Electric

Transport Options in South Africa

Eskom

Introduction

Bimodal Transport Options

Transportation is the means to carry raw materials, goods, and people from one location to another. Different methods of transport in South Africa include road, air, rail, water, cable, space and pipelines. Transportation is extremely important in each stage of human civilisation. If the present means of transportation had not been developed, the world would be very different.

Transportation has contributed a great deal to the development of economic, social, political and cultural sectors and has uplifted people's lives overall. Speedy industrialisation is impossible without the development of transportation. It is a necessity to promote suitable transport systems for the proper development of all sectors, both in urban and rural areas. Without the development of transportation, neither mass production nor distribution is possible.

In the electric transportation sector private electric vehicles (EVs) are currently the public focus, but there is also need to consider the use of other transportation methods for freight and raw materials which will also save huge amounts of fossil fuel. South Africa does not have easy access to oil for fuel manufacture and we are therefore highly dependent on importation of oil, the Rand-Dollar exchange rates and a fluctuating oil price.

In deciding on the most suitable transport option the aim should be to determine which technologies are best suited for specific transportation requirements. These transport requirements may vary according to the lead distance, terrain, throughput requirements and geographical location, to name but a few factors. This brochure provides a high level guide to selecting the most appropriate technology to best satisfy these requirements in a cost-effective and safe manner. Although the focus is on materials and freight, most of the transport methods covered can also be used for the transportation of people – specifically in larger numbers.

The following aspects are covered in this brochure:

- Alternative transport options, their characteristics, advantages, disadvantages, and cost impacts;
- The applicability and feasibility of each transport mode for South African conditions;
- Normalised comparison of transportation options.

This brochure should be used in conjunction with the presentations made at the ICUE, Transportation Workshop, 25 November 2019. (Imbed the hyperlink "https://aiue.co.za/programme-2/?preview=true" \t "_blank")

1

Transport Options Explained

Electricity solution - Carbon Tax benefits with incentives or grant funding available:

Electrical transport options are more environmentally friendly and often more cost-competitive than liquid fuel (i.e. diesel) solutions both from a capital and operations perspective. This is due to utility electricity supply being more efficient than diesel fuel, not considered part of Scope 1 emissions and the facility or consumer will not be liable for paying any Carbon Tax. Tax incentives and government grant funding are also available for being more energy-efficient.

Consider the following as an example:

Carbon Tax[1]	:	**R0.10 per litre** (payable when purchasing diesel)
Section 12L Tax Incentive	:	**R2.82 per litre diesel (saved)**
Diesel consumption	:	**451 764 litres per annum**
Diesel combustion emissions	:	**2.64kg CO_2/litre diesel[2]**

Then, the monetary amounts:

Total Carbon Tax paid	=	**R45 176.00** (amount saved when converting to an electrical solution)
Total 12L Tax Incentive	=	**R1 273 976.00** (for 1 year; claimed via the company's tax return) and,
Total emissions	=	1 192 658.82kg or 1.193million tonnes of CO_2/annum (saved)

NOTE:

- Electrical transport solutions are comparably cheaper than diesel fuel solutions which would create additional and continued monetary saving (this saving has not been included anywhere)
- Grant funding for conversions may be available under certain conditions
- Diesel engine efficiencies are at best 30%
- Truck-trailers currently average just 2.55 kilometres per litre in the US[3]

[1]To increase annually with CPI

[2]https://ecoscore.be

[3]http://www.fleetwatch.co.za

2

Road Systems

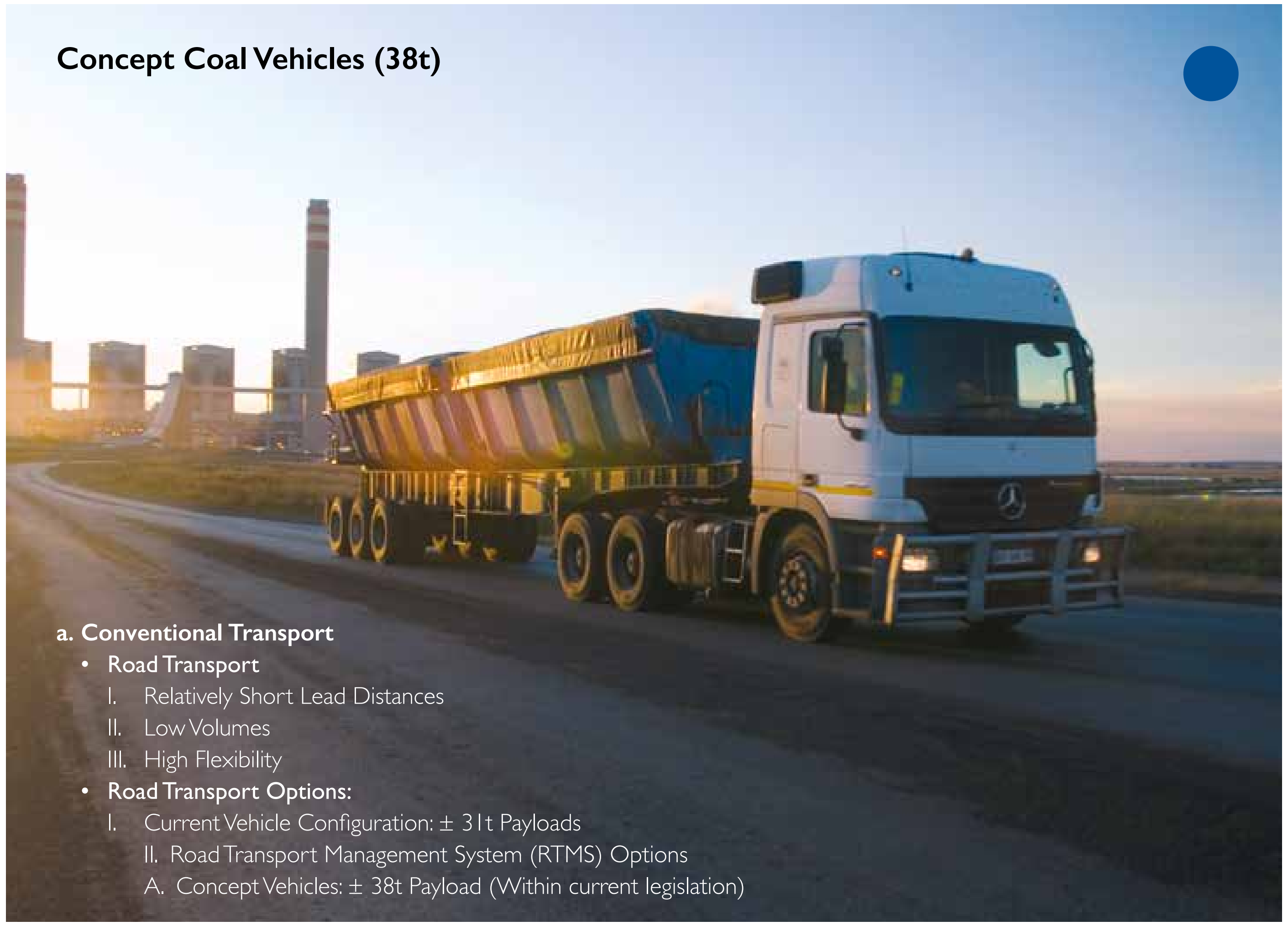
Transport types, modes or technologies

The following section expands on the characteristics of grouped transport modes. Most available transport options are covered regardless of whether such options were found to be feasible or not.

Current Road Trucks

Road and rail transportation account for 99% of South Africa's national logistics costs, with road transportation being the dominant mode. The road network infrastructure is shared by heavy vehicles used for the conveyance of freight, light delivery vehicles and the general public in the form of motor cars, and panel vans. The total active vehicle population is close to 9 million motorised vehicles of which approximately 330 000 are defined as heavy load vehicles. It is further estimated that the aforementioned complement of heavy load vehicles travel up to 12 961 million km per annum.

Road transportation, as commonly found in bulk materials handling, comprises of two major components - the vehicle and the road infrastructure. Road transport in general offers a variety of advantages, with probably the biggest advantage being the available vehicle combinations offering high levels of flexibility



in changing of routes, as opposed to fixed infrastructure type transport modes such as conveyors, rail and pipelines. The response time within which this can be done is also very short and is the single biggest advantage over most other transport modes.

In addition, road transport demands reasonably low initial capital costs, which is easily justifiable when the source of freight has a relatively short life span of less than five years as opposed to conveyors, rail or pipelines. Unlike many of the other transport modes, road transport has typically thousands of transport companies offering services, which allows for a greater deal of competition in the market which then further reduces operating costs, as opposed to a captive national rail supplier.

The disadvantages of road transport, relative to other transport modes such as rail, conveyers and pipelines, is that road transport is management and labour intensive, with up to three drivers employed to operate one vehicle over a 24-hour period. Furthermore, there is a direct correlation between road conditions and vehicle operating costs. Due to the backlog of maintenance on national and provincial roads, partly due to under-funding and accelerated road wear associated with overloading, the general condition of the road infrastructure is not ideal. Thus, the operating cost of road transport is currently elevated beyond what it should be.

The single biggest disadvantage of road transport is the fact that trucks often have to return empty to be reloaded, which increases the operational cost drastically due to being operated empty for 50% of the time. The maintenance costs for trucks are typically very high when compared to alternative modes of transport. Road transport also has an increased operator and public safety risk. Due to the fact that road transport shares the road infrastructure with the general population, road transport has a higher risk of accidents than other forms of transport such as conveyors and pipelines where access can be greatly restricted. This risk increases exponentially as the freight volume increases, which requires a general increase in the number of vehicles and hence results in a very high vehicle concentration in certain geographical areas, as is currently the case in southern Mpumalanga.

The capacity of road transport systems, i.e. its productivity and throughput, has traditionally been affected by lead distance, terminal times, road conditions, payloads and scheduling. Current truck configurations are legally capable of carrying between 31 and 33 ton payloads, depending on vehicle configuration. In addition, these trucks can operate over a multitude of conditions and scenarios ranging from a very short lead distance of less than 5 km to in excess of 1 000 km, as is the case with long haul road freight.

Road transport therefore provides a very flexible distribution option, which imposes a comparatively low capital investment requirement, is extremely scalable and could justifiably be employed for very short contract periods. The main concerns around this mode of transport, however, are the harmful greenhouse gasses being emitted, operational costs, the increased safety risk that it presents, and the accelerated deterioration of the public road infrastructure that results from large numbers of trucks transporting freight in a relatively concentrated area.

Quantum 1 Road Trucks

The payload efficiency of the vehicles currently employed in the trucking industry has significant room for improvement. Opportunities to improve the payload through better truck and trailer design and load cell technology are under investigation in the coal industry specifically.

This design concept, currently referred to as Quantum 1 road trucks, aims at maximising the legal payload carrying capability of a truck, within the current legal limits. Quantum 1 concept designs have recently suggested that a legal payload of 38 ton is possible, within current legislation. The Quantum 1 design was conceptualised after trips to Europe and Australia in 2006 by a well-respected trailer design specialist. Unfortunately, detailed drawings could not be made available as these are considered confidential. However, two of the larger role players in the South African trucking industry are currently considering testing the theory, by building and operating a few Quantum 1 trucks on a trial basis.

The system characteristics, advantages and disadvantages of these Quantum 1 trucks are similar to the aspects described under normal road trucks in the previous section. The main benefit of the Quantum 1 vehicles will be that they can continue operating within the legal road transport framework, therefore being able to operate on current public roads. The only major difference is a 22% increase in current average payloads and a 15% increase in legal payloads, which will significantly decrease the transport unit costs when compared to conventional trucks.

