

Aurecon Australia Pty Ltd
ABN 54 005 139 873
Level 14, 32 Turbot Street
Brisbane QLD 4000
Locked Bag 331
Brisbane QLD 4001
Australia

T +61 7 3173 8000
F +61 7 3173 8001
E brisbane@arecongroup.com
W arecongroup.com

The Aurecon logo features a small green square above the letter 'a' in the word 'aurecon', which is written in a bold, lowercase, sans-serif font.

25 September 2012

Paul Bilyk
Director
Queensland Competition Authority
GPO Box 2257
Brisbane QLD 4001

rail@qca.org.au

Dear Paul

**QR Network Electric Traction Services - Draft Amending Access Undertaking:
Request for Submissions**

We refer to QR Network's submitted Draft Amending Access Undertaking (DAAU) to the Queensland Competition Authority (QCA), in particular the issues relating to the proposed electric traction pricing amendments.

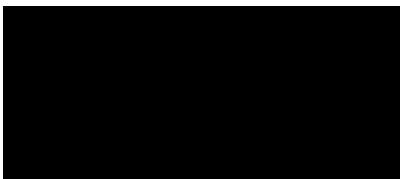
Aurecon was commissioned by QR National to provide an independent review of the international market for electrified railways. Whilst QR National engaged Aurecon to undertake this work, this report represents Aurecon's view of the market and QR National has not sought to influence Aurecon's opinion whatsoever to their own benefit.

Aurecon provides engineering, management and specialist technical services for public and private sector clients globally. The group, with an office network extending across 24 countries, has been involved in projects in over 80 countries across Africa, Asia Pacific, the Middle East and the Americas and employs around 7 500 people throughout 11 industry groups. We seek to foster human achievement in all aspects of our work.

Aurecon's diverse rail team has skills ranging from permanent way engineering, bridges and tunnels to signalling, communications and power systems. A broad technical base is strengthened by Aurecon's multi-disciplinary approach. Projects are analysed from a diverse range of planning, environmental, engineering and commercial perspectives.

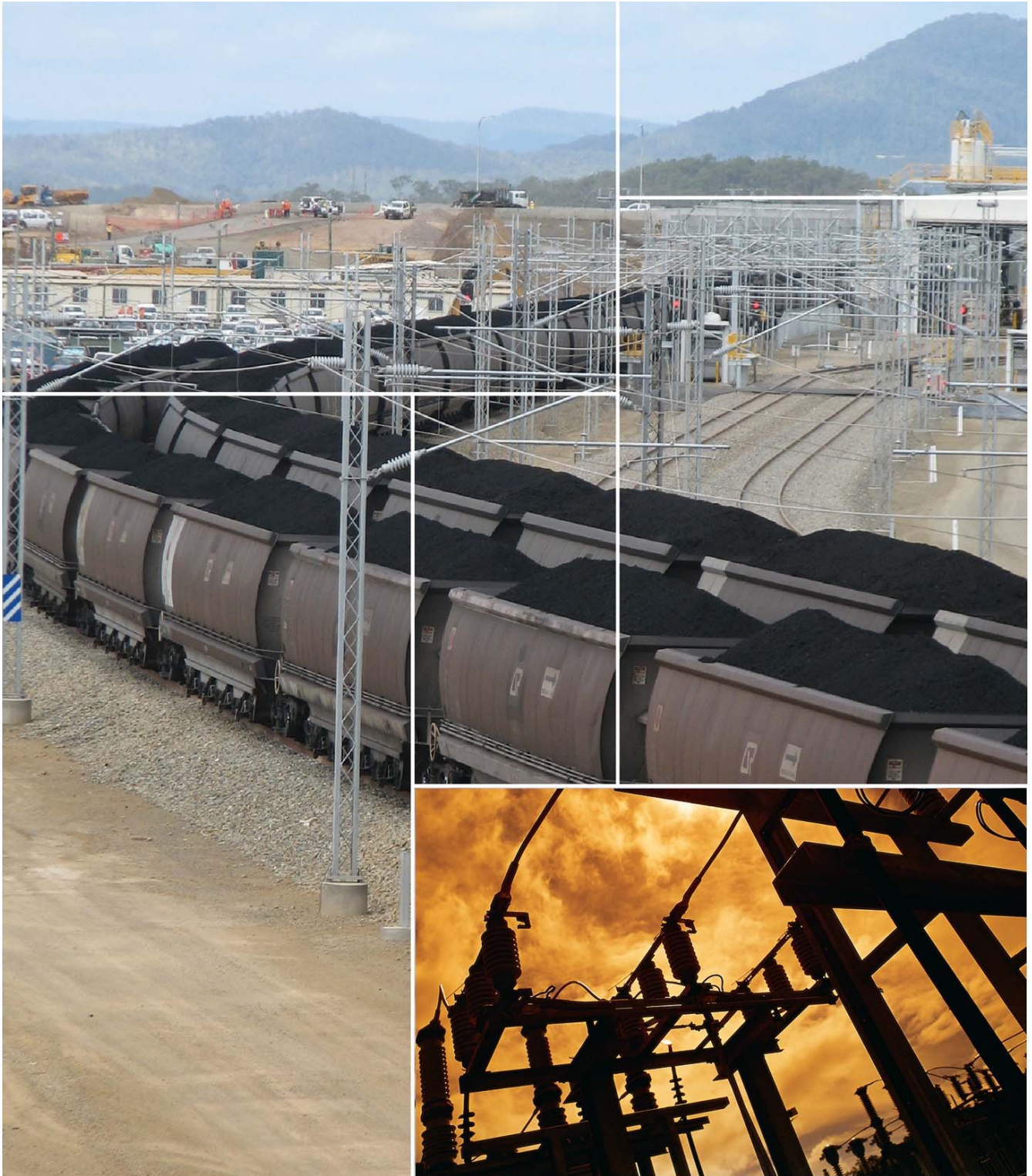
Should you have any queries in regard this submission, please do not hesitate to contact Alex Pey on 07 3173 8456 or 0437 401 128.

