaged to ensure human well-being

A key principle that plays a vital role in the protection of environment within South Africa is the duty of care, which is detailed in Section 28 (1), which states that *"Every person who causes, has caused or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring, or, in so far as such harm to the environment is authorized by law or cannot reasonably be avoided or stopped, to minimize and rectify such pollution or degradation of the environment".*

> Duty of care (Section 28 of NEMA) ensures that any development that may result in pollution is properly managed and ensures responsibility if the pollution falls on the polluter (including financial responsibility). This becomes important in determining the financial viability of energy technologies. Energy storage technologies that have a higher environmental impact potential may result in higher expenditure on prevention, mitigation or remediation of the associated impacts.

2.3 Environmental Impact Assessment Regulations

Chapter 5 of NEMA is designed to promote integrated environmental management. Environmental management must place people and their needs at the forefront of its concerns, and serve their physical, psychological, developmental, cultural and social interests equitably. Activities which are likely to impact on any of these are identified by Regulations promulgated under NEMA, including the new Environmental Impact Assessment (EIA) Regulations published under Government Notice Regulations (GNR) 982, 983, 984 and 985 for those activities that require environmental authorization. Government Notice (GN) No. R982 of 2014, promulgated in terms of section 24 of NEMA, 1998 (Act No. 107 of 1998) identifies two separate administrative processes for EIAs, depending on the nature of the activity and the affected environment. A Basic Assessment process is identified for those activities that are likely to have less of a detrimental environmental impact. A Scoping and EIA process is necessary for those activities that are likely to have a more detrimental environmental impact.

Listed activities exist for the development of energy **generation** facilities for both **non-renewable** and **renewable** energy sources, for the **generation** of energy through nuclear generation and for the **transmission** of energy. The legislative requirement in terms of the process to be followed varies depending on the proposed size of the development or the high-risk nature of the development. However, currently there is no existing listing notice for the storage of energy. This is regarded as a fatal flaw in the legislative process and the inclusion of energy storage in the environment impact regulations is recommended as an outcome of this study. Gaps in legislation may result in delays in construction, prolonging or inhibiting development.

This gap may exist due to generation of electricity in terms of the Environmental Impact Regulations not being defined. If "generation" is defined to include ESS, then the development of any energy storage system would require the undertaking of an Environmental Impact Assessment process.

Additional listed activities may be triggered due to the nature of certain technologies. These activities include the storage of dangerous goods (listing notice 1, activity 14) relating to the chemicals stored for use in batteries exceeding a storage capacity of $80m^3$. Chemicals used in battery technologies cannot be regarded as storage as this is an actual process being undertaken.

There are various environmental risks that are associated with various energy technologies that may not be accounted for in the current environmental impact regulations due to energy storage being a relatively new concept in South Africa and the development of such a facility not being provided for.

2.4 National Environmental Management: Waste Act

The National Environmental Management: Waste Act (NEM:WA), 2008 (Act. No. 59 of 2008) gives effect to the White Paper on Integrated Pollution and Waste Management. It is the intention of this Act to address the current fragmentation in waste legislation in South Africa.

More specifically, the objectives of the NEM:WA are to:

- Protect health, well-being and the environment by providing reasonable measures for:
  - Minimization of the consumption of natural resources;
  - Avoidance and minimization of the generation of waste;
  - Recovery, re-use and recycling of waste;
  - Treatment and safe disposal of waste as a last resort;
  - Prevention of pollution and ecological degradation;
  - Securing ecologically sustainable development while promoting justifiable economic and social development;
  - Promoting and ensuring the effective delivery of waste services;
  - Remediation of land where contamination presents, or may present, a significant risk of harm;
  - Achieving integrated waste management reporting and planning; and
  - Ensure that people are aware of the impacts of waste on health and the environment;
- Provide for compliance with the measures set out in first bullet; and

- Generally give effect to section 24 of the Constitution in order to secure an environment that is not harmful to the health and well-being of people.

The waste management activities are governed by two administrative processes, depending on the category in which the activity is undertaken. Category A listed activities require a Basic Assessment process; while Category B listed activities require a full Environmental Impact Assessment. The Basic Assessment process is identified for those activities that are likely to have less of a detrimental environmental impact. A Scoping and EIA process is necessary for those activities that are likely to have a more detrimental environmental impact.

Activities in Category A are listed according to:

- Storage and transfer of waste;
- Recycling and recovery;
- Treatment of waste;
- Disposal of waste on land;
- Storage, treatment and processing of animal waste; and
- Expansion or decommissioning of facilities and associated structures and infrastructure

Activities in Category B are primarily listed according to:

- Treatment of waste; and
- Disposal of waste on land

> The NEM:WA and in particular the listed waste activities currently has the greatest jurisdiction over facilities that may be developed for energy storage, in particular relating to the decommissioning phase. However, the maintenance of certain technologies may also have triggers.
>
> In particular, chemicals and plates used in batteries may become a concern once the battery needs to be decommissioned or if these chemicals need to be replaced within the system. The chemicals will become regarded as a hazardous waste once it is no longer part of the energy storage process. The NEM:WA requires either a basic assessment process or an environmental impact assessment depending on the end-use of these materials and the quantity being recycled, reused or disposed of as well as the manner in which this is undertaken.

2.5 NATIONAL ENVIRONMENTAL MANAGEMENT: AIR QUALITY ACT

The aim of The National Environmental Management: Air Quality Act (NEM:AQA), 2004 (Act No. 39 of 2004) is to:

- Protect and enhance air quality in South Africa;
- Prevent air pollution and ecological degradation; and
- Secure ecologically sustainable development while promoting justifiable economic and social development

The NEM:QA makes provision for the establishment of ambient air quality and emission standards at a national, provincial and local level. Government Notice No. 893 of 2013 lists activities that result in atmospheric emissions and which have, or may have, a significant detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage.

The Government Notice No. 893 of 2013 that lists activities that result in atmospheric emissions are only applicable in terms of the production of chemicals used within the battery technologies and does not list anything that may relate to the storage of energy. This may be a flaw in the regulatory requirements due to the potential of Compressed Air Energy Storage facilities. However, currently no recommendations for this regulatory framework are provided for in this study.

2.6 National Forests Act

The main objective of the National Forests Act, 1998 (Act No. 84 of 1998) is to promote the sustainable management and development of forests and to provide protection for certain forests and trees. This protection is provided through the protection of all natural forests (Section 7(1)), the protection of all trees declared to be protected in terms of section 12(1) of the Act, and the regulation of certain activities in a proclaimed State forest (Section 23(1)(a) – (k)). It should be noted that there are other environmental legislation administered by other State Departments that also regulate natural resources.

There are at the moment 47 protected tree species in terms of the National Forests Act of 1998. In terms of the Act these trees may not be cut, destroyed, damaged or removed. Neither may the tree or their products be collected, removed, exported or donated, unless a licence has been granted by the Department of Agriculture, Forestry and Fisheries. A licence is required if activities are conducted in terms of Section 7(1), 15(1) and 23(1) of the National Forest Act. Section 7(1) requires any person wishing to cut, disturb, damage or destroy any indigenous tree in a natural forest, or possess, collect, remove, transport, export, purchase, sell, donate or in any other manner acquire or dispose of any tree or any forest product derived from a natural forest to apply for a license from the Minister or any delegated institution or authority.

South African environmental legislation contains various acts that are focused on the management of particular sensitive features within the country. The National Forests Act is focused on the promotion of sustainable management and development of forests and to provide protection for certain forests and trees. This illustrates the siting issues that may arise for the development of energy storage technologies within South Africa and should be considered in terms of land demands and specific operational requirements (water, caverns etc.) when determining the viability of energy storage technologies.

2.7 National Water Act

The purpose of the National Water Act (NWA), 1998 (Act No. 36 of 1998) is to ensure the protection, usage, development, management and control of water resources in South Africa by taking into consideration the following principles:

- Meeting the basic human needs of present and future generations;
- Promoting equitable access to water;
- Redressing the results of past racial and gender discrimination;
- Promoting the efficient, sustainable and beneficial use of water in the public interest;
- Facilitating social and economic development;
- Providing for growing demand for water use;
- Protecting aquatic and associated ecosystems and their biological diversity;
- Reducing and preventing pollution and the degradation of water resources;
- Meeting international obligations;
- Promoting dam safety; and
- Managing floods and droughts

The most potentially relevant areas of the NWA are those that deal with the management, protection and usage of water resources. In accordance with Section 21 of the NWA the following are regarded as water uses and therefore need to be licensed:

- Taking water from a water resource;
- Storing water;
- Impeding or diverting the flow of water in a watercourse;
- Engaging in a stream flow reduction activity;
- Engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);
- Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
- Disposing of waste in a manner which may detrimentally impact a water resource;
- Disposing in any manner of water which contains waste from, or which has been heated in any industrial or power generation process;
- Altering the beds, banks, course or characteristics of a watercourse;
- Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people;
- Using water for recreational purposes

> The applicability of the National Water Act is mainly dependent on the final siting and the final discharge and disposal mechanisms that will be employed by the relevant applied energy storage technology. The siting and development of each technology may or may not trigger activities.

2.8 National Heritage Resources Act

The National Heritage Resources Act (NHRA), 1999 (Act No. 25 of 1999) aims to protect and encourage communities to nurture and conserve their legacy so that it may be bequeathed to future generations. In terms of the National Heritage Resources Act, 1999 (Act No. 25 of 1999), a development area larger than 5,000m^2 requires that a heritage impact assessment be conducted prior to the development thereof, if the competent authority has reason to believe that a heritage resource may be present on site. In addition, the notification of development outlines the following activity:

Any person who intends to undertake the following must at the very earliest stages of initiating such a development, notify the responsible heritage resources authority and furnish it with details regarding the location, nature and extent of the proposed development.

- the construction of a road, wall, power line, pipeline, canal or other similar form of linear development or barrier exceeding 300m in length;
- the construction of a bridge or similar structure exceeding 50m in length;
- any development or other activity which will change the character of a site such as:
  - exceeding 5,000m^2 in extent;
  - involving three or more existing erven[1] or subdivisions thereof; or
  - involving three or more erven or divisions thereof which have been consolidated within the past five years;
- a development for which costs will exceed a sum set in terms of regulations by SAHRA or a provincial heritage resources authority;
- the rezoning of a site exceeding 10,000m^2 in extent; or
- any other category of development provided for in regulations by SAHRA or a provincial heritage resources authority,

> The National Heritage Resources Act is another legislative framework that deals with specific sensitive features within South Africa, and requires any development exceeding 0.5ha or 300m (linear) to undertake a heritage impact assessment. Again, this provides insights into the governance of environmental issues in South Africa and has bearing on technologies that require large areas of land for development, thereby affecting their viability.

2.9 National Environmental Management: Biodiversity Act

The object of the National Environmental Management: Biodiversity Act (NEM:BA), 1993 is to provide for the management and conservation of South Africa's biodiversity within the framework of NEMA; the protection of species and ecosystems that warrant national protection; the sustainable use of indigenous biological resources; the fair and equitable sharing of benefits arising from bio-prospecting

[1] In South Africa, "erven" refers to a plot of land , urually urban, marked off for building purposes.

involving indigenous biological resources; the establishment and functions of a South African National Biodiversity Institute; and for matters connected therewith.

The objectives of NEM:BA are:

- Within the framework of the National Environmental Management Act, to provide for:
  - the management and conservation of biological diversity within South Africa and of the components of such biological diversity;
  - the use of indigenous biological resources in a sustainable manner; and
  - the fair and equitable sharing among stakeholders of benefits arising from bio-prospecting involving indigenous biological resources;
- To give effect to ratified international agreements relating to biodiversity which are binding to South Africa;
- To provide for cooperative governance in biodiversity management and conservation; and
- To provide for a South African National Biodiversity Institute to assist in achieving the objectives of this Act.

Another sensitivity-specific act that should be complied with is the National Environmental Management: Biodiversity Act, which ensures the protection of important and endangered ecosystems across South Africa. Although this should hold the least bearing on the viability of energy storage technologies as it deals mainly with the siting of the technology, it is important as it emphasizes the "green tape" that a development must undergo.

2.10 HAZARDOUS SUBSTANCES ACT

The objective of the Hazardous Substances Act (HSA), 1973 (Act. No. 15 of 1973) is to provide for the control of substances which may cause injury, ill-health to, or death of human beings by reason of their toxic, corrosive, irritant, strongly sensitizing or flammable nature or the generation of pressure thereby in certain circumstances, and for the control of certain electronic products; to provide for the division of such substances or products into groups in relation to the degree of danger; to provide for the prohibition and control of the importation, manufacture, sale, use, operation, application, modification, disposal or dumping of such substances and products; and to provide for matters connected therewith.

Hazardous substances described according to this act are grouped according to four classes:

- Group I, II and III refer to hazardous substances as any substance or mixture of substances which, in the course of customary or reasonable handling or use, including ingestion, might, by reason of its toxic, corrosive, irritant, strongly sensitizing or flammable nature or because it generates pressure through decomposition, heat or other means cause injury, ill-health or death to human beings; and
- Group IV refers to hazardous substances as any radioactive material which is outside a nuclear installation defined in the Nuclear Energy Act, 1993 and is not a material which forms part of or is used or intended to be used in the nuclear fuel cycle, and

- has an activity concentration of more than 100 becquerels per gram and a total activity of more than 4,000 becquerels; or
- has an activity concentration of 100 becquerels or less per gram or a total activity of 4,000 becquerels or less and which the Minister has by notice in the *Gazette* declared to be a Group IV hazardous substance, and which is used or intended to be used for medical, scientific, agricultural, commercial or industrial purposes, and any radioactive waste arising from such radioactive material.

The hazardous substances act needs to be considered for battery technologies that use hazardous substances in the energy storage process. This act provides mechanisms for the "*prohibition and control of the importation, manufacture, sale, use, operation, application, modification, disposal or dumping of such substances and products; and to provide for matters connected therewith*."

2.11 Conclusions

There are regulatory concerns in existing policy and legislative frameworks regarding the use and application of energy storage technologies. The legal requirements in terms of the environmental legislative framework requires an EIA process to be undertaken for issues relating to siting and storage of hazardous substances. However, in the event that a technology does not trigger a siting issue or a specific operational aspect the need for an EIA process does not exist. This does not mean that the impacts are such that a process should not take place, rather that there is an inherent gap in the legislation. It is recommended that the relevant departments are consulted to introduce energy storage technologies as a listed activity in terms of the Environmental Impacts Assessment Regulations. This gap may exist due to generation of electricity in terms of the Environmental Impact Regulations not being defined. Although, if "generation" is defined to include energy storage, then the development of any energy storage system would require the undertaking of an Environmental Impact Assessment process in terms of the Environmental Impact Assessment Regulations (2014).

An overall environmental regulatory framework needs to consider energy storage technologies in their planning and development tools. Without a clear regulatory framework and guidelines, delays in development may arise due to concerns of environmental impacts.

Existing regulatory frameworks do not accommodate for the implementation of ESS, it is therefore recommended that ESS be considered during policy planning in the short term future for adoption in the long term future. This will essentially reduce delays that may arise during conceptual planning and development of ESS.

The regulatory framework also provides insights into the legislative setting which governs the environment and that will have an influence on the viability of energy storage technologies. Risks associated with a storage technology are vital in determining the viability. Costs involved in the development of energy storage technologies are often viewed from a construction and operational cost perspective. However, regulatory requirements and the prevention and/or mitigation of potential impacts will increase the pre-construction, construction, operational and decommissioning costs of the development. Therefore, both the potential impacts as well as the potential costs of the technology play a role in the overall sustainability of the energy storage technology.

3 Potential Environmental Impacts

A significant environmental benefit of the adoption of ESS is the reduction of use of fossil fuels and the subsequent reduction in emissions of greenhouse gases. ESS can assist in better energy management including reducing the use of peaking generation (gas peaker plants or diesel generators). Additionally, energy storage can support the extended introduction of variable RE generation by firming, smoothing, and shifting/shaving the power generated by these resources. In doing so, ESS helps to eliminate the need for fossil fuel (coal) base generation. Lastly, energy storage can provide ancillary services that can significantly reduce the need for spinning reserves and allow the base load generation to operate more efficiently.

A trade-off between reducing reliance on fossil fuels and the cumulative impacts of the lifecycle of the energy storage technology necessary to achieve the reduction requires a complex analysis. Therefore, both positive and negative environmental impacts associated with the use of specific energy storage systems are examined and recommendations for maximizing positive environmental impacts and minimizing negative environmental impacts are suggested.

ESS are mostly self-contained systems that rarely involve significant emissions to air, water or soil during normal operating conditions. Some technologies have the potential for environmental impact or release in upset or emergency conditions. Emissions and other environmental impacts associated with manufacture and construction phases can be significant, especially for battery storage systems. Lastly, the decommissioning of ESS projects can pose a risk for significant negative impact, particularly for storage technologies that involve hazardous substances if materials are not properly disposed of or recycled. The proceeding section examines these aspects.

3.1 Benefits from Adoption of Energy Storage and How it is Applied

The introduction of large-scale energy storage may have significant indirect environmental benefits to South Africa. The main benefits from adopting energy storage includes; the ability to assist in the integration of RE into the electricity grid; supporting the existing generation facilities to operate at optimal levels; reducing the dependence on inefficient energy generation technologies that would be utilized during peak times and; the potential to defer the need to develop additional "dirty" energy generation infrastructure or infrastructure that has a higher environmental footprint than that of the energy storage system [0317].

Including RE into the electricity grid provides significant environmental benefits relating to lower carbon cycles as well as a smaller environmental footprint, as opposed to the net greenhouse gas (GHG) emissions and associated environmental impacts resulting from "dirty" energy generation infrastructure. Furthermore, at a policy level, South Africa aims to introduce more RE into the energy mix, therefore, adopting energy storage will provide support in this regard.

Existing energy generation facilities should operate at optimal levels to ensure that the environmental impact associated with this generation is equal to the benefit received, rather than the net emissions, waste produced, resources used i.e. environmental cost being higher than the social and economic paybacks. Energy generation facilities could be utilized to "charge" energy storage systems during off-peak times, where previously the facilities would be running at a lower efficiency to supply a reduced demand, with a potential of unused energy being lost.

The charging of energy storage systems during off-peak times through optimizing energy generation facilities provides the necessary capacity to provide the next indirect environmental benefit of energy storage. Storage of energy allows for reducing the dependence on expensive fossil fuel based peaking plants. The benefits of this scenario is not only in relation to the reduced net emissions or to the reduced associated environmental impacts, but to the social benefits of reduced electricity costs of using the diesel generators less as well as the positive social impacts relating to the availability of a stable electricity grid.

The final major benefit of energy storage revolves around the concept of "charge clean and displace dirty". There are three major factors that dictate the net emissions associated to energy storage during operation, which includes "*the emissions associated with the electricity that charges the energy storage system, the round-trip efficiency of the storage technology, and the emissions associated with the displaced generation resource.*" [0298]. Figure 2 provides the net emissions relating to various charge-displace scenarios. The green areas are a representation of the charge-displace scenarios that result in a reduction of net emissions from grid generation, while scenarios that result in an increase in net emissions are shown in red. This provides an illustration of the potential that energy storage has on reducing net emissions, however, the importance of fuel type and generator efficiency has a significant influence on this potential [0298].

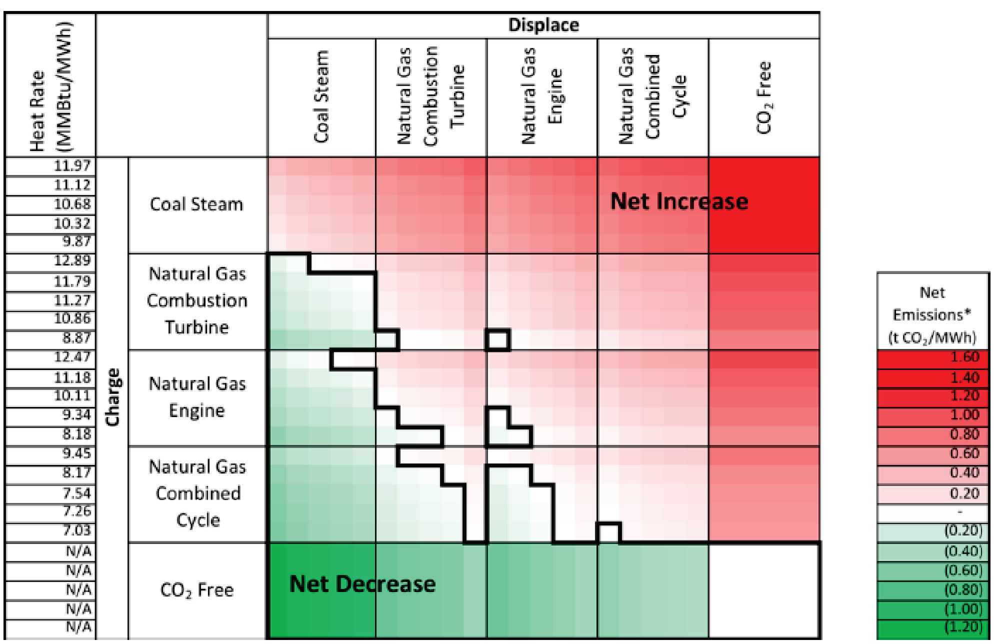

Figure 2-1 – GHG emissions in different charge-displace scenarios for an energy storage system with 75% round-trip efficiency [0298]

3.2 PRINCIPLES FOR GREEN ENERGY STORAGE IN GRID APPLICATIONS

To ensure a positive environmental impact, the environmental benefits of the energy storage technology must out-weigh the potential impacts. A recent paper from University of Michigan identified twelve principals for green energy storage in grid applications and grouped them into three main categories. The categories include system integration for grid applications, the maintenance and operation of energy storage, and the design of energy storage systems including materials and production. The twelve principles that relate this these categories are presented in Figure 3 [0298].

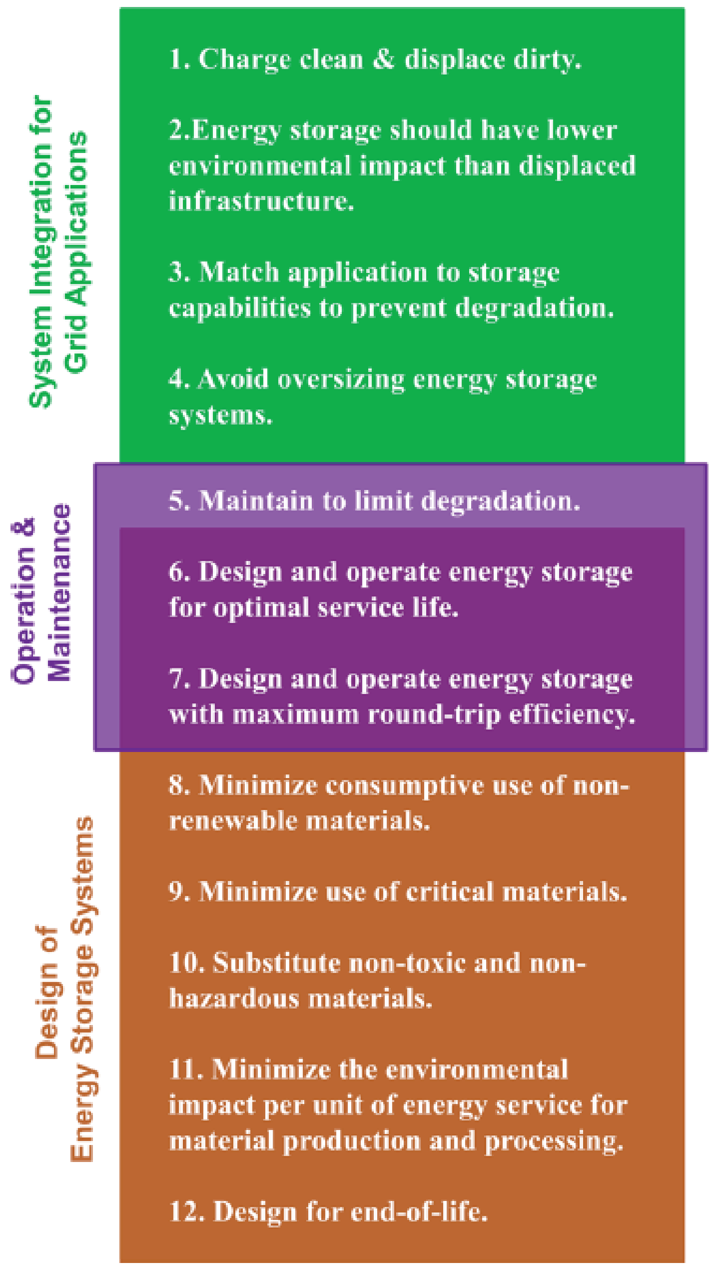

Figure 3-1 – Principles for green energy storage in grid applications [0298]

3.3 Energy Storage Technologies and their Associated Impacts

The "Market Research and Needs Assessment" conducted by the Parsons team highlighted various energy storage technologies that could be applied within South Africa. Based on criteria detailing performance requirements, economic viability, operational characteristics and technology-specific manufacturing or operational features, the technologies to be considered will be outlined below (Figure 4). There are a number of technologies available; however, identifying the most feasible technology will entail detailed studies looking at various aspects; one of which is the potential environmental impact. Many of the technologies mentioned in Figure 4 are also still undergoing extensive research to enhance and improve efficiencies and the overall functioning of the technology. This is especially pertinent to the use of advanced battery-type energy storage systems. Pumped-hydroelectric storage (PHS) is a commonly used technology for time-shifting and load-levelling needs; however, South Africa has already adopted this technology in various parts of the country. Batteries seem to be the more commonly implemented energy storage technology, but at small scale.

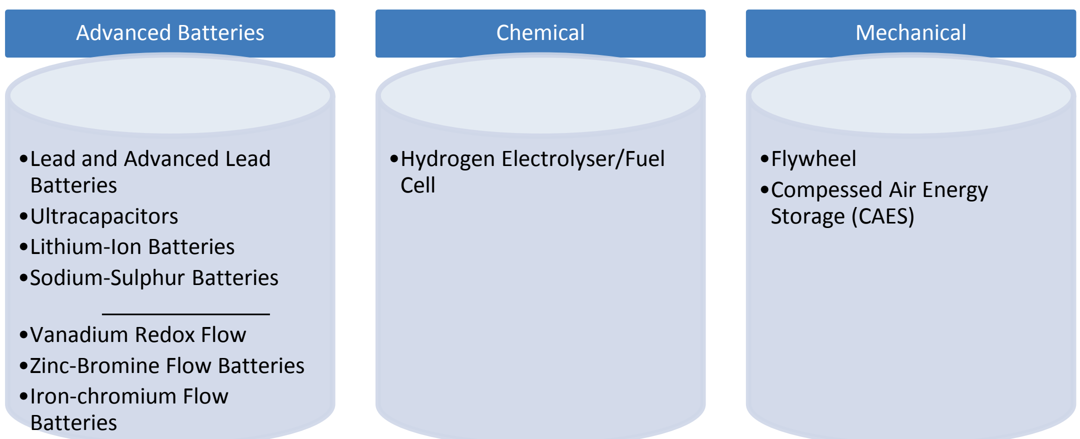

Figure 3-2 – Prospective energy storage technologies

The diversity of energy storage technologies and their applications present opportunities for South Africa to address a variety of issues, such as the adoption of renewable forms of energy generation and relieving congestion in transmission and distribution networks. Energy storage has great potential to provide relief on the current energy situation in South Africa. The energy storage technologies detailed have advantages and disadvantages in a number of aspects (Table 1); however in view of the environmental impacts hereto there are opportunities and improvement areas.

To accurately understand the impacts that are specific to each of the technologies, the impacts that are common among the technologies such as production of steel etc., general construction impacts are not discussed. These are associative processes that will be common among all of the energy technologies as well as any alternative energy technology and does not give a realistic indication of the specific risks that the energy storage technologies pose on the environment.

Table 3-1 – Energy Storage Challenges [0279]

Technology	Characteristics	Challenges / Issues
Advanced Battery Systems		
Lead and Advanced Lead Acid Batteries	• Mature battery technology • Low initial cost • High recycled content • Shorter battery life	• Limited depth of discharge • Low energy density • Large footprint • Electrode corrosion limits useful life • Limited durability • High maintenance requirements
Ultracapacitors	• High energy efficiencies • Stable electrolytes / solvents • Extremely high cycle life	• High cost • Limited discharge duration
Lithium Ion Batteries	• High energy densities • Good cycle life • High charge /discharge efficiency	• High production cost - scalability • Extremely sensitive to overheating, overcharge and internal pressure build up • Intolerance to deep discharges
Vanadium Flow Batteries Zinc Bromine Flow Batteries Ion-Chromium Flow Batteries	• Ability to perform high number of discharge cycles • Lower charge/discharge efficiencies • Very long system life	• Developing technology, several manufacturers entering commercial market • More complex mechanical systems • Lower energy density
Sodium Sulphur Batteries	• High energy density • Long discharge cycles • Fast response • Long life • Good scaling potential	• Operating Temperature required between 250° and 300° C • Liquid containment issues (corrosion and brittle glass seals)
Chemical		
Hydrogen electrolysis/Fuel Cell	• Capable of storing large amounts of energy • Energy can be stored for several days.	• Requires water for operation • Low round trip efficiency
Mechanical		
Flywheel Storage Systems	• Modular technology • Proven growth potential to utility scale • Long cycle life • High peak power without overheating concerns • Rapid response • High round trip energy efficiency	• Rotor tensile strength limitations • Limited energy storage time due to high frictional losses
Compressed Air Energy Storage	• Better ramp rates than gas turbine plants • Established technology in operation since the 1970's • Long duration discharge	• Geographically limited • Lower efficiency due to roundtrip conversion • Slower response time

The challenges presented in Table 1 assist in understanding where potential environmental impacts may arise as a result of deficiencies in each technology. Each technology presents its own challenges that can be translated into potential environmental impacts. Therefore, each technology has been assessed to determine the potential environmental impacts during various phases of its lifecycle.

3.3.1 Advanced Battery Systems

A battery is an energy storage system that produces electrical energy, when required, from chemical reactions. The general method of operation is the use of two same or different chemicals within a battery with different loads. These are connected with a negative (cathode) and positive (anode) electrode. For energy storage applications, only rechargeable battery types are considered. The components of a typical battery system include the battery, monitoring and control systems and power conversion systems.

3.3.1.1 Lead and Advanced Lead Acid Batteries

Lead acid batteries are electrochemical cells containing lead and sulphuric acid. It is also one of the oldest and most developed battery technologies. The materials used in lead acid batteries are high-density materials and therefore typical energy densities tend to be lower than other types of advanced battery systems. The positive electrode is composed of lead dioxide, while the negative electrode is composed of metallic lead. The active material in both electrodes is highly porous to maximize surface area. The electrolyte is a sulphuric acid solution (Figure 5). Corrosion of these batteries is common, and begins immediately when the electrolyte is filled in the battery.

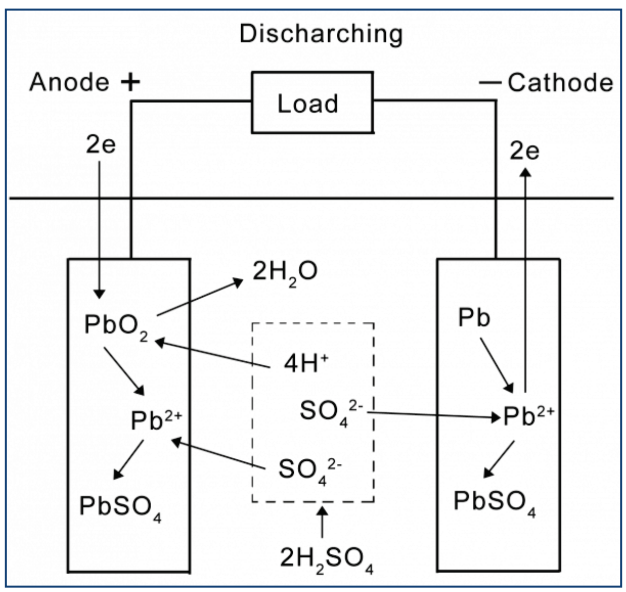

Figure 3-3 – Discharged lead sulphate plates [0280]

The lead used in these batteries is toxic and will pose a health risk to operators over long periods of time. Although lead can be recycled, vast quantities are transported to landfill sites. In addition, sulphuric acid is highly corrosive and when overcharged the battery generates hydrogen which presents an explosion risk. These batteries are used in all cars and therefore are used extensively, albeit at a small scale in South Africa. There is also a very strong recycling system in South Africa for lead-acid batteries, however, this is again at a smaller scale and generally situated within larger metropolitan areas.

Table 3-2 – Potential Environmental Impacts: Lead and Advanced Lead Batteries

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Raw Material Extraction and Processing	Lead and Advanced lead batteries will require lead to be extracted from the ground through mining operations. Most of the lead ore is obtained as a byproduct of other metal mining, usually zinc or silver. Lead is not extracted from the ground in pure form and will need to undergo processing to produce a product. This process will have various associated environmental impacts. However, due to the recyclable nature of lead, this material may be sourced alternatively to material extraction.	• Opencast mining of ore containing lead will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution. Due to pyrite (among others) being associated with lead, acid mine drainage and the consequential impacts associated to the contamination of both ground and water resources will ensue. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the lead will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. This could be in the form of toxic fumes and vapors produced by molten lead, generation of sulphur dioxide during the smelting process or wastewater containing high levels of lead. • Processing of lead also has a number of health risks associated to the smelting process. • The processing of lead requires a large amount of both water and energy.	• The lead recycling market is a mature and well-established industry. Lead is one of the most recycles metals in the world industry. • Environmental regulations prohibit disposal of lead waste in general landfills, thus need to be disposed of at a hazardous landfill facility.
	Chemical Production	The majority of batteries require chemicals as an integral part of the energy storage process. The production of such chemicals will have substantial negative effects.	• The main risk to water resources is contamination from either the routine or accidental release of hazardous substances, either in the form of the chemicals being produced, raw materials or from waste effluent. • Contamination of land from leaks or spills of hazardous materials used in or produced by the process or stored on-site. The greatest considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • A chemicals production or storage facility has the potential to affect local air quality and climate, and to contribute to global climate change due to routine and accidental releases of emissions resulting from the chemical production process. In 1994, the USA chemical industry was the biggest emitter of carcinogens released [0275]. • Chemical production may result in the discharge of water at higher than ambient temperature thereby affecting aquatic organisms.	• Chemical production is a well regulated industry with requirements for air and water emissions.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
			• The chemical production sector has extremely high-energy consumption (7% of world energy use in 1998) [0275], which will add to the overall carbon footprint of the technology.	
Construction	Land Requirements	Lead and advanced lead batteries tend to require a somewhat larger development footprint then other solid-state battery technologies but less than flow batteries.	• The higher land requirements results in the technology having a greater impacts in terms of site specific construction issues such as excavation, removal of natural resources, the removal of vegetation etc.	• Lead-acid ESS will require somewhat more real estate than more energy dense battery technologies but less than most flow battery technologies.
	Hazardous Substance Storage	Hazardous substances in the form of chemicals (e.g. sulphuric acid) are an integral part of the workings of batteries. Therefore, these chemical will need to be stored on-site during construction.	• Containment loss is the greatest concern relating to the storage of any hazardous substance on-site. This will have the most severe negative impact specifically associated to batteries, as the chemicals will cause irreparable damage to the ecosystem through contaminating soil and watercourses. • Loss of containment will also have resounding negative impacts on the health of construction workers. Contact with the sulphuric acid solution may cause irritation or burns to the skin, or irritation to the mucous membranes of the eyes or the upper respiratory system. • The greatest soil pollution considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • Fugitive emissions from the volatilization of chemicals in storage.	• Lead-acid batteries are generally shipped already filled with electrolyte. Should insure batteries are stored in a protected area prior to installation
	Logistics	Batteries can be sourced locally.	• Increase carbon footprint transporting materials from overseas suppliers. However, local suppliers are available for lead batteries. • Leakages from transportation vehicles are unlikely but may occur. Such a containment breach may result in high levels of contamination in the area where the spillages occurred, and could be situated in a highly sensitive area. • Fugitive emissions from the volatilization of chemicals in transit.	• There are several Lead-acid battery manufacturers in South Africa.
Operation	Hazardous Substances	Hazardous substances in the form of chemicals (e.g. sulphuric acid) are an integral part of the workings of batteries. Furthermore, the battery includes the use of heavy metals (lead).	• Sulphuric acid is highly corrosive and may result in containment failure. In the event of containment failure, hazardous substance may contaminate surrounding water resources as well as soil resulting in negative impacts to the ecosystem. • The release of lead into the environment will adversely affect water resources and the ecosystem as a whole. Lead is a	• Lead-acid ESS should have secondary containment systems that prevent environmental release following spill or damage

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
			common and toxic trace metal that readily accumulates in living tissue causing serious harm to biota. • Siting the battery within a coastal region will increase the effects of corrosion, thereby increasing the potential for containment failure and associated negative impacts.	
		Emissions may arise due to reactions occurring within the battery.	• If overcharged, batteries have a high explosion risk, due to the emission of hydrogen. • Toxic fumes and vapors are produced by molten lead, which may be emitted from the battery through containment breaches etc. These pose risks to both air quality and to the health of battery operators.	• Large ESS should be in an isolated location or containerized with battery management, and monitoring systems
	Maintenance	Batteries have a shorter lifespan then other technology types and may require more maintenance.	• Maintenance of batteries may result in the generation of waste which will need to be disposed of. Hazardous waste has severe negative impacts on the environment. • Maintenance of batteries will also have a degree of risk in terms of spillages during the maintenance procedure. These pose risks to the ecosystem and to the health of battery operators due to the hazardous nature of the chemicals used.	• Lead is one of the most recyclable metals • Maintenance personnel should be properly trained, knowledable in hazardous materials and have the necessary equipment to deal with leaks and spills personnel
Decommissioning	Disposal of Waste	Certain materials within the battery can be recycled; however, a significant amount will be disposed of. Hazardous landfill sites are generally the main route for disposal of a hazardous substance. However, other mechanisms are available. These mechanisms include incineration and disposal of the hazardous waste to land (not in a government owned landfill site). These mechanisms will be governed by the NEMWA.	• The recycling of lead requires significantly less energy than producing primary lead from ore. Recycling also reduces dispersal of lead in the environment. • The disposal of hazardous substances will need to be at a hazardous waste disposal facility. There are only a few of these facilities in the country; therefore, there will be an increase in the overall carbon footprint of the technology. • Decreasing the available "airspace" within the hazardous landfill site. • The transportation of the hazardous waste to either a recycling facility or a hazardous waste disposal facility will have associated risks, namely concerning contamination emanating from spillages. • Contaminated run-off emanating from the disposal of hazardous substances to land will be detrimental to the surrounding ecosystem. • Sterilization of land for the disposal of the hazardous substances. • Toxic emissions as a result of the incineration of lead. If incinerated volatilized lead from batteries may be released via flue gases and also remain in the resultant bottom ash.	• The lead recycling market is a mature and well-established industry. Lead is one of the most recycles metals in the world industry • Environmental regulations prohibit disposal of lead waste in general landfills, thus need to be disposed of at a hazardous landfill facility. • Sulphuric acid in lead-acid electrolyte requires neutralization and propoer disposal • Some programs provide for disposal and decommissioning of battery systems at end of life. Alternately the project should have a set aside for decommissioning and disposal.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Positive Impacts				
• Reduced reliance on fossil fuels as energy is being stored. • No release of emissions or effluent as a result of the energy storage process. • Minimal impacts associated with noise generation. • No additional natural resources required for operation. • No intensive loss of visual quality (technology not extremely large and cumbersome).				
Discussion				
The impacts relating to the manufacturing of the battery systems will be a common theme throughout each battery technology. Technologies that require a specific element as part of the energy storage process will result in additional material extraction, other than materials associated with the containment facility (i.e. steel etc.). Additionally, chemical production relating to battery systems will also be a common theme among each battery technology. The differentiating factor will be between battery technologies and other energy storage technologies that do not require chemical production. Furthermore, the additional materials required for batteries also increase the associated carbon footprint, although local suppliers of these batteries do exist. The impacts of most concern with battery technologies are associated to the use of hazardous substances. Lead and Advanced Lead batteries are no exception. However, being a closed system the risks associates to hazardous substances are mainly related to the storage during construction, overcharging resulting in the production of hydrogen and oxygen gas, corrosion resulting in contamination (leakages) and the disposal of the hazardous waste at the end of life. Although the occurrence of these impacts may not be highly probable, the severities of such impacts are a cause for concern. Lead and Advanced Lead batteries also have lower lifespans and require more maintenance compared to other battery systems, increasing the probability of the occurrence of the aforementioned impacts. Moreover, the potential cumulative impacts arising from the lifecycle of Lead and Advanced Lead batteries need to be considered when evaluating the various energy storage technologies.				

3.3.1.2 Ultracapacitors

The ultracapacitor is a technology that primarily contains non-hazardous materials, including metal and plastic. Ultracapacitors (sometimes referred to as Supercapacitors or formerly as electric double-layer capacitors) are sealed metal containers (steel or aluminum) which enclose layers of activated carbon saturated by an electrolyte solution. The electrolyte solution contains a quaternary salt compound (such as tetraethyl aluminum tetrafluoroborate) dissolved in the solvent. Examples of solvents are acetonitrile, propylene carbonate, tetrahydrofuran, diethyl carbonate and Υ-butrolactone. The assembled layers are inserted into the outer metal container and are saturated with the electrolyte, sealed and stored in an uncharged state (Figure 6). There are minor hazards that can arise from exposure to the activated carbon. If the contents of these ultracapacitors remain sealed in the outer shell and are kept uncharged, persons handling this product will avoid most of the risks described herein for all hazardous components of the electrolyte. As such, precautions should be taken to avoid rupture or overheating the sealed metal containers. Ultracapacitors can store energy in the electric field between a pair of charged plates. They contain a significantly enlarged electrode surface area compared to conventional capacitors. This type of ESS is capable of very fast charging and discharging times and is able to go through many cycles without degradation.