Concept Coal Vehicles (38t)

Table 33: Impact on bridges of 46 tonnes – 25.25 m vehicles (2-axle tractor)

Spans		Extreme loads		Fatigue	
		Local effects	General effects	Local effects	General effects
Short	C				
	S				
Medium	C				
	S				
Long	C				
	S				

Performance Based Standard Road Vehicles

Performance Based Standards (PBS) is a mechanism designed to improve payloads, subject to predefined performance criteria that allow approved vehicles to operate beyond what is possible within current legislation.

Mechanisms have been developed to promote a line of thinking that argues that legislation should not dictate what the vehicle should look like, but rather how it should perform. Around 2001, the timber industry began to realise the potential of gaining concessions from government if it could demonstrate its ability to govern itself. With the help of the National Productivity Institute (NPI), Crickmay & Associates, the Department of Transport (DoT) and the South African National Roads Agency Limited (SANRAL), the initial industry specific self-regulation work which focused on overloading was broadened to include driver wellness, vehicle fitness, productivity and safety standards. This later became known as the Road Transport Management System (RTMS).

The RTMS is comprised of a set of consignor, consignee and haulier standards that are approved by the South African National Standards (SANS) as a National Recommended Practice (ARP). These standards aim to assist the consignor, consignee and haulier in complying with government legislation and are also designed to work hand-in-hand with the various internal HR and SHEQ systems. This system of self-regulation has led to vehicles being marked with the RTMS sign, to indicate that these companies and vehicles comply with the standards and are therefore RTMS accredited.

During the running of the first two PBS vehicles in the timber industry, payload increases of between 12% and 15% were realised, with an average 25% reduction in transport costs, over a lead distance of 150 km. An added benefit is the corresponding decrease in the number of vehicles operating due to an additional 30 new PBS vehicles introduced which resulted in increased payloads. A significant reduction in carbon emissions has been recorded in the timber industry, which was achieved through a reduction in the amount of fuel used per ton of product delivered.

The biggest advantage of PBS is that these vehicles are allowed to run, under concessions, on public roads.

Road Transport Management System [RTMS] and Road Safety

PBS is aimed primarily at increasing the achievable vehicle payload. Based on investigations being undertaken in the coal and timber industries, it is expected that the current average 31 ton payload of coal trucks can be increased to approximately 48 ton, using the PBS guidelines.

The capital investment required for PBS vehicles, relative to existing vehicles, is approximately 31% more on a per vehicle basis. However, when applying the principle over larger tonnages, the overall capital requirement decreases, because fewer vehicles are required as a result of higher payloads. In comparison, although still high, operating and maintenance costs are also reduced based on the lower fuel consumption and fewer vehicles on the road.

Road trains

A Road train is a trucking concept used in remote areas of Argentina, Australia, Mexico, the United States, Canada and Southern Africa to move bulky loads efficiently where little infrastructure exists. A Road train consists of a relatively conventional prime mover unit, but instead of pulling one trailer, semi-trailer or interlink combination, the Road train pulls multiple trailers. The Road train transport concept is highly flexible and versatile and can be deployed on different routes very easily with relatively low capital cost, when compared to conveyor or rail infrastructures. Furthermore, Road trains are becoming a common feature in the South African mining landscape for the efficient transport of raw and beneficiated minerals over distances of between 5 and 100 km.

Road trains are permitted to only travel on private or semi-private roads in South Africa, Zimbabwe and Swaziland. This prevents any direct importation of overseas technology and therefore direct comparisons are not applicable, as the regulatory environment is vastly different. However, the concept of increased payloads being transported on dedicated heavy haul roads in order to decrease the transport unit cost, when compared with conventional road transport, is universally applicable.

Most related Road train equipment runs on axles and tyres and the axle load seldom exceeds 9 000 kg. The reason for this is that the road infrastructure required does not have to be built to a specification any higher than national roads, and in certain circumstances in remote areas the government has granted permits to run these vehicles on roads also used by the public. Standard payloads of between 105 and 180 ton are common and, with the assistance of powered trailers, payloads of up to 300 ton are feasible and steeper gradients are able to be negotiated at increased speeds.

Dedicated off-road Road trains adopt the advantages of the modified on-road type Road trains, with the ability to navigate increased road gradients and payloads. These vehicles employ such technology as dedicated 3.5 or 4.0 m wide, high power and torque prime movers (similar to the Bell and Terex dumpers used in open cast mining) and individual supplementary engines on trailers. These vehicles can climb gradients in excess of 6% and can cruise at 80 km/h. Payloads of 200 ton (minimum) are common, with examples of 400 ton combinations being used in some mining applications.

Road trains usually have to be confined to private roads or semi-private roads. This effectively means that companies would be required to build private roads, with the associated road construction and maintenance cost. Because of these factors, and the inherent characteristics of Road trains, the technology is not feasible at long lead distances in excess of 200 to 300 km.

Theoretically there are no limits to the size of a Road train operation, which means that the number of Road trains in the system will directly influence capacity and throughput and is therefore one of the significant advantages of the system. However, caution needs to be exercised where a large number of Road trains is operated on a particular route, to prevent vehicle congestion.

Also, Road trains of similar capacities and capabilities should be used otherwise bunching will occur when lighter Road trains catch up with heavier or lower capacity ones. The operating and maintenance costs for Road trains are similar to that of normal road trucks but decrease per ton transported due to the increased loads.

3

Rail Systems

Conventional rail transport

Conventional rail transport is statistically the safest form of transport and is generally proven to be capable of high throughput rates. Electric rail transport is extremely energy efficient and does not emit localised emissions, however it lacks flexibility and is capital intensive.

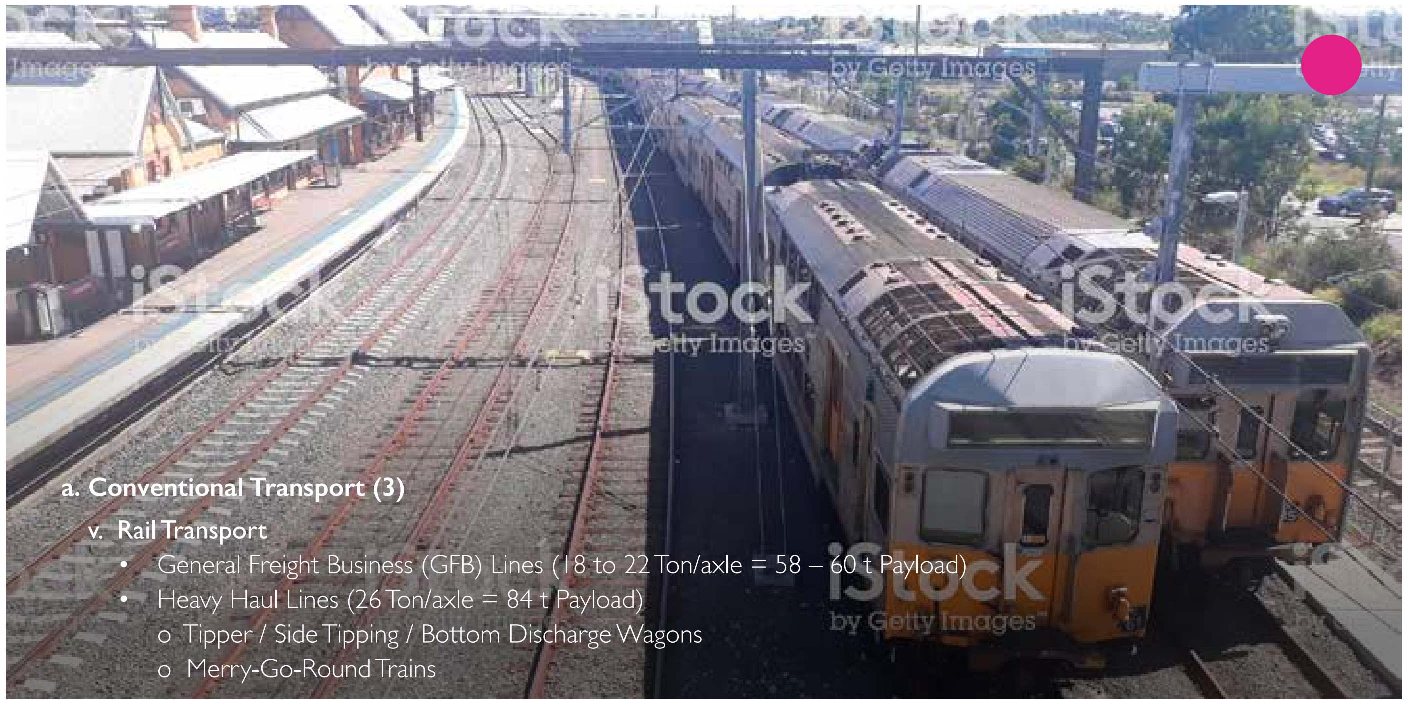
Reduced friction between rail tracks and wheels makes rail transport very sensitive to gradients. The narrow gauge system used in South Africa, means trains becomes unstable at high speeds. This impact on the minimum achievable radius of turns and bends in a rail line, is a distinct disadvantage on undulating and winding routes.

Under South African conditions, the majority of the country's rail lines are for general freight purposes and often referred to as General Freight Business (GFB). These rail lines are designed to carry rail wagons with maximum axle mass loads of 18, 20 or 22 ton. With four axles per wagon, this equates to a gross mass of 72, 80 or 88 ton per wagon. In comparison, Heavy Haul lines are constructed for the transportation of high volume freight on a dedicated rail line. Two such major heavy haul lines exist in Southern Africa: the Mpumalanga to Richards Bay CoalLink Line, and the Sishen-Saldanha Iron Ore Line. These lines are designed to carry rail wagons with maximum axle mass loads of approximately 26 ton. With four axles per wagon, this equates to a gross mass of 104 ton per wagon, which is significantly higher than GFB lines. It is not uncommon for rail transport systems to deliver in excess of 100 Mega Tons per Annum (MTPA).

While the current national (Transnet) rail network needs to be upgraded and strategically expanded, these initiatives are severely hampered by inadequate electricity supply, theft and vandalism, as well as the unavailability of rolling stock, which negatively impact on operating capacity and ultimately on service delivery. Transnet has indicated that the main focus is on eradicating these and investment backlogs while focusing on operational improvements.

When faced with a transport requirement over a long distance, crossing relatively flat terrain, with few obstacles and where most of the crossed land is owned or accessible, rail transport is arguably superior to most other transport options. However, in South Africa, where the rail network and rail transport in general is managed by a public company without any direct competition, any expansions to the existing networks are extremely slow, while inadequate maintenance and unreliable service delivery have forced a significant volume of bulk freight onto road transport. A number of privately owned rail networks exist in South Africa. Most of these are however not electrified and use diesel locomotives, with certain inherent disadvantages.

Mono Rails are categorised as conventional rail transport as it is used widely but has a single rail. Supporters of monorail and other sleek structures argue that because the structures are thinner than conventional rail viaducts, they're cheaper and more aesthetic. They even argue that viaducts, which are more expensive than at-grade construction, are actually better. Urban monorails are usually put above-ground, where their sleekness is a major advantage over conventional rail since they do not darken the street as much. The resource with the most information is a JRTR article about Japanese intermediate-capacity rail, including both monorail and significantly less sleek automated guideway transit (AGT).



source: https://www.chinadiscovery.com/shanghai/shanghai-maglev.html

Magnetic levitation systems

Magnetic Levitation, or Maglev, is a transportation system that suspends, guides and propels vehicles, predominantly trains, using magnetic levitation from a large number of magnets for lift and propulsion. This method of transportation has the potential to be faster, quieter and smoother than wheeled mass transit systems, such as conventional rail transport systems. The power needed for levitation is usually not a particularly large percentage of the overall consumption; most of the power used is needed to overcome air drag, as with most other high speed trains. The technology has the theoretical potential to exceed 6 400 km/h if deployed in an evacuated tunnel.