Regards



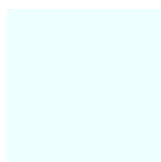
Alex Pey

Services Leader Heavy Haul Rail



Project: QR Network Electric Traction
Services - Draft Amending Access
Undertaking
Submission to Qld Competition Authority

Reference: 232062
Prepared for: QCA
Submission
Revision: 0
25 September 2012





Contents

1. Executive Summary	3
2. Background	5
3. Why do countries electrify their railways?	6
3.1 The international experience	6
3.2 The Queensland experience	6
3.3 The China experience	7
4. Market Structure	12
4.1 Background	12
4.2 Current situation	12
4.3 Upcoming Electric Locomotive Orders	14
4.3.1 Asia	14
4.3.2 North America	15
4.3.3 Africa	16
4.3.4 Australia	18
4.4 Heavy Haul Locomotives in South Africa	18
4.4.1 Diesel locomotives	18
4.4.2 Electric locomotives	19
4.5 International trade	20
4.6 Second-hand market for locomotives	21
5. Relative efficiency of electric traction	23
5.1 Technical efficiency	23
5.1.1 Power	23
5.1.2 Noise	24
5.1.3 Emissions	24
5.2 Operational efficiency	26
6. Technological development opportunities for electric traction	28
7. Supply chain risk	30
7.1 Impact of peak oil production and dislocation	30
7.2 Benefits of an electrified system	31
7.3 Alignment of risks	31
8. Concluding Comments	33
9. Bibliography	36



Appendices

Appendix A

Calculations

Index of Figures

Figure 1: China's Rail Network (note blue represents electrified lines)	8
Figure 2: China's Coal Rich Northern Regions and its Rail Networks	10
Figure 3: Market volume for new electric locomotives (SCI Verkehr, 2011)	13
Figure 4: World market for diesel locomotives (SCI Verkehr, 2003)	13
Figure 5: Levels of electrification in Asia (SCI Verkehr, 2011)	14
Figure 6: Rail Electrification in North America and Mexico (SCI Verkehr, 2011)	15
Figure 7: Rail electrification in Africa and Middle East (SCI Verkehr, 2011)	17
Figure 8: Railway traction well to wheel analysis based on low heating value (Hoffrichter, et al., 2012)	25

Index of Tables

Table 1: Coal Rail Networks in China (Clarke & Cheung, 2012)	9
Table 2: Market development in North America	16
Table 3: Market development in diesel locomotive in South Africa	19
Table 4: Electric locomotive market development in South Africa	20
Table 5: Comparison of Above Rail Cost per 1000 gross tonne-kilometre (000's GTKM)	26
Table 6: Projections of world oil production peaking	30
Table 7: Impact on Blackwater and Goonyella systems	33



1. Executive Summary

Electrification of rail in countries were generally influenced by whether it had abundant energy resource such as coal, centralised ownership of the rail and/or supply chain or employed a strategy to mitigate any perceived risk based on uncertain supply of oil from overseas sources. After the shocks of the 1973 oil crisis countries such as China and India, abundant in supply of natural resource such as coal, reviewed their dependence on imported sources of oil and reshaped their strategy to electrify their rail networks. It also provided them an opportunity to boost their local economy, decrease dependence on imported oil and increase production of domestic energy resource.

China, with its key central planning, was able to develop the lowest whole-of-life supply chain and was also able to take into account wider issues such as emissions and supply risks, and was able to do so looking at the long term impact of these on the supply chain.

Such developments led to the global market for electric locomotives predominantly being concentrated in Western Europe, Asia and the former Soviet Union, accounting for almost 84% of the market share. Australia/Asia Pacific and Africa/Middle East account for 10% of the global electric locomotive share. It is expected that 38% of the global market supply of electric locomotives will be consumed in Asia with China, India and South Korea leading the way

South Africa has the highest degree of electrification in Africa with 43% of its network electrified and has recently placed a USD \$400 million order with CSR to supply electric locomotives. South Africa is looking to invest \$US 26bn in South African railways and major acquisition of locomotives are planned in future.

