RESEARCH DIRECTION REPORT (2019-2024)

Eskom

A WORKING DOCUMENT

Eskom Research, Testing and Development Research Direction Report: a working document (RaDaR) 2019 - 2024

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Foreword

Eskom, like many other global power utilities, is undergoing fundamental changes shaped by technology drivers, resulting in changing business models, which threaten to disrupt the century-old centralised business model in the power industry. Klaus Schwab, President and Chair of the World Economic Forum (WEF), highlights that disruptive innovation development and diffusion are faster than previously experienced in the history of the world.

These disruptions are on the brink of driving important changes in economies and societies. We expect that the next generation of power utilities will be as significant as the impact of technology drivers on the IT and telecommunication industries.

Eskom's research strategy and programme have been developed from detailed analysis of technology trends, economic, social, and market drivers, perspectives of international utilities, collaboration in the local industry, and executives in Eskom, which has resulted in the presentation of this Research Direction Report (RaDaR). The strategy is focused on 13 grand challenges and prepares Eskom for the future by taking advantage of opportunities and threats from emerging innovations. The Fourth Industrial Revolution is changing the world – aided by a combination of technologies in the physical, digital, and biospheres. Eskom research needs to prepare the organisation for these technology and business changes.

The accelerated pace of change and technological renewal means that the traditional ways in which electric utilities operate the plant, as well as serve their customer, is changing. New strategies and solutions need to be developed to take advantage of this changing world. Disruptive innovations in the electricity industry affect the commodity price, which, in turn, has an impact on consumers, economic growth, and universal access to energy.

The Eskom research strategy and programme allow Eskom to envision the future and align its scarce resources and efforts to develop new solutions to optimise existing business and create new business opportunities to grow. The Eskom Research, Testing, and Development mandate has been expanded from providing solutions focussed only on optimising the existing assets to developing business case solutions for emerging technologies.

I am proud to endorse the 2019 to 2024 RaDaR as an ambitious plan to push the boundaries of science and engineering to ensure innovative solutions to solve Eskom's challenges and, in some portfolios, deliver ground-breaking research. I invite external parties to collaborate and partner with us to align our resources to ensure common research goals for maximum benefit to all South Africans.

Kerseri Pather
(Acting) General Manager
Risk and Sustainability

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1 OVERVIEW: RESEARCH PROJECT

The Role of Eskom Research

This five-year research review is based on extensive consultation within Eskom and broader external participation.

It is vital to recognise that electricity/energy-based technology development and innovation is imperative to Eskom's and the country's productivity and success. The electricity industry is facing significant challenges associated with the need for greater flexibility, rapid technology advances across the entire value chain and changing business models. Electricity and associated technology development, innovation and leadership must play a profound role in assisting South Africa to grasp the opportunities and manage the threats in the immediate future.

Globally electric utilities are facing challenges like no other time in their history, and South Africa too is no different. Electric utilities are dealing with declining sales and revenues, environmental concerns and rising costs. Balancing social, environmental and economic imperatives relies heavily on technology development and breakthrough to provide a way forward when all other routes appear blocked. The Eskom Research, Testing & Development (RT&D) business unit is dedicated to finding technology solutions that can be applied primarily within the company to ensure it fulfils its mandate to the nation.

The Eskom Holding Corporate Plan (2016/17 – 2020/21) affirms that RT&D performs research, selects and develops next horizon technologies that support Eskom's future strategic objectives by:

- Understanding the context and applicability of emerging technologies in Eskom.
- Developing and securing promising technology options.
- Choosing the optimum future technologies that are fully aligned with Eskom's strategy.
- Implementing and transferring knowledge into the relevant areas of the Eskom business.
- Accelerating the implementation of technologies by utilising Eskom's project life cycle management (PLCM) processes.
- Utilising clear customer requirements and expectations, stakeholder management and advocacy to ensure ease of adoption. of new technologies into normal business operations.
- Fostering an innovative culture to encourage an effective ideation process through an innovation circuit.
- Generating intellectual capital that is harnessed towards organisational and national commercial benefit.
- Fostering a multinational network of memberships and technical collaborations.

The RT&D business unit introduces next horizon 'flagship' technologies into Eskom by:

- Managing an effective pilot and demonstration project programme.
- Submitting project proposals for approval in line with the defined PLCM process.
- Ensuring effective programme management of progress, cost and quality of projects.
- Managing the integration of research and demonstration projects into approved business and technical processes.

Eskom Research is guided by the following beliefs;

- "We are predominantly a technology early follower" - Except for a few carefully chosen areas, Eskom does not wish to lead technology development. Rather it will focus on technology identification, acceleration and application, not technology development.
- "Emerging technologies must be proven to reduce risk" - Through a well-managed pilot and demonstration programme, risk of the introduction of new technologies to Eskom is reduced.
- "Our core competence is Electrical Power generation, transmission and delivery and associated systems and

processes" - We explore technologies aimed at the optimal delivery of our product to the satisfaction of all stakeholders - we have low levels of investment in the creation, invention, design and manufacture of new technologies or those not directly aligned with Eskom's core business.

- "We embrace sustainable development" - Solutions must be economically, socially and environmentally balanced and have practical application.

Research Vision

A world-class research and innovation facility staffed by internationally respected researchers verified by international benchmarking and peer review and enabled by increasing existing funding investment in people, laboratories and equipment.

Research Mission

To select and develop next horizon technologies that support Eskom's future strategic objectives through

- Focus on the Customer – We identify and understand our key customers. The inclusion of key customers in our planning and research steering committees ensures the work we do is responsive, practical and focused on their needs.
- Added Value – We do research to create value for our customers, and this value is measured objectively.
- Produce quantifiable outputs – Research produces tangible and defined results that can be implemented in our customers' business.

Research Mission

The vision and mission have led to the adoption of the following objectives of Eskom Research and Development:

- Focussed Research Outputs – research programme focussed on needs inherent in operational and strategic imperatives that produces value add tangible outputs encapsulated in a five-year research work plan.
- A multinational network of supporting research institutions by selective development of relationships with institutions that can provide Eskom with knowledge, know-how and insight into current and future business challenges.
- Understand the technology future – fully understand the emerging technologies and their context and applicability in Eskom.
- Develop and secure technology options – Promising technologies are thoroughly researched and all risks and opportunities are well understood.
- Choose the optimum technologies – Of all options available, those that show strong alignment with Eskom's strategy and have high executability are pursued.
- An effective programme of pilot and demonstration projects by investing capital funds in projects that assess technical and financial risks of future innovations and thus enable proper business investment decisions to be made at the appropriate time.
- Accelerate Implementation – Ensure chosen technologies are fast tracked to implementation.
- Improve Acceptance – Stakeholder management and advocacy to ensure ease of insertion of new technologies into normal business operations.
- Clear research technology roadmaps for the organisation by highlighting the choices available and consequences of strategic technology decisions.
- Systematic development of an innovation culture in Eskom through the catalysing effect of a robust and effective innovation circuit and its processes and systems.
- Optimise Asset Operation – Consult closely with the line divisions to identify operational issues and provide expertise to address technology issues.
- Develop Skills – Drive for greater increase in internal resources to perform research, release skills into the organisation.

Thus, we are a needs-driven organisation focussed on the systematic acquisition of knowledge and the application, development, refinement or demonstration of new and innovative technologies and solutions to satisfy Eskom's operational and strategic requirements through centres of expertise.

Sumaya Nassiep
(Acting) General Manager of Research, Testing and Development

Eskom RT&D Structure & Functions

Research, Testing and Development is a business unit within the Risk and Sustainability Division of Eskom and is responsible for the planning and implementation of the (figure 1) Eskom research programme in line with the annually allocated research budget.

The Technology Strategy and Research Management (TS&RM) department is responsible for the strategic alignment with Eskom and industry challenges, ensuring that the right research is undertaken. TS&RM is responsible for scanning the local and international environment to identify and contextualise issues facing the industry. The outcomes guide the development of the research strategy, which is published as a five-year Research Direction Report or RADAR (this document). TS&RM has ensured that the processes to initiate the programme have been put in place including the research Project Life Cycle Model (PLCM), Research Steering Committees and the RT&D Investment Committee. Additional functions include the assurance that the research is strategically aligned with Eskom's needs, both short and long-term; the research programme adds value and avoids duplication; governance of the research process; the programme is monitored and reported on to senior management; and the delivery against time, cost and quality is measured.

The Plant Performance and Optimisation, Power Delivery and Utilisation, and Sustainability departments are responsible for the execution and implementation of the research programme. The Centres of Expertise (CoE's) within these departments deliver the products and services to the RT&D customers against the approved research programme, ensuring that the right research is conducted. The CoE's ensure that the Eskom stakeholders' requirements are met and continually improves its performance through innovative and sustainable solutions, satisfying their customers' requirements and expectations for the benefit of all stakeholders. RT&D has a staff complement of highly skilled persons that provide research, innovative solutions, technology direction, special investigations and testing for Eskom's business challenges.

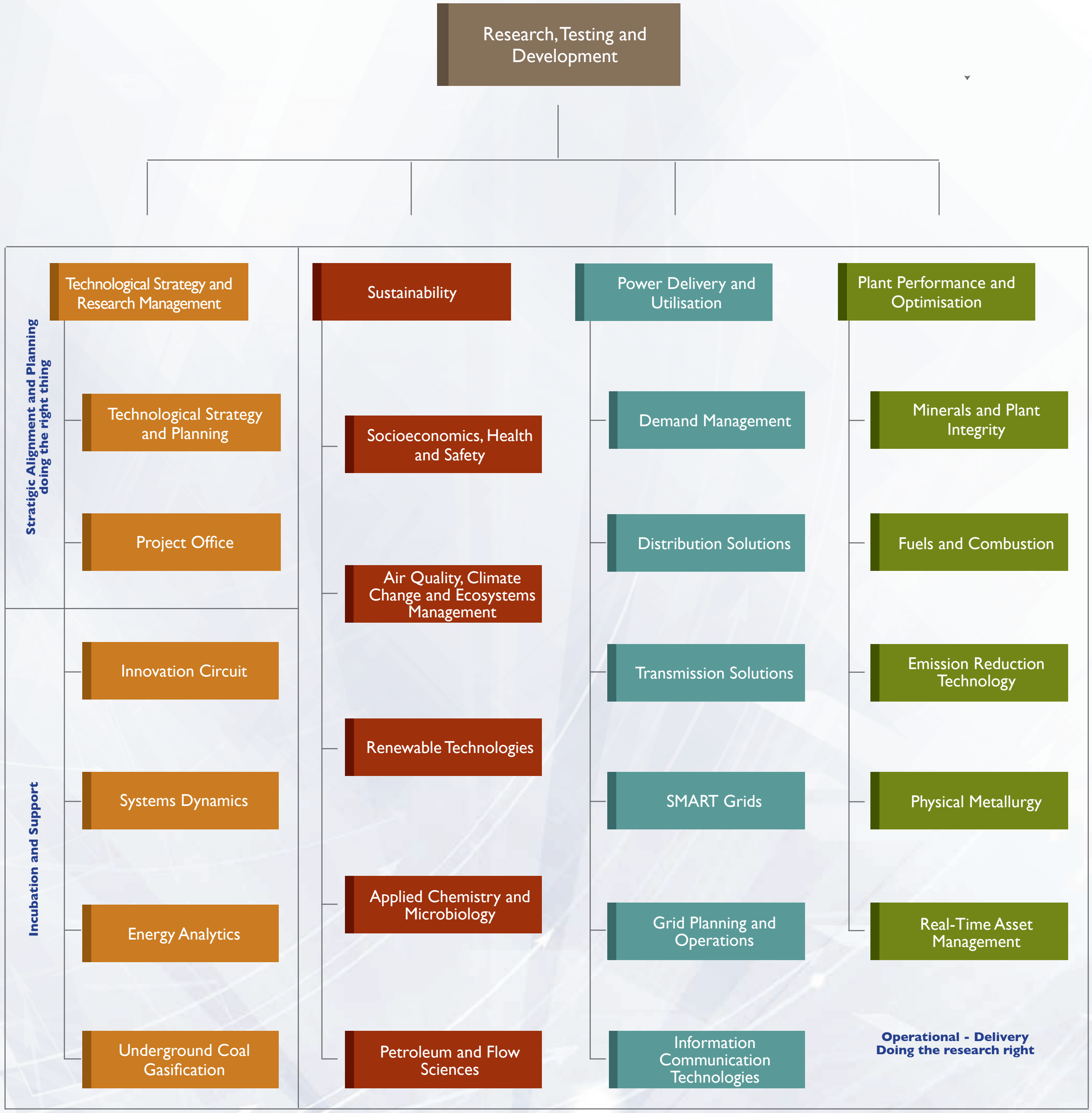


Figure 1: Eskom RT&D Structure

Research Strategic Plan 2019 - 2024

The RT&D five-year strategy and plan allows Eskom RT&D to envision the future, to identify threats and opportunities and then to align our resources to best address the solutions. The Eskom Holding Corporate Plan (2012/13 – 2016/17) includes the following statement: "Eskom has the ambition of becoming a highly innovative company and being on par in research, testing and innovation with internationally leading power utility companies". This is an ideal to ensure Eskom is resilient and successful and realises the value from its investment in R&D. The Research, Testing and Development business unit delivers this value by providing Eskom's leaders with technical and business knowledge that empowers them to make confident decisions about the current and future business.

The strategic planning process included an extensive scan of the technology environment, global and national energy policies, changing national and international energy landscape and discussion on business needs across the company. The Eskom RT&D Radar was compiled with extensive consultation within Eskom and broader input from industry, external to Eskom (Academia, CSIR, SAIEE, Cigre, etc.) An in-depth analysis was then conducted of the findings and three major questions emerged as being key to the immediate and longer term sustainability of Eskom, namely:

1. What would our technology choices and future generation mix be in 2050?
2. How do we support (operate and maintain) our existing Generation, Wires & Retail business with constrained budgets?
3. How will Eskom adapt its business to the imminent strong technology disruptors and develop new business?

The RaDaR 13 Grand Challenges have been identified under each of these questions as detailed in the figure 2 below.

Future Generation Mix	Supporting the Existing Business	Focus on New Business
Coal	Coal	Future Customer
Water	Transmission Asset Management	Flexibility - Generation & Wires
Clean Coal	Transmission Build	Digital Revolution
Gas	Distribution Performance (SAID)	
Nuclear		
Renewables		

Figure 2: The 13 Grand Challenges

The current RaDaR has focussed on three fundamental questions that needed to be answered to guide the business in the future. These include:

- What future generation businesses and technology choices should Eskom be in to remain profitable in 2050?
- How does Eskom maintain and operate the existing Generation, Retail and Wires businesses under severely constrained servitudes and budgets?
- How does Eskom adapt its business to survive the imminent technology disruptors and grow new business?

Against these questions, thirteen focus areas, referred to as Grand Challenges, have been identified to align the research programme with the strategic direction identified. All new research projects need to align with these challenges to maintain the strategic alignment. These challenges, together with their primary research question, include:

1. **Coal:** RT&D will support Eskom in developing and implementing solutions within five-years that guarantee the quality of coal in line with the design of the plant whilst ensuring the price of coal remains competitive relative to other resources.
2. **Water:** Achieve fleet water security through risk-based analysis including (longer-term) climate change and environmental compliance to entire fleet, including fleet renewal.
3. **Clean Coal:** RT&D will provide cutting-edge cost-effective design solutions for low emission coal options for Eskom in the next five years.
4. **Generation Asset Management and Plant Performance:** RT&D will provide greater insight into plant condition for asset management purposes and demonstrate technology solutions to drive Performance to 80:10:10.
5. **Gas:** RT&D will provide Eskom with gas strategic options and improve business case definitions based on the latest technologies, new applications and trends in the gas market within three years?.
6. **Nuclear:** RT&D will develop Advanced High Temperature Gas Cooled Reactor technology options for Eskom in the next five years.
7. **Renewables:** RT&D will provide optimised solutions in support of Eskom's Corporate Plan through the delivery of at least 3-Renewables' applications in the next three years.
8. **Transmission Build Solutions:** RT&D will provide design solutions for the evacuation of power from new generation, including the Southern African Development Community, and refurbish plant without customer interruption in constrained servitudes and constrained budgets within five years.
9. **Transmission Asset Management and Technical Performance:** RT&D will provide greater insight into Transmission plant condition for asset management purposes and demonstrate technology solutions to improve operations and maintenance under constrained budgets whilst maintaining system minutes performance, within five-years.
10. **Distribution Asset Management and Technical Performance:** RT&D will improve technical performance (SAIDI & SAIFI in the next five years on a constrained budget and implement a proactive strategy for Asset Management.
11. **Future Customer:** Can RT&D formulate affordable value added, business products and services for Eskom's existing and new customers based on an integrated, smart, green localised and energy efficient technologies in the next three-years?
12. **Flexibility:** How do we operate our plant in a real-time trading environment in the next 5 years?
13. **Digitial Revolution Grand Challenge:** Can RT&D identify, research and demonstrate digital technologies that will realise R10Bn of savings through step improvements in people, process and technology in the next 5 years?

The Eskom Research Process

The Eskom Research, Testing and Development business unit is built around the relevant mix of research, testing, consulting and demonstration projects. The research programme is built upon a robust research process (figure 3) and staff with excellent technical expertise.

Figure 3 - High-level overview of the Eskom Research Process

A defined governance structure ensures that strategic alignment as well as operational inputs are achieved. A multi-layered governance structure is in place. The Research processes as well as the Demonstration and Pilot and processes are being aligned with the Eskom Project Life Cycle Model (PLCM). In addition to the governance processes required by the PLCM, three committees internal to RT&D ensure alignment with Eskom's needs;

• **The Research Steering Committee**, one for each Research programme identified. These committees are made up of Eskom staff chosen for their expertise in their field. Each member represents a customer group, usually a line division. As a member they articulate the needs of the division to the committee. They meet twice a year to collectively determine the research activities to be pursued in the coming period and to agree on the allocation of resources to those activities. The steering committee members nominate working group members to assist in achieving the research goals, which must align with the needs of Eskom. Throughout they are guided by a need to seek high value add activities and reject those of little value. Their role is also to ensure that outputs are defined and achieved and to communicate these back into their respective part of the organisation.

• **The Demonstrations and Pilots Steering Committee** who meet at least four times a year (or more regularly if required) to review and monitor the implementation of the Demonstration and Pilot Projects carried out under the auspices of the Risk & Sustainability Division. This committee considers proposed Demonstrations and Pilots Projects for inclusion into the programme and assesses proposed Demonstration and Pilot Projects against the selection criteria for Demonstration and Pilot Projects (as defined later in this document). This committee provides the necessary strategic direction for the projects to ensure that they are aligned with the Eskom vision, priorities and needs by monitoring the progress of the project outputs and addresses any issues, variances or problems identified. They also review the projects for risks related to sustainability. Committee member duties include the review of proposed costs for outputs and prioritisation of proposals as necessary in terms of the programme budget.

• **RT&D Investment Committee** meets at least four times a year and provides governance to ensure that the initiatives, items, activities, outputs and financial investments are aligned with the RT&D Grand Challenges and maximise value for Eskom. This committee provides the necessary strategic direction for the projects to ensure that they are aligned with Eskom vision, priorities and needs. They also review the projects for risks related to sustainability. Included in their duties is to review the proposed costs for the outputs and prioritise as necessary in terms of the programme budget.

The ultimate deliverable arising from the governance framework is a programme of research projects, and these are further broken down into research activities. Many activities make up one project. The activities are allocated to Centres of Expertise in departments within RT&D to project manage and ensure delivery, and activity leaders are appointed. External organisations can also be utilised either through membership agreements or contract research, and these partnerships expand the scope of available resources to perform the work required.

It is crucial to align the research strategy with Eskom's strategic imperatives and operational risks in order to ensure focussed applied research and development that enables the meeting of Eskom's short- and long-term objectives and thus adds value. Electricity/energy-based technology development and innovation is closely coupled to productivity and growth of the Eskom business and the country. Electricity and, in particular, technology development, innovation and leadership around electricity/energy, plays a profound role in assisting society to grasp the opportunities and manage the threats emerging in the immediate future.

To guarantee this alignment, the planning process begins every year with a critical review of the existing portfolio. Structures, processes and systems are in place to manage the portfolio. The portfolio is examined for fit against the latest Eskom and Divisional plans, emerging market and technological trends and changing energy policy and revised accordingly. As part of this process, and on a continuous basis, customer feedback is incorporated and used to motivate changes where required. The primary mechanisms for this is the interaction with the organisation in the development of this report and the Research Steering Committees. As far as possible, divisional customers are consulted individually to seek their input into the research portfolio. As a final check for fit, the portfolio is also compared against the company stakeholder compact, corresponding performance incentives and adjusted if gaps are still evident.

The choice of research projects is crucial since these become the cornerstones upon which to build the entire programme. Steering Committees are formed at these project levels and if they are not correctly chosen or constituted, parts of the programme can be misaligned. The projects can be selected based on certain technologies or based on internal customers, or, as is the case at the moment, on a best fit combination of both.

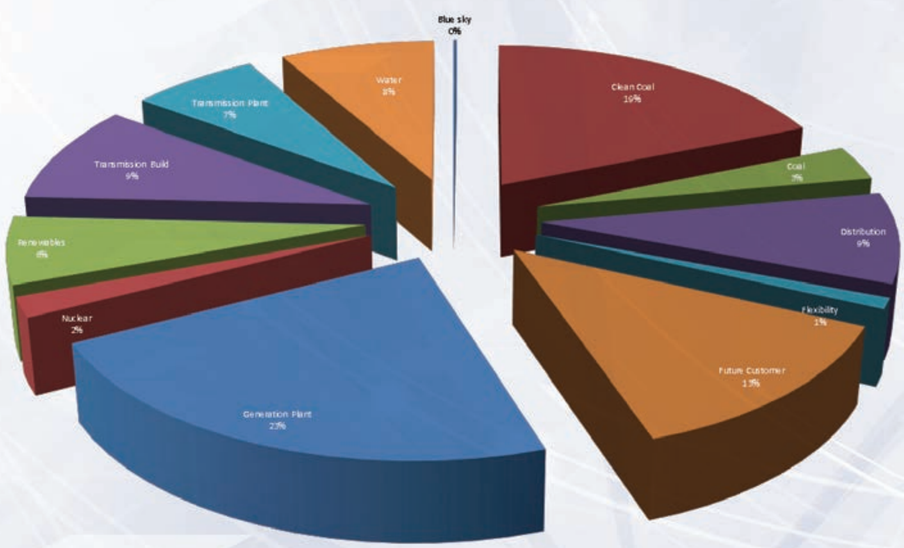
In addition, an annual strategic direction workshop is hosted for external stakeholders from the power industry and academia to review and provide input into the research programme and strategy.

The pace and scope of technological change in the electricity industry is greater today than ever before and, as such, the need to appropriately position Eskom, from a technology perspective, is critically important.

2018/2019 Eskom RT&D Research Portfolio

The Eskom Research budget is included in the price discussions and negotiations with the South African National Energy Regulator and fully recovered through the tariff.

An annual workshop with industry stakeholders is convened to shape and direct the research programme. Each research project follows a strict governance process through the respective technical steering committees and Divisional Investment Committee.