These Maglev trains were primarily designed for high speed passenger transport systems between dedicated, high passenger volume origins and destinations, such as airports, train stations and city centres. The technology further offers the advantages of being much faster, quieter and more energy efficient than conventional trains, although this all comes at a much higher price.

Some companies have started with the experimentation of Maglev cargo transport systems which is combined with other new technologies, such as hydrogen fuel cells. In terms of freight transport, however, the system has the disadvantage that it does not allow for backward compatibility with existing rail infrastructure, as Maglev trains cannot operate on conventional rail systems. This means that existing rail networks would be defunct and that an entire new network will have to be constructed, which massively increases the capital costs – this is the biggest disadvantage of Maglev systems for commercial freight applications. Due to these disadvantages, this system is deemed unfeasible for freight and materials transport in SA currently.

4

Pipe and Tube Systems

Product log pipelines

The experimental Product Log Pipeline system is based on the concept that the product (i.e. coal) can be compacted into large cylindrical shapes, called Logs, for pipeline transportation using water or another liquid as the carrier fluid. When transported via pipeline in water at 2.5 to 3 m/s, sufficient hydrodynamic lift is generated to move the logs. The logs become waterborne and they make only light contact with the pipe. Consequently, the wear of coal logs and the pipe are both minimal and the power required for pumping is also minimal.

Product Log Pipeline transportation is often compared with Slurry Pipelines, although in product slurry pipelines the product is transported in a paste format and not in a log format. Product Log Pipelines therefore require much less water, the dewatering of the product at the destination is much easier, it uses less energy to transport each ton of product, and it makes the clean-up process much easier in the event of spills.

The biggest disadvantage of Product Log Pipeline transport is that the success of the operation is entirely dependent on the type of product being transported. Product type and the compacting method determine the characteristics and durability of the product log during transportation. To accurately ascertain whether a product from a specific area could be successfully transported using this method, means that the product needs to be tested in trial applications first, which is relatively expensive.

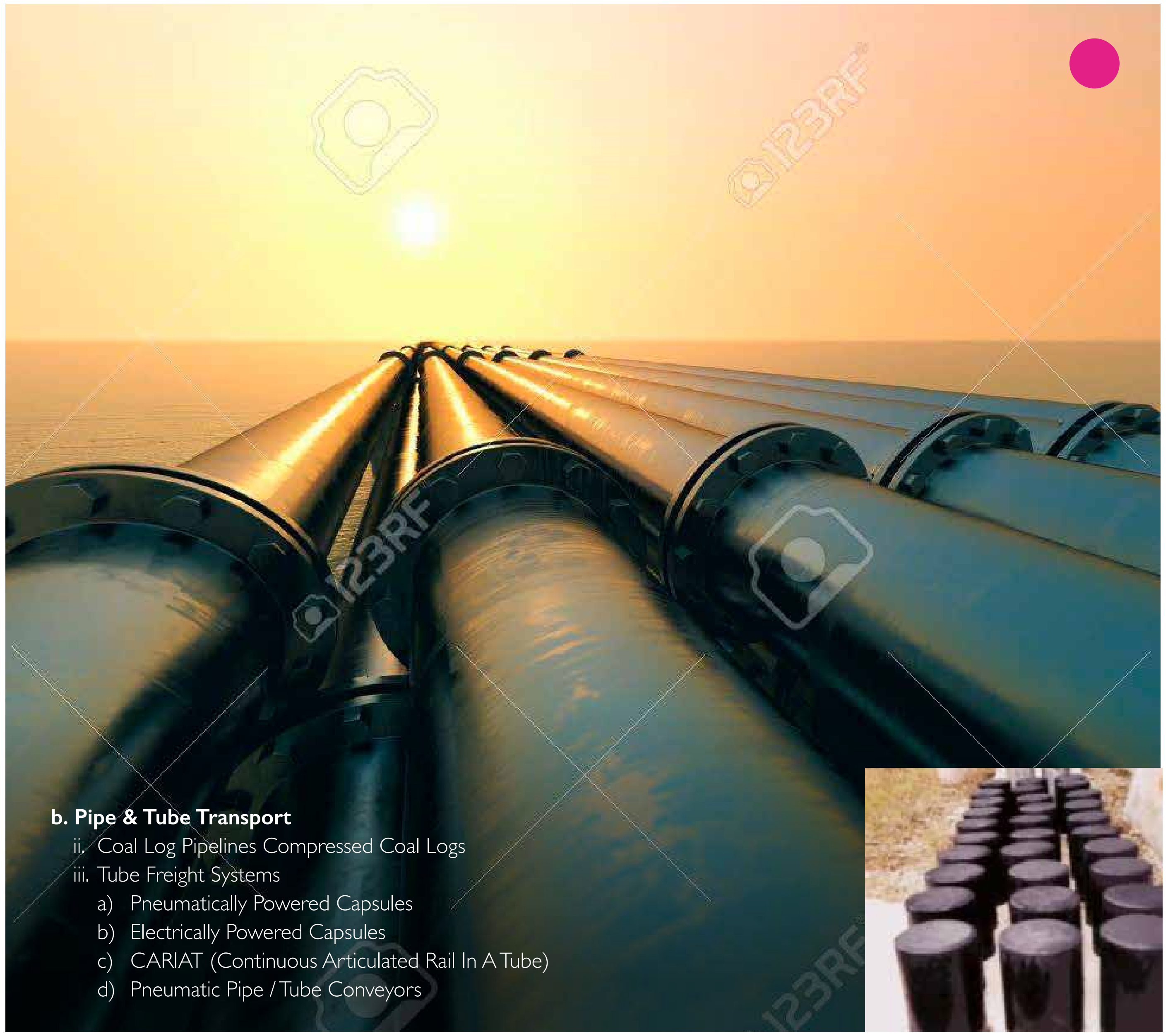
The other major limiting factor of the Product Log Pipeline system, especially under South African conditions, is the need for large quantities of water to transport the product efficiently. For example; for every ton of coal transported, the system requires 250 to 333 litres of water. This rapidly grows into a substantial water requirement as the product throughput increases.

The maximum achievable throughput capacity of this method is currently a theoretical calculation and depends on various factors, including pipeline distance, pipe diameter, pumping system and product characteristics, to name a few. However, pilot plant tests revealed that throughput rates of up to 17 MTPA are achievable for a pipeline system with a 508 mm diameter, across distances in excess of 3 000 km.

The capital investment cost for this system is relatively high, and is mainly dependent on the pipe diameter and the transport lead distance. It should be noted that the Inlet Subsystem cost has a significant impact on the transport unit cost and decreases the attractiveness of the system over short distances. It is therefore suggested that this system should be considered only for transport distances longer than 30 km. Water and energy charges dominate the operating and maintenance costs, but these are relatively low when compared to other pipeline-based transport systems.

The Product Log Pipeline concept is still experimental and has only been tested under pilot plant conditions, and no commercial application of the technology has taken place since its demonstration in 2001. The main stumbling block against using this new technology revolves around the product properties, as discussed earlier.

The Product Log Pipeline appears to be a very high risk option, but it promises significant savings potential if the product characteristics match the optimum operating conditions. However, this will require more research and investment before it can be accurately determined.



b. Pipe & Tube Transport

ii. Coal Log Pipelines Compressed Coal Logs
iii. Tube Freight Systems
  a) Pneumatically Powered Capsules
  b) Electrically Powered Capsules
  c) CARIAT (Continuous Articulated Rail In A Tube)
  d) Pneumatic Pipe / Tube Conveyors

b. Pipe and Tube Transport

i. Slurry Pipelines Crushed Coal / Water Mixture

Slurry pipelines

Slurry Pipelines are used to transport mineral concentrate from mineral processing plants near a mine, to ports or other intermediate or final destinations. These pipelines use a slurry of water and pulverised product, mixed to a ratio of approximately one ton of product to one ton of water (this mixture is however product dependent). The product slurry is then pumped through a dedicated pipeline to a processing facility where dewatering takes place and the material is separated from the slurry and dried before being used. The resulting water is usually subject to a waste treatment process before disposal, or it is returned to the origin station, at an additional cost, where it can be reused.

Slurry Pipelines provide an unobtrusive, environmentally friendly, safe and secure transport mode with a continuous flow and a very low maintenance requirement. The single biggest limiting factor of the Slurry Pipeline system, especially under South African conditions, is the necessity for large quantities of water to transport the product efficiently. For example, for every ton of coal transported the system requires around 1 000 litres of water, which is three times more than the water requirement for the Product Log Pipeline. The requirements rapidly grow into a substantial water volume as the throughput increases.

The maximum achievable capacity of a Slurry Pipeline system depends on various factors, including pipeline distance, pipe diameter, pumping system, material density, dewatering requirements and water availability, to name a few.

Most operations today transport less than 5 MTPA, which seems to be a practical limit. The up-front capital cost of a Slurry Pipeline system is dominated by the construction of the preparation plant and terminal station, which remains constant, regardless of the pipeline length. For this reason, Slurry Pipelines are more suited to longer distance transport. Water and energy charges dominate the operational expenses of Slurry Pipelines, but, although the energy cost increases incrementally with distance, the water cost remains constant if the throughput remains unchanged. Consequently, Slurry Pipelines are more economical at longer distances.

Based on these factors it can be concluded that slurry pipelines become very expensive at low volumes, and that the optimum application of the technology is found around the designed maximum throughput rate of approximately 5 MTPA at distances beyond 500 km.

Regardless of the benefits of Slurry Pipelines, the biggest risk to the feasibility of this technology is the extensive water requirement and the strain that it would place on the local water supply, especially in most inland locations within South Africa.

Tube freight transportation systems

Tube freight transportation is a class of unmanned transportation in which close-fitting capsules, or trains of capsules, carry freight through tubes between terminals. All historic systems were pneumatically powered and often referred to as pneumatic capsule pipelines. Newer and recent proposed systems now use capsules that are electrically powered, with linear induction motors and run on steel rails in a tube, with a diameter of approximately 2 m. The system can ultimately be thought of as a small unmanned train in a tube, carrying containerised cargo.

These underground tube transportation systems were developed primarily for the transportation of cargo in highly congested, urbanised areas. The main benefits of these systems are that they can carry high volume freight, into highly congested areas, with minimum effect on surface transportation systems. If this system were implemented in congested areas, passenger vehicles could be separated from freight vehicles with improvements in efficiency and safety for both modes.

The transportation of product in such containerised tube systems is theoretically possible, but given the capital expenditure required to build a 2 m diameter tube across the entire transport lead distance, either above or below ground, may make this system prohibitively expensive. Since raw materials are mostly transported in rural areas, it is much more practical and economical to employ a form of surface transport. In this light, tube freight systems have not been investigated further.

Continuous articulated rail in a tube

The Australian company, DeVere Mining Technologies, has for over ten years been developing a hybrid transport system, combining rail and conveyor technologies, which is able to convey bulk materials over distances from 0.5 km to over 500 km. The CARIAT (Continuous Articulated Rail in a Tube) Conveyor System is designed to carry materials made up of particle sizes less than 300 mm.