Electric locomotives, with a higher power to weight ratio, can deliver as much as 2½ times the tractive power output of an equivalent diesel locomotive with lesser track damage. Thus electric units with higher speed, better acceleration can provide faster timetables and greater slot utilisation increasing the capacity in the system.


Electric locomotives are more reliable; five to ten decibels quieter than diesel and at the rolling stock level do not emit greenhouse gases. In a 'Well to Wheel' study done in UK and US, electric traction was found to emit 20% less CO₂ than diesel traction with similar efficiencies.

The major benefit of electric traction as opposed to diesel traction is the lower operational cost- likely to be fuel savings and rolling stock maintenance expenses. Use of regenerative braking in electric trains further reduces energy demands and can provide a saving of 5%-20%.

Research shows that the majority of peak oil studies indicate that the oil peak would occur between 2004 and 2020. With Australia's dependence on imported oil, any disruptions to the oil supply chain has the potential to increase the cost of oil dramatically thereby jeopardising the feasibility of oil based rail freight transport.

International energy outlook 2011 predicts the demand for liquid fuels in transport sector will grow more rapidly than in any other sector. This presents critical supply and demand issues and in "constrained supply", regardless of the cause of disruption, will profoundly affect economic, environmental, energy and national security realities.

An electrified rail system has a significant long term advantage because the electrified network is provided for by electricity from power stations that can be coal fired (as many are currently in



Queensland), gas, hydro, or nuclear. Future shortages in one or the other fuel sources will drive investments in other power stations, or conversion of existing power stations.

An alignment of risk with electric traction is a significant advantage compared with the risks associated with the supply of diesel fuel for the locomotive fleet. In the event of a diesel supply interruption in a high cost energy market, the demand for coal is likely to be strong. An electrified supply chain would in that situation have a significant competitive advantage and is likely able to gain market share from other supply chains.



2. Background

In December 2011, QR Network Pty Ltd submitted a Draft Amending Access Undertaking (DAAU) to the Queensland Competition Authority (QCA) for its approval.

The DAAU proposed three changes to the 2010 Access Undertaking (AU):

1. Pricing to reflect network benefits - Introduction of a single network AT5 charge, determined based on the total costs and total forecast utilisation of the electric network as a whole.
2. Electric utilisation rebate - Introduction of a requirement that operators pay AT5 for at least 90% of train services that *could* feasibly be operated with electric trains.
3. AT5 to provide long term price signal - Amendments to provide that, where revenue adjustments in a single year are substantial, QR Network may defer recovery of revenue cap amounts so that the total increase in AT5 is no greater than 5% per annum. Any unrecovered amount will be carried forward for recovery in a following year.

A number of submissions were received by the QCA, most of which contradicted QRN's claims to justify its proposed tariff changes, and questioned whether those changes were efficient and promoted effective competition.

The QCA in its Draft Decision proposed not to approve the DAAU.

Aurecon has reviewed the case put forward by QR Network, in particular the stated fact that on a Total Cost of Ownership (TCO) basis, the electrified rail systems of the Blackwater and Goonyella Systems would provide a lower overall Above and Below Rail cost. This report is provided to improve the understanding of the technical and international market conditions relevant to locomotives used in heavy haul rail supply chains, and allow more informed decisions to be made on this important aspect of the Blackwater and Goonyella coal supply chains.

As such the report covers the following areas:

- Why do countries electrify their railways?
- Market Structure
- Relative efficiency of electric traction
- Technological development opportunities for electric traction
- Supply chain efficiency, and
- Concluding comments



3. Why do countries electrify their railways?

3.1 The international experience

Electrification of rail, beginning from 1910, has offered reliable, superior performance as well as significant savings in traction operation costs, fuel expenditure, inspection, maintenance, repairs, and provision for backup facilities, including spare units and parts.

The world's primary energy sources consist of coal, natural gas and oil. From a global perspective, rapid urbanisation in developing countries has created unprecedented demand for energy and in the coming years, imbalance in energy consumption between industrialised and developing nations is going to level out. The consequence of this will be that the price of energy will rise and the resources will be consumed at a faster rate.

The oil crisis of 1973 demonstrated that oil is a precious fossil fuel resource with limited availability. Post 1973 oil crisis, greater emphasis was placed on switching demand to, where available, domestic sources of fuel and using more efficient methods of energy consumption. Countries such as India and The Netherlands reviewed their dependence on imported oil and adopted a strategically safe energy policy of rail electrification to guard against uncertain supply of oil from overseas sources.


In a country such as India, energy policy considerations and decision to switch to an overhead electric source of energy for traction was facilitated by the fact that all elements of supply chain, i.e. coal mining, infrastructure, rail and port ownership is government controlled and the country is blessed with natural energy resource such as coal. Electric locomotive haulage has also shown to involve greater local labour content that has a significant impact on the economy and an opportunity to boost the use of locally produced energy resource.

In South Africa, the policy to electrify most of their rail network was driven by a desire to be less reliant on imported fuel, made more critical due to supply constraints arising from embargoes imposed during the Apartheid era. It too had an abundance of coal to power its own energy requirements including electrification of its rail network.