(A)	Blue Sky	(R240 667.00)
(B)	Clean Coal	19%
(C)	Coal	3%
(D)	Distribution	9%
(E)	Flexibility	1%
(F)	Future Customer	13%
(G)	Generation Plant	23%
(H)	Nuclear	2%
(I)	Renewables	6%
(J)	Transmission Build	9%
(K)	Transmission Plant	7%
(L)	Water	8%

Figure 4 – Eskom RT&D Operational Research Budget FY 2018/19

Eskom RT&D's current research portfolio for the 2018/19 financial year is tabulated in table 1 below:

Table 1 – Eskom RT&D Operational Research Projects FY 2018/19

Advanced Sensing, Control & Communications	System Dynamics Memberships
Substation IED - Change Monitoring & Reporting Tool Investigation	Supply Side Dynamics
Field Effects Research	Fuel Cell Technologies for Distributed Generation
Distribution Safety	Improving LCOE Solar PV
Distribution MV and LV Network Safety	Integration of Renewables
Power Quality in the Future Grid	Potential PV Penetration in WC
Relocation of KIPTS (Research)	Facility Power Curve
Battery Management and Monitoring System	Small Scale Solar PV Power Estimation
Non-destructive Testing of Wood Poles to Reduce Cost and Improve Reliability	Solar PV Testing Facility
Cable Theft Detection, Mitigation and Prevention	Constrained Rietfontein Feeder PV Generation & Battery Storage Demonstration Plant
D-VAR: A Dynamic Solution that Addresses Threats to Distribution Voltage	Solar Heat for Industrial Processes (SHIP): Desalination
Planning and Tariff Approaches to Models for Grid Connected Renewable Energy	Capacity Credit Study for Wind Installations in South Africa
Load Forecasting Modelling Project	Short-term energy forecasting for renewables
Feasibility Study Large Penetration of Renewables	Water Dynamics
Energy Management Technologies	Saline Water Chemistry
Demand Side Technologies	Improve Water Utilisation and Efficiency within Generation
Customer Research	Optimised water recovery and treatment for Generation
Load Studies Data Store	Resource Assessments
Network Performance Assessment	Concentrating Solar Power
Nissan Leaf Electric Vehicles Pilot (Large-scale Energy Storage)	Wind Power
Smart Home	PV at Critical Substations
Eskom Heritage Park LV Network Embedded Rooftop PV Project	Air Quality Research
Thermal Energy Generation & Trading	FGD Slurry Characterisation Tests
Small Scale Embedded Generation	Climate Change
Revenue Management	Clean Coal Technologies
Smart Electricity	IEA - Clean Coal Centre
Underground Pumped Hydro Energy Storage (UPHES)	Gypsum Utilisation
Advanced e-Mobility Solutions	SA Centre for Carbon Capture and Storage
Distributed Energy Resources (DER)	Ash Utilisation Large-scale
e-Mobility Advocacy	Ash Roads
e-Mobility Platform-Based Services	New Ash Technologies
Bulk Power Transfer Technologies	Torrefied Biomass Co-firing at Arnot Power Station
Overhead Line Capacity Uprate	Geohydrology Mine Backfilling
DFACTS Technologies	CFB FGD Demonstration Plant at Kendal Power Plant
Bulk to Beyond-the-Meter Energy Storage	Ash Handling Plant
Battery Technology Development	Coal Combustion & Characterisation
Energy Storage Use Cases and Forecasting	Development of the South African UCG Field Map
HTLS Conductor Investigation	Provision of Legal Services
Insulator Research Facilities	Coal Sampling Standards
Life Management of Substations	Materials Life Assessment Technology
Improving the AC System Performance	Non Destructive Examination
Improvement of the Cahora Bassa HVDC System	Plant and Material Integrity
Wireless Field Area Network (FAN) for the Smart Utility of the Future	Welding Technology Research and Innovation
Enhanced Situational Awareness through Advanced Analytics	TWI (The Welding Institute)
Application of RPAS for Power Line Inspection	Life Management of Transformers
Legacy Interfaces/Protocols to IP Migration	Doble Engineering
Automated Vegetation Monitoring of Power Lines	Laser Shock Peening
Investigation into the Fibre Optic Cable Deployment Technologies for Installation on the Power System Infrastructure	Boiler Superheater Temperature Maldistribution
Reak Time Digital System	Ecosystem Management
Advanced AC System, Design and Development	Membership: Source Testing Association
Lightning	Turbo Generator Life Management
Distribution Emergency Restoration Tower Development	Rotating Blade Health Monitoring
Distribution Reliability and Power Quality	Advanced High Temperature Reactor
Energy Storage	Fossil Fuel Foundation
Life Management of Lines	Fireside Corrosion Monitoring
Development of Power Series Books	Waste Management
Electrical Utility: Technometrics	Eskom/CSIR NDT Facility Establishment
Energy Markets: Econometrics	

Demonstration and Pilots

Eskom has a pivotal role to play in ensuring that the electricity technology vision of the country is realised.

In order to ensure that the key technologies which can fundamentally change Eskom's and South Africa's current technology path are part of our overall strategy, a technology innovation and demonstration process is in place. This process takes into consideration financial constraints, status of technology, potential to change current technology paths and funding options. It is critical now more than ever, given the long-term nature of our sector and current financial challenges in Eskom, that technology innovations are optimised and that longer-term risks are considered. The Eskom Research Demonstration and Pilots programme and process ensures new technologies are explored and introduced effectively.

Eskom's definition of a demonstration project is, "a production scale asset that is constructed to evaluate and validate prior research findings and recommendations to enable future business decisions (especially the understanding of risk and certainty of costs) regarding the applicability of the technology in an Eskom context." It is clear that certain technologies have the potential to transform the Eskom business model. By building demonstration plants, emerging technologies can be introduced into the mainstream of Eskom with minimal risk. The diagram below shows how the demonstration projects follow a path parallel to but not separate from the 'usual' Eskom project life cycle model and need to compete against other projects in the portfolio for priority of resource allocation. All approvals make use of the defined strategic, financial and commercial governance institutions within Eskom and comply with existing delegations of authority.

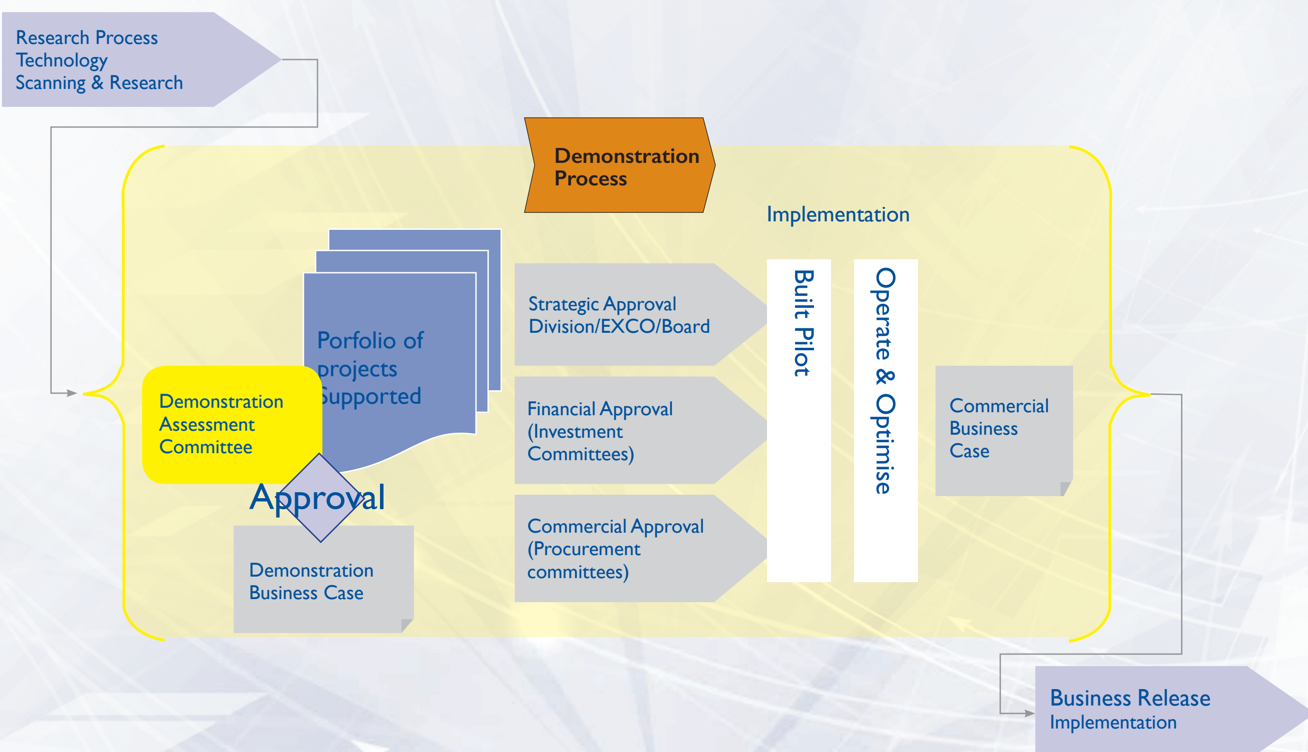


Figure 5 - Governance Process for Pilot and Demonstration Projects

It should be noted that there are two main business case requirements; a demonstration business case and sometime later a commercial plant business case. The former is required to launch a new demonstration project and is assessed by the Pilots and Demonstration Committee. The following criteria need to be met before a demonstration business case is approved:

- The demonstration portfolio can accommodate the project in terms of available resources.
- The technology will have a direct and beneficial impact on Eskom operations and the achievement of operational and strategic objectives.
- The proposed solution addresses a specific need of the organisation that cannot be met through common, existing technology solutions (e.g. reduced emissions) or South Africa is well positioned to leverage the proposed solution (e.g. High solar radiation footprint).
- The approach is one of early follower, not proof of concept. The technology has been sufficiently proven elsewhere to reduce risk to acceptable levels. The project utilises component parts that are well entrenched in other parts of the world.
- There are justifiable reasons to pursue an early follower approach (e.g. addresses capacity constraints, emissions targets, reduced lead times, local manufacture capacity building, etc.).
- There is a sound business case for the pilot based on stated and measurable assumptions.
- Costs of the pilot are well identified and known and the pilot process will improve confidence in costing methodologies for a commercial plant.
- All potential benefits are identified, quantified and conservative. This is one baseline for assessment of the pilot before making a commercialisation decision.
- The schedule (timeline) is well defined and realistic.
- Technology risks have been quantified.
- Alternate technology partners, guarantees, long-term support agreements are explored and proposed.

  At the end of a successful demonstration phase the technology is considered for widespread application in Eskom. The following criteria are used to assess the commercial readiness of any technology after successful demonstration:

- The primary fuel stream is sustainable, i.e. proven availability and cost at production scales.
- The project has run sufficiently long to enable operational learning and exposure to risks pertaining to the technology solution. An inclusive process has been established to review and mitigate these risks.
- A thorough and robust business case is developed based on the learning from the pilot and encompasses:
  - Mitigation of all risks identified.
  - The full life cycle of the asset.
  - The organisational resources and skills required to absorb the solution into 'normal' business operations.
  - The impact on health, safety and the environment.
  - The project can leverage local manufacture and in this way reduce cost and increase manufacturing capacity and growth.
  - The project places South Africa in a strategically advantageous position in the World Energy Market.
  - Funding alternatives have been explored and exploited.
  - Relevant research partnerships have been established.
  - Stakeholder engagements have been forthcoming and issues resolved, including licensing issues.

A commercial business plan is prepared at this point and motivated into the mainstream project approval structures. The benefit inherent in this process is that the demonstration phase of a project reduces overall business risk and ensures all longer-term and implementation risks are considered and mitigated. The innovation process and the use of demonstration plants aim to reduce risk for the rollout of a commercial unit or fleet, as well as fast track the implementation of a new technology which has positive benefits for the company. In particular, the range of uncertainty is reduced and negative impacts are better understood and mitigated whilst positive effects are exploited, i.e.

- Calculation of efficiencies and outputs.
- Operating cost reduction opportunities identified in pilot applied to commercial projects.
- Design of future business structures and processes required to manage new technology.
- Skills development in new technology to ease implementation and integration with line division.
- Establishment of robust networks of supporting companies and institutions.

Table 2 – Eskom RT&D Pilot and Demonstration Research Projects FY 2018/19

Pilot and Demonstartion Projects for Financial Year 2018/2019	
Underground Coal Gasification (UCG)	R480 000
Carbon Capture & Storage	R5 000 000
Biomass Torrefaction	R38 000 000
CFBC Pilot Scale Test Facility	R46 000 000
Majuba UCG Partnering	R17 598 400
Low Fuel Igniters	R13 000 000
Smart Metering (Smart Grid Technologies	R500 000
Robotics and UAV Inspections and Maintenance	R5 000 000
Smart Integration of Embedded Generation	R2 353 212
ESP Smmonia Conditioning	R2 000 0000
TOTAL	R129 931 612
Asset Purhase - RT&D	R59 194 542
TOTAL (as per Corporate Plan)	R189 126 154

Membership and Partnerships

Research enables an organisation like Eskom to maintain its viability and competitiveness in a rapidly evolving energy market. Research answers many of the questions that face the organisation in its challenge to remain sustainable and grow.

Eskom does not have the resources to undertake all of the research it requires to keep abreast of the latest technologies and trends worldwide. Co-operation and collaboration with national and international research organisations provides an opportunity to leverage investment while maximising Eskom's information and knowledge base. The focus of this approach is to:

- Complement Eskom's research and development resource base with national and international expertise;
- Provide rapid and reputable support for specific research needs; and
- Ensure effective knowledge and technology transfer to maximise the return on the investment.

Membership

- EPRI (Electric Power Research Institute)
- Doble
- IEA Clean Coal Centre
- TWI (The Welding Institute)
- ESA (Electricity Storage Association)
- EUTC (European Utility Telecommunication Committee)
- STA (Source Testing Association)
- FFF (Fossil Fuel Foundation)
- CorrISA (Corrosion Institute of Southern Africa)

Collaborative agreements or memoranda of understanding are also in place with the following organisations:

- CSIR (Council for Science and Industrial Research)
- SANEDI (South African National Energy Development Institute)
- CRIEPE (Central Research Institute for the Electric Power Industry in Japan)
- WRC (Water Research Commission)
- IERE (Electric Power Technology Platform)

Memberships and partnerships will continue to play an important part of the Eskom research programme. They provide and important access to knowledge would not necessarily be easy to obtain using internal resources. Technology transfer is critical to the effective leverage of these memberships and is managed through the research governance processes..

2 THE COAL GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Coal Grand Challenge

Coal is deeply imprinted in the South African economy, driving the industrialisation of this country for more than 150 years.

Coal provides the highest foreign exchange income of any commodity in South Africa including gold, platinum, iron ore and diamonds. It is an important source of primary energy, providing 91% electricity and 30% liquid fuels. Coal also provides 98% carbon reductants in the metallurgical industry, producing more than 200 major chemicals and over 7 000 carbon-based products such as paints, plastics, fertilisers, explosives, etc.

Coal is the largest primary energy input for the Eskom business and is the biggest cost. Eskom annual reports indicate that the cost of primary energy has escalated over the years by an increase of approximately 33% in 2012, 15% in 2013, 19% in 2014 and 2% in 2015 [5]. The National Energy Regulator of South Africa (NERSA) has approved a 5,23% price increase for electricity for the period 2018–2019.

Pressure is mounting on the fossil fuel industry as countries transition towards low carbon economies. The impact on the global market is over-supply and declining prices. International global coal prices have been on a downward trend since 2013 and are predicted to continue on this trend. The South African Department of Energy has circulated a draft carbon tax policy for implementation by 2020. A carbon tax will increase pressure on an already shrinking market and increase the cost of coal in Eskom. The threat of possible coal mine closures poses a risk of security of supply to Eskom power stations and increases Eskom's price of electricity.

There are several major concerns for coal in South Africa. Central Basin coal resources in Mpumalanga are being depleted or substantially unproven, and remaining reserves are of a declining quality. Currently the run-of-mine coal qualities are generally higher in ash content and therefore lower in grade. Most of the better quality coals have already been extracted and exported as they attract higher market prices.

There is an increasing demand for lower quality South African coal exports, particularly to markets in India. This creates competition for the quality of coal that Eskom has traditionally enjoyed sole demand for.

In order to operate a financially sustainable business model, the coal grand challenge supports the Eskom business in developing and implementing solutions within five years that guarantee the quality of coal in line with the design of the plant whilst ensuring the price of coal remains competitive relative to other sources.

Vision

To support Eskom's Generation Division by researching, evaluating and optimising coal combustion performance. To support Eskom's Primary Energy Division by researching and evaluating alternative coal resources, varying coal quality specifications and opportunity fuel supplies.

Research alignment with Eskom priorities

Coal is Eskom's largest operating cost item, contributing approximately 30% to the operating cost base. Following coal cost escalation of >12% since FY2010/11, Primary Energy reduced this escalation to just 3% (against a 12% target).

For the next five years, Eskom will be pursuing strategic objectives, including:

- Building on the successes of FY2016/17 to deliver a further R43 billion in coal savings over the period.
- Ensuring the optimal dispatch of coal-fired power stations.
- Achieving an acceptable balance of security of coal supply and risk exposure.
- Optimising logistics to achieve cost efficiencies across the coal supply network.

Key technical research questions are:

- Understanding the country's coal resources and reserves, and matching these to Eskom's coal-fired power station specifications and Primary Energy Division's.
- Improving long-term coal forecasts.
- Understanding the cost components and market norms for mining, beneficiation and delivery of coal to Eskom.
- Understanding opportunity fuels and suitability for Eskom coal-fired power stations.
- Understanding opportunities for optimising the Eskom coal quality specifications to accommodate the declining quality of coal supplied in the country.
- Understanding and quantifying combustion performance of alternative coal resources and reserves in closer proximity to Eskom's coal-fired power stations, thereby optimising coal logistics.
- Understanding opportunities to improve coal combustion on existing stations.
- Understanding the suitability of existing coal supplies for other power stations, given the potential closure of older generating assets.

Landscape

Coal is the largest cost for the Eskom business, and changes in coal-related policy in the energy landscape will have significant impacts on the Eskom business and operating model.

There are several pieces of legislation that govern the primary energy landscape both directly and indirectly. These are listed below:

- National Environmental Management Act 197 of 1998
- Mineral and Petroleum Resources Development Act, No. 28 0f 2002.
- South African Mining Charter
- National Water Act 36 of 1998
- Occupational Health and Safety Act (No 85 of 1993
- Environmental Conservation Act 73 of 1989
- National Road Traffic Act No 93 of 1996
- State Land Disposal Act 48 of 1961
- Mine Health and Safety Act 29 of 1996
- Carbon Tax Policy
- White Paper on Science, Technology and Innovation

- National Development Plan
- Integrated Energy Plan
- Integrated Resource Plan
- National Environmental Management Act 197 of 1998
- The National Climate Change Response Policy
- Carbon Tax Policy
- White Paper on Science, Technology and Innovation
- Industrial Policy Action Plan
- Beneficiation Strategy for the Minerals Industry of South Africa
- Occupational Health and Safety Act (No 85 of 1993
- National Transport Master Plan
- State Land Disposal Act 48 of 1961

Future strategic focus areas

• Financial sustainability – research coal market costing norms, support Eskom Primary Energy strategy and operations, inform Eskom's multiyear price determination with the National Energy Regulator of South Africa and inform the negotiation of year-on-year escalation in the total cost of delivered coal with suppliers.

• Generation least-cost dispatch of production – research varying coal quality specifications and opportunity fuel supplies in order to improve coal-fired power station flexibility, cost of generation and environmental compliance. Research technologies that can monitor evaluate and optimise coal quality and combustion performance.

• Security of supply – research and quantify combustion performance of alternative coal resources and reserves, and technologies suitable for utilising such coal, to inform Primary Energy's coal supply and risk management planning.

• Logistics optimisation – research and quantify combustion performance of alternative coal resources and reserves in closer proximity to Eskom's coal-fired power stations, thereby optimising coal logistics.

Technological advances

The existing Eskom GIS database of the country's coal resources and reserves can be updated to include their advanced analyses and combustion behaviour, evaluated in Eskom's world-class facilities. This will enable these coals to be pre-matched to specific power stations, with an indication of likely cost to mine, beneficiate, and transport the coal, and likely power station impact. This database needs to be developed to also include opportunity fuels.

Gaps

Limited investment by mining houses in new coal mines, has resulted in reduced supply and less competition.

There are stricter ownership, environmental and safety requirements for mine owners, while increasing coal-mining cost inflation reports above the general consumer price index. This may pose risks to Eskom given the recent NERSA determination allowing lower coal cost inflation.

Policy measures need to address both the long-term and short-term challenges associated with generation from coal. Ultimately, a long-term carbon price signal will be needed to set adequate investment incentives and hence enable a low-carbon energy transition. For the short term, carbon pricing and more stringent pollution control regulations may be used to reduce emissions, minimise local air pollution, and limit and ultimately phase out generation from subcritical coal-fired power stations. Examples are emissions performance standards in Canada and the United Kingdom for power generation capacity additions as well as the carbon price support in the United Kingdom. In OECD countries, and especially in many emerging economies, where coal-fired power generation is set to expand in the near future, new-build coal-fired power units should aim for best available efficiencies (currently, through application of supercritical or ultra-supercritical technologies), where feasible, and be designed in view of potential future carbon capture and sequestration (CCS) retrofits, if they are not equipped initially with CCS. Further, coal plant designs should ensure sufficient operation flexibility to balance electricity supply and demand and to support the introduction of increasing shares of intermittent renewables onto the power grid.

Value, opportunities and risks of this portfolio

This project contributes to the financial sustainability of the Eskom business by reducing the cost of coal and securing long term supply of suitable coal for Eskom.

The risk to this portfolio is the decreasing costs of renewable and energy storage systems. Coal fired stations will be forced to closure due to high emissions and lack of competitiveness against other generating technologies.

Partnerships and collaboration

- **Centre for Science and Industrial Research (CSIR)** - Specialised analyses and skills for water, coal, environment, nanotechnology and new materials;
- **VGB, EPRI, KEMA, CRIEPI** - Partnerships to keep abreast of latest technologies, setting of guidelines and standards, sharing research results and possible joint research collaborations;
- **Coaltech 2020** - Coal analytical, ash management and mine water treatment research partnerships;
- **Fossil Fuel Foundation** - Specialised group providing a network throughout the entire coal, carbon and energy sectors both within South Africa and across the region;
- **Chamber of Mines and Colliery Owner Associations**
- **Council for Geoscience**
- **University of Witwatersrand, North West University and Vaal University of Technology** - Partners in coal research and testing; and
- **International Energy Association** – International collaborative partner.

The Research Framework

<table>
<tr><th colspan="4">COAL</th></tr>
<tr><th>Understand the industry</th><th>Improving Quality and Security of Suppy</th><th>Logistics</th><th>Technology</th></tr>
<tr><td rowspan="4">• Policy changes - research gaps to influence policy
• Industry structural changes
• Consolidation in the market
• Cost components to mine and deliver the coal
• Labour action
• Understanding discard coal</td><td rowspan="3">• Long term and short term forecasting
• Characterization and blending
• Measurement and quantification
• Sampling & analysis
• Where are the new coal seams?
• How much is minable in South Africa and globally?</td><td>• Road to rail
• Port to rail
• Costing and impact to price
• Optimisation to improve logistics</td><td>• Novel solutions
• Increase plant efficiency to use less coal
• Improve existing technology
• Business case to redesign boilers
• Reduce LCOE
• Technologies that improve sales and protect revenue</td></tr>
<tr><th>Environmental</th><th>Pricing</th></tr>
<tr><td>• Environmental concerns when redesigning boilers
• Understanding environmental aspects</td><td rowspan="2">• Contracting strategies and best options
• Which mine must be retained?
• Foreign risk and inefficiencies in the market
• Incentives for market
• Penalty clause vs benefit clause - benefits and incentives</td></tr>
<tr><td colspan="2">GRAND CHALLENGE: How can RT&D support Eskom in developing and implementing solutions within 5 years that gaurantee's the quality of coal in line with the design of the plant whilst ensuring the price of coal remains competitive relative to other recources</td></tr>
</table>

3 THE WATER GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Water Grand Challenge

The semi-arid conditions; the abundance of coal; and the urgent need for economic growth in South Africa (SA) are aspects that are inter-related and necessitate innovation for cost-effective, coal-based electricity production. The significance of water security is critical in this regard.

The responsible Ministry has stated unequivocally, that "we are fast approaching full utilisation of available surface water yields". It is estimated that there will be a 1.7% shortfall of water by 2025 (DWA, 2013a).

Eskom's Water Strategy is prefaced with the issue of the national constraint of water security of supply. This is due to (a) an increasing trend of usage that could outstrip the available supply capacity of the infrastructure; and (b) supply reduction as a result of pollution, inefficient management and lack of infrastructure maintenance.

Although Eskom is recognised as a "strategic water user" by the Department of Water and Sanitation (DWS), the above constraint; legal non-compliance (related to water-use license conditions) and delays in obtaining licenses are potential threats to our ability to sustainably produce electricity.

Vision

The Eskom Water Strategy aspires to a reduction in raw water consumption from 1.39 (2014) to 1.34 l/kW sent out by the 2019/20 financial year. This is ambitious, given: the legislative requirement for the retro-fitting of gaseous emission control technologies (that are projected to increase water consumption by 20%); aging plant with decreasing levels of overall efficiency; and deteriorating water quality (Eskom, 2015).

Our vision is to have improved scientific knowledge and technologies to reduce and/or mitigate all negative aspects and enhance positive aspects of water utilisation and waste management, related to our business activities. We will anticipate environmental legislation and agreements on water and waste aspects and ensure that we have credible, accredited systems to monitor and report according to best practice. Tools and technologies for appropriate mitigation and remediation will be researched for implementation.