The CARIAT system is essentially a small-scale train, moving along a fixed rail infrastructure, housed inside a tube. It is electrically powered, and in some instances the system also has the capacity to generate energy back into the grid - in effect, partially recycling its own energy on declines.

The developers of the CARIAT system claim that the system can operate at a combined capital and operating cost of around 20-40% of conventional belt conveyors and railways, and around 10-25% of the cost of trucking, yielding savings of 60-90% over traditional transport systems. However, these claims are untested as the system has not been commercially implemented as yet.

The company further claims that the improved energy efficiency of the CARIAT means a dramatically reduced carbon footprint. It also presents a low noise transport option, with a low environmental impact, because the system is capable of travelling underground safely, eliminating dust and other impacts in environmentally sensitive areas. The system further minimises the impact on existing communities due to its slim, streamlined size and ability to travel underground where necessary, resulting in reduced visibility and intrusion. The CARIAT can successfully traverse 45 degree inclines.

However, the system is still under development and only a life-size demonstrator section is available for inspection south of Perth, in Australia and 3-D CAD design drawings for all key components are in place. The University of Newcastle Research Associates (TUNRA) Limited has pledged its initial support in assisting DeVere in the final stages of the development of the technology. With adequate investment, DeVere anticipates premiering the first completely operational CARIAT in the near future.

It should be noted that the CARIAT is not commercially available and that it is remarkably similar to the Rail-Veyor System, still to be elaborated on, which is already available locally. It is expected that the Rail-Veyor system will be more economical, since it travels on an open rail system, while the CARIAT requires the rail to be housed inside a tube for both the outward and return legs. Based on the aspects described above, as well as the fact that no detailed or independent information is available, the CARIAT has been earmarked for further research and will not be comparatively evaluated elsewhere in this brochure.

5

Conveyor Systems

Overland conveyor systems

Conveyor-based systems have been around for over a century, beginning with the typical movement of lightweight materials over short distances. The continuous drive to improve efficiency, improving the development, reducing costs and socio-economic impacts, has led to a variety of conveyor belt types suited to a range of applications. The most common conveyor belt designs found today include:

a. Trough conveyors	b. Sandwich conveyors	c. Straight trough conveyors	d. Sicon conveyors
e. Pipe conveyors	f. Pocket conveyors	g. Pouch conveyors	

Troughed and pipe conveyor systems are commonplace where transportation distances exceed the normal interplant distances and will therefore be the main focus of this section. The major components of the troughed conveyors are the rubberised belt, idlers and pulleys. For pipe conveyors, the basic design concepts remain generally similar to the troughed conveyor, at the tail end where the material is loaded. The difference in structure occurs when the belt passes through a series of transition idlers, which transform the belt from a troughed shape into a pipe shape.

By nature conveyor systems in general are more automated than other forms of transport such as rail and road. Conveyor systems are generally controlled remotely from a control room. Operational information, such as throughput, is often conveyed back to the central control room via SCADA systems. Furthermore, certain maintenance elements such as cleaning the belt can be incorporated as an automated function into the design of the overall system.

The main advantages of conveyor systems are that they can transverse gradients of between 30° and 35° and can provide high levels of throughput, with some conveyors transporting as much as 11 000 ton per hour. Conveyors further provide a continuous feed of materials, they are reliable, offer a good level of availability, have low operating costs and some conveyors can even create their own energy on downhill gradients.

The disadvantages of conveyor systems are that they demand a relatively high capital investment in the infrastructure, which requires a long lifespan of operation and large and sustained product volumes. In addition, conveyor systems do not allow any flexibility and often cause

operations to come to a complete standstill when a breakdown occurs on the conveyor system.

Conveyor productivity and throughput is determined by a number of factors such as belt width and belt speed. These in turn impact the drive pulley and subsequent power requirements, which increase capital and operating costs. In addition, the factors of belt width and speed are continually being increased in the pursuit of higher productivity. Where in the 1980s a belt throughput of 1 500 ton per hour on a 1 500 mm belt would have been considered large, conveyor systems with a capacity of up to 30 000 tons per hour are now in production. However, it must be mentioned that the high capacity conveyor systems operate over a significantly shorter lead distance, typically below 10 km.

As an example; Coal from Zibulo Colliery in Kriel is processed at the Phola Processing Plant in Ogies, Mpumalanga Province. A 16 km coal conveyer is used with an installed capacity of 6 000 tons, 3 000 kW and belt speed of 4.71 m/s. The Zibulo Overland Conveyor connects the colliery to the processing plant.

Conveyor system costs are generally affected by the terrain, the configuration of the loading and offloading points, transport lead distances and the annual throughput requirements. As stated previously, the capital investment costs are relatively high and the operating costs are dominated by the cost for energy and lubricants, while maintenance and related labour charges are also relatively high.

Based on all these aspects, conveyor transport is a trusted mode that is widely used in the South African industry. It is ideally placed for high volume, short haul transport between sources and destinations, where the system life is long enough to warrant the capital investment required and where the material supply is generally guaranteed.

6

Combination Systems

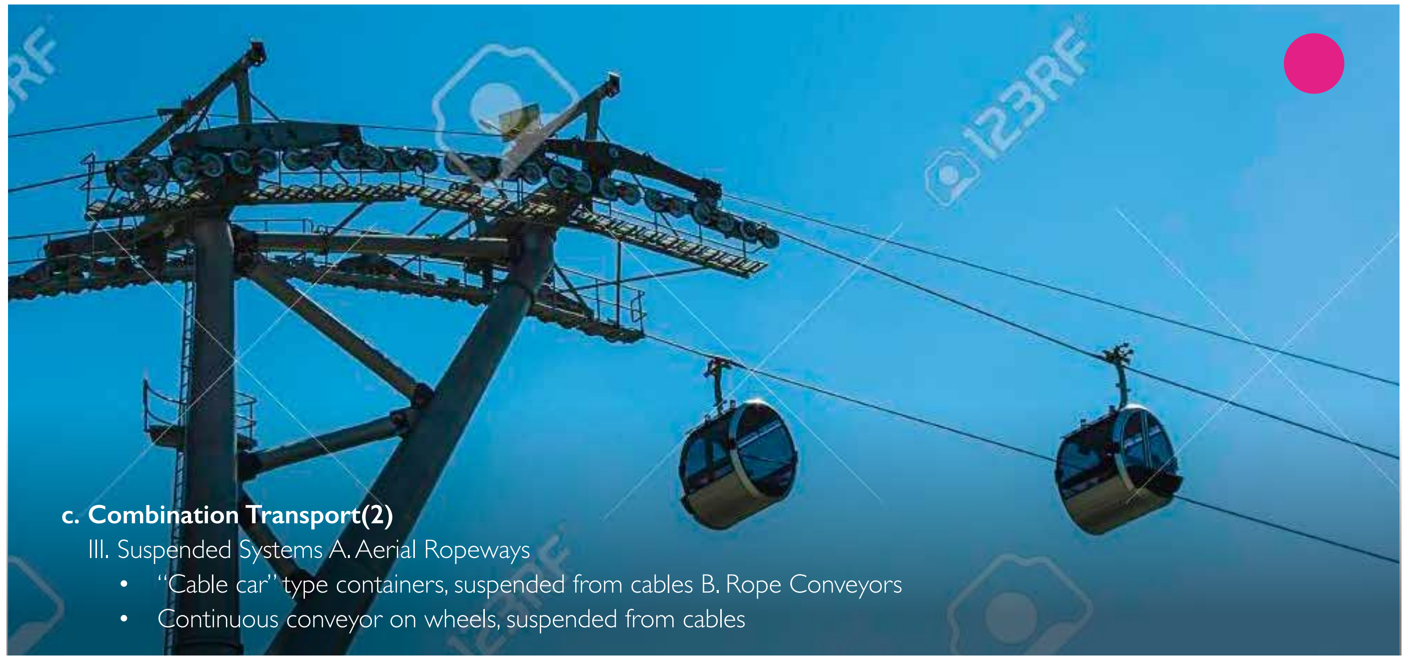
Aerial ropeway systems

An aerial ropeway is essentially a subtype of cable car, from which the bucket containers or passenger cars are suspended. Aerial ropeways are operated worldwide with a wide range of application areas, based on the specific transport requirements. They are usually employed across difficult terrain, where conventional transport is challenging, such as steep inclines and declines of up to 45 degrees.

These systems are used with success in the transport of bulk materials, unit loads and even passengers, sometimes all on the same system. The system consists of one or two fixed cables called track ropes, one loop of cable called a haulage rope and the carriages or haulage buckets. The fixed cables provide support for the buckets while the haulage rope, by means of a grip, is solidly connected to the bucket, via the wheel set that rolls on the track cables. The haulage rope is usually driven by an electric motor and, being connected to the buckets, moves them up or down the cableway, usually traversing a steep incline or other obstacles.

The aerial ropeway systems have almost limitless application possibilities, for the transportation of any type of bulk material between two points. Systems are usually individually designed for a specific application and two or more systems can be operated in parallel to increase throughput.

The biggest advantage of an aerial ropeway system is the fact that it minimises the transport lead distance, because the system can be erected across the shortest possible distance between two points, by crossing obstacles and traversing steep inclines. These systems have been used to cross mountains, rivers, forests, highways, roads, railway lines and even settlements, without the need for expensive bridges or tunnelling.



c. Combination Transport(2)

III. Suspended Systems A. Aerial Ropeways

- "Cable car" type containers, suspended from cables B. Rope Conveyors
- Continuous conveyor on wheels, suspended from cables

The disadvantages of an aerial ropeway system, on the other hand, are that it is not suited to low product volumes, short contract periods or very short lead distances, typically less than 8 km. The main reason for these constraints is the relatively high capital requirements for the loading and off-loading stations, which are required regardless of the system length or design life.

However, the business case for installing an aerial ropeway system is not normally based on the basic transport unit cost, but rather on the fact that it can easily and economically cross immovable obstacles, which would require excessive capital investment for any other mode of transport.

The maximum achievable throughput capacity of the aerial ropeway system is difficult to quantify and depends on various factors, including transport lead distance, slopes, loading and offloading requirements, material density and product characteristics, to name a few. However, in previous projects it has been found that an annual throughput rate of 5 Mton seems to be the feasible maximum capacity of one system. For increased volumes, multiple systems can be operated in parallel and, as the capital and operating cost multiply, so do the volumes, which keep the transport unit costs constant as long as each system is used to maximum capacity.

Ropeway systems are designed to operate across a maximum distance of approximately 10 to 15 km, depending on the slope and the required material transfer rate. For transport lead distances longer than this, transfer stations are employed to transfer the loaded buckets from one segment of the ropeway to a following section, while moving. This effectively means that the aerial ropeway system can be infinitely long.

Aerial ropeway transport is a very old and well established technology that is used worldwide in various applications. It is estimated that there are more than 13 000 aerial ropeway installations around the world and that industrial ropeways account for approximately 10% of the total number of ropeway systems in use. From a South African perspective, Fairview Mine near Barberton operates a 27 km aerial ropeway system transporting around 150 000 t/annum. The system is now about 50 years old. It is also interesting to note that the Havelock Ropeway system (also near Barberton), built in the 1930s but now defunct, was the largest aerial ropeway system in the world at the time.

It can be concluded that aerial ropeway systems were specifically developed to address certain shortcomings in conventional transport solutions, predominantly to provide a cost-effective way of crossing obstacles such as mountains, rivers, roads, railway lines, forests and settlements. In particular, the aerial ropeway technology is superior to most other technologies in transporting material up and down steep inclines, such as mountains, or even out of open cast mining pits.