Some countries have low levels of rail electrification. Closer examination reveals that many of these countries either had an abundance of oil, lack of other energy resources, fragmented ownership of rail, or are heavy influenced by lobby groups, or just did not have the volume of traffic. The fragmented private ownership and influence of the major oil companies in the United States contributed to the lack of rail electrification in that country. In fact, in 1939, the United States was the global leader in railway electrification, with over 20 per cent of the world's total. In the decade after World War II, seven systems were shut down, victims of diesels, ageing electrical equipment, changing traffic patterns, and likely pushed by the oil lobby.

3.2 The Queensland experience

In Queensland, the rail electrification began with planning approval in 1974. The oil crisis of 1973 would have influenced government thinking of the day. The changeover to electric traction for coal services was completed by 1989. The important thing to remember is that at that time the major elements of the supply chain were state controlled. The electrification of the coal lines followed the successful electrification of the Brisbane suburban network. The State Government at the time deemed it a logical progression to proceed to electrify the main revenue earning coal rail network. Some of the considerations for the electrification project, which were not evaluated in hard dollar terms, but which nevertheless, were important arguments for electric traction were (Drake, et al., 2009):

- 
- Electric traction provides the opportunity to use locally produced coal in Queensland's power stations as the traction power source to move our export coal to the coast.
 - Elimination of the dependence on expensive imported liquid fuels where the continuity of supply is beyond local control.
 - The electrification project provided an employment generator amounting to 14,800 man years and considerable emphasis was placed on maximising Queensland content under the State Purchasing Policy which existed at that time and this has had significant positive impact on the Queensland economy.

3.3 The China experience

China's rail transport volume is one of the highest in the world, with 25% of the world's total rail freight carried on its railway network, despite only representing 6% of the world's operating railways (in terms of track kilometres). As at the end of 2011, China's railway network was 93,000km in length, of which 46,000km was electrified. (People's Republic of China Ministry of Railways, 2011)

The electrification rate of China's railways increased gradually during 1975-2007. It was less than 5% in the early 1980s, increased to more than 10% in the late 1980's, more than 20% in the late 1990s, and increased to 37.8% in 2007. According to the China's Mid-Long Term Railway Network Plan, the electrification rate of China's railways will be more than 60% in 2020.

The growth in rail network development has been phenomenal over the past two decades, and not likely to abate in the near future. Figure 1 shows a map of the railways in China. The electrified lines are shown in blue.

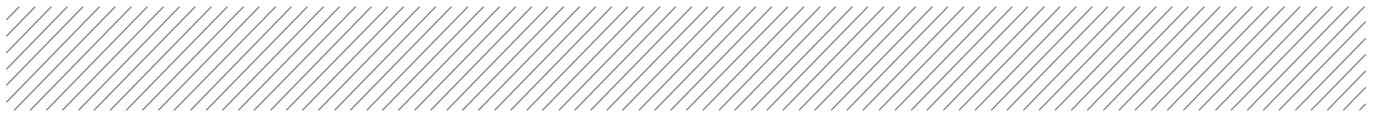


Figure 1: China's Rail Network (note blue represents electrified lines)

China has constructed a number of dedicated coal rail networks over the past two decades. These have all been centrally planned by the Ministry of Railways who handles most rail operations. This central coordination covered the development of coal mines, railways, power stations, ports, in fact the entire supply chain. The table below summarises the major coal rail lines in China.

Table 1: Coal Rail Networks in China (Clarke & Cheung, 2012)

Railway Name	Distance (km)	2011 Throughput (mt)	2020 Forecast (mt)	Electrified	Comments
Xilinhote-Chifeng	336	10	35	N	
ShenShuohuang	799	177	350	Y (part)	
Mengji			157	E	Under construction; 120 mt from 2015
Jitong	945	35	35	N	Low capital option, initially powered with steam locomotives due to surplus of steam locomotives, gradually replaced by diesels
Jingbao	824	120	120	E	
Mengxi-Huazhong	1837		200		Construction commenced in 2012; 200 mt from 2020
Daqin	653	440	480	E	Operated by Daqin Railway Company Limited, a publicly-traded stock company, listed on the Shanghai Stock Exchange.
Central South Corridor	1260		200		From Lvliang to Rizhao Port; Under construction, expected to be complete by September 2014
Fengshada	457	80	85	E	
Jintai/Jinyuan	437	20	20	E	
Hanchang	220	20	62	N	
Houyue	252	89	120	E	
Shitai	251	110	130	E	
Taijiao	434	50	85	E	
Longhai	1759	40	120	E	
Xikang	260	16	90	E	
Ningxi	953	25	70	E	
TOTAL		1,232	2,359		

Most of these dedicated coal rail networks are in the northern part of the country, transporting the coal from the coal fields to the power stations and steel plants elsewhere in the country.

Figure 2 shows the northern part of China where most of the coal rail networks are located.