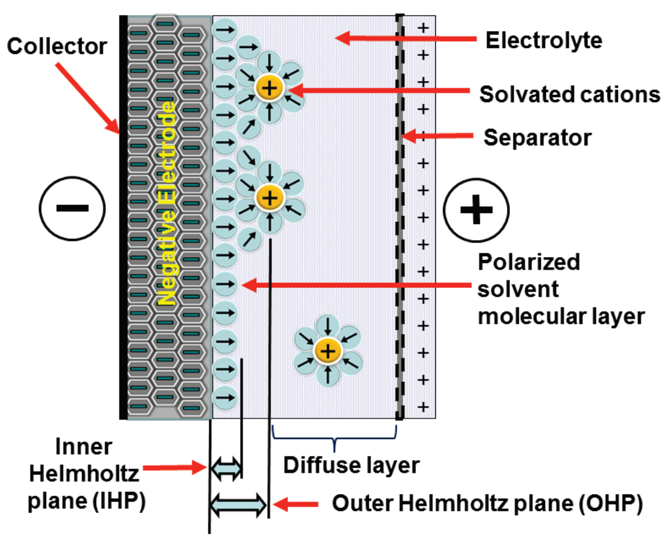

Figure 3-4 – Representation of an ultracapacitor [0282]

Ultracapacitors can be used to enhance energy performance of automotive transport through regenerative braking systems, which promotes fewer emissions. Ultracapacitors have low maintenance, however, potential negative impacts arise from the materials and compounds used during construction and during operations. The use, disposal or recycling of materials used in ultracapacitors is influenced by the relevant legislation.

Table 2-3 – Potential Environmental Impacts: Ultracapacitors

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Material Extraction	A key component of the Ultracapacitors is the electrode, which is typically made from aluminium. Aluminium is extracted from bauxite through large open-cast mining operations and need to undergo extensive processing. However, due to the recyclable nature of aluminium, this material may be sourced alternatively to material extraction.	• Opencast mining of ore (bauxite) containing aluminium will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution due to the common caustic red sludge (from caustic chemical baths) associated to aluminium as well as toxic mine tailings [0257]. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the aluminium will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. • Emissions are one of the greatest concerns with regard to aluminum processing. The processing of aluminium results in the release of carbon dioxide, perfluorocarbons, sodium fluoride, sulphur dioxide etc., some of which are regarded as potent greenhouse gases. • Processing of aluminium also has a number of health risks associated to the smelting process. • The processing of the aluminium requires a large amount of both water and energy.	• There is over 40 million tons of aluminum produced each year in the world [0257]. The amount of aluminum used in South Africa for ESS would be a very small fraction of world production and would not constitute a significant additional impact.
	Chemical production	The majority of ultracapacitors require chemicals as an integral part of the energy storage process. The production of such chemicals will have substantial negative effects.	• The main risk to water resources is contamination from either the routine or accidental release of hazardous substances, either in the form of the chemicals being produced, raw materials or from waste effluent. • Contamination of land from leaks or spills of hazardous materials used in, produced by the process, or stored on-site. The greatest considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • A chemicals production or storage facility has the potential to affect local air quality and climate, and to contribute to global climate change due to routine and accidental releases of emissions resulting from the chemical production process. • Chemical production may result in the discharge of water at higher than ambient temperature thereby affecting aquatic organisms.	• Chemical production for the manufacture of supercapacitors for ESS would be a very small fraction of world production and would not constitute a significant additional impact.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
			• The chemical production sector has extremely high energy consumption (7% of world energy use in 1998) [0275], which will add to the overall carbon footprint of the technology.	
Construction	Hazardous substance storage	Ultracapacitors are factory sealed components, which do not required storage of additional hazardous chemicals during construction.	• The toxicity of organic solvents used in Ultracapacitors are lower than chemicals used in other battery technologies, although the tetraethyl aluminum tetrafluoroborate salts are of concern in terms of toxicity [0285]. • Loss of containment during construction (due to rupture or severe damage to the Ultracapacitor) will have minor negative impacts on the health of construction workers.	• Supercapacitors are small sealed devices and the risk of significant leakage is low
	Logistics	There are no known suppliers of Ultracapacitors in South Africa.	• Increase carbon footprint transporting materials from overseas suppliers. • Leakages from transportation vehicles are unlikely but may occur. Such a containment breach may result in the contamination of the area where the spillages occurred, and could be situated in a highly sensitive area. • Fugitive emissions from the volatilization of chemicals in transit.	• Supercapacitors are small sealed devices and the risk of significant leakage is low
Operation	Hazardous Substances	Ultracapacitors primarily contain non-hazardous materials, including metal and plastic. Small amounts of Hazardous substances in the form of chemicals may be found in Ultracapacitors.	• In the event of containment failure, hazardous substance may contaminate surrounding water resources as well as soil resulting in negative impacts to the ecosystem.	• Supercapacitors are small sealed devices and the risk of significant leakage is low
	Maintenance	Ultracapacitors have a longer lifespan then other technology types and require less maintenance.	• Maintenance of Ultracapacitors will also have a low degree of risk in terms of spillages during the maintenance procedure. Additionally, Ultracapacitors require little to no maintenance and are generally considered field replaceable units.	• Supercapacitors are small sealed devices and the risk of significant leakage is low
Decommissioning	Disposal of Waste	Certain materials within the Ultracapacitors can be recycled; however, a significant amount will be disposed of. Hazardous landfill sites are generally the main route for disposal of a hazardous substance. However, other mechanisms are available.	• The disposal of hazardous substances will need to be at a hazardous waste disposal facility. There are only a few of these facilities in the country; therefore, there will be an increase in the overall carbon footprint of the technology. • Decreasing the available “airspace” within the hazardous landfill site. • The transportation of the hazardous waste to either a recycling facility or a hazardous waste disposal facility will have associated risks, namely with regards to contamination emanating from spillages.	• Owners should consider provisions for disposal at end of life to ensure proper disposal. • Licensed hazardous landfill sites should have the infrastructure to sufficiently handle the disposal of waste.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		These mechanisms include incineration and disposal of the hazardous waste to land (not in a government owned landfill site). These mechanisms will be governed by the NEMWA.	• Contaminated run-off emanating from the disposal of hazardous substances to land will be detrimental to the surrounding ecosystem. • Sterilization of land for the disposal of the hazardous substances.	
Positive Impacts				
• No known impacts to air quality as acetonitrile is degraded by the atmosphere. • Very fast charging and discharging times and is able to go through many cycles without degradation. • Ultracapacitors have low maintenance. • Relatively non-corrosive technology. • Reduced reliance on fossil fuels as energy is being stored. • No additional natural resources required for operation. • No release of effluent as a result of the energy storage process. • Minimal impacts associated with noise generation. • No intensive loss of visual quality (technology not extremely large and cumbersome).				
Discussion				
As with all battery technologies, the extraction of specific elements and the production of chemicals that form an important basis of the energy storage process have significant environmental impacts. Aluminium processing, in particular, results in significantly high levels of greenhouse gas emissions. The impacts of most concern with the Ultracapacitors are associated to the use of hazardous substances in the form of tetraethyl aluminum tetrafluoroborate (quartenary ammonium salt) and acetonitrile (organic solvent). Although the organic solvents are regarded to be less volatile and toxic then typical chmicals used in battery technologies. However, being a closed system the risks associates to hazardous substances are mainly related to leakages and the disposal of the hazardous waste at the end of life. Although the occurrence of these impacts may not be highly probable, the severities of such impacts are a cause for concern. As the Ultracapacitors have higher lifespans due to being non-corrosive, do not easily degrade and require low maintenance, the probability of the aforementioned impacts occurring becomes less likely. It is important to note that there are a variety of organic solvents and quartenary ammonium salts that could be applied with this technology. For the purpose of understanding environmental impacts this study assessed ultracapacitors using tetraethyl aluminum tetrafluoroborate (quartenary ammonium salt) and acetonitrile (organic solvent). If exposed to water tetraethyl aluminum tetrafluoroborate exhibits a high degree of contamination relating to aquatic plants and animals and if exposed to soil, tetraethyl aluminum tetrafluoroborate is volatile and affects soil microorganisms adversely.				

3.3.1.3 Lithium Ion Batteries

A lithium-ion (Li-ion) battery is a rechargeable electrochemical battery. Rather than a single electrochemical couple like nickel-cadmium, "lithium-ion" refers to a wide array of chemistries in which lithium ions are transferred between the electrodes during the charge and discharge reactions.

A Li-ion cell is comprised of three main components; cathode and anodes electrodes, and an electrolyte that allows lithium ions to move from the negative electrode to the positive electrode during discharge and back when charging. When the battery is charging, lithium ions flow from the positive metal oxide electrode to the negative graphite electrode. When the battery is discharging the reverse flow of ions takes place.

Li-ion battery cells contain two reactive materials capable of electron transfer chemical reactions. The reaction is facilitated through electric contact or direct contact, through wire (Figure 7). Ion exchange must take place to maintain overall charge neutrality as electrons are transferred.

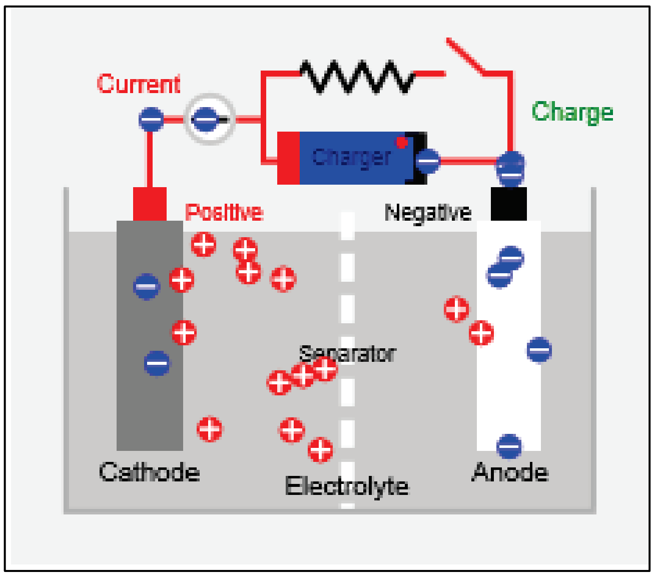

Figure 3-5 – Principles of Lithium Ion Battery Systems [0281]

Lithium ion batteries utilise both lithium and a heavy metal (typically cobalt or manganese) in the reactions required to store energy, resulting in extensive environmental impacts during the pre-construction phases of this technology. Lithium can be recycled; however, the practical application of lithium recycling within the South African context should be further investigated.

Table 3-3 – Potential Environmental Impacts: Lithium Ion Batteries

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Raw Material Extraction and processing	Lithium occurs as a compounded form within the environment, such as lithium carbonate (although some lithium oxide sources also exist) thereby requiring chemical processing to be developed into lithium. Lithium carbonate is generally situated within salt flats, which are typically water scarce areas. The mining of such resources requires large amounts of water.	• Mining of lithium carbonate in salt flats has extensive negative impacts to these highly sensitive ecosystems and will have resounding effects on biodiversity [0286]. • Mining of lithium requires extremely high amounts of water, which is cause of concern due to the already scarce supply of water connected to areas being mined for lithium [0286]. • The extraction of raw materials can also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the lithium will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. This is due to the toxic chemicals that are used in the leaching process required in producing elemental lithium [0286]. • Lithium is highly volatile when exposed to water thereby is a high health and safety risk [0254]. • The toxicity of chemicals used in the leaching process can also have significant health risks.	• Lithium batteries are not the only source of lithium demand, therefore, lithium will still be mined irrespective of whether the energy storage system is adopted.
		Heavy metals (such as cobalt) are used within the lithium ion battery as part of the reactions required to store energy. Therefore, lithium ion batteries require the extraction of an additional battery specific element for its manufacture.	• Opencast mining of ore containing cobalt will have biodiversity and agricultural impacts relating to the disturbance of land. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the cobalt will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. This could be in the form of sulphur acid used in the stripping process, magnesium hydroxide used in the processing plant to extract cobalt or from emissions such as sulphur dioxide. • Processing of cobalt also has a number of health risks associated to the smelting process. • The processing of the cobalt requires a large amount of both water and energy.	• The amounts of heavy metals used in the manufacture of lithium ion batteries depends on the specific anode and cathode chemistry but is generally small enough not to pose a significant potential for environmental impact due to production
	Chemical production	The majority of batteries require chemicals as an integral part of the energy storage process. The production of such chemicals will	• The main risk to water resources is contamination from either the routine or accidental release of hazardous substances, either in the form of the chemicals being produced, raw materials or from waste effluent.	• Chemical production is a well regulated industry with requirements for air and water emissions.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		have substantial negative effects.	• Contamination of land from leaks or spills of hazardous materials used in or produced by the process or stored on-site. The greatest considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • A chemicals production or storage facility has the potential to affect local air quality and climate, and to contribute to global climate change due to routine and accidental releases of emissions resulting from the chemical production process. • Chemical production may result in the discharge of water at higher than ambient temperature thereby affecting aquatic organisms. • The chemical production sector has extremely high energy consumption (7% of world energy use in 1998) [0275], which will add to the overall carbon footprint of the technology.	
Construction	Hazardous substance storage	Hazardous substances in the form of chemicals are an integral part of the workings of batteries however, most Li-ion batteries are factory sealed devices and no additional hazardous or toxic chemicals are required to be stored on-site during construction.	• Containment loss is the greatest concern relating to the storage of any hazardous substance on-site (breach of sealed devices). This will have the most severe negative impact specifically associated with batteries as the chemicals will cause irreparable damage to the ecosystem through contaminating soil and watercourses. • Loss of containment will also have resounding negative impacts on the health of construction workers. Contact with the lithium solution may cause irritation or burns to the skin. • The greatest soil pollution considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • Fugitive emissions from the volatilization of chemicals in storage.	• MSDS and other standards exist to ensure proper storage of hazardous susbtances.
	Logistics	Battery suppliers are generally sourced from overseas.	• Increase carbon footprint transporting materials from overseas suppliers. However, there are local suppliers of lithium ion batteries. • Leakages from transportation vehicles are unlikely but may occur. Such a containment breach may result in high levels of contamination in the area where the spillages occurred, and could be situated in a highly sensitive area.	• Local suppliers of lithium batteris can be found • MSDS and other standards exist to ensure proper transport of hazardous susbtances.
Operation	Hazardous Substances	Hazardous substances in the form of chemicals (e.g. solvents) are an integral part of the workings of batteries. Furthermore, the battery	• Lithium batteries may contain heavy metals such as cobalt and manganese, as well as an organic solvent solution of lithium perchlorate, acetonitrile solution with lithium bromide. In the event of containment failure, hazardous substance	• Some Lithium ion batteries under development use an aqueous electrolyte which significantly reduces the hazards associated with

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		includes the use of heavy metals. The use of hazardous substances also increases the risk of combustion etc. during operation.	may contaminate surrounding water resources as well as soil resulting in negative impacts to the ecosystem. Lithium, for example, causes long-term biodegradation [0254]. • Siting the battery within a coastal region will increase the effects of corrosion, thereby increasing the potential for containment failure and associated negative impacts. • Lithium batteries are subject to thermal run-away and can rapidly overheat if operated outside of normal parameters. Most Lithium batteries use organic electrolytes, which are combustible.	organics and acids • Lithium ion batteries require battery management systems to monitor and protect cells from overcharging or damaging conditions. • Large ESS systems should be designed with appropriate fire detection and suppression systems.
	Maintenance	Li-ion batteries have a shorter lifespan then other technology types but are generally factory sealed, field replaceable components.	• Maintenance of batteries may result in the generation of waste which will need to be disposed of. Hazardous waste has severe negative impacts on the environment. • Lithium ion batteries require low maintenance and are generally considered field replaceable components. • When exposed to water and air (moisture), lithium emits flammable gases; therefore, maintenance procedures may result in safety risks.	• Maintenance of Lithium ion batteries is generally limited to replacement (and disposal) of battery cells at the end of life.
Decommissioning	Disposal of Waste	Certain materials within the battery can be recycled; however, a significant amount will be disposed of. Disposal is particularly significant as lithium ion batteries do not have a long lifespan. Hazardous landfill sites are generally the main route for disposal of a hazardous substance. However, other mechanisms are available. These mechanisms include incineration and disposal of the hazardous waste to land (not in a government owned landfill site). These mechanisms will be governed by the NEMWA.	• The recycling of lithium is an extremely complicated process as the material is toxic, highly reactive and flammable. Furthermore, due to the high costs of recycling lithium and the associated risks, there is a global absence of lithium recycling [0286]. • The disposal of hazardous substances will need to be at a hazardous waste disposal facility. There are only a few of these facilities in the country; therefore, there will be an increase in the overall carbon footprint of the technology. • Decreasing the available "airspace" within the hazardous landfill site. • The transportation of the hazardous waste to either a recycling facility or a hazardous waste disposal facility will have associated risks, namely with regards to contamination emanating from spillages. • Contaminated run-off emanating from the disposal of hazardous substances to land will be detrimental to the surrounding ecosystem. • Sterilization of land for the disposal of the hazardous substances.	• Owners should consider provisions for disposal at end of life to ensure proper disposal. There are currently a limited number of facilities that recycle Lithium Ion batteries. • These batteries can be incinerated if you have a large quantity and they will need to be packaged as lithium ion batteries. Incineration must be performed by an approved and permitted waste treatment facility that handles lithium ion batteries. • Owners should consider provisions for disposal at end of life to ensure proper disposal

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Positive Impacts				
• Reduced reliance on fossil fuels as energy is being stored. • No release of emissions or effluent as a result of the energy storage process. • Minimal impacts associated with noise generation. • No additional natural resources required for operation. • Lithium ion batteries require low maintenance. • No intensive loss of visual quality (technology not extremely large and cumbersome).				
Discussion				
As with all battery technologies, the extraction of specific elements and the production of chemicals that form an important basis of the energy storage process have significant environmental impacts. However, lithium ion batteries require both lithium and an additional heavy metal (typically cobalt or manganese) for the reactions needed to store energy. The impacts of most concern with the operation of lithium ion batteries are associated to the use of hazard substances in the form of lithium and heavy metals. However, being a closed system the risks associates to hazardous substances are mainly related to the storage during construction, leakages and the disposal of the hazardous waste at the end of life. Although the occurrence of these impacts may not be highly probable, the severities of such impacts are a cause for concern. The largest concern associated with li-ion batteries is the possibility of thermal run-away and resulting fire. Most new systems employ sophisticated and integrated battery management systems to limit the battery operation to within safe parameters and prevent thermal runaway.				

3.3.1.4 Redox Flow Batteries

Three flow battery systems are considered and discussed in this study: vanadium flow batteries, zinc-bromine flow batteries and iron-chromium flow batteries. Flow batteries consist of external tanks filled with electrolyte, which flows through an electrochemical cell or reaction stack [0263]. Environmental impacts for batteries are dependent on a number of influencing factors. Location of battery technologies will need to be considered due to the coastal regions increasing susceptibility to corrosiveness.

Redox Flow Batteries (RFB) are a class of electrochemical energy storage technology. It entails a chemical reduction and oxidation reaction that stores energy in liquid electrolyte solutions, which flows through a battery of electrochemical cells during charge and discharge (Figure 8).

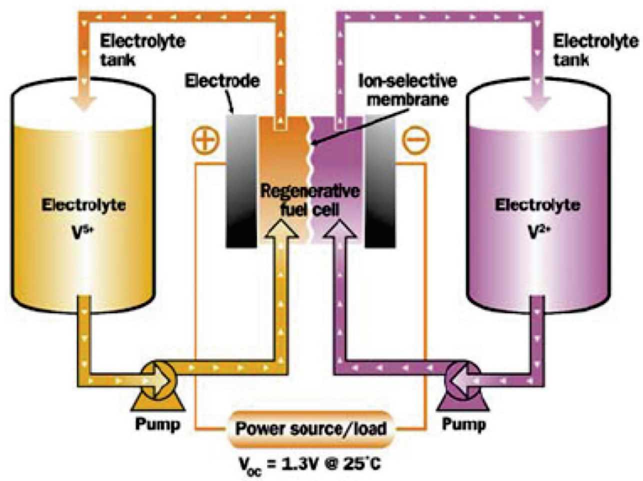

Figure 3-6 – Redox Battery System [0267]

3.3.1.4.1 Vanadium Flow Batteries

Flow batteries store and release energy through a reversible electrochemical reaction between two electrolytes. These batteries provide an energy output greater than or equal to lead acid batteries [0260]. These systems feature the separation of chemical reactants from the electrochemical cells through which charging and discharging takes place (Figure 8). The energy storage capacity is dependent upon the size of the electrolyte tanks while the power output is dependent on the size of the reaction stack.

3.3.1.4.2 Zinc-Bromine Flow Batteries

This energy storage system is a type of hybrid flow battery where a solution of zinc bromide is stored in two tanks. When a battery is charged or discharged, electrolytes are pumped through a reactor stack and back into the tanks. One tank stores the positive electrolyte while the other tank stores the negative electrolyte.

3.3.1.4.3 Iron-chromium Flow Batteries

The iron-chromium flow battery is an RFB where energy is stored by using the Fe^{2+} - Fe^{3+} and Cr^{2+} - Cr^{3+} redox couples. The active chemicals are fully dissolved in the aqueous electrolyte at all times. The power and energy ratings of iron-chromium systems are independent of each other.

The size and scale of this type of energy storage system is likely to determine the extent to which environmental impacts are significant. Larger quantities of land use may be required for electrolyte storage tanks. These electrolytes are not specifically toxic; however, care must be taken at the design and operational phases as other chemicals used may be toxic (e.g. Bromine). There are no significant waste products associated with the operation due to the storage system having the capability to perform discharge cycles indefinitely.

Table 3-4 – Potential Environmental Impacts: Vanadium Flow Batteries

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Material Extraction	Extracting vanadium is done through mining or recovery from petroleum residues. Vanadium occurs in the minerals vanadinite, partonite and carnotite.	• Opencast mining of ore containing vanadium will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution due to the smelting process and exposure of ore to precipitation. Vanadium pollution can cause toxicity to aquatic organisms thereby is a high risk to water resources through discharges and contaminated runoff [0284]. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the vanadium will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment.	• Vanadium batteries are not the only source of vanadium demand. Principly it is used as a steel alloy. Vanadium will still be mined irrespective of whether the energy storage system is adopted.
	Chemical production	Flow batteries require chemicals as an integral part of the energy storage process. Vanadium is stored in sulphuric acid solution in tanks. The production of such chemicals could have substantial negative effects on the environment.	• The main risk to water resources is contamination from either the routine or accidental release of hazardous substances, either in the form of the chemicals being produced, raw materials or from waste effluent. • Contamination of land from leaks or spills of hazardous materials used in or produced by the process or stored on-site. The greatest considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • A chemicals production or storage facility has the potential to affect local air quality and climate, and to contribute to global climate change due to routine and accidental releases of emissions resulting from the chemical production process. • Chemical production may result in the discharge of water at higher than ambient temperature thereby affecting aquatic organisms. • The chemical production sector has extremely high energy consumption (7% of world energy use in 1998) [0275] which will add to the overall carbon footprint of the technology.	• Chemical production is a well regulated industry with requirements for air and water emissions.
Construction	Hazardous substance storage	Hazardous substances in the form of chemicals are an integral part of the workings of flow batteries. Many large	• Containment loss is the greatest concern relating to the storage of any hazardous substance on-site. This will cause irreparable damage to the ecosystem through contaminating soil and watercourses.	• MSDS and other standards exist to ensure proper storage of hazardous substances.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		scale systems do not ship with electrolytes loaded and therefore, these chemicals will need to be stored on-site during construction.	• Both electrolytes in the VRFB are composed of vanadium ions in an aqueous sulfuric acid solution at very low pH. The acidity of the sulfuric acid is comparable to that of the electrolyte found in lead-acid batteries, with a pH of between 0.1 and 0.5 [242]. • Several newer VRFB manufacturers use a mixed acid solution of hydrochloric and sulfuric acid however, the concerns are similar. • Although vanadium is relatively non-toxic, only large spills may lead to pollution. Sulphuric acid on the other hand is a corrosive strong acid and could lead to severe risks if not stored correctly. • Loss of containment will also have negative impacts on the health of construction workers as sulphuric acid is has highly toxic effects on the environment and humans.	
	Logistics	Chemicals such as Vanadium and sulphuric acid are manufactured in South Africa. Other components may be sourced from overseas.	• Vanadium and sulphuric acid can be locally sourced; however, other components (dependent on the type of material used) may be sourced internationally, adding to carbon footprint. • Leakages from transportation vehicles are unlikely but may occur. Such a containment breach may result in the containment of the area where the spillages occurred, and could be situated in a highly sensitive area. • Fugitive emissions from the volatilization of electrolytic chemicals in transit.	• MSDS and other standards exist to ensure proper transport of hazardous substances. • Vanadium electrolyte can be manufactured locally to reduce risks and costs asscociated with transportation.
	Non-chemical components	Polypropylene tanks, flow frames and steel stacks are utilized to construct the plant	• The use of this technology requires large amounts of land, leading to possible habitat fragmentation and removal of potential agricultural land.	• Conventional materials of construction pose very limited potential impact
Operation	Hazardous Substances	Hazardous substances in the form of chemicals are an integral part of the workings of batteries.	• In the event of containment failure, hazardous substances may contaminate surrounding water resources as well as soil resulting in negative impacts to the ecosystem.	• Secondary containment systems that prevent environmental release following spill or damage reduces risk
Decommissioning	Disposal of Waste	Certain materials within the battery can be recycled; however, a significant amount will be disposed of in landfill sites. Hazardous landfill sites are	• Based on the high value of vanadium, it would most likely be recycled at decommissioning as a matter of economics. Toxic effects of vanadium can occur if Vanadium electrolyte were to be dumped; however, very minimal impact as vanadium is readily taken up in ecosystems [0284]. • The disposal of acid based electrolyte will need to be at a hazardous waste disposal facility. There are only a few of these facilities in the country; therefore, there will be an	• Due to the high value of vanadium, it would most likely be recycled at decommissioning as a matter of economics.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		generally the main route for disposal of a hazardous substance. However, other mechanisms are available. These mechanisms include incineration and disposal of the hazardous waste to land (not in a government owned landfill site). These mechanisms will be governed by the NEMWA.	increase in the overall carbon footprint of the technology. • Decreasing the available "airspace" within the hazardous landfill site. • The transportation of the hazardous waste to either a recycling facility or a hazardous waste disposal facility will have associated risks, namely with regards to contamination emanating from spillages. • Contaminated run-off emanating from the disposal of hazardous substances to land will be detrimental to the surrounding ecosystem. • Sterilization of land for the disposal of the hazardous substances. • Polypropylene is used for incineration and the energy is used for heating, however, this increases the carbon footprint of the technology.	

Positive Impacts

- Vanadium has a high economic value and can be recycled. .
- Largest sources of vanadium are found in South Africa.
- Vanadium is taken up by most flora and fauna and is very soluble.
- This battery type does not require the use of heavy metals.
- Fewer emissions than lead acid batteries, reducing global warming potential.
- Reduced reliance on fossil fuels as energy is being stored.
- No additional natural resources required for operation.
- No release of effluent as a result of the energy storage process.
- Minimal impacts associated with noise generation.
- Redox flow batteries have a longer lifespan than conventional batteries and generally require little maintenance as it is a self-discharging system.

Discussion

- Much research has been conducted comparing Vanadium Redox Flow Batteries to Lead Acid Batteries. The overall consensus it that Vanadium Flow Redox Batteries are preferred according to most assessment aspects, including environmental impacts. Since it is a low maintenance technology and no heavy metals are used in this technology, there are fewer environmental impacts. The largest environmental concerns are, however, associated to the extraction of the chemicals and construction of the holding tanks. Mostly due to the types of material used and the large portions of land required. A positive aspect is that no waste is generated during operation due to the system having the capability to perform cycles indefinitely. Vanadium is reusable; therefore disposal presents little environmental impacts. The electrolyte used, in this case sulphuric acid, may present the most concern when a plant is decommissioned.

Table 3-5 – Potential Environmental Impacts: Zinc-Bromine Flow Batteries

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Material Extraction: Zinc	Extracting zinc is done through mining.	• Extraction process may require large amount of water, energy and produce large amount of greenhouse gases emissions. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust.	• Zinc in batteries are not the only source of zinc demand, therefore, zinc will still be mined irrespective of whether the energy storage system is adopted.
	Chemical production	Flow batteries require chemicals as an integral part of the energy storage process. Bromine is produced in an intensive heating, condensation, separation, and purification process.	• A chemicals production or storage facility has the potential to affect local air quality and climate, and to contribute to global climate change due to routine and accidental releases of emissions resulting from the chemical production process. • The main risk to water resources is contamination from within the routine or accidental release of hazardous substances, either in the form of the chemicals being produced, raw materials or from waste effluent. • Contamination of land from leaks or spills of hazardous materials used in or produced by the process. The greatest considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • High temperatures are required in the bromine production process; this process converts organobromine compounds to free bromine atoms. In sunlight, the converted product contributes to ozone depletion.	• Chemical production is a well regulated industry with requirements for air and water emissions.
Construction	Hazardous substance storage	Hazardous substances in the form of chemicals (Bromine) are an integral part of the workings of flow batteries. Therefore, these chemical will need to be stored on-site during construction.	• Containment loss is the greatest concern relating to the storage of any hazardous substance on-site. This will cause irreparable damage to the ecosystem through contaminating soil and watercourses. Bromine is very toxic to aquatic organisms [0308]. • Loss of containment will also have negative impacts on the health of construction workers since bromine is corrosive and reactive in air. • Bromine is also considered highly toxic to humans and result in numerous health issues such as cognitive failure and disruption of thyroid function [0308].	• MSDS and other standards exist to ensure proper storage of hazardous substances. • Zinc-Bromine electrolyte generally has complexing agents that reduce the emmisison of toxic Bromine to the air • Some Zinc-Bromine systems ship with electrolyte loaded into the individual cells. This eliminates handling the electrolyte at the construction site.
	Logistics	Zinc is readily available in South Africa. While there are few bromine producers in South Africa it is readily	• Bromine may be sourced internationally, adding to carbon footprint. • Leakages from transportation vehicles are unlikely but may occur. Such a containment breach may result in the	• MSDS and other standards exist to ensure proper transport of hazardous susbtances. • Some Zinc-Bromine systems ship with

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		available internationally.	containment of the area where the spillages occurred, and could be situated in a highly sensitive area. • Fugitive emissions from the volatilization of chemicals in transit.	with electrolyte loaded into the individual cells. This avoids handling the electrolyte at the construction site. • Electrolyte can be manufactured locally reducing transportation risks
	Non-chemical components	Polypropylene tanks, flow frames and steel stacks are utilized to construct the plant	• The use of this technology requires large amounts of land, leading to possible habitat fragmentation and removal of potential agricultural land.	• Conventional materials of construction pose very limited potential impact
Operation	Hazardous Substances	Hazardous substances in the form of chemicals are an integral part of flow batteries.	• In the event of containment failure, hazardous substance may contaminate surrounding water resources as well as soil resulting in negative impacts to the ecosystem. • Bromine is a highly toxic material through inhalation and absorption and as a result the possibility of hazardous environmental event or personnel exposure must be addressed through adequate design features and operational practices. Maintaining a stable amine complex with the bromine is one key to system safety. Active cooling systems are provided by system manufacturers to maintain stability of the bromine-amine complex when ambient temperatures may exceed 95°F. • The electrolyte for Zn-Br Flow Batteries is acidic and has bromine vapors. Personal Protection Equipment (Rubber Gloves, safety glasses, etc.) and neutralizing agents such as baking soda and water are used to mitigate such risks.	• Secondary containment systems that prevent environmental release following spill or damage reduces risk • Monitoring systems to detect leaks or emissions reduces risk • The addition of complexing agents to electrolyte reduces potential for air borne release of toxic bromine
Decommissioning	Disposal of Waste	Zinc-bromine is not recyclable and must therefore be neutralized with sodium carbonate, decanted and then neutralized with hydrochloric acid (6M). The final solution must be diluted with excess water and flushed into the sewer or absorbed with non-organic absorbents (e.g. clay) and disposed of in landfills. Hazardous landfill sites are generally the main route for disposal of a hazardous	• The disposal of hazardous substances will need to be at a hazardous waste disposal facility. There are only a few of these facilities in the country; therefore, there will be an increase in the overall carbon footprint of the technology. • Decreasing the available “airspace” within the hazardous landfill site. • The transportation of the hazardous waste to either a recycling facility or a hazardous waste disposal facility will have associated risks, namely with regards to contamination emanating from spillages. • Contaminated run-off emanating from the disposal of hazardous substances to land will be detrimental to the surrounding ecosystem. • Sterilization of land for the disposal of the hazardous substances. • Polypropylene is used for incineration and the energy is used	• Licensed hazardous landfill sites should have the infrastructure to sufficiently handle the disposal of waste.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		substance. However, other mechanisms are available. These mechanisms include incineration and disposal of the hazardous waste to land (not in a government owned landfill site). These mechanisms will be governed by the NEMWA.	for heating, however, this increases the carbon footprint of the technology.	
Positive Impacts				
• This battery type does not require the use of heavy metals, decreasing ecological footprint. • Fewer emissions than lead acid batteries, reducing global warming potential. • Reduced reliance on fossil fuels as energy is being stored. • No additional natural resources required for operation. • No release of effluent as a result of the energy storage process. • Minimal impacts associated with noise generation. • Chemicals used are non-flammable.				
Discussion				
Although redox flow batteries present fewer environmental impacts compared to conventional battery types, the different types of redox batteries differ comparatively with regard to potential environmental impacts. Zinc is a trace metal, and therefore its toxicity and negative effects on the environment are considered to be less serve then heavy metals. However, consideration for the serve effects of bromine should be considered.				

Table 3-6 – Potential Environmental Impacts: Iron-Chromium Flow Batteries

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Material Extraction	Extracting chromium from chromate through mining.	• Opencast mining of ore containing chromium will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution due to the smelting process and exposure of ore to precipitation. Leaching from this exposure increase the hexavalent chromium levels in the environment. Hexavalent chromium is a highly toxic form of chromium metal and may result in weakened immune system, genetic material alteration as well as kidney and liver damage. It is also highly toxic to aquatic organisms [0265], [0266].	• Chromium in batteries are not the only source of chromium demand, therefore, chromium will still be mined irrespective of whether the energy storage system is adopted.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
			• The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the chromium will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment.	
		Extracting iron from iron ore (e.g. haematite) through mining.	• Opencast mining of ore containing iron will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution due to the smelting process and exposure of ore to precipitation. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the iron will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. In particular, the processing of iron results in the release of greenhouse gases (carbon dioxide) as well as toxic carbon monoxide and sulphur dioxide.	• Iron in the electrolyte is insignificant compared to quantity of steel produced.
	Chemical production	Flow batteries require chemicals as an integral part of the energy storage process. The production of such chemicals will have substantial negative effects.	• The main risk to water resources is contamination from wither the routine or accidental release of hazardous substances, either in the form of the chemicals being produced, raw materials or from waste effluent. • Contamination of land from leaks or spills of hazardous materials used in or produced by the process or stored on-site. The greatest considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased. • A chemicals production or storage facility has the potential to affect local air quality and climate, and to contribute to global climate change due to routine and accidental releases of emissions resulting from the chemical production process. • Chemical production may result in the discharge of water at higher than ambient temperature thereby affecting aquatic organisms. • The chemical production sector has extremely high energy consumption (7% of world energy use in 1998) [0275] which will add to the overall carbon footprint of the technology.	• Chemical production is a well regulated industry with requirements for air and water emissions.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Construction	Hazardous substance storage	Hazardous substances in the form of chemicals are an integral part of the workings of batteries. Therefore, these chemicals will need to be stored on-site during construction.	• Containment loss is the greatest concern relating to the storage of any hazardous substance on-site. This will cause irreparable damage to the ecosystem through contaminating soil and watercourses.	• MSDS and other standards exist to ensure proper storage of hazardous susbtances.
	Logistics	Iron and chromium are abundant components and are readily available in South Africa.	• Iron and chromium can be locally sourced; however, other components (dependent on the type of material used) may be sourced internationally, adding to carbon footprint. • Such a containment breach may result in the containment of the area where the spillages occurred, and could be situated in a highly sensitive area. • Fugitive emissions from the volatilization of electrolytic chemicals in transit.	• MSDS and other standards exist to ensure proper transport of hazardous susbtances.
	Non-chemical components	Polypropylene tanks, flow frames and steel stacks are utilized to construct the plant.	• The use of this technology requires large amounts of land, leading to possible habitat loss and removal of potential agricultural land.	• Conventional materials of construction pose very limited potential impact
Operation	Hazardous Substances	Hazardous substances in the form of chemicals are an integral part flow batteries.	• The iron and chromium chemistry is environmentally benign compared to other electrochemical systems, in that the iron and chromium species present have very low toxicity and the dilute, water-based electrolyte has a very low vapor pressure. These factors combine to make the iron-chromium RFB one of the safest systems for energy storage in personnel and environmental terms. • In the event of containment failure, hazardous substance may contaminate surrounding water resources as well as soil resulting in negative impacts to the ecosystem.	• ESS should have secondary containment systems that prevent environmental release following spill or damage • ESS should have monitoring systems to detect leaks or emissions •
Decommissioning	Disposal of Waste	Certain materials within the battery can be recycled; however, a significant amount will be disposed of in landfill sites. Hazardous landfill sites are generally the main route for disposal of a hazardous substance. However, other	• The electrolyte used may be corrosive in nature. Any corrosive substance is considered to be hazardous and would need to be disposed of at a hazardous waste facility. • The disposal of hazardous substances will need to be at a hazardous waste disposal facility. There are only a few of these facilities in the country; therefore, there will be an increase in the overall carbon footprint of the technology. • Decreasing the available "airspace" within the hazardous landfill site. • The transportation of the hazardous waste to either a	• Licensed hazardous landfill sites should have the infrastructure to sufficiently handle the disposal of waste.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		mechanisms are available. These mechanisms include incineration and disposal of the hazardous waste to land (not in a government owned landfill site). These mechanisms will be governed by the NEMWA.	recycling facility or a hazardous waste disposal facility will have associated risks, namely with regards to contamination emanating from spillages. • Contaminated run-off emanating from the disposal of hazardous substances to land will be detrimental to the surrounding ecosystem. • Sterilization of land for the disposal of the hazardous substances.	

Positive Impacts

- Iron and chromium are relatively safe elements, compared to chemicals used in other batteries
- Large sources of iron and chromium are found in South Africa.
- This battery type does not require the use of heavy metals, decreasing ecological footprint.
- Fewer emissions than lead acid batteries, reducing global warming potential.
- Reduced reliance on fossil fuels as energy is being stored.
- No additional natural resources required for operation.
- No release of effluent as a result of the energy storage process.
- Minimal impacts associated with noise generation.

Discussion

In essence, redox flow batteries follow the same operational principles, and as an electrochemical technology is less impactful than lead acid, lithium and sodium sulphur batteries. Between the three redox flow batteries, environmental impacts are dependent on size, mining and chemical production activities. Although iron and chromium are readily available, mining activities have more environmental impacts than using just one element, such as vanadium. The electrolyte used redox flow batteries also introduce a number of environmental impacts therefore the type of electrolyte used must carefully be studied to ascertain environmental impacts.

3.3.1.5 Sodium Sulphur Batteries

Sodium Sulphur battery systems are electrochemical and are also the most developed type of high temperature battery. These batteries consist of liquid (molten) sulphur at the positive electrode and liquid (molten) sodium at the negative electrode, separated by a solid beta alumina ceramic electrolyte (Figure 9). The electrolyte only allows positive sodium ions to pass through it and combine with the sulphur to form sodium polysulphides [0267].

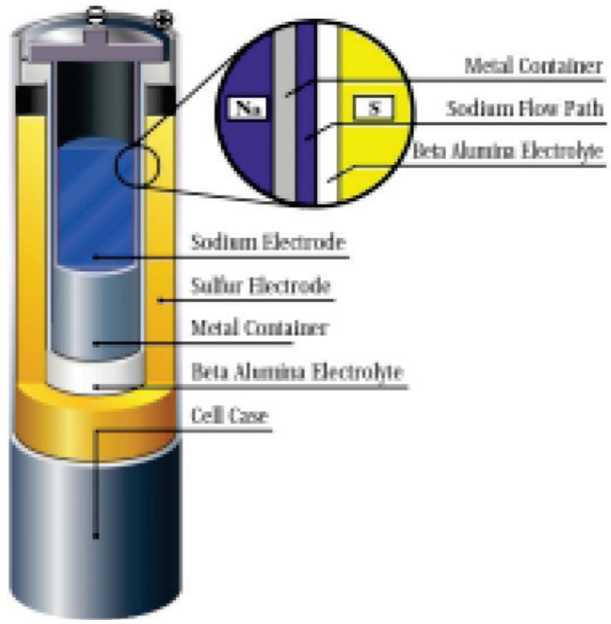

Figure 3-7 – Composition of a Sodium-Sulphur Battery [0267]

There are limited environmental concerns associated with sodium sulphur batteries, since the materials used in their construction are relatively environmentally inert. There is a small risk associated with the high temperature at which the battery must be operated in order to maintain the sulphur in its molten form.

Table 3-7 – Potential Environmental Impacts: Sodium Sulphur Batteries

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Material Extraction	Extracting sodium chloride and sulphur through mining. Sodium chloride then undergoes a separation process to produce sodium.	• Extraction process may require large amount of water, energy and produce large amount of greenhouse gases emissions. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Mining operations generally result in high levels of water pollution. Increase in salinity of water resources, acid mine drainage and the consequential impacts associated to the contamination of both ground and water resources will ensue. • Sulphur and sodium spillage risks arising from accidents results in contamination of surrounding water sources and because both sulphur and sodium are highly volatile, when exposed to air, toxic gases are produced such as hydrogen sulphide.	• Sodium in batteries are not the only source of sodium demand, therefore, sodium will still be mined irrespective of whether the energy storage system is adopted.
	Chemical production	Sodium-sulphur are inert chemicals, however, pose severe risks when these chemicals come into contact with other components (e.g. water).	• Extraction process may require large amount of water, energy and produce large amount of greenhouse gases emissions. • A chemicals production or storage facility has the potential to affect local air quality and climate, and to contribute to global climate change due to routine and accidental releases of emissions resulting from the chemical production process. • Chemical production may result in the discharge of water at higher than ambient temperature thereby affecting aquatic organisms. • The main risk to water resources is contamination from within the routine or accidental release of hazardous substances, either in the form of the chemicals being produced, raw materials or from waste effluent. • Contamination of land from leaks or spills of hazardous materials used in or produced by the process. The greatest considerations are associated to the potential issues with contaminated land that may persist long after operations have ceased.	• Chemical production is a well regulated industry with requirements for air and water emissions.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
	Non-chemical components	Sodium-sulphur batteries require a beta-alumina solid electrolyte (BASE). The beta-alumina is an isomorphic form of aluminium oxide. It is not the main component, but is critical as it acts as a fast ion conductor. Aluminium oxide is derived from refined bauxite through the Bayer process.	• Opencast mining of Bauxite ore containing will have biodiversity and agricultural impacts relating to the disturbance of land. • Bauxite Mining has been associated with areas in the highlands, which poses a significant threat to water resources. • Mining operations generally result in high levels of water pollution due to the common caustic red sludge (from caustic chemical baths) associated to aluminium as well as toxic mine tailings [0257]. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the aluminium will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. • Emissions are one of the greatest concerns with regards to aluminium processing. The processing of aluminium results in the release of carbon dioxide, perfluorocarbons, sodium fluoride, sulphur dioxide etc., some of which are regarded as potent greenhouse gases. • Processing of aluminium also has a number of health risks associated to the smelting process. • The processing of the aluminium requires a large amount of both water and energy.	• There is over 40 million tons of aluminum produced each year in the world [0257]. The amount of aluminum used in South Africa for ESS would be a very small fraction of world production and would not constitute a significant additional impact.
Construction	Hazardous substance storage	Hazardous substances in the form of chemicals are an integral part of the workings of batteries. Therefore, these chemical will need to be stored on-site during construction.	• Containment loss is the greatest concern relating to the storage of any hazardous substance on-site. This will cause irreparable damage to the ecosystem through contaminating soil and watercourses.	• MSDS and other standards exist to ensure proper storage of hazardous susbtances.
	Land requirements	Land will be required for this technology; however the sodium-sulphur battery does not require a large portion of land due to the way the cells are arranged in the battery.	• Even with less extent of land require, the construction phase will still have issues such as excavation, removal of natural resources, the removal of vegetation etc. • Siting the battery within a coastal region will increase the effects of corrosion, thereby increasing the potential for containment failure, increasing exposure to moisture which could result in explosions.	