Research alignment with Eskom priorities

Water, for electricity generation, is mainly used for the steam cycle (demineralised), cooling system (specified quality thresholds) and management of ash (lower quality). This is the annually reported utilisation, based on quantities of raw water purchased. This excludes water that is used for coal mining.

In 2015/16, Eskom used 314 685Ml of raw water, used with a total fleet consumption of 1.44 l/kWh sent out (Eskom, 2016). Wassung (2010) analysed the impact of coal-fired electricity generation on water resources, including the water footprint of coal extraction. It was concluded that the range was closer to 1.53 - 3.33 l/kWhSO rather than the Eskom-reported 1.34 l/kWhSO (Eskom fleet performance in 2010). With aging plant, it is expected that various aspects of performance will decline. In the case of water consumption, it is critical that the relevant plant be monitored and maintained for optimal performance. In addition, with advanced treatment technologies (e.g Eutectic Freeze Technologies), it is possible to increase the reuse of water and thereby reduce overall consumption.

Deteriorating water quality, the prevailing stresses on water availability due to drought and future climate change scenarios and increased plant system leaks have to be addressed to ensure operational sustainability. As such, a distinct focus area is to "develop contingency water-supply plans for the prevailing drought, and ensure an adequate water supply, improved water conservation, as well as better management and usage of water resources" (Eskom, 2016). Supply for power generation, especially for new plant in the Waterberg region, has been a focal point as Medupi is built and commissioned. It must be noted that the Waterberg coalfield is one of the largest coal resources remaining in the country and is a region regarded as arid. The first phase of the Mokolo Crocodile water augmentation activities is projected to increase water supply to the region, by 37%. The upstream and downstream implications of this, the effects on water quality and the longer-term effects on the regional hydrological systems, especially in the face of impacts, vulnerability and adaptations to climate change need to be understood.

Key technical research questions

- What tools, techniques and guidelines would enable Eskom to efficiently and effectively manage water and waste aspects relating to our business activities?
- What are the opportunities to reduce the amounts of water used and waste produced in the Eskom value chain?
- What optimised treatment processes can be used to clean water and mitigate the impacts of waste production?
- What opportunities exist to source water coincident or arising with the fuel resource?
- Where in the value chain are there opportunities to re-use water and "repurposed" waste?
- What innovative solutions would mitigate operational chal lenges associated with fluctuating availability and quality of water resources?
- What innovative processes or advanced materials will result in the replacement of resources used and/or the reduction of wastes produced?

Landscape

Eskom has expressed a "moral and legal obligation to safeguard and protect people, the environment and its assets while providing sustainable electricity solutions to grow the economy and improve the quality of life of people in South Africa and in the region". This is applicable to all water and waste aspects relating to the Eskom value chain.

Responsible environmental management (relating to water and waste) is pursued through organisational adherence to the SHEQ Policy, the ISO 14001 standard and compliance to national regulation (National Environmental Management Act (NEMA)) and international agreements. Eskom is also a member of the United Nations Global Compact (UNGC) which defines principles for responsible environmental management.

Various national and international commitments define the drivers for research relating to water and waste. These include but are not limited to:

- United Nations (UN) Agenda 21 and the Rio+20 outcomes;
- UN Global Compact;
- Sustainable Development Goals;
- South African Constitution;
- SA National Strategy on Sustainable Development and Action Plan 2010-2014;
- 2011-2030 National Planning Commission – National Development Plan;
- National Environmental Management Act 107 of 1998;
- National Water Act 36 of 1998;
- National Water Resource Strategy;
- Companies Act 2008;
- King IV;
- ISO 14001 Environmental Management Systems; and
- SANS 14040 Environmental Management – Life Cycle Assessment.

A phased, prioritised approach has been adopted with regard to emission reduction (criteria pollutants: sulphur dioxide, oxides of nitrogen and particulate matter). This includes upgrading and optimisation of plant (electrostatic precipitators and fabric filters), and developments for retrofitting of low NOx burners and flue gas desulphurisation technologies. It is noted (Eskom 2015, 2016) that the "capex required to implement the 2020 Minimum Emissions Standards is significant, and would require an estimated additional 10% increase in the electricity price". In addition, it has been estimated that upgrades to meet the standards, may result in a 20% increase in water consumption (Eskom 2015). Part of the phased approach is an air quality offset programme. This addresses residential ceiling insulation (space warming) and cooking fuel alternatives, amongst other initiatives. The primary objective is to reduce ground source air pollutants. Dust suppression on ash dams is a major use of water in Eskom. Sales of ash have been increasing (increased from 7.35% in the prior year to 8.32%), largely due to a focus on ash utilisation (32.6Mt were produced in 2015/6). It is critical that this trend continue with the concomitant savings in water utilisation. Integrated, systematic assessments of human health and well-being, water availability and consumption and the provision of electricity for economic prosperity are urgently required. These should include Water Accounting & Water Footprint (ISO14046) and Energy Management (ISO50001) assessments.

Future strategic focus areas

- Water Treatment Facility – design, building and commissioning of a state-of-the-art water treatment facility for in-house testing, validation and optimisation of treatment technologies.
- Flow Laboratory – undertake scanning and review of the most recent technological developments relating to flow measurement and instrument calibration. Optimisation of the flow laboratory towards world-class functionality.
- Groundwater Monitoring and Management – initiation of groundwater monitoring functionality with the aim of accredited capability, laboratory and personnel.
- Water-Energy-Food Nexus – optimisation of water utilisation across competing sectors with the aim of striving for a sustainable balance.
- Waste Management and Utilisation – identification of all points of waste production across the Eskom value chain; implementation of innovative solutions for product replacement, reuse and recycling.
- Treatment and Storage – effective techniques and technologies for optimised treatment and storage of all types of wastes.
- Heavy Metal Emissions – monitoring, establishment of trends, reporting and remediation and mitigation of the impacts of heavy metal emissions.

Technological advances

With the urgent need for economic growth to address the high levels of social inequity in South Africa, there are ambitious infrastructure plans for the country. This will necessitate increasing amounts of energy and resources. While this will result in more water being used and increasing waste production, there are opportunities to (a) invest in technologies to reduce the amount of water used and (b) divert the wastes produced into resources that can be used for the development activities. A tangible example of this is the increase in the reuse of ash for civil infrastructure rather than mining for building material. Best practices for achieving these outcomes will be investigated and its implementation will be championed. Life cycle assessment will be increasingly applied in the analysis of water utilisation and waste production. This is in keeping with the shift from the previous "cradle to grave" to currently accepted philosophy of "cradle to cradle". It is also being called for in the global discourse on the post-2015 Sustainable Development Goals. It is therefore intended that capability in the application of LCA standards and analysis of water and waste aspects relating to Eskom business activities be established. Studies on the implications of shale gas on water in the US (Rahm and Riha, 2012) and China (Granoff et al, 2015) conclude with recommendations to realise the potential of the gas resource. Both highlight the importance of collective and co-ordinated policy and regulatory actions. In addition, both underline the potential for water-related risks. In the US, it is contended that "planning-based assessments of policy alongside and in coordination with project-focussed environmental assessments are needed to identify region-appropriate strategies". The Chinese study notes, interestingly, that "if shale gas development can displace coal-fired electricity generation, it may reduce pressure on water resources". This is highlighted as being due to the life-cycle water consumption characteristics of the two primary resources. While significant amounts of water are required for the gas extraction, it is less than that for the coal mining, processing and combustion. This is, however, dependent on various assumptions. A thorough review of the effect of shale gas extraction on water is required. The implications of this for Eskom need careful consideration, noting South Africa's status as a semi-arid country.

Gaps

Groundwater use is considered an important under-utilised source of water. The Department estimates a potential 5 000 Mm3/a available yield (DWS, 2015). Water reuse, rain water harvesting and treated acid mine drainage are other approaches that are intended to increase available water (DWA, 2013a). Desalination is also being increasingly viewed as a potential solution to the constrained water supply into the future, making up 10% of our needs in 2030. Technologies have been implemented in Mossel Bay, Plettenberg Bay and Knysna. Feasibility studies are underway for Cape Town and Durban and completed for Port Elizabeth. Cost, energy intensity and the accompanying, increased carbon emissions are some of the concerns raised with regard to desalination.

Historically, ash utilisation in South Africa has been low. Efforts to promote this have not been successful and we need to understand the regulatory and economic reasons for this. Recommendations to overcome the barriers are urgently required if we intend to synchronise with the infrastructure plans.

Value, opportunities and risks of this portfolio

The research provides a greater understanding of the impacts of our business activities relating to water utilisation and waste production. This will enable us to work towards the continuous improvement of our performance with regard to responsible resource utilisation and management of impacts associated with waste.

Optimisation of water use will free up water for other sectors and result in financial savings. In collaboration with the regulators, opportunities to qualify these savings as "offsets" will be pursued. These actions will be supportive of and contributory to the national growth imperatives.

A major risk in this research area is the shortage of skills. The potential also exists for the promulgation of regulation that is based on poor or inaccurate information that is as a result of this lack of technical capacity. The impact of this on the organisation could be severe if the water and waste impacts are deemed to be sufficiently severe to warrant cessation of operations. The ramifications of this for the economy will be serious.

It is therefore considered important that credible, peer-reviewed research is undertaken to improve our scientific knowledge.

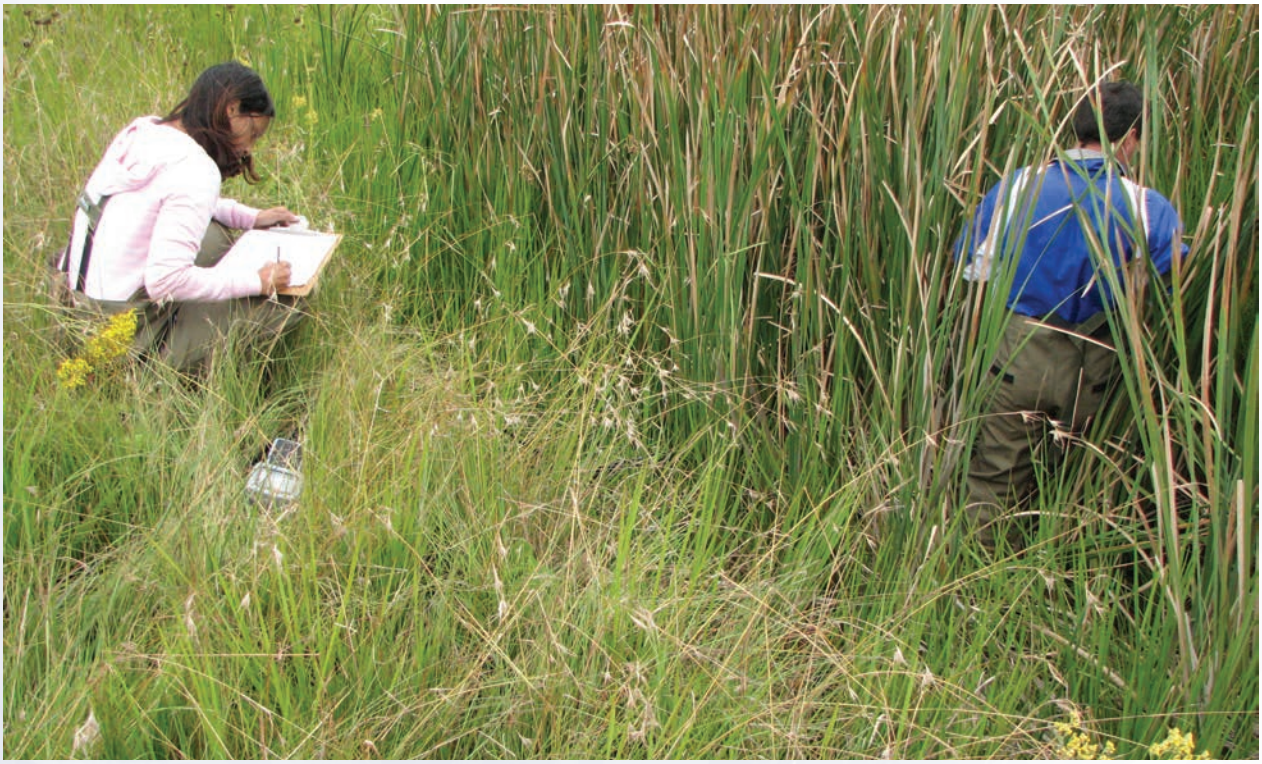
The consequences for Eskom are increasing raw water treatment costs and the burden of having to safely manage the wastes from these processes. The importance of a healthy ecological reserve cannot be overemphasised in:

- Buffering against extreme events related to climate change;
- Mitigating negative impacts of land use;
- Minimising evaporation (riparian vegetation); and
- If well-managed, storage (as groundwater).

In this regard, Eskom, as an emitter to air, soil and water, needs effective monitoring and management of water impacts. Innovation and novel approaches to achieve this will reduce costs and contribute towards water security.

Partnerships and collaboration

- University of Free State – Groundwater Monitoring and Water-Energy-Food Nexus;
- Universities of Witwatersrand – Heavy Metals;
- University of Western Cape – Water Treatment Technologies and Ash Research;
- CSIR – Water Treatment, Wetland Research and Mercury Monitoring;
- University of Pretoria – Water-use Optimisation;
- Water Research Commission – Surface Water and Wetland Management;
- Department of Water Affairs – National Department – collaboration and consultation on national water and waste-related research;
- Department of Science and Technology – Impacts on Hydrogen fuel cell, biotechnology and nanotechnology;
- VGB, EPRI, KEMA – Partnerships to keep abreast of latest technologies, setting of guidelines and standards, sharing research results and possible joint research collaborations;
- Coaltech 2020 – Coal analytical, ash management and mine water treatment associative research partnerships; and
- United Nations Environmental Programme – Collabo rating on chemistry-related environmental research.



The Research Framework

WATER SECURITY			
Supply and Utilisation (Including major impoundments and inter-basin transfers)	**Surface and Ground water impacts**	**Water - Energy Nexus**	**Operational Aspect of Electricity Generation**
• Key resourses and Dam status • Stategic storage • Changing utilisations practice eg irrigation at night • Supply & delivery optimisation (including infrastructure theft & non-revenues loss) • Projections - new users eg hydrofracturing • Trans-boundary water management • Skill shortages • Service delivery • Waters Conservation offsets	• Water quality impacts and monitoring • Acid mine drianage • Ecological reserve • Water treatment **Climate, Weather and Meteorology** • Modelling and forcasting • El Nino La Nina • Floods and droughts • Climate Change Projections	• Desalination • AMD treatment & re-use; seawater/brackish water; RE • Water Accounting & Water Footprint (ISO14046) & Energy Management (ISO50001) stds • Energy/water requirements of the PICC Strategic Infrastructure Projects (SIPs)	• Coal mining water utilisation • Raw water quality and treatment • Waste resin re-use • Plant optimisation (including leak management & sewerage treatment) • Wet-FGD: Reducing water consumption • Low/No-water FGD • Flue-gas water recovery • Waste-stream management (FGD) • Ash water-use reduction/recovery

GRAND CHALLENGE: Can Eskom achieve fleet water security through risk-based analysis including (longer-term) climate change, environmental compliance of the entire fleet, including fleet renewal.

4 THE CLEAN COAL GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Clean Coal Grand Challenge

The scope of the Clean Coal Grand Challenge will be to provide innovative, cost-effective design solutions for low-emission coal options for Eskom in the next five years.

This includes research related to enhancing the techno-economic and environmental performance of Eskom's existing fossil generation fleet and defining and researching the requirements for future High Efficiency Low Emissions (HELE) technologies. The focus is on the capture and control, as well as the reduction and eventual elimination of, emissions from fossil fuel-powered generation of criteria air pollutants and GHGs.

The World Economic Forum, in assessing the top fifty global risks (2018), ranks three relating to the environment, and specifically, climate change with the highest (a) likelihood of occurring and (b) impact. These are: failure of climate change mitigation and adaptation; natural disasters and extreme weather events. The former and latter are attributable to emissions of anthropogenic greenhouse gases (GHGs). As Eskom is a significant contributor, in terms of fossil-fired electricity generation, as well as vulnerable to the impacts of these risks, it is imperative that research solutions to these be pursued.

A target of achieving decarbonised electricity by 2050 is expressed in the South African Intended Nationally Determined Contribution (INDC) (SA-UNFCCC, 2015). This is projected to cost approximately $350 billion. Innovative R&D is required to contribute to realising this goal whilst still utilising the energy derived from the rich resources of coal that we have while maintaining levels of economic and social development.

This research project focusses on fuels and their HELE utilisation, emission reduction technologies, and pilots and demonstrations of technologies linked to the coal value chain. These relate to coal resource optimisation, its associated quality and impact to the power plant, human health and the environment.

Vision

Reduce and/or mitigate negative environmental aspects and enhance positive aspects relating to the use of coal and coal-derived products for power generation. We will anticipate environmental legislation and agreements and ensure that we have credible, accredited systems to monitor and report according to best practice. Tools and technologies for appropriate mitigation and remediation will be researched for implementation.

Research alignment with business priorities

In the pursuit of continual improvement of emissions management, RT&D will undertake research on technologies to assist Generation to meet the commitments made to the regulators. This includes work on particulates, NOx and FGD control technologies.

Key technical research questions

The following are the key technical research questions required to be addressed within the project:

- Which coal, co-firing fuel and sorbent resources are potentially available and suitable for new HELE clean coal technologies?
- What are the likely environmental, logistical, commercial and market constraints for new coal, co-firing fuel and sorbent resources? What HELE clean coal technologies are best matched to the coal, co-firing fuel and sorbent resources of the country, and how do they perform with regard to current and future emissions legislation and economic and social sustainability drivers?
- What HELE clean coal technologies are currently evolving towards commercialisation that potentially suit local fuels and conditions, and meet Eskom's strategic drivers?
- What HELE clean coal technologies can absorb or recycle the waste products from coal-fired power stations, including carbon, gaseous, particulate and water emissions?
- What are the characteristics, transport pathways and fate of emissions from Eskom power generation stacks and how do they impact on human health and the environment?
- What are the impacts of Eskom business activities on the receiving environment and how can these be effectively avoided or mitigated?

Landscape

The main policy, regulatory and market drivers within the portfolio relate to climate change, environmental compliance and electricity planning, all of which need to be balanced off against affordability and social needs. In 2011 the South African Government produced a National Climate Change Response White Paper on intended Green House Gas (GHG) targets for South Africa which follows a peak, plateau and decline approach. A strategic imperative for Eskom is reducing or mitigating our carbon footprint and pursuing low carbon growth opportunities, without sacrificing the social and economic agenda. Eskom is committed to environmental duty of care and has identified key initiatives to achieve its carbon footprint reduction aspirations in the short, medium and long-term.

A Carbon Tax Policy paper was published in May 2013 for public comment and proposes that a carbon tax be introduced at R120 per tonne CO_2-eq above the tax-free thresholds on 1 January 2015 and be increased at a rate of 10% per annum until 31 December 2019. This will add further pressure to the cost of electricity and Eskom's revenue streams, and carbon reduction therefore becomes a key consideration for future plant. The Department of Environmental Affairs (DEA) has also taken a stance relating to GHG emissions requiring all future fossil-fired power plants to be carbon capture ready.

In 2015 South Africa submitted its INDC on adaptation, mitigation and financing. The mitigation commitment has shifted from a "slight deviation in business as usual" to an "absolute peak, plateau and decline greenhouse gas emissions trajectory range". A National Climate Change Adaptation Strategy and Plan is to be developed and integrated into all relevant sector plans. It is based in six goals that address, inter alia, planning, costing of adaptation investment requirements, equity, and means of implementation.

In terms of Section 21 of the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004) (NEM: AQA), the DEA has gazetted the Minimum Emission Standards to be met in South Africa. This standard regulates emissions of particulate matter, oxides of nitrogen (NOx) and oxides of sulphur (SOx) emitted from solid, liquid and gaseous fuel combustion installations. Full compliance with these standards would see Eskom having to retrofit certain power stations with fabric filter plants and low NOx burners and all power stations with flue gas desulphurisation (FGD). The implementation of conventional FGD technologies would in addition require vast quantities of water and limestone, which are not currently available for the majority of Eskom Power Stations.

The Integrated Resource Plan 2010 defines the nationally approved electricity supply plan for the country. This plan is based on forecasted demand and takes into account technology options, environmental requirements, costs and other national objectives. The IRP 2010 is currently being updated to take into account recent market changes and will be made available for public comment. The plan is expected to be revised once the Integrated Energy Plan (IEP) for the country is finalised, which would define the energy plan and carriers for the country. The IRP, based on input from the IEP, defines the electricity mix as well as allocating the minister of energy with the authority to determine who would build future generating capacity in the country through ministerial determinations. As technology options mature, this would influence the electricity mix deployed within the plan.

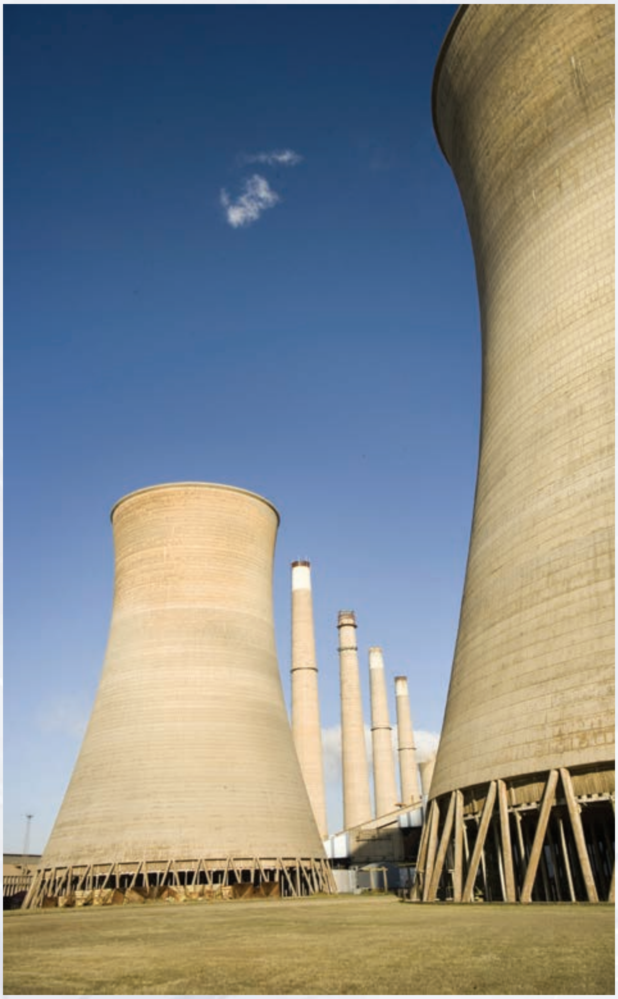
Future strategic focus areas

The following focus areas will enable future strategic support to Eskom:

• **Financially viable and sustainable** – the HELE clean coal technologies will be specifically researched that consume more abundant and affordable coal, co-firing fuel and sorbent resources. Advanced coal characterisation and assessment will be undertaken for these materials. Emissions abatement technologies are required for South Africa that consume less water and utilise sorbents that are available and affordable. South Africa is in a vulnerable position in terms of its coal resources and reserves. Most of RSA's best quality coals in the accessible and conventional coal fields have been mined out, and only moderate to poor grades remain. Many of the remaining coal reserves lie in the remote coal fields, most of which lack infrastructure, logistics and water, and, in many cases, the coal qualities in those locations are too low in grade to be of economic value to mine under current circumstances. Of those reserves that are currently being mined, the best quality products as well as some of the middling grades (including those needed by Eskom) are being exported, thereby leaving even significantly lower grades for use by Eskom.

• **Reduced environmental impact** – HELE clean coal technologies are more efficient and produce less pollutants. Furthermore, the Eskom coal and emissions research focus will be on low water consuming technologies due to the country's aridness, and include carbon abatement requirements, such as capturing and sequestration (disposal) of CO_2 through for example, carbon nanotubes, CO_2 conversion to commodities and tracking new technological developments.

• **Responsive to changing energy landscape** – the HELE clean coal technologies that offer load-following flexibility will be specifically researched to assist in balancing the grid that has an increasing proportion of renewable energy plant.



Technological advances

Carbon Capture Readiness

The potential risk of CO_2 emissions over the next 50 years from new power stations is considered to be significant, as it is anticipated that GHG emission legislation will be introduced and is likely to become increasingly stringent over this period. Carbon capture and hence readiness to undertake this is therefore highlighted as being critical to prevent stranded assets or inability to optimally operate plant.