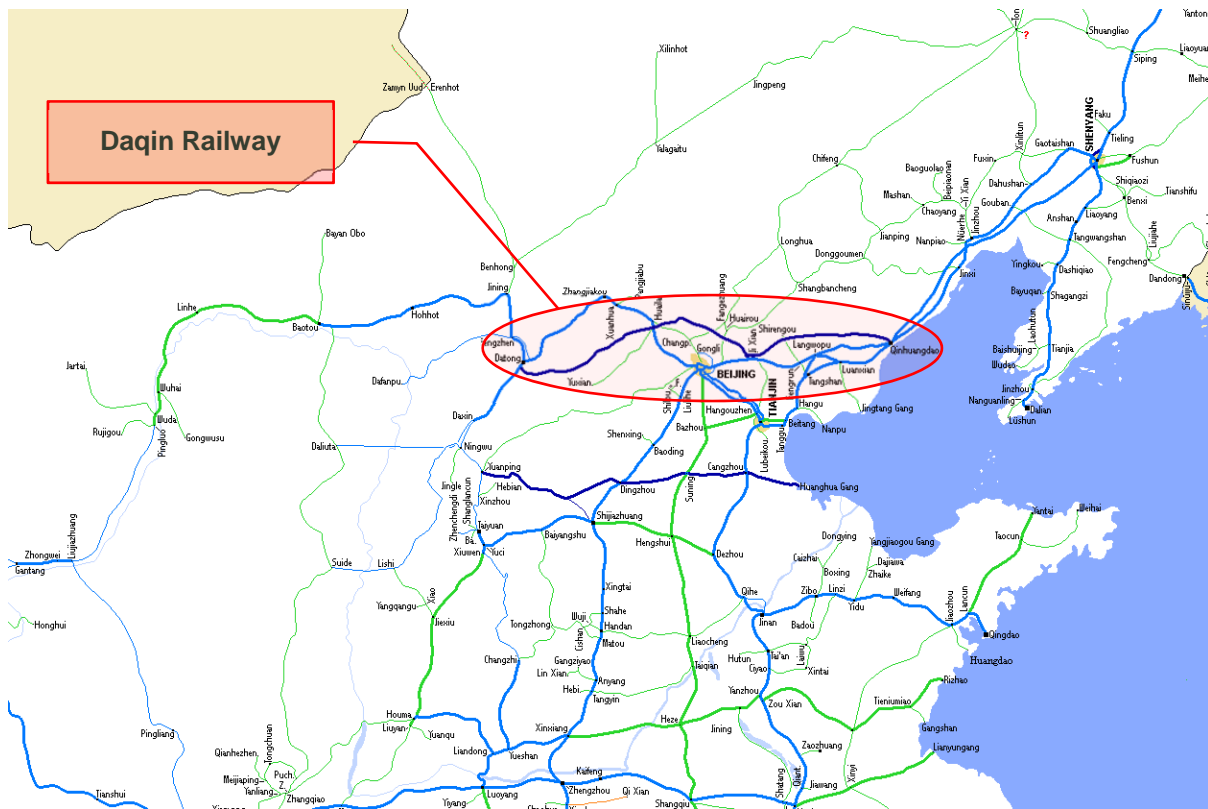


Figure 2: China's Coal Rich Northern Regions and its Rail Networks

The largest coal railway in China is the 653 km Daqing Railway in north China (highlighted above). Its name is derived from its two terminal cities, Datong, a coal mining centre in the Shanxi province, and Qinhuangdao, of Hebei province, on the Bohai Sea.


Unlike most other railways in China, which are run by the Ministry of Railways, the Daqing Railway is operated by Daqing Railway Company Limited, a publicly-traded stock company, listed on the Shanghai Stock Exchange.

The Daqing Railway comprises electrified duplicated track and serves as a major conduit for the transportation of coal produced in Shanxi, Shaanxi and Inner Mongolia to Qinhuangdao, China's largest coal-exporting seaport. From Qinhuangdao the coal is shipped to south China and other countries in Asia. It carries more coal than any other railway line in China and the world.

The line was constructed in two phases between December 1984 and December 1992, with specifications changed from single-track to double-track during construction. The original design capacity was for 100 million tonnes per year, which was reached after ten years. Continuous upgrades involving wider subgrade, 75 kg/m rails, higher capacity wagons and higher speeds, longer trains and more powerful locomotives, radio operation and centralised traffic control, automatic train inspection resulted in capacity currently being quadrupled from the original design.

More than 440 million tonnes of coal were transported on the Daqing line in 2011. Coal transportation represented approximately 86% of Daqing's freight business in 2011; they also carry passengers.

As one can see from Table 1 above, most of the Chinese coal rail networks are electrified. This is not a surprise, since the country is rich in coal resources, and poor in oil. The ability to plan the development of the coal supply chain centrally enabled it to develop the lowest whole-of-life supply



chain irrespective of ownership of parts of the supply chain. Through this central planning it was also able to take into account wider issues such as emissions and supply risks, and was able to do so looking at the long term impact of these on the supply chain.