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
	Logistics	Sulphur may be readily available, while sodium may have to be sourced internationally.	• Leakages from transportation vehicles are unlikely but may occur. Such a containment breach may result in the containment of the area where the spillages occurred, and could be situated in a highly sensitive area. • Increase carbon footprint transporting materials from overseas suppliers. • Fugitive emissions from the volatilization of electrolytic chemicals in transit.	• MSDS and other standards exist to ensure proper transport of hazardous susbtances.
Operation	Hazardous Substances	Hazardous substances in the form of chemicals are an integral part of the workings of batteries. Sodium combusts when it is in contact with water. This means the cells and casings cannot be disintegrated in anyway and may not be in contact with any moisture.	• The NaS batteries use hazardous materials including metallic sodium, which is combustible if exposed to water. In the event of containment failure, hazardous substance may contaminate surrounding water resources as well as soil resulting in negative impacts to the ecosystem. • A potential explosion will result in the loss of habitat (faunal and floral) and loss of lives.	• NaS batteries are constructed in airtight, double-walled stainless-steel enclosures that contain the series-parallel arrays of NaS cells. Each cell is hermetically sealed and surrounded with sand both to anchor the cells and to mitigate fire [235].
	Operational Requirement s	High temperatures are required to maintain sodium and sulphur in molten state. If the sulphur is not contained and comes into contact with oxygen in the atmosphere it may react and form Sulphur dioxide (highly toxic gas).	• Maintaining high temperatures is an energy intensive, which still adds reliance on current electricity sources. • If overcharged, batteries have a high explosion risk, due to the emission of hydrogen.	
	Maintenance	Batteries have a shorter lifespan then other battery technologies and may require more maintenance.	• Maintenance of batteries may result in the generation of waste which will need to be disposed of. Hazardous waste has severe negative impacts on the environment. • Maintenance of sodium-sulphur batteries is especially of concern due to the strict requirements of having no moisture, as this poses an explosion risk.	
Decommissioning	Disposal of Waste	Sodium and sulphur are inert and are not classified as hazardous. Disposal may be allowed at a suitable general landfill site.	• The sodium, sulfur, beta-alumina ceramic electrolyte, and sulfur polysulfide components of the battery are disposed of by routine industrial processes or recycled at the end of the NaS battery life [235]. • Although not hazardous the disposal of the sodium-sulphur	• Licensed hazardous landfill sites should have the infrastructure to sufficiently handle the disposal of waste.

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		Thermal decomposition will evolve with large quantities of sulphur dioxide, which in dry state forms electrostatic charges if stirred, transported pneumatically or poured.	batteries, at a general landfill site, may result in increased potential for spontaneous combustion within the landfill site.	

Positive Impacts

- No release of effluent as a result of the energy storage process.
- Reduced reliance on fossil fuels as energy is being stored.
- Minimal impacts associated with noise generation.
- No intensive loss of visual quality (technology not extremely large and cumbersome).
- Increases RE generation penetration.

Discussion

There is a large risk associated with the high temperature at which the battery must be operated in order to maintain the sulphur in its molten form. Additionally, the chemicals used in this technology are highly reactive when they come into contact with water or moisture, causing explosions that can last for weeks, dependent on the size of the plant.

In addition, this plant may be limited geographically. Due to humidity along the coastal regions, this technology is better suited for areas where there is less moisture in the air. A well-known example of the explosion risk is that of a plant in Japan: the fire resulting from the battery resulted in it being shut down. Considering all major impacts associated with maintenance and the volatility of this technology, the location will be a key deciding factor when positioning the plant.

3.3.2 FLUID (CHEMICAL) STORAGE SYSTEMS

3.3.2.1 Hydrogen Electrolyzer/Fuel Cell

Fuel cells are able to convert chemical energy to electrical energy by combining hydrogen and oxygen to produce water, thereby producing water. A combination of a Hydrogen Electrolyzer and a Hydrogen Fuel Cell could store energy by using electricity to produce hydrogen through an electrolyzer which separates water into hydrogen and oxygen. The hydrogen is compressed and stored from where it is then discharged into a fuel cell (Figure 10) to generate electricity. Fuel cells are capable of holding energy in high densities and capacities over long periods of time.

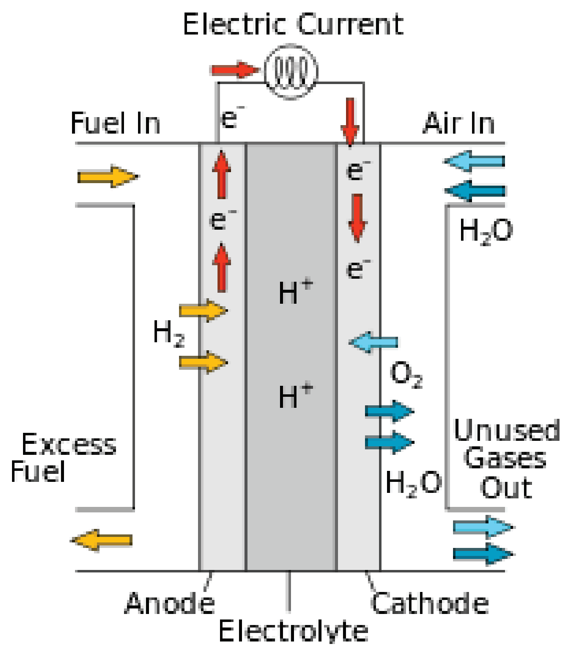

Figure 3-8 – Schematic of a Hydrogen Fuel Cell [0283]

The electrolysis process has no emissions other than air. Electrification in fuel cells results in water vapour and combustion engines emit water vapour and small amounts of nitrogen oxide. Fuel cells are capable of holding energy in high densities and capacities over long periods of time.

Table 3-8 – Potential Environmental Impacts: Hydrogen Electrolyzer/Fuel Cell

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material Manufacturing	Material Extraction	Aluminium alloys are a key material used in the manufacturing of Hydrogen Electrolyzer/Fuel Cells. Aluminium is extracted from bauxite through large open-cast mining operations and need to undergo extensive processing. However, due to the recyclable nature of aluminium, this material may be sourced alternatively to material extraction.	• Opencast mining of ore (bauxite) containing aluminium will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution due to the common caustic red sludge (from caustic chemical baths) associated to aluminium as well as toxic mine tailings. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the aluminium will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. • Emissions are one of the greatest concerns with regards to aluminium processing. The processing of aluminium results in the release of carbon dioxide, perfluorocarbons, sodium fluoride, sulphur dioxide etc., some of which are regarded as potent greenhouse gases. • Processing of aluminium also has a number of health risks associated to the smelting process. • The processing of the aluminium requires a large amount of both water and energy.	• There is over 40 million tons of aluminum produced each year in the world [0257]. The amount of aluminum used in South Africa for ESS would be a very small fraction of world production and would not constitute a significant additional impact.
Construction	Logistics	No known local suppliers in South Africa.	• Increase carbon footprint transporting materials from overseas suppliers.	
	Biodiversity Disturbance	Due to the water requirements for the Hydrogen Electrolyzer/Fuel Cells, this technology will need to be established near water resource.	• Siting of the Hydrogen Electrolyzer/Fuel Cells will likely be close to water resources, thereby impacting on these sensitive features through disturbances and general construction related impacts.	• Siting in sensitive features must minimize the environmental footpint in these areas
Operation	Hazardous Substances	Reactions occurring within the Hydrogen Electrolyzer and the subsequent storage of Hydrogen in the Fuel Cells results in various health and	• Large volumes of stored hydrogen (highly flammable) could lead to fires and explosions if there is a malfunction. • Hydrogen is an asphyxiant at high	

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		safety risks.	concentrations. • Intensive chemical reactions and high temperatures to produce hydrogen gas.	
	Resource Consumption	The main source of energy storage within the Hydrogen Electrolyzer/Fuel Cells is hydrogen, which is produced from reactions occurring between water and air.	• The storage of energy through hydrogen will require large volumes of water. The abstraction of water will reduce available water within the area that the battery operates affecting water supply for agriculture, households and within the environmental reserve (affecting aquatic ecology as well as the large ecosystem).	• Energy storage technology must be sited in areas that have sufficient supply that will not affect the local reserve.
Decommissioning	Disposal of Waste	Disposal of the Hydrogen Electrolyzer/Fuel Cells will mainly consist of the materials that formed part of the structure; therefore no hazardous wastes are expected.	• Decreasing the available “airspace” within a general landfill site.	

Positive Impacts

- No emissions other then oxygen, water vapour and small amounts of nitrogen dioxide.
- No production of hazardous chemical required.
- No hazardous chemicals that are toxic and can have deterimental effects on the environment.
- No risks with regards to transportation or onsite storage before operation.
- Reduced reliance on fossil fuels as energy is being stored.
- No release of effluent as a result of the energy storage process.
- Minimal impacts associated with noise generation.
- Hydrogen Electrolyzer/Fuel cells require low maintenance and have a long lifespan.
- No intensive loss of visual quality (technology not extremely large and cumbersome).

Discussion

Similar to battery technologies, the extraction of specific elements (aluminium alloys) form an important part of the Hydrogen Electrolyzer/Fuel cells and have significant environmental impacts. Aluminium processing, in particular, results in significantly high levels of greenhouse gas emissions. However, due to the recyclable nature of aluminium, this material may be sourced alternatively to material extraction.

In general, Hydrogen Electrolyzer/Fuel cells are a low environmental impact energy storage technology. There are concerns regarding safety due to the storage of hydrogen, however, in terms of emissions, effluents and end of life disposal, very few risks exist. The greatest cause for concern is the large water requirements. Considering South Africa is a water-scarce country, this impact has a high degree of importance. That being said, the emissions that are generated by the Hydrogen Electrolyzer/Fuel cells include water vapor, which suggests that the inputs in terms of water are returned to the system, although the dispersed nature of the return does not account for the direct lose at the source.

3.3.3 Mechanical Storage Systems

3.3.3.1 Flywheel Energy Storage

Flywheels are a form of mechanical energy storage in which kinetic energy is generated by a rapidly spinning cylinder containing stored energy (Figure 11). Modern flywheel systems consist of rotating cylinders supported by magnetically levitated bearings that eliminate wear and tear and extend lifespans. Flywheels can be operated in low pressure environments to reduce friction with air. Flywheel energy storage systems draw electricity from a primary source to spin the high-density cylinder at speeds of 200,000 rpm and greater.

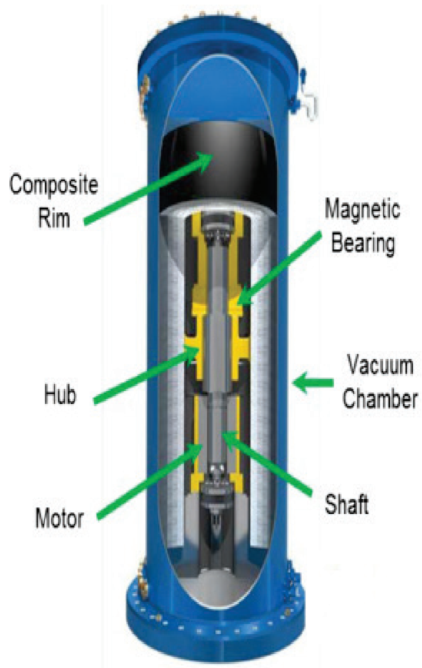

Figure 3-9 – Representation of Flywheel Storage System [0277]

Early flywheels were generally made of steel which resulted in a lower revolution rate compared to modern flywheels which are made of carbon fiber materials; they are also stored in vacuums to reduce drag and use magnetic bearings which enable rotation at up to 60,000 rpm.

Since the flywheel is a form of mechanical energy storage, there is no chemical element and therefore does not require chemical management or disposal thereof. Operationally, there are a number of risks associated such as the operation of heavy, rapidly rotating objects. Flywheel energy storage systems generally pose little environmental risk to the area.

Table 3-9 – Potential Environmental Impacts: Flywheel Energy Storage

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material/Component Manufacturing	Material Extraction	Extracting iron from iron ore (e.g. haematite) and other mineral through mining.	• Opencast mining of ore containing iron will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution due to the smelting process and exposure of ore to precipitation. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the iron will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. In particular, the processing of iron results in the release of greenhouse gases (carbon dioxide) as well as toxic carbon monoxide and sulphur dioxide.	• Flywheels are likely to contain a higher percentage of steel than other energy storage technologies, however, the total steel content is still insignificant compared to world wide steel production. • Newer flywheels will use a higher percentage of carbon fiber and other materials
	Component Manufacturing	Fabrication of mechanical equipment (motors, rotors, bearings, and casings,) requires an extensive amount of fabrication, machining of large carbon and alloy steel components	• Large amount of energy necessary to form, forge, and machine components • Large amount of wastes generated during component manufacturing in the form of scrap metal, solvents, and lubricants • Flywheels will require more energy and cause more industrial waste during manufacture.	
Construction	Biodiversity Disturbance	Flywheels require stable structure. Some required excavated foundations that require sub grade land disturbance	• The higher land requirements results in the technology having a greater impacts in terms of site specific construction issues such as excavation, removal of natural resources, the removal of vegetation etc.	• The construction of subgrade foundations is a small additional impact during construction over other energy storage technologies.
Operation	Safety Risks	Modern flywheel systems are comprised of high speed rotating parts.	• Rapidly rotating parts may cause injury if there is a malfunction.	• Flywheel systems should be designed and tested to ensure that any debris is safety contained during reasonable malfunction or failure.
Decommissioning	Disposal of Waste	Disposal of the Flywheel will mainly consist of the materials that formed part of the structure; therefore, no hazardous wastes are expected.	• Decreasing the available "airspace" within a general landfill site.	

Positive Impacts
• No emissions are produced in the operation of a flywheel. • No production of hazardous chemical required. • No specific material extraction is required other then the metal needed for the housing and the structure. • No hazardous chemicals that are toxic and can have deterimental effects on the environment. • No risks concerning transportation or onsite storage before operation. • Reduced reliance on fossil fuels as energy is being stored. • No release of effluent as a result of the energy storage process. • Flywheels require low maintenance and have a long lifespan. • No additional resource consumption for the storage of energy.
Discussion
The Flywheel has little to no major environmental implications associated to its operation or its disposal. Furthermore, it does not contain any hazardous chemical nor does it require specific elements to be extracted for its manufacture. Land requirements are the only notable concern regarding Flywheels.

3.3.3.2 Compressed Air Energy Storage (CAES)

Compressed Air Energy Storage (CAES) relies upon geological formations such as underground caverns or reservoirs. During low electricity demand air is compressed into the cavern. During high electricity demand air is expanded and mixed with natural gas, which is then burned to increase heat energy which then passes through a turbine to generate electricity. For energy storage air is compressed using a motor; this process heats up air (Figure 12). Heat is then removed as more air is directed into the cavern. During the discharge, air is expanded which then allows the air to cool. This process then requires the use of gas (e.g., natural gas) for reheating. Heat derived from the process then forms two types of CAES. One is the diabatic method where heat is removed and then fuel is used to reheat the air during discharge. The other is an adiabatic method which results in fewer emissions as excess heat is stored for use during the discharge process.

CAES storage systems are highly beneficial in that they can be integrated with forms of RE such as wind farms, enhancing additional energy storage generated off-peak. The use of this technology can be explored in the context of abandoned mine shafts, which are numerous in mining parts of South Africa, since underground caverns are relatively few. Caverns must, however, have the appropriate geology as well as be able to contain high pressures.

This form of energy storage can have potential environmental impacts due to the underground storage space required. Locality is a major constraint of this energy storage system as a result of the need for caverns (or similar underground structure). Competition may arise for underground stores where other technologies may utilise the caverns for large-scale storage of carbon (e.g. from coal-fired electricity generation).

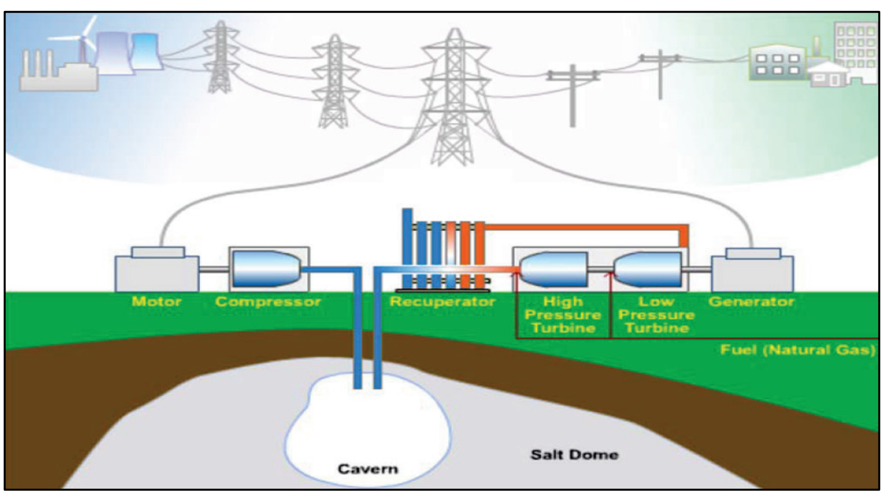

Figure 3-10 – Schematic of Compressed Air Energy Storage [0278]

Table 3-10 – Potential Environmental Impacts: Compressed Air Energy Storage

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
Material/Component Manufacturing	Material Extraction	Extracting iron from iron ore (e.g. haematite) through mining.	• Opencast mining of ore containing iron will have biodiversity and agricultural impacts relating to the disturbance of land. • Mining operations generally result in high levels of water pollution due to the smelting process and exposure of ore to precipitation. • The extraction of raw materials will also have negative effects on air quality due to heavy use of machinery as well as the generation of particulate matter in the form of dust. • Processing of the iron will result in various forms of waste, such as emissions, effluent discharges as well as solid waste that will all have negative impacts on the environment. In particular, the processing of iron results in the release of greenhouse gases (carbon dioxide) as well as toxic carbon monoxide and sulphur dioxide.	• CAES components likely contain more iron and steel than other energy storage technologies, however, the total steel content is still insignificant compared to world wide steel production.
	Component Manufacturing	Fabrication of mechanical equipment (compressors, turbines, heat exchangers) requires an extensive amount of fabrication, machining of large carbon and alloy steel components	• Large amount of energy necessary to form, forge, and machine components • Large amount of wastes generated during component manufacturing in the form of scrap metal, solvents, and lubricants	• CAES components will require more energy and generate more industrial waste during manufacture due to forging and machining operations.
Construction	Land Disturbance	The CAES facility will require turbines, compressors as well as generators. These components will be constructed above an underground storage facility. This energy storage technology is expected to require the most land.	• The higher land requirements results in the technology having a greater impacts in terms of site specific construction issues such as excavation, removal of natural resources, the removal of vegetation etc. • The nature of CAES requires specific site conditions for establishment. This requirement increase the probability of sensitive feature being impacted on during construction.	
	Cavern Development	Considering the low probability of the presence of salt domes and spent natural gas caverns in South Africa, abandoned mining operations and new caverns are most likely the going to be used for CAES.	• Large areas of land will need to be developed in order to create a suitable underground storage area for CAES. • Development of underground storage areas may affect underground water tables, reducing recharge for surrounding water resources as well as affecting water supply for other users. • Development of underground storage areas may affect soil habitats. • Overburden material will be generated and will create additional waste that must be disposed of.	• Need to closely evaluate the environmental issues associated with underground features.
Operation	Compressed Air Storage	In CAES air is compressed, cooled and stored in	• The cyclic injection and withdrawal of fluid (compressed air) has broad negative impacts for the subsurface local geology. Impacts that	

Phase	Aspect	Description	Potential Impacts	Potential Mitigation
		underground storage areas.	may arise for compressed air storage includes the creation of cavities and localized cracks, altering the stress loads and strength of the rocks as well as thermal alteration. These factors coupled with the increase in subsurface erosion and weathering could potentially lead to a cavern collapse causing massive social and environmental issues [0256]. • The cyclic injection and withdrawl of compressed air will also result in significant noise and vibration, potential affecting surround sensitive receptors such as fuana and communities.	
	Gas Turbine Operation	CAES is a hybrid system and is generally linked to the burning of gas in gas turbines.	• Gas turbines have a set of environmental impacts associated with its operation. Gas turbines generate waste, discharge wastewater and require a large amount of water for operations. In particular, the operation of the gas turbine will release of fossil fuels (sulphur dioxide, particulates, carbon monoxide etc.) thereby affecting local air quality and contributing to climate change. • Noise and vibration will also persist into the combustion stage of CAES.	• The use of biofuel as a replacement for natural gas reduces the net GHG emissions from CAES.
Decommissioning	Mothballing Facility	CAES facilities have very long lifespans, however, various oils and lubricants are used which may need to be disposed of in a hazardous waste facility.	• The disposal of hazardous substances will need to be at a hazardous waste disposal facility. There are only a few of these facilities in the country; therefore, there will be an increase in the overall carbon footprint of the technology. • Decreasing the available “airspace” within both general and hazardous landfill site. • Large recycling opportunities exist for scrap metal.	• Disposal is similar to other large mechanical industrial systems • Plans and procedures for dismantlement and decommissioning should be developed • General large steel componenets are good candidates for recycling

Positive Impacts

- Consumes approximately 2/3 less fuel then standard gas power generation facilities although significantly more than other energy storage technologies.
- CAES does not utilize hazardous substances in the energy storage process.
- Does not require specific elements to be extracted for its establishment other than typical metals for housing and structures.
- Lower transportation carbon footprint, however, overall carbon footprint will still be quite high.

Discussion

The CAES technology has the greatest number of environmental concerns. The development of the energy storage technology still requires the burning of fossil fuels and the operation of a gas turbine (with its associated environmental impacts). Additionally, this technology potentially requires the most construction activities for its establishment and may also require the largest amount of land.

The technology also has massive environmental implications on the subsurface geology, which poses a huge risk to the area in which it is located.

4 Suitability Analysis

The potential impacts identified for each of the ESS provide a qualitative description and indication of the effects each technology may have on the surrounding environment. However, the impacts identified are essentially a potential impact and each impact may vary in terms of the probability or severity. In order to provide a more quantitative assessment of the ESS, a suitability analysis has been undertaken to determine which ESS is the most feasible from an environmentally sound perspective.

4.1 Potential Impact Matrix

The suitability analysis utilizes an impact matrix (refer to Table 12) wherein a weighting system is utilized to provide a rating for each potential impact associated with each technology. This rating system will provide the cumulative score for each impact (refer to Table 13), in order for a comparative analysis to be conducted for each technology to determine suitability.

Table 3-11 – Potential Impact Matrix

Criteria	Rating Scales	Rating Value	Notes
Extent (Footprint)	Small-Moderate	1	The impact only affects **a small to moderate area** in which the proposed activity will occur.
	Moderate-Large	2	The impact only affects **a moderate to large area** in which the proposed activity will occur.
	Local	3	The impact affects the **development area and adjacent** properties / surrounding ecosystems.
	Regional / International	4	The effect of the impact extends **beyond local and international boundaries**.
Duration	Temporary	1	The duration of the activity associated with the impact will **last 0-6 months**.
	Short term	2	The duration of the activity associated with the impact will **last 6-18 months**.
	Medium term	3	The duration of the activity associated with the impact will **last 18 months-5 years**.
	Long term	4	The duration of the activity associated with the impact will **last more than 5 years**.
Severity	Low	1	Where the impact affects the environment in such a way that natural, cultural and social functions and processes are **minimally affected**.
	Moderate	2	Where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way; and valued, important, sensitive or vulnerable systems or communities are **negatively affected**.
	High	3	Where natural, cultural or social functions and processes are altered to the extent that the natural process will temporarily or permanently cease; and valued, important, sensitive or vulnerable systems or communities are **considerably affected**.
	Very high	4	Where natural, cultural or social functions and processes are altered to the extent that the natural process will temporarily or permanently cease; and valued, important, sensitive or vulnerable systems or communities are **quite substantially affected**.
Probability (the likelihood of the impact occurring)	Improbable	1	It is highly unlikely or less than **50 % likely** that an impact will occur.
	Probable	2	It is **between 50 and 70 % certain** that the impact will occur.
	Definite	3	It is **more than 75 % certain** that the impact will occur or it is definite that the impact will occur.
Cumulative Potential Impacts Rating	Low	1-10	A function of the risk ranking ((Extent + Duration + Severity) X Probability)
	Moderate	11-20	
	High	21-30	
	Very high	>30	

4.2 Quantitative Assessment of Potential Impacts

Table 4-1 – Energy Storage Technology Suitability Analysis

Phase	Aspect	Risk Rankings				Cumulative Potential Impacts Rating	Explanatory Note
		Extent (E)	Duration (D)	Severity (S)	Probability (P)	((E+D+S) X P)	
Advanced Battery Systems							
Lead and Advanced Lead Batteries							
Material Manufacturing	Raw Material Extraction and Processing	4	4	3	3	33	Lead extraction
	Chemical Production	4	4	4	3	36	Chemical production of toxic substances
Construction	Land Requirements	2	2	2	3	18	Requires a greater development footprint
	Hazardous Substance Storage	3	2	3	2	18	Corrosive and highly toxic substances. Greater likelihood of spillages and containment loss etc. during construction
	Logistics	4	1	3	1	8	Suppliers are available in South Africa
Operation	Hazardous Substances	3	4	3	1	10	Corrosive and highly toxic substances
	Maintenance	4	4	3	2	22	Shorter lifespan then and may require more maintenance
Decommissioning	Disposal of Waste	4	4	3	2	22	Certain materials can be recycled; however, limited recycling facilities (i.e. long distances) may result in disposal being more feasible
Ultracapacitators							
Material Manufacturing	Raw Material Extraction and Processing	4	4	3	2	22	Aluminium is extracted. Aluminium is often recycled; therefore probability is not considered a definite
	Chemical Production	4	4	3	3	33	Chemical production - less volatile and toxic solvents
Construction	Hazardous Substance Storage	3	2	2	2	8	Ultracapacitors are factory sealed components and less volatile and toxic solvents that are non-corrosive
	Logistics	4	1	2	2	14	No known local suppliers

Phase	Aspect	Risk Rankings				Cumulative Potential Impacts Rating	Explanatory Note
		Extent (E)	Duration (D)	Severity (S)	Probability (P)	((E+D+S) X P)	
Operation	Hazardous Substances	3	4	2	1	9	Less volatile and toxic solvents that are non-corrosive
	Maintenance	3	4	1	1	8	Longer lifespan and require less maintenance
Decommissioning	Disposal of Waste	4	4	2	2	20	Certain materials can be recycled; however, limited recycling facilities (i.e. long distances) may result in disposal being more feasible
Lithium-ion Batteries							
Material Manufacturing	Raw Material Extraction and Processing	4	4	4	3	36	Extraction of lithium and heavy metals (such as cobalt)
	Chemical Production	4	4	3	3	33	Chemical production of toxic substances
Construction	Hazardous Substance Storage	3	2	3	1	18	Corrosive and highly toxic substances. Greater likelihood of spillages and containment loss etc. during construction
	Logistics	4	1	2	2	14	No known local suppliers
Operation	Hazardous Substances	3	4	4	2	22	Subject to thermal run-away and can rapidly overheat
	Maintenance	3	4	3	2	20	Shorter lifespan but are generally factory sealed, field replaceable components
Decommissioning	Disposal of Waste	4	4	3	3	33	Recycling of lithium is an extremely complicated process and high costs of recycling lithium
Vanadium Flow Batteries							
Material Manufacturing	Raw Material Extraction and Processing	4	4	3	3	33	Extraction of vanadium
	Chemical Production	4	4	3	3	33	Chemical production of toxic substances
Construction	Land Requirements	2	2	2	3	18	Use of this technology requires large amounts of land
	Hazardous Substance Storage	3	2	3	2	16	Electrolyte can be considered corrosive. Greater likelihood of spillages and containment loss etc. during construction
	Logistics	4	1	3	1	8	Chemicals such as Vanadium and sulphuric acid

Phase	Aspect	Risk Rankings				Cumulative Potential Impacts Rating	Explanatory Note
		Extent (E)	Duration (D)	Severity (S)	Probability (P)	((E+D+S) X P)	
							are manufactured in South Africa
Operation	Hazardous Substances	3	4	3	1	10	Electrolyte can be considered corrosive
	Maintenance	3	4	3	1	10	Redox flow batteries have a longer lifespan than conventional batteries and generally require little maintenance as it is a self-discharging system
Decommissioning	Disposal of Waste	4	4	2	1	10	High value of vanadium, it would most likely be recycled. Toxic effects of vanadium can occur if Vanadium electrolyte were to be dumped; however, very minimal impact as vanadium is readily taken up in ecosystems. System has the capability to perform discharge cycles indefinitely
Zinc-Bromine Flow Batteries							
Material Manufacturing	Raw Material Extraction and Processing	4	4	3	3	33	Extraction of zinc
	Chemical Production	4	4	3	3	33	Chemical production of toxic substances
Construction	Land Requirements	2	2	2	3	18	Use of this technology requires large amounts of land
	Hazardous Substance Storage	3	2	3	2	16	Bromine is also considered highly toxic but is non-corrosive. Greater likelihood of spillages and containment loss etc. during construction
	Logistics	4	1	3	1	8	Zinc is readily available in South Africa, although there are limited bromine producers
Operation	Hazardous Substances	3	4	3	1	10	Bromine is also considered highly toxic but is non-corrosive
	Maintenance	3	4	3	1	10	Redox flow batteries have a longer lifespan than conventional batteries and generally require little maintenance as it is a self-discharging system
Decommissioning	Disposal of Waste	4	4	2	1	10	Materials are designed to be recycled; however, limited recycling facilities (i.e. long distances) may result in disposal being more feasible. System has the capability to perform discharge cycles indefinitely

Phase	Aspect	Risk Rankings				Cumulative Potential Impacts Rating	Explanatory Note
		Extent (E)	Duration (D)	Severity (S)	Probability (P)	((E+D+S) X P)	
Iron-Chromium Flow Batteries							
Material Manufacturing	Raw Material Extraction and Processing	4	4	4	3	36	Extraction of chromium and iron
	Chemical Production	4	4	3	3	33	Chemical production of toxic substances
Construction	Land Requirements	2	2	2	3	18	Use of this technology requires large amounts of land
	Hazardous Substance Storage	3	2	2	1	7	The iron and chromium chemistry is environmentally benign
	Logistics	4	1	3	1	8	Iron and chromium can be locally sourced
Operation	Hazardous Substances	3	4	2	1	9	The iron and chromium chemistry is environmentally benign
	Maintenance	3	4	2	1	9	Redox flow batteries have a longer lifespan than conventional batteries and generally require little maintenance as it is a self-discharging system
Decommissioning	Disposal of Waste	4	4	1	1	9	Certain materials can be recycled; however, limited recycling facilities (i.e. long distances) may result in disposal being more feasible. System has the capability to perform discharge cycles indefinitely
Sodium Sulphur Batteries							
Material Manufacturing	Raw Material Extraction and Processing	4	4	4	3	36	Extraction of sodium and aluminium
	Chemical Production	4	4	3	3	33	Sodium-sulphur are inert chemicals, however, pose severe risks when these chemicals come into contact with other components (e.g. water).
Construction	Land Requirements	2	2	1	3	15	Does not require a large portion of land due to the way the cells are arranged in the battery
	Hazardous Substance Storage	3	2	3	2	24	Both sulphur and sodium are highly volatile. Greater likelihood of spillages and containment loss etc. during construction
	Logistics	4	1	3	1	8	Sulphur may be readily available, while sodium may

Phase	Aspect	Risk Rankings				Cumulative Potential Impacts Rating	Explanatory Note
		Extent (E)	Duration (D)	Severity (S)	Probability (P)	((E+D+S) X P)	
							have to be sourced internationally
Operation	Hazardous Substances	3	4	4	2	22	Large risk associated with the high temperature at which the battery must be operated in order to maintain the sulphur in its molten form
	Maintenance	4	4	3	2	22	Shorter lifespan then and may require more maintenance
Decommissioning	Disposal of Waste	4	4	1	1	9	Sodium and sulphur are inert and are not classified as hazardous. Disposal at a general landfill site
Fluid (Chemical) Storage Systems							
Hydrogen Electrolyzer/Fuel Cell							
Material Manufacturing	Raw Material Extraction and Processing	4	4	4	3	36	Extraction of aluminium
Construction	Biodiversity Disturbance	2	2	2	3	18	Needs to be established near water resource
	Logistics	4	1	2	2	14	No known local supplier
Operation	Hazardous Substances	1	4	3	1	8	Reactions occurring within the Hydrogen Electrolyzer and the subsequent storage of Hydrogen in the Fuel Cells results in various health and safety risks
	Resource Consumption	3	4	3	3	30	Storage of energy through hydrogen will require large volumes of water
Decommissioning	Disposal of Waste	4	4	1	1	9	Disposal of the Hydrogen Electrolyzer/Fuel Cells will mainly consist of the materials that formed part of the structure; therefore no hazardous wastes are expected
Mechanical Storage Systems							
Flywheel Energy Storage							
Material Component	Material Extraction	4	4	2	2	20	Flywheel components likely contain more iron and steel than other energy storage technologies
	Component Manufacturing	4	4	2	2	20	Flywheels will require more energy and cause more industrial waste during manufacture

Phase	Aspect	Risk Rankings				Cumulative Potential Impacts Rating	Explanatory Note
		Extent (E)	Duration (D)	Severity (S)	Probability (P)	((E+D+S) X P)	
Construction	Biodiversity Disturbance	2	2	2	3	18	Higher land requirements results in the technology having a greater impacts in terms of site specific construction issues such as excavation, removal of natural resources, the removal of vegetation etc.
Operation	Safety Risks	1	4	4	1	9	Rapidly rotating cylinders may cause injury if there is a malfunction
Decommissioning	Disposal of Waste	4	4	1	1	9	Certain materials can be recycled; however, a limited recycling facilities (i.e. long distances) may result in disposal being more feasible
Compressed Air Energy Storage (underground)							
Material Component	Material Extraction	4	4	2	3	30	CAES components likely contain more iron and steel than other energy storage technologies
	Component Manufacturing	4	4	2	3	30	CAES will require more energy and cause more industrial waste during manufacture
Construction	Land Requirements	3	4	4	3	33	The higher land requirements have greater impacts in terms of site specific construction issues such as excavation, removal of natural resources, the removal of vegetation etc.
	Cavern Development	3	4	4	3	33	Considering the low probability of the presence of salt domes and spent natural gas caverns in South Africa, abandoned mining operations and new caverns or hard rock mines are most likely the going to be used for CAES
Operation	Compressed Air Storage	3	4	4	3	33	The cyclic injection and withdrawal of fluid (compressed air) has broad negative impacts for the subsurface local geology
	Gas Turbine Operations	3	4	4	3	33	Gas turbines have a set of environmental impacts associated with its operation
Decommissioning	Mothballing Facilities	4	4	2	3	30	CAES facilities have very long lifespans, however, various oils and lubricants are used which may need to be disposed of in a hazardous waste facility

4.3 COMPARATIVE ASSESSMENT SUMMARY

A comparative assessment summary (refer to Table 14), shows that between the different storage systems, mechanical storage is considered to have the fewest environmental impacts. However, other technologies within the various storage systems can also be considered viable.

Table 12-2 – Comparative Assessment Summary

Technology	Average Cumulative Risk	Summary of Issues
Advanced Battery Systems		
Lead and Advanced Lead Batteries	21	The major issues relating to the use of advanced battery systems is the use of hazardous substances in the reaction process. This has implications during various phases of the project, however, most notably during operation where Large risk associated with the high temperature for certain technologies. This can be mitigated against through the utilization of battery technologies that use less toxic chemicals (such as ultracapacitors) or technologies that have a remarkably reduced risk of contamination from containment failure, maintenance and disposal (such as redox flow batteries).
Ultracapacitors	16	
Lithium-ion Batteries	25	
Vanadium Flow Batteries	17	
Zinc-Bromine Flow Batteries	17	
Iron-Chromium Flow Batteries	15	
Sodium Sulphur Batteries	21	
Fluid (Chemical) Storage Systems		
Hydrogen Electrolyzer/Fuel Cell	19	The main concern regarding the use of a Hydrogen Electrolyzer/Fuel Cell is that is relies on water as a source of energy generation. Considering that South Africa is a water stressed country, intense drought experienced in 2015 and the effects of climate change, the use of the technology should be undertaken cautiously and site selection would be paramount. In terms of hydrogen, 3 to 4 l of water is required to produce the equivalent of 1 l of petrol [0355].
Mechanical Storage Systems		
Flywheel Energy Storage	18	The only major consideration for flywheel energy storage is that there is considerable disturbance during establishment. However, flywheel energy storage can be considered as “green energy storage” since the potential impacts can be regarded as minimal.
Compressed Air Energy Storage	32	Compressed Air Energy Storage is considered to potentially have very significant impacts and a relatively larger scale then the other technologies. Smaller CAES with above ground tanks storage will have significantly fewer potential environmental concerns

5 Conclusion

Storing electricity has the potential to indirectly provide environmental benefits. Each energy storage technology presents environmental impacts in varying degrees depending on the specific technology, design, and materials of construction. The net impact is also dependent on how the systems are operated and the manner in which they are integrated onto the grid. However, physical impacts are not the only concerns relating to the introduction of large-scale energy storage systems. Issues relating to the South African environmental regulatory framework are also of concern and must be understood and considered.

5.1 Regulatory Concerns and Recommendations

There are regulatory concerns in existing policy and legislative frameworks regarding the use and application of energy storage technologies. The legislative framework only accounts for potential siting issues as well as specific operational aspects such as storage of hazardous substances. In the event that a technology does not trigger a siting issue or a specific operational aspect the need for an environmental impact process does not exist. This does not mean that the impacts are such that a process should not take place, rather that there is an inherent gap in the legislation. It is recommended that the relevant departments are consulted to introduce energy storage technologies as a listed activity in terms of the Environmental Impacts Assessment Regulations.

5.2 Environmental Impact Statement

The introduction of large-scale energy storage may have significant indirect environmental benefits to South Africa. The main benefits from adopting energy storage includes the ability energy storage has to assist in the integration of RE into the electricity grid, supporting the existing generation facilities to operate at optimal levels, reducing the dependence on inefficient energy generation technologies that would be utilized during peak times and the potential to defer the need to develop additional “dirty” energy generation infrastructure or infrastructure that has a higher environmental footprint then that of the energy storage system.

To ensure that the environmental benefits of the energy storage technology out-weigh the potential impacts, the principles for green energy storage should be considered and employed.

Considering the potential risks associated with the various energy storage technologies, it is recommended that the energy storage technologies capable of meeting operational and performance requirements and with the least risk to the environment within each system be considered feasible. Each energy storage system (i.e., advanced battery, fluid storage and mechanical) has its own merits and the selection of the most feasible technology will have to be based on various factors associated with use case, site selection etc.

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Legal and Regulatory Assessment

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ACRONYMS

BAU	business as usual
CAES	Compressed Air Energy Storage
CEO	Chief Executive Officer
COR	Contracting Officer's Representative
CPUC	California Public Utilities Commission
CSP	Concentrating Solar Power
DBSA	Development Bank of Southern Africa
DER	Distributed Energy Resources
DOE	Department of Energy
EDI	Electricity Distribution Industry
ERCOT	Electric reliability Council of Texas
ESS	Energy Storage System
ESSP	Energy Storage Service provider
FERC	Federal Energy Regulation Commission
GUMP	Gas Utilization Master Plan
IDC	Industrial Development Corporation
IEC	Integrated Energy Plan
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor-Owned Utilities
IPPP	Independent Power Producer Procurement Programme
IRP	Integrated Resource Plan
ISO	Independent System Operator
M&V	Measurement and Verification
NDA	Non-Disclosure Agreement
NERC	National Electricity Reliability Council
NERA	National Electricity Regulation Act
NERA	National Energy Regulator Act
NEA	National Energy Act
NERSA	National Energy Regulator of South Africa
NIRP	National Integrated Resource Plan
NT	National Treasury
PPA	Power Purchase Agreement
PPP	Public-Private Partnerships
PHS	Pumped Hydro Storage
PJM	A regional transmission organization in the United States (eastern interconnection)
PSC	Project Steering Committee

PV	Photovoltaic
REDs	Regional Electricity Distributors
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RPS	Renewable Portfolio Standard
SADC	South African Development Community
SADOE	South African Department of Energy
SANEDI	South African National Energy Development Institute
SAPVIA	South African Photovoltaic Industry Association
SAWEA	South African Wind Energy Association
TNSP	Transmission Network Service Provider
TOU	time-of-use
TS	transmission systems
UPS	Uninterrupted Power Supplies

1 Introduction

This document provides the results of the Objective 5 "Legal and Regulatory Assessment" performed under the overall USTDA South Africa Energy Storage Technology and Market Assessment.

1.1 Approach

Section 2 provides an overview and summary of the international best practices for legislation, regulations, policies and incentives to support the deployment of energy storage technologies.

Section 3 provides an overview of the key players and organizations involved in electrical generation and distribution in South Africa.

Section 4 provides a review and assessment of the legislation, regulations, policies and incentives that are currently in place or being considered related to the adoption of energy storage technologies in South Africa.

Section 5 identifies key gaps in South Africa's existing legislation, regulations, policies and incentives related to the adoption of energy storage technologies.

Finally, Section 6 provides recommendations for improving South Africa's existing legislation, regulations, policies and incentives related to the adoption of energy storage technologies. A specific recommendation related to the inclusion of energy storage technologies, particularly in conjunction with solar photovoltaic and wind power plants, under the REIPPPP and as a stand-alone energy storage procurement program is provided in Section 5.3.