Apart from the obvious advantageous application areas described above, aerial ropeways are perfectly placed to play a crucial part in a multimodal and fully integrated product supply chain. The technology could be successfully applied to breach the gap between other transport modes in specific cases where existing infrastructures need to be linked, with minimal cost to cross obstructions, or to transport product over medium distances into the final destinations from hubs or product pantries, without having to establish expensive land-based infrastructure.

Ropeway conveyor systems

The ropeway conveyor system, or RopeCon, is a suspended, long-distance, continuous conveyor system suitable for the transportation of bulk materials and unit loads of any kind. They are usually employed across difficult terrains, where conventional transport is challenging, such as steep inclines and declines, or where obstacles need to be crossed cost effectively. These bulk transport systems are used with great success across the world today.

In simple terms, the RopeCon system can be described as a continuous conveyor system in the air, running on ropes. However, a very significant difference between conventional conveyors and the RopeCon system is that in conventional conveyors the belt itself moves over a series of rollers, whereas in the RopeCon system, movement is obtained by attaching the conveyor belt to a wheel set and the wheels roll across the static suspended ropes, much like rail cars on a track. The RopeCon belt also differs from conventional conveyor belts in that it has built-up, corrugated sides, which provides a channel-like shape, as opposed to a flat surface.

The RopeCon system has the same basic advantages and disadvantages as the aerial ropeway systems, described in the previous section. The main difference between these systems is the fact that aerial ropeway systems transport in unit or bucket loads, while the RopeCon system provides continuous conveying capability, which dramatically increases the achievable throughput capacity.

The maximum achievable throughput capacity of the RopeCon system is difficult to quantify and depends on various factors, including transport lead distance, slopes, belt speeds, loading and offloading requirements, as well as the specific product characteristics. However, based on the generally accepted design criteria obtained from the manufacturers, it is indicated that throughput rates of below 10 000 t/h are best, but this can be increased to 20 000 t/h under ideal conditions. This effectively means that RopeCon systems can transport in excess of 100 MTPA, dependent on the specific application.

RopeCon systems are designed to operate across a maximum distance of approximately 20 to 25 km, depending on the slope and the required material transfer rate. For transport lead distances longer than this, transfer stations are employed to transfer the bulk material between belt segments. This effectively means that the RopeCon system can be infinitely long.

There are at present no installations of the RopeCon system in South Africa and the cost of other international installations is not readily available, which makes it difficult to obtain an accurate cost indication of the system. To present some guideline figures, limited cost estimates were obtained for an implemented system in Jamaica, as well as a few quotations for the installation of local systems. As can be expected, from a capital perspective the basic infrastructure, consisting of the loading terminal, towers, belts and wheel sets, the ropeway and offloading terminal have a significant impact on the total system cost, which decreases the attractiveness of the system over short distances. Based on the substantial addition of equipment and moving parts, the system is also markedly more expensive to construct than a normal aerial ropeway system.

However, the operations and maintenance cost of the system is very similar to a normal overhead conveyor system, which increases its economic attractiveness. Based on the fact that it also has a significantly higher throughout rate, when compared to unit load aerial ropeway systems, the transport unit cost reduces substantially.

In conclusion, the ropeway conveyor system competes directly with aerial ropeway systems and provides the same basic advantages of cost effectively crossing immovable obstacles. It is therefore also perfectly suited for niche applications or for inclusion into an integrated supply chain, where it can easily breach the gap between more conventional infrastructures. The distinguishing factor of the RopeCon system is that it can provide a service where a very high and constant material throughput rate is required.

Rail-Veyor system

A rail-veyor is the only technology with a competitive transport cost across all distances.

The Rail-Veyor transport system represents a novel, practical approach to moving materials economically over short, intermediate and long distances from a few meters up to around 800 km. The Rail-Veyor moves materials by use of a light rail track system with a series of two-wheeled, inter-connected cars that effectively represent a long, open trough moving along the track. Each car is connected to the car in front with a joint that allows articulated movement for curves and dumping. The gap between cars is sealed by overlapping urethane flaps, which prevent leakage of the material and act as discharge chutes for dumping loads at their destination. The driving force to move the train consists of a series of equally spaced, dual stationary drive stations. AC motors and gear reducers turn horizontal foam filled tyres against the side drive plates of the cars, providing forward thrust. Speed is controlled by an inverter, which allows operation in either forward or reverse directions with sufficient power to start a loaded train from any position on the track.

These drive stations shut down when the train is not in contact and a sensor-based system starts the drive up again upon arrival of a train from a previous station, which significantly reduces the energy required to power the system.

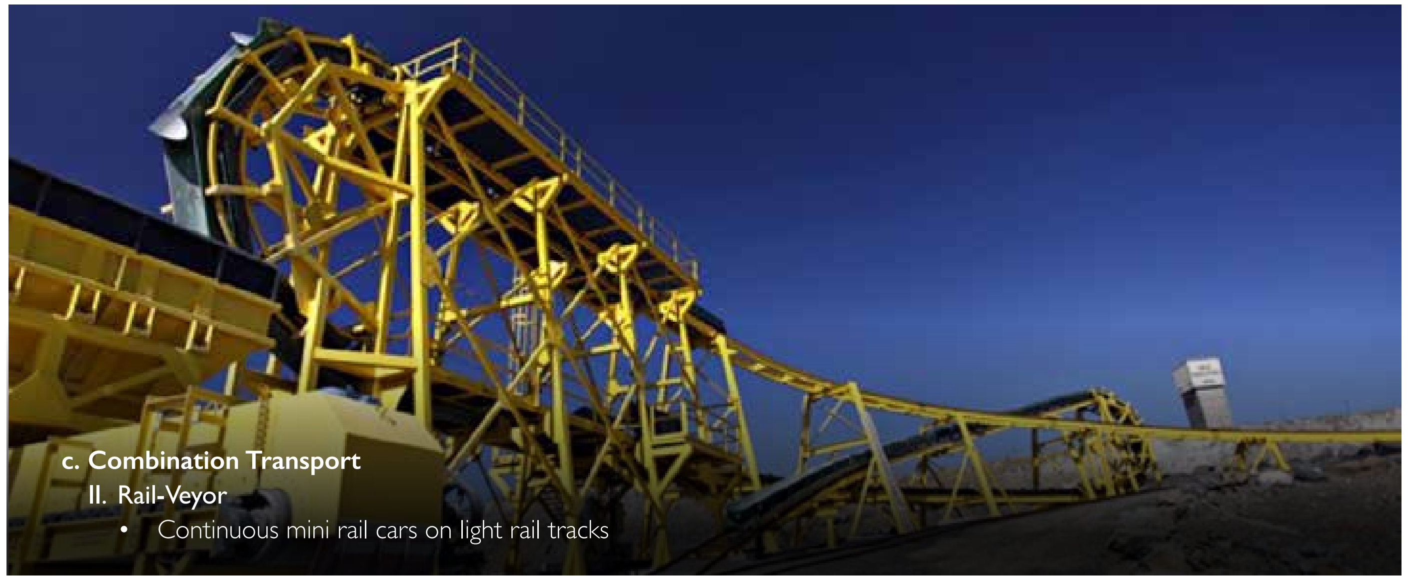
Loading and tipping loops are erected at the ends of the Rail-Veyor system, to accommodate loading and offloading while the train is moving. When tipping, the train enters the loop in the upright position on a horizontal plane and as it moves through the loop the train turns 180 degrees on a vertical plane, effectively inverting the train, based on rollercoaster technology. During this movement the loaded cars discharge the material by means of gravity, similar to normal conveyor belts. The train is then returned to the upright position for reloading.

The Rail-Veyor system has the advantage that it combines the best aspects of conventional conveyors and conventional rail, at a fraction of the capital and operating costs of these technologies. This is based on the fact that it provides an almost continuous material throughput rate, while it operates on a very lightweight rail track, which is significantly cheaper to construct and maintain than conventional railways. The system is fully automated and is controlled from a central control room.

The optimum operating conditions for the Rail-Veyor system would be similar to those of a conventional conveyor or rail system, with the advantage that it can operate at inclines of up to 11° and it can negotiate bends of up to 30 degrees at relatively high speeds. The small-scale and lightweight systems also allow for relatively simple bridging and tunnelling over and under roadways, rivers and other obstructions.

There are no theoretical limits to the size of the Rail-Veyor cars, which means that the unit train lengths and the number of trains on the system will directly influence capacity. The maximum operational speed has not been established, but based on torque, gear ratios and drive tyre diameters; speeds of up to 12 m/s or 32 km/h are realistic. During system tests in South Africa and Canada, pilot 2.4 m long cars, with a 610 mm radius and 203 mm sideboards were fabricated for demonstration purposes. Utilising these cars, in a series of trains totalling 500 equally sized cars, it loaded, moved and dumped nearly 11 000 ton/h of material over a 1.6 km haulage distance. This equates to a throughput potential of 76 MTPA. To maintain this throughput rate at longer distances, additional trains will be added to the system.

The system has been proven to provide an economical, practical approach to moving materials over short, intermediate and long distances from 400 meters to 100 km. The maximum feasible transport distance has not been established and the system has not been proven at excessively long distances, nor has it been costed for longer than 100 km. However, the system designers claim that it is feasible to run the system economically at distances of up to 800 km.



c. Combination Transport
II. Rail-Veyor
• Continuous mini rail cars on light rail tracks

Source: https://news.bulk-online.com/news-english/rail-veyor-now-hauling-all-deep-1-production-material-at-agnico-eagles-goldex-mine.html

As indicated previously, the capital investment cost of the Rail-Veyor system is extremely competitive, while the operating costs, which are dominated by energy charges, are significantly reduced by shutting down the drive stations when they are not in use. Based on the fact that each loaded car weighs less than 3 ton, the maintenance costs on the fixed infrastructure is also significantly reduced.

A Rail-Veyor system, with a length of around 5 km, is currently in operation at the Harmony Gold Phakisa Mine. Indications are that the system was operating at R3.58/ton delivered. However, since the introduction of a second train in September 2008, the operating costs have reduced to R3/ton delivered, and the mine management feels that at full capacity of 3.5 MTPA, this cost could drop below R2/ton – note these are the costs as quoted during 2009.

Rail-Veyor systems are one of the most prominent new bulk transport systems that have recently become available, and it seemingly remains competitive from very short to very long lead distances, which is rather unique. The major limiting factor, however, is that the system has not been commercially applied for distances longer than 5 km, and there is only one reference site available locally.

The potential benefits of the system warrants consideration, research and investigation into the overall characteristics and specific applicability of this system, while the integration possibilities of multiple Rail-Veyors also needs to be tested. From the information available, it seems that the system can fulfil the unique function of providing economic long distance transport where no other infrastructure is available, while also being suitable for short distance, high volume transfers to final destinations.

Futran, a local designer and manufacturer of a unique system, with some plans for a Rail-Veyor, has opened up in Midrand, Gauteng and is doing business throughout Africa. Local manufacturing may make this method a more cost competitive solution.

Source: Futran Group

Bimodal transport options

Bimodal freight transport involves the transportation of freight in a bimodal container or vehicle, using two modes of transport, namely conventional rail and road transport, without any handling of the freight itself when changing modes. This transport method reduces material handling, and so improves security, reduces losses, and allows freight to be transported faster through the supply chain. The technology further combines the flexibility of road transport with the efficiency of rail transport, especially in supply chains where no dedicated rail line exists between the product source and the final destination.