More than 1.2 billion tonnes of coal was transported on China's main coal rail networks in 2011, of which only 5% was not transported under overhead wires. China's railways have placed greater emphasis on improving energy use efficiency, decreasing energy consumption, and reducing the emissions of greenhouse gases. China, similar to Australia, is an oil poor but coal abundant country which despite its geographic logistical challenges is driving an energy policy of rail electrification based on domestic sources of energy such as coal. This is done to insulate their industry from a possible, as yet undetermined, future energy situation.

Electrification of rail in countries was generally influenced by whether that country had abundant domestic energy reserves such as coal, centralised ownership of the rail and/or supply chain or as a strategy to mitigate any perceived risk based on uncertain supply of oil from overseas sources. After the shocks of the 1973 oil crisis countries such as China and India, abundant in such domestic energy reserves, reviewed their dependence on imported sources of oil and reshaped their energy policy to electrify their rail networks. It also provided them an opportunity to boost their local economy, decrease dependence on imported oil and increase production of domestic energy resources.

China, with its key central planning, was able to develop the lowest whole-of-life supply chain and was also able to take into account wider issues such as emissions and supply risks, and was able to do so looking at the long term impact of these on the supply chain.



4. Market Structure

4.1 Background

As mentioned above, the choice to electrify is often country specific based on a number of factors influencing the often unique situations in those countries. The resultant market structure for electrification and the market for electric locomotives reflect that outcome. This chapter illustrates the outcome from these strategies in terms of the market structure for electric locomotives.

4.2 Current situation

Globally, electric locomotives account for approximately 30% of all locomotives. Currently, there are 47,000 electric locomotives in operation with an average age of 27 years (Schuchmann & Wittke, 2012). Asia, the former Soviet Union, and Western Europe account for almost 84% of the share. Diesel traction continues to dominate in Australia with Australia's electric locomotive fleet accounting for only 2% of global fleet numbers. North and South America also have low levels of electrification and hence represent an insignificant market for electric locomotives. In North America, sales of electric locomotives have been sporadic and predominantly concentrated in passenger transport.

Notwithstanding, nearly 6,200 electric locomotives were manufactured in the past five years. These have mainly been equally supplied by

- (a) large manufacturers such Siemens, Bombardier and Alstom,
- (b) Chinese manufacturers, and
- (c) Other local providers.

There has also been an increase in the number of dual-power locomotives manufacturers. Dual-power is a small but growing market, where the locomotives can operate on both non-electrified and electrified lines. These are typically (Environ, 2012) used by mainline passenger transport operators in the USA and private freight transport operators in Europe.

In comparison there are almost 92,000 diesel-electric locomotives operating worldwide and in rail vehicle manufacture value represents a global market share of more than A\$4.3 billion. In Western Europe, the largest market potential for the sale of diesel-electric locomotives is in Germany and France, each of which accounts for some 15 per cent of the total diesel-electric locomotive fleets in the whole of Europe.

In North America, around 1,000 new diesel-electric locomotives are sold annually (SCI Verkehr, 2003). The demand for diesel-electric locomotives in Australia can be quantified at around EUR 200 million per year; this is similar to the demand of each of South America and Africa (SCI Verkehr, 2003). The total number of diesel-electric locomotives in the Australia/Pacific region is 2,600 locomotives; with 1,871 of these locomotives in operation in Australia (Environ, 2012).

Figure 3 illustrates the current market volumes of electric locomotives. As can be seen, Asia represents the largest market for purchases of new electric locomotives (39%), followed by Western Europe and the CIS. By comparison, the Australia/Pacific region represents 3% of global market share for new electric locomotives.