1.2 Sources

A complete list of the sources investigated for this objective is listed under references that include the following South African legislation and regulations:

- Integrated Energy Plan (IEP)
- Integrated Resource Plan for Electricity (IRP)
- National Energy Act (2008) as amended
- National Energy Regulator Act, 2004
- National Electricity Regulation Act (2006)

International best practices are referenced from the list in the reference section.

2 International Best Practices

This section identifies USA and international best practices for legislation, regulations, policies and incentives to support the deployment of energy storage technologies. General types of methods that could be employed to encourage the adoption of energy storage at all levels in the value chain are also included. Many of these approaches have been adopted by other countries and can be used as a set of options for South Africa to investigate further. The EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications, 2015 [0242] may also provide guidance on the approach listed below.

2.1 General Methods to Promote the Adoption of Energy Storage

2.1.1 Condition Market Initiatives

For storage to be a valued and substantial part of the power system, certain market changes may need to implement. The marketplace has to be set to reward or allow storage to participate with attached revenue stream. On the long run, subsidies should not be necessary but what is needed is a marketplace that recognizes and monetizes the real benefits that storage can deliver to the system. The following approaches may be followed to get the market ready to adopt storage:

1. Field experience with storage systems through field trials that include realistic business cases. As R&D and demonstration projects demonstrate the safety, technical effectiveness and business case of storage systems, potential users will feel more comfortable specifying their use.

2. Storage devices needs to be allowed into utility rate base for all applications. Utilities should be allowed to use (and recover costs from) storage devices as they would from generation, wires or transformers.

3. Tariffs and internal revenue streams which differentiate by quality of service and location, and recognize the cumulative benefits of multiple storage devices. If customers and system operators begin to pay or have real costs associated with improved power quality, reliability, ancillary services the value of storage systems becomes obvious. Similarly, if customers are providing benefits to utilities due to their storage systems, the utility should be encouraged to share those benefits with their customers. Tariffs should be designed to minimize penalties for customers solving their own problems.

4. Commercial and regulatory environment that allows the sharing of benefits over a wide platform and by multiple organizations. Without the ability to write the performance based contracts referenced above, storage will probably remain a niche product.

5. Tax credits or incentives that reward the grid security, ancillary services and reliability increases due to the use of storage.

6. A clear environment for “upstream” benefits such as release of transmission and distribution capacity, reduction of peaking generation capacity, ancillary services, voltage regulation and line

loss reductions. While many storage benefits are real, very few mechanisms exist to reward the owners of systems for the benefits they provide. The transaction costs of rewarding benefits need to be transparent.

2.1.2 Cultivating the Energy Storage Environment

The following are general types of methods that could be employed to encourage the adoption of energy storage at all levels in the value chain. Many of these approaches have been adopted by other countries:

1. Promote awareness and understanding of benefits of Energy Storage
   a. Studies to determine and monetize the value of Energy Storage
   b. Promote briefings to government and legislative bodies
   c. Inclusion of Energy Storage planning results in national planning documents
2. Promote Energy Storage Technology Development
   a. R&D funding for private, university, and institutional organizations
   b. Provide test facility for evaluation of emerging energy storage technologies/systems
   c. Standards for measurement and evaluation of energy storage performance
3. Promote Manufacturing of Energy Storage Equipment / Systems
   a. Investment tax credits for manufacturing
   b. Tax credits for purchase and installation of technology by public/industry
4. Promote Utility-Scale Energy Storage Project Initiation
   a. Public-Private Partnerships (PPP)
   b. Investment tax credits
   c. Loan guarantees for technology projects
   d. Cash grants for systems when operational
   e. Benefit monetization and grid integration
   f. Master limited partnerships
   g. Financial and planning incentives for projects
5. Remove Barriers for Energy Storage Projects
   a. Grid interconnection standards
   b. Standards for communication and control
   c. Technology to track value streams

Internationally, energy storage is an active and fast growing area and several best practices are available and listed below. This study focuses and examines the current and emerging practices from the following regions: Hawaii (very high PV penetration and 100% renewable energy goal); California (high Renewable Portfolio Standard (RPS)); New York (reinventing the distribution markets into transactive energy markets); Australia (geographic similarities with South Africa, off-grid and high PV penetration); Germany (long experience with various renewable incentives and integration issues with both wind and PV connected to the grid).

2.2 USA Regulatory Framework

The Independent System Operators (ISO) in the different reliability regions controlled by NERC, develops most of the USA best practices for legislation, regulations, policies and incentives. The most active ISOs and regions for development of energy storage regulations are PJM, CA-ISO and ERCOT (Texas) and these are mainly as a result of the high penetration levels of renewables on the grid mandated by the Renewable Portfolio Standards (RPS) [0309] with Hawaii at 100% by 2045 and California 50% by 2030.

California also introduced the most aggressive initiative to install energy storage through a procurement target. The state has taken action to advance energy storage, including the passage of Assembly Bill 2514 and the resulting California Public Utilities Commission (CPUC) decision to include energy storage procurement targets. Each of the Investor Owned Utilities (IOUs) are targeted to procure 1,325 MW by the end of 2020 and implemented by 2024. Additionally, the CPUC provides funding programs including Permanent Load Shifting and the Self Generation Incentive Program that provide incentives for adoption of customer-side energy storage [0328].

The main regulations, initiatives and incentives that support the deployment of energy storage technologies in the USA are summarized in Table2-1.

Table 2-1: Summary of Main Regulatory Initiatives and Incentives in USA

Initiative & Regulation - USA	Description	Impact
FERC Order 755 [0298]	Clarifies frequency regulation compensation for quick-response storage services in the wholesale markets (Since Oct. 2011)	More revenue for fast response frequency regulation that promotes energy storage.
FERC Order 745 [0312]	FERC's Order 745, approved in 2011 and revoked 2014. Called for grid operators to pay the full market price to economic demand response (DR) resources in real-time.	Opened DR market but resides now in states and ISOs. Energy storage can play in DR market.
U.S. STORAGE Act S.1845 [0313]	Introduced 2011, but was not enacted. Legislation would provide tax incentives (up to 30%) for grid storage as well as for on-site and residential.	Possible mechanism to help growth of energy storage.
California State Law (AB 2514) [0290]	Sets energy storage procurement targets in the State of California (Enacted 2010). • Reduce emissions of greenhouse gases. • Reduce demand for peak electrical generation. • Defer or substitute for an investment in generation, transmission, or distribution assets. • Improve the reliable operation of the electrical transmission or distribution grid.	Each IOU utility has to procure and deploy 1.325 GW of energy storage by the year 2020.
Texas – ERCOT Value of Distributed Energy Storage. (ONCOR) [0291]	Distributed 25 kW, 25 kWh battery storage. Established a 'break-even point' of $350/kWh. Point of diminishing returns reached at approx. 5,000 MW of storage in ERCOT.	Proposed policy to improve Voltage Quality and reliability during storms.
ISO/RTO Ancillary Services [0309]	Markets Currently Open to Storage PJM, NYISO, ISO-NE, MISO, CAISO, ERCOT. Mainly frequency regulation and capacity charge.	Provide solid value-stream for storage. Drive most of the business cases.
New York PSC - "Reforming the Energy Vision" (REV) strategy (2015) [0292, 0314]	White Paper on Clean Energy Standard to transform the retail electricity market and overhaul New York's energy efficiency and renewable energy programs. The stated goals are to create a cleaner, more affordable, more modern and more efficient energy system in New York, through the increased development of distributed energy resources, like rooftop solar, energy efficiency, and battery storage.	New tariff design to help DER including storage. Distributed Energy Service Provider – Straw Proposal.
Energy Storage Service Provider (ESSP) [0315, 0323]	New business models and energy companies are introducing the energy storage market that provides ancillary services to the utility and ISO sectors.	The ESSP model provides low risk deployment for energy storage systems.
Renewable Portfolio Standards (RPS) [0309]	29 states & DC – 16 state w/solar, wind, energy efficiency and DER provisions. RPS mandates and set goals to increase the relative share of renewable capacity / generation. Targets range from 10% - 40%. Possible upgrade to 50% by CA. PG&E and PSE&G develop incentives to go up to 100% renewable with Community Solar Programs. Federal and State incentives are also available [0309]. Federal tax credit of 30% on capital investment. Mostly Net Metering and Feed-in Tariffs are used for customer owned facilities.	Increased need to mitigate impacts of intermittency using energy storage Load following; Regulation; Volt-VAR; Spinning reserves, etc.

2.3 Other International Regulations and Incentives

Some of the successful initiatives and regulatory best practices from other international locations are summarized for the countries listed in the tables below:

- China
- Japan
- India
- Germany
- United Kingdom
- Italy
- Spain
- Australia

Table 2-2: Successful Initiatives and Regulatory Best Practices in China

Initiative & Regulation	Description	Impact
Document/Policy No. 9 / "Further Deepening the Reform of the Electric Power System". (2015) [0332, 0333]	The landmark policy piece of China's New Power Sector Reform's establishments including: • Maintain a monopolized transmission system, but open up generation and distribution to market competition • Open up competitive electricity retail pricing • Establish the groundwork for diversified energy trading • Promote demand-side management and energy efficiency programs • Increase the ratio of renewable energy in the country's generation mix.	Opening up **new opportunities for energy storage**, particularly in demand response, ancillary services, and distributed generation.
"Announcement on Promoting Electrical Storage Participation in Peak Regulation Ancillary Service in the 'Three Norths' Region" (2016) [0297]	**Peak regulation** which allows energy storage to generate revenue by absorbing the oversupply – allowing coal-fired generators to improve efficiency and reducing curtailment for wind and solar.	Opening up tangible regulatory pathways for energy storage deployments in China's northeastern, north-central, and northwestern provinces, where high penetrations of wind power and must-run coal-fired power plants have created a need for better grid balancing.
Demonstration project model	Projects are expected to be focused on microgrid, distributed generations, industrial solar and even end user demand management applications. In addition, the Central government is promoting up to 100 "Smart-Cities" to be set up where they believe solar storage modular packages are to be used in large numbers in the power distribution network. An example demonstration project is the Zhangbei wind-solar-storage project by State Grid in Northern China.	The demonstration project model appears to be effective in slowly building an energy storage market, leading to commercialization of the product. This gives China time to create the market structures, technical learnings and design standards to support commercialization of the energy storage market.
Pairing generation with storage [0334]	A new policy directive requires intermittent generators to pair their generator with energy storage as a grid-connection requirement. This policy applies across all levels, including rooftop solar through to utility scale plants.	
RFP for thermal solar procurements totaling 1 GW [0333]	National Energy Administration announced an RFP for thermal solar procurements totaling one gigawatt.	Notable for energy storage providers is the fact that the government required each project to **include at least one hour of**

Initiative & Regulation	Description	Impact
		energy storage at rated capacity. Looking at the projects submitted so far, industry watchers could expect to see a 4 GWh bump in energy storage capacity in China by 2018 from these procurements alone.
Support for Energy Internet [0333]	With government support, companies are combining devices and big data analysis to shift from traditional sales to infrastructure-as-a-service. Meanwhile, leading inverter manufacturers are expanding into energy storage. In the EV space, EV charging stations are built across the country. Events such as "Energy Storage and Energy Internet Research Summit" took place. In July 2015, the State Council released the "Guiding Opinion on Actively Promoting the 'Internet Plus' Action Plan" & the NEA followed up with a document further specifying the role of microgrids in opening up electricity retail and distribution to society at large, titled "Guidelines on Promoting the Construction of New Energy Microgrid Demonstration Projects".	Events focused on the common needs of the energy storage industry and the Energy Internet in order to help clarify new opportunities and business models for energy storage. The confluence of power sector reforms and favorable regulations for distributed generation and microgrids suggest that non-hydro energy storage may soon be ready for its China debut.
Retail Reforms and New T&D Reform Pilots (2015) [0333]	NDRC published a document announcing an expansion of T&D reform pilot programs and signaling the intention to hasten tariff reform. Grid operators will be compensated based on "authorized costs plus a reasonable profit" – essentially a regulated grid transmission fee. Two major Chinese cities, Guangzhou and Chongqing, announced the launch of new electricity distribution pilot projects (2016).	With the opening of China's retail market come opportunities for innovative retailers to provide new services to end-use consumers and to tap into new value streams through distributed generation, EVs, smart homes, and energy storage.
Policies on electric vehicles [0333]	Subsidies, support mechanisms and policies supporting EV charging infrastructure deployment. "2015-2020 EV Charging Infrastructure Development Guidelines" calling for "12,000 new centralized charging stations and 4.8 million distributed charging stations to meet demand from the national goal of 5 million electric vehicles," by 2020. A draft paper guiding industrial policy for EV battery manufacturing and recycling was published.	Policies supporting EV charging infrastructure supports the energy storage sector indirectly.
"Guiding Opinions on Establishing Renewable Energy Portfolio Standards" [0334]	Setting renewable energy consumption targets for China. The country aims to rely on renewable energy for 15% of total primary energy consumption by 2020 and 20% by 2030. Non-hydro renewables should produce 9% of consumed electricity by 2020.	Opportunities for deployment of energy storage.
12th Five-year plan (2011-2015) [0001]	Both the Central government and the provincial and local government have issued as many as **25 documents regarding energy storage**, including the State Plan, regulations, standards, white papers and subsidizing guideline to support achieving the Central Government's ambitious renewable targets.	Promote energy storage across China.
13th Five-year Plan (2016-2020) [0332]	The development of micro grids is being encouraged and Energy Storage is formally introduced as a targeted energy sector with specific policy support.	Signaling the Chinese government's vision for future reforms and communicates this to other parts of the bureaucracy, industry players and Chinese citizens.

Table 2-3: Successful Initiatives and Regulatory Best Practices in Japan

Initiative & Regulation	Description	Impact
Lithium-Ion Subsidy Program [0332, 0336, 0079]	Announced in May 2014, supporting the installation of stationary Li-ion batteries by individuals and businesses. The subsidy is set to cover up to two thirds of the cost of the storage system, paid by Ministry of Economy, Trade and Industry (METI) with a budget of US$98.3 million. Payments are capped at US$9,846 for individuals and US$982,000 for businesses installing battery systems with a capacity of 1kWh or more.	The total volume of applications received has already exceeded the allocated budget before the end of 2014. Subsidies available in 2013 prompted more than 100 MWh in household storage installation.
Other subsidies [0332, 0338]	Available for 50% of stand-alone renewable energy generation with batteries (less than 30m JPY), with separate schemes for community renewables (up to 2/3) and Earthquake affected areas.	Effective support of the battery sector.
Improving energy efficiency [0332]	Japan's Ministry of Economy, Trade and Industry (METI) has allocated US$779 million to help factories and small businesses improve energy efficiency.	Encouraging the usage of storage systems at solar power stations or substations.
Deregulation for promoted batteries [0338]	In case of installation, applications and permissions are required. Some procedures have been simplified or removed for promoting batteries (Deregulation). E.g. technical requirements guideline of grid interconnection, Grid Interconnection Code (JEAC 9701-2006), Electricity Business Act, Fire Service Act, Fire Prevention Ordinance & Building Standards Act.	Simplified process makes the installation of batteries more attractive.
Solar Feed-in-Tariff (FiT) Cut [0336, 0338]	Reducing the incentives for developers of solar power projects for the fiscal year 2015. The new FIT rate for residential solar photovoltaic (PV) systems will be ¥33/kWh, down from ¥37/kWh the previous fiscal year (promoting the use of residential ESS for use with solar PV, an expected targeted increase in capacity from 3.68 GW in 2010 to 28 GW by 2020).	Excess generated electricity (via PV) will be stored (instead of being sold) due to declining FIT incentive rates and raising electricity prices (pushed by upcoming events such as the retail electricity deregulation in 2016 and utility restructuring of unbundling generation, transmission, and distribution in 2020)

Table 2-4: Successful Initiatives and Regulatory Best Practices in India

Initiative & Regulation	Description	Impact
Bids for ESS demonstration projects [0332]	PGCIL (Power Grid Corporation of India) invited bids for **Energy Storage Systems (ESS) demonstration projects** for 500kW / 250kWh capacity under three categories, namely, Lithium Ion Battery, Advanced Lead Acid Battery and Sodium Nickel Chloride/ Alkaline/ Flow Battery.	Test ESS technologies.
Energy storage demonstration program [0332]	The Ministry of New and Renewable Energy (MNRE) in India has called for Expression of Interest (EOI) for energy storage demonstration projects to support renewable energy generation. MNRE has set up a capacity addition target of 175MW by 2022. MNRE proposes to support **demonstration projects** for ESS to assess feasibility of ESS technologies for small scale and grid connected MW scale renewable energy applications.	The demonstration projects are expected to help in acquiring the desired technical knowledge, economic & market assessment and insights on the approaches for shaping up a focused program in this key area.
Contract for Li-Ion battery energy storage [0001]	India is pursuing renewable energy and energy storage as a secure power resource for more than 300,000 telecom towers, and announced a US$40 million contract in July 2013 for Li-ion battery energy storage systems to meet that need. It is estimated that	Evaluate Li-Ion technology for telecommunication power supplies.

Initiative & Regulation	Description	Impact
	100,000 towers are already using storage.	
Investment in automotive batteries [0332]	Auto-components manufacturer Minda industries, will partner with the Japanese multi-national Panasonic **for manufacturing of automotive batteries** in India and is planning to invest Rs 700-800 crore (~ US$ 120-130 Million) in three years towards capacity expansion and acquisitions.	Build local manufacturing capability in energy storage.
Building smart cities [0332]	Indian government plans to build 100 smart cities with a budget of Rs 7,000 crore (~ USD 1.2 billion). Over 130 million smart meters are likely to be installed under this scheme and smart net metering might discourage storage at customer end. However, there is a possibility of application of ESS for improvement of power quality, which will be one of the key agendas of this program.	Market for energy storage in Smart City initiatives.

Table 2-5: Successful Initiatives and Regulatory Best Practices in Germany

Initiative & Regulation	Description	Impact
New renewable energies program entitled “Storage”/ KfW275 [00001, 0340, 0341, 0342, 0343]	In May 2013, Germany introduced a €25 million storage subsidy program, providing financial support to all photovoltaic systems containing battery energy storage that are installed in Germany in 2013 (with a maximum capacity of 30kW). The program gives subsidies via low-interest loans from state-owned KfW bank and principal grants from the Environment Ministry. The subsidies amount to €660/kW of solar power for each system, improving the economic logic for BES take-up in the residential and commercial sector.	Support mechanisms like grants and low interest finance are used for the storage purpose of peak shaving; Aiming to improve integration of small-to-medium solar PV systems into the electricity grid.
Follow-up program for promoting battery storage systems [0343]	Relaunched the now changed program on 1 March 2016, since the predecessor one expired at the end of 2015. Offering low-interest KfW loans and repayment bonuses from BMW-I funds.	Aimed at encouraging the market and technological development of battery storage systems; Incentivizing manufacturers to pass on the technology and production-related cost reductions to the customers.
KfW 203 [0001, 0340]	Financing for energy efficiency projects (energy storage projects included) for the target group municipalities, interest rate: 0.6-1.3 percent up to 30 years.	Financing options for energy storage.
KfW 204 [0001,0340]	Financing for energy supply projects (thermal storage projects included) for Municipal utilities and PPPs, with €50 million loan limit, negotiated interest rate & 1-5 year period of no repayment.	Financing options for energy storage.
KfW 207 & 274 [0001, 0340]	Energy Storage in combination with PV for private consumers.	Provide a PV + Storage investment plan.
KfW 291 [0001, 0340]	For large-scale investments of large enterprises in the German “Energiewende” (energy supply, efficiency, storage and transmission). Target group are companies and storage purposes are **storage for energy efficiency or load management, or R&D for general storage**. Loans from €25 to €50 million. Fixed interest rate for 10 years	Implement initiatives for Energiewende.
KfW 230 [0001, 0340]	Environmental Innovation Program for companies. Grant up to 30 percent of investment. 5 year minimum.	Investment credit to promote energy storage.
Joint RD&D Initiative “Energy Storage	Promoting research and development for storage technologies and has made €290 million available for the “Energy Storage	Joint funding initiatives in key areas such as energy storage and grids can generate the

Initiative & Regulation	Description	Impact
Technologies" [0345, 0346, 0350]	Funding Initiative". At the end of 2013, the relevant federal ministries had approved €255 innovative research projects totaling €260 million in the field of energy storage.	momentum needed to push relevant developments.
Renewable Energy Sources Act (EEG) (2000) [0344]	The legislation requires grid operators to purchase a certain amount of electricity from renewable energy sources first before they feed in electricity generated from non-renewable sources. Hence, investments in renewable energy projects are protected through the guaranteed feed-in tariff (fixed for 20 years), while at the same time periodically decreasing, tariffs (through a yearly digression) require plant builders to systematically innovate and reduce costs.	Tremendously successful in widely expanding the integration of renewable energies into Germany's energy mix, all the while strengthening the country's global leadership in the market of eco-friendly technologies

Table 2-6: Successful Initiatives and Regulatory Best Practices in UK

Initiative & Regulation	Description	Impact
Low Carbon Networks (LCN) Fund [0001]	Established by The British Office of Gas and Electricity Markets (OfGem), funded through the distribution tariffs and is aimed at pilot/demonstration projects. Allowing up to £500 million facilitating the take up of low carbon and energy saving initiatives by NSPs.	LCN Fund has supported a number of the schemes, which involve different types of storage configured in different parts of the networks to achieve various objectives.
Transport Sector Policy [0347]	Energy storage in transport is not directly supported, but there are **policies to support lower carbon vehicles**. EU regulation sets targets to reduce CO2 emissions from new UK passenger cars by 2020 by 26% from 2013 levels. The 2010-2015 Government committed to spending £500m on low-emission vehicles over 2015-2020, of which £200m is on grants to increase vehicle uptake (including car and van grants of up to £5,000 and £8,000) and £100m on R&D. There are also regional policies offering benefits to low carbon vehicles such as free parking.	Reduce carbon in transportation sector. Promote hybrid and EVs
Energy Storage Technology Demonstration program [0001, 0347]	Since 2010, the public sector has provided more than £50 million for research, development and demonstration of energy storage. The Department of Energy and Climate Change (DECC) has **allocated a £17m fund for Energy Storage Technology Demonstration**. In 2013, public sector energy storage spending on R&D was £9m and on demonstration £5m.Research and development (R&D) spending aims to develop lower cost technologies, while demonstration spending is also looking to tackle regulatory and commercial barriers.	Recently, this program awarded £8m to the below four projects: • A 5MW / 15MWh Liquid Air Energy Storage system using waste heat from landfill gas to balance supply and demand. • 0.5MW demand response batteries installed across 300 households. • 1.26MWh Vanadium Redox flow system in the Isle of Gigha (Scotland), primarily to support the high amounts of wind penetration. • The development of a potential solution to use recycled EV batteries for network reinforcement and support intermittent renewable integration.

Table 2-7: Successful Initiatives and Regulatory Best Practices in Italy

Initiative & Regulation	Description	Impact
Terna energy storage projects [0001]	Terna is a leading Transmission Network Service Provider (TNSP) in Italy and has invested €31 million in energy storage projects. Terna launched a **program that focuses on development and implementation of energy storage projects for the transmission network**. The program consists of: • An energy-focused project which consists of three storage systems in southern Italy, totaling 34.8MW. • A power-focused project which will install 40MW of energy storage capacity to increase security of electricity networks and develop smart grid applications. • The Regulatory Authority of Electricity and Gas set new rules stating that **batteries must be considered as production facilities** and will be incentivized accordingly.	Ensuring reliable and cost-effective integration of renewables to the grid with the help of energy storage.

Table 2-8: Successful Initiatives and Regulatory Best Practices in Spain

Initiative & Regulation	Description	Impact
Climate Change Strategy [0347]	Red Eléctrica approved this specific strategy and an action plan by May 2014, following the main principles of: • Integration of renewable energies • Energy efficiency • Emission reduction • Woodland protection • Adaption to climate change • Extending commitment to stakeholders While working to integrate the largest possible amounts of renewable energy, REE is working on the **development of energy storage tools**, based on both hydraulic systems and other technologies (R&D&i). Carrying out **prospective evaluations** on the impact of new storage facilities for the integration of renewables, **identifying the technical and management characteristics required** to ensure the greater integration of renewables.	These systems will also contribute to a notable improvement in the efficiency of the electricity system as a whole and help to optimize the electricity infrastructure.
"ALMACENA" Project (2013/14) [0348]	A technological project analyzing and assessing the challenges and capabilities associated with an **energy storage battery connected to the transmission grid**. Installation of a lithium-ion battery, with a power of about 1MW and a capacity of at least 3MWh (large-scale), located in the Carmona substation (Seville).	Allowing two functionalities to be tested aimed at promoting the integration of renewable energies and improving operation services (load curve modulation and frequency - power regulation).
Flywheel Project (2013/14) [0348]	Installation and commissioning of a flywheel; energy storage system using a rotating mass. Both projects are partially financed by the Centre for Industrial Technological Development and EU.	Stabilizing the frequency of the electricity system of Lanzarote-Fuerteventura, installed in Mácher (Lanzarote).

Table 2-9: Successful Initiatives and Regulatory Best Practices in Australia

Initiative & Regulation	Description	Impact
Australian Energy Storage Roadmap [0349]	The roadmap launched by the Clean Energy Council focuses on five key objectives for the sector: • Analyzing growth and gathering key information about the sector. • Ensuring the development of vital standards and the integrity of the storage sector. • Locking in effective regulation and policy to support storage. • Leadership and coordination of the emerging sector. • Promoting the potential of storage technologies.	Help developing the foundation to deliver the technology's full potential through collaboration with industry, regulators and careful strategic planning to ensure consumers would benefit from this exciting emerging technology.
Energy Storage for Homes	• AGL in partnership with Sunverg is developing energy storage solution for Australian Homes to tap solar surge. AGL Energy Ltd. plans to announce a program within a few months to roll out about 1,000 energy storage systems for Australian homes with rooftop solar panels amid forecasts that falling prices will stimulate demand. • Enphase announced similar solar homes program in partnership with ELIIY in Japan.	PV + Energy Storage for Australian Homes.
Incentive program in Adelaide [0001, 0349]	In the first example of storage specific subsidies in Australia, the City of Adelaide is offering businesses, residents, schools and community organizations in the city of Adelaide an **incentive of up to US$5,000 for installing energy storage**, as part of an expanded Sustainable City Incentives Scheme.	The incentive is aimed at driving community investment in solar + storage, as well as in energy efficiency and electric vehicles as part of the state government's plans for a carbon neutral Adelaide.

2.4 Technical Interconnection Procedures and Demonstrations

In most of the regions mentioned in the previous sections where energy storage is being integrated at large scale, the interconnection process, Grid Codes and requirements are continuously being reviewed and updated. In most cases, Energy Storage is considered as a generation resource from an interconnection perspective. In some cases, the energy storage systems (ESS) are also considered capable of providing ancillary services and voltage ride-through. In the FERC jurisdiction areas, above a specific power level capacity of 20MW, the storage system also needs to be compliant with the large standard agreement for interconnecting generators [0295].

Distributed Energy Resources (DER) that include customer owned energy storage, have specific interconnection standards enforced and part of the interconnection requirements set by national reliability commissions like NERC, ISOs and different utility Grid Codes. DER-related standards, like the IEEE-1547, are currently being updated to allow DER to regulated voltage, reactive power and provide grid support [0330]. To ease the interconnection of DER systems, the IEEE Smart Grid Interoperability Series of Standards are currently under development [0330].

Germany and California have the most advanced standards for interconnecting DER inverter-based variable generation systems. The industry association of grid operators and electric utilities in Germany, BDEW, has created guidelines for inverter capabilities. While the law does not require these guidelines, similarly to IEEE 1547 in the USA, electric utilities require interconnecting generators to comply with the BDEW guidelines, in effect turning the guidelines into standards requirements. The BDEW guidelines provide specifications for generator control and communications, frequency control, dynamic reactive support, dynamic grid support including low voltage ride-through, and certification [0350].

In California, Rule 21 Guidelines are required by most California utilities for interconnecting DER inverter-based DER facilities [0296].

In most of the initiatives mentioned in the previous paragraphs, demonstration and pilot projects are developed to prove technological maturity and commercial readiness [0325, 0326, 0328]. In most cases in the USA, these demonstration projects are utilizing public-private partnerships and financial incentives through the DOE and other agencies. In most cases, funding is on a cost-share basis between the DOE, interconnecting utility and ISO. Typical in most of the demonstration projects, an effort is made to do extensive Measurement & Verification (M&V) on the benefits, economics and lesson-learned.

In the last couple of years, Eskom performed two battery-based ESS demonstration installations at their Rosherville location [0351]. No specific findings are reported yet. This demonstration project is at a research facility and good for evaluating technical requirements.

3 South Africa's Electrical Legal and Regulatory Framework

For policies and programs to be effective, they will need to be developed and implemented with an understanding of the legal and regulatory framework and organizations structure of electrical power generation and distribution in the country or region. Thus in order to assess best potential practices and approaches, it is necessary to understand and appreciate the situation in South Africa with regard to the generation, distribution and current regulatory framework of South Africa.

3.1 National Energy Regulator South Africa (NERSA)

The National Energy Regulator (NERSA) is a regulatory authority established as a juristic person in terms of Section 3 of the National Energy Regulator Act, 2004 (Act No. 40 of 2004). NERSA's mandate is to regulate the electricity, piped-gas and petroleum pipelines industries in terms of the Electricity Regulation Act, 2006 (Act No. 4 of 2006), Gas Act, 2001 (Act No. 48 of 2001) and Petroleum Pipelines Act, 2003 (Act No. 60 of 2003). The structure of the Energy Regulator consists of nine members, five of whom are part-time and four are full-time, including the Chief Executive Office (CEO). The Energy Regulator is supported by personnel under the direction of the CEO.

The mandate of NERSA is derived from legislation governing and prescribing the role and functions of the Regulator. The mandate of the Electricity Regulation is Economic Regulation of the electricity industry and is derived from the Electricity Regulation Act. The division has four departments that serve as a platform to achieve its mandate.

1) Licensing and Compliance Department

The Licensing and Compliance Department issues licenses with terms and conditions for; generation, transmission and distribution of electricity; Import/export of electricity and; Traders in electricity. This department also registers those who provide the above services but do not require licensing; and monitors compliance with license terms and conditions by licensees.

2) Pricing and Tariffs Department

The Pricing and Tariffs Department takes care of the economic regulation of the electricity supply industry by setting of tariff guidelines and structure, defining tariff methodologies (e.g., Rate of Return, Multi Year Price Determination), evaluating tariff applications from licensees and setting pricing frameworks.

3) Electricity, Infrastructure and Planning Department

The Electricity, Infrastructure and Planning Department takes care of planning for the country's future electricity demand/needs (National Integrated Resource Plan). It also promotes alternative electricity generation technologies (e.g. Renewable Energy, Cogeneration) and promotes demand side management and energy efficiency initiatives.

4) Regulatory Reform Department

The Regulatory Reform Department sets the design of the regulatory framework for the restructured Electricity Distribution Industry, i.e. the introduction of Regional Electricity Distributors (REDs). This department also takes care of research and development of the Electricity Distribution Industry and the international trading framework.

3.2 ESKOM

Eskom generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa. Eskom generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers and redistributors. Additional power stations and major power lines are being built to meet rising electricity demand in South Africa. Eskom will continue to focus on improving and strengthening its core business of electricity generation, transmission, trading and distribution.

Eskom buys electricity from and sells electricity to the countries of the Southern African Development Community (SADC). The future involvement in African markets outside South Africa (that is the SADC countries connected to the South African grid and the rest of Africa) is limited to those projects that have a direct impact on ensuring security of supply for South Africa.

Power Stations:

Like most other power utilities, Eskom's Generation Division maintains a varied portfolio of plant. In addition to the coal fired plants, Eskom owns and operates four open cycle gas turbines, two hydroelectric plants, three pumped storage, two wind farms and one nuclear power station.

A list and location map of all the existing and planned Eskom power stations are shown in Figure 3-1.

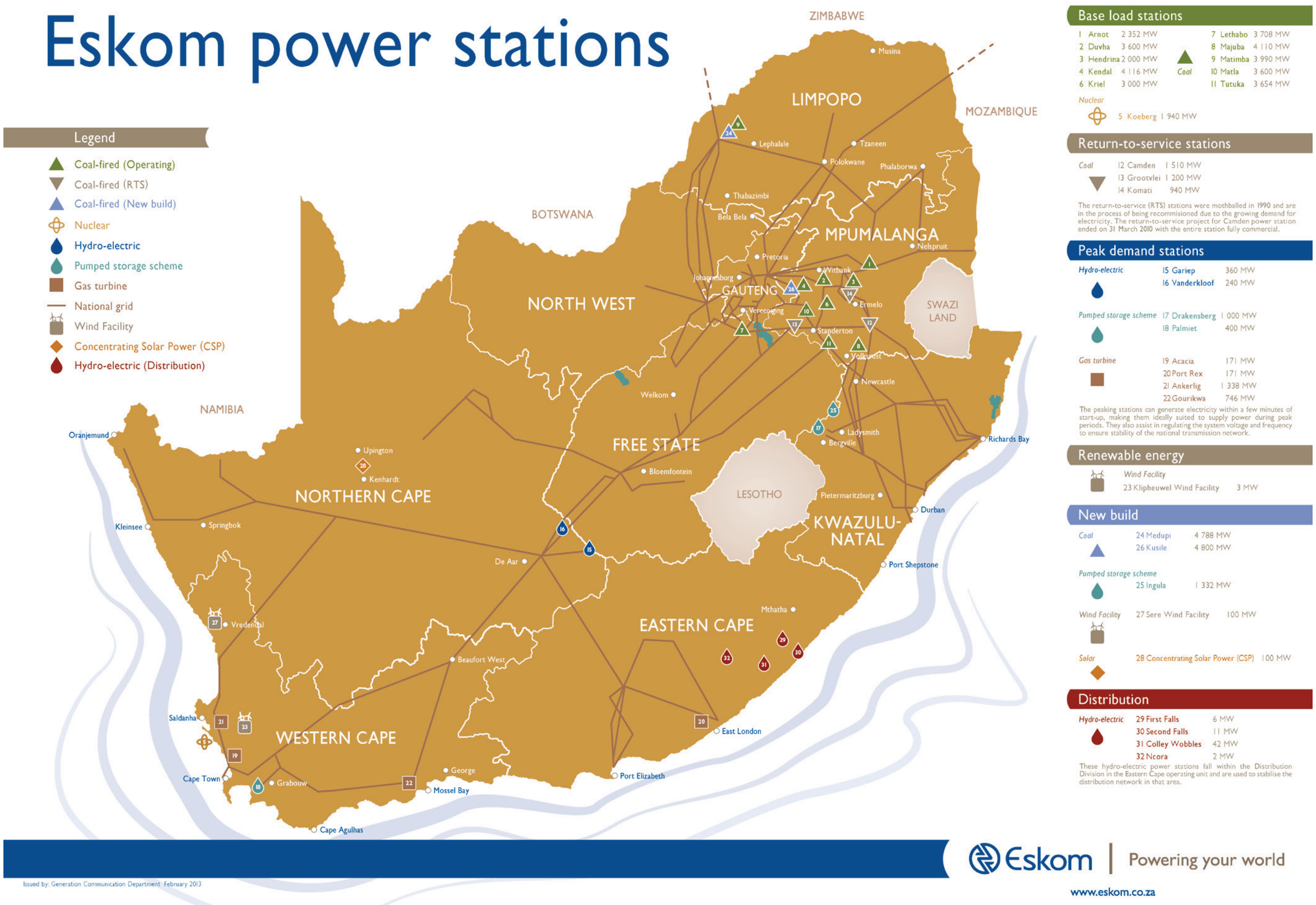


Figure 3-1: List and Location Map of All Existing and Planned Eskom Power Stations

Transmission:

Eskom is the largest producer of electricity in South Africa and it also transmits electricity via a transmission network, which supplies electricity at high voltages to a number of key customers and distributors. Eskom is a vertically integrated utility company licensed to generate, transmit and distribute electricity. The transmission license is held by the transmission network service provider (TNSP) of Eskom. Planning the transmission network is the responsibility of the Grid Planning Department in the Transmission Group. The TNSP is required to abide by the regulatory requirements to publish a document annually, detailing the plans for the way that the transmission network will develop in the next five years. This plan covers a 10-year window. The requirements, furthermore, stipulate that the published document should include:

- the acquisition of servitudes for strategic purposes;
- a list of planned investments, including costs;
- diagrams displaying the planned changes to the transmission system (TS);
- an indication of the impact on customers in terms of service quality and cost; and
- any other information as specified by NERSA from time to time.

A further requirement is that the TNSP should hold public forums to share such plans with stakeholders in order to facilitate a joint planning process with them. The sixth TDP was published early in October 2014; this is the seventh publication based on the TDP for 2016 to 2025.

Distribution:

The electricity distribution industry (EDI) is a vital link between the supplier, usually Eskom, and customers that buy and use electricity.

Traditionally, Eskom and some local municipalities have managed distribution. At one time, there were nearly 500 distributors of electricity in South Africa, but this number has been reduced through consolidation to less than 300.

For nearly 20 years, Eskom has been talking to central government and the other stakeholders mainly the National Energy Regulator (NERSA) and the local government sector - about further rationalizing the EDI. The proposal is to form six regional electricity distributors (REDs) whose sole responsibility would be to manage and drive all electricity distribution throughout the country. This would allow tariffs to be aligned, service to be improved and the equipment to be better maintained and updated. Interruptions of service (blackouts) because of old equipment would be much reduced.

However, there are challenges that must be overcome before progress can be made. Before they will agree to support this initiative, all stakeholders need reassurance that their assets and investments will be protected, and that the new structures will provide a clear benefit to all involved.

Because of the uncertainty hanging over the sector, many players have been reluctant to allocate resources to it, and some equipment and levels of service have been allowed to deteriorate. Coupled with a reduced amount of spare generation capacity in the country, which has affected many construction projects, electricity supply has been added to developers' lists of issues that could be problematic.

Unreliable power supplies have caused many organizations to invest in their own backup supply equipment at considerable cost.

The South African electricity supply industry, long the envy of the developing world, must be allowed to restore its reputation and resume giving its customers excellent service.

To achieve this, there must be cooperation and support (Thekga) from everyone. The rebuilding of a world-class electricity supply must become a national issue a social rallying call.

Until that happens, domestic customers would do well to have gas bottles and other emergency equipment prepared for use, in case of unexpected interruptions.

Tariffs:

Eskom sells electricity to both wholesale and private customers in South Africa and also exports electricity to neighboring countries. Most of the South African wholesale customers are municipalities, who do the local electricity distribution and resell the electricity to their customers. For the electricity volumes per customer type, see Figure 3-2. The entity responsible for the distribution is controlled geographically and a customer is not free to choose the distributor.

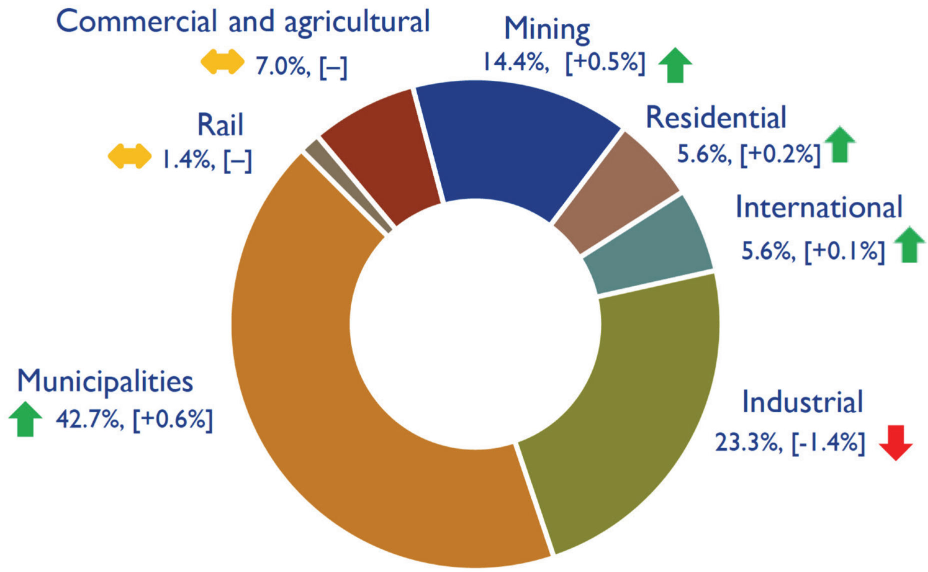


Figure 3-2: Electricity volumes by customer type for the six months ended 30 September 2015 [0316]

Eskom applies to NERSA for tariff increases. Electricity to large users is typically charged at fixed rates plus a metered capacity and active energy charges. The active energy charge is typically done at set time of use (TOU) rates for specific times of the day, day of the week and time of the year. See Figure 3-3. Smaller customers are most often only charged for active energy use at an inclining block tariff.