Older versions of bimodal semi-trailers combined normal rubber tyres for road freight, with their own integrated train wheel sets for rail transport. However, these versions were extremely heavy due to the additional steel train wheels, which dramatically reduced the payload carrying capability of the trailers. More modern versions of the bimodal trailers do not include integrated railroad wheels, but ride on specially manufactured rail bogies, that do double-duty, by providing the train wheel sets and serving as articulation points between multiple trailers in a train.

These modern bimodal systems use custom built semi-trailers, which are designed to be connected to the rail bogie, which lifts the rubber wheels clear off the ground. Several trailers are then connected to each other, using the rail bogies, in order to form a long train of trailers. Locomotives are then used to transport the trailers like normal trains.

A third variation on the bimodal transport option is the use of open top containers. Normal 6 or 12 metre open top containers or intermodal containers are customised to provide tipping rear doors. These containers are loaded with product and then lifted onto custom designed, rear tipping road vehicles, with forklifts or reach stackers, which are used to transport the containers to a rail siding. At the rail siding the containers are removed from the trucks and placed onto a flatbed rail wagon, again using a forklift, reach stacker or gantry crane. The containers are then transported via rail as close as possible to the final destination.

Source: https://urovesa.com/en/applications/tt-uro/civilian/camiones-bimodales/construccion-y-mantenimiento

At the final rail siding the containers are once again removed from the train and placed back onto a back tipper truck, which transports the product for the last few kilometres to the final destination. Here the product is simply tipped through the swinging back doors of the container.

While these bimodal transport options eliminate the need for double handling, the most significant disadvantage is that the trailers are much smaller than normal rail wagons, which significantly decreases the payload carrying capacity and increases the transport unit cost. This is due to the fact that the same trailer is also transported via road, which is currently restricted by a gross vehicle combination mass of 56 ton.

The total transport cost is therefore made up of the rail transport portion, as well as the road transport portion, which are separately slightly higher than the normal rail and road transport rates, due to the specialised

equipment and handling requirements. In combination, however, the total cost should be lower than road transport for the entire lead distance. This combination transport cost should also be lower than having to establish and operate a transfer station in order to transfer product between conventional road and rail modes.

The abovementioned combination transport cost makes it impossible for this bimodal transport option to be compared directly with any other mode of transport and should be evaluated on a per case basis. For this reason, bimodal transport options will not be comparatively evaluated in this brochure.

7

Water and Air Systems

Water-based transport options

Water transport is the process of transporting passengers or freight with a watercraft, such as a barge, boat, ship or sailboat, across a body of water, such as a sea, ocean, lake, canal or river. The two most prominent freight transport options are barging and deep sea shipping.

Under South African conditions, product is mainly mined inland, which would require that it be transported across the country to the nearest port from which it can be shipped. If, for example, the coal was mined on the west coast and used on the east coast, it would make sense to ship the coal via short sea shipping, instead of overland transport. However, the predominant coal mining region is currently in the northern part of the country. This means that the coal would have to travel further overland to get it to a suitable port, than the distance required to get it to the final local customer.

While deep sea shipping is generally the preferred mode of transport for large product exports, it does not make economic sense to employ any form of shipping for local raw materials distribution.

Air transport options

Air transportation is the process whereby passengers or freight are transported from point to point, making use of fixed-wing or rotary-wing aircraft, travelling through the air, following the shortest, safest or approved route. The main benefit of this form of transport is that it is very fast, based on the speed of the aircraft and the directness of the route, which shortens the lead distance.

The major disadvantages of air cargo transport is that the payloads are generally very small compared to any other mode of transport, which makes the transport unit cost extremely expensive. Based on these factors, air transport is not an option for the transportation of high volume bulk commodities such as raw materials.

8

Transport System Comparisons

Feasibility of Transportation Types in South Africa

Different transport options are generally classified into modes, based on the infrastructure that is required to enable such transport. Similar guidelines are used and the 18 identified transport modes are grouped in **Table 1** below.

Table 1: Summary of available transport modes:

Transport Mode	In commercial use	Feasible in SA
Road-based transport options		
Current Road Transport	Yes	Yes
Quantum 1 Road Transport	Yes	Yes
PBS Vehicles	Yes	Yes
Road trains	Yes	Yes
Rail-based transport options		
General Freight Rail Transport	Yes	Yes
Heavy haul Rail Transport	Yes	Yes
Magnetic Levitation Systems	Not Freight, but people	Not freight
Pipeline & tube-based transport options		
Product Log Pipelines	No	To be validated
Slurry Pipelines	Yes	To be validated
Tube Freight Transportation Systems	Not bulk materials, but people	Not bulk materials
Continuous Articulated Rail in a Tube (CARIAT)	No	To be validated
Conveyor & cable transport options		
Overland Conveyor Systems	Yes	Yes
Aerial Ropeway Systems	Yes	Yes
Rope Conveyor Systems	Yes	Yes
Combination transport systems		
Rail-Veyor Systems	Yes	Yes
Bimodal Transport Options	Yes	Yes
Other transport options		
Water-based Transport Options	Yes	To be validated
Air Transport Options	Yes	To be validated

Eleven of these identified transport options are already being used commercially and are applicable under South African conditions, while a further five options need further evaluation and testing before a definitive answer can be provided on its suitability for the transportation of freight or raw materials. Most systems are however suitable for the transportation of people.

Comparison of the different transportation modes

To accurately compare transport modes against each other, it is imperative that these technologies be evaluated using the same criteria. To achieve this objective, the evaluation criteria are structured according to the physical system characteristics, its local applicability and any further information requirements that were uncovered.

Transportation mode characteristics

In order to coherently report on and logically compare each option, based on the aforementioned criteria, the completed evaluation matrices for the physical system characteristics and the system capacities are provided in the following table:

Table 2: Summary of system characteristics:

Transport Mode	System characteristics					
	Infra-structure	Vehicles	Operations	Major Advantage	Major Disadvantage	Optimum Operating Conditions
Road & Rail Based Transport Options						
Road-based transport options						
Current Road Transport	Public Road Networks	31t Payload Truck & Trailers	Private Haulers	Extreme flexibility, local support services	Road damage, 50% empty, high vehicle concentration, high maintenance, high CO_2 pollution, road damage, public safety risk	Less than 8% Gradients, Short Terminal Times
Quantum I Road Transport	Public Road Networks	38t Payload Truck & Trailers	Private Haulers	Extreme flexibility, less vehicles required, local support services	High vehicle concentration, high CO_2 pollution, road damage, 50% empty, high maintenance, public safety risk	Less than 8% Gradient, Short Terminal Times
PBS Vehicles	Public Road Networks	48t Payload Truck & Trailers	Private Haulers	Extreme flexibility, high product volume, low vehicle concentration, local support services	Sensitive to Gradients, Comparatively Reduced CO_2 Pollution, Road Damage, Requires Private Road Infrastructure, High Maintenance, 50% Empty	Less than 2% Gradient, Few Bridges, Wide Corners
Road trains	Private Heavy Haul Roads	105t – 108t Payload Truck & Multiple Trailers	Private Haulers or In-house Fleets	Extreme flexibility, high product volume, low vehicle concentration	Sensitive to Gradients, Comparatively Reduced CO_2 Pollution, Requires Private Road Infrastructure, High Maintenance, 50% Empty	Less than 2%Gradient, Few Bridges, Wide Corners
Rail-based transport Options						
General Freight Rail Transport	Public Rail Networks	18t – 22t Axle Load Wagons	Public Company (Transnet Freight Rail)	High Capacity, Economical over Long Distances, Low Direct Pollution, Enables Trade, Increased Public Safety	Lacks Flexibility, Capital Intensive, No Competition	Flat Terrain, Less than 1% Gradient, Wide Turn Radius
Heavy Haul Rail Transport	Dedicated Rail Line	26t Axle Load Wagons	Public Company (Transnet Freight Rail)	High Capacity, Economical over Long Distances, Low Direct Pollution, Enables Trade, Increased Public Safety	Lacks Flexibility, Capital Intensive, No Competition	Flat Terrain, Less than 1% Gradient, Wide Turn Radius

Transport Mode	System characteristics					
	Infra-structure	Vehicles	Operations	Major Advantage	Major Disadvantage	Optimum Operating Conditions
Pipeline, Tube, Conveyor, Cable and Combination Transport Options						
Pipeline & tube-based transport options						
Product Log Pipelines	Dedicated Pipeline, Public or Private	None – Compacted Product Logs	Private	High Water Usage, High Volume, Low Pollution, Local Production	Dependent on Specific Product Characteristics, High Water Requirement	Compactable Product, Flat Terrain, Sufficient Water Supply
Slurry Pipelines	Dedicated Pipeline, Public or Private	None - Slurry Product Mixture	Private	High Volume, Low Pollution, Local Production	Extremely High Water Requirement	Less than 16% Gradient, Few Crossings, Ample Water Supply
Tube Freight Transportation System	Dedicated Tube System, Public or Private	Pneumatic or Electric Capsules	Public or Private	Sub-surface Transport in Congested Areas, Low Direct Pollution, Local Production	Capital Intensive	Highly Congested Area
Continuous Articulated Rail in a Tube (CARIAT)	Private, Dedicated Tube & Rail System	Continuous Articulated Train	Private	Economical, Small Footprint, Energy Efficient, Low Pollution, Local Production	Still Under Development	Less than 11% Gradient
Rail-based transport Options						
Rail-Veyor System	Light Weight (22kg/m) RailSystem, Electric Drive Stations	Series of 2 Wheeled, Inter-connected Cars	Private	Low Cost Option High Volume, Energy Efficient, Low Pollution, Local Production	Limited Current Examples	Less than 11% Gradient
Bimodal Transport Options	Private Road & Public Rail Network	Customised Road Trailers & Rail Bogeys or Open Top Containers & Customised Back Tipper Trucks	Private Road & Public Rail (Transnet Freight Rail)	Reduces Double Handling of Material to Change Between Transport Modes, Moderate CO_2 Pollution, Local Support Services	Smaller Payloads due to Same Trailer Travelling on Road and Rail, within Legal Limits	Majority of Route via Rail, Short Fina Distance via Road

Transportation mode capacities

The various transport options have capacity and distance limitations and due to differing operational modes will manage differing total loads per annum.