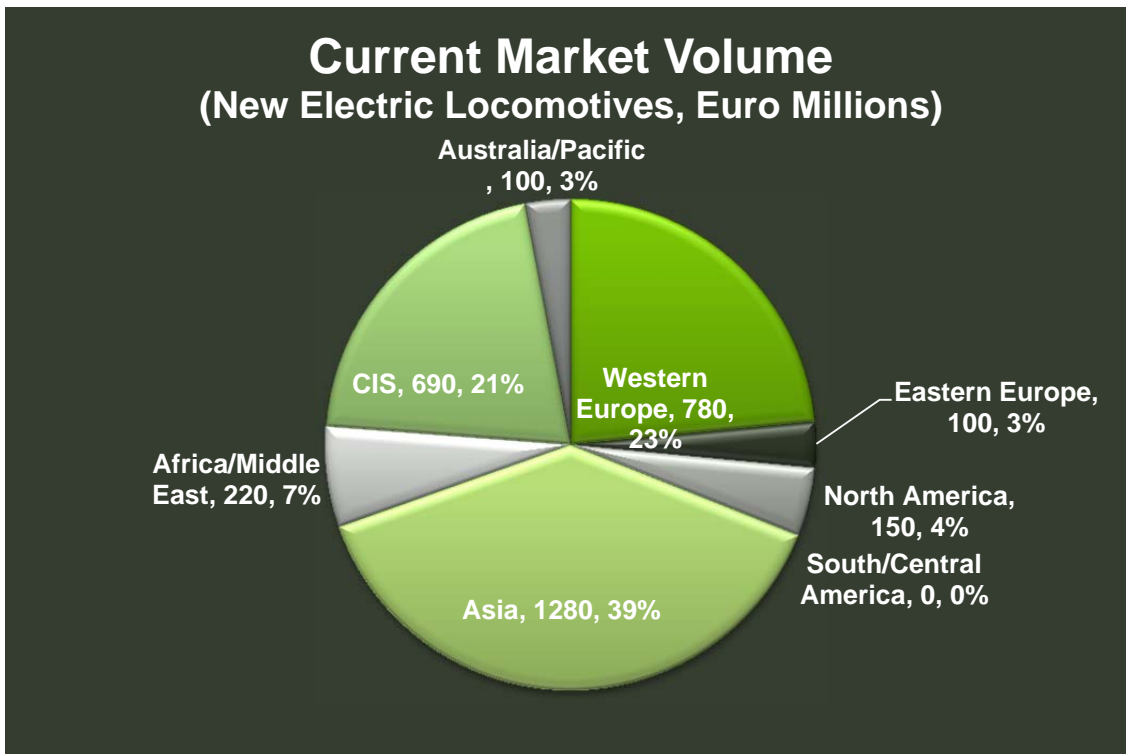


Figure 3: Market volume for new electric locomotives (SCI Verkehr, 2011)

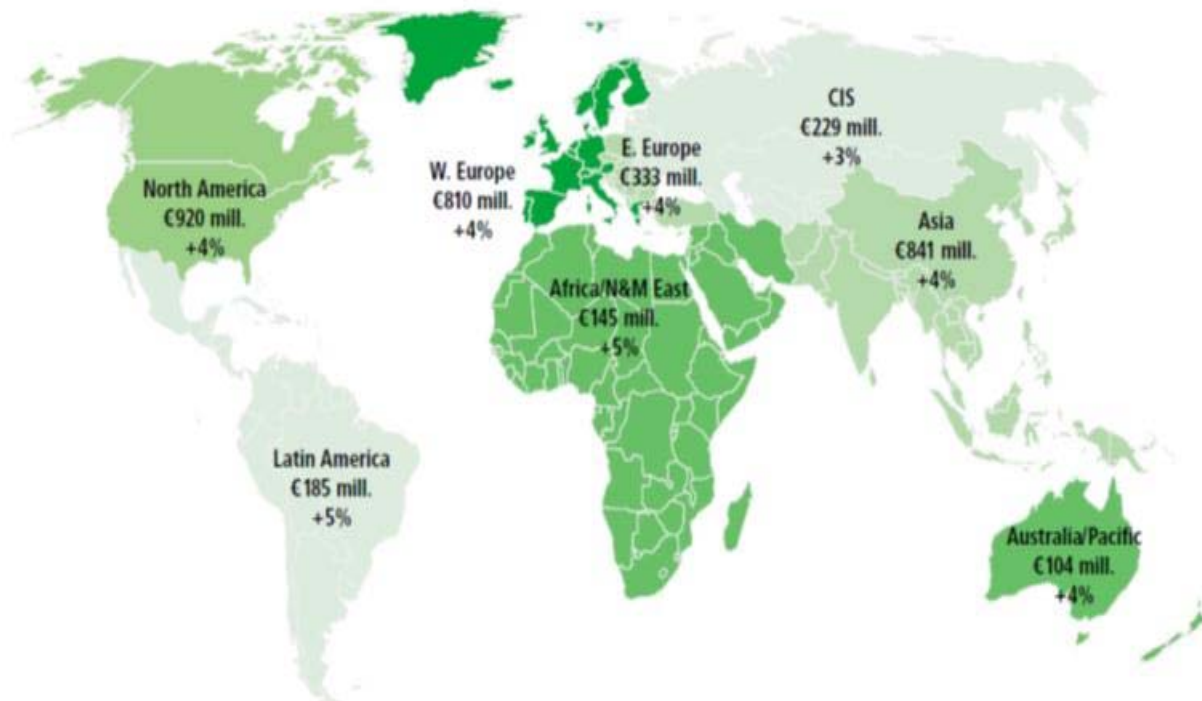


Figure 4: World market for diesel locomotives (SCI Verkehr, 2003)¹

¹ Although potentially dated, the current relativities in the diesel market have not changed significantly.

4.3 Upcoming Electric Locomotive Orders

The market for new electric locomotives is influenced by six key drivers:

1. Fleet Structure (the current size and proportion of installed base)
2. Private Competition (deregulation of the rail freight transport market)
3. Transport Demand (transport volume)
4. Operational Requirements (to comply with changing operating environments)
5. Infrastructure (degree of electrification)
6. Life-cycle costs/technology trends (including operating costs)

These drivers influence behaviour in the following markets resulting in the nominated situations:

4.3.1 Asia

Asia is currently the largest sales region for electric locomotives. The local production capacities are fully utilised as demand has to be covered by local content on a large scale. The focus is on high performance locomotives for freight transport, particularly in China.

The Asian rail network has an average degree of electrification of approximately 34%.

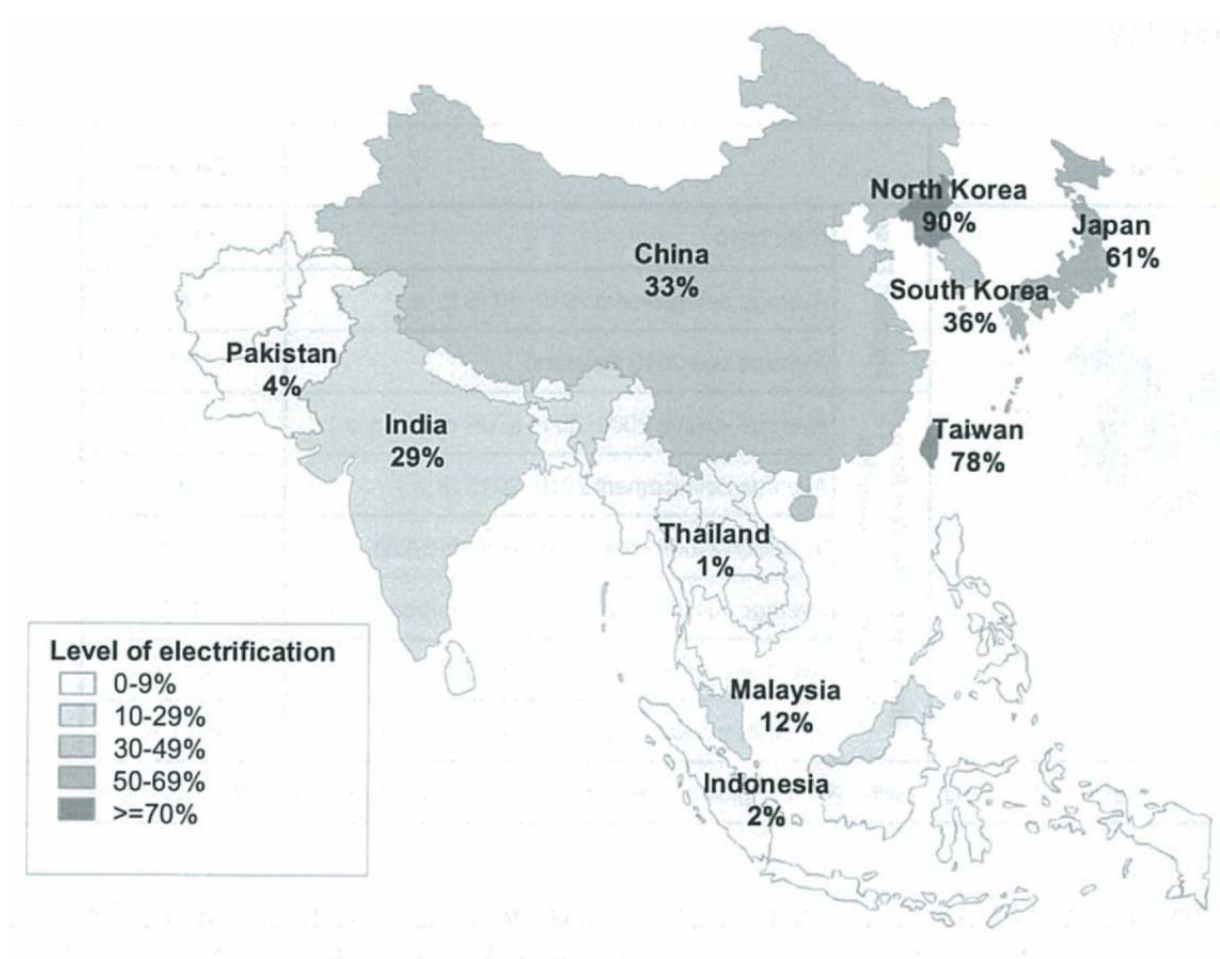


Figure 5: Levels of electrification in Asia (SCI Verkehr, 2011)

It is expected that 38% of the global market supply of electric locomotives will be consumed in this region with China, India and South Korea leading the way. Procurement in China is mainly focussed on high-performance locomotives for freight transport and these locomotives are partly used in multiple locomotive consists (SCI Verkehr, 2011). The rate of electrification in China is progressing fast, with the latest figures from Ministry of Railway showing that 49% of the railway lines are electrified, up 3600km from the previous year. (People's Republic of China Ministry of Railways, 2011)

4.3.2 North America

The North American electric locomotive fleet is very small, with only 200 units. Between 2002 and 2010 no new electric locomotives were procured for the North American market. More recent activity suggests a pick-up in this market, with a large number of dual-power locomotives being delivered for urban passenger rail operators, as well as 70 new electric locomotives for US passenger transport operator Amtrak. In the near future, the US passenger rail operators are expected to acquire more electric locomotives.

The very low level of electrification infrastructure is a key constraint to freight rail operators acquiring electric locomotives.