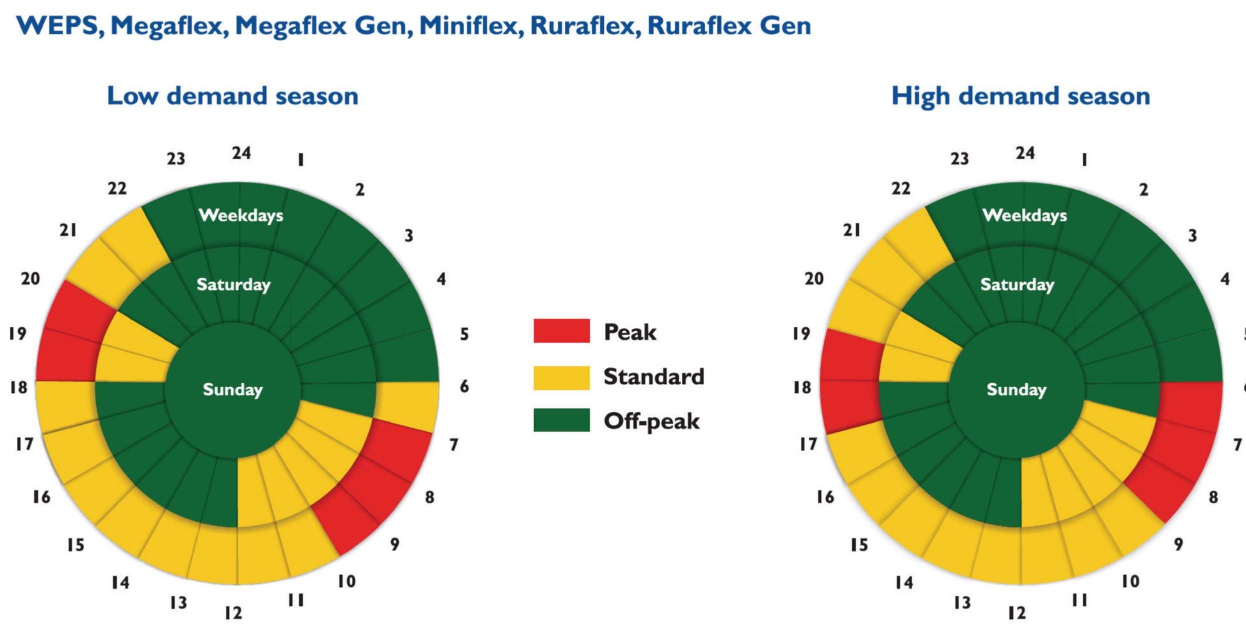


Figure 3-3: Eskom's defined time periods for TOU tariffs in low- and high demand seasons

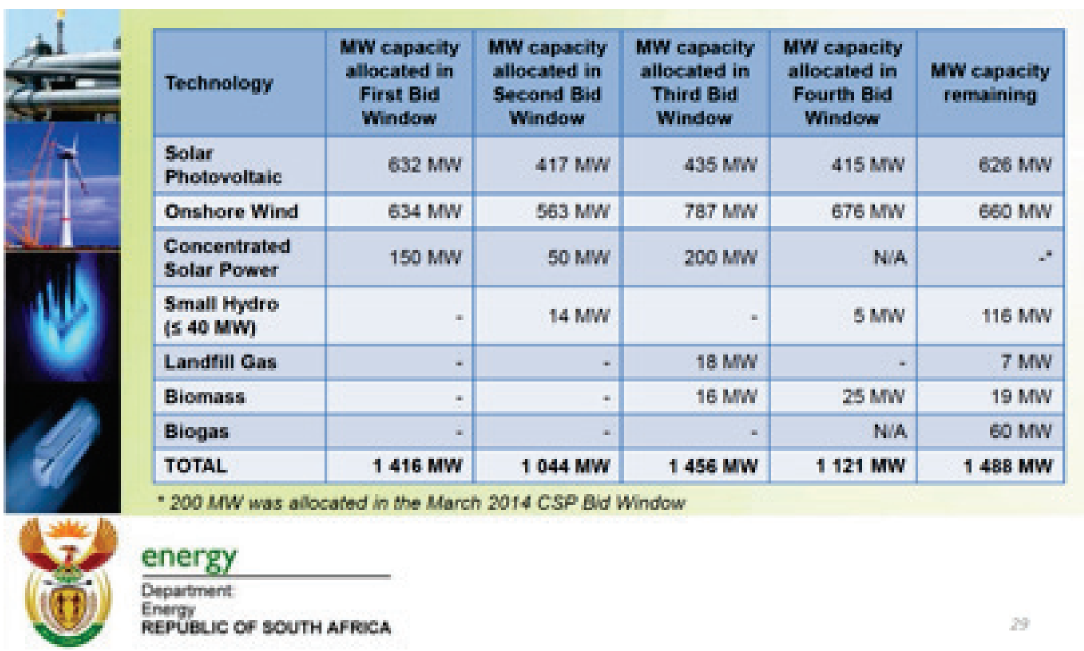
3.3 Independent Power Producer Procurement (IPP) Programme

The independent power producer procurement programme (IPPPP) is a key vehicle for securing electricity capacity from the private sector for renewable and non-renewable energy sources as determined by the minister of energy.

The Department of Energy (DoE), National Treasury (NT) and the Development Bank of Southern Africa (DBSA) established the IPPPP Unit for the specific purpose of delivering on the IPP procurement objectives. The activities of the office are in accordance with the capacity allocated to renewable energy and non-renewable generation in the Integrated Resource Plan (IRP) 2010; subsequent ministerial determinations and DoE support service requirements.

The IPPPP activities continue to evolve in order to effectively respond to the planning and development needs in the current energy context. As an example, the IPPPP Office has been requested to coordinate the development of the Gas Utilization Master Plan (GUMP) that will in turn guide the procurement of the required gas capacity as per the IRP 2010.

The IPPPP Office provides professional advisory services, procurement management services as well as monitoring, evaluation and contract management services.



Technology	MW capacity allocated in First Bid Window	MW capacity allocated in Second Bid Window	MW capacity allocated in Third Bid Window	MW capacity allocated in Fourth Bid Window	MW capacity remaining
Solar Photovoltaic	632 MW	417 MW	435 MW	415 MW	626 MW
Onshore Wind	634 MW	563 MW	787 MW	676 MW	660 MW
Concentrated Solar Power	150 MW	50 MW	200 MW	N/A	-*
Small Hydro (≤ 40 MW)	-	14 MW	-	5 MW	116 MW
Landfill Gas	-	-	18 MW	-	7 MW
Biomass	-	-	16 MW	25 MW	19 MW
Biogas	-	-	-	N/A	60 MW
TOTAL	1 416 MW	1 044 MW	1 456 MW	1 121 MW	1 488 MW

* 200 MW was allocated in the March 2014 CSP Bid Window

Figure 3-4: Analysis of MW Allocation and Remaining

3.4 Local Distribution Entities

In addition to transmission, Eskom provides distribution to approximately 60% of the country. The remaining 40% is distributed by many electricity distributors that operate in South Africa, ranging from large metros to small municipalities. At one stage there were nearly 500, although this figure has since been reduced by means of consolidation to an estimated 180. National government together with key stakeholders are currently working towards reducing this number further, and to this end have initiated a program aimed at establishing regional electricity distributors that will manage and drive all electricity distribution throughout the country. This will allow tariffs to be aligned, service to be improved and equipment to be better maintained and updated. Two of the largest distribution systems are that of Johannesburg's City Power and the Electricity Services Department within the City of Cape Town.

4 Review of Existing South African Regulations

This section provides an assessment of all relevant legislation, regulations, policies and incentives that are currently in place or being considered related to the adoption of energy storage technologies in South Africa.

Although there is little current initiative to encourage the adoption of energy storage, South Africa has been proactive in encouraging the development of renewable energy resources. These attempts to introduce renewable energy (RE) to South Africa date back to the White Paper on Renewable Energy of 2003 and is addressed in the recent Integrated Resource Plan (IRP-2010 updated for 2030) documents [0004, 0005].

The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) has the most proactive plan for SA to integrate renewables but with no specific procurement goal or plan for energy storage. A total of 6925 MW capacity of renewable energy is planned to be online by 2020 [0008] which represent around 10% of the total installed capacity in the IRP. The existing coal and nuclear fleet is however incapable of load following with relative low ramp-rates. With this amount of intermittent renewables (wind and PV) planned to be online by 2020, the stability and reliability of the grid might be negatively impacted.

Only Pumped Energy Storage is addressed in the SA IRP-2010 [0004, 0005]. Eskom Transmission Development Plans are also listed in the transmission plans [0037 to 0041] with the IPP procurement announcements. The IRP does mention the need for research on energy storage options, but specifically mentioned thermal energy storage linked to Concentrated Solar Plants (CSP). No mention of PV or wind + storage is included. Furthermore no specific incentives or plans to promote energy storage are mentioned or proposed.

The interconnection requirements are developed and maintained by NERSA in cooperation with Eskom. The Grid Code related to renewable interconnections are adequate for the renewable energy related IPPs that are currently interconnected on the T&D grid in South Africa. This Grid Code is also relevant and mostly adequate for interconnecting energy storage systems [0353]. Other relevant codes on DER and IPPs can be found on the Eskom website [0354]. Although these grid codes do not address energy storage directly, they are relevant and mostly adequate.

A few PV plus Energy Storage initiatives are currently evaluated and demonstrated by energy companies active in South Africa. Enel Green Power, the renewable energy unit of Italy's biggest utility, is rolling out a version of Tesla's Powerwall home-power kit to help South African retail customers buffer against rising electricity prices and rolling outages. Enel entered the SA power market in 2012, bidding for commercial-scale renewable projects in the order of 150MW [0352].

The independent Energy Storage Service Provider, Alevo, has done some first cut analytical evaluation on the benefits of using substation level energy storage. These results should however be reviewed and independently verified.

5 Key Gaps in South Africa Regulatory Framework

This section identifies key gaps in South Africa's existing legislation, regulations, policies and incentives related to the adoption of energy storage technologies.

As can be seen from the international best practices there are several countries that provide detailed incentives and initiatives to support energy storage development. In South Africa, a very limited environment exists to support the development of energy storage. Some of the key gaps are summarized below:

5.1 Technical Interconnection Procedures and Demonstrations

There are key grid codes that exist in South Africa for interconnecting Distributed Generation and IPPs. These address the generation interconnection requirements, but do not address energy storage specifically. By identifying energy storage as generation, these standards are relevant but not adequate for development of large-scale roll-out of energy storage. Interconnection standards related to customer owned DER and storage devices, which may operate off-grid in an island or on a microgrid especially need to be developed. This will help to bring clarity to PV plus storage roll-out in South Africa.

There are no interconnection requirements, communications and control protocols for substation-level energy storage devices that provide ancillary services to Eskom or one of the municipality directly as an IPP. These should be developed to be ready for a future storage related IPP call.

5.2 Financial and Procurement Options

No procurement targets or specific incentives for providing ancillary services exist. As is currently proven in the USA and Japan, energy storage procurement targets for utilities are one of the quickest ways to develop energy storage.

Financial incentives and subsidies for energy storage are not available in South Africa. Germany and other European countries are focusing extensively on the financial incentive options for industrial, commercial and even residential customers to install and operate energy storage systems. In the USA, the U.S. Storage Act that would provide a 30% tax credit for installed energy storage was not enacted, but is an excellent instrument as proven in the PV market.

Furthermore, demonstration and pilot projects are not embraced to test and evaluate the different use cases. There are two installations at Eskom, but they are only used to verify different energy storage technologies with arbitrage algorithms and are not set up to demonstrate and verify the value proposition or ancillary services.

6 Recommendations for South Africa Regulatory Framework

This section provides recommendations for improving South Africa's existing legislation, regulations, policies and incentives related to the adoption of energy storage technologies.

In the South African regulatory environment, it will be difficult to distinguish and differentiate recommendations in a 5, 10 and 15-year horizon but it is important provide guidance on the short and medium to long term. Recommendations of what can be done now with minimal regulatory changes, versus what needs to be kept for longer-term regulatory actions should be identified. The regulatory recommendations are therefore separated into short-term (first five years) recommendations that include changes to the interconnection process in Section 6.1 and medium to long term (five to fifteen years) regulatory change recommendations in Section 6.2. Additionally, Section 6.3 provides a specific recommendation related to the inclusion of energy storage technologies, particularly in conjunction with solar photovoltaic and wind power plants, under the REIPPPP and as a stand-alone energy storage procurement program.

6.1 FIVE-YEAR TIME FRAME

A summary of the regulatory and interconnection requirement actions are shown in the Table 6-1:

Table 6-1: Regulatory and Interconnection Actions

USE Case Role	Interconnection Standard and Status	Regulatory Actions - 5 years
Bulk Energy Services	• Eskom and NERSA Grid Codes make provision for IPP interconnections but need to be amended for ESS systems.	• Consider energy storage as generation, including large generator ancillary services in IPP and IRP development process.
	• The ESS interconnection standard should comply with the generator interconnection standard.	• Provide the renewable IPPs incentives to make their renewable generation dispatchable, so that it can participate as regular generation in the IRP.
Ancillary Services	• Grid Codes needs to be updated to include ancillary services.	• Allow/provide for direct contracting by Eskom and municipalities to provide ancillary services through Independent ESSP and PPA contracts.
	• Requires energy storage vendors to provide ancillary services with oversized ESS converters.	• IRP does not address ancillary services directly. IRP should be revised to include anticipated requirements for grid level ancillary services.
	• Develop Grid Code to operate distributed energy storage in Virtual Power Plant (VPP) environment.	• New IPP call should be expanded to include ancillary services. • Provide demonstration / pilot ESS projects to demonstrate/validate the value of ESS ancillary services.
Grid Infrastructure Services	• Grid Code updates as recommended.	• Develop value proposition for T&D deferral in IPP evaluation process
Customer Energy Management Services	• Grid Code needs to be updated to include power quality and arbitrage support by customer owned energy storage. • Grid Code needs to be updated to include MicroGrid and islanding operation. • Update Grid Code for customer owned storage. • Grid Code to enable PV + storage systems.	• Provide incentives to customers that provide grid reliability and power quality support. • Develop Net Metering, Time-of-Use and/or Feed-in Tariffs to provide benefits to energy storage, including for islanded and MicroGrid systems • Provide demonstration / pilot ESS projects to proof ESS can operate in MicroGrid and islanded system in SA. • Provide financial incentive for PV + Storage, typical capital or production tax credit.

6.2 Ten To Fifteen Year Time Frame

A summary of the proposed changes and regulatory actions are summarized in the Table 6-2:

Table 6-2: Regulatory Actions

USE Case Role	Regulatory Actions – 0-15 years
Bulk Energy Services	• Promote and provide R&D and local manufacturing support for bulk energy storage solutions with Flow Batteries. • Contract according to IRP bulk energy storage as generation, including large generator ancillary services.
	• Develop ESSP energy market so that bulk energy storage can be provided by IPPs through a PPA contract. • Open IPP calls for bulk substation level energy storage that include ancillary services. • Provide financial incentive as loan guarantee programs for large capital projects
Ancillary Services	• Develop ESSP energy market so that ancillary service can be provided by IPPs through a PPA. • Open new IPP calls for all level energy storage that include ancillary services, also in a Virtual Power Plant (VPP) environment.
	• Adopt a fast ramping frequency regulation market to benefit from fast acting energy storage in the ancillary services market.
	• New IPP call needs to be expanded for ancillary services. • Provide demonstration / pilot ESS projects to prove ESS can provide ancillary services.
Grid Infrastructure Services	• Provide revenue stream for T&D deferral in PPA contracts.
Customer Energy Management Services	• Develop Net Metering, Time-of-Use and/or Feed-in Tariffs to provide benefits to energy storage, including for islanded and MicroGrid systems. • Provide demonstration / pilot ESS projects to proof ESS can operate in MicroGrid and islanded system in SA. • Develop transactive Energy market for customers to participate in the market with customer owned energy storage and demand response technologies.

In summary, the main objective should be to development an energy market with clear revenue streams to value Demand Response, Ancillary Services and Transactive Energy for IPPs, customers and Eskom owning energy storage and DR technologies in South Africa. With such an established market, energy storage can clearly participate in the market as discussed in Section 2.1 and 2.2.

6.3 Inclusion of Energy Storage Under the REIPPPP or as Stand Alone

Energy storage technologies, particularly in conjunction with solar and wind power plants, should not be procured directly under the REIPPPP program, but the renewable IPPs should be provided with incentives to make the renewable generation dispatchable, so that it can participate as regular generation in the IRP with clear market initiatives.

There needs to be a clear investment and production incentives for stand-alone energy storage or PV + Storage in customer owned procurement programs.

6.4 Proposed Field and Demonstration Projects

Develop demonstration/pilot projects with an independent Measurement and Verification (M&V) scope to proof technology maturity, grid operations, ancillary services and commercial readiness.

Utilize public-private partnerships, and financial incentives (such as time-of-use tariffs, tax and production subsidies promoting energy storage.

Provide R&D support and incentives for joint ventures to provide local manufacturing of energy storage systems or components.

Proposed demonstration and proof-of-value projects:

1. Stacked USE cases including Ancillary services
2. Behind the meter and microgrid solution.

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Roadmap

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ACRONYMS

SSA	Sub-Saharan Africa
ADS	Agency Development and Support
AfDB	African Development Bank
AMEU	Association of Municipal Electricity Utilities
AMI	advanced metering infrastructure
BAU	business as usual
BTM	behind the meter
CAES	compressed air energy storage
CEO	Chief Executive Officer
CO2	carbon dioxide
CPP	critical peak pricing
CSIR	Council for Scientific and Industrial Research
DBSA	Development Bank of South Africa
DDM	Due Diligence Matrix
DER	distributed energy resource
DMS	data management system
DoE	South Africa Department of Energy
DRMS	demand response management system
DST	South Africa Department of Science and Technology
dti	South Africa Department of Trade and Industry
EDI	electricity distribution industry
EIA	environmental impact assessment
EIUG	Energy Intensive Users Group
EPRI	Electric Power Research Institute
ES	energy storage
ES-DER	hybrid energy storage-distributed energy resource
ESS	energy storage system
EV	electric vehicle
FIT	feed-in tariff
FOM	front of meter
GDP	gross domestic product
GHG	greenhouse gas
GUMP	Gas Utilization Master Plan
HVAC	heating, ventilating, and air conditioning
ICT	Information and communications technology
IDC	Industrial Development Corporation
IEEE	Institute of Electrical and Electronics Engineers
IP	Intellectual Property

IPP	independent power producer
IPPPP	Independent Power Producer Procurement Programme
IRP	integrated resource plan
IT-OT	information technology and operation technology
KPI	key performance indicator
Li-ion	lithium ion
M&V	measurement and verification
MW	megawatt
NaS	sodium-sulfur
NEEA	National Energy Efficiency Agency
NEM	net energy metering
NERSA	National Electric Regulator South Africa
NOC	network operating centre
NT	National Treasury
O&M	operations and maintenance
PV	photovoltaic
R	South African Rand
R&D	research and development
RCC	Renewable Control Center
RE	renewable energy
RED	Regional Electricity Distributor
REIPP	Renwable Energy Independent Power Producer
RESOLVE	Renewable Energy Solutions model
REV	Reforming the Energy Vision
RFI	request for information
RFP	request for proposal
RFQ	request for quotation
RMC	Regional member county
RPS	renewable portfolio standard
SA	South Africa
SADC	Southern African Development Community
SAIPPA	South African Independent Power Producers Association
SALGA	South African Local Government Association
SANEDI	South African National Energy Development Institute
SAPVIA	South African Photovoltaic Industry Association
SAREC	South Africa Renewable Energy Council
SAWEA	South African Wind Energy Association
SCADA	supervisory control and data acquisition
SGIP	Self-Generation Incentive Program
SOW	scope of work

T&D	transmission and distribution
TDP	Transmission Development Plan
TE	Transactive Energy
TNSP	transmission network service provider
TOU	time of use pricing
TRC	total resource cost
TS	transmission system
UL	Underwriters Laboratories
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USTDA	US Trade and Development Agency
VRE	Variable Renewable Energy

1 Introduction

This report "Roadmap for the Adoption of Energy Storage Technologies in South Africa is based on the findings from Objectives 1 through 5 and provides recommended activities for effective adoption of energy storage technologies in South Africa through 2030. The key steps to this effort are as follows:

- Identify key stakeholders, including their roles and responsibilities.
- Provide recommendations for concrete steps to be taken by key stakeholders to support the adoption of energy storage technologies in South Africa.
- Develop a recommended schedule for implementing those recommendations, including recommendations for phasing and milestones.
- Provide a business case that assesses the overall costs and benefits of, as well as alternatives to, the adoption of energy storage technologies in South Africa.

1.1 Approach to Study

Although some energy storage technologies are mature or are near maturity, many are still in the early stages of development and currently struggle to compete with other non-storage technologies due to high costs. They will require additional refinement and development before their potential can be fully realized. Governments can help accelerate the development and deployment of energy storage technologies by supporting targeted demonstration projects for promising storage technologies and by eliminating price distortions that prevent storage technologies from being compensated for the suite of services they provide. Energy storage technologies have the potential to support evolution of South Africa's energy system. Affordable and reliable electrical power in turn will improve the standard of living and promote industrial development in the country. Realizing this potential will require government, industry, academia and financial stakeholders to work together to help overcome existing barriers [0065].

1.1.1 Meetings with Stakeholders

The key to the development of Roadmap Activities is frequent discussion and buy-in from the Stakeholders. Significant meetings and visits are listed in Table 1-1.

Table 1-1: Key Meetings with Industrial Development Corporation, Steering Committee, and Stakeholders

Date	Activities
October 2015	Initial kick-off meeting and discussion of market needs
May 2016	Meetings with Reverse Trade Delegation to further explore assessment objectives and to meet with technology providers to better understand the attributes and maturities of various storage technologies
July 2017	Follow-on meetings with stakeholders (Steering Committee, Municipalities, Eskom, Energy Intensive Users Group)

1.2 Key Findings of Objective Activities

The following subsections summarize the findings from the previous five objectives in this study.

1.2.1 Market Needs

South Africa has a number of challenges related to operation, maintenance, development, and expansion of its electric utility grid. Some of these challenges may be addressed through efficient adoption of Energy Storage. Table 1-2 describes the four basic use areas and the underlying specific uses/purposes to be addressed by this study.

Table 1-2: Identified Use Cases for South Africa Energy Storage Study

Area	Use / Main Purpose	Range
Bulk Energy Services	• Time-shifting of electric energy (arbitrage) • Schedulable capacity • Re-dispatch ("> 15-minute reserves")	100MW+ 600MWh+ Minutes & Hours
Ancillary Services	• Frequency support (reserves) • Voltage support (reactive power) • Bottleneck management (congestion relief / N-1) • Black-start capability	1 – 10 MW+ 3 – 50 MWh+ Seconds & Minutes
Grid Infrastructure Services	• Transmission upgrade deferral • Distribution upgrade deferral	10MW+ 60MWh+ Hours up to Days
Customer Energy Management Services	• Power quality • Power reliability (security of supply) • Energy-charge management (arbitrage) • Demand-charge management (peak shaving) • Island and off-grid	3kW – 100MW 10kWh – 500MWh Seconds, Minutes & Hours

This study will consider power-to-power energy storage (e.g., electricity-in and electricity-out) applications. The relevant technologies are therefore the storage of available electrical energy – in the form of electricity – as mechanical, electromechanical, or chemical energy, in a form that can later be efficiently converted back to electricity.

A preliminary needs assessment was conducted for the short (1–5 years), medium (6–10 years) and long term (11–15 years) for the various market sectors (residential, commercial, industrial, utility) across two qualitative growth scenarios: (1) a business as usual (BAU) scenario in which electrical demand continues at current levels, and (2) a growth scenario in which electrical demand increases significantly. The results were as follows:

- **Short Term** (1–5 years): The consensus was that use cases for time-shifting of energy, schedulable capacity, reserves for frequency support, black-start capability, and power reliability would be needed at the utility level and only in the growth scenario.

- **Medium Term** (6–10 years): During this period, additional use cases of power reliability, security of supply for commercial customers, and island and off-grid by residential and industrial customers were also identified as likely priorities but only in the growth scenario.
- **Long Term** (11-15 years): Significantly more use cases would be required by all users (utility, industrial, commercial, residential) in the growth scenario. This was the first period that identified use cases for the BAU scenario, including schedulable capacity by the utility, and island and off-grid by residential, commercial, and industrial customers.

The economic assessment performed under Task 2.2 will be used to confirm or refute these conclusions in a more quantitative manner.

1.2.2 Technology Assessment

Many energy storage technologies have been deployed commercially for some time, others are still under commercial development, and others are in the research and development phase. This effort provided a description of relevant power-in/power-out technologies and included a summary of their performance capabilities and a comparison of strengths and weaknesses specifically in general and in regards to South Africa.

Figure 1-1 summarizes the potential of competing energy storage technologies to be mature and competitive over the near, middle, and long-term time frames. The top-level conclusion was that Lithium ion (Li-ion) batteries will be the dominant energy storage technologies over the next 15 years. Some older technologies such as advanced lead acid and sodium sulfur may continue to be deployed in niche applications; however, these technologies will be increasingly overcome by Li-ion through further performance improvements and additional cost reductions. This effort also predicted that several flow battery technologies are poised to have a significant impact on the energy storage market for longer cycle applications over the next 5 to 10 years. Liquid air and compressed air energy storage (CAES) are also on the verge of being competitive in this time frame. Lastly, several research and development (R&D) technologies with strong potential (liquid-metal, metal-air) may not emerge commercially for another 10 to 15 years.

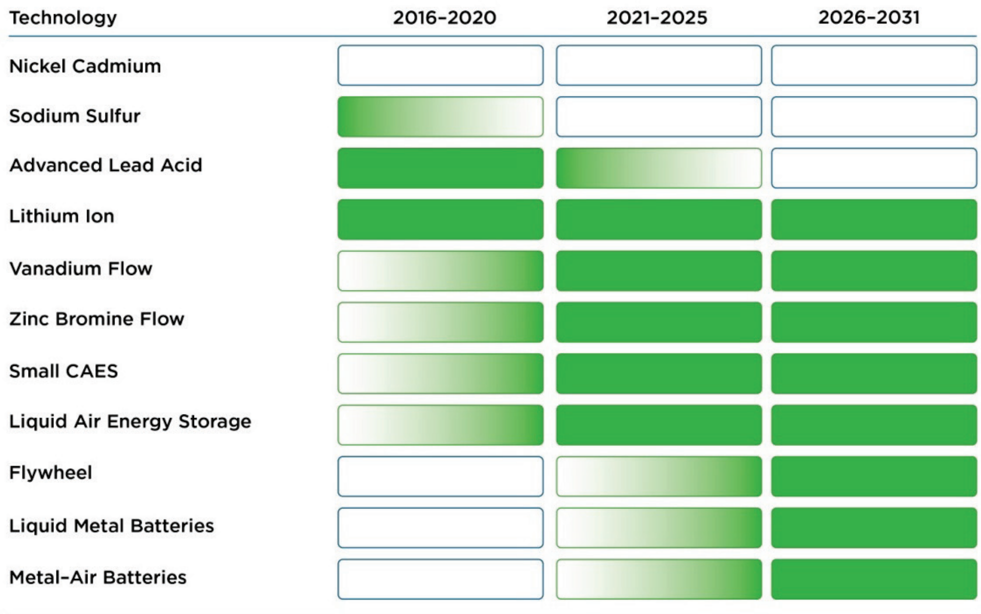


Figure 1-1: Potential Competitive Time Frames for Technologies

This effort identified and provided profiles of 35 US and South African companies that could provide energy storage equipment or service providers for energy storage projects in South Africa (SA). Each profile included a description of the company, its energy storage offerings, and some history of past and current deployment.

This effort also included the results of a survey of potential US manufacturers to determine how they viewed the potential South Africa Energy Storage market. The following potential barriers were identified:

- Long distance between the United States and South Africa complicates communications (time differences), and requires long and expensive travel to find competent project partners, identify sites, create proposals, and develop projects.
- Perceived lack of experienced regional partners with established relationships with subcontractors and equipment vendors, particularly in-country deployment, engineering, and operations and maintenance (O&M) support.
- The SA electric utility is based on an older centralized generation, transmission and distribution (T&D) model rather than on the more open and decentralized system emerging in other countries.
- The current SA regulatory or market framework has no specific mechanisms to motivate companies to invest in energy storage projects and allow them a consistent and reasonable return on investment.
- A lack of project financing for energy storage projects and a lack of familiarity (and confidence) by the domestic financial sector for new energy storage technologies.
- High interest rates (linked to country/client risk profiles) are a huge barrier for renewables and storage projects due to the capital expense-heavy nature of the projects.

- High local content requirements on energy storage procurements limit or preclude reasonable competition for non-domestic suppliers.
- Import customs issues and foreign exchange issues are related to the volatility and strength of the Rand.
- High crime rate in South Africa and the need for increased levels of facility and equipment security was cited by two companies.
- It was generally felt that all of the above, compounded by a perceived low probability of success due to limited funding and a highly chaotic political atmosphere with regard to energy, makes any current strategic decisions risky.

1.2.3 Economic Assessment

The economic assessment was concerned with determining the cost of storage both now and in the future through the year 2030 and how those costs compare to the value of the benefits that storage can offer to the grid. We discussed storage costs for each storage technology, with detailed focus on lithium ion and flow battery because those two technologies are currently the most promising. We then used an optimal investment model called RESOLVE to determine at what price point storage would be part of a least-cost resource planning solution to meet South Africa's future system needs.

The difference between the forecasted price for storage and the price point at which storage is part of the economic plan is the funding gap — a key output of the economic analysis. The economic analysis quantitatively evaluated at system-level storage benefits, including energy, capacity, and ancillary services. The funding gap therefore describes the "missing money" to cover the cost of storage that could be recovered from other use cases, particularly local T&D deferral. Alternatively, the funding gap could be covered through subsidy, and the rate increases necessary to offer such a subsidy is presented.

The cost benefit analysis used to calculate the funding gap was performed for a series of different scenarios describing possible future system conditions in South Africa. These scenarios included integrated resource plans (IRPs) determined through the South African planning process, different levels of geographic diversity of renewables, the capability of pumped hydroelectric storage to offer instantaneous reserves, and several other sensitivities to test the economics of storage.

The funding gap is shown in Figure 1-2. The gap is the difference between the forecasted cost, shown by the dotted lines, and the modelled cost shown by the squares for each of the eight cost cases. The bars show how much storage is built in each of three different scenarios. In the figure below we assume that pumped storage does not offer instantaneous reserves.

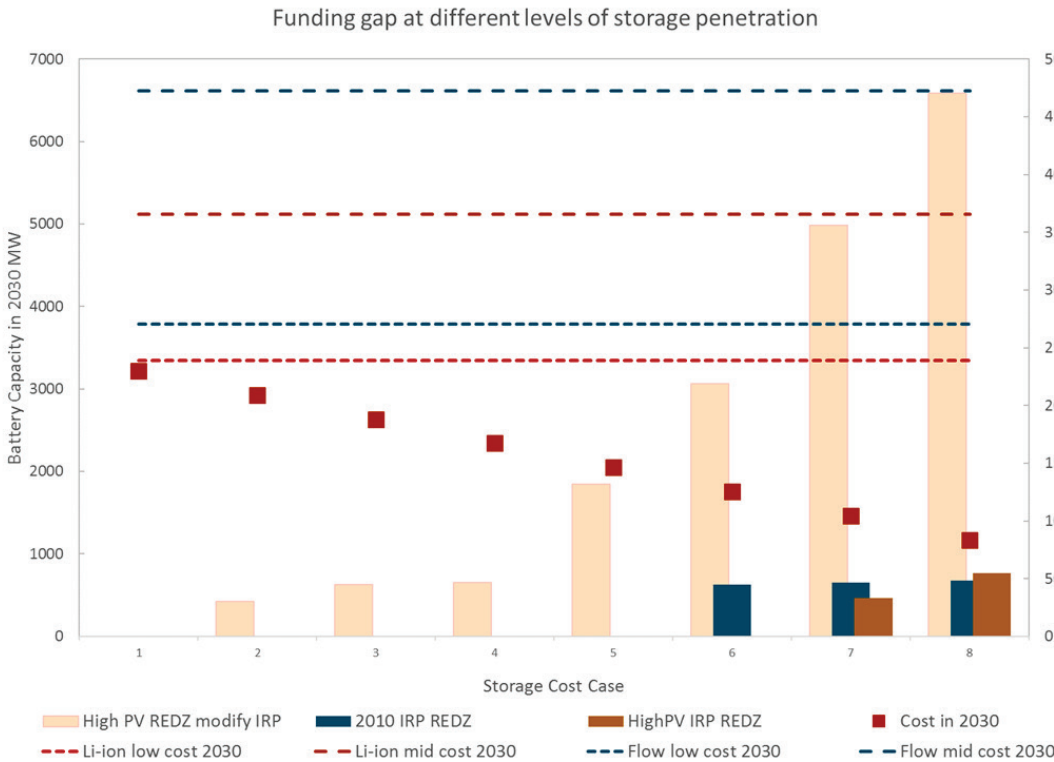


Figure 1-2: Funding Gap for Different Levels of Storage Penetration

The findings of the economic assessment led to recommendations for how increased value from storage could be realized in the future. These recommendations are found in the Roadmap activities in Section 3. The key findings from the economic assessment are as follows:

- The most valuable use of storage is for instantaneous reserves. The high value comes from avoiding having to use coal generation to provide that service. The extent to which storage can take advantage of this valuable use case in justifying its investment depends on how much of the instantaneous reserve requirement can be provided by pumped storage. Even when offering instantaneous reserves, we found a funding gap of approximately 1,100 Rand (R)/kWh in the 2010 IRP scenario before storage is built, relative to the low cost storage cost projections for lithium ion in 2030.
- If all the resources identified in the IRP are built, storage will have no capacity value through 2030. Storage only has capacity value if it can avoid construction of a system-level generation resource. We therefore analyzed a sensitivity on the rooftop photovoltaic (PV) scenario that allows storage to avoid capital investment. The funding gap is significantly reduced in this case to 297 R/kWh relative to the low-cost storage cost projections for lithium ion in 2030.
- At the bulk system level, storage competes against traditional generating resources and curtailment of renewables in the determination of cost-effective procurement and operations. The renewable penetration is low in the 2010 IRP case at approximately 11.5% of load in 2030, and only about 25% of load in the rooftop PV case. This is significantly lower than renewable penetrations on other

systems for which models predict economic storage procurement on the bulk system. One planning benefit for storage that is currently not available in South Africa is the avoidance of renewable overbuild caused by curtailment under renewable portfolio standard (RPS) policies. The requirement of delivering renewable energy as sales under an RPS makes curtailment of renewables more expensive because for every megawatt-hour curtailed, another megawatt-hour from another renewable resource must take its place. If in the future South Africa transitions to an RPS policy and greater levels of renewable penetration, bulk system storage benefits will increase.

- To investigate whether, despite realizing no capacity benefits in the IRP scenarios, feasible system or policy conditions could trigger cost-effective storage procurement based on bulk system benefits, we examined several sensitivities. These include reduced renewable diversity, an RPS constraint, uncurtailable renewables, a more inflexible coal fleet, and a greater efficiency loss related to the coal fleet offering instantaneous reserves. We found that economic storage is selected in none of these cases. These conditions would increase the bulk system benefits for storage; however, they would lower the funding gap and the benefits that storage needs from other non-bulk system use cases to fill it.
- In areas with local capacity constraints, the capacity value for energy storage can be significantly higher and sufficient to make storage cost-effective in select cases.
- Stacking customer-sided and utility-sided benefits with behind-the-meter (BTM) storage, allowing for some utility dispatch can also reduce the funding gap. Bill savings for the customer are not a total resource cost (TRC) benefit. Nevertheless, customers are willing to pay for reliability benefits and bill savings provided by storage, reducing the cost that must be paid by the utility. If sufficient system and T&D capacity benefits are realized with utility dispatch of BTM storage, net benefits for the utility and its ratepayers can be achieved.

1.2.4 Financial Assessment

A financial assessment (Objective 2, Task 2.3) evaluated and assessed key financing considerations for the deployment of energy storage technologies in South Africa. The results are summarized below:

- An overview of the bankability and key financial risks associated with the energy storage technologies concluded that lithium-ion is currently the battery of choice and arguably the most bankable technology for grid-scale energy storage. Individual projects based on Li-ion are scaling up to the tens and soon hundreds of megawatts. Several technologies, including advanced lead acid, sodium-sulfur (NaS), and flywheels, are mature and are considered bankable. Bankability is a reflection of the maturity of the technology and certainty of performance and reliability; however, it does not necessarily mean that these are the most competitive technologies for any given application.
- A number of evolving energy storage technologies are nearing bankability. Several companies have deployed flow batteries on a smaller industrial or commercial scale and are now expanding to deploy demonstration and pilot projects at a utility scale. Reliable, long-term operation and performance of the initial utility scale systems will be the precursor to bankability of these technologies. Other

technologies such as CAES small reservoir, liquid air, and gravity storage are in the process of showcasing demonstration projects.

1.2.5 Development Impact Assessment

Objective 3 evaluated the anticipated development impacts that might be realized through the overall adoption of energy storage in South Africa, as well as specific impacts realized through specific energy storage technologies and specific IDC investments in energy storage projects through 2030. The findings are summarized below:

With regard to supporting the ability to secure financing for energy storage projects in SA, adoption of energy storage in SA will:

- Provide better access and availability to financing
- Increase the number and types of financial products available to fund energy storage projects and facilities.
- Facilitate new connections and relationships between stakeholders in the energy storage industry.

With regard to supporting regulations that promote effective governance, adoption of energy storage in SA will:

- Generate new tender processes for energy storage
- Promote direct investment in South Africa.
- Further open the energy storage market to greater competition.

With regard to improving power delivery and continuity of service, adoption of energy storage in SA will:

- Allow utility resources and funding to be prioritized to critical upgrades or the expansion of transmission and distribution infrastructure.
- Provide for small increases in or the extension of the availability of electricity,
- Allow increase in overall system efficiency and to reduce losses
- Increase ability to incorporate significant amounts of VRE onto the SA electrical grid
- Will expand commodity diversification.

With regard to reducing/avoiding greenhouse gas emissions, adoption of energy storage in SA will:

- Enable Greenhouse Gas (GHG) emission reductions.

With regard to creation of temporary and permanent Jobs in SA, adoption of energy storage in SA will:

- Add permanent jobs to SA economy
- Add temporary jobs to SA economy.
- Provide additional training and skills development to SA workforce

1.2.6 ENVIRONMENTAL ASSESSMENT

The findings of the Environmental Assessment are summarized in the following subsections.

1.2.6.1 Benefits of Storage

The introduction of large-scale energy storage may have significant indirect environmental benefits to South Africa. The main benefits from adopting energy storage include the ability to assist in the integration of renewable energy (RE) into the electricity grid (reducing greenhouse gas [GHG] emissions); supporting the existing generation facilities to operate at optimal levels, reducing the dependence on inefficient energy generation technologies that would be used during peak times, and the potential to defer the need to develop additional "dirty" energy generation infrastructure or infrastructure that has a higher environmental footprint than that of the energy storage system [0317].

To ensure that the environmental benefits of the energy storage technology outweigh the potential impacts, the principles for green energy storage should be considered and employed (Figure 1-3) [0298].

1.2.6.2 Regulatory Concerns and Recommendations

There are regulatory concerns in existing policy and legislative frameworks regarding the use and application of energy storage technologies. The legislative framework only accounts for potential siting issues as well as specific operational aspects such as storage of hazardous substances. If a technology does not trigger a siting issue or a specific operational aspect, the need for an environmental impact process does not exist. This does not mean that the impacts are such that a process should not take place; rather, it indicates an inherent gap in the legislation. It is recommended that the relevant departments be consulted to introduce energy storage technologies as a listed activity in terms of the Environmental Impacts Assessment Regulations, or alternately to define "generation" in terms of the regulations to include energy storage.

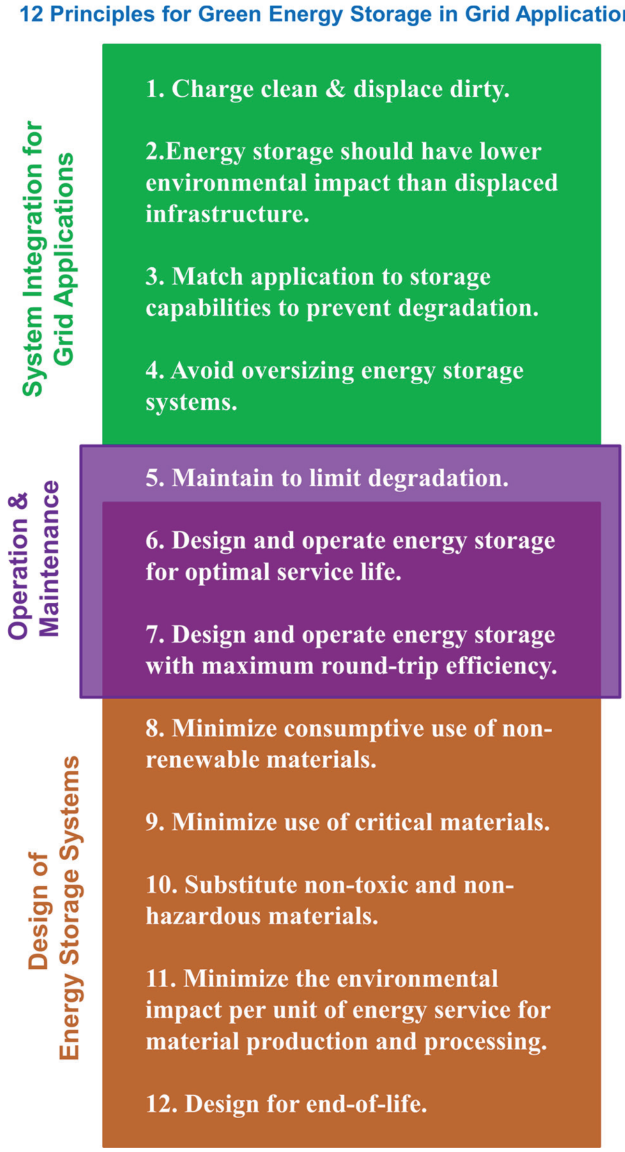


Figure 1-3: 12 Principles for Green Energy Storage in Grid Applications [0298]

1.2.6.3 Environmental Impact Statement

Considering the potential risks associated with the various energy storage technologies (refer to Table 1-3), it is recommended that the energy storage technologies with the least risk to the environment within each system be considered feasible. Each energy storage system (i.e., advanced battery, fluid storage and mechanical) has its own merits and the selection of the most feasible technology will have to be based on various factors associated with use case, site selection, etc.

Table 1-3: Comparative Assessment Summary

Technology	Average Cumulative Risk	Summary of Issues
Advanced Battery Systems		
Lead-Acid and Advanced Lead-Acid Batteries	21	The major issues relating to the use of advanced battery systems is the use of hazardous substances in the reaction process. This has implications during various phases of the project, however, most notably during operation. High operating temperatures for some technologies also poses a significant risk.. However, this can be mitigated against through the utilization of battery technologies that use less toxic chemicals (e.g., ultracapacitors) or technology that has a remarkably reduced risk of contamination from containment failure, maintenance and disposal (such as redox flow batteries).
Ultracapacitors	16	
Lithium-Ion Batteries	25	
Vanadium Flow Batteries	17	
Zinc-Bromine Flow Batteries	17	
Iron-Chromium Flow Batteries	15	
Sodium Sulfur Batteries	21	
Fluid (Chemical) Storage Systems		
Hydrogen Electrolyzer/Fuel Cell	19	The main concern regarding the use of a hydrogen electrolyzer/fuel cell is that it relies on water as a source of energy generation. Given that South Africa is a water-scarce country, the intense drought experienced in 2015, and the effects of climate change, the use of the technology should be undertaken cautiously and site selection is paramount.
Mechanical Storage Systems		
Flywheel Energy Storage	18	The only consideration for flywheels is that there may be some additional underground disturbance for flywheel containment in the case of catastrophic equipment failures. However, flywheel energy storage can be considered as “green energy storage” since the potential impacts can be regarded as minimal.
Compressed Air Energy Storage	32	CAES using underground storage (caverns) is considered to potentially have very significant impacts and a relatively larger scale than the other technologies.