The Electric Power Research Institute (EPRI) undertook a study and produced a report on a review of international definitions of "Carbon Capture Readiness". Published definitions and guidelines from non-profit organisations and energy institutes were reviewed. The application of these to the Medupi, Kusile, a new Greenfield Power Station and Circulating Fluidised Bed (CFB) Plant were examined.

It was concluded that there were "no insurmountable barriers" identified to retrofitting Post Combustion Capture (PCC) and Oxy-fuel Capture to Medupi and Kusile Power Stations; however, the overall efficiency penalties need to be understood (7.7 – 11.2% reduction in efficiency). Further, while there is sufficient "plot space" available for the retrofits, it was highlighted that the location may not be optimal. Pre-feasibility studies to accurately understand the implications are required.

Supercritical carbon dioxide (sCO_2) cycle technologies

The International Energy Agency recently issued a review of sCO_2 cycle technologies (2017) that is an innovative approach to the production of electrical energy from fossil fuel (coal and gas). Utilising CO_2 in a closed or semi-closed Brayton cycle, it is highly efficient with a small plant footprint and potential for carbon capture.

Existing and future emissions compliance technology option

There has been a renewed interest globally in the introduction of low water consumption technologies for power generation and emissions abatement. This has seen in recent years greater interest in technologies such as dry flue gas desulphurisation such as SNOx and ReAct, etc.

Carbon Abatement

This area continues to receive strong global focus in the areas of carbon capture and sequestration. Advances in oxy-fuel firing systems have also been made with three major pilot projects currently operating in Australia, Germany and Spain. The main research trends currently are in the development of the concept and design of oxy-circulating fluidised bed combustion boilers. The intent of oxy-fuel firing is to increase the CO_2 concentration, allowing more cost-effective capture and storage (CCS). The storage aspect has seen enormous development in the last decade, and technologies now exist for geological storage, and for converting (fixing) the CO_2 into biomass (algae, bamboo etc.), petrochemicals and high-value materials such as activated carbons for gas and water purification; pitch-based needle cokes for high-tech metallurgical processes; carbon nanotubes for ultra-strong materials; and carbon-based graphite for nuclear processes.

Fluidised Bed Combustion

Circulating fluidised bed combustion (CFBC) has emerged as a competitive technology to pulverised fuel (PF). The first super critical CFBC plant has been commissioned and another is under construction, providing a significant improvement in thermal efficiency whilst now allowing unit sizes similar to PF units. CFBC provides the opportunity for resource optimisation in the South African context, as it enables the combustion of very poor quality coals and other opportunity fuels, whilst using poorer quality sorbents to scrub sulphur emissions, and using less water in the process compared to PF technology.
It therefore needs to remain a viable commercial coal technology choice, depending on the specific coal, project and local surroundings.

Underground Coal Gasification

UCG technology has the potential to extract energy from poor quality coal from depths normally inaccessible with conventional mining technologies, making it ideally suitable for unlocking the energy from the almost three-quarters of South Africa's coal resources that are regarded as unminable. Furthermore, it can be a net water-producer, and have equal or lower emissions than current conventional coal plant. The current UCG pilot plant has been prepared and approved to seek a public-private partnership, to complete the commercial development of the technology.

Gaps

Governments should assess the value and impact of CCS for their climate strategies. Early CCS deployment requires targeted financial and policy support to deliver deep emissions reductions. The current absence of adequate policy support is impeding progress with CCS, with implications for the achievement of long-term climate targets. Furthermore, an observed trend in decreasing CCS-related public RD&D investment over the last few years by IEA member countries should urgently be reversed. Investment in specifically geological CO_2 storage is an urgent priority due to long lead-times, and government leadership is essential. Co-ordinated and extensive CO_2 storage assessment programmes are required to prove secure, practical and bankable CO_2 storage areas and sites in all key regions. Governments and industry should also ensure appropriate planning for and development of large-scale CO_2 transport and storage infrastructure, across jurisdictions where applicable. Creating the conditions for a separate CO_2 transport and storage business could address challenges experienced with integrated projects and underpin investment in CO_2 capture technology across power and industrial applications.

Value, opportunities and risks of this portfolio

The focus of this research project is on enhancing the performance of Eskom's existing fossil fuel generation fleet, informing future plant specifications, providing testing and analysis services to evaluate current and future raw material supply options, finding means to meet current and future emissions compliance criteria and developing options to unlock the continued use of fossil fuels in a more environmentally acceptable and sustainable manner. The ability to influence the reliability of existing power plants has a significant impact on Eskom's ability to manage a capacity constrained system and enhance business performance.

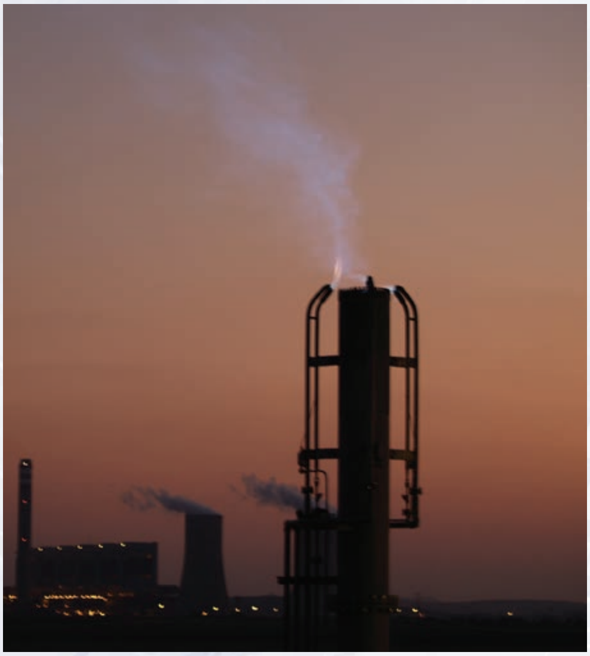
In the execution of the research activities a strong focus is placed on internal skills development, knowledge transfer and capacitation of local universities to support Eskom-associated research. Through the activities of this research project Eskom is enhancing its linkages with national and international academia, industry and other utility organisations.

A National Microalgae Workshop was held to produce a roadmap on pilots/demonstrations to support CO_2 reduction initiatives for the country.

Skills are being developed in the fabric filter plant (FFP) research area with a focus on the establishment of testing methodologies and programmes for the accelerated aging test rig and filter test rig, with correlation thereof to routine laboratory analysis and full-scale routine sampling.

UCG potentially enables access to the coal resources in South Africa that are deemed as presently "unminable", with current mining technology. Approximately three quarters of the country's coal resources fall into this category, and these resources cover provinces that were previously considered to have no viable primary energy resource (such as the Eastern Cape).

Eskom is leading the UCG development in South Africa, which enables Eskom to secure the mining rights and potentially its own gas supply with minimal 3rd party involvement (and implied commercial mark-up). In conducting the overall UCG Pilot project, synergistic opportunities for technology development will be pursued for the wider Eskom benefit. Eskom's further UCG project development has been approved for a public-partnership, to ensure the continued development of this technology opportunity despite the current Eskom financial limitations.



Partnerships and collaboration

- Eskom's further UCG project development has been approved for a public-partnership, to ensure the continued development of this technology opportunity despite the current Eskom financial limitations.
- South African Centre for Carbon Capture and Storage & OCTAVIUS – National Carbon Reduction.
- RWE - Knowledge and Information Transfer in: National Carbon Reduction / Power Plant Performance / Environmental Management.
- Council for Scientific and Industrial Research (CSIR) – Specialised analyses and skills for water, coal, environment, nanotechnology and new materials.
- Fossil Fuel Foundation – Knowledge transfer intervention. Provides a platform to disseminate and market information to the local and international players.
- Anglo Research Laboratories – Collaborative research – Optimal Coal Processing Initiative. Strategically important to maintain the relationship so that the interest of coal analysis/QEMSCAN is synergised.
- University of Stuttgart – Knowledge transfer of Coal Analysis aiding Primary Energy Sourcing.
- University of Clausthal – fuel sources associated with biomass co-firing.
- University of the North-West – EPPEI Chair for Emissions.
- University of the Western Cape - Collaboration with the hydrogen enrichment of UCG syngas.
- University of the Free State – Collaboration in the field of bioremediation of hydrocarbon contaminated water.
- KEMA – Collaboration in the field of biomass and CCT research.
- University of Witwatersrand – EPPEI centre of specialisation in combustion engineering.

The Research Framework

CLEAN COAL

Technology

- Focus only on particulates, SOx and CO_2
- Improve existing technology
- Novel water and plant energy efficient solutionns
- Pilots and demonstrations
- Safety
- Risks

Finance

- Finance modelling for cost effective solutions
- Business case development
- Financing over the life of plant

Social and Environmental

- How can new jobs be created around proposed technology solution
- Environmental screening and impact studies.

Policy and Regulation

- Licenses required
- Measurements and monitoring
- Regulation compliance
- Lobbying for new policy and regulation

IP & Legal

- IP identification and models
- SD&L issues

GRAND CHALLENGE: R,T&D will provide cutting edge cost effective design solutions for low emission coal options for Eskom in the next 5 years.

Partnerships and collaborations

- Identify partners and stakeholders
- Share/transfer risks
- Share resources and facilities
- Increased funding and technical skills

5 THE GENERATION, ASSET MANAGEMENT AND PLANT PERFORMANCE GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Generation Asset Management & Plant Performance Grand Challenge

Asset Management is a global management process through which the highest value decisions about the use and care of assets are reliably made and consistently executed.

This definition implies attaining reliability of people, process and equipment throughout the business/plant life cycle, of design, manufacture, construction, operation, monitoring, maintenance, testing and decommissioning phase. Like many global power utilities, Eskom is currently challenged with an aging fleet of power stations. In addition, the organisation is constrained by investments for both expansion and refurbishment, together with increased incidents of unplanned outages resulting from overloaded infrastructure and statutory pressure to reduce emissions, which increases plant modification and cycling risk. Asset Management provides an approach to optimise multiple business goals: the performance of the assets; lifecycle costing; effective use of resources and organisational risks.

Eskom has traditionally followed a time-based maintenance programme. A superior and effective approach is to move from a purely time-based strategy to a hybrid methodology which is a time based programme that uses conditioned-based maintenance information built on real-time and off-line data. This will allow a greater focus on the maintenance of equipment that actually needs servicing. To successfully operate such a programme, the utilisation of reliable, accurate and comprehensive real-time and off-line asset management data is essential. The focus of this research project is providing knowledge, tools and techniques
to support the asset management initiatives in Generation. The focus will be to ensure the outputs are of a high quality, are cost-effective and remain focussed on Eskom's business needs in the areas of failure investigations, remaining plant life, integrity and risk assessments, corrosion, materials characterisation, experimental stress and vibration analysis, welding and non-destructive testing.

Power plant components are subject to various degradation mechanisms that are influenced by design, materials, manufacturing and in-service conditions that can cause premature exhaustion or failure of these components. To ensure continued safe operation with minimum risk and cost it is important to perform systematic evaluation of these materials using the best technologies available. The vision for this project is to ensure that a comprehensive understanding of the materials evaluation technologies is gained, the behaviour of these materials due to various degradation mechanisms during operation is clearly understood and best practice repair, testing and assessment technologies are applied.

Vision

RT&D will provide greater insight into plant condition for asset management purposes and demonstrate technology solutions to drive performance to 80:10:10. The power utility will deliver electricity in a cost-effective manner with enhanced levels of efficiency, reliability, security, and safety with aged base load designed plant operated in an increased cycling mode.

Research will support, investigate and recommend the best asset management processes and procedures to become a top-performing utility by:

- Intimately testing leading-edge asset management technologies and providing recommendations to the organisation;
- Developing, adopting and adapting technologies to test, monitor, model and assess key operating and plant conditions as well as decision-making tools to inform highest value risk and maintenance decisions for Eskom;
- Monitoring existing condition and operation of existing plant and increasing the use of condition base to inform plant risk and highest value maintenance processes;
- Improving the financial sustainability of the organisation by extending the life of the assets and increasing the scope of flexible usage of assets;
- Influencing the resource plan with productive human resources managed for improved asset-centric planning and focussed skills development;
- Introducing, maintaining and improving streamlined business processes that support organisational efficiency and highest value decision-making;
- Effectively and timeously making decisions based on real-time, accurate and reliable information of the plant; and
- Providing clear and unambiguous direction to Eskom with regard to the future direction that asset management processes and procedures will take.

RESEARCH ALIGNMENT WITH ESKOM PRIORITIES

Water, for electricity generation, is mainly used for the steam cycle (demineralised), cooling system (specified quality thresholds) and management of ash (lower quality). This is the annually-reported utilisation, based on quantities of raw water purchased. This excludes water that is used for coal-mining.

In 2015/16, Eskom used 314 685Ml of raw water used with total fleet consumption of 1.44 l/kWh sent out (Eskom, 2016). Wassung (2010) analysed the impact of coal-fired electricity generation on water resources, including the water footprint of coal extraction. It was concluded that the range was closer to 1.53 - 3.33 l/kWhSO rather that the Eskom-reported 1.34 l/kWhSO (Eskom fleet performance in 2010). With aging plant, it is expected that various aspects of performance will decline. In the case of water consumption, it is critical that the relevant plant be monitored and maintained for optimal performance. In addition, with advanced treatment technologies (eg Eutectic Freeze Technologies), it is possible to increase the re-use of water and thereby reduce overall consumption.

Deteriorating water quality, the prevailing stresses on water availability due to drought and future climate change scenarios and increased plant system leaks have to be addressed to ensure operational sustainability. As such, a distinct focus area is to "develop contingency water-supply plans for the prevailing drought, and ensure an adequate water supply, improved water conservation, as well as better management and usage of water resources" (Eskom, 2016). Supply for power generation, especially for new plant in the Waterberg region has been a focal point as Medupi is built and commissioned. It must be noted that the Waterberg coalfield is one of the largest coal resources remaining in the country, and is a region regarded as arid. The first phase of the Mokolo Crocodile water augmentation activities is projected to increase water supply to region by 37%. The upstream and downstream implications of this, the effects on water quality and the longer term effects on the regional hydrological systems, especially in the face of impacts, vulnerability and adaptations to climate change need to be understood.

Key technical research questions

- How can Eskom better assess the condition of its plant to inform highest value risk decisions regarding asset operation, maintenance and life extension?
- What technologies, processes and resources are best suited or can be developed for effective condition monitoring (inspection, testing and online monitoring), data analysis and decision-making?
- Which interactive, real-time models are available to analyse data and facilitate efficient highest value decision-making?
- How are these technologies, processes and resources tested and commercialised in a sustainable and effective way?
- What management tools can be employed to effectively manage Eskom assets?
- How to improve reliability and availability of Eskom's plant?
- How can Eskom use the highest value inspection, testing, condition monitoring, modelling technologies and processes to inform risk, operation and maintenance decisions?
- What are the highest value repair and/or replacement technologies that Eskom can use in its asset management strategy?
- How can spares and works management processes be developed and optimised to allow for highest value maintenance?
- What are best practice methodologies for real-time asset management?
- How can the evolving challenges from human resources, financial and stakeholder and customer expectations as well as the rising opportunities from information technology developments be incorporated into Eskom's approach to asset management?

Landscape

The regulator has demonstrated increasing requirements for better performance of the power utility together with an overall requirement for being cost-effective. These challenges from the regulator will inspire accelerated deployment of technologies into the grid for improved performance and reduction of capital costs, as well as operations and maintenance costs.

ISO 55000 is the international standard for asset management based on the British standard PAS 55. The standard has widespread use in power and other utilities, transport, mining, process and manufacturing industries. The standard identifies the organisation's essential business processes and system integration to optimise the performance benefits.

Eskom operates a diverse fleet of generation assets which includes coal, nuclear, open cycle gas turbine, pumped stored, hydro, wind and solar photovoltaic units. It is the expectation that these assets be managed to ensure low-cost and reliable electricity supply while progressively moving towards decarbonising the grid. With many contradictions in this fluid and often fast-changing scenario, highest value decisions in terms of plant operation, maintenance, monitoring and risk is the big asset management challenge.

Future strategic focus areas

- **Asset Management Best Practices:** – Scanning global utility best practices that can be adapted for Eskom use.
- **Life Management for Turbo-Generators** – Use of condition monitoring technologies to provide insight into the performance of this asset; emphasis on integration of the asset management information into existing Eskom systems.
- **Life Management for Boilers** – Development of condition monitoring systems of the boiler.
- **Life Management for Auxiliary Plant** – Development of asset management systems to determine the condition of the balance of plant in the generation environment.
- **Highest Value Inspection and Testing Programmes** – Deliver on a non-destructive testing development facility for the SA industry that can do effective performance demonstration and competency evaluations of systems and people.
- **Small Sampling and Testing Technology for Reliable Quality Control and Plant Condition Life/Integrity Assessment** – Develop and implement sampling, testing, modelling and assessment processes for accurate plant condition assessment.
- **On-Line Monitoring and Data Evaluation Technology for Reliable Real-Time Plant Condition Life/Integrity Assessment** – Develop and implement on-line monitoring and modelling processes for real-time and accurate plant condition assessment.
- **Big Data Analysis and Systems Dynamics Modelling** – Use of decision-making tools to support highest value risk, operation and maintenance decisions.
- **Repair and Component Enhancement Processes** – Develop and refine repair and component enhancement processes for highest value life extension and failure prevention.

Technological advances

- Condition-Based Monitoring (across the utility for real-time decision-making)
- Automatic Fault Analysis
- Enhanced monitoring techniques
- Generator Foreign objects detection
- Generator Rotor temperature monitoring
- Inspection and test systems (value from inspections and testing)
- Condition assessment
- Modelling and big data analysis

Gaps

The most significant gap in the research portfolio is the organisational knowledge of asset management in the business. Asset management is not clearly defined, and currently there is no consensus whether Eskom will implement ISO 55000.

There are significant challenges with operations, incident investigations, scoping, outage execution and planning, project management, spares management, resources management, quality of inspections and repairs, instrumentation maintenance and data integrity.

An immediate focus will be to initiate literature scans into the best practices for asset management in the area of generation asset management.

Value, opportunities and risks of this portfolio

Asset management research presents a number of significant opportunities for the organisation. The approach will result in improved operating performance from the assets as a proactive approach towards planning and executing maintenance will ensure that the correct maintenance is provided at the optimal time and will be specifically tailored to the asset in question based on its condition and workload. The result of which will be increased plant availability, reduction of failure rates and efficient and effective productivity of the human resources, thus resulting in reduction of operating costs.

The proactive maintenance based in part on the condition of the plant will result in the avoidance of catastrophic failures to assets and mitigates safety risks to both people and the environment. Asset management confirms the compliance with regulatory performance targets and provides a risk management approach to reduce the legal risks associated with operating assets.

Partnerships and collaboration

- **EPRI:** Leverage on the wealth of knowledge on modes of failure from key plant experiences as well as templates for the APM tool.
- **VGB:** Provides an international platform for creation, exchange and transfer of technical know-how in the area of power and heat generation.
- **Doble Engineering:** Condition monitoring and predictive tools.
- **University of Pretoria:** Expert academic research group primarily involved in asset management.
- **University of Cape Town:** Expert academic research group primarily involved in asset management.
- **University of KwaZulu-Natal:** Expert academic research group primarily involved in asset management.
- **Nelson Mandela University:** ENtsa for small sampling and small sample testing and the cHRTEM for advanced microstructural analysis.
- **University of the Witwatersrand:** Wear, erosion, tribology and welding support to asset management.
- **Centre for Science and Industrial Research:** Laser welding and material treatment, as well as establishment of a non-destructive testing facility.

The Research Framework

GX ASSET MANAGEMENT & PLANT PERFORMANCE			
Boiler	**Turbine**	**Draught Plant**	**Asset Management**
• Boiler Tubes • Corrosion • Critical fatigue and stresses • Water quality • Sludge • Condition monitoring • Outage planning • Coal quality • Coal combustion • Statistical analysis	• Vibration • Material • Ingress of water • Turbine blades • Quality of steam • Condition monitoring • Critical fatigue and stresses • Rotor and Stator • Shaft deformities • Statistical analysis	• Motors • Fans • Milling plant • C&I systems • Spares • Condition moni-toring • Statistical analysis on OEM • Statistical analysis on age of plan	• Bathtub curve for plant caus-ing outrage slippages • Statistical models for early failure indicators • Detection for knee point on bathtub curve • Analysis for OEM and mean time to failure • Analysis of age of plant • Analysis of mode of failure • Condition monitoring • Spare strategy • Outage management
	Grand Challenge: RT&D will provide greater insight into plant condition for asset management purposes and demonstrate technology solutions to drive performance to 80:20:00		

6 THE RENEWABLES GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Renewables Grand Challenge

With some of the best wind and solar conditions around the globe, South Africa is fast becoming an emerging market in renewable energy.

The Department of Energy's plans to develop the renewable energy industry in South Africa has seen investment leap from a few hundred million dollars to approximately US$5.7-billion according to the Renewables 2013 Global Status Report (Ren21, 2013).

While renewable energy accounted for less than 1% of the energy mix in South Africa in 2012, this is expected to reach 12% by 2020, which would place South Africa in the "global top 15 countries" with regards to the implementation of renewable energy projects. As water and coal prices escalate, renewable energy is becoming the preferred choice of energy generation in South Africa.

Eskom will need to define its role in the renewable energy landscape of South Africa. Should Eskom decide to build and own renewable energy plant it will need to consider a strategy for new site identification, as prime locations may have already been taken during the four windows of bidding in the REIPP programme. However, Eskom does own a considerable amount of land in and around power stations and substations which can be utilised for project development. Eskom will also need to consider its in-house skill base and expertise to develop such projects. There are certainly lessons to be learnt from the building of Medupi and Kusile power stations with respect to labour issues and project management.

A risk to the build programme is that renewable energy is import intensive. The South African rand volatility presents significant risks to these projects. The depreciation of the rand has the potential to increase the cost of a project as well as the hedging fees, which impacts on the overall levelised cost of electricity. Currently, Eskom is facing financial constraints and would need to consider alternative forms of funding and partnerships.

Vision

To provide optimised solutions to enable Eskom to be a key role player in the renewables market in South Africa and regionally, and to enable Eskom to take advantage of the declining wind, pv and energy storage prices. As Eskom transitions into a new business model, this portfolio will provide research and investigations that strategically position Eskom as a competitor in the renewables market.

Research alignment with business priorities

Eskom is in support of the country's REIPPP programme, which aims to increase renewables capacity while ensuring that South Africa begins the journey to meet its COP21 carbon emission targets. To date, Eskom has connected IPPs to the grid, enabling sales of over 11GWh. In the medium term, the dynamics and assumptions underlying the original REIPP have shifted, particularly with slower growth in electricity demand and declining costs of renewables technology. With an expected excess capacity of approximately 3 000 MW in FY2020/21, there is limited opportunity to connect new IPPs to the grid unless they are economical at a tariff of 77c/KWh. In the long-term, as the costs of renewables further decline and the SA economy shows strong growth, Eskom will fully support growth in renewables in order to lead the country in reducing its carbon emissions while delivering electricity at the most competitive price possible. Eskom is also investing in energy storage technology over the next five years in support of this long-term commitment to renewables. Eskom's strategy is aligned with its Statement of Strategic Intent as set out by the Minister of Public Enterprises and important country strategies such as the NDP, REIPPP and IRP. It will be updated once South Africa's position on COP 21 and emissions targets is clarified.

Key technical research questions

- Which renewable technologies can be adopted in the Eskom business, achieving the lowest cost of electricity production?
- How can renewable technologies be integrated into the Eskom grid, ensuring lowest cost of integration, acceptable grid integrity, stability and continued high reliability with optimal or appropriate reserve capacities?
- What is the potential for the different renewable resources available in the country?
- What are the most appropriate technologies and relative costs associated for each of the various energy storage opportunities identified?
- Which new emerging technologies have the potential to disrupt current cost economics by order of magnitude?
- What role is nanotechnology development likely to play in renewable energy applications?