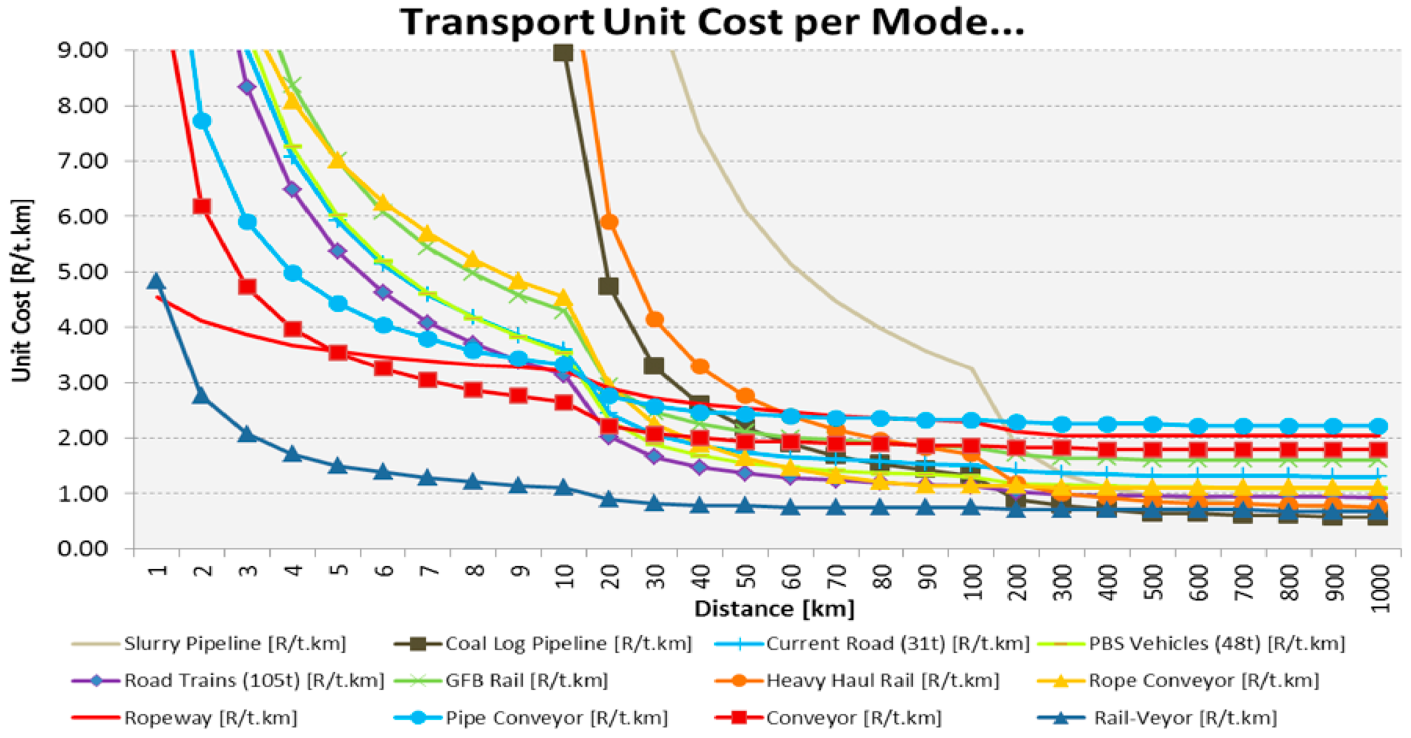
Table 3: Below provides a summary of these:

Transport Mode	Capacity		
	Payload	Throughput capabilities	Maximum operating distances
Road-based transport options			
Current Road Transport	31t Payload Truck & Trailers	Network specific, based on number of vehicles: 50MTPA achievable	Theoretically unlimited, Practically less than 1 000km
Quantum 1 Road Transport	38t Payload truck & trailers	Network specific, based on number of vehicles: 50MTPA achievable	Theoretically unlimited, Practically less than 1 000km
PBS Vehicles	48t Payload truck & Trailers	Network specific, based on number of vehicles: 50-100 MTPA achievable	Theoretically unlimited, Practically less than 1 000km
Road trains	105-180t Payload Truck & Multiple Trailers	Network specific, based on number of vehicles: 100MTPA achievable	Theoretically unlimited, Practically less than 300km
Rail-based transport options			
General Freight Rail Transport	18 - 22t Axle Load Wagons: 58-60t Payload per Wagon	Infrastructure Specific: 10MTPA Achievable	Theoretically Unlimited, Practically less than 500km
Heavy Haul Rail Transport	26t Axle Load Wagons: 84t Payload per Wagon	Infrastructure Specific: 100MTPA Achievable	Theoretically Unlimited: Practically less than 1 00km
Pipeline & Tube-based Transport Options			
Product Log Pipelines	N.A.	Determined by Pipe Diameter: 17MTPA Achievable	Theoretically up to 3 000km
Slurry Pipelines	N.A.	Determined by Pipe Diameter: 5MTPA Achievable	Theoretically Unlimited, Practically less than 500km
Tube Freight Transportation System	N.A.	Unknown: Determined by Pipe Diameter and Capsule Capacity	Theoretically Unlimited, Practically less than 50km, within Urban Limits
Continuous Articulated Rail in a Tube (CARIAT)	Unknown	Unknown: System Still Under Development, 70 MTPA Anticipated	Theoretically Unlimited, Practically less than 800 km
Conveyor & cable transport options			
Overland Conveyor System	N.A.	Determined by Belt Width & Speed: 200MTPA achievable	Theoretically Unlimited, Practically less than 200km
Aerial Ropeway Systems	Design Specific: 3-5t typical	Depends on Slopes & Material Density: 5MTPA achievable, per Cable	Theoretically Unlimited, Practically less than 50km
Rope Conveyor Systems	N.A.	Depends on Slopes & Material Density: 100MTPA Achievable	Theoretically Unlimited, Practically less than 50km
Combination transport options			
Rail-Veyor System	Design Specific: Approximately 3t per Car, 110t per Train Typical	Determined by Infrastructure & Rail Car Design: 76MTPA achievable	Theoretically Unlimited, Practically less than 800km
Bimodal Transport Options	Design Specific: Approximately 22-30t per Container/ Trailer Typical	Road network & Rail Infrastructure Specific: 10-50MTPA Achievable	Theoretically Unlimited, Practically less than 500-1 000km

Rough order of magnitude overall costs per transportation mode

The evaluation from a capital, operating and maintenance cost perspective is provided below. The following graphical representation provides guidance on the operational costs per mode of transport:

Graph 1: Rough Order of Magnitude (ROM) Overall costs



The graph provides the Unit Cost in Rand per ton per kilometre (R/t.km) for various distances up to a maximum of a 1 000 km.

All R/t.km figures are adjusted to August 2019 actual energy (electricity and diesel) costs. All costs are based on Rough Order of Magnitude (ROM) principles, include capital, operations and maintenance cost, but with no annual escalation on capital and maintenance cost.

This broadly conforms to expectations, where conveyor type technologies are suitable across shorter lead distances, with the flexibility and scalability of road transport ensuring that it remains an option in most applications. It however has more disadvantages. The different versions of rail transport further indicates that it is very competitive at intermediate to long lead distances, while the pipeline-based technologies are seemingly an option at mid-volume and long lead distance applications. An important finding is the comprehensively competitive possibilities for Rail-Veyor systems, which proved to be the only technology that was competitive under every single scenario.

However, note that the selection of a specific transport mode is not a simple economic calculation, but rather a complex decision based on various influencing factors including **the availability of infrastructures, individual system characteristics, system integration possibilities and various socio-economic implications.**

Feasibility options per transport mode per load and distance scenarios

Cost comparisons, based on the transport unit cost, at various lead distances ranging from 1 to 1 000 km, based on three distinct freight volume scenarios of 1, 5 and 50 Million Tons per Annum (MTPA) respectively should then be considered.

The individual transport modes are ranked per lead distance segment for each of the three volume scenarios and then averaged per distance grouping, which resulted in the overall ranking indicated in **Table 4** below. From **Table 4** it is possible to also determine **which transport mode, based on cost only, is the most competitive option at a given lead distance and for a specified product throughput**.

These comparisons are summarised and the transport options ranked in order of economic competitiveness.

Table 4: Summary of feasible transport options per scenario

SHORT DISTANCE (<10km)					
Scenario A 1 MTPA	Rank	Scenario B 5 MTPA	Rank	Scenario C 50 MTPA	Rank
Rail-Veyor	1	Rail-Veyor	1	Conveyor	1
Road train (180t)	2	Aerial Ropeway	2	Pipe Conveyor	2
Road train (105t)	3	Conveyor	3	Rail-Veyor	3
PBS Vehicles (48t)	4	Pipe Conveyor	4	Rope Conveyor	4
Aerial Ropeway	5	Road train (180t)	5	Aerial Ropeway	5
Quantum 1 Road (38t)	6	Road train (105t)	6	Road train (180t)	6
Conveyor	7	PBS Vehicles (48t)	7	Road train (105t)	7
Current Road (31t)	8	Quantum 1 Road (38t)	8	PBS Vehicles (48t)	8
Pipe Conveyor	9	Current Road (31t)	9	Quantum 1 Road (38t)	9
Rope Conveyor	10	Rope Conveyor	10	Current Road (31t)	10

***Note:** Based on 2009 data*

The table above shows that depending on tonnages, the **Rail-Veyor, Ropeways or Conveyors** are best ranked (most feasible) for short distances up to 10 km (more detailed elaboration in the transport methods described above).

For distances between 10 and 100 km the following table refers:

MEDIUM DISTANCE (10 - 100km)					
Scenario A 1 MTPA	Rank	Scenario B 5 MTPA	Rank	Scenario C 50 MTPA	Rank
Heavy Haul Rail	1	Rail-Veyor	1	Conveyor	1
PBS Vehicles (48t)	2	Heavy Haul Rail	2	Pipe Conveyor	2
Quantum 1 Road (38t)	3	Road train (180t)	3	Rail-Veyor	3
GFB Rail	4	Conveyor	4	Rope Conveyor	4
Road train (180t)	5	Product Log Pipeline	5	Product Log Pipeline	5
Road train (105t)	6	Road train (105t)	6	Road train (180t)	6
Current Road (31t)	7	PBS Vehicles (48t)	7	Heavy Haul Rail	7
Product Log Pipeline	8	Aerial Ropeway	8	Road train (105t)	8
Rail-Veyor	9	GFB Rail	9	Heavy Haul Rail (Priv.)	9
Conveyor	10	Pipe Conveyor	10	PBS Vehicles (48t)	10
Aerial Ropeway	11	Quantum 1 Road (38t)	11	GFB Rail	11
Pipe Conveyor	12	Slurry Pipeline	12	GFB Rail (Priv.)	12
Slurry Pipeline	13	Current Road (31t)	13	Quantum 1 Road (38t)	13
GFB Rail (Priv.)	14	Heavy Haul Rail (Priv.)	14	Slurry Pipeline	14
Heavy Haul Rail (Priv.)	15	GFB Rail (Priv.)	15	Current Road (31t)	15
Rope Conveyor	16	Rope Conveyor	16	Aerial Ropeway	16

***Note:** Based on 2009 data*

The table above shows that depending on tonnages, **Heavy haul rail, Rail-Veyor or conveyors** are best ranked (most feasible) for distances between 10 and 100 km (more detailed elaboration in the transport methods described above).

For distances between 100 and 1 000 km the following table refers:

LONG DISTANCE (100 - 1000km)					
Scenario A 1 MTPA	Rank	Scenario B 5 MTPA	Rank	Scenario C 50 MTPA	Rank
Heavy Haul Rail	1	Heavy Haul Rail	1	Product Log Pipeline	1
GFB Rail	2	Product Log Pipeline	2	Rail-Veyor	2
Product Log Pipeline	3	Slurry Pipeline	3	Heavy Haul Rail	3
PBS Vehicles (48t)	4	GFB Rail	4	Slurry Pipeline	4
Quantum 1 Road (38t)	5	Rail-Veyor	5	Heavy Haul Rail (Priv.)	5
Road train (180t)	6	Road train (180t)	6	GFB Rail	6
Current Road (31t)	7	PBS Vehicles (48t)	7	GFB Rail (Priv.)	7
Slurry Pipeline	8	Road train (105t)	8	Road train (180t)	8
Road train (105t)	9	Quantum 1 Road (38t)	9	Road train (105t)	9
Rail-Veyor	10	Current Road (31t)	10	PBS Vehicles (48t)	10
GFB Rail (Priv.)	11	GFB Rail (Priv.)	11	Quantum 1 Road (38t)	11
Heavy Haul Rail (Priv.)	12	Heavy Haul Rail (Priv.)	12	Current Road (31t)	12

***Note**: Based on 2009 data*

The aforementioned table shows that depending on tonnages, **Heavy Haul Rail or Product Log Pipelines** are best ranked (most feasible) for distances between 100 and 1 000 km (more detailed elaboration in the transport methods described above).