1.2.7 Legal and Regulatory Assessment

The key findings for the legal and regulatory assessment of adopting energy storage in South Africa are summarized below:

- South Africa stakeholders such as the South Africa Department of Energy (DoE) and National Energy Regulator South Africa (NERSA) should provide financial initiatives to support energy storage development by providing a value proposition for energy storage. In South Africa, a very limited environment exists to support the development of energy storage.
- Key grid codes exist in South Africa for interconnecting distributed generation and independent power producers (IPPs). These address the generation interconnection requirements, but they do not necessarily address energy storage specifically. By identifying energy storage as generated by NERSA, these standards are relevant and can help to integrate energy storage. However, they are not adequate for the large-scale roll-out of energy storage.

- Interconnection standards related to customer-owned distributed energy resource (DER) and storage devices, which may operate off-grid on an island or on a microgrid, must be developed or updated. This will help to bring clarity to PV plus storage roll-out for South Africa within customer premises.
- Interconnection requirements, communications, and control protocols are required for substation-level energy storage devices that provide ancillary services to Eskom or one of the municipalities directly as IPPs.
- The existing interconnection standards and grid codes at Eskom and the various municipalities are currently not in sync. It is recommended that the grid codes are consolidated by NERSA to have the same requirements for all the utilities.
- Procurement targets for providing ancillary services do not exist and should be developed. As is currently proven in the United States and Japan, energy storage procurement targets for utilities are one of the quickest ways to develop energy storage.
- Currently demonstration and pilot projects are not structured to test and evaluate many of the potential use cases for energy storage. There are currently two installations at Eskom, but they are only used to verify different energy storage technologies with arbitrage algorithms; they are not set up to demonstrate and verify the value proposition of energy storage on the grid or specifically providing grid-level ancillary services. Eskom and the municipalities currently do not have the control infrastructure and communications protocols necessary to effectively control behind the meter or end of line devices across multiple use cases from its control centers.
- The utilities have no visibility to DERs and storage performance behind the meter, nor to monitoring and data collection for end-of-line devices in front of the meter. Another aspect is the potential for aggregators to make the utility-storage interaction simpler, and what infrastructural changes would have to be made.

2 Key Stakeholders

This section identifies the key stakeholders in developing proposed activities for adoption of energy storage in South Africa and discusses their roles and responsibilities.

2.1 National Energy Regulator South Africa

The National Energy Regulator South Africa (NERSA) is a regulatory authority established under the National Energy Regulator Act, 2004 (Act No. 40 of 2004). NERSA's mandate is to regulate the electricity as well as piped-gas and petroleum pipelines industries. The structure of the Energy Regulator consists of nine members, five of whom are part-time and four are full-time, including the Chief Executive Office (CEO). NERSA is supported by personnel under the direction of the CEO. The division of NERSA responsible for economic regulation of the electricity industry has four departments:

- The **Licensing and Compliance Department** issues licenses with terms and conditions for generation, transmission and distribution of electricity; Import/export of electricity and; Traders in electricity. This department also registers those that provide the above services but do not require licensing, and monitors compliance with license terms and conditions by licensees.
- The **Pricing and Tariffs Department** manages economic regulation of the electricity supply industry by setting tariff guidelines and structure, defining tariff methodologies (e.g., rate of return and multi-year price determination), evaluating tariff applications from licensees, and setting pricing frameworks.
- The **Electricity, Infrastructure, and Planning Department** provides planning for the country's future electricity demand/needs (National Integrated Resource Plan). It also promotes alternative electricity generation technologies (e.g., renewable energy, cogeneration) and promotes demand-side management and energy efficiency initiatives.
- The **Regulatory Reform Department** sets the design of the regulatory framework for the restructured Electricity Distribution Industry, i.e., the introduction of Regional Electricity Distributors (REDs). This department also takes care of research and development of the Electricity Distribution Industry and the international trading framework.

2.2 Department of Energy (South Africa)

The South Africa Department of Energy (DoE) is mandated to ensure the secure and sustainable provision of energy for socioeconomic development. This is achieved by developing an integrated energy plan, regulating the energy industries, and promoting investment in accordance with the integrated resource plan.

The DoE's strategic goals are as follows:

- Ensure that the energy supply is secure and demand is properly managed.
- Facilitate an efficient, competitive, and responsive energy infrastructure network.
- Ensure improved energy regulation and competition.

- Ensure an efficient and diverse energy mix for universal access within a transformed energy sector.
- Ensure that environmental assets and natural resources are protected and continually enhanced by cleaner energy technologies.
- Implement policies that adapt to and mitigate the effects of climate change.
- Implement good corporate governance for effective and efficient service delivery.

The DoE places emphasis on broadening electricity supply technologies to include gas and imports as well as nuclear, biomass, and renewable energy resources (wind, solar, and hydro) to meet the country's future electricity needs and reduce its carbon dioxide (CO_2) emissions. The DoE is responsible for ensuring exploration, development, processing, utilization, and management of South Africa's mineral and energy resources. As the country's economy continues to grow, energy is increasingly becoming a key focus. The Electricity and Nuclear Branch is responsible for electricity and nuclear energy affairs; the Hydrocarbons and Energy Planning Branch is responsible for coal, gas, liquid fuels, energy efficiency, renewable energy and energy planning, including the energy database.

The DoE performs the following specific functions:

- Develop, maintain and implement an integrated energy policy (legislation, regulations, etc.) and planning framework.
- Manage the regulation of petroleum and petroleum products.
- Manage the South African Nuclear Energy Industry.
- Manage and facilitate the development of clean energy initiatives.
- Manage, coordinate and monitor programs and projects focused on access to energy.
- Provide corporate support to the DoE.
- Provide financial, information and supply chain management support to the DoE.
- Provide governance and compliance functions to the DoE and Energy Sector.
- Render ministerial and parliamentary services.
- Provide audit services for the DoE.
- Render an administrative and support service to the Director General.

The DoE plays an essential role in the adoption of energy storage onto the SA grid in that the development of energy storage strategy, policy, and legislation will be developed and overseen by the DoE.

2.3 Eskom

Eskom generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa. Eskom generates, transmits, and distributes electricity to industrial, mining, commercial, agricultural and residential customers and redistributors. Additional power stations and major power lines are being built to meet rising electricity demand in South Africa. Eskom will continue to focus on improving and strengthening its core business of electricity generation, transmission, trading and distribution.

Eskom buys electricity from and sells electricity to the countries of the Southern African Development Community (SADC). The future involvement in African markets outside South Africa (i.e., the SADC countries connected to the SA grid and the rest of Africa) is limited to those projects that have a direct impact on ensuring security of supply for South Africa.

2.3.1 Power Stations

Like most other power utilities, Eskom's Generation Division maintains a varied plant portfolio. In addition to the coal-fired plants, Eskom owns and operates four open-cycle gas turbines, two hydroelectric plants, three pumped storage, two wind farms and one nuclear power station.

All existing and planned Eskom power stations are shown in Figure 2-1.

2.3.2 Transmission

Eskom is the largest producer of electricity in South Africa; it also transmits electricity via a transmission network, which supplies electricity at high voltages to a number of key customers and distributors. Eskom is a vertically integrated utility company licensed to generate, transmit, and distribute electricity. The transmission license is held by the transmission network service provider (TNSP) of Eskom. Planning the transmission network is the responsibility of the Grid Planning Department in the Transmission Group. The TNSP is required to abide by the regulatory requirements to publish a document annually, detailing the plans for the way that the transmission network will develop in the next 5 years. This plan covers a 10-year window. Furthermore, the requirements stipulate that the published document should include the following information:

- The acquisition of servitudes for strategic purposes
- A list of planned investments, including costs
- Diagrams displaying the planned changes to the transmission system (TS)
- An indication of the impact on customers in terms of service quality and cost; and
- Any other information as specified by NERSA from time to time

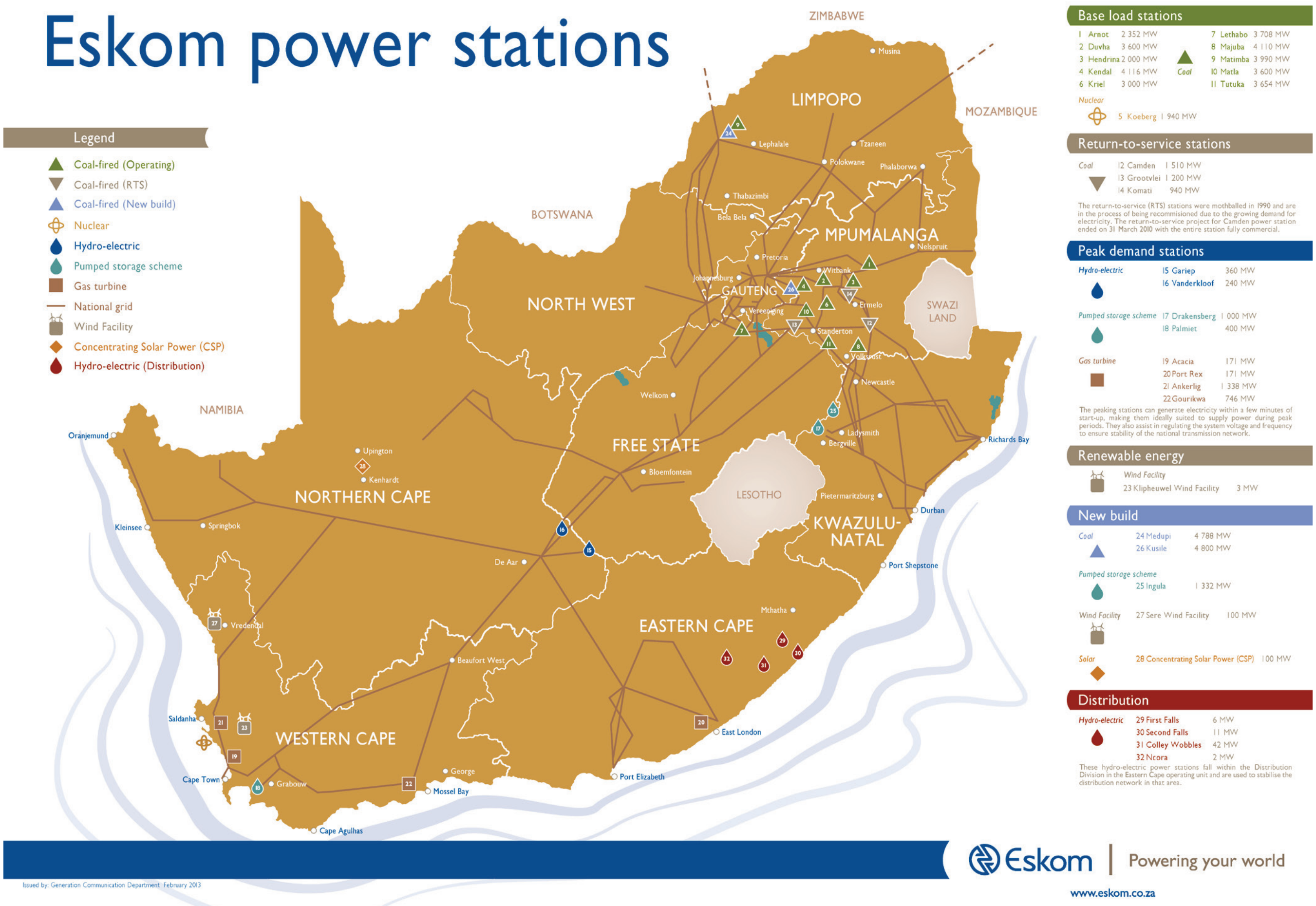


Figure 2-1: List and Location Map of All Existing and Planned Eskom Power Stations

A further requirement is that the TNSP hold public forums to share such plans with stakeholders in order to facilitate a joint planning process with them. The sixth Transmission Development Plan (TDP) was published early in October 2014; this is the seventh publication based on the TDP for 2016 to 2025.

2.3.3 Distribution

The electricity distribution industry (EDI) is a vital link between the supplier (usually Eskom) and customers that buy and use electricity. Traditionally, Eskom and some local municipalities have managed distribution. At one time, nearly 500 distributors of electricity were operating in South Africa, but through consolidation this number has been reduced to less than 300.

For nearly 20 years, Eskom has been talking to central government and the other stakeholders – mainly the NERSA and the local government sector – about further rationalizing the EDI. The proposal is to form six REDs whose sole responsibility would be to manage and drive all electricity distribution throughout the country. This would allow tariffs to be aligned, service to be improved, and the equipment to be better maintained and updated. Interruptions of service (blackouts) because of old equipment would be much reduced.

However, challenges must be overcome before progress can be made. Before they will agree to support this initiative, all stakeholders need reassurance that their assets and investments will be protected, and that the new structures will provide a clear benefit to all involved.

Because of the uncertainty hanging over the sector, many players have been reluctant to allocate resources to it, and some equipment and levels of service have been allowed to deteriorate. Coupled with a reduced amount of spare generation capacity in the country, which has affected many construction projects, electricity supply has been added to developers' lists of issues that could prove problematic.

Unreliable power supplies have caused many organizations to invest in their own backup supply equipment at considerable cost.

The South African electricity supply industry, long the envy of the developing world, must be allowed to restore its reputation and resume giving its customers excellent service.

To achieve this, there must be cooperation and support (Thekga[1]) from everyone. The rebuilding of a world-class electricity supply must become a national issue.

Until that happens, domestic customers would do well to have gas bottles and other emergency equipment prepared for use in case of unexpected interruptions.

2.3.4 TARIFFS

Eskom sells electricity to both wholesale and private customers in South Africa and also exports electricity to neighboring countries. Most of the South African wholesale customers are municipalities, which manage the local electricity distribution and resell the electricity to their customers. Figure 2-2 shows the electricity volumes per customer type. The entity responsible for the distribution is controlled geographically and a customer is not free to choose the distributor.

[1] Thekga: from Northern Sotho language meaning "support"

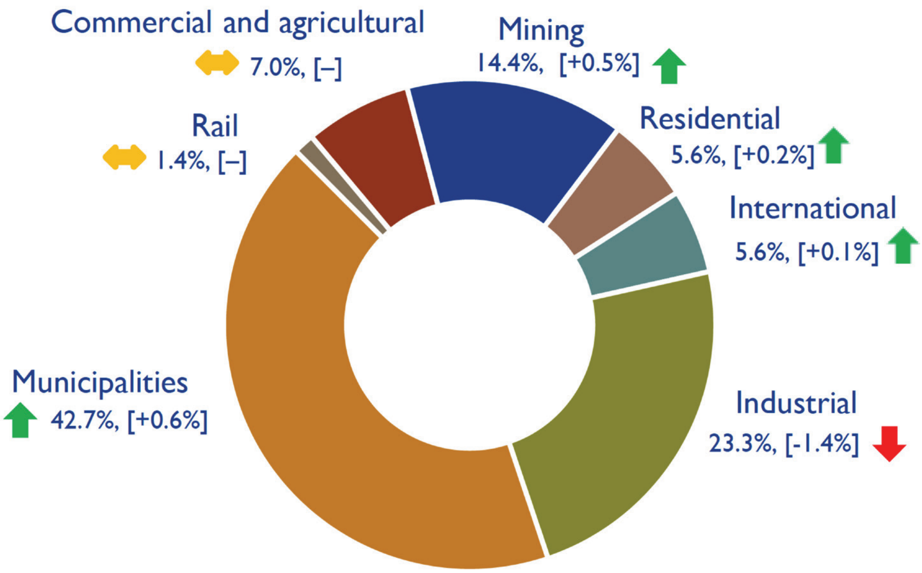


Figure 2-2: Electricity Volumes by Customer Type for Six Months ending 30 September 2015 [0316]

Eskom applies to NERSA for tariff increases. Electricity to large users is typically charged at fixed rates plus a metered capacity and active energy charges. The active energy charge is typically performed at set time of use (TOU) rates for specific times of the day, days of the week and time of the year. Smaller customers are most often only charged for active energy use at an inclining block tariff.

2.4 Council for Scientific and Industrial Research Energy Centre

The Council for Scientific and Industrial Research (CSIR) established an Energy Centre with the mandate to define and implement the CSIR's energy research agenda. It hosts all energy-related research that focuses primarily on energy, and it works closely with other CSIR researchers on energy-related research topics for which energy is not the primary focus.

The centre provides thought leadership in energy research for the country and the region, and informs business decisions, investments into new technologies, and policymaking.

Research is conducted in five dimensions:

- Demand side: Energy efficiency (more Rand of gross domestic product [GDP for the same amount of energy in the different energy end-use sectors)
- Supply side: Renewables (higher share of renewables in energy supply)
- Energy system technologies:
  - Mobility (including electric and gas-driven vehicles)
  - Power-to-gas/power-to-fuel (generation of synthetic fuels/natural gas via electrolysis and subsequent processes)

- Energy storage (including batteries, hydrogen, thermal storage)
- Energy system planning and operations (technical aspects of how renewables interact with conventional, including "smart" and island grids, system operations, energy planning)
- Energy markets and policy (efficient markets, regulations, policy, standards, norms, advise to South African industries)
- Energy industry support (industry relevance of research as second "end-user" next to policymakers)

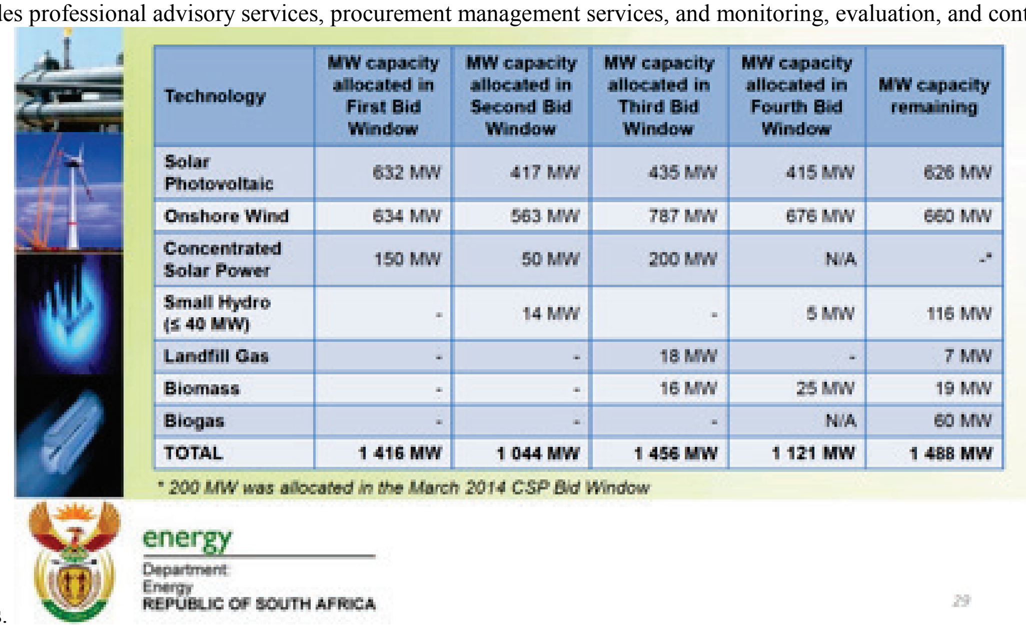
2.5 INDEPENDENT POWER PRODUCER PROCUREMENT PROGRAMME

The Independent Power Producer Procurement Programme (IPPPP) is a key vehicle for securing electricity capacity from the private sector for renewable and non-renewable energy sources as determined by the minister of energy.

The DoE, National Treasury (NT), and the Development Bank of Southern Africa (DBSA) established the IPPPP for the specific purpose of accomplishing the Independent Power Producer (IPP) procurement objectives. The activities of the IPPPP are in accordance with the capacity allocated to renewable energy and non-renewable generation in the Integrated Resource Plan (IRP) 2010, subsequent ministerial determinations and DoE support service requirements. Figure 2-3 shows MW capacity allocations through the first four bid windows and remaining capacity to be allocated in the future.

The IPPPP activities continue to evolve in order to effectively respond to the planning and development needs in the current energy context. As an example, the IPPPP Office has been requested to coordinate the development of the Gas Utilization Master Plan (GUMP) that will, in turn, guide the procurement of the required gas capacity per the IRP 2010.

The IPPPP Office provides professional advisory services, procurement management services, and monitoring, evaluation, and contract management services.



Technology	MW capacity allocated in First Bid Window	MW capacity allocated in Second Bid Window	MW capacity allocated in Third Bid Window	MW capacity allocated in Fourth Bid Window	MW capacity remaining
Solar Photovoltaic	632 MW	417 MW	435 MW	415 MW	626 MW
Onshore Wind	634 MW	563 MW	787 MW	676 MW	660 MW
Concentrated Solar Power	150 MW	50 MW	200 MW	N/A	-*
Small Hydro (≤ 40 MW)	-	14 MW	-	5 MW	116 MW
Landfill Gas	-	-	18 MW	-	7 MW
Biomass	-	-	16 MW	25 MW	19 MW
Biogas	-	-	-	N/A	60 MW
TOTAL	1 416 MW	1 044 MW	1 456 MW	1 121 MW	1 488 MW

* 200 MW was allocated in the March 2014 CSP Bid Window

Figure 2-3: IPPPP Megawatt Allocation and Remaining Unallocated Capacity

2.6 Department of Trade and Industry (South Africa)

The Department of Trade and Industry (dti) is the department of the South African government with responsibility for commercial policy and industrial policy. The dti and its subsidiary agencies are involved in promoting economic development, Black Economic Empowerment, implementing commercial law (including companies law and intellectual property law), promoting and regulating international trade, and consumer protection. The five strategic objectives of the dti are to:

1. Facilitate transformation of the economy to promote industrial development, investment, competitiveness and employment creation;
2. Build mutually beneficial regional and global relations to advance South Africa´s trade, industrial policy and economic development objectives;
3. Facilitate broad-based economic participation through targeted interventions to achieve more inclusive growth;
4. Create a fair regulatory environment that enables investment, trade and enterprise development in an equitable and socially responsible manner; and
5. Promote a professional, ethical, dynamic, competitive and customer-focused working environment that ensures effective and efficient service delivery.

2.7 Department of Science and Technology (South Africa)

The Department of Science and Technology (DST) is the South African government department responsible for scientific research, including space programmes. Much of the Department's work is ultimately carried out through various quasi-independent agencies (although still usually government bodies) including:

- the National Research Foundation of South Africa, which receives a substantial proportion of the DST budget to carry out various research support tasks, including supporting key national research infrastructure ("National Research Facilities"), scientific research grant administration and a student grant scheme;
- the Council for Scientific and Industrial Research, which acts as a quasi-privatised research and development agency with a specific focus on research of application to industry;
- the Technology Innovation Agency, which serves to provide funding to turn innovative research into commercial products;
- the South African National Space Agency, which covers space-related research and development initiatives;
- the Human Sciences Research Council (South Africa), which focuses its research on human health and disease.

2.8 National Treasury

The Ministry of Finance is at the heart of South Africa 's economic and fiscal policy development. The Minister of Finance and Deputy Minister of Finance are responsible for a range of state entities that aim to advance economic growth and development, and to strengthen South Africa 's democracy.

The National Treasury is responsible for coordinating macroeconomic policy and promoting the national fiscal policy framework. Its role is defined by the Constitution of the Republic of South Africa and in the Public Finance Management Act. The National Treasury coordinates intergovernmental financial relations, manages the budget preparation process and exercises control over the implementation of the annual national budget, including any adjustments budgets. The National Treasury also performs functions assigned to it in other legislation.

2.9 Local Distribution Entities

In addition to transmission, Eskom provides distribution to approximately 60% of South Africa's electricity users, especially the larger consumers. The remaining 40% is distributed by many electricity distributors that operate in South Africa, ranging from large metros to small municipalities. In terms of the South African constitution, municipalities have the "executive authority and right to administer" "electricity reticulation" in their area of jurisdiction subject to legislation and regulation by national and provincial government. There are six large distributors (Eskom and five metropolitan governments), about 11 of medium size and about 170 small distributors as shown in Figure 2-4. This situation is a key contributing factor to poor performance. There are significant economies of scale in the distribution of electricity and it is generally accepted internationally that, other factors being equal, larger distributors are better able to provide the service more reliably, effectively and at a lower cost compared to smaller distributors [0413].

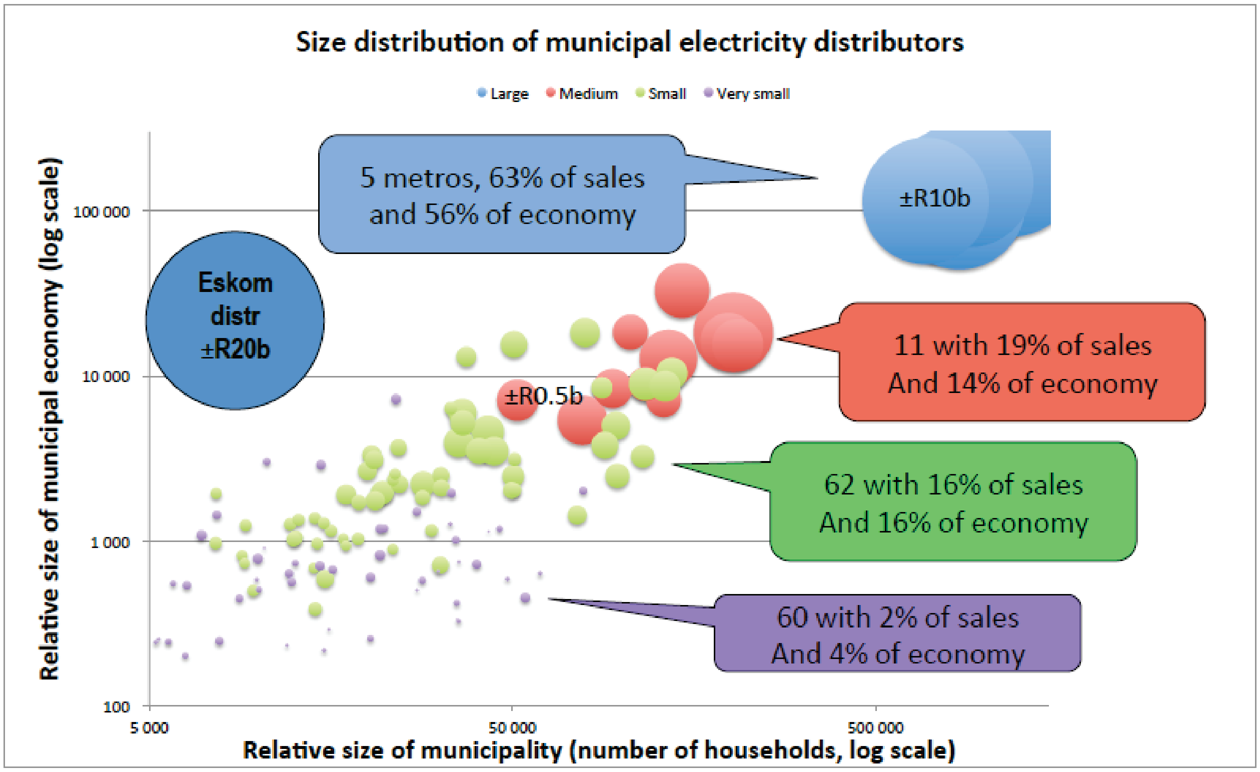


Figure 2-4: Distribution of Electrical Municipal Distributors

2.10 South African Industry Organizations

2.10.1 Association of Municipal Electricity Utilities

The Association of Municipal Electricity Utilities (AMEU) is an association of municipal electricity distributors as well as national, commercial, academic and other organisations that have a direct interest in the electricity supply industry in South Africa

The AMEU promotes quality of service and management excellence amongst its members in the field of electricity supply, and facilitates communication between its members and between members and the technical, economic and political environment, in order to influence that environment. In the interest of electricity distributors and all categories of end users in the electricity supply industry in South Africa it also provides an advisory service to its members and the customers of its members.

2.10.2 South African Local Government Association

The South African Local Government Association (SALGA) is an autonomous association of municipalities with its mandate derived from the Constitution of the Republic of South Africa. This mandate defines SALGA as the voice and sole representative of local government. SALGA interfaces with parliament, the National Council of Provinces (NCOP), cabinet as well as provincial legislatures.

The association is a unitary body with a membership of 257 municipalities, with its national office based in Pretoria and offices in all nine provinces. Our strength at SALGA lies in the intellectual capital we have acquired through our people over the years and our values to be Responsive, Innovative, Dynamic and Excellent underpin all that we do. Our mission to be consultative, informed, mandated, credible and accountable ensures that we remain relevant to our members and provide value as we continuously strive to be an association that is at the cutting edge of quality and sustainable services.

SALGA's role can be summarized into four key roles: policy analysis, research and monitoring, knowledge exchange, and support to members. More specifically:

- Represent, promote and protect the interests of local government
- Transform local government to enable it to fulfill its developmental role
- Raise the profile of local government
- Ensure full participation of women in local government
- Perform its role as an employer body
- Develop capacity within municipalities

2.10.3 South African Wind Energy Association

The South African Wind Energy Association (SAWEA) was established in 1998 and was operated on a voluntary basis until mid-2010.

The mission of SAWEA is to remove obstacles to the implementation of sustainable wind energy activities in South Africa, e.g.:

- Develop a cogent and sustainable South African energy policy that fully facilitates the development of the country's wind power potential.
- Promote the harnessing of wind energy in large- and small-scale applications.
- Promote excellence in wind energy and related areas of business.
- Provide information to government, media, and the public on behalf of the industry.
- Provide pertinent information to members.

2.10.4 South African Photovoltaic Industry Association

The South African Photovoltaic Industry Association (SAPVIA) is a not-for-profit body that consists of active players in South Africa's PV market who have a genuine, invested presence in the country.

The association is devoted to promoting the growth of the country's solar PV electricity market and aims to contribute to the country's renewable energy (RE) roll-out.

2.10.5 South African Renewable Energy Council

The South African Renewable Energy Council (SAREC) was formed by four industry associations in South Africa, namely SAWEA, SAPVIA, SATELA (Southern Africa Solar Thermal and Electricity Association) and SESSA (Sustainable Energy Society of South Africa). The main objectives of SAREC are to promote the renewable energy sector in South Africa by acting as an umbrella body to the industry associations representing specific renewable energy technologies, such as wind, solar, and biogas, and to act as a collective custodian and voice for the RE industry in South Africa.

Other objectives include the following:

- Collectively remove barriers to entry for renewable energy.
- Provide expert resources that government can draw on in the formulation and execution of energy policy.
- Promote public and private sector coordination toward the cost optimization of renewable energy generation and the localization of the renewable energy industry.
- Engage with other South African organizations active in the broader fields of climate change mitigation/adaptation and sustainable development, including the private sector and civil society, in order to facilitate common goals and interests.
- Liaise with local and international media regarding renewable energy in South Africa.
- Promote excellence in renewable energy and related areas of business and to provide information to government, media and the public on behalf of the industry.

2.10.6 South African Independent Power Producers Association

The South African Independent Power Producers Association (SAIPPA) seeks to promote the collective interests of IPPs in South Africa, assist with public policy formation and implementation, and serve as a platform for information dissemination to its members. To this effect, SAIPPA:

- Represents its members in various platforms including political institutions at Provincial, National and municipal levels
- Informs its members on the latest policy, legislative, and regulatory developments
- Lobbies key decision-makers on appropriate policies to develop a sustainable independent power production market
- Mobilizes the independent power production sector via working groups, seminars and workshops to define clear positions on political, technical and economic issues
- Promotes all power technologies irrespective of type
- Supports peer organizations in achieving common objectives; SAIPPA is part of the IPP Platform, which is a collective of 12 IPP formations

2.10.7 South African National Energy Development Institute

The South African National Energy Development Institute (SANEDI) is a Schedule 3A state-owned entity that was established as a successor to the previously created SANERI and the National Energy Efficiency Agency (NEEA). The main function of SANEDI is to direct, monitor, and conduct applied energy R&D, demonstration, and deployment, as well as to undertake specific measures to promote the uptake of green energy and energy efficiency in South Africa.

SANEDI's current portfolios include advanced fossil fuels, clean energy solutions, energy efficiency, Green Transport programme, smart grids energy data and knowledge management, and the Working for Energy Programme.

2.10.8 Energy Intensive Users group

The Energy Intensive User Group (EIUG) of Southern Africa represents the bulk of technical expertise relating to energy issues in the country. It is a respected and nonpartisan organisation dedicated to the effective and efficient transformation of the energy industry.

The EIUG plays several crucial roles in supporting South Africa to achieve a sustainable and affordable energy industry. The group provides a forum for internal advocacy (providing support to members on technical and policy issues). This ensures that members are educated on issues of concern; are provided with opportunities to discuss solutions to these issues; and gain a better understanding of possible regulatory changes and the impact this would have on their organisations. In an external advocacy role, the EIUG assists key stakeholders (including local and national government, NERSA, and other associations and political bodies) by clarifying issues and also by lending its support and expertise.

Through the collective expertise of its membership, the EIUG is able to offer technical leadership to both members and external stakeholders. This internal and external approach provides members and stakeholders alike with the necessary insight required to ensure a quantitative decision making platform is available.

Furthermore, the group acts as the industry monitor, providing insights and information on the likely changes to the industry, as well as clarity on the impacts of these changes across industry to members and key stakeholders.

2.11 South African Universities and Research Organizations

South Africa has 26 public universities that are divided into three broad groups: research universities, comprehensive universities, and universities of technology (Table 2-1). All six research universities, as well as two comprehensive universities, have engineering faculties offering degrees leading to registration as professional engineers. The six universities of technology offer engineering diploma programmes and a 3-year bachelor's degree in technology.

All engineering faculties have electrical engineering departments that engage in research in power and energy storage systems. In addition, the University of Western Cape has a research activity in hydrogen and lithium-ion batteries. Stellenbosch University has a strong focus on renewable energy facilitated by the Centre for Renewable and Sustainable Energy Studies.

Table 2-1: South African Universities and Research Organizations

Research Universities	Comprehensive Universities with Engineering	Universities of Technology
University of Pretoria University of the Witwatersrand North West University University of KwaZulu/Natal University Stellenbosch University of Cape Town	Nelson Mandela Metropolitan University University of Johannesburg Walter Sisulu University (Only diploma programme)	Cape Peninsula University of Technology Central University of Technology Vaal University of Technology Tshwane University of Technology Durban University of Technology Mangosuthu University of Technology

2.12 South African Financiers

2.12.1 African Development Bank

The African Development Bank Group (AfDB) is a multilateral development finance institution established to contribute to the economic development and social progress of African countries. The AfDB was founded in 1964 and comprises three entities: The African Development Bank, the African Development Fund, and the Nigeria Trust Fund. The AfDB's mission is to fight poverty and improve living conditions on the continent through promoting the investment of public and private capital in projects and programs that are likely to contribute to the economic and social development of the region. The AfDB is a financial provider to African governments and private companies investing in the regional member countries (RMC). AfDB was originally headquartered in Abidjan, Côte d'Ivoire; however, the bank's headquarters moved to Tunis, Tunisia in 2003, due to the Ivorian civil war and returned to Abidjan in September 2014.

The AfDB's strategy for 2013–2022 reflects the aspirations of the entire African continent. It is firmly rooted in a deep understanding and experience of how far Africa has come in the last decade, and where it wishes to go to in the next.

Africa has embarked on a process of economic transformation. This process has seen solid and sustained growth over a decade, but it has been uneven and without a sufficiently firm foundation, and it is not—by any estimation—complete.

This strategy is designed to place the Bank at the center of Africa's transformation and to improve the quality of Africa's growth. It aims to broaden and deepen that process of transformation, mainly by ensuring that growth is shared and not isolated, for all African citizens and countries, not just for some. It also aims to bring about growth that is not just environmentally sustainable, but also economically empowering. When growth is inclusive as well as "green," it creates the jobs that the continent needs now and that it will need in ever greater numbers as millions of young people enter the job market, with energies and aspirations to match.

The Bank's vision is thus Africa's vision, and its future is Africa's future. The Bank's many successes reflect the successes of the continent it serves; the gaps in its achievements reflect the impediments to true transformation across its regional member countries. The goal of a regionally integrated and economically diverse Africa—determined to include young and old, women and men, rural and urban communities alike, while being increasingly green—will establish Africa as the next global emerging market. The AfDB will be its development voice and its development partner of choice.

The strategy is built around two objectives, supported by five operational priorities in which the AfDB has unmatched advantage, expertise, access and trust.

2.12.2 Development Bank of Southern Africa

The Development Bank of Southern Africa (DBSA) is a development finance institution wholly owned by the government of South Africa that seeks to "accelerate sustainable socioeconomic development and improve the quality of life of the people of the Southern African Development Community (SADC) by driving financial and nonfinancial investments in the social and economic infrastructure sectors." The bank was established in 1983 to perform a broad economic development function within the homeland constitutional dispensation that prevailed at the time. The DBSA has prioritised water, energy, transport and information and communication technology (ICT) as its key focus areas.

2.12.3 Industrial Development Corporation

The Industrial Development Corporation (IDC) is a self-financing, national development finance institution established in 1940 to promote economic growth and industrial development in South Africa. The IDC recognizes the importance of a dynamic private sector in securing and stimulating rapid and sustainable economic growth, creating employment and reducing poverty. The IDC serves as a catalyst for balanced, sustainable development and identifies and supports opportunities that are not addressed by the market. The cooperation also provides risk capital in partnership with private sector financial institutions.

As one of the IDC's initiatives, the Agency Development and Support (ADS) Department is tasked with advancing and leveraging the development and job creation potential inherent in various geographic areas, particularly those falling outside the industrialised centres, via the establishment of development agencies. These focus on the following:

- Developing the economic potential on a local or regional basis by building on the unique competitive strengths of each region's economy and assets
- Leveraging public and private resources for development opportunities
- Fostering innovative thinking and entrepreneurial activity which support and drive economic growth
- Managing the spatial organization of the area in a socially efficient manner, through the use of public land and targeted private projects in particular

To date, the IDC has supported the establishment of 30 development agencies throughout South Africa, including Blue Crane Development Agency, Hibiscus Coast Development Agency, and Mandela Bay Development Agency.

2.12.4 Commercial Banks

The commercial banking sector in South Africa is highly concentrated within the four major banks:

- Barclays Africa Group
- FirstRand
- Nedbank
- Standard Bank

3 Recommended Actions

This section provides recommendations for concrete actions to be taken by key stakeholders to support the adoption of energy storage technologies in South Africa. It should be understood that some of these activities may only be performed once; however, the majority should be continuing processes. This Roadmap merely identifies the first iteration of what would be an ongoing activity. The recommendations are organized into six high-level topics as listed below and shown in Figure 3-1.

- Understanding global, regional, and SA energy storage market opportunities
- Determine where South Africa is best positioned to participate in the ES market
- Level the playing field so that ES can reasonably compete with alternatives
- Introduce transformative policy that encourage prioritized storage development in South Africa
- Support demonstration projects to gain experience in effective application of ES
- Invest in infrastructure to rapidly and effectively assimilate ES facilities

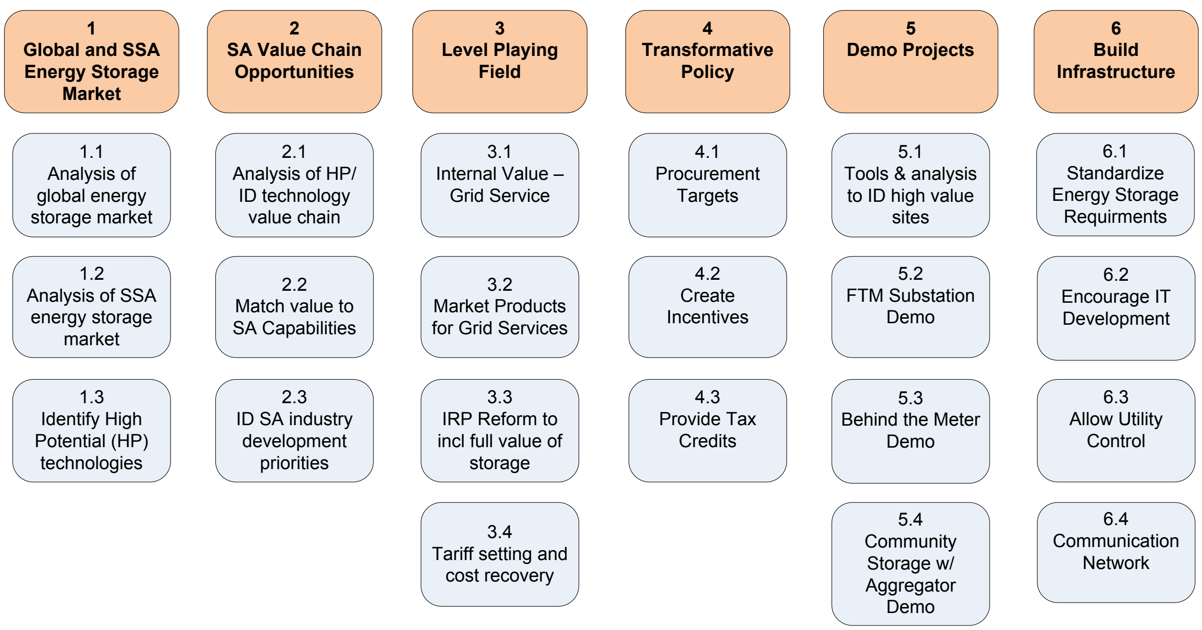


Figure 3-1: Recommended Roadmap Activities

3.1 Global and Sub-Saharan Africa Energy Storage Market

Adopting energy storage into the SA electrical grid may increase the quality and availability of electricity and may also enhance production cost efficiencies; however, just as important to development of the SA economy will be the development of an energy storage industry within South Africa. This will allow SA companies to grow organically and through teaming arrangements with more established companies to provide energy storage equipment and services both within South Africa, Sub-Saharan Africa (SSA), and globally. To maximize industrial development and growth of the SA energy storage industry, it is important to identify where South Africa can most effectively participate in the global and SSA energy storage value chains.

3.1.1 Analysis of Global Energy Storage Market

The global energy storage market will expand significantly over the next 10 to 20 years. Energy storage can help electrical grids and utilities operate more efficiently, run more reliably, and rely less fossil fuels that promote greenhouse gases (GHGs) and contribute to global warming. The global expansion in energy storage market offers South Africa a significant opportunity to expand its economic base through the development of an energy storage industry. The production of high-performance and cost-efficient energy storage equipment and services will allow South Africa to develop its energy storage capabilities across all portions of the market (utility scale, industrial, commercial, and residential). South Africa must understand the global market and must identify areas where it can effectively compete as a preferred provider of a technology, systems, or components through its own internal capabilities. Effective market entry may be supported in the short term by additional transformative policy to develop in-country storage experience, both in manufacturing and in effective use of the devices for grid services.