Landscape

Disruptive innovations in the power industry are driving a revolution of change towards a renewable energy future. The REN 21 "Renewables 2018: Global Status Report" states that renewable power generation capacity saw its largest annual increase ever with an approximately 178 gigawatts added globally. New solar photovoltaic generating capacity alone was greater than additions in coal, natural gas and nuclear power combined. China, Europe and the United States accounted for nearly 75% of the global investment in renewable power and fuels. When measured per unit of gross domestic product, developing countries such as the Marshall Islands, Rwanda, the Solomon Islands and Guinea-Bissau are also investing as much as or more in renewables than developed and energing economies. Trends show that corporate sourcing of renewable power is also increasing. Initially, many companies saw the adoption of renewable energy solutions mainly as an act of corporate social responsibility. However, significant reductions in renewable energy costs and maturing market and policy environments have made renewables cost-competitive and attractive sources of energy in their own right. Corporate renewable energy sourcing has moved beyond the United States and Europe and is now being adopted in countries such as Burkina Faso, Chile, China, Egypt, Ghana, India, Japan, Mexico, Namibia and Thailand. This trend is mirrored in South Africa with Eskom reports indicating that the market had installed approximately 285 MW as at December 2017.

The Ren 21 "Renewables 2017: Global Status Report" identified five technologies as the biggest global renewable technologies by installed capacity and investments. These are (in no particular order) bioenergy (biomass, biofuels biogas); geothermal; hydropower; wind; and solar energy (solar PV, concentrating solar power, solar water heating). The report further states "as of 2015, renewable energy provided an estimated 19.3% of global final energy consumption. Of this total share, traditional biomass, used primarily for cooking and heating in remote and rural areas of developing countries, accounted for about 9.1%, and modern renewables (not including traditional biomass) increased their share relative to 2014 to approximately 10.2%. In 2015, hydropower accounted for an estimated 3.6% of total final energy consumption, other renewable power sources comprised 1.6%, renewable heat energy accounted for approximately 4.2%, and transport biofuels provided about 0.8%."

In 2016, global renewable electricity generation grew by an estimated 6% and represented around 24.5% of global power. Hydropower remained the largest source of renewable power, accounting for around 70%, followed by wind (16%), bioenergy (9%) and solar PV (5%). Solar PV annual additions surpassed that of wind, breaking another record, with 70 GW to 75 GW coming on line, almost 50% higher growth versus 2015. Annual grid-connected solar PV capacity in China more than doubled in 2016 versus 2015, with 34.5 GW becoming operational. In the United States, solar PV annual additions doubled, with over 14 GW coming on line in 2016, followed by Japan (8.5 GW). The European Union's annual solar PV market contracted by about 15% to 6 GW in 2016 as growth slowed in the United Kingdom. India's annual solar PV additions doubled, with 4 GW added to the grid last year (Ren 21 Global Status Report, 2017).

Still in 2016, onshore wind capacity grew by 50 GW to 55 GW, about 15% less versus 2015. This decline was mainly due to China, which connected 19 GW of new onshore wind capacity, significantly less than 32 GW in 2015, when developers rushed to complete their projects to benefit from higher FiTs. However, despite slower capacity growth, China curtailed around 50 terawatt hours (TWh) of wind power last year, with average nationwide curtailment rate increasing from 15% in 2015 to around 17% in 2016. The European Union added over 11 GW, led by Germany and France, followed by the United States (8.2 GW), India (3.6 GW) and Brazil (2.5 GW). In 2016, global offshore wind new additions are estimated to have declined versus 2015 by a third, with annual grid-connected capacity decreasing by about half in Europe as a result of a stagnation in the United Kingdom and Germany project pipelines.

Hydropower additions are estimated to have decreased for the third consecutive year since 2013, with fewer projects becoming operational in China (12.5 GW). Brazil added almost 5 GW of new capacity.

In 2016, concentrated solar power (CSP) capacity grew by almost 0.3 GW, driven almost entirely by Africa. Phase 1 of Morocco's NOOR Ouarzazate Plant, a 160 MW parabolic trough plant with three hours of storage, came on line, while NOOR 2, a 200 MW parabolic Trough plant, continued construction, with COD planned at the end of 2018. The "CSP Today Global Tracker" as at March 2017 reported, 1,542 MWe Tower plants and 5,161 MWe Parabolic Trough plants in operation and under construction. At that point, there were 3,558 MWe Tower and 1,469 MWe Trough plants in development, signifying a shift in international trends in CSP from Parabolic Trough to Tower.

In the recent past, renewable policies for utility-scale projects continued to shift from government-set tariffs to competitive tenders with long-term power purchase agreements. By 2016, almost 70 countries had employed auction/tender schemes to determine support levels, compared with fewer than 20 in 2010. While the first adopters were primarily emerging economies (Brazil and South Africa), this trend has now spread to mature renewable markets (the European Union and Japan). Tender schemes have become a preferred policy option, because they combine competitive pricing with volume control and can support a cost-effective deployment of renewables. As a result, record low prices were announced over the last year in markets as diverse as Latin America, Europe, North America, Asia and North Africa.

In Chile and the United Arab Emirates, solar PV developers signed contracts for projects at below USD 30/MWh, a global record low. In Mexico's energy auctions, winning bids ranged from USD 30/MWh to USD 55/MWh for both solar PV and onshore wind. In India, solar PV contract prices decreased on average by more than a third to USD 55/MWh in 2016 versus 2015/14. For offshore wind, record low contracts were signed in the Netherlands (USD 55/MWh to USD 73/MWh) and Denmark (USD 65/kWh) for a near-shore project, excluding grid connection costs. These contract price announcements reflect a subset of projects that are expected to be commissioned over 2017-20 and should not be directly compared to average generation costs that indicate higher values. Still, they signal a clear acceleration in cost reductions, increasing the affordability and improving the attractiveness of renewables among policy makers and investors.

In South Africa, the national commitment to transition to a low carbon economy informed the Department of Energy's Integrated Resource Plan (IRP 2010) which was promulgated in May 2011. This set a target of 17 800 MW of renewable energy to be achieved by 2030, which represented approximately 42% of the electricity generation mix. Within this 20-year planning horizon, about 5000 MW were planned to be operational by 2019, with a further 2000 MW expected to come online by 2020. Implementation of the IRP 2010 is carried out through Ministerial Determinations, which are regulated by the Electricity Regulations on New Generation Capacity based on the Electricity Regulations Act No. 4 of 2006. The DoE website (http://www.energy.gov.za, as at 13 June 2018) reports that in 2017, 6 422 MW of electricity had been procured from 112 Renewable Energy Independent Power Producers (IPPs) using the competitive bidding process known as bidding windows. By June 2017, 3,262 MW of electricity generation capacity from 57 IPP projects was connected to the national electricity grid, made up of 1468.35 MW wind; 1479.19 MW PV; 300 MW CSP; 5.28 MW land fill gas; and 14.22 small hydro.

Future strategic focus areas

Di Solar PV: Eskom RT&D market analysis found, as at 31 August 2017, that there were 138,212 small-scale embedded generation installations using pv technology in South Africa, with an installed capacity of 285 MW (DC), and that commercial and industrial customers are migrating rapidly to such systems. It is expected that the rapid migration to a "prosumer" environment, where customers become both producers and consumers, will continue. Eskom's focus should be on retaining customers through innovative solutions that embrace these technological advances and rapid price reductions. Such solutions should include holistic service offerings incorporating e-mobility, energy storage, smart metering, and the internet of things.

Wind: Wind generates throughout the day and provides much-needed support during peak hours. However, in current methodologies sites are selected based on wind resource and distance to the grid as the primary consideration for the construction of wind farms. The problem with this approach is that the system operator is left with the challenge of balancing the system with much more backup/reserve power than would have been the case had the sites been selected through an approach of aggregation (and geographical spread) to maximise the capacity credit from all wind installations. In this manner, the system operator would have found that the current installed wind capacity, which translates to 100 MW of baseload energy input to the grid, would have increased to approximately 300 MW, and the cost of having spinning reserve would have reduced proportionately. Research needs to focus on this aspect of wind technology as it would allow for more wind installations in the country with maximum benefit to the system operator.

Small Hydros: Eskom has an installed Capacity of 62 MW from four small hydro power stations. Small hydros present a good opportunity to add generation capacity into existing waterways and pipelines at exceptionally competitive levelised cost of electricity and should be explored further.

Storage for network support: There are currently approximately 2000 Distribution feeders across Eskom that are constrained below tolerable levels, due largely to the thermal capacity and voltage constraints associated with these networks. Renewable energy can be used together with storage to address network constraints and add new customers while deferring expensive infrastructure upgrades.

Solar Thermal: Aside from the ability to store thermal energy to generate power as and when required, solar thermal offers the additional advantage of generating heat at site and feeding such heat into industrial processes without the inefficiencies of generating electricity, transporting that electricity to site and then converting it back to heat as input into the plant processes. The added advantage is that it could be coupled to water treatment processes to address a countrywide and continental problem of providing safe drinking water using a purely renewable resource as well as recovering and treating polluted mine water. These solutions could offer opportunities for spin-off businesses, providing water for agricultural, industrial and domestic applications, and also in reducing Eskom's absolute water consumption. South Africa has limited natural resources in geothermal. Bioenergy is not a widely adopted renewable source of energy. They should therefore not be considered strategic focus areas, but should be monitored for development and introduced into the energy mix as the technologies advance.

Technological advances

Renewable power is forecast to grow by 36% over 2015-21, making it the fastest-growing source of electricity generation globally. Generation is expected to exceed 7 650 TWh by 2021. Solar PV and onshore wind are the only two renewable power technologies that are on track to reach their IEA targets by 2025. Electricity generation is forecast to treble for solar PV and double for onshore wind over five years, driven by strong policy support and further cost reduction expectations. This growth is driven by China, with higher targets announced under China's 13th Five-Year Plan (FYP), and the United States with the multi-year extension of federal tax credits combined with continued supportive policy environment at the state level. India's solar PV growth is also expected to accelerate, driven by auctions. However, challenges concerning grid integration and the financial health of utilities hamper a faster growth towards the country's ambitious renewable targets. In Europe, the growth of both solar PV and onshore wind is expected to slow as incentive reductions, policy uncertainties at the country and EU level, and overcapacity remain challenges (IEA World Outlook Report, 2017).

Offshore wind continues to make technology improvements, faster-than-expected cost reductions and grid connection improvements. In addition, the deployment is forecast to accelerate in China with improving economic attractiveness. Hydropower also needs improvement to reach its generation target. Overall, hydropower new capacity additions are expected to slow over 2015-21 compared with the previous six years owing to the large influence of China's slowdown in large-scale project development due to increasing environmental and social concerns. However, large hydropower growth is forecast to be robust in emerging markets in Southeast Asia, Latin America and sub-Saharan Africa for large-scale projects, though environmental concerns and the availability of financing remain challenging.

Although the global installed capacity of CSP (5GW) is significantly lower than PV (300 GW), the price of CSP is reducing internationally and is almost comparable to grid connected PV. Numerous examples including Solar Reserve's purchase power agreement at 6.1 UScents/kWh for the 150 MW Aurora CSP plant at Port Augusta in Australia [0.824 R/kWh @ROE of 13.5] confirm the cost reduction trajectory of the technology. CSP with thermal energy storage supports generation at any time of the day and can through proper contracting, support the system operator in balancing the system.

For bioenergy, despite a more optimistic outlook in Asia, with increasing co-firing and waste generation, most generation costs remain higher than conventional alternatives. For geothermal, pre-development risks remain high overall, and drilling costs have been increasing over the last decade. Ocean technology holds a great potential but requires faster cost reductions.

Gaps

In the grid scale energy storage arena there are many technologies that have been developed mainly for renewable energy generation and for grid stability applications. In addition to electro-chemical energy storage technology, there are others being pursued, including compressed air, fly wheel, gravity storage using existing abandoned mine caves, nano-technology applications and hydrogen fuel cells. The gaps that need to be addressed are the ability for these technologies to be packaged correctly for utility scale applications and the reduction of the costs of these systems. A number of these emerging technologies are being pursued by new technology ventures in Europe, North America and Japan.

Approximately 18% of South African homes are not electrified, many of them with no cost-effective transmission access. The most suitable method of electricity provision, together with a combination of the geographical context, the consumer needs, and the possibilities that are available and affordable to provide the energy requirements, needs to be investigated. The low load demand, the dispersed nature of rural settlements, and the high fixed costs of grid extensions make it unlikely that grid will reach remote areas in the medium term.

Value, opportunities and risks of this portfolio

Eskom is viewed as a key stakeholder and the enabler of renewable energy in the country in terms of both providing grid despatch and long-term power purchase agreements from IPP renewable energy projects. As such, Eskom plays a huge role in sustainable and successful development of renewable energy in South Africa. Eskom's grid capacity planning for the country facilitates the long-term deployment of renewable technologies around the country. This renewables research portfolio presents the organisation with cutting-edge renewable technologies, services and solutions, which assists in making green energy available and increasingly more affordable on the South African grid. This portfolio demonstrates the commitment of Eskom to pursue low carbon growth opportunities. Eskom has a critical national role to serve as the catalyst to help reduce renewable energy cost to grid parity and eventually make it more affordable to the South African consumers.

A concern worth noting is the lack of allocation of new renewable energy generation capacity to Eskom in the IRP 2010 post the development of the 100 MW Sere wind farm and 100 MW concentrated solar power plant. While Eskom is hopeful of eventually obtaining its fair share of renewable energy capacity allocation from the 17.6 GW target by 2030, Eskom's RT&D strategy for the next few years needs to factor this into account.

Despite the lack of clear support from government in terms of subsidies and incentives for renewable generation, several applications have been received from IPPs outside the limited REIPPP programme. It is therefore clear that alternative drivers (e.g. favourable contracting terms) are providing major support for renewable technologies. Major risks are the take-or-pay nature of the contracts that forces Eskom to take supply from IPPs even though own generation may be cheaper, the absence of energy storage with wind and PV plants, and the inability of the IPP plants to provide ancillary services to the system operator. These limitations are not technology related but rather the contracts that favour IPPs that have been put in place.

Small-scale generators such as residential and commercial rooftop solar PV are also being installed across the country and will accelerate if NERSA allows "feed in" tariffs. This creates a strategic problem in loss of revenue and opportunity for a new business model that seeks to participate in this space. It will also will also call for greater use of smart grid technology. The loss of revenue may also impact funding for adequate maintenance at low voltage level, and to some extent medium voltage networks. A key risk is that many existing installations do not comply with appropriate safety requirements, resulting in increased operational and safety risks.

The draft Gas Amendment Bill released on 9th of May 2013 makes provision for the harnessing of unconventional gas as well as alternate sources of large-scale natural gas: both imported as LNG and domestic shale and offshore oil/gas exploration, development and production. Unconventional gas in South Africa is experiencing rapid development, and with the country's diminishing conventional gas resources, shale gas would play a valuable role and may counterbalance current pipeline gas shortage at an affordable price. It is envisaged that the price of shale gas would be much cheaper than green energy making back-up power from gas peaking to intermittent renewable energy more affordable. The risk with imported LNG is that the process to liquefy natural gas is energy-intensive with a high carbon footprint in conversion and transport. This, together with the impact on balance of payments, and reliance on an imported product for power generation when natural solar and wind resources are abundantly available in the country, is often ignored or overlooked in discussions around LNG.

Technological advances in renewable energies and battery storage, particularly vanadium redox flow batteries, could reduce demand for fossil fuels, while making the grid more suitable for adoption of intermittent sources such as renewables in the medium and long-term. The added advantage (and opportunity) of vanadium redox flow batteries is the potential for localisation and creating an industry around the technology.

Partnerships and collaboration

- CSIR – enhance the skills and knowledge base within the portfolio.
- SANEDI – Enables Eskom to partner and collaborate on countrywide strategic research that benefits the organisation.
- University of Stellenbosch Centre of Renewable and Sustainable Energy Studies (CRSES) - CRSES holds the renewables chair within the Eskom Power Plant Engineering Institute programme for the development of highly skilled engineers within the renewables portfolio. CRSES, together

with the University of Cape Town, undertakes several contract research assignments, mainly in the solar, wind and grid integration focus areas within the portfolio.

- **University of Cape Town** – Has skills and experiences in planning, resulting in key support research towards renewables integration on the grid.
- **GIZ** – German development agency funding research programmes on renewable energy technologies and grid integration, as well as capability building and training in renewable energy.
- **Danish Energy Agency** – Danish research programme building capacity and skills on renewable energy integration into the power system and flexible operations.

The Research Framework

RENEWABLES			
Supply	**Finance**	**Technology**	**Operations**
• Resource location • Quantification of availability and reliability of resource • Integration issues and implications • Land availability • Investment cost of the technology	• Levelised cost of electricity • Lifestyle costs of the technology • Labour and plant maintenance	• Technology advancements and availability • Novel solutions • Costs • Skill requirements • Life expectancy of equipment • Social concerns • Environmental concerns	• Environmental • Plant Performance • Asset Management • Operating Costs • Training • O&M • Optimisation of spares • Optimisation of logistics • Social issues • Decommissioning plans • Safety
	Grand Challenge: RT&D will provide optimised solutions in support of Eskom's Corporate Plan through the delivery of at least three renewable energy applications in the next three years.		

7 THE GAS GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Gas Grand Challenge

The 2018 draft Integrated Resource Plan (IRP) indicates a 46% share of coal in the 2030 energy mix of South Africa. The global transition to cleaner energy and away from fossil is well underway.

Eskom has the opportunity to diversify its future energy mix and gas is one option to be considered, with a projection made in the 2018 IRP for the installed capacity of 16% gas (11.9 GW out of a total of 75.4 GW) in 2030.

According to the International Energy Agency (World Energy Outlook, 2015), Black & Veatch (Impact of Coal Plant Requirements on the Capacity and Energy Market in PJM, 2012) and Navigant Research (The Phenomenon of Coal to Gas Switching, 2012), as power utilities decommission/retire aging coal plants they are increasingly transitioning to natural gas for electricity generation. Utilities around the globe are choosing natural gas over coal for meeting electricity demand, a trend driven by a decline in natural gas prices over the years, standards/policies aimed at limiting global carbon emissions, quick response to demand peaks and short plant construction times (18 months to two years) as compared to nuclear and coal power plants.

Vision

The challenge that Eskom faces is can we adapt to a rapidly evolving energy landscape? The vision is to provide Eskom with strategic gas options and higher investment definitions based on the latest technologies, new applications and trends in the gas market within three years. This research and investigations will provide a stepping stone for the assessment of other gas types in the future as they become commercially viable.

Research alignment with business priorities

Gas power plants are a cleaner energy technology than coal-fired power plants. Earths Future (Switching from Coal to Natural Gas with Combined Cycle Technology, 2014) and National Energy Technology Laboratory (Cost and Performance baseline for fossil energy plants, volume 1, 2010), report that the burning of natural gas as a fuel source for electricity generation offers immediate benefits, including reduced air and water pollution, reduced carbon emissions (approximately 40%-60% less carbon dioxide than conventional coal for an equivalent amount of electricity generated), less power plant water consumption, greater flexibility of the power grid and greater economic development in gas-rich areas.

Gas is an option which can provide flexibility in a power system. As power systems evolve to incorporate more renewable energy and responsive demand, regulators and system operators are recognising that flexibility across all elements of power systems must be addressed. Renewable energy penetration increases the variability and uncertainty of a power system. Eskom has already connected approximately 2000 MW of renewable energy onto the national power grid from Independent Power Producers (IPPs) and signed over 4000 MW of power purchase agreements for renewable energy. The National Development Plan of South Africa aspires to connect 20 000 MW of renewable energy onto the grid by 2030. Gas-fired units are often considered to be the most flexible dispatch option, providing a rapid response to variability.

Key technical research questions

- Where are the gas resources (natural gas, Coal Bed Methane, Underground Coal Gasification, Shale Gas, LPG and LNG) available, at what quality and quantity?
- How can these gas sources be bought to market, given that there is limited gas infrastructure nationally?
- What existing infrastructure (Transnet ports and pipelines, Eskom substations and transmission lines) can be modified or co-utilised?
- From a supply point of view, how can gas be optimally integrated into power generation?
- What are the associated water required, and emissions and wastes from power generation with the various gas resources?
- What are the financial models, levelised costs of energy and life-cycle costs that are associated with the gas value chain?
- Where are there regional reserves of gas that can be leveraged through partnerships within the SAPP, and when is the opportune partnership entry time to secure gas reserves?
- Who are the local, regional and international partners that could foster efficient entry into the gas sector with Eskom?

Landscape

Recent finds of natural gas reserves in the Southern African Development Community (SADC) have unlocked the potential for the leveraging of this primary energy resource for electricity generation. The recent finds in Mozambique and United Republic of Tanzania are significant enough to consider the resource in the national and regional energy mix. The IRP considers the allocation of 16% to gas resource, a nominal allocation of 11.9 GW (2030).

OCGT and CCGT technologies are attractive since the execution time (post ERA approval) to deploy the plant is typically 18 months and is usually located near large load centres, thus offsetting the cost for additional electrical evacuation infrastructure. Gas technology is also, in order of magnitude, 50% to 60% "cleaner" than fossil-based coal technology. Natural gas is a cleaner fuel when compared to other fossil fuels; the combustion of natural gas produces negligible amounts of sulphur, mercury, and particulates.

An important consideration, however is the associated emissions from the gas extraction, refining and transportation value chain. This is especially true for emissions that have a global impact, such as CO_2. Within the lifetime of any new gas-fired power plant (25+ years), it is reasonable to assume that the power utility will bear consequence for the CO_2 emissions that happen "over the fence" on the fuel supplier side.

The variable nature of the future energy mix will require fossil-based technologies to be flexible enough to dynamically shift the energy output to either fill an energy chasm or to ramp downwards when there is excess generation on the grid. A key attribute of gas-based generation is that the technology is well apt to very fast response times. This quick response characteristic of gas makes it an attractive asset for a utility, as in a market-operated environment, the ability to quickly respond to dynamic demands of the grid attracts premium prices.

The natural gas business is completely different from the familiar coal-based business. In particular aspects such as, inter alia, whom to partner with to address the strategic sourcing of the gas; the technology & finance models; build programme; operations and maintenance; safety, health, environmental, quality (SHEQ); and legal and regulatory compliance remain unanswered for Eskom to take a position on the Gas business.

Future strategic focus areas

In the short term, the focus will be on the provision of research products to assist the organisation to understand the implications of the IRP relating to gas, for Eskom. This will include scans of local development with regard to the up-stream (Mozambique and the Outeniqua Basin), midstream (storage, conversion technologies and supply infrastructure) and downstream (storage, processing and power generation).

In the mid to longer term; the macro- and micro-economics; LCOE and life-cycle aspects of natural and unconventional gas (including shale gas) will be investigated. This will be critical input data for modelling to understand the systemic implications of including gas in the generation mix of the organisation.

The above focus areas will include the benefits of the reduction of GHG emission (and hence reduction of organisational carbon footprint) and the socio-economic implication of the new fuel source (implications for the overall national employment status).

Technological advances

The role of natural gas-fired power generation is twofold: first, to provide flexibility to support the integration of renewables, and second, as a lower-carbon alternative to coal-fired generation or a lower cost alternative to diesel. Whilst diesel-to-gas shift is very well understood in Eskom, all the opportunities of the coal-to-gas switching are not. The latter can occur in many ways, by eg. decommissioning coal-fired plant and replacing them with gas turbines (simple or combined cycle), or by co-firing gas and coal in the same boiler to decrease CO_2 emissions, improve load following capability or reduce NOx. The latter opportunities need to be researched. The IRP maps gas-fired power generation to increase over the next decade by roughly 2.4% per year. While this is markedly lower than the 2.2% observed in 2014 and the average over the last decade (3.9%), the volatility of the growth path over the last several years and pronounced regional differences indicate the fragility of gas generation growth.

Additional progress in also needed in efficiency and flexibility performance of plants to provide support for the integration of variable renewables and serve as a short-term, lower-carbon alternative to coal plants, while preventing long-term stranding of gas plants. Gas is, however, increasingly competing not only with coal but also with other low-carbon alternatives that are already contributing to decarbonising the power sector in many regions, such as energy efficiency and renewable power generation.

Gaps

The competitiveness of natural gas relative to alternative generation technologies in the electricity system is highly dependent on regional market conditions. Carbon pricing, maximum emission caps and strict pollution regulations have proven their ability to establish competitiveness of gas with coal, and technology-neutral competitive mechanisms can ensure electricity supply security. With gas being a source of carbon emissions, R&D should increasingly also focus on gas power generation with CCS, because unabated gas, just like coal, is too carbon-intensive in the long run to reach the global targets.

Value, opportunities and risks of this portfolio

Combined-cycle plants accounted for roughly three-quarters of the world-wide additions in 2015. The Middle East, China and the United States were responsible for over half of the investment activity. Infrastructure considerations remain the main obstacle to stronger gas-fired power development in many developing countries, because the gas pipeline network needed to take advantage of low liquefied natural gas (LNG) prices often remains underdeveloped. As a result, coal remains the preferred fuel in many regions. In the United States, where gas prices are low and coal plants are being retired for economic and environmental reasons, investments have remained robust, although capacity additions were slightly lower than in previous years.

A major focus of gas turbine design is on flexibility performance, both for new-build plants and for retrofits of existing plants. Improvements in ramping capabilities, start-up times, turndown ratios and part-load behaviour are continuing in parallel with more moderate full-load efficiency improvements. Research on novel thermal coatings and cooling technologies continues to enable higher temperatures and efficiencies. State-of-the-art combined-cycle gas turbine (CCGT) efficiency now exceeds 60%, with expected improvements to 65% efficiency over the next decade. Top open-cycle gas turbine (OCGT) efficiency is at around 42%, up from around 35% in 1990.

Partnerships and collaboration

- Department of Energy – Integrated Resource Plan
- SANEDI - Shale gas research
- CEF – Energy Solutions for the South Africa and the region
- PetroSA – Gas exploration
- Academia – Shale gas research
- CSIR – Shale gas research
- Transnet – Pipeline transport infrastructure

The Research Framework

GAS			
Supply	**Technology Finances**	**Build**	**Operations**
• Resource location • Quantification, availability and reliability (volumes available) • Integration issues and implications • Investment cost of the technology • Production costs	• Levelised cost of energy • Lifecycle costs of the technology • Labour and plant maintenance • Financing options • Technology options, using other gas types	• Environmental • Technology (advancement) • Skills • Technology availability • Life expectancy • Construction • Commissioning • Social • Regulation • Strategic partnerships	• Environmental • Plant performance • Asset management • Operating costs • Skills (core competency) • Training • O&M
	Grand Challenge: Can RT&D provide Eskom with gas strategic options and improve business case definitions based on the latest technologies, new applications and trends in the gas market within 3 years		

8 THE NUCLEAR GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Nuclear Grand Challenge

Nuclear power is considered in the electricity generation mix of several countries as an option to improve energy security and provide base load for development.

It provides a number of strategic, economic and environmental advantages. Nuclear energy is competitive relative to other electricity generation technologies, offers protection from the volatility of fossil fuel pricing and assists in climate change mitigation. The Department of Energy's Integrated Resource Plan (2010-2030) as well as the South African National Development Plan 2030, both indicate government's intention to include more nuclear energy into the South African energy mix.

South Africa is a semi-arid country currently with water restrictions in place in most areas. The Department of Water Affairs' long-term plans indicate further fresh water shortages going into the future. Nuclear appears attractive as an electricity generation technology as it utilises very little fresh water in its processes. Eskom's nuclear power station, Koeberg, situated on the coast, utilises sea water for cooling and uses 0.005 l/kWh of fresh water. On 5 October 2016, 132 countries, including South Africa, ratified the Paris Agreement which formed part of the United Nations Framework Convention on Climate Change. This increases pressure on the fossil industry as more countries are transitioning towards low carbon economies. Operating nuclear power plants emit near zero carbon emissions and are therefore preferable compared to coal-fired generation.

The Integrated Resource Plan (IRP) outlines the country's electricity demand, how this demand might be supplied and what the likely costs could be for new generation. Balanced scenarios represent the best trade-off between least cost investment, climate change mitigation, diversity supply, localisation and regional developments. According to the IRP (2010-2030), nuclear represents 11.3% of the total generation mix, which is 9.6 GW of new nuclear capacity in the balanced scenario. The model indicates this new build should be commissioned by 2025. The updated IRP, which was released in November 2016 for public comment, extends the planning horizon to 2050 and models down the nuclear new build target to 4.9% in the base case scenario. This represents approximately 20.4 GW and the suggested timeframe for this new build to come online is from 2037 to 2050. Under the carbon budget scenario, new nuclear is likely to come online by 2026. Eskom will continue to proceed with its request for proposals at the 9.6 GW level, and anticipates a levelised generation cost of R1000/MWh.

Vision

Eskom RT&D has initiated a research and development programme to focus on the next generation of nuclear power plants to meet the demands of future electricity grids. The RT&D Nuclear Grand Challenge focusses on developing advanced high temperature gas-cooled technology reactor (AHTR) options for Eskom within the next five years. The technology of the reactor will focus on the High Temperature Reactor technology that was developed in South Africa as the Pebble Bed Modular Reactor in the 1990's.

Research alignment with business priorities

The need for nuclear in the Eskom environment arises from the following: climate change, the existing power generation fleet approaching end of life, future security of supply, and maintaining strategic relevance in South Africa/ Africa.

To achieve climate change goals; Eskom needs to diversify its electricity generation mix over time as 85% of Eskom's installed generation capacity is from coal power generation. Approximately 10 GW of Eskom's existing fleet will be retired by 2030, considering a 50 year life. The capacity will greatly decline afterwards; in 2040 approximately 30 GW will be decommissioned. No other large baseload beyond Kusile is currently committed to, only the 900 MW from IPPs. Life extension of existing power stations can postpone the requirement for any new large base load power plant, but will not be a long-term solution and will be limited by environmental laws and cost of compliance. Further, given the unique regulated nature of a nuclear programme in any country, Eskom is the best state-owned vehicle to implement nuclear power in South Africa, and this will further secure Eskom's position in the electricity market for many years to come.

Key technical research questions

- Can the Advanced High Temperature Reactor utilise a combined cycle to maximise efficiency as well as the incorporation of heat storage systems to enable load following?
- Can the reactor be designed to simplify the licencing process whilst eliminating many possible accident modes? Key features include efficiency above 50% and 66% of load following capability with energy storage to maintain maximum average output.
- The primary focus of the research and development tasks is on developing novel nuclear components based on proven technologies to meet the above-mentioned objectives.
- Research and development of pre-stressed concrete pressure vessel development based on known and proven technology.
- The research and development of the high temperature core barrel components.
- The design and demonstration of high temperature gas turbines.
- Development and testing of Helium-Helium, Helium-Molten Salt and Helium-Steam heat exchangers.
- Prototyping of auxiliary and control systems.
- The research and prototyping of materials, qualification, system design and manufacturing process development.

Landscape

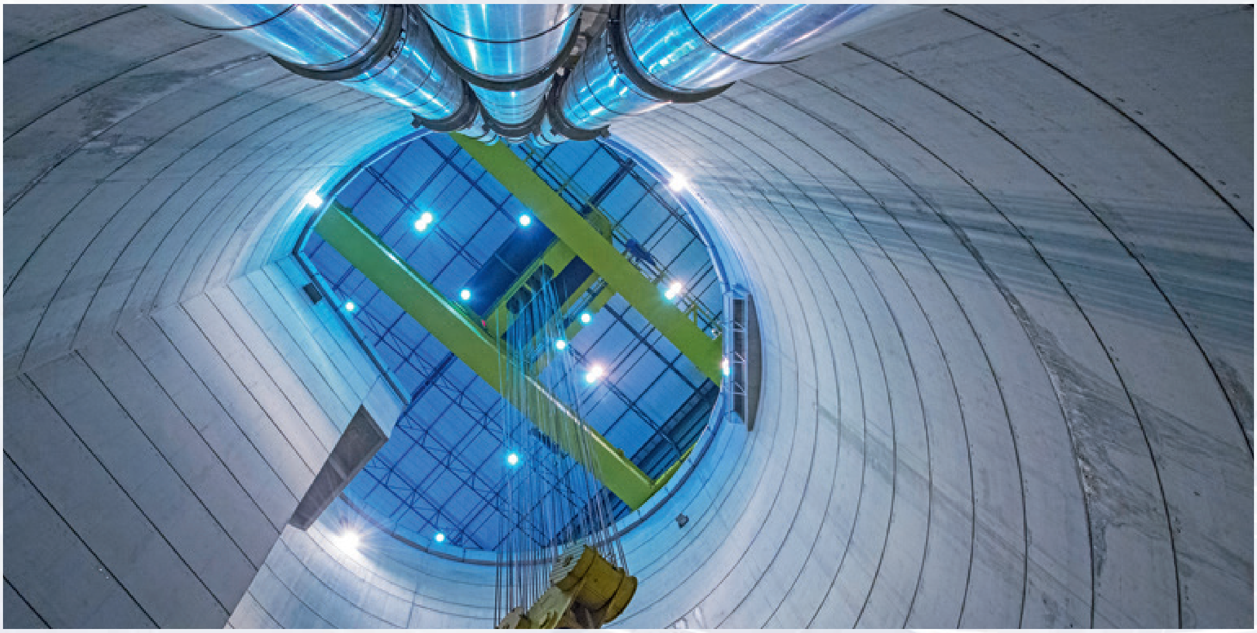
Nuclear generation in 2050 will account for a nominal generation capacity of approximately 13GW (11% of the generation mix). Although nuclear plants are highly capital intensive to build the operating and fuel costs of a nuclear station are significantly lower than that of coal as well as natural gas. The business model requires high levels of management during the construction of the asset to manage and monitor the high exposure to capital costs; however, the plant is sufficiently shielded from fuel costs for the life of the plant, typically 50 years to 60 years.

Nuclear generation plant does not emit any greenhouse gases (similar to renewable generation) and makes the technology very attractive towards achieving environmental targets whilst being a very dispatchable generation source. In addition, nuclear technology does not require raw water for its cooling systems, another attractive reason as South Africa is a semi-arid country. Large economies such as the USA and China have expressed in their energy policy decision a need to build and operate significant nuclear plant, which may perhaps provide the economies of scale to reduce the capital costs associated with the commissioning of nuclear plant.

Key issues to quantify and qualify are the evolving financing models for nuclear plant; using robotic and other smart technologies to provide safe operations and maintenance; and the mammoth task of providing a sustainable solution to address waste management.

Future strategic focus areas

- Fuel Reliability – Develop the technical basis for preventing fuel failures through research into failure mechanisms analysis of failed fuel rods, and development of fuel reliability guidelines.
- Nuclear Fuels – Enhance understanding of fundamental in-reactor behavior of fuel, cladding, control materials, and other core components to support safe, reliable, and economical use of light water reactor core materials and components.
- Nondestructive Evaluation and Material Characterisation – Develop and qualify nondestructive evaluation technologies that can be used to guide decisions on whether and when to replace, repair, or continue operation of components.
- Equipment Reliability – Develop tools, techniques, and practices that can increase overall nuclear plant reliability and safety.
- Safety and Risk Technology – Develop risk and safety assessment tools and techniques that enable nuclear plant owners to make technically sound design, maintenance and operational decisions.
- Chemistry and Radiation Safety – Develop guidance and technologies to improve water chemistry practices, enhance low-level waste management, reduce radiation exposure, and inform plant decommissioning efforts.



Technological advances

The Nuclear Grand Challenge aims to improve the economy of current nuclear power plants. It is expected that a demonstration plant will be completed by 2022 at the Pelindaba Nuclear Facility for piloting and testing the Advanced High Temperature Reactor concept, with a commercialisation process following the successful demonstration.

The research will include business case investigations for commercialisation, macro-economic impact studies, socioeconomic studies for localisation benefits to the country and skills development opportunities in communities. The pilot plant will provide new knowledge that will be utilised to quantify levelised costs of energy and operation and maintenance costs. It is anticipated that this project will yield many new patents for the country.

In terms of technology, the majority of reactors under construction today are Generation III/III+ designs. The first APR1400 and VVER1200 (Novovoronezh 2 in Russia) were connected to the grid in 2016. Efforts to develop and deploy small modular reactor (SMR) designs continued, with Argentina's CAREM reactor and Russia's and China's floating NPPs. In the United States, NuScale Power submitted the first-ever design certification application for an SMR to the US Nuclear Regulatory Commission. All of these SMRs are 100 megawatts electrical (MWe) or smaller.

Gaps

Increasing nuclear capacity deployment could help bridge the gap and fulfil the recognised potential of nuclear energy to contribute significantly to global decarbonisation. This requires clear and consistent policy support for existing and new capacity, including clean energy incentive schemes for development of nuclear alongside other clean forms of energy. In addition, efforts are needed to reduce the investment risk due to uncertainties, such as licensing and siting processes that have clear requirements and that do not require significant capital expenditure prior to receiving a final approval or decision. Industry must take all actions possible to reduce construction and financing costs in order to maintain economic competitiveness.

Value, opportunities and risks of this portfolio

The need for nuclear in the Eskom environment arises from the following: climate change, the existing power generation fleet approaching end of life, future security of supply, and maintaining strategic relevance in South Africa/ Africa.

To achieve climate change goals; Eskom needs to diversify its electricity generation mix over time as 85% of Eskom's installed generation capacity is from coal power generation. Approximately 10 GW of Eskom's existing fleet will be retired by 2030, considering a 50-year life. The capacity will greatly decline afterwards; in 2040 approximately 30 GW will be decommissioned. No other large baseload beyond Kusile is currently committed to, only the 900 MW from IPPs. Life extension of existing power stations can postpone the requirement for any new large base load power plant, but will not be a long-term solution and will be limited by environmental laws and cost of compliance. Further, given the unique regulated nature of a nuclear programme in any country, Eskom is the best state-owned vehicle to implement nuclear power in South Africa, and this will further secure Eskom's position in the electricity market for many years to come.

Partnerships and collaboration

- CSIR – Enhances the skills and knowledge base within the portfolio.
- NECSA – The South African Nuclear Energy Corporation.
- DOE – The South African Department of Energy.
- PBMR – Pebble Bed Modular Reactor (SOC) (PBMR™) was established in 1999 with the intention to develop and market small-scale, high-temperature reactors both locally and internationally.
  The PBMR is a helium-cooled, High Temperature Reactor (HTR). Very high efficiency and attractive economics are possible without compromising the high levels of passive safety expected of advanced nuclear designs.
- University of North West – Research partner.

The Research Framework

NUCLEAR

Supply

- Challenges
- Uncertainty of IRP
- Excess generation capacity
- Environmental aspects (waste management and water challenges)
- Expensive plant

Pilot and Demonstration

- EIA
- Concept design
- Licensing

Core Physics

- Fuels/coolants/moderator analysis to meet plant configuration demand

Technology

- Novel solutions
- Control systems investigation and design
- Heat exchanger and turbine design and core barrel development
- Thermal loading and material investigations
- High temperature fuel performance analysis investigations
- Understanding flexibility aspects power conversion unit
- Material selection and qualification
- Simulation code development

Training and Tech Transfer

- Business case investigations for Commercialisation
- Macro-and-socio-economic studies for benefits (direct, indirect and induced job creation)
- Skills development opportunities in the communities
- Levelized cost of energy analysis
- Operation and maintenance cost quantification patenting

Stakeholders

- PBMR
- Eskom Nuclear Engineering
- NECSA
- DOE
- CSIR
- Universities

Partners

- International agencies
- Universities
- Suppliers
- CSIR

GRAND CHALLENGE: RT&D will develop Advanced High Temperature Gas Cooled. Reactor technology options for Eskom in the next five years

9 THE TRANSMISSION ASSET MANAGEMENT AND PLANT PERFORMANCE GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Transmission Asset Management & Plant Performance Grand Challenge

The transmission grid has transitioned from a scenario of deficit capacity to a surplus capacity over the past five years.

The grid is rapidly evolving towards complex and flexible operations:- i. to integrate large intermittent sources of generation and future storage; ii. trade electricity in the region; and iii. balance a far more complex and dynamic nature of variable supply and demand. In addition, Transmission is currently challenged with an aging network and limited resources. The organisation is constrained by investments for both the expansion and refurbishment of infrastructure together with increased incidents of unplanned outages. Asset Management provides for an approach to optimise multiple business goals: the performance of the assets; lifecycle costing; effective use of resources and managing organisational risks.

The Research focus with respect to existing plant is the improvement of network performance; extension of the life of the plant and proactive management of aging infrastructure. This will be accomplished through the resolution of technical problems through sound engineering principles and in-depth technical investigations of technologies. This research challenge will provide technical knowledge for informed decision-making towards this achievement, through scanning, experimentation and piloting of transmission technologies.

Vision

Research will support the future transmission grid that will be intrinsically intelligent and highly automated. The grid will be flexible to enable system-wide integration of all energy sources as well as large-scale storage. It will also become flexible to facilitate participation of different grid stakeholders whilst delivering electricity in a cost-effective manner with enhanced levels of efficiency, reliability, security, and safety. The future transmission grid will further be characterised by:

- Providing for high levels of reliability, availability and maintain ability leveraging on the use of the latest smart technologies and automation.
- Demonstrating improvements in performance by reducing system minutes lost and major incidents by applying smart technologies onto the grid for real-time measurement and control.
- Flexibility to support the integration of variable generation sources and large-scale storage technologies.
- It will be robust, secure, and highly resilient to cyber-attacks and other attacks such as theft, including natural disasters.
- It will leverage and integrate both existing technologies and new technologies and techniques to provide for predictive maintenance, optimal levels of asset utilisation and greater efficiencies.

Research alignment with business priorities

Transmission research provides key characteristics that will result towards achievement of the organisation's zero harm goal. Examples include the adoption of robotics for live line operations which is a measure to ensure that employee's lives are not put at risk. Application of advanced sensors would reduce probability failures to transformers and other plant; these failures usually result in oil fires, which will be avoided, thus the protection of the environment.

Novel intelligent technologies have the potential to result in cost efficiency improvements whilst maintaining or improving plant performance of the utility. These sources of real-time data from synchrophasor measurements, advanced equipment health sensors, and future load and variable renewable output forecasts, provide operators with increased situational awareness and advanced decision-support tools. Research will, keep a track of key technologies and best practices from utilities, experiences around the globe. These experiences will be adapted for the Eskom environment by prototyping and demonstrating with a view towards narrowing the technical performance gap to the top utilities globally.

Intermittent variable generation resources provide a new challenge to utilities to integrate and operate the grid with these generation sources. Research into the technologies choices, coupled with innovative engineering, will result in a flexible transmission grid which accommodates both traditional and intermittent generation sources.

Key technical research questions

- Conduct research into the root cause and design new and retrofit solutions to mitigate faults (birds, fires and lightning) and broader performance of both AC and DC schemes. What can be done to improve and optimise the performance of the overall grid?
- Investigate novel technologies and innovations for the improvement of capacity throughput per kilometre; reduction of losses & improved stability of the network.
- Develop models that guide utilities on what data is important for developing failure rates, quantifying health condition of assets, prioritising which assets need monitoring, formulating spares policies.
- Development of maintenance, inspection and assessment guidelines for Transmission plant and components.
- Developing fact base technical recommendations to assist Transmission with the maintenance programmes; extend equipment life of assets and reduce maintenance costs via condition-based maintenance.
- How can Eskom improve practices for live line working, worker safety & public safety in a view to developing guidelines?

Landscape

The regulator has, through its MYPD determinations, indicated increasing requirements for improved performance of the transmission grid (Grid Code compliance) together with an overall requirement for a significant reduction of operational costs. These challenges from the regulator will necessitate accelerated deployment of technologies into the grid for improved performance and cost efficiencies in both capital and operational costs.

Environmental legislation has become much more stringent. Existing load centres such as cities and industrial areas are growing, thus requiring additional energy. However, the acquisitions of additional servitude for transmission line routes have become increasingly difficult due to environmental legislation. This challenge requires innovative thinking into optimal use of existing servitudes. There is also a significant drive for greener sources of energy. The transmission grid will need to be flexible to integrate the grid to greener resources located in different geographical positions. In addition, the short-term balancing of the supply and demand will require application of new technologies to monitor and control the dynamic and intermittent nature of both the supply and demand.

Future strategic focus areas

- Line Performance: This research focus will be on the improvement of the operational performance of lines on the transmission grid. These will include work of the various voltage levels on the network. Additionally, the research will focus on causes of faults, including birds, lightning and fires.
- Plant Performance: This research is focussed on the improvement of the operational performance of substation plant. These will include the use of advanced analytics tools for analysis of plant at different voltage levels; focus on failures specific to geographical areas; modes of failure; OEM-related failures; and age-related analysis.
- Spares & Workforce Management: This research area is focussed on the improvement of the spares and workforce management. This includes the location of the spares, its geographical location in relation to the poor performing plant and lines. Logistics and time delays to retrieve spares until commissioning. New tools for the workforce in terms of deploying the correct skills, spares to the correct site. Optimisation of works orders using tools such as field devices, internet of things, RF ID tags, etc.
- Bathtub Curve Analysis: Utilising various intelligence sensory data as well as advanced analytics tools to conduct bathtub curve analysis on knee points for all line and plant components. The research to focus on detection of early indicators of failure and applying statistical models on and relationships with voluminous and complex data sets.
- Age Analysis of Lines and Plant: Typical commissioning of technologies is based on a commercial philosophy which results in batch commissioning of plant and components. The analysis will provide insight into the mode of failure as well as the mean time to failure. An understanding of the failures plant reliability beyond the OEM specified MTTF.
- OEM Failure Analysis: This research area is focused on failure analysis of OEM-specific batch manufactured equipment.

Technological advances

- Assess new and existing materials, components and technologies for failure modes, reliability and life expectancy.
    - *Superhydrophobic/Icephobic coatings, Coatings for Fibreglass, Surface Doping of Aluminium Conductors, Nano Based Dielectrics, optical CT and VT.*
- Techniques and technologies will enable safe and efficient work practices on transmission lines.
    - *Utilisation of Robotics.*
- Reduction of transmission line losses.
    - *LiDAR & Conductor Temperature Technologies, Unmanned Airborne Inspection, Robotic Inspection.*

Gaps

- Tools to specify and assess new and existing materials/components/designs for failure modes, reliability and life expectancy in a rapidly changing manufacturing environment.
- Tracking new materials being developed that are easier to apply, reliable, cost-effective and enable real-time in-service assessment (predictive) of material condition and risk.
- A fundamental understanding of components and materials degradation and failure.
- Rising fault levels of the network and its implications.
- Variable generation interconnection as well as regional transmission interconnection.
- Advances in sensors, monitoring hardware and intelligent microprocessor relays will provide utilities with a robust foundation to incorporate real-time information in their as set management decision support.
- Tools and techniques will enable the confident selection, specification, installation and maintenance of new component technologies.
- Components will be safe and friendly to work practices.

Value, opportunities and risks of this portfolio

The risk of not developing these new technologies is that the industry will be limited by the performance and powerflow of multi-decade old designs and practices. If new technologies are not developed and effectively evaluated prior to widespread application, the potential exists for reduced safety and reliability of the transmission system due to unforeseen performance issues. This in turn will impact maintenance budgets. The performance of transmission assets will degrade, resulting in a reduction of reliability and an increase in safety incidents and fatalities.

Partnerships and collaboration

- **EPRI** – Collaboration in the areas of Overhead Lines, HVDC and Integration of Renewables on the Power System.
- **Cigre** – An international Council on Large Electric Systems established for the collaboration of global experts by sharing knowledge and joining forces to improve electric power systems of today and tomorrow.
- **University of Witwatersrand** – Expert academic research group in primarily HVAC technologies and power systems with some interest in HVDC technology
- **University of KwaZulu-Natal** – Expert academic research group in primarily HVDC technologies and power systems
- **State Grid Corporation of China (SGCC)** – Widely seen together with India as the emerging technology leaders in the field of transmission technologies including HVAC, UHVAC and HVDC.
- **India** – Widely seen together with China as the emerging technology leaders in the field of transmission technologies including HVAC, UHVAC and HVDC.

The Research Framework

TRANSMISSION ASSET MANAGEMENT & PLANT PERFORMANCE

Line Performance

- Anaylsis of the various volatage networks
- Contributions from bird
- Contributions from fires
- Contributions from lightnening

Spares

- Location of spares
- Relation to poor performing plant or lines
- Time to collect spares and move to site

Supplier

- Life of plant
- Mode of failure
- Other utility experences

Stakeholders

- Analysis of all plant against the bathtub curve
- Indications of early failure
- Detection of the knee point of the curve
- Statistical models

Plant Performance

- Plant performance ito voltage
- Modes of failure related to suppliers
- Related to age
- Related to geographical load area

Work Management

- Skills relating to line volatge or plant
- Optimising work orders

Age

- Batch commissioning of certail plant
- Years of operation
- Failure before end of life
- Failure long after OEM predictions of end of life

Mode of Failure

- Related to network loading
- Material fatigue
- Changing climate conditions

GRAND CHALLENGE: RT&D will provide greater insight into transmission plant conditions for asset management purposes and demonstrate technology solutions to improve operations and maintenance under constrained budgets whilst maintaining systems minutes performance, within five years

Commercial Stategy

- OEM at point in time

10 THE TRANSMISSION BUILD GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Transmission Build Grand Challenge

There are several industry-related factors that are driving the expansion of the transmission grid.

The current infrastructure is aging, together with the challenge of increasing demand within the urban and city load centres, and this requires refurbishment and upgrading of the Transmission infrastructure. The changing Generation landscape requires bulk power evacuation from the new sources of generation, located at new geographies, over long distances towards the load centres. Additionally, power highways are required to integrate the regional grid to ensure both export as well as import of power.

Recycling of existing servitudes for upgraded infrastructure requires innovative engineering of designs of compact and multi-circuit tower structures operating at much higher voltages. The industry is undertaking an exceedingly large generation build programme which aims at introducing new sources of generation onto the power network. A key challenge is evacuating power from these new sources to the transmission grid in the most optimal and efficient manner. This is accomplished through the resolution of technical problems and through sound engineering principles and in-depth technical investigations of technologies. The research project will provide technical knowledge for informed decision-making towards this achievement, through scanning, experimentation and piloting of transmission technologies.

Vision

Research will support the future transmission grid that will be intrinsically intelligent and highly automated. The grid will be flexible to enable system-wide integration of all energy sources and large-scale storage. It will also become flexible to facilitate participation of different grid stakeholders whilst delivering electricity in a cost-effective manner with enhanced levels of efficiency, reliability, security, and safety. The future transmission grid will further be characterised by:

- Providing for high levels of reliability, availability and maintainability leveraging on the use of technologies and automation.
- Flexibility to support the integration of variable generation sources and large-scale storage technologies.
- It will be robust, secure, and highly resilient to cyber-attacks and other attacks such as theft, including natural disasters.
- It will leverage and integrate both existing technologies and new technologies and techniques to provide for predictive maintenance, optimal levels of asset utilisation and greater efficiencies.
- Being highly resilient by compliance to the N-1 grid code criteria.
- Becoming a Supergrid by interconnection of the various neighbouring transmission grid networks, facilitating both bulk imports and exports.

Research alignment with business priorities

Intermittent variable generation resources provide a new challenge to utilities to integrate these generation sources onto the transmission grid. Research into the technologies choices, coupled with innovative engineering, will result in a flexible transmission grid which accommodates both traditional and intermittent generation sources.

A key organisational priority is the execution of the capital expansion programme and in particular the evacuation of power from the new sources of generation. Research will support the transmission business in recommendations of technology choices and engineering solutions by investigation of novel technologies that could be adopted for the new tower and lines designs with a view to optimise the capacity throughput per kilometre; the reduction of line losses and improved stability of the national grid. The research will expand into identifying opportunities in the SADC region aimed at the efficiency of use of generation and potential generation supply against the regional energy demands, fostering regional support and collaboration.

Key technical research questions

- What is the optimal design of AC and HVAC single circuit, double circuit & multi-voltage compact tower structures supporting the upgrade of Transmission infrastructure in existing servitudes?
- What are the optimal technical design parameters as well as the design of the new 600kV HVDC towers and lines in support of the Strategic Grid Plan?
- Investigate novel technologies and innovations for the improvement of capacity throughput per kilometre; reduction of losses & improved stability of the network.
- Identify opportunities and technology solutions in the SADC region to collaborate on the balance of regional generation potential against regional energy load growth.
- Can new designs be principled on Reliability, Availability & Maintainability (RAM) centric transmission technologies?

Landscape

The regulator has, through its MYPD determinations, indicated increasing requirements for improved performance of the transmission grid together with an overall requirement for being cost-effective. The regulator will be closely monitoring the Grid Code, in particular the N-1 compliance which required new infrastructure build.

Environmental legislation has become much more stringent. Existing load centres such as cities and industrial areas are growing, thus requiring additional energy. However, the acquisitions of additional servitude for transmission line routes have become increasingly difficult due to environmental legislation. This challenge requires innovative thinking into optimal use of existing servitudes. There is also a significant drive for greener sources of energy. The transmission grid will need to be flexible to integrate the grid to greener resources located in different geographical positions. In addition, the short-term balancing of the supply and demand will require application of new technologies to monitor and control the dynamic and intermittent nature of both the supply and demand.

Future strategic focus areas

- (U)HVAC Tower and Line Design: Design of solutions for the evacuation of power from the new build power stations as well as solutions for the recycling of existing or constrained servitudes. Research will address, inter alia, location of servitudes, foundations, conductors and insulation co-ordination.
- HVDC Tower and Line Design: Design of DC solutions for bulk point-to-point power transfer from the new build power stations. Research will address, inter alia, corona, space charge, RI, RIV, earth electrode, conductors and insulation coordination.
- Substations Design and Components: Research into aspects such as a smaller footprint substation with increased reliability as well as the vision of an automated unmanned substation. Research will address aspects such as substation insulation, circuit breakers (air, CO_2, SF_6), materials inside breakers, disconnector circuit breakers, bushings and performance of existing schemes.
- SADC Transmission Opportunities: Identify opportunities and technology solutions in the SADC region to collaborate on the balance of regional generation potential against regional energy load growth.

Technological advances

- Assess new and existing materials, components and technologies for failure modes, reliability and life expectancy.
  - *DC Circuit Breakers, compact reliable substations; unmanned substations; optical CT and VT.*
- Designs that maximise capacity throughput per kilometre while reducing losses and allowing multiple circuits to utilise the servitude.
  - *Dynamic Thermal Circuit Rating, Structural Materials (Fibre), Higher temperature operation, Carbon nanotubes, Carbon core for aluminium, AC to DC conversion; 500kV Backbone.*
- Techniques and technologies will enable safe and efficient work practices on transmission lines.
  - *Live Working Practices for AC & DC, Improved Construction Practices, Live Reconductoring.*

Gaps

- Empirical studies on the behaviour of various DV phenomenon at high voltage and high altitude, inter alia, space charge, corona, electric field (bipolar designs).
- Empirical studies on the behaviour of various AC phenomenon at high voltage and high altitude, inter alia, corona, radio interference, audible noise.
- Rising fault levels of the network and its implications.
- Environmental monitoring of proposed line routes from new sources of generation such as lightning, bird and pollution activity.
- Mechanical and Electrical clearance of the designs as well as electromagnetic effects of new designs at the servitude boundary.
- Reliability, Availability & Maintainability (RAM) of new Tower and Substation designs.

Value, opportunities and risks of this portfolio

New well evaluated designs and construction techniques will enable optimal assets to be constructed which enable increased power flow, increased reliability and reduced maintenance and is more compatible with the environment. In turn these benefits will result in reduced capital and maintenance budgets. The value of research to enable effective operation and maintenance of transmission and substation assets lies in the ability of the asset owners and operators to manage their transmission assets at a high level of reliability, availability and safety.

The risk of not developing these new technologies is that the industry will be limited by the performance and powerflow of multi-decade old designs and practices. If new technologies are not developed and effectively evaluated prior to widespread application, the potential exists for reduced safety and reliability of the transmission system due to unforeseen performance issues. This in turn will impact maintenance budgets. The performance of transmission assets will degrade, resulting in a reduction of reliability and an increase in safety incidents and fatalities.

Partnerships and collaboration

- EPRI – Collaboration in the areas of Overhead Lines, HVDC and Integration of Renewables on the Power System.
- Cigre – An international Council on Large Electric Systems established for the collaboration of global experts by sharing knowledge and joining forces to improve electric power systems of today and tomorrow.
- University of Witwatersrand – Expert academic research group in primarily HVAC technologies and power systems with some interest in HVDC technology.
- University of KwaZulu-Natal – Expert academic research group in primarily HVDC technologies and power system.
- Trans Africa Projects – Collaboration in the specialised areas of Tower design.
- State Grid Corporation of China (SGCC) – Widely seen together with India as the emerging technology leaders in the field of transmission technologies including HVAC, UHVAC and HVDC.
- India – Widely seen together with China as the emerging technology leaders in the field of transmission technologies including HVAC, UHVAC and HVDC.

The Research Framework

TRANSMISSION BUILD SOLUTIONS

Location

- Location of generation resource
- Load capacity of generation resource
- Geographic landscape
- System studies
- Bird patterns
- Pollution patterns
- Lightening
- Fires and vegetation

Cultural Aspects

- Cultural issues
- Language issues
- Responsibility for O&M
- Perception of stakeholders

Constructability

- Ease of access to site
- Logistics of pant to site
- Civil and mechanical skills

Operations and Maintenance

- Nature of the lines
- Location of the plant
- Typical benchmark of performance
- Availability of skill

Technology Options

- UHVAV
  - Insulation
  - HV Plant
  - Line design
  - Tower costs
- HVDC
  - Line design
  - Space charge
  - Insulations
  - Convertor station
  - Earth return
  - AN, RIV, etc
- Multicircuit
- Narrow servitude
- Cable

New versus refurbishment

- System studies
- Customer impact
- State infrastructure
- State of earthing
- Access to servitudes

Financial costings

- Economic studies
- Life of plant
- Technology Options
- Capex vs Opex
- Lifecycle costings

GRAND CHALLENGE: RT&D to provide design solutions for the evacuation of power from new generation, including SADC and refurbish plant without customer interruptions in constrained servitudes and constrained CAPEX within five years

11 THE DISTRIBUTION ASSET MANAGEMENT AND PLANT PERFORMANCE GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Distribution Asset Management & Plant Performance Grand Challenge

The rapid and unprecedented pace of technology innovation in the electricity industry is currently challenging the structure, model and operation of the power utility.

The majority of these technology innovations will be deployed onto the Distribution network, inter alia, distributed generation, storage, photovoltaic, internet of things and electric vehicles. The Distribution network will be modernised by leveraging on these innovations, which will improve business productivity, network performance and operations of the network. The vibrant growth of distributed generation will change the nature of the distribution network. Whereas Distribution formerly served to transport electricity from the higher voltage transmission network towards end consumers connected to the distribution networks, the distribution network is now used more and more to attune localised supply to local demand.

Key plant performance areas will need ongoing analysis to improve grid operations. Supporting technologies such as smart grids including mobile computing technologies will provide additional operational support towards reducing interruption duration (SAIDI) and less frequent interruptions (SAIFI). The opportunities presented by the Fourth Industrial Revolution will be evaluated for the distribution business and an enabler to improve grid operations. Traditional maintenance philosophies will need to be challenged by the introduction of distributed sensor networks. These networks would provide more accurate information about the health of the grid and will provide proactive maintenance or replacement philosophies for existing plant.

Vision

The traditional Distribution network has been designed for reliably, and to service its customers in a safe and cost-effective manner. However, the future vision of Distribution includes accommodating high levels of DG, increasing resiliency, improving operational efficiency, and actively using distribution systems to provide bulk system services. Tools and technologies such as distribution management systems, automation systems, protection systems, and planning tools must adapt to facilitate the needs of this future integrated distribution system.

Research alignment with Eskom priorities

The organisation is currently faced with a constrained financial environment which is the result of limited capital availability over the medium term. Thus, innovation technology solutions to maintain or improve business operations with a focus on cost efficiency will be a priority into the future. Distribution challenges in time to connect customers, in voltage regulation and in outage restoration time have been highlighted as a regulation compliance challenge. There are also high levels of vandalism and equipment theft, resulting in energy losses, together with an increasing number of outages due to overloading from illegal connections.

Distribution aims to build and maintain its aging network by:

- Maintaining current network performance levels.
- Limiting energy losses to 6.54% through targeted interventions.
- Reducing refurbishment and reliability investment backlogs through disciplined execution.

Electrification remains a priority for Distribution, with one million households to be connected over the planning period, and Eskom hopes to expedite the implementation of Government's Universal Access Programme.

Distribution plans to invest sufficiently in the networks to support the Segmented and predictive maintenance. The division will look to accelerate its transition from time-based to condition-based maintenance. The division will ensure discipline in the implementation of its maintenance strategy by accelerating the roll-out of its mobility and real-time dispatching tools. Using real-time data of employee time and productivity, Distribution can improve the scheduling, dispatch and allocation of tasks for dispatch staff. These field-force tools and applications have the potential to improve field-dispatch schedules and shorten the response time to customer calls, as well as monitoring and improving productivity.

Key technical research questions

1. How would Eskom plan and operate the changing, integrated and increasingly complex distribution system?
2. Can research provide new analytic methods for existing planning tools (e.g. hosting capacity methodology, advanced distribution automation and control, dynamic protection, etc.)?
3. How can research support the implementation of advanced distribution control functions for reliability improvement, voltage control, and the dynamic grid management?
4. Assess the techno-economic benefits of smart grid applications and advanced technologies.
5. Scan industry best practices in the management and operation of modern distribution systems.
6. Can research identify and apply new approaches and strategies for managing aging assets?
7. Pilot and demonstration advanced diagnostics, inspection and assessment methods, tools, and techniques.
8. Integrate advanced distributed sensor technologies into the Distribution network.

Landscape

The regulator has, through its MYPD determinations, indicated increasing requirements for improved performance of the Distribution grid together with an overall requirement for being cost-effective. The regulator will be closely monitoring the Distribution Code, in particular in time to connect customers, in voltage regulation and in outage restoration time.

Environmental legislation has become much more stringent. Existing load centres such as cities and industrial areas are growing, thus requiring additional energy. However, the acquisitions of additional servitude for distribution line routes have become increasingly difficult due to environmental legislation. This challenge requires innovative thinking into optimal use of existing servitudes.

Future strategic focus areas

- **Modernisation of the distribution grid** – This is a broad range of activities which is aimed at identifying ways to improve the present business through advances in information systems, asset optimisation and distribution network support technologies.
- **Enhancing security and reliability** – While grid modernisation focusses on a range of infrastructure deployment, this will focus on protection, prevention and detection of grid-related faults that impact employee and public safety.
- **Energy Infrastructure** – Focus will be on looking at alternative ways of electrification and new load types. This would be ideally look at network planning and operations of distributed generation, microgrids and electric vehicles on the grid. A particular area of concern would be the grid control systems to manage a previously passive grid with new active elements on the distribution network.
- **Customer centricity** – The focus will be on improving service performance through better customer contact management and customer relationship management. Additionally, this includes managing quality of supply to meet acceptable technical standards.

Technological advances

- **Electric vehicles** – Based on international data, EVs will become significant contributors to load. The initial impact of EVs is anticipated as small, but as the number of vehicles increases, the grid could potentially become constrained. The research will provide solutions on how to best manage the grid due to the impact of EVs.
- **Distribution Generation and Microgrids** – With new advances in technology the distribution customer have other energy options. These would include natural gas and solar as sources of energy. The integrity of the power system may be disrupted when distributed generation is added to the existing distribution grid. Distributed generation could introduce power quality challenges, reduce system reliability, cause overvoltages and safety issues. Research needs to be conducted on how best to manage the grid integration at distribution level.
- **Customer Engagement** – Utilities around the world are redefining their relationships with customers, transitioning from a traditional regulated ratepayer mentality to a more interactive and enabling relationship. The Smart Grid will ensure that there is co-dependency between the utility and the customer. This transition has changed the method of communication between utilities and its customers as well as the content of the communications. Forward-looking utilities are considering using smartphones in more interactive ways. Instead of relying on traditional single-purpose, in-home display devices (IHDs) to support pre-payment programmes, utilities can leverage their AMI (Advance metering infrastructure) systems in conjunction with back-office billing applications and conduct all customer notification and interaction via smartphones – significantly lowering the programme costs and ease of enrolment in these programmes. Utilities are starting to enable outage notification and anticipated response times to be delivered via smart devices – a particular challenge as the utility must balance the desire to minimise notification latency with the desire to provide complete outage scope information to customers.
- **Smart Grid** – Today, electric utilities are challenged to incorporate the core elements of the technology and the business process improvements into their operations by harnessing the vast amount of information made available by smart grid solutions. The focus of the utility will be to determine how smart grid technologies can be utilised to deal with the significant challenges of addressing SAIDI and SAIFI on the distribution grid.

Gaps

A significant part of the present Distribution research in Eskom is longer-term focussed on developing technology options to strengthen the grid. The research will also start focussing on areas to address gaps on the impact of small-scale grid integration and the impact of active grid elements on the performance of the grid.

Value, opportunities and risks of this portfolio

The Distribution system is critical as the final leg of the electricity supply chain to customer being both residential, industrial and commercial sectors. The quality and reliability of supply affects both the level of economic activity in South Africa as well as the quality of life experienced by its citizens.

Eskom Distribution faces a number of risks in the short-to medium-term future. These include:

- The introduction of embedded generation onto the network.
- Aging infrastructure.
- Limited revenue projections to achieve outcomes.
- The introduction of smart grid technologies.
- Higher customer expectations.

Partnerships and collaboration

- EPRI – Electricity Power Research Institute (EPRI) has been a key partner to supplement the research programme with advanced sensor networks, electric vehicles, distributed generation and storage.
- University of Cape Town – Expert academic research group in primarily ICT technologies focussed on power quality.
- University of Witwatersrand – Has a smart grid research group under the leadership of Prof Willie Cronje. This group consists of both key academics in both power and IT/OT sectors and will help lead research topics that are industry-driven.
- University of Pretoria – Expert academic research group in primarily ICT technologies focussed on the electric power utility.
- University of North West – Expert academic research group in primarily in ICT technologies focussed on Distribution systems.
- University of Stellenbosch – Expert academic research group in primarily ICT technologies focussed on Network support technologies.
- Cigre – An international Council on Large Electric Systems established for the collaboration of global experts by sharing knowledge and joining forces to improve electric power systems of today and tomorrow.
- IEEE – An organisation directed towards the advancement of the theory and practice of Electrical, Electronics, Communications and Computer Engineering, as well as Computer Science, the allied branches of engineering and the related arts and sciences.

The Research Framework

DISTRIBUTION PLANT PERFORMANCE & ASSET MANAGEMENT

Contribution to SAIDI/SAIFI

- Geography
- Location of spares
- Availability of hire failure plant
- Regional analysis
- Load centre analysis
- Customer segment considerations

Geographical footprint

- Types of customers
- Residential
- Agricultural
- Industrial
- Mining
- Time to restore per customer segment in the region

Performance of the network

- Network voltage analysis
- Modes of failure of plant
- Identification of long lead times

Spare & workforce management

- Location of spares
- Availability – spares
- Contracting strategy – suppliers
- Optimal skills

Loading of plant/lines

- Types of customers
- Load profiles
- Overloading faults root cause – birds, fires, lighting, human error
- Design assumptions

Mode of failure

- Determine mode of failure
- Failure database
- Benchmark plant to other utilities

Run to failure philosophy

- Implications
- Asset tracking of commissioned plant
- Recording of failure

Age of plant

- Identification of various plant ages
- Relating to supplier
- Records of failure
- Methodology of determining the knee point

Supplier

- Faults relating to the supplier
- Types of plant
- Design limitations of plant material in the
- Poor design of certain equipment

GRAND CHALLENGE: Can distribution improve technical performance (SAIDI and SAIFI) To ten hours in the next five years on a severely constrained budget and shift to a just in time (instead of run to failure) refurbishment strategy for Asset Management

12 THE FUTURE CUSTOMER GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Future Customer Grand Challenge

There are revolutionary changes for the future of the electric utility customer driven by a variety of technology disruptors thus, enabling multiple futures in terms of operating and business models for the industry.

Since the discovery of the electric light bulb in 1879 by Thomas Edison, the race to light up Manhattan in the USA had begun. The economics of the operating model resulted in centralised large generation sources with efficient transportation, and distribution of the electric product remained the only cost-competitive model for over a century.

The incumbent utilities spread throughout the globe have invested, built and operated their organisations based on this cost model. In fact, this investment into the business model, although optimal at a point in time, may result in the utilities, inflexibility to respond to the technology disruptors into the future.

The business model is certainly changing and evolving rapidly into the future. In the short-to medium-term timeframe, the industry will be dominated by a business model that mirrors the flow of power and priced by market forces closely related to supply and demand characteristics. In particular, policy enablers will create opportunities for renewable sources of generation and bidirectional power flow onto the electric grid.

These adaptations driven by policy factors will result in a dynamic state of the grid and management thereof leveraging on sensor technology and big data and analytics to manage the dynamic response of the grid. In particular, this model will see further investment into the wires infrastructure and smart technologies to manage multidirectional time-dependent power flows.

Vision

There are many evolutionary and revolutionary technologies, each having some bearing on shaping many technology-based industries. The key question for the power utility is whether these potential technologies will have a major bearing on the industry which requires a resolute response or, alternatively, the potential technology disruption has a minor bearing on the industry and can essentially be overlooked. Can the incumbent utilities react? Can the power utility leverage on these technologies to reinvent itself by developing and supporting new customer-centric products and services?

Research alignment with business priorities

These disruptive technologies will challenge the cost model of investments into large sources of generation, as well as transportation and distribution of energy. The technology drivers will result in a commercial and residential scale generation which is comparable or cheaper than the current cost base of grid tied energy. This model, commonly termed the "Microgrid", will serve to radically revolutionalise the electric industry in the future. It renders the investments in large generation, transmission and distribution irrelevant. The future customer related products and services will serve to reinvigorate the electric power utility to attract new revenues that are based on value added customer-centric products and services.

Key technical research questions

- What are the characteristics and behaviour of customers on energy consumption?
- Analyse the customer market segments for integrated, smart, green localised and energy-efficient technologies in South Africa?
- Quantify the implications for Eskom should key customer segments diversify to self-generation or alternative generation, such as rooftop PV?
- When would these technology options threaten the centralised generation model?
- What happens if the national government implements a subsidy or regulation to support alternative localised generation technologies?
- Investigate the complementary technologies (e.g. energy efficiency) and product or service offerings to the future customer?
- Analyse various financial models that would amortise the cost of technology adoption and catalyse the technology uptake?
- Quantify the demand growth impact of Electric Vehicles, the adoption rates, location, cost and profit models, regulation and incentives to develop the market opportunity?
- Should Eskom consider partnerships, joint ventures, as well as mergers & acquisitions to lead the market opportunities? Investigate opportunities to create product and service strategies that are near impossible to replicate by competitors.

Landscape

Technology disruptors can and do impact industries and business models. Microsoft, although very dominant for many decades in the computer industry, failed to quantify the impact and response to mobile devices. The results thereof have significant bearing on this revenue, market share and profitability. Similarly, the technology disruptor of streaming high-definition movies over the internet has disrupted the cable and satellite industries, rendering investment in infrastructure irrelevant. Some operators responded by leveraging the disruptive technology and evolving the organisations' role in the market.

Unlike many industries where one disruptor changed the marketplace, there are several technology disruptors that will come to bear on the power utility at or about the same point in time. Consider a customer buying an electric vehicle, who will probably want to charge the vehicle with renewable energy and would want to then change behaviour to be energy efficient. These technologies are complementary products and thus should not be viewed in isolation.

Future strategic focus areas

- Customer Segment – This is a non-traditional broad range of market-related research focus areas aimed at analysing and understanding the various customer segments and sub-segments in terms of demand and various price points for integrated, smart, green, localised and energy-efficient technologies.
- Technology Management – The research and development of a variety of future utility-based products and services based on the customer analysis. The research includes a deep understanding of the technology components, including performance, MTTF, integration and construction.
- Financial Modelling – The financial modelling of the technology, business, operational and commissioning aspects of the product and service. The various financing options including amortisation over the life of the integrated solution inclusive of operation and maintenance cost. This analysis will provide an indication of a profitable business venture.
- Core Competencies – Which product and services offering leverage on Eskom's core competencies? This will include aspects such as does Eskom have a local presence near the targeted customer segments. The effort required to upskill and train the current field staff. Turnaround times to support and maintain new products, including a spares strategy.

Technological advances

- Clean Energy Technologies – The IEA World Energy Outlook (2017) noted that in 2016, growth in solar PV capacity was larger than for any other form of generation; since 2010, costs of new solar PV have come down by 70%, wind by 25% and battery costs by 40%.
- Solar Photovoltaic (PV) – enewable power capacity additions continued to reach new record highs in 2016, driven by cost reductions and policies aimed at enhancing energy security and sustainability and improving air quality. In 2016 the IEA notes that global renewable electricity generation grew by an estimated 6% and represented around 24% of global power output. In 2016, solar PV annual additions surpassed that of wind, breaking another record, with 70 GW to 75 GW coming on line, almost 50% higher growth versus 2015.
- Electric Vehicles (EV) – IEA reports indicate that globally, 753 000 plug-in EVs were sold in 2016, 60% of which were battery-electric cars (BEVs). These sales were the highest ever registered and allowed the global EV stock to hit the threshold of 2 million units in circulation. China remained the largest EV market for the second consecutive year and, in 2016, accounted for close to half of global EV sales. Europe represented the second-largest global EV market (215 000 EVs sold), followed by the United States (160 000 EVs sold). Battery costs kept declining between 2015 and 2016, and energy density continued to increase (EVI, 2017). Battery technology improvements will enable longer ranges to be achieved at lower costs, increasing the cost-competitiveness of EVs and lowering barriers to adoption.
- Energy Storage – The IEA notes that beyond the technologies themselves, innovative business models that capitalise on the benefits of storage have seen timid growth in some regions. While there are positive moves by regulators in Europe and in the United States to create enabling environments for aggregators, virtual power plants and other platforms.