It should be noted that six transport options were omitted from aforementioned ***Table 4*** *for the Short lead distance applications below 10 km, as these rail and pipeline type options are simply not competitive at such short distances. Similarly, four transport options were also omitted from the longer lead distance applications above 100 km, as conveyor type technologies are not really practically suited to such long distances, except under special conditions.*

The main conclusion is therefore that no single transport technology exists that could cost-effectively satisfy all the divergent transport requirements, across all distances, at different volumes and across all types of terrain. Rail-veyors, conveyors, heavy-haul rail and product log pipelines however proved to be most feasible.

The optimum distribution solution lies in the effective combination of all the available transport options into an integrated and well managed network, where individual technologies are applied on merit. This approach allows for the safest and most cost-effective transport application for each individual route, while protecting and enhancing the available transport infrastructure.

Rail-veyors, conveyors, heavy-haul rail

Although most of the transport options mentioned may proof feasible depending on the distances, tonnages and product to be transported, the options found to be the most feasible were Rail-veyors, conveyors and heavy-haul rail. Product log pipelines were not considered due to the substantial amounts of water required for this transportation method.

All these methods use electricity as the main energy driver and pose significant opportunities for utilities and customers due to the cost benefit advantage and limited localised harmful emissions.

Summary – electrical transport options

The most feasible transport solutions consist of mostly tried and tested technologies and processes with installations worldwide. Some of these technologies still have not been taken up comprehensively throughout South Africa, which may pose opportunities.

The latest diesel Carbon Tax liability (R0.10/litre paid for at source) has an operational cost impact on those technologies or processes which use diesel as an energy fuel source. Diesel usually has to be stored, paid up-front, is prone to theft, and with transportation options usually operating with no load 50% of the time when empty trucks return to be loaded again. The quality of road surfaces for road transport will also have an impact but has not been considered or quantified.

Due to the disadvantages of the aforementioned, electrical transport options are often more competitive than liquid fuel solutions from a capital, operations and environmental perspective. Alternative solutions lie in the effective combination of all technologies into an integrated and well managed network: hence applying the best technology for specific distances, at an acceptable operational / capital cost and environmental conditions.

The uptake of the most sustainable transport options should be promoted. Further investigations are required to address some of the gaps identified, the opportunities for conversions and new installations, with the possible funding opportunities.

With road transport being one of the largest localised polluters, government should consider implementing regulations to drive the uptake of more efficient technologies, moving transportation from diesel consumption (roads) to the identified alternative technologies (rail, conveyors, etc.) and promoting technology change with factual research or project findings

NOTE:
This brochure provides very high level and intentionally generic information. The information provided is valuable and adequate for guiding selected transport and distribution related decisions, in cases where the **lead distance, basic geography and product volumes are known**.

A logical next step in this field would be to investigate the integrative and cooperative approaches that could be followed to improve distribution productivity, efficiency, reliability and cost effectiveness of the supply chain at an industry level. The introduction of an industry-wide supply chain network optimisation initiative and the establishment of hubs are two possible options to achieve this level of cooperation, which warrants further investigation.

Eskom Advisory Services

Eskom's role is to aid the client with basic information in the decision-making process. Thereafter the Eskom Advisor will fulfil the role of energy advisor as part of the team that the business selects.

Optimise your energy use
Eskom's Energy Advisors, in regions across South Africa, offer advice to business customers on how to optimise their energy use by:

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- Understanding their electrical systems (including QOS) and processes
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- Optimising energy use patterns in order to grow businesses and industries

Call 08600 37566, leave your name and number and request that an Energy Advisor in your region contacts you. Alternatively, e-mail an enquiry to **advisoryservice@eskom.co.za.**

References:

a. Andries Louw, CEO, Futran Holdings, https://futrangroup.com/, FUTRAN Podcars,https://www.sanedi.org.za/Cleaner%20Mobility/images/Presentations/FutranPodcast_UNIDO_Sustainable_Transport_and_Mobility_for_Cities_Workshop_AndriesLouw_20170330.pdf
b. Armstrong, Nordengen et al (2009). Performance Based Standards for Heavy Vehicles: Monitoring report on two PBS vehicles operating in the forestry industry: November 2007 to July 2008
c. Brad Lawson and Laing O'Rourke, Bulk Materials Handling Efficiency through Advanced Overland Conveyor Technology, pg 1-16
d. BookRags, Transportation and Storage of Coal, http://www.bookrags.com/research/coal-transportation-and-storage-of-mee-01/
e. Balloon loop, http://ww.en.wikipedia.org/wiki/Balloon-loop
f. Ample use of the COALTECH Transport Investigation, Largely Assisted by Crickmay & Associates (Pty)Ltd., December 2009, www.scribd.com
g. Conveyor Equipment Manufacturers Association, Belt Conveyors for Bulk Materials, 6th Edition, 2nd Printing, pg 1-15
h. Capsu.org, Facts About Coal Log Pipeline, http://www.capsu.org/library/documents/0027.html
i. Commercial Benefits (2009). http://www.railfreightgroup.com/new/why/
j. Conditions critical to ensuring vibrant freight and passenger rail, http://www.transportationvision.org/docs/vision_FreightRail.pdf
k. Desmond Armstrong, Transport Technical Manager, Mondi Business Paper
l. DEEBAR Group: Rail-VeyorTM, An Efficient Economical and Environmentally Friendly Way to Move Materials (2009), http://www.deebar.co.za/railveyor.htm
m. Doppelmayr, RopeCon Simberi, REM Construction Consultants, www.remcons.co.za
n. Doppelmayr, RopeCon – The Innovation in Bulk Material Handling, REM Construction Consultants, www.remcons.co.za
o. Doppelmayr, RopeCon, http://www.doppelmayr.com/defualt/php?lid=2&frs=210
p. Dr Henry Liu.(2002), Coal Log Pipeline Transportation System, Office of Industrial Technologies Energy Efficiency and Renewable Energy, U.S. Department of Energy, Inventions and Innovative Project Fact Sheet, www. Cclabs.missouri.edu/~cprc
q. Freight Train. http://en.wikipedia.org/wiki/Rail_Freight
r. Guide%20April%202008.pdf
s. Hopper car, http://ww.en.wikipedia.org/wiki/Hopper_car
a. Howard L Hartman, SME mining engineering handbook, Volume 1, pg 1350
b. Hans Prem and Luan Mai (2004). Presentation to the South African Delegation: PBS Analysis of Truck/Trailer for Timber Transport in South Africa Mechanical System Dynamics, Melbourne, Australia

c. http://www.thomasandmuller.com/belt_conveyors.htm
d. http://www.bateman.co.za
e. http://www.batemanengineering.com/TECHNOLOGY/ConveyorSystemsBrochure.pdf
f. http://www.batemanengineering.com/TECHNOLOGY/JapanPipeConveyors%20bro.pdf
g. http://www.krupprobins.com/References/Conveyors/overland.html
h. http://www.krupprobins.com/References/Conveyors/1019-TKR-Ref-CV-Overland-2006.pdf
i. http://books.smenet.org/Surf_Min_2ndEd/sm-ch06-sc05-ss03-bod.cfm
j. http://www.ckit.co.za/
k. http://www.bulk-online.com/forum/
l. http://en.wikipedia.org/wiki/Roadtrain
m. http://www.gouldtransport.com.au/world_records.html
n. http://www.jowells.co.za/index.php?option=com_content&task=view&id=51&Itemid=94
o. http://www.haulmore.co.za/services.htm
p. http://www.fleetwatch.co.za/magazines/aug01/27-UnitransRBM.htm
q. http://www.miningweekly.com/article/transport-safety-milestone-at-rbm-2004-07-09
r. http://www.legislation.vic.gov.au/
s. http://www.transport.sa.gov.au/pdfs/freight/route_maps/418%20Road%20Train%20Information%20
t. http://www.etftrucks.nl/Products/Roadtrains/
u. http://www.nra.co.za/live/content.php?Category_ID=40
v. J Lane, MaxLegal Technical Description, 17 February 2009, Crickmay and Associates
w. Jorgensen AA (2004), The regeneration of railways in South Africa and intermodal opportunities for the road transport sector. https://repository.up.ac.za/upspace/handle/2263/5698
a. Kuka Mining Logistics, email and presentations information, https://kukaropeways.com/, www.kmls.co.za
b. Mark A Alspaugh and Grzegorz Dewicki, Advanced Design Considerations for Overland Aggregate Conveyors, www.overlandconveyor.com, pg 1-10.
c. MA Alspaugh, Overland Conveyor Co Inc., Latest Developments in Belt Conveyor Technology, presented at MINExpo 2004
d. Mpumalanga to Richards Bay Freight Coal Line, South Africa. http://www.railway-technology.com/projects/richardsbay-coaline/
e. Merry-go-round train, http://ww.en.wikipedia.org/wiki/Merry-go-round_train
a. ProfTrans Vehicle Costing Model, Seidel and Associates
b. Personal communications:
  i. Peter Koschel - LCR Mining Group
  ii. Scott McFarlane - Powertrans
  iii. c. Prof Alex Visser - University of Pretoria
iv. d. Dr Phil Paige-Green – CSIR
c. Rail-VeyorTM – Bulk Material Transportation System (2009), http://www.railveyor.com/index2.html
d. Robinson WL, RopeCon Systems, Emails, REM Construction consultants, www.remcons.co.za
e. Road Infrastructure Strategic Framework for South Africa, National Department of Transport, http://www.ddl.stanford.edu/files/avec2ktalk.pdf
f. Rail Transport. http://en.wikipedia.org/wiki/Rail_Transport
g. Rail Transport Operations, http://ww.en.wikipedia.org/wiki/Rail_transport_operations
h. South African Yearbook 2015/16: Transport, https://www.southafrica-newyork.net/consulate/Yearbook_2016/Transport-SAYB1516.pdf
i. South African Yearbook 20017/18, Transport: https://www.gcis.gov.za/print/9315
j. Stander, H J, Pienaar W J, Perspectives on freight movement by road and rail in South Africa, http://hdl.handle.net/2263/7696
a. T Cummingham, Long-Distance Transport of Baucite by Pipeline, E-Book, http://www.bechtel.com/assets/files/TechnJournal/M&M%2002%20Long%20Distance%20Transport%Final.pdf
b. Transnet Freight Rail, http://www.transnet.co.za
c. TR Marrero, Long-Distance Transport of Coal by Log Pipeline, Capsule Pipeline Research Center (CPRC), University of Missouri Pacific Northwest Laboratory for the U.S. Department of Energy, Innovative Concepts Program 590240
d. Transnet National Infrastructure Plan, http://www.transnet.net/TNIfraPlans.Html
e. Unit train, http://ww.en.wikipedia.org/wiki/Block_train
a. Van der Walt, Industrial Aerial Ropeways, presentation and information by Kuka Mining Logistics
b. Wikipedia, Aerial Tramway, http://en.wikipedia.org/wiki/Aerial_tramway
c. WAC Smith and GH Spriggs, Long Overland Conveyors, http://www.saimh.co.za/beltcon/beltcon1/paper112.html, pg 1-11
d. Wikipedia, Slurry Pipeline, http://en.wikipedia/wiki/Slurry_pipeline
e. Why we need rail freight, http://www.freightonrail.org.uk/PDF/FoR%20Flyer%20Final.pdf
a. www.selfregulation.co.za
b. www.rtms-forestry.co.za

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