Developing the strategy for development of the in-country storage industry (Sections 3.2.2 and 3.2.3) will require studies of the global opportunities for development of energy storage industries. . This should include an evaluation of global markets, regional needs, and use case applications that will have the highest demand.

This study can be started immediately and can rely on other industry reports. This study should be completed within 6 months and should provide a ranking of geographical areas or countries with the highest potential for expansion and the types of energy storage applications most likely in demand in these areas. This study should include an analysis of the state of the energy storage industry in each of these areas..

This study could be led by the IDC and supported by dti, DST, SANEDI and organizations with significant knowledge and expertise in energy storage. In addition, support could be captured through consultants with experience in these types of studies. It could also be coordinated or conducted in cooperation with activities being performed by other countries or international organizations.

3.1.2 Analysis of Sub-Saharan Africa Energy Storage Market

Because of its locality, SSA energy storage market will be particularly important to South Africa. Energy storage will significantly accelerate the electrification of Africa. South Africa is well positioned to develop export trade with other African countries; however, the challenges faced by SSA may differ significantly from those in South Africa, and this market should be clearly understood. The SSA markets with less electrical penetration specifically may approach electrical expansion differently and may favour microgrid application over the more expensive development of regional transmission and distribution systems. This could significantly affect the ways that energy storage is applied and the technologies which are favoured.

It is recommended that a study be performed to evaluate the energy storage market potential in significant SSA countries. It is suggested that this study group the SSA countries by similarities in their electrical grids, electrification rates, and political environment. It would evaluate dominant use cases across country types, assess energy storage needs, assess market growth, segmentation and size for each use case and country type. Such a study would be used to prioritize market opportunities and develop an understanding of what technologies and type of energy storage systems would provide the best opportunities for development.

This study could also be commissioned immediately and could be conducted in parallel with the global study suggested in Section 3.1.1 within a 6-month period. This study would lend itself to building relationships on a government and utility level. This effort could be led by IDC and supported by DST, dti, SANEDI, a SA university or outside consultant with experience and knowledge of SSA electrical systems.

3.1.3 Identify High Potential Technologies

Based on an understanding of the global and SSA energy storage value chains, the next step would be to determine the highest potential in terms of energy storage technologies, services, and products. In addition, it is important to understand where the greatest competition will be and other hurdles that could impede industrial growth and development. A study in this area would evaluate which technologies have the highest potential.. This effort would examine the value chain for the production of energy storage equipment and services within each of the most promising technologies.

As discussed in Objective 2, Task 2.2 Technology Assessment, this study should closely evaluate those technologies which are most likely to be mature and competitive over the next 5 to 15 years — the time in which the energy storage industry is expected to expand significantly. These technologies would include lithium ion, compressed air and liquid air energy storage, and flow batteries (including vanadium and zinc-bromide) chemistries. This study could be completed in 4 to 6 months.

This effort would follow activities outlined in Sections 3.1.1 and 3.1.2 and could be led by DST, and supported by CSIR, a SA university, or a technical consultant with experience and knowledge of energy storage technologies.

3.2 Value Chain Opportunities for South Africa

It is important that SA industries be able to participate in the adoption of energy storage globally, in SSA, and on the SA grid. In particular, SA companies should be positioned to participate in technology development and manufacturing, rather than just in the balance of plant and construction labour, as is generally experienced currently with RE under the IPPPP.

3.2.1 Analysis of Identified High Potential Technology Value Chain

This activity identifies areas of high potential for the SA industry to participate in the energy storage value chain by examining the supply chains necessary for each high-potential energy storage technology developed in Section 3.1.3.

An evaluation of the manufacturing methodologies, materials, and processes being employed by major technology providers is needed to ascertain which technologies and which technology providers have a higher potential and /or willingness for localisation of parts/assemblies or for the entire value chain. Another portion of the study would involve an estimation of the relative cost components for each element of the energy storage system (ESS) life cycle value chain depicted in Figure 3-2, which shows generic activities for a battery or flow battery across the three basic sectors of activity: extraction of raw materials (primary), manufacturing (secondary), and services (tertiary). Balance of systems and monitoring and control can also be subdivided into extraction and manufacturing sub activities, but these are less important than the sub activities associated with the main storage technology.

- Lithium ion
  - Raw Materials
  - Manufacturing
  - Construction
  - Operations and Maintenance
  - Decommissioning and Recycling
- Compressed Air and Liquid Air Energy Storage
  - Raw Materials
  - Manufacturing
  - Construction
  - Operations and Maintenance
  - Decommissioning and Recycling
- Flow Batteries: Vanadium
  - Raw Materials
  - Manufacturing
  - Construction
  - Operations and Maintenance
  - Decommissioning and Recycling
- Flow Batteries: Zinc-Bromide
  - Raw Materials
  - Manufacturing
  - Construction
  - Operations and Maintenance
  - Decommissioning and Recycling

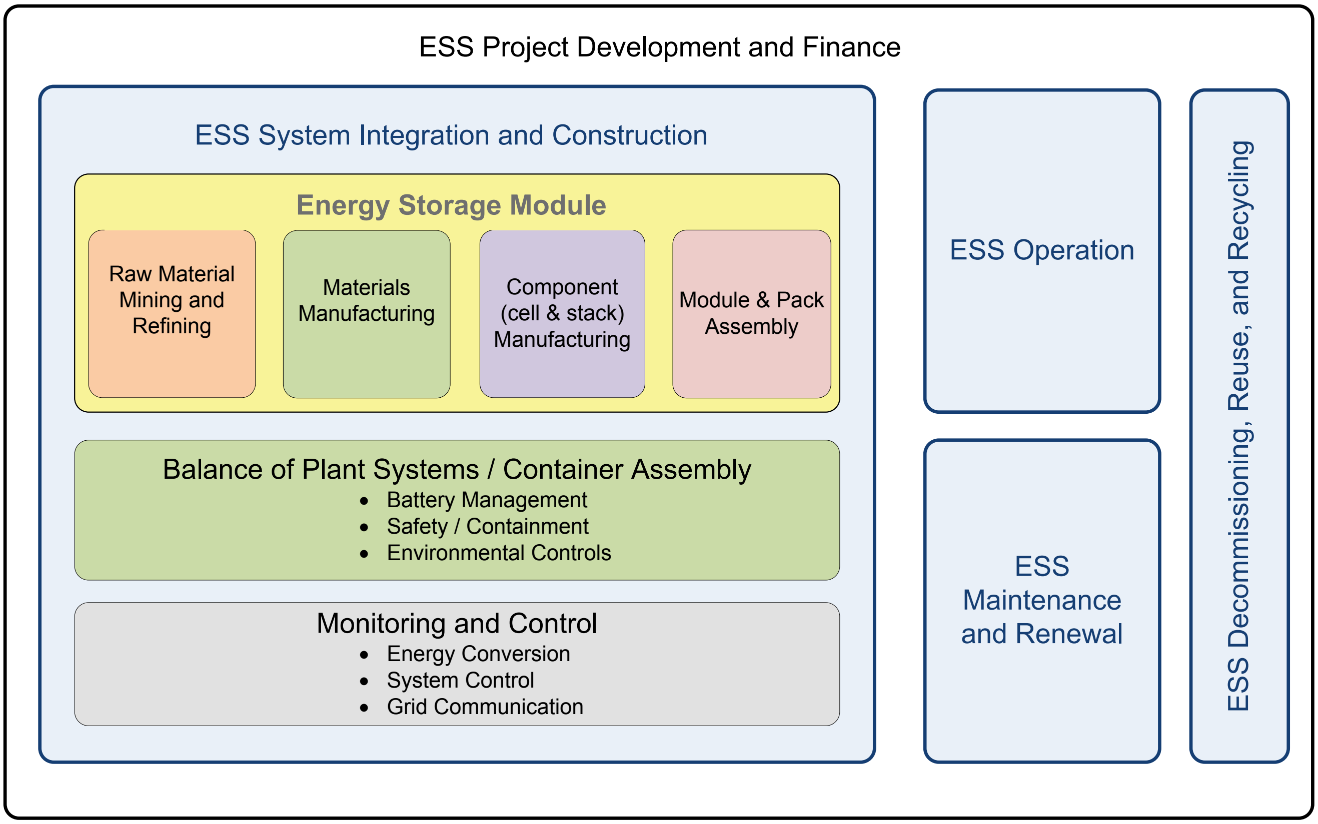


Figure 3-2: Life Cycle Value Chain for a Generic Energy Storage System

This activity would follow the activities outlined in Sections 3.1.1 and 3.1.2 and will require some additional manufacturing and cost estimating expertise in other to develop an understanding of the relative orders of magnitude. A number of similar studies have been performed and are available on the cost components of various technologies. This effort would involve collecting and normalizing this data for the technologies of interest in South Africa. This effort would take 4 to 6 months to complete and could be led by DST and could be supported by DoE, dti, IDC, SANEDI, or a technical consultant with experience and knowledge of energy storage technologies.

3.2.2 Match Value to South African Capabilities

This activity identifies areas in which the SA industry (based on current capabilities, expertise, or natural resources) has the strongest potential and is best able to participate competitively in the energy storage industry. South Africa has a number of manufacturers of electrical equipment that could benefit from a growth in the storage market. By using existing legislation and regulations, local manufacturers of products and systems could be encouraged or mandated. This would allow presence of SA project content alongside imported energy storage technologies that may not be available in South Africa.

This activity would build on the results of Section 3.2.1 and requires an analysis of each component of the technology supply chain for each promising energy storage technology. This requires an evaluation of which components of each supply chain could effectively be performed by SA companies and/or resources either due to regional expertise, or capabilities/labour mix, or through the beneficiation of available natural resources. Sequential activities in a single supply chain that could be adopted in South Africa, would further leverage the benefit available to the SA industry.

Specific attention should be given to the evaluation of global technology providers who have developed specific technologies and hold intellectual property on that technology or manufacturing processes that are appropriate to implement in South Africa. This study should seek to identify companies that would be willing to receive additional support in their value chain and that would be prepared to invest or support the development of these activities by SA companies or entities.

It is suggested that many companies have mature technologies that have been developed over a period of many years. It would be difficult for these same technologies to be developed organically within South Africa in the near term. However, these companies may be willing to develop manufacturing or assembly activities and facilities in South Africa to support deployment of storage technologies in SA or in SSA countries.

This activity would generally follow the identification of high-potential technology value chain elements (Section 3.2.1). It could be led by the IDC and supported by a DST, dti, a SA university, or technical consultant with experience and knowledge of energy storage technologies and SA industrial capabilities and resources. This activity could likely be further supported by other SA trade agencies (SAWEA, SAPVIA, etc.) and could be completed in 4 to 6 months.

3.2.3 Identify South African Industry Development Priorities

Once the energy storage value chain is understood and high potential opportunities have been matched to SA strengths, an effort should be made to prioritize where SA industry should be stimulated or incentivized. The result of this analysis can be used to inform activities for transformative policy.

The SA government entities should identify high potential activities related to energy storage value chains where there South Africa could play a significant role and then to determine what programs or policies could be put into place to encourage the development of these capabilities. This would include the development of skills generation in line and adoption of manufacturing development programmes through universities or technical training programmes.

At a facility level this support could be expanded to include financing of manufacturing or assembly facilities or tax breaks for the development of these facilities in areas that would most benefit industrial growth. These could be optimized to attempt to encourage the siting of facilities in places or in ways that could further support the developmental plans for the SA electrical grid.

This activity would follow the identification of high potential technology value chain elements (section 3.2.1). It could be led by the dti and could be supported by DST, DoE, a SA university or technical consultant with experience and knowledge of energy storage technologies and SA industrial capabilities and resources. It might take 6 months to developed proposals and then up to 1 year to implement the proposed changes.

3.3 Level the Playing Field

There is an apparent bias in planning for development of the South African electrical grid for solutions based on large generation or addition of transmission and distribution infrastructure. "Levelling the playing field" would include reforms (adjustments and changes) in existing planning processes and system regulatory structures to allow fair compensation for all services and benefits that energy storage can provide so that it can be evaluated appropriately against other solutions.

3.3.1 Internal Value – Grid Service

The value proposition for storage relies on stacking benefits from offering multiple grid services. Some of those benefits are not explicitly valued by Eskom for third-party providers to offer. These include ancillary service products that Eskom identifies as required for grid reliability. By not defining a value for ancillary services, Eskom cannot evaluate different resources against one another when procuring for grid needs. Third parties cannot receive benefits for offering them, thus missing out on a potentially lucrative income for storage, or at least having significant uncertainty about the value they will receive for their services. Uncertainty in value can dampen market interest.

By explicitly valuing grid services internally at Eskom, storage can be used more effectively and third party providers can be paid for more of storage's potential offering without changes in current market design. Ancillary services will become a more important component of system reliability as more renewable generation is integrated. Internally pricing grid services at Eskom can lead to a lower cost system over time and give storage, as well as other unconventional resources such as demand response, a fair chance of competing against more traditional resource options.

Grid services can be valued at their avoided costs, i.e., what is the cost to the existing system of offering the services that storage would displace? This methodology of valuation can be applied to all grid services. For example, the value of storage capacity is the avoided building of new generation to meet load in the future. Grid service valuation can be done in several ways. Grid services can be valued on a marginal or long term basis, unbundled into individual services or rolled together as a bundled avoided cost of storage, applied on different time scales from hourly to annually, and determined based on a reference avoidable generator type (e.g., new coal) or on detailed systems operations analysis. The latter would be done through observing total cost reductions through detailed production simulation modelling with storage in and out of the case. Determining how best to implement valuation will be a choice for Eskom and the appropriate stakeholders.

This activity could start immediately and would be led by Eskom, with support from DoE, IPP Office, Eskom, Munics, and other appropriate stakeholders. It is estimated that this could be completed in 6 months.

3.3.2 Market Products for Grid Service

The above internal evaluation of grid services facilitates compensation for storage through bilateral contracts with Eskom. This may be effective for large-scale storage applications connected to the transmission system. However, many of the storage opportunities, and perhaps the highest value ones, are on the distribution system, and are smaller in scale. For Eskom, many small-scale systems not directly connected to the Eskom grid could become cumbersome from a contracting and controls perspective. Instead, market products for grid services that provide a price signal for distributed storage systems to respond to could be an effective control option.

If, for example, a municipality currently procures energy, capacity, and ancillary services from Eskom through market products instead of the current tariff, a storage device connected to the municipality's distribution system could offset those payments, avoiding the actual cost to the municipality and to Eskom of offering those services. In addition, that storage device could realize the benefits of deferring infrastructure investment for the municipality. The municipality could control the storage system directly, however if price signals are passed through to the storage device and income is based on arbitrage of the available price streams, it is not necessary for the municipality to control the system. Aggregators or third-party storage owners can interact directly with the market by bidding their services. The response of storage is then autonomous, but profit maximizing behaviour of the storage devices will be to respond optimally to the price signals available.

Market products can act as signals for behaviour that result in least cost system operations, not just from storage, but other distribution such as local gas turbine generation and even behind-the-meter resources such as flexible customer heating and cooling loads.

This activity could be conducted in parallel with the valuation of grid services, but it will likely take considerably longer to implement given the changes to tariffs and regulatory structures required. Implementation of markets for grid services will require a shift in the fundamentals of wholesale power sales in South Africa. Storage alone is likely not enough motivation to drive such a change, particularly if bilateral contracts with IPP storage and Eskom owned storage can operate effectively on the distribution grid. However, in the long term, wholesale market products for grid services may be an effective way of lowering electricity costs by allowing participation of potentially lower cost distribution level resources in serving South Africa's loads. It would be led by the DoE and Eskom with support from IPP Office, Munics, Eskom, and dti.

3.3.3 IRP Reform to Include Full Value of Storage

The Integrated Resource Plan (IRP) represents the National Electricity Plan for South Africa and is a subset of the country's Integrated Energy Plan. The IRP is intended to provide long-term electricity planning to ensure sustainable development. During its initial release in March 2011, it was indicated that the IRP should be a "living plan" and that it would be revised every 2 years (i.e., an update was required in 2013).

This activity would update the IRP to reflect the full value of storage by evaluating the resources required to meet ancillary service needs in the future at least cost. Valuation of ancillary services extends beyond storage to change the value proposition in the IRP of all potential resources. As renewable penetrations increase, this component of resource planning will increase in importance.

In addition to incorporating ancillary services, the benefits that storage can offer in deferring infrastructure investments on the distribution system could be incorporated into the IRP. Storage resources that are not justified on system benefits alone, but are cost effective when stacking local deferral benefits, may be part of a least cost resource portfolio to meet grid needs in the future. This is difficult to include in a system planning exercise, yet it is important when incorporating storage in an IRP — the highest value storage sites are likely to be where infrastructure investments can be deferred.

This activity would build off the results of grid service valuation and storage product development (Sections 3.3.1 and 3.3.2). This activity would be led by DoE in parallel with the normal IRP development process and would include support and input from CSIR, Eskom, IPP Office, and the same players and partners that currently participate in IRP development. Results of the this effort should be used to inform and update Eskom's Transmission Ten-Year Development Plan. Based on the political volatility of the process, this effort could take a year or longer.

There is additional learning that can be gained from Energy Master Plans being developed and used currently by cities and states in Europe and the US. These plans span the entire states and continents, and extend beyond the power sector; having significant implications with regard to sector coupling.

3.3.4 Tariff Setting and Cost Recovery

If energy storage is the least cost solution to offering reliable electricity service to customers, Municipalities should not be discouraged from investing in storage due to a lack of clarity concerning cost recovery entitlements. Municipalities are allowed to recover the cost of investments in distribution infrastructure through their customer tariffs. These rules should be explicitly extended to investments in storage if municipality storage ownership models are shown to be cost effective to the system.

This study would evaluate the current tariffs and cost recovery mechanisms and develop recommendations for how these processes and policies could be revised to allow municipalities to include energy storage in their efficient development of distribution services. This activity could be led by NERSA with support from DoE, Munics, and SA trade organizations. This activity could be completed in 4 to 6 months, but it could take substantially longer to implement its recommendations.

3.4 Transformational Policy

The adoption of energy storage in South Africa may have benefits and value beyond the economic case. These benefits might be in the development of education and training as well as experience in various industries associated with energy storage (manufacturing, installation, operation). In this case, South Africa may want to develop policy in the form of incentives for procurement targets to build this experience base prior to when energy storage becomes independently cost effective. These activities would be analogous to programs adopted in other countries to promote/incentivize energy storage adoption. The education and experience gained may result in better storage value over time as installers gain in efficiency, control systems, and programs to offer storage services evolve to offer the grid higher value, and local storage manufacturing, if part of the transformational program, gains economies of scale.

These policies can be implemented at various levels in the SA context, from the national, by the DoE or NERSA, utility, e.g. grid codes developed to Eskom, to the local level by municipalities and metros. In the past, policies and regulations have proven to be very effective to promote green technologies, e.g., RE feed-in tariffs in Europe, RE obligations in the United States, or building regulations. It may therefore be possible that, by developing appropriate policies and regulations, a market for storage technologies may be developed in South Africa.

It should, however, be acknowledged that in the SA context it is very difficult to add any unnecessary cost to energy charges because of the large number of low-income customers that cannot afford to support above market transformational programs. Any additional cost would have to be offset against gains in other sectors of the economy.

A macroeconomic study will be required to investigate the feasibility of any policy or regulatory measures and the probable impact thereof. This is a task that must be undertaken by the DoE as the primary government department responsible for energy policy in the country. Before such a study can commence, a list of possible measures must be defined and tested. The output of Objective 5 of this study could be used as the input to such a discussion.

3.4.1 Procurement Targets

Procurement targets are an effective method of developing an above market installation base. In California, this has been the primary means for both renewable energy and storage procurement. The Renewable Portfolio Standard (RPS) approach is the most widely used, mandating utilities to procure a fraction of their energy sales from renewable resource or incur stiff penalties. RPS policy, combined with the other transformational policies, has been effective in driving the prices for renewable down over time and establishing many manufacturing, installation, service, and operation companies to support the renewable industry. Likewise for storage, procurement targets, such as the 1,325 MW by 2020 goal in California, support the industry and allow for development of the skills necessary for efficient deployment of storage in the future.

Target levels would be developed based on input from the identification of SA industry development priorities (Section 3.2.3) and tools and analysis to identify high value sites (Section 3.5.1) that will help to set reasonable, achievable goals that balance the desire to develop SA energy storage technology and learn effective implementation of energy storage without overburdening the utilities and municipalities.

The development of procurement targets and dates for implementation directed by NERSA would provide specific goals for each significant organization tasked. Given the concurrent implementation of other activities identified by this Roadmap, it is hoped that these procurements can be implemented in a cost efficient "below market" manner — in which case the targets serve only to place organizations on initial notice of intent and might be easily exceeded over the implementation period.

This effort would have to be led by the DoE and supported by Eskom, Munics, IPP Office, dti, SANEDI, and the National Treasury. Goals should be reasonable low so as not to place an significantly adverse financial or resource burden on the tasked organizations. This effort could be completed and implemented in 6 months.

3.4.2 Create Incentives

Many types of incentive programs are available for distributed energy resources. Examples of common incentive programs, include feed-in-tariffs (FITs) that were used most notably in Germany to develop the solar market, net energy metering (NEM), used in various jurisdictions, including several US states and in India to develop rooftop solar markets, rebates on a kilowatt installed basis that offset capital costs such as the California Self-Generation Incentive Program (SGIP), and payments for the right to use a service as typically used for demand response. Each incentive type can be effective when applied to tightly controlled transformational policy, although not all are appropriate for storage. Potential storage incentive options are described below:

- **Storage Capital Cost Subsidy.** This refers to subsidies that cover a part of the capital costs such that investment in storage by a developer or customer becomes cost effective. If the payment is higher than the benefits that the storage device offers the grid, the difference between the payment and the benefit is the incentive. This is perhaps the most easily implementable incentive for storage because it does not compensate for performance, although it could be tied to a technology meeting particular performance conditions or program participation. However, because it does not pay for performance, it does not ensure that storage is used effectively for grid benefits. To ensure that storage is used effectively, additional programs or incentives are required. From a retail electricity customer perspective, storage that is incentivized this way is best used for rate arbitrage and demand charge reduction, which may not align well with system needs. This incentive may be best combined with a utility program that controls the storage device for grid needs. This type of incentive could also be applied upstream of the device itself at other points in the supply chain.
- **Leasing programs.** The utility or third parties can administer leasing programs in which the customer pays a daily or monthly charge for use of a storage device. This can be paired with utility programs, allowing the utility to take control of the battery when needed. Leasing programs are an effective way for utilities to keep tighter control of the battery systems by retaining ownership. Leasing programs are well suited to limited pilot programs or early transformational policy.
- **Direct payments for grid services.** Payments for grid services such as energy, capacity, ancillary services, and peak load reductions to realize deferrals may be efficiently set at the avoided cost of offering those services with some other energy technology. However, the avoided costs may not be high enough to justify investment in storage. A market transformational incentive policy could involve paying an above market value for these services, thus incentivizing both the construction of storage and highest value operations. However, this approach is not recommended unless the income to the device for offering storage services is guaranteed. The financial success of a storage investment is tied to the prices and frequency of payments for the services it offers and these are

hard to predict, particularly outside of the utility. This is true even for cost-effective technologies. The difficultly of balancing efficient compensation for grid services over time with the uncertainty to developers of receiving sufficient compensation for long lived asset is ever present in market design, particularly in high renewable penetration or fast changing environments.

- **Monthly payment for use of the storage device.** By paying to take control of storage devices, the utility can use them for grid benefits. This can be implemented as permanent control or selective control on only days when control is highest value to the utility. Fixed payments to the customer guarantees income for the device when enrolled in the program, thus shifting the risk of device performance in offering grid services to the utility. This payment can become a market transformational incentive when paid at above market value for the services the technology provides. However, customers may not be willing to invest in storage under this form of incentive unless the program is guaranteed for the lifetime of the asset.

It is recommended that DoE lead the effort supported by CSIR, EIUG, other energy trade organizations, and the National Treasury to study existing international incentive programs and develop a proposal for an energy storage incentive program tailored around the specifics of the SA electrical grid that could be used in developing a positive business case for proposed demonstration projects and meeting procurement targets. It is believed that this effort could develop one of more proposals for implementation within 4 to 6 months although it may take somewhat longer to implement.

Appendix A provides details of existing international incentive schemes for battery storage technologies and their applications.

3.4.3 Provide Tax Credits

Tax credits are a form of incentive administered by the government rather than the utility. This is a powerful tool to achieve market transformation that is aligned with governmental policy objectives. Because tax credits are through general taxation and not through rates, they can reduce the burden on utilities in jurisdictions where raising rates is politically or economically unpalatable. Tax credits may be particularly attractive in South Africa as a means of administering transformational policy, given the steep rate increases forecasted in many jurisdictions. These may be applied to the technologies themselves, or to the supporting industries, for example manufacturing. Allowing energy intensive industries to offset costs through tax credits for investments in energy storage to reduce demand charges and increase power quality and reliability further allows them to better manage costs and competitiveness.

This effort would evaluate where and how tax credits could be effectively implemented to support the SA energy storage industrial growth and adoption goals. This effort could be performed in parallel with the tariff incentive effort described in Section 3.4.2 and in a similar time frame. The recommendation from this effort would be compared to the recommendations related to tariff incentives to determine the optimal approach. This effort would be led by the National Treasury and supported by CSIR, DoE, dti, EIUG, and SA trade organizations.

3.5 Demonstration Projects

Eskom and the municipalities need to identify locations where energy storage demonstration projects would be effective in demonstrating the value of energy storage for South Africa and SSA. Demonstration projects should be designed to serve two main purposes: (1) highlighting the challenges, experience and solutions to the siting, constructing, interconnecting, controlling, and compensating storage for the services it provides in different settings and business models on the electrical system; and (2) identifying opportunities that are economically viable or close to economically viable in the near and medium term for storage.

The DoE must develop the necessary incentives and provide procurement targets for installing ES projects. These incentives and targets can be tested with the installed demonstration projects. NERSA needs then to ensure that the regulatory framework and interconnection standards are in place to install the demonstration projects. The demonstration projects can then be used to evaluate the interconnection standards, test the business cases and update the regulations, incentives and required targets by all stakeholders.

These goals will need a set of tools, studies, and analysis to best identify the opportunities for storage and to model the types of utility and customer programs and business models that will dispatch storage for highest value, and potentially incentivise procurement or adoption of cost effective storage systems in the future. These are discussed in the following subsections. The subsections following that outline various locations and business models for storage identified as potentially high value and worth exploring through demonstration projects.

3.5.1 Tools and Analysis to Identify High Value Sites

As the Task 2.2 Economic Analysis shows, the highest value locations for storage will be where transmission and distribution infrastructure investments can be deferred or even avoided through use of the storage device. Storage will be most economical when multiple different use cases can be served by the same device. These use cases include for example, system energy and capacity services, ancillary services, both locally and at a system level, and local infrastructure deferral. The entity controlling the storage device must dispatch it so that the maximum value can be realized. However, depending on regulatory structures, tariff designs, control systems, and electricity market product availability, these entities may not have enough information to dispatch the device for highest value, or their incentives to do so may conflict with those of the system as a whole. Storage controlling entities could include:

- **Eskom.** Eskom has all of the information to dispatch a storage device for maximum operational system benefits because Eskom knows the avoided marginal costs of offering grid services with other grid technologies. Storage dispatch can therefore be incorporated into day-to-day system dispatch to minimize system operating costs. Eskom also has information on the costs of identified investments in grid infrastructure necessary to meet load growth on their own system. With the correct analysis toolkit, Eskom has all of the information to control a storage device located on their own system under its control for highest benefits.

- **Municipalities.** The municipalities can dispatch generation on their own system and under their control for their own benefits. Similar to Eskom, they also identify infrastructure investments on their own systems to serve new load growth. Municipalities procure power from Eskom through a tariff. The municipality objective when operating storage is therefore to lower power costs and realize deferral benefits so that the storage system provides the maximum value. Depending on the tariff structure and the types of products procured from Eskom, the optimal storage operations from the municipality perspective may differ from the least cost operations of storage from a system perspective.
- **Customers.** Customers can install and control their own storage systems. The benefits to the customer include backup power services, and lower energy bills. Depending on the tariff structure the customer pays, the use of the storage device may not align with the lowest cost operations of the storage device from a system perspective. For example, ancillary services are a key part of highest value storage operations, as identified in Task 2.1. Customers do not pay for ancillary services directly; instead, all system costs are recovered through a combination of energy, demand and fixed charges. Customers will not therefore control their battery to offer ancillary services because (1) they are not incentivized to do so through their tariff design, and (2) they are not exposed to ancillary service price or control signals that they could respond to.
- **Third-party aggregators.** The final control entity is the third party aggregator. Currently no aggregators are operating in South Africa. Aggregators take control of typically BTM meter storage systems and control them as an aggregated offering of grid services to potentially either the municipalities or Eskom. Because they can deal more directly with the utilities, either through market products (if they exist) or through other arrangements, the aggregator may be able to realize higher system value for their combined storage product than the storage owners could themselves. This will be ideally suited to be piloted in low-cost housing areas with backyard homes, representing much higher load profiles than originally planned. The business case will be value the anticipated distribution upgrade deferral.

Each potential storage controlling entity above faces its own challenges and opportunities to realizing the highest benefits of storage to them. Analysis to study these challenges and opportunities can be divided into two categories:

1. How to maximize value of storage to them given the current electricity regulatory, market and tariff structures. In other words, does storage make sense right now? This includes identification of highest value grid locations, and most attractive financing options.
2. How much is storage worth given changes in regulatory, market and tariff structures, and control systems, (collectively referred to going forward as the storage ecosystem)? How does the value of storage increase with Eskom, municipality, or regulatory action to change the way storage is incentivized, compensated and operated?

In determining demonstration projects, both of these categories should be considered. Ideal demonstration projects should be close to cost effective under Category 1. Poorly performing or expensive demonstration projects may dampen market interest from storage investors and developers.

However, demonstration projects can also be used to investigate pilot programs on regulatory, market, and tariff structure changes or control system changes before incurring the risk and expense of doing so at a larger scale. Ideal demonstration projects should therefore also incorporate novel aspects of more efficient storage ecosystems that have been determined through initial economic modelling work.

Potential demonstration projects that are located under the control of each of the entities identified above are proposed in the following subsections. This effort calls for the initial development of tools to identify high-value locations for energy storage demonstration projects and then the initial analysis to demonstrate the capabilities of the tools and to identify specific locations. This effort would be led by CSIR with support from DoE, SA university, Munics, Eskom, and technology consultants. This effort might take 6 months to develop tools and another couple months to demonstrate the tools' capabilities.

3.5.2 Front of the Meter Substation Sites

The most immediately cost effective deployment of storage in South Africa is likely to be front-of-the-meter storage or substation located storage facility, controlled by either Eskom or a municipality that enables deferral of infrastructure upgrades, ancillary services associated with possible PV / wind integration.

Although this activity does not have to wait for the completion of identification of SA industry development priorities (Section 3.2.3), it should be guided by intermediate conclusions. The following scope and timelines are proposed:

- Preparation and Specification Led by Eskom or Municipalities – 9 months
  - Analysis of the Eskom and municipality distribution capacity expansion plans to identify site.
  - Perform technical analysis and studies to develop technical requirements, including information technology and operational technology (IT-OT(, ancillary services and control aspects to develop inputs to specification by Eskom or municipalities and their consultants.
  - Incentives and funding identified by DOE with inputs from Eskom and municipalities.
  - Develop business case by Eskom or municipalities together with third-party CSIR or Electric Power Research Institute (EPRI_.
  - Develop or update technical requirements and interconnection standard for demonstration project at site by Eskom or municipalities.
  - Regulatory aspects to be reviewed by DOE for NERSA.
  - Develop technical specification – Eskom or municipalities
  - Determine construction scope of work (SOW; turnkey or subcontracts)
  - Request Requests for Information (RFIs) from prospective vendors and contractors
  - Develop key performance indicators (KPIs) and measurement requirements for measurement and verification (M&V) process
- Bidding and Construction led by Eskom or municipalities – 9 months
  - Review specification with selected bid vendors.
  - Submit request for quotation (RFQ) and bid package

- Evaluate proposals and select construction contractor
- Manage construction and integration with substation automation, Data Management System (DMS), and supervisory control and data acquisition (SCADA).

- M&V led by DoE with Eskom or municipalities support (3–5 years)
  - Develop M&V plan with stakeholders
  - Collect data and verify performance
  - Validate business case
  - Document lessons learned
  - Assimilate and publish information on annual basis
  - Adapt regulations for inviting independent storage producers
  - Develop incentives and procurement targets as needed

Front-of-meter (FOM) demonstration projects would be planned and led by Eskom/AMEU and supported by Munics, DoE, and CSIR. Developers would be involved in the design and construction of these projects. SA and international financiers may be involved in financing these projects.

3.5.3 Behind the Meter Sites

This demonstration project is intended to take advantage of potential locations where customers such as residential developments and shopping centres may be in the process of, or already have, installed significant energy storage at their sites BTM because of perceived benefits of the device to themselves. That customer might be willing to be involved in a demonstration project in which a municipality (or Eskom) could take control of its storage device under specific conditions and at particular times for grid services. This might require the Eskom/municipality to hold the customer harmless against any losses incurred by Eskom or municipality use, or offer compensation to the customer for their services to the grid.

This demonstration project is contingent on finding a group of customers in which storage makes sense or is close to making sense from their personal economic perspective or resiliency against rolling brownouts. In these situations, the municipalities have the opportunity to realize higher value from these systems around critical infrastructure and reduce the cost shift they cause by using their services for high value grid needs as well. Compensation for grid services from BTM storage devices that is lower than the benefits received by the grid for those services is a net benefit to the utility, if customers were expected to install storage anyway. However, incentivizing additional storage adoptions through offering compensation could have the secondary effect of increasing the cost shift if those net benefits are relatively small.

Although this activity does not need to wait for the completion of identification of SA industry development priorities (Section 3.2.3), it should be guided by intermediate conclusions. The following scope and timelines are proposed:

- Preparation and Specification led by municipalities (or Eskom) – 9 months

- Selecting neighbourhood or commercial development area where customers have interest in energy storage and DER such as roof-top PV.
- Identify critical infrastructure (e.g., hospital, fire station, schools) in the area that may need backup power during power outages.
- Analyse the development's distribution system and identify upgrade, backup power and demand response opportunities and needs.
- Perform technical analysis and studies to develop technical requirements, including IT-OT, distributed ancillary services, demand response management system (DRMS) and control aspects.
- Incentives and funding identified by DoE with inputs from municipalities on the shared cost/revenue model for the customers.
- Develop business case by municipalities together with developers and customer base.
- Develop or update technical requirements and interconnection standard for demonstration project at site by municipalities and developer.
- Regulatory aspects for bundling services through customer owned energy storage need to be reviewed by DoE for NERSA.
- Develop technical specification for interfacing and controlling customer owned energy storage – municipalities.
- Determine construction SOW (turnkey or subcontractors)
- Establish a network operating centre (NOC) that can integrate data and control of the distributed storage systems.
- Request RFIs from prospective vendors and contractors.
- Develop KPIs and measurement requirements for the M&V process.

▶ Bidding and Construction led by municipalities – 6 months
- Review specification with selected bid vendors.
- Submit an RFQ and a bid package for the integration and DRMS.
- Evaluate proposals and select construction contractor
- Manage construction and integration with NOC and DRMS.

▶ M&V led by DoE with municipality support (3–5 years)
- Develop M&V plan with stakeholders
- Collect data and verify performance
- Validate business case
- Document lessons learned
- Assimilate and publish information on annual basis.
- Adapt regulations for inviting independent storage producers

- Develop incentives and procurement targets as needed.

BTM demonstration projects would be planned and led by AMEU and large energy users working in conjunction with Munics, SALGA, Eskom Distribution, IPP Office, Industry Associations, and the EIUG. SA universities and developers would be involved in the design and construction of these projects. South Africa and international financiers may be involved in financing these projects.

3.5.4 Community Storage with Aggregator

Community storage combines attributes of the two previous categories. Storage is located at the ends of the distribution lines but it is under utility ownership and control or operating through an aggregator. The community storage model has all of the storage benefits of the FOM systems with the additional capability of supporting more local electricity services, e.g, voltage regulation on long radial lines, and peak mitigation due to fast growth in low-cost housing. This demonstration project will be ideally suited to be piloted in low-cost housing areas with backyard homes, representing much higher load profiles than originally planned. Community storage may also have the benefit of being more easily sited than larger substation connected storage devices close to the grid edge. Effective control of the devices by an aggregator relies on signals being passed between the distributed community energy storage devices, Eskom/municipalities and the developing energy markets.

Although this activity does not have to wait for the completion of identification of SA industry development priorities (Section 3.2.3), it should be guided by intermediate conclusions. The following scope and timelines are proposed:

- Preparation and specification led by aggregator, supported by municipalities (or Eskom) – 9 months
  - Identifying and selecting low-cost neighbourhood developments where customers have added back-yard dwellings where load and peak demand growth are rising much faster than originally planned.
  - Analyse the development’s distribution system and identify cost of system upgrades to keep up with load and peak demand growth.
  - Perform technical analysis and studies to develop technical requirements, including IT-OT, distributed ancillary services, DRMS, and control aspects.
  - Incentives and funding identified by DoE with inputs from aggregator on the shared cost/revenue model for aggregator, municipalities, and customers.
  - Develop business case by aggregator together with municipalities and customer base.
  - Study various energy market models and propose a market for aggregating distributed services to be provided by aggregator and his customers.
  - Develop or update technical requirements and interconnection standard for demonstration project at site by aggregator and municipalities.
  - Regulatory aspects for bundling services through aggregators need to be reviewed by DoE for NERSA.

- Develop technical specification for interfacing and controlling customer owned energy storage – municipalities.
- Determine construction SOW (turnkey or subcontractors)
- Establish an NOC that can integrate data and control of the aggregated distributed storage systems.
- Request RFIs from prospective vendors and contractors
- Develop KPIs and measurement requirements for M&V process

▶ Bidding and construction led by aggregator with support from municipalities – 6 months
- Review specification with selected bid vendors.
- Submit RFQ and bid package for the integration into NOC and DRMS
- Evaluate proposals and select construction contractor
- Manage construction and integration with NOC and DRMS.

▶ M&V led by DoE with municipality support (3–5 years)
- Develop M&V plan with stakeholders
- Collect data and verify performance
- Validate business case
- Document lessons learned
- Assimilate and publish information on annual basis.
- Adapt regulations for inviting independent storage producers
- Develop incentives and procurement targets as needed.
- Update energy market design.

Community storage demonstration projects would be planned and led by the AMEU with support from DoE, SALGA, Eskom Distribution, and Munics. SA universities and developers would be involved in the design and construction of these projects. South African and international financiers may be involved in financing these projects.

3.6 Create Supporting Infrastructure / Environment

The previous parallel activities will be facilitated by IT infrastructure and by the utility using installed storage devices for the highest value uses. Additional communication infrastructure includes the smart metering infrastructure over the entire territory that allows participants to install storage and other types of demand response and distributed control technologies. Some progressive utilities have built out smart metering with advanced metering infrastructure (AMI) across the entire system, based on future use cases and showed several stacked value propositions for the AMI roll-out. Another approach by more balanced utilities, is to build out the smart metering on specific feeders as required. The approach by some conservative utilities, is to build out the smart metering infrastructure as required for particular customers as requested. The following sections describe suggested changes to the electricity system that changes the ecosystem for storage and enable larger storage benefits.

3.6.1 Standardize Energy Storage Requirements

The existing interconnection standards and grid codes at Eskom and the various municipalities are currently not in sync. In some cases, they have opposing requirements that make it difficult for energy storage to be adopted. It is recommended that the grid codes be consolidated by NERSA to have the same requirements at all the utilities.

The IEEE-1547 set of interconnection standards provide a good starting for adoption of a consolidated set of grid codes and standards. These are continuously updated and developed by international stakeholders and experts.

South Africa needs to developed coordinated, consistent, interconnection standards, communication standards, and implementation guidelines for energy storage devices (ES), power electronics connected distributed energy resources (DER), and hybrid generation-storage systems (ES-DER). This activity should assess codes and standards to identify gaps and best practices.

This effort would include a working group to review and determine applicability, scope, and consistency of Underwriters Laboratories (UL) and other certification requirements for energy storage systems. The working group would draw from a broad set of stakeholders including Eskom, NERSA, DoE, CSIR, manufacturers, and SA research organizations. This effort must address residential, commercial, and industrial applications at the grid distribution level and utility/regional transmission organization applications at the grid transmission level.

As part of this effort stakeholders should identify, evaluate, and adopt international best practices. These practices should be implemented at the Eskom Energy Storage test pad and on demonstration and pilot projects implemented within South Africa. This effort would be led by Eskom/NERSA with support from AMEU, Munics, and Industry Associations. This effort might take 6 months and should be completed so that the result can be incorporated into RFPs for the energy storage demonstration projects listed in Section 3.5.

In conjunction with this effort, South Africa should consider the formation of an energy storage trade organization similar to SAWEA or that could lobby for and advance the cause of energy storage industry in South Africa on behalf of the SA energy storage industry.

3.6.2 IT Development

The South African utilities currently do not have the control infrastructure and communications protocols from their dispatch centers to control devices at the grid edge (end-of-line) or BTM. This infrastructure is needed to integrate energy storage on the distribution network and to collect the value streams for the various use cases. This IT infrastructure should have both IT and OT functionality. Part of a pilot study would identify and develop the IT infrastructure to make these distributed energy storage devices accessible from the dispatch centers.

There are some best-practices for interoperability of these distributed infrastructure that is currently developing at international utilities, such as Duke Energy with its Open Field Message Bus device interoperability framework [0414] and NY-ISO with the "Reforming the Energy Vision" regulatory initiative [0415]. This effort would be led by DST with significant technical support DoE, Eskom, Munics, IPP Office, a SA University, dti, CSIR, and renewable energy trade associations. This activity could be expected to take 6 to 9 months.

3.6.3 Utility Control

Most of the energy storage infrastructure will be installed on distribution networks in sub-stations or close to DER systems like distributed PV plants. Some utilities are developing Distribution Control and Operating Centres to manage these distributed assets. One example is Duke Energy's Renewable Control Center (RCC) in Charlotte, North Carolina. This control center uses secure command and control technology to monitor more than 3,500 megawatts of wind and solar energy plants across the U.S [0416]. As well as optimizing Duke Energy's own assets, the RCC offers operations and maintenance services to third-party IPP renewables operators as well.