Gaps

Customers are growing more and more sophisticated, with increasing expectations of value, speed, and reliability based on service interactions with other business sectors, such as home entertainment, business computing and communications. These expectations are carrying over to the electricity sector. At the same time, customers are beginning to consider options related to electricity supply and use, with choices often coming from third parties, not their utility. Technology advances are giving customers more choice and control over when and how they use electricity, including smart appliances, plug-in electric vehicles, and options for residential generation. The choices customers make are already having recognisable impacts on the electricity system, particularly on energy consumption and load profiles, and these impacts will continue to change into the future. Utilities are finding that traditional methods for forecasting customer electricity needs are not adequate in an environment with increasing customer choice and expectations.

Value, opportunities and risks of this portfolio

Customer choice and control can also enhance the value of electricity service to the individual customer and to customers as a whole. Eskom's established relationships with our customers can be leveraged as change agents towards offering customers choices that align with both customer and Eskom objectives. Eskom has opportunities to meet customer expectations and to dynamically integrate customers and their choices into the power system. However, with the increasing sophistication of customers, new and diverse strategies to integrate customers are needed going forward. Eskom can apply this knowledge of customer interests and values to devise products and services that meet diverse demands, and then develop appropriate offers to targeted customers. Similarly, Eskom needs strategies for creating and offering compelling choices for electricity service.

Partnerships and collaboration

- EPRI – Electricity Power Research Institute (EPRI) has been a key partner to supplement the research programme with skills and common research challenges facing the industry.
- University of Cape Town – Expert academic research group on Customer behavioural economics.
- University of Pretoria – Expert academic research group within the university for the energy efficiency hub.
- University of Witwatersrand – Expert academic research group primarily focussed on the future electric power utility.
- University of North West – Expert academic research group primarily focussed on the future electric power utility.
- CSIR – Identified future energy trends as a key research priority and has a number of excellent technical skills to collaborate on Eskom challenges and leverage the Eskom-CSIR MOU.

The Research Framework

<table>
<tr><th colspan="4">FUTURE CUSTOMER</th></tr>
<tr><th>Customer Segment</th><th>Finance</th><th>Technology Management</th><th>Eskom Competencies</th></tr>
<tr>
<td rowspan="4">• Who are the customers?
• Light commercial
• Residential
• Where are they?
• How much do they pay?
• How much are they willing to pay?
• Insurance issues?
• Safety issues?
• Do they value green?</td>
<td rowspan="3">• Finance model to pay back the technology
• Build and operational costs
• Lifespan of the technology
• Financing costs
• Market analysis and competition
• Risk evaluation and quantification</td>
<td rowspan="3">• PV technology
• PV process
• Storage technology
• Inverter technology
• Energy efficiency
• Construction
• Commissioning
• Regulation
• Strategic partnership
• Safety and risk</td>
<td>• Location of customers
• Spares
• Skills
• Working in roofs?
• Response times
• Insurance</td>
</tr>
<tr><td>Strategic partnerships</td></tr>
<tr><td rowspan="2">• Suppliers of the technology
• Instillation
• Support
• Warranties</td></tr>
<tr><td colspan="2">GRAND CHALLENGE: Can RT&D formulate affordable value added, business products and services. For Eskom's existing and new customers based on an integrated, smart, green localised and energy efficient technologies in the next three years</td></tr>
</table>

13 THE FLEXIBLE OPERATIONS GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Flexible Operations Grand Challenge

Eskom currently operates 29 power plants, which include coal, open cycle gas, hydroelectric, pumped stations, nuclear, solar and wind plants with a nominal capacity of 46,407 MW and maintains more than 384,712 km of distribution and transmission lines.

The South African Renewable Energy Independent Power Producer Programme (REIPP) has added 5027 MW of renewable energy (Wind, solar PV and CSP) with further capacity additions considered in the medium to long-term.

The power system's flexibility is a key element to rapid and diverse deployment of variable generation. Variable generation combined with future uncertainty in fuel prices (primarily coal and gas) for power generation drives power plant economics, the generation mix, and the order and frequency of plant dispatch. Also driving the need for greater power system flexibility is the shift of customers to prosumers and their expanding technology options such as solar photovoltaic (pv) panels, plug-in electric vehicles, smart appliances, and on-site energy management systems.

Vision

The vision of the Flexibility grand challenge is to prepare the national power system to supply reliable power from variable generation. The goal is to be able to adapt and operate plant and system in a real-time market environment in the next five years. Power system flexibility is the ability to adapt to dynamic and changing conditions on the power system, for example, balancing supply and demand by the hour or minute, or deploying new generation and transmission resources over a period of years. The transition to a more flexible power system requires a new portfolio of technologies and methodologies. There is also a strategic need for Eskom to systematically assess, from a generation fleet planning and asset management perspective, the steps necessary to ensure that the future coal fleet has adequate operational flexibility capabilities while at the same time maintaining cost-effective operations and compliance with environmental regulations.

Research alignment with Eskom priorities

Eskom as the national power system owner and operator has committed to the integration of renewables onto the grid. Transmission plays a critical role in facilitating flexibility derived from resources with changing demand and renewables production. Ensuring system flexibility presents a new challenge to transmission system planning and operation. Demand and renewables typically are concentrated geographically, either co-located or separated by significant distances. Similarly, the distribution of conventional generation around a network may vary significantly. As demand and renewable production change at a faster rate, the location of the responding resources, and the ability of the network to manage fluctuating power flows will be a critical part of system balancing.

The increased penetration of distributed generation (DG) mainly from rooftop pv across the distribution system is profoundly affecting electric distribution designs and operating practices that have existed for a century or more. Distribution system operators (DSOs) need to be able to reconfigure the system (i.e. serve sections of the system from alternative local substations or feeders) due to load growth changes over time, system maintenance, and system contingencies such as unplanned outages. Increased levels of DG can limit this reconfigurability (i.e. flexibility).

Key technical research questions

- What is the viability of cycling conventional generation (coal, natural gas, nuclear, hydro)?
- What is the viability of polygeneration (cycle between output products)?
- Can renewable technologies be used as a solution for resolving challenges associated with flexible power systems (concentrating solar thermal storage, wind for active power control)?
- How can energy storage be utilised to resolve challenges associated with flexible power systems in a cost-effective manner (buffer for bulk energy, ancillary services, T&D infrastructure, customer energy management)?
- How can clean flexibility concepts be utilised to resolve flexibility challenges (fast ramping gas turbines, DER for emissions reduction by switching fuels, wind/solar forecasting)?
- What new technologies can be deployed at both Transmission and Distribution to enhance flexibility of the grid (power electronics devices, HVDC, dynamic ratings, enhanced reconfigurability via DMS, smart inverters)?
- What tools should be provided to the system operator to enhance power system balancing and operation (situational awareness, operating practices, new power market products, inter-area co-ordination)?
- Can power system planning be enhanced to consider a more flexible system (renewable integration planning, flexibility metrics, advanced assessment tools and models)?
- How can customer behaviour and adoption be monitored to forecast demand and inform energy supply balance (energy efficiency, fast-reacting loads, distributed storage, dispatchable DER, communications for connectivity)?
- What is the impact of increased utilisation of assets in a manner for which they were not originally designed and how does this new operation impact: scheduling of maintenance, development of operational techniques to maximise line and cable performance, and deployment of FACTS devices?

Landscape

Technology disruptors can and are likely to impact the electricity industry and its century old centralised business models. Globally, many existing coal-fired power plants are being decommissioned as a result of their age or difficulty in meeting new emissions requirements. Operating in flexible modes can cause damage to plant and equipment and incur costs. Cycling of coal power plants can accelerate thermal fatigue, thermal expansion, fireside corrosion, and rotor bore cracking. Cycling units not designed for these operating modes can lead to more component failures, unplanned outages, increased heat rate, decreased revenue, and staff scheduling and training challenges. At the same time, constraints on cycling operation can be imposed by new or upgraded emission controls such as flue gas desulphurisation (FGD) and mercury controls.

Electric energy storage has the potential to enhance grid flexibility in several ways. Energy storage provides an inventory of electricity to the power system, adding a buffer to the current "just in time" system. It can be used to manage peak load, follow power system ramps, provide responsive reserves, relieve T&D congestion, and mitigate service outages. Storage offers the opportunity to create a more flexible grid by accommodating more variable, renewable generation resources. It can reduce strain on the grid caused by power fluctuations and can help optimise dispatch of both variable and conventional generators. Grid energy storage can respond quickly to second-to-minute changes in electricity demand and to supply changes resulting from variable generation. As a temporary "shock absorber" it can dampen transient electric conditions on local generation, transmission, and distribution network equipment.

Future strategic focus areas

- Coal-Fired Power Generation – Depending on the type of plant and design, the output of coal plants can be varied within a range in response to market conditions. The need for flexibility can be achieved through: 1) more frequent shutdowns when market or grid conditions warrant, 2) more aggressive ramp rates (rate of output change), and 3) lower desired minimum sustainable load, which provides a wider operating range and hence, enhanced usefulness.
- Gas Generation – The open cycle gas unit's role in a large grid system has been to provide peaking services and in many cases black start services. Key attributes of peaking services include reliable start up, fast ramping, and reliable service for the hours requested. With low capacity factors, these units are called into service for a small number of hours.

- **Energy Storage** – Storage can make the overall grid more flexible by accommodating more variable, renewable generation resources. It can reduce strain on the grid caused by power fluctuations and can help optimise dispatch of both variable and conventional generators. Grid energy storage can respond quickly to second-to-minute changes in electricity demand and to supply changes resulting from variable generation. As a temporary "shock absorber" it can dampen transient electric conditions on local generation, transmission, and distribution network equipment.
- **Transmission** – Transmission system design and operation is evolving to consider more uncertain and variable power flows. The adoption of power electronics devices also known as flexible AC transmission system [FACTS] technologies, such as unified power controllers, and high voltage DC lines has enhanced operators' abilities to control active power network flows and aid balancing operations.
- **Distribution** – The increased penetration of distributed generation across the distribution system is profoundly affecting electric distribution designs and operating practices that have existed for a century or more. Distribution system operators need to be able to reconfigure the system (i.e. serve sections of the system from alternative local substations or feeders) due to load growth changes over time, system maintenance, and system contingencies such as unplanned outages. Increased levels of DG can limit re-configurability (i.e. flexibility).
- **Planning** – The next generation of planning tools and processes will consider variability and uncertainty as fundamental to the power system's reliable, efficient, and sustainable operation. Fuller integration of information on demand-side resources, conventional and renewable generation will enable better power system coordination. More distributed generation will require stronger collaboration among transmission owners and operators and distribution network owners and operators. Network management will become increasingly important to manage a system's flexibility needs.

Technological advances

- **Smart Inverters** – Utility grids with variable distributed generation, such as solar PV systems, on their medium- and low-voltage circuits must take special precautions to maintain power quality, reliability, and safety. Variable distributed resources make it more difficult to keep voltage within acceptable limits, and they introduce the potential for unintentional islanding that could create a safety hazard or damage critical grid equipment. The inverters and converters that connect solar PV, energy storage systems, and other distributed resources to the power grid have the potential to mitigate these and other negative impacts, and to bring grid operators benefits beyond renewables integration.
- **Distribution Management Systems** – A distribution management system (DMS) assists control room and field operating personnel with the monitoring and control of the electric distribution system in an optimal manner while improving safety and asset protection. Four years ago, fewer than five major DMS projects were underway in North America. Now, dozens of DMS projects are planned or being implemented by utilities small and large. However, DMS technology is still in its infancy, and many utilities are using small-scale field trials for proof of concept of advanced application software for distribution system optimisation.
- **"Balancing resources"** are those that can respond to an operator's instruction or that automatically prevent a power imbalance or restore energy balance in a range of events. Balancing resources may respond to different triggers in various time scales, providing a service critical to maintaining a reliable and efficient power system. Variability and uncertainty can cause this response to be called upon: demand variability that is not met by production variability gives rise to unstable operating conditions. Unforeseen events such as generation or transmission outages or wind or solar generation forecast errors also require a response from balancing resources.

Gaps

Coal-fired cycling units that are not designed for flexible operating modes can result in component failures, unplanned outages, increased heat rate, decreased revenue, and staff scheduling and training challenges. Impacts of plant operations, including cycling, start up, and shutdown, on mercury, filterable particulate matter, and hydrochloric acid emissions compliance strategies based on field data obtained from selected power plants. Additional plants will include electrostatic precipitator (ESP), baghouse and wet FGD systems.

Energy storage characteristics need to be incorporated into Eskom's operational planning models which consider emerging needs for power system flexibility. Technical requirements for the procurement of energy storage equipment for its intended use and point of connection, and for communication with vendors need to be outlined. Methodologies and tools for consistent comparison of cost-effectiveness to support decisions and proposal assessment need to be investigated. Test protocols based on Eskom's needs to provide performance measurements that support consistent assessment need to be defined.

Understanding the implications of flexibility for the integrated development and maintenance of transmission networks is still a gap. The increased utilisation of assets in a manner for which they were not originally designed may have implications for the scheduling of maintenance, development of operational techniques to maximise line and cable performance, and deployment of FACTS devices. Further research will be required to understand the implication of flexibility for the integrated development and maintenance of transmission networks.

The increased penetration of distributed generation across the distribution system is profoundly affecting electric distribution designs and operating practices that have existed for more than a century. Distribution system operators need to be able to reconfigure the system due to load growth changes over time, system maintenance, and system contingencies such as unplanned outages. Increased levels of DG can limit this re-configurability (i.e. flexibility).

Value, opportunities and risks of this portfolio

New technologies such as smart electric vehicle charging, battery storage, digitisation with intelligent control and demand side management enhance system flexibility. Companies proving these technologies such as Google, Tesla and BMW may come to dominate the power sector in the coming decades, forcing changes on the political and regulatory environment of the electricity industry. Cost reductions in batteries driven by increased uptake of electric vehicles are enabling affordable static grid level storage, which enhances power system flexibility. Digitalisation of the electricity industry will lead to significant advances in system efficiency and flexibility.

Electric utilities face the challenge that there will be a greater deployment of renewable energy technologies into power systems assisted by increased development in flexibility technologies. This will challenge the role of large power stations in system balancing and place further strain on electric utility business models that are based on the concept of large centralised electricity generation.

Whilst there are several threats for today's electric utilities there are also several opportunities for those that are able to transform and take advantage of the emerging technologies. As the electric vehicle market grows, utilities can offer smart charging tariffs that encourage staggered electric vehicle charging at lower unit prices. The battery storage market offers opportunities to develop new businesses and services to maintain market dominance. Residential flexible-demand markets also present new opportunities for utilities that have established retail relationships with household customers. Digitilisation could support business models with the administration of energy service platforms for consumers who own distributed energy resources, as these consumers seek not only to purchase electricity but also to sell it back into the market. There is also an opportunity to enable peer-to-peer transactions and services by providing the digital platform.

Partnerships and collaboration

- EPRI – Electricity Power Research Institute (EPRI) has been a key partner to supplement the research programme with skills and common research challenges facing the industry.
- University of Stellenbosch – Expert academic research group on power system flexibility and customer behavioural economics.
- GIZ – German development agency funding research programmes on renewable energy integration and flexible operations.
- Danish Energy Agency – Danish research programme building capacity and skills on renewable energy integration into the power system and flexible operations.
- University of Witwatersrand – Has a smart grid research group under the leadership of Prof Willie Cronje. This group consists of both key academics in both power and IT/ OT sectors and will help lead research topics that are industry driven.
- Cape Peninsula University Technology – Has a real-time digital simulator as well as cluster computing capabilities to model ad simulate flexibility impacts on the grid, as well as generator dispatching criteria.

The Research Framework

FLEXIBLE OPERATIONS WORK PLAN		
Plant – all plant connected to grid	**Power Systems**	**Market – Electricity supply industry**
• Determine range for ramping Gx fleet • Determine inertia, SCO and voltage control for ramping scenarios • Define current base for flexibility • Determine future of the Tx grid • How do we strategically position the wirel business with a focus on the technical issues? • Techno economic studies for minimum generation and beyond increasing ramping capabilities of stations • Investigate small modular cheap pump storage schemes	• Investigation of PV response to system during thunderstorms and extreme events • Investigate the contribution of wind to inertia and fault ride through and determine the impact on the power system • Investigate the like hood of small PV inverters and functionalities on the power system • Investigate AGC at Sere wind farm • Investigate storage for the ancillary services to the grid • Map changes to system and related issues on grid **GRAND CHALLENGE:** How do we adapt and operate plant and system in the real time market environment in the next five years.	• Includes South Africa and SADC • Investigates real time use of pricing and incentivising models • Investigate dynamic pricing models • Pilot and demo of energy storage on Dx and Tx lines and investigate costs deferment and power quality challenges • Investigate the locations of growth areas and growth rates of roof top PVs. Predict future market growth • Five to ten-year time frame • Identify what technologies are likely to be disruptive and anticipate changed future for the grid

14 THE DIGITAL REVOLUTION GRAND CHALLENGE

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RESEARCH DIRECTION REPORT

The Digital Revolution Grand Challenge

Digital revolution will soon impact the global power industry. Digital technologies will enhance the power utility making it more interconnected, intelligent, efficient and sustainable

Advancements in data analytics, artificial intelligence and block chain technology are being piloted and demonstrated in several power utilities. These technologies are creating new capabilities and are triggering new business models. Big data collection is growing exponentially, creating cybersecurity threats; however, the opportunities outweigh these risks. Customers are requesting multiple new channels to interact with the utility: whilst the Internet of Things promises new products and services.

The power utility of the future will be a fully digital system. Thus this research portfolio has been initiated to prepare Eskom for the digital transformation of the business, operations and processes. This portfolio aims to leverage on the low hanging fruit such as customer transformation journey, efficiencies in work and asset management. The strategic rollout of these digital technologies can be deployed in phases: productivity and efficiency, the customer experience, and new services.

Vision

Digital technologies will improve operations, efficiency and increase flexibility, which can be applied to the entire power value chain. The digital revolution will bring enhancements in productivity, reliability, safety, customer experience, compliance, and revenue management. Experiences from similar industries have reported that digital optimisation can boost profitability by 20 to 30 percent.

The predictive analytics capabilities within customer management function have started making use of machine learning technologies. This provides insight into customer attributes and behaviours and thus insight into customer's willingness to pay for specialised services. The field workforce is an immense opportunity for digitalisation; equipping the workforce with the correct digital tools will simplify and enhance the daily activities of the employee. The step changes in increasing the workforce productivity and satisfaction will directly impact the customer experience. Information is as important as material assets.

Research alignment with Eskom priorities

The digital revolution within the power industry aligns to many of Eskom's key challenges: cost savings; improved productivity; customer centricity and predictive plant and asset management. Power utilities that have focussed on areas such as asset maintenance, contractor productivity, employee safety, or reporting are likely to span across silos and thus deliver value across the entire organisation. Utilities often focus on operational improvements; however; utilities can gain the same benefits by focussing on support functions such as human resources, procurement and safety - all of these probably have mature solutions available and can be deployed much faster to realise benefit.

Key technical research questions

- How can a digitalsed energy system assist utilities with the key challenges related to power generation?
- How can digital technologies like machine learning, blockchain and cloud computing be used to enhance the power system?
- How can the digital energy system assist with balancing system reserves and tapping into power from

self-generators such as owners of rooftop solar systems?
- How will the fully digital energy system assist with forecasting and optimising energy production?
- How can digital technologies assist with the integration of renewable energy into current power generation systems?
- How will blockchain technology provide a peer-to-peer energy market such that distributed energy production systems can participate in an energy market?

Landscape

Digital technologies will impact the power industry and the manner in which the future utility operates. These technologies can be leveraged to provide many new opportunities for the utility; however the risks need to be closely managed and mitigated by informed engineering of the solutions. Many regulatory bodies are grappling with the balance of investing in smart digital technologies whilst not risking the key national energy infrastructure to threats such as cybersecurity.

Future strategic focus areas

Customer Relation Management

Customer experiences area dictated by the customer business processes which are the foundation for success for the utility. Digital technologies will assist to create superior customer experiences and in turn increase revenue.

Workforce Management

The revolution will re-engineer the entire business processes to drive efficiency, slash costs, and ensure a safe environment for employees. Work processes must be redesigned to focus on high-value tasks and eliminate waste, wandering, repetition, and risky practices.

Plant Operations and Management

Digital twin technology can be used to predict the operations of plant as well as solve for physical plant issues in a rapid manner. Autonomous plants will in the future be able to change operating parameters in real time to respond to the changing grid conditions. Data visualisation tools can give executives a consolidated, real-time view of performance of all production processes at all plants.

Technological advances

Digital Twins

A digital twin is an as-built plant that is modelled using extensive real time, real-world data measurements based on the plant's real world defects, wear and tear and performance. The digital twin model responds in the same manner as the real world stimuli. This will enable power utilities to solve physical issues faster in the digital simulation to predict the accuracy of plant responses to various technical scenarios.

Advanced Analytics

The value of analytics is derived from embedding data analytics as a core capability in the organization and using it to detect pain points, design solutions, and enable decision making.

Machine Learning, Internet of Things and 4th Industrial Revolution

The digital technologies are able to monitor the state of plant in real time and digitally predict performance curves and failure points. The machine learning aspects will autonomously enable machines to learn from its own operating mistakes and improve the output of plant in real time automatically.

Block Chain Technology

The emergence of blockchain introduces a new measure of uncertainty at a time when the industry is changing rapidly due to renewable and distributed energy, energy efficiency, energy storage, and digitisation. Blockchain technology could provide the infrastructure for sophisticated networks that manage payments, sales, trading, and distribution.

Cyber Security

Embarking on the digital journey requires extensive use of sensors, data and control systems. Cybersecurity of all these ICT systems are integral to the digital transformation journey. Recent examples of cybersecurity breaches in the power utility environment are increasing in frequency and the risk to both company and national energy stability makes this a priority area.

Gaps

Digital technologies and their application in the power utility are still in their infancy. Many case studies from sister industries have demonstrated that there are significant advantages for application of the technology within the power utility environment which may result in similar realisation of value. Eskom is currently facing financial challenges. In order to realise the benefits of digital technologies, research should be undertaken to investigate quick hit projects which can be rolled out at scale into the organisation to reduce operating costs.

Value, opportunities and risks of this portfolio

The risk of not leveraging on digital technologies will be significant lost opportunities to address Eskom's key pain points. In particular the digital revolution will provide tangible solutions to reduction of costs, improvement in productivity as well as revenue management. Another risk is that, in time, comparisons to the performance of similar utilities by regulatory bodies will depict Eskom as inefficient. Essentially, when the digital technologies are demonstrated on a pilot scale in research and benefits quantified, these solutions become no-regret solutions for scaled-up rollout in the organisation.

Partnerships and collaboration

- EPRI – Electricity Power Research Institute (EPRI) has been a key partner to supplement the research programme with skills and common research challenges facing the industry.
- University of Pretoria – Expert academic research group within the university in the area of the fourth industrial revolution.
- University of Witwatersrand – Expert academic research group primarily focussed on the future electric power utility.
- AUTC – identified as a utility-based consortium to provide utility trends in the uptake of ICT technologies as well as lobbying various local, national and international regulatory bodies.

The Research Framework

THE DIGITAL REVOLUTION

Digital and data driven offerings	Digitalisation of core business	Digital capabilities	Digital transformation accelerators
• Business model development • Digitally enhanced products • Data driven services • Digital services • Software products	• Sales, channels and marketing • Generation and supply chain • HR, finance and support functions	• Agile organisation, IT and development • Systems and technology platforms • Analytics and data integration • Digital partner ecosystem	• Start up incubation, venture capital and prototyping • Digital program and change management

GRAND CHALLENGE: Can RT&D identify, research and demonstrate digital technologies that will realise R10Bn of savings through step improvements in people, process and technology in the next 5 years?

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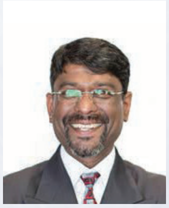

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