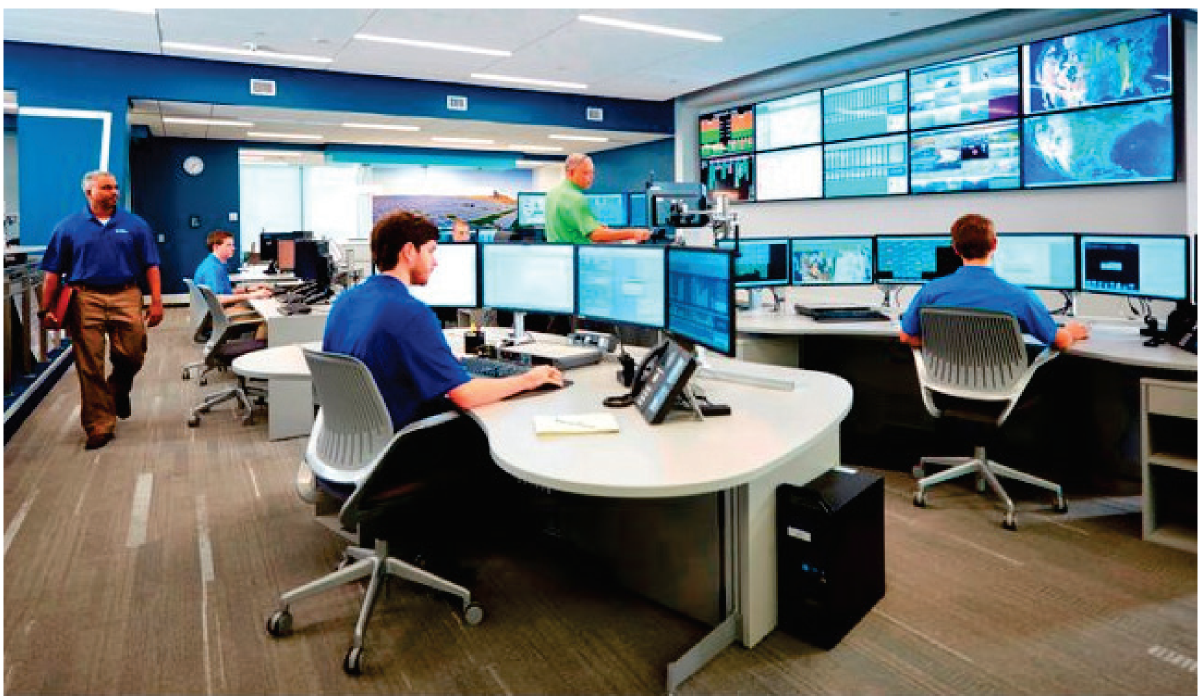


Figure 3-3: Duke Energy Renewable Control Center in Charlotte NC

This effort provides for a study that identifies the necessary functional requirements, defines a design concept, and proposes an implementation plan and associated top level schedule for the development of an initial Distribution Control and Operating Center. This would include the definition of procedures, protocols, and standards necessary to effect distributive control and operation of distributed resources and would indentify a proposed implementation plan to gradually introduce this system across the SA electrical grid. This effort would be led by Eskom with significant technical support from DoE, Munics, IPP Office, and CSIR. This study might take 6 to 9 months to complete and then more than a year to procure, construct, and place in operation.

3.6.4 Communication Network

Transactive energy (TE) requires a highly distributed IP-based communication and sensor network, capable of economic (billing) and operational functionality. This network can use several protocols via wireless, optic fibre or wired network. Such a TE communication network must mitigate issues of privacy, free will, and cybersecurity.

Utilities primarily use DNP3 and IEC-61850 communication protocols to integrate the distributed assets into the SCADA head-end systems for command and control. DNP3 has been the dominant North American protocol while IEC 61850 is currently dominant in Europe and India and growing internationally. [0417]. Distributed network protocols are a set of communications protocols used between the distributed components in process automation systems.

This effort would include the development of a vision statement and implementation plan and associated top level schedule for the development of a distributed IP-based communication and sensor network. This would include the definition of procedures, protocols, and standards necessary to effect integrated grid wise operation and would indentify a proposed implementation plan to gradually introduce this system across the SA electrical grid. This effort would be led by Eskom with significant technical support from DoE, Munics, IPP Office, and CSIR. The initial study could take 6 to 9 months to complete and substantially longer to implement.

4 Recommended Schedule

To gain best value from the proposed activities, their performance must be sequenced to allow the results and conclusions of earlier activities to inform and direct the subsequent follow-on (dependent) activities. Although the initiation of some follow-on activities may be delayed due to the unavailability of funding, this logic identifies some of the key activities that should be prioritized to begin at the earliest opportunity.

Table 4–1 summarizes the proposed activities identified and described in Section 3. The table lists the recommended leadership and supporting groups and participating organizations. It also identifies precursor activities that must be started and completed in order to inform the follow-on activities. Depending on the desire to expedite some of the later activities, some might be started earlier than indicated at a risk that some portion of the study might need to be reperformed or re-evaluated.

From the logic identified in the last column of Table 4-1, an initial logic diagram (Figure 4-1) has been developed to show the general flow and sequencing of the proposed Roadmap activities. When this logic is entered into scheduling software with estimated durations, a first-order schedule approximation is generated (Figure 4-2). This schedule suggests that multiple activities can be performed in parallel and that the proposed energy storage demonstration projects should be initiated without waiting for the results and implementation of planning efforts.

Table 4-1: Proposed Roadmap Activities, Participants, and Predecessor Activities

No.	Activity	Led by:	Supported by:	Other potential resources/involvement	Activity Duration (months)	Precursor Activities
1.1	Analysis of global energy storage market	IDC	dti, DST, SANEDI, Universities, Consultants, CSIR	IRENA, IEC, Power Africa, World Energy Counsel, IEA, EPRI	6	n/a
1.2	Analysis of SSA energy storage market	IDC	DST, dti, SANEDI, Universities, Consultants, CSIR	IRENA, IEC, Power Africa, World Energy Counsel, IEA, Industry Associations	6	n/a
1.3	Identify High Potential (HP) technologies	DST	CSIR, Universities, Consultants, SANEDI	IRENA, IEC, Power Africa, World Energy Counsel, IEA	4	1.1, 1.2
2.1	Analysis of HP/ID technology value chain	DST	DoE, dti, IDC, SANEDI, Universities, Consultants, CSIR	IRENA, IEC, Power Africa, World Energy Counsel, IEA, EPRI	4	1.3
2.2	Match value to SA Capabilities	IDC	DST, dti, Universities, Consultants, CSIR	IRENA, IEC, Power Africa, World Energy Counsel, IEA, Industry Associations	4	2.1
2.3	ID SA industry development priorities	dti	DST, DoE, Universities, Consultants, CSIR	IRENA, IEC, Power Africa, World Energy Counsel, IEA, Industry Associations	6	2.2
3.1	Internal Value – Grid Service	Eskom	DoE, IPP Office, Eskom, Munics, Universities, CSIR	IRENA, IEC, Power Africa, World Energy Counsel, IEA	6	n/a
3.2	Market Products for Grid Services	DoE	IPP office, Munics, Eskom, dti	IRENA, IEC, Power Africa, World Energy Counsel, IEA, Industry Associations	12	3.1
3.3	IRP Reform to incl full value of storage	DoE	CSIR, Eskom, IPP office	IRENA, IEC, Power Africa, World Energy Counsel, IEA	9	3.1
3.4	Tariff setting and cost recovery	NERSA	DoE, Munics, Energy Industry Orgs, consultants, universities, CSIR	IRENA, IEC, Power Africa, World Energy Counsel, IEA	4	2.3, 3.1, 3.3
4.1	Procurement Targets	DoE	Eskom, Munics, IPP office, dti, SANEDI, treasury	IRENA, IEC, Power Africa, World Energy Counsel, IEA	9	2.3, 3.1
4.2	Create Incentives	DoE	CSIR, EIUG, Industry Associations, National Treasury	IRENA, IEC, Power Africa, World Energy Counsel, IEA	9	2.3, 3.1
4.3	Provide Tax Credits	National Treasury	CSIR, DoE, dti, EIUG, Industry Associations	IRENA, IEC, Power Africa, World Energy Counsel, IEA	9	2.3, 3.1

No.	Activity	Led by:	Supported by:	Other potential resources/involvement	Activity Duration (months)	Precursor Activities
5.1	Tools & analysis to ID high value sites	CSIR	DoE, Universities, Consultants, Municipalities, Eskom, dti	IRENA, IEC, Power Africa, World Energy Counsel, IEA, EPRI	8	n/a
5.2	FTM Substation	Eskom / AMEU	AMEU/Eskom, Munics, DoE, CSIR	Developers, Financiers, USTDA, Industry Associations	18/36	5.1
5.3	Behind the Meter	AMEU	Munics, SALGA, Eskom Distribution, IPP Office, Industry Associations, EIUG	Developers, Financiers, USTDA	18/36	5.1
5.4	Community Storage with Aggregator	AMEU	DoE, SALGA, Eskom Distribution, Municipalities	Developers, Financiers, USTDA	18/36	5.1
6.1	Standardize Energy Storage Requirements	Eskom / NERSA	AMEU, Munics, Industry Association , NERSA/Eskom	IRENA, IEC, World Energy Counsel	9	n/a
6.2	Encourage IT Development	DST	DoE, Eskom, Munics, IPP Office, Universities, dti, CSIR	Energy Organizations, Industry Associations, NERSA	9	6.1
6.3	Allow Utility Control	Eskom	DoE, Munics, IPP Office, CSIR	Energy Organizations, Industry Associations, NERSA	9	6.1
6.4	Communication Network	Eskom	DoE, Eskom, Munics, IPP Office, CSIR	Energy Organizations, Industry Associations, NERSA	9	6.1

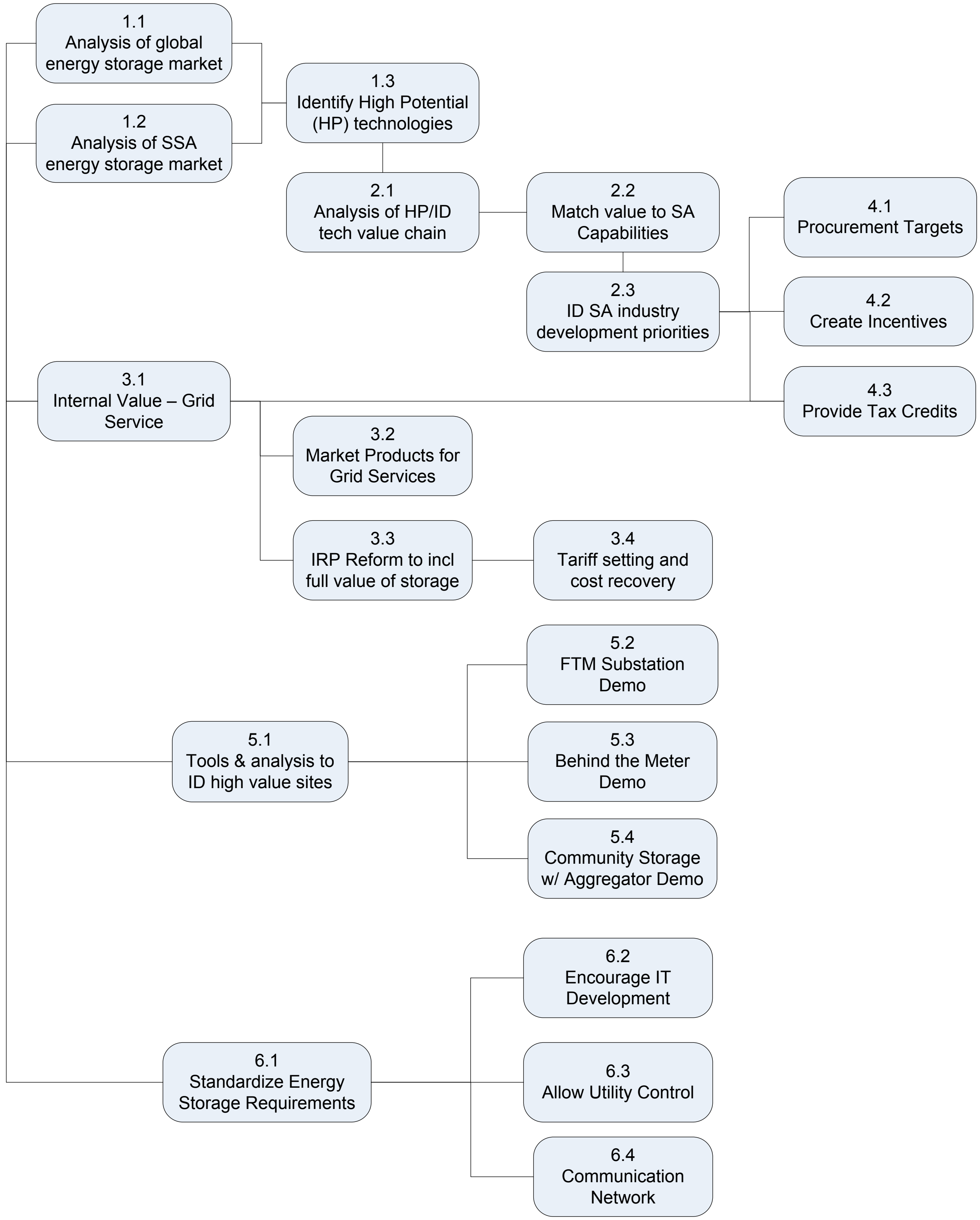


Figure 4-1: Logical Sequence of Proposed Roadmap Activities

Preliminary Draft schedule for
South Africa Energy Storage Assessment Roadmap Activities

ID	Duration	Task Name	Predecessors
1	120 days	1.1 Analysis of global energy storage market activity	
2	120 days	1.2 Analysis of SSA energy storage market activity	1SS
3	80 days	1.3 Identify High Potential (HP) technologies activity	1,2
4	80 days	2.1 Analysis of HP/ID technology value chain Activity	3
5	80 days	2.2 Match value to SA Capabilities activity	4
6	120 days	2.3 ID SA industry development priorities activity	5
7	120 days	3.1 Internal Value – Grid Service activity	1SS
8	240 days	3.2 Market Products for Grid Services activity	7
9	180 days	3.3 IRP Reform to incl full value of storage activity	7
10	240 days	Incorporation of ES reform into next IRP	9
11	80 days	3.4 Tariff setting and cost recovery activity	7,9
12	200 days	Implement new tariff and cost recovery	11
13	180 days	4.1 Procurement Targets activity	7,6
14	180 days	4.2 Create Incentives activity	7,6
15	180 days	4.3 Provide Tax Credits activity	7,6
16	160 days	5.1 Tools & analysis to ID high value sites activity	1SS
17	360 days	5.2 FTM Substation Demo development activity	16
18	720 days	Procure construct & operate FTM ESS Demo	17
19	360 days	5.3 Behind the Meter Demo development activity	16
20	720 days	Procure construct & operate BTM ESS Demo	19
21	360 days	5.4 Community Storage w/ Aggregator Demo development	16
22	720 days	Procure construct & operate Comm. Storage w/ Agg Demo	21
23	180 days	6.1 Standardize Energy Storage Requirements	1SS
24	180 days	6.2 Encourage IT Development	23
25	240 days	Implement IT Development Planning	24
26	180 days	6.3 Allow Utility Control	23
27	240 days	Implement Utility Control Plan	26
28	180 days	6.4 Communication Network	23
29	240 days	Implement Communication Network Plan	28

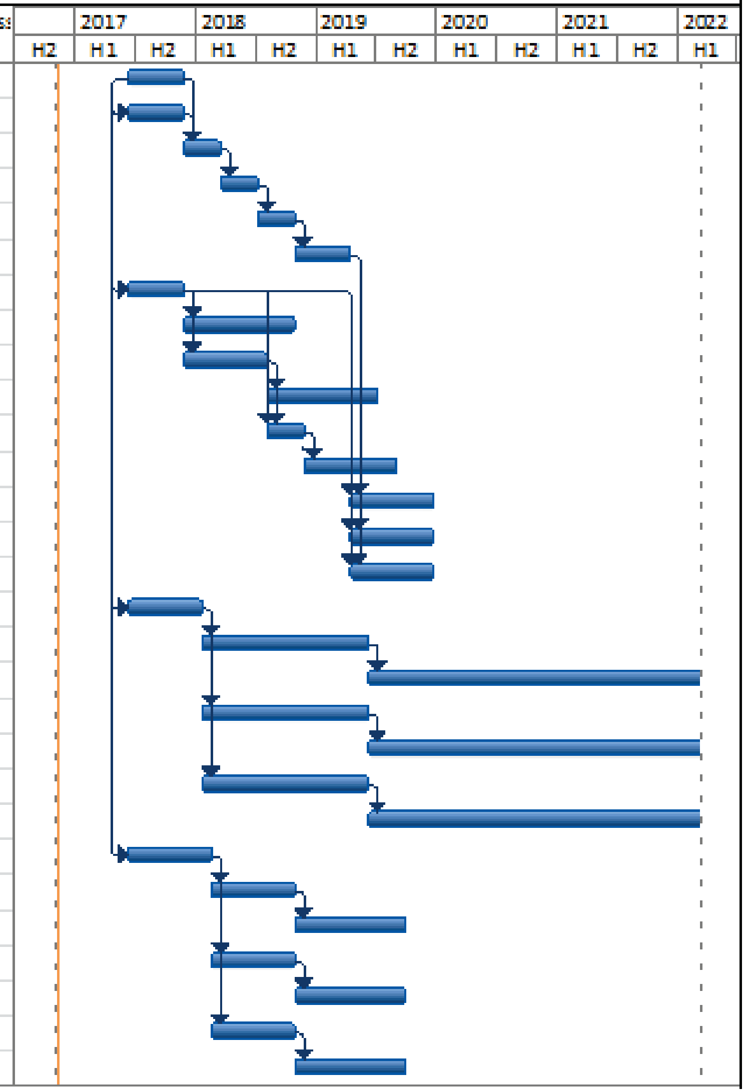


Figure 4-2: Draft Schedule for Energy Storage Assessment Roadmap Activities

5 Roadmap Business Case

This section discusses a potential business case for the adoption of energy storage technologies in South Africa.

5.1 Business Problem

The energy storage industry will expand significantly over the next 5 to 15 years. During this time, many new technologies will be placed into commercial services by many different providers. Some of these companies will experience rapid growth and expansion as their products and facilities are deployed and increasing sales and production allows them to further advance and fine tune their products and manufacturing processes.

Other companies will invest equity in the development of new products that may not experience sufficient adoption and growth to remain viable. These companies will be out competed by those companies with similar technologies but with a higher level of performance, lower costs, or better sales strategies.

It takes 5 to 10 years and significant resources to develop a energy storage technology and advance it to a point at which it is ready for production and deployment on a commercial scale. A company just now beginning to develop a technology or new products based on evolving technology is at a severe disadvantage compared to those that have already made significant time and financial investments. One opportunity is for a company to take advantage of the upcoming growth in energy storage by providing resources, materials, or services required by major dominant companies. Another strategy would be to team with existing companies to play a role in their value chain.

South Africa sees the imminent rapid growth of energy storage as an opportunity to expand and evolve its electrical grid into a more reliable and affordable system. This in itself will stimulate economic growth and industrial expansion. A greater opportunity is for South Africa to support the rapid expansion of its energy storage industrial capabilities within its own borders. These capabilities will be used to supply equipment and service for South Africa; more importantly, they can also be a source of export to developing SSA countries as well as to countries on other continents. With the development of specific capabilities or beneficiation of natural resources, South Africa could play a competitive role in the development and deployment of energy storage in established dominant manufacturing countries such as the United States and China, or those of the European Union.

These changes will not likely occur by themselves. The SA electricity grid is dominated by a single government owned utility that seeks to play a central and dominant role in the further development and growth of the electrical grid. Although South Africa has made significant advancements in the development of Variable Renewable Energy (VRE) generation sources through its IPPPP there is nothing in the current IRP that addresses the consideration for energy storage onto the national grid[2]. As

[2] Draft IRP 2016 update Oct 2016 indicates a sensitivity analysis to be included for "new technologies (energy storage)"

evidenced by the current IRP, the culture surrounding the existing SA electrical grid is likely to favor the procurement and construction of coal plants, and/or natural gas peaking power plants.

5.2 Business Case

A business case is intended to capture the reasoning for initiating a project or task. The logic of the business case is that the consumption of resources by an organization should be justified by a specific business need or objective. A compelling business case is evolved over time until it adequately captures both the quantifiable and nonquantifiable attributes of a proposed project.

Business cases can range from comprehensive and highly structured (as required by formal project management methodologies) to informal and brief summaries. This section describes three arguments concerning energy storage. The first is the justification for utility-scale energy storage adoption. The second is a rationale for South Africa to become proactively involved in the energy storage industry through participation in specific parts of the extraction/manufacturing/service value chain. The third is the desire to promote green energy and a reduction in green house gases through favourable applications of energy storage. Included in this discussion is an evaluation of the “do nothing” alternative. Lastly, a discussion of the risks involved in initiating the proposed roadmap activities is discussed.

Many of the recommended Roadmap activities are presented at a high level in a summary manner; therefore, the specific costs for these activities and the resultant impacts are difficult to predict at this point. The descriptions of these activities are intended to be a starting point for discussion by the steering committee and the working groups assigned to study them further. It is expected that these working groups will evaluate, plan and initiate these activities on a scale and to the extent that provides the greatest anticipated impact for the cost and effort involved.

5.2.1 Adoption of Utility Scale Energy Storage

The economic modeling performed under Task 2.2 showed limited economical application for utility scale energy storage on the SA electrical grid. Due to several assumptions built into the modelling effort, the largest capacity was identified under the high-growth scenario and towards the end of the evaluation period (15 years).

The model used current costs for energy storage and assumed moderate cost reductions in the out-years. The rate of future energy storage cost reductions and the degree increased future performance may be substantially greater in reality. Costs in particular are impacted by a number of factors beyond manufacturing costs including the perceived bankability of energy storage technologies and the resultant financing cost necessary to cover these perceived risks.

The current modelling did not consider sub-hourly power demand data. Many of the potential benefits of storage will occur in sub-hourly time domain (seconds and minutes). The current study assumed that PHS resources, such as the Ingula pumped-storage hydroelectric project can adequately support the majority of sub hourly ancillary services. An expanded modelling effort using sub-hourly data would provide better analysis of ancillary services and would identify additional economical energy storage uses.

The economic modelling did not attempt to identify high value locations such as congested substations or T&D lines with insufficient capacity for current or future loads. In these areas, it is believed that a specific business case could be made today for the installation of utility-scale energy storage systems over other potential solutions such as substation expansion or reconductoring of power lines.

The culture of the current SA electrical management favours a rigid centralized structure rather than a more flexible distributed system of generation, transmission, and distribution such as those being developed in other countries. This is reflected by a lack of a progressive tariff structure that aligns the interests of the consumers with those of the utilities. Currently, the adoption of energy storage by consumers could be seen to threaten the profitability of the utility because utilities recover revenue for system fixed costs through a combination of rate components to the consumer. These can include energy, demand, and customer charges. Normally in avoiding energy charges, the consumer actually avoids paying some of their share of system fixed costs. Although demand charge is designed to recover fixed costs, the demand charge does not align well with the actual capacity needs of the system. Therefore customers that avoid demand charges do not reduce the system fixed costs to the utility by the same amount. The result is that the savings made by customers installing storage will be larger than the reduction in utility costs of operating the system. By losing the revenue previously recovered from a customer installing storage, the utility has to recover that revenue from other customers. Installing BTM storage will therefore result in higher rates for the utility's customers, and shift fixed cost recovery to customers without storage. Higher rates for other customers will drive some of them to adopt storage, further increasing rates on others. Utilities fear the development of a positive feedback loop in which system costs must be recovered from a diminishing number of kilowatt-hours of usage, and potentially a diminishing customer base if higher rates cause grid defections. The same problem has been noted for many DER technologies, but distributed PV in particular.

There is also no current means to value many of the ancillary benefits that energy storage can provide. As discussed in Objective 5, other grid systems have provided for energy storage service providers to collect revenue through long term fixed contracts with utilities or bid bidding into a utility on a recurring basis. Additionally, when energy storage service providers are defined as generators it places them at a further disadvantage. These factors prevent the development of an economic justification based on multiple services and stacked benefits that can expand potential revenue to a point where energy storage is a favoured alternative.

Overall, an argument can be made for the adoption of utility scale energy storage at high-value locations on a case by case basis. The benefits of energy storage can also be enhanced by valuing all its potential uses and by adopting a tariff structure that aligns consumer and utility goals with regard to energy usage. These changes will allow the utility to make decisions based on a future structure that allows procurement of energy storage facilities and services over alternate investments that will result in a long-term dependence on fossil fuels.

5.2.2 Economic Development through an Energy Storage Industry

Manufacturing remains an important sector within the South African economy given its potential to generate positive and significant spillover effects on the economy. Therefore, a separate business case can be made that energy storage represents a new and rapidly expanding industry in which South Africa should develop a position. The eventual adoption of energy storage will increase the quality and reliability of electrical service in South Africa while reducing the overall supply costs. However, if South Africa waits for the international energy storage industry to mature to a pint where energy storage justifies itself, the country will likely miss a significant opportunity to develop its own energy storage industrial base, increase extraction manufacturing capabilities, and support economic development. This is accomplished through the supply of domestic product and services as a participant in a portion of the energy storage value chain for one of more specific technologies. These same products and services can be exported to regional SSA countries and globally/internationally in niche areas or with markets and technologies where South Africa can develop a competitive advantage.

As discussed in Objective 5, Legal and Regulatory Assessment, many countries such as the United States and China are actively adopting policies and programs to encourage their own domestic development of energy storage technologies and industries and accelerate the adoption of energy storage. Waiting for the energy storage market to mature before actively promoting adoption will significantly reduce benefits of the economic growth realized by South Africa. As discussed in Objective 3, over the next 15 years, more than 85 GW of energy storage is anticipated to be deployed internationally. SSA will account for about 20 GW of this development. It is conservatively estimated that, if properly incentivized, South A alone could account for 2GW of this expansion. If SA were to participate in the energy storage market it could reasonably capture 20% of the SA market across the entire value chain, 5 to 10% of the SSA market, and 2 to 3% of the global market. This could represent a total economic increase of over 25 billion Rand.

5.3 The "Do Nothing" Alternative

The "Do Nothing" alternative considers the implications of not taking proactive action to promote the adoption of energy storage and of not incentivizing the development of portions of the energy storage industry within South Africa. In this case, the global energy storage industry will continue to develop and improve energy storage technologies, to increase performance, and to achieve continued cost reductions in manufacturing and production. The companies and countries producing the best of these products will become the dominant suppliers in the world.

Energy storage is thought to be an inevitable component of the evolving electrical grids worldwide and in time it will be more economical to adopt energy storage than to ignore it. During that time however, South Africa will have to make decisions on the continued development of electrical infrastructure and may make investment and procurement decisions concerning fossil fuel generation that locks the country into dependence on these sources for another 20 to 30 years. Additional procurement of fossil fuel generation will continue to contribute to green house gas production and the advancement of global warming.

Failure to adopt transformative policies or to make progressive changes in tariffs structures or cost recovery mechanisms will delay the adoption of energy storage and may increase the death spiral of defection from the electrical grid as consumers remove themselves from dependence on the electrical grid in favour of less expensive self-generation and consumption.

5.4 RISKS

A number of significant risks are associated with the recommend Roadmap activities:

- Failure to recognize the potential benefits of a flexible distributed supply, transmission, and distribution system and work toward progressive changes in Eskom's current centralized structure
- Failure to gain adequate support to craft and adopt transformative legislation and incentivize the development and adoption of energy storage
- Substantial bias against energy storage such that it is not reasonably represented or incorporated into future IRP
- Lack of funding or inability to commit funding to support energy storage Roadmap activities including the near term development of demonstration energy storage projects
- Failure to adequately include municipalities in discussions and address their positions

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IDC Findings Workshop

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ACRONYMS

AMEU	Association of Municipal Electricity Utilities
BTM	behind the meter
CAES	compressed air energy storage
CSIR	Council for Scientific and Industrial Research
DDM	Due Diligence Matrix
DoE	South Africa Department of Energy
DST	South Africa Department of Science and Technology
dti	South Africa Department of Trade and Industry
EIUG	Energy Intensive Users Group
ES	energy storage
ESS	energy storage system
EV	electric vehicle
FOM	front of meter
GHG	greenhouse gas
IDC	Industrial Development Corporation
IRP	integrated resource plan
IT-OT	information technology and operation technology
Li-ion	lithium ion
MW	megawatt
NERSA	National Electric Regulator South Africa
NT	National Treasury
PV	photovoltaic
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SA	South Africa
SAIPPA	South African Independent Power Producers Association
SALGA	South African Local Government Association
SANEDI	South African National Energy Development Institute
SAREC	South Africa Renewable Energy Council
SAWEA	South African Wind Energy Association
SSA	Sub-Saharan Africa
T&D	transmission and distribution
US	United States
USTDA	US Trade and Development Agency

1 Introduction

On December 2, 2016 between 9:00 am and 1:00pm, a Presentation of Findings Work Shop was conducted at Industrial Development Corporation (IDC) facilities in Sandton, South Africa (SA). The Workshop was presented by the Parsons Assessment Team and attended by USTDA, IDC, and members of the Steering Committee. The purpose of the workshop was to present the findings of the Objective deliverables not yet briefed to the IDC and Steering Committee and to discuss the results and potential path forward in the implementation of the proposed Roadmap activities. Following a presentation of findings on deliverables Objective 2.3 Financial Assessment, Objective 6 Roadmap for the Adoption of Energy Storage in South Africa, and Objective 3 Development Impact Assessment.

2 Attendees

Name	Organization
Bertie Strydom	IDC
Tshepiso Kadiaka	DTI
Paul Vermeulen	City Power (Johannesburg) and AMEU
Mike Levington	SAPVIA
Cosmas Chiteme	DST
Peter Klein	CSIR Energy Centre
Robbie van Heerden	CSIR Energy Centre
Jarred Wright	CSIR Energy Centre
Tobias Bischoff-Niemz	CSIR Energy Centre
Crescent Mushwana	CSIR Energy Centre
Kenneth Ozeoemena	CSIR
Deon Fourie	IPP Office
Piet van Staden	EIUG
Jacob Flewelling	USTDA
Paul Frink	Parsons (Assessment Team)
Johan Enslin	Smart Energy Solutions (Assessment Team)
Jeremy Hargreaves	E3 (Assessment Team)
Ryan Nel	GIBB (Assessment Team)
Dave Crombie	GIBB (Assessment Team)
Karin Kritzinger	Stellenbosch University (Assessment Team)
Wikus van Niekerk	Stellenbosch University (Assessment Team)

3 Discussions During Presentation

3.1 Objective 2.3 Financial Assessment

With reference to the general bankability of energy storage technologies, it was questioned whether the bankability of Compressed Air Energy Storage (CAES) Adiabatic - Cavern could be considered to be strong when no actual plants (pilot or demonstration) were in operation. It was corrected that CAES Cavern could be considered strong while adiabatic applications would be considered weak. This will be clarified in Objective 2.3.

3.2 Objective 6, Road Map for the Adoption of Energy Storage in South Africa

It was pointed out that the slides for Activities 1.1 and 1.2 should be corrected to remove South Africa from the description. The objective was to evaluate and assess the global and Sub-Saharan Africa (SSA) energy storage markets without regard to the capabilities of South Africa. Similarly, Activity 1.3 was intended to evaluate high value opportunities within global and SSA value chains without regard to SA capabilities.

With regard to Activity 2.1, it was suggested that "Reuse" could be added under the category of "ESS Decommissioning and Recycle" on the Typical ES Value Chain diagram. Another comment was that mobile energy storage in the form of electric vehicle batteries should be considered for South Africa. It was agreed that this is a valid point but beyond the scope of this study which was focused on stationary utility scale energy storage.

With regard to Activity 2.2, "Match Value to SA Capabilities," it was pointed out that while the REIPPPP was successful in deploying renewable energy generation in SA, there was limited SA industry participation in solar or wind power generation such that all the technology and equipment was sourced from other countries. Renewable energy took off 15 years ago. If it had been proactive in 2005, SA might have been a supply to the heavily subsidized European market

Energy storage will come to SA and will be integrated into the SA electrical grid eventually (along with all other countries with a utility-scale grid). The question is whether the SA industry will be positioned to participate in that value chain. Similar to renewables in 2005, energy storage has "arrived" globally and will grow exponentially over the next 5 to 15 years. SA doesn't have to wait for ES to arrive in SA before becoming involved in the global ES market.

As part of the studies included under "Value Chain Opportunities for SA" it is important that the reports specifically identify the materials and minerals and potential quantities that might be required to fill identified global market needs.

With regard to Activity 3.1, "Internal Value Grid Service," it is important to remember that the value of these grid services are important to all system operators including both the municipalities as well as Eskom.

Relative to Activity 3.3, "IRP Reform to include Storage Value," there is additional learning from Energy Master Plans being developed and used in Europe. These plans span the entire continent, extend beyond the power sector and have significant implications with regard to sector coupling.

With regard to Activity 3.4, "Tariff Setting and Cost Recovery," the need was mentioned for Munics to be able to effectively procure for their systems. Another approach discussed was to develop the ability to procure centrally for the interests of individual Munics.

With regard to Activity 4.1, "Procurement Targets," there was a concern that with a rapid price decline in energy storage, SA might procure energy storage at prices that would be rapidly undercut in the future. It was suggested that procurement targets initially be established at modest levels and ramped up over time. There are likely high value areas right now on the grid that show a positive business case for energy storage when compared to alternatives (to be evaluated under Activity 5.1). The market will determine the price based on a competitive procurement so targets would be set based on MW or MWh. Again it was suggested that the potential of electric vehicles as an energy storage resource on the electric grid be considered.

It was suggested that Activity 6.1, "Standardize Energy Storage Requirements" might be better led by dti rather than DST.

With regard to demonstration projects there was discussion as to applications at utility substations. These could be Eskom or by Munics. Additionally, how to procure with MFMA and PFMA and budget cycles. It was suggested that there are a lot of micro grids where a demonstration project could be sited (particularly in eastern Cape that has lots of wind and solar). Such a demonstration should also include an energy management system for when batteries are depleted. Lastly, it was suggested that a micro grid demonstration in a metro area at a business rate tariff would be better for behind the meter rather than in front of the meter.

There was significant discussion as to the potential impact of energy storage on greenhouse gas (GHG) emissions. It was pointed out that since energy storage is not a net generation source but rather a net generation load, its use cannot directly impact the rate of greenhouse gas reduction except negatively. However, it can be a tool depending on what charging source for storage and what generation source is displaced by energy storage discharge. It was suggested that the mention of GHG be removed from the roadmap business case discussion.

4 Discussion of Results and Take-aways

Following the formal presentation, the steering committee representatives were asked to bring forward any significant "take-away" ideas or thoughts that resulted from the Energy Storage Assessment and the workshop. The following items were discussed:

- Lithium ion will be the dominant energy storage technology for the next 5 to 10 years.
- When assessing energy storage needs it is important to understand the difference between energy capacity requirements (MWh) and power capacity (MW) requirements.
- Currently, there is not an existing positive business case for the adoption of energy storage at the bulk power level in SA. There are however, niche type application areas, especially on the distribution-level, where energy storage competes economically with other options.
- The SA electric grid can accept significantly more renewable generation before energy storage becomes necessary for bulk power balancing.
- Although not currently bankable, micro-grids will play an important role in SA. Energy storage can play a significant role in the design of micro grids.
- Development and export of off-grid power supply systems should not be overlooked.
- Off-grid systems, based on renewable generation with storage capability, can offset the need for (dependence on) fossil-based generation.
- Off-grid power supplies can be produced in a variety of sizes (household, small commercial, or larger commercial (i.e., game reserves).
- There are off-grid applications within South Africa as well as SSA.
- Energy storage should be addressed as a standalone resource/program in SA and not an extension of renewable generation or the REIPP.
- The implications of ES in the auto industry are significantly larger than have been previously considered.
- More study is needed to better understand the actual energy storage battery needs in SA for all applications.
- Need to better understand what the actual SA industry capabilities are with regard to energy storage. What SA companies are out there?
- SA cannot be everything to everyone in the energy storage value chain and needs to understand where it can be competitive and what its advantages are.
- If something is going to happen with building an energy storage industry in SA then bold decisions to be made.
- Decisions need to be made based on long-term economics. Investments may not have near-term payoffs.
- Electrification of SSA is dependent on finding funding. Who pays is the biggest question.
- Bureaucracy significantly slows infrastructure projects that are based on external funding. It can take five years to complete and route applications for funding on a project that takes 6 months to construct/install.

- It can be difficult to get financing for smaller infrastructure projects. Financial institutions prefer to fund large projects. Bundling of smaller projects into a generic program could be considered.

USTDA Presentation of Findings

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ACRONYMS

BESS	Battery energy storage system
DDM	Due Diligence Matrix
ES	energy storage
ESS	energy storage system
IRP	integrated resource plan
Li-ion	lithium ion
MW	megawatt
SA	South Africa
U.S.	United States
USTDA	US Trade and Development Agency

1 Introduction

On March 13, 2017 between 1:00pm and 3:30pm, a Presentation of Findings Workshop was conducted at U.S. Trade and Development Agency (USTDA) offices in Arlington, Virginia. The workshop was presented by the Parsons Assessment Team and attended by representatives from USTDA, other US Government organizations, banks/financiers, and industry. The purpose of the workshop was to present the key findings and recommendations for Objectives 1 through 6, with a particular focus on the current state of the international energy storage sector, U.S. sources of supply, and the applicability of the key findings and recommendations for Objectives 1 through 6 to other lower and middle income markets around the world.

2 Attendees

The following people were in attendance in the USTDA office, attendance for others on the teleconference are not listed:

Name	Organization
James Alford	King & Spalding
Siddharth Anyan	USIBC
Robert Batt	
Sandeep Baidwan	Continuum Associates, LLC
Rafael Chaparro	Quanta Technology, LLC
Rochelle Chernikoff	Parsons
Eliza Chon	USTDA
Michael Chung	Parsons
Ryan Franks	CSA Group
Jillian Foerster	USTDA
Randall Gentry	USTDA
Lenny Golbin	K&M Advisors, LLC
Varun Hallikeri	Delphos International, Ltd
Katrien Hinderdael	USTDA
Powell Holly	Broad Cove Group
Lauren Hovis	USTDA
Darnley Howard	Advansa International
Chinedu Igbokwe	NEC Energy Solutions
Renee Ingram	Diversified Enterprises Group
John Janik	Electronic Power Design, Inc.
Mike Jennings	Louisiana Cat
Randell Johnson	Alevo
Praveen Kathpal	AES
Jess Kersey	AECOM
Kendra Kintzi	USTDA
Carl Kress	USTDA
Manish Kumar	AES Energy Storage
Alissa Lee	USTDA
Tracy Mathieu	Partnership International, Inc.
Bernie Marable	Premier Consultants International, inc.
Chris Massaro	MAECI
Michael Mock	The Electric Alliance
Samuel Nana-Sinkam	MAECI
Parashu Nepal	International Development Institute

Ru Nyambuya	Standard Bank
Julian Oteng	Xago Africa Limited
Sarah Owen	UL, LLC
Gabe Paoletti	Eaton
Blair Pasalic	U.S. Department of Energy
John Rezaiyan	3E Consulting, LLC
Gustavo Segredo	GES Solutions, LLC
Douglas Shuster	Tuatara Group, LLC
Kate Steel	Power Africa
Charlene Sullivan	IFC
Ben Todd	Export-Import Bank of the United States
Daniel Tomlinson	IFC
Raoul Youssef	Global Development Associates. LLC
Seree Weroha	Alexandria Exim, LLC
John Works	Mott MacDonald
Nathan Younge	USTDA
Yilong Xu	USTDA

3 Presentation /Agenda

Opening introductions were made by Michael DeRenzo (USTDA Country Manager Southern Africa), followed by opening comments by Lida Fitz (USTDA Regional Director for Sub-Saharan Africa). Parsons Team members Paul Frink (Parsons, Project Manager) and Jeremy Hargreaves (E3, Economic Assessment) then presented a set of PowerPoint slides (included as Appendix A) based on the following outline:

- Team Introductions
- Description of Task Order
- Needs/Technical Assessment
    - Status of Energy Storage Internationally
    - U.S. Sources of Supply
    - Storage Use Cases
- Financial Assessment
- Economic Assessment
- Roadmap and Key Features
- Questions and Answers
- Survey

4 Questions and Answers

There were a number of short questions posed by attendees during the presentation.

- Grid Storage – Just Emerging slide: Does the "battery cost" include the whole system or just the Battery?
  Response: Costs for the Battery Energy Storage System (BESS) this is generally the DC-DC storage system and does not include the Power Conversion and Control system.
- US Vendors slide: What does PCC stand for?
  Response: Power Conversion and Control.
- Generic Technology Comparison slide: Why are Li-ion batteries only shown up to 10 MW?
  Response: Agreed, Li-ion is fully scalable technology. This is an older and more general chart. The full report contains a much more detailed chart (too large to fit on a slide) which provides more updated ranges for each parameter.
- Bulk Energy Storage slide: What is the basis of these numbers?
  Response: This is just an example, not absolute info.
- Instantaneous Reserves (on slide): The analysis assumed that storage was used perfectly
- Funding Gap slide: Yes, these values include benefits
- Funding Gap slide: Requested further explanation of slide. It was discussed and noted that the actual Economic Assessment report contains a detailed discussion of how to interpret the graph.
- Energy payback: What is the basis of these numbers?
  Response: This is based on ZAR and expressed in weeks/months

A question and answer session following the presentation included the following general questions and discussions:

- Electric cars and black water storage heaters are other examples of Energy Storage (comment from audience)
- During the economic analysis was energy storage paired with renewable generation?
  Response: It was assumed that renewable storage is located on the grid and did not constrain storage use to only store renewable energy
- Is storage considered to be "generation" in South Africa.
  Response: Yes, if it is located in front of the meter it is currently considered generation and a generation license is required. Behind the meter applications are considered generation if they put energy back onto the grid (rather than self-consumption) and require a generation license depending on the amount of energy placed back on the grid.
- Avoided costs for ancillary services were not included/not available for this analysis.
- It was mentioned that adoption of energy storage will require changes to existing regulation and tariff structures.
  There will be a challenge if SA government and the vertically integrated South Africa utility do not believe that energy storage has significant positive impact and should be encouraged.
- How committed is South Africa to energy storage?

Response: There is a very active, and somewhat political, discussion in South Africa right now related to the considered revisions to the 2016 Integrated Resource Plan. The results of that discussion will determine the degree of commitment.

- Is the cost of disposal/recycling of Li-ion batteries included?
  Response: Generally no. There are limited Li-ion battery recycling programs. A number of different companies and technologies will include recycling and disposal costs in their initial price for the system that have valuable or toxic components. About 90% of lead acid batteries are currently recycled. That is good but there is still room for improvement.
- What are the associated environmental issues?
  Response: This is discussed in detail by technology under the Environmental Impact Assessment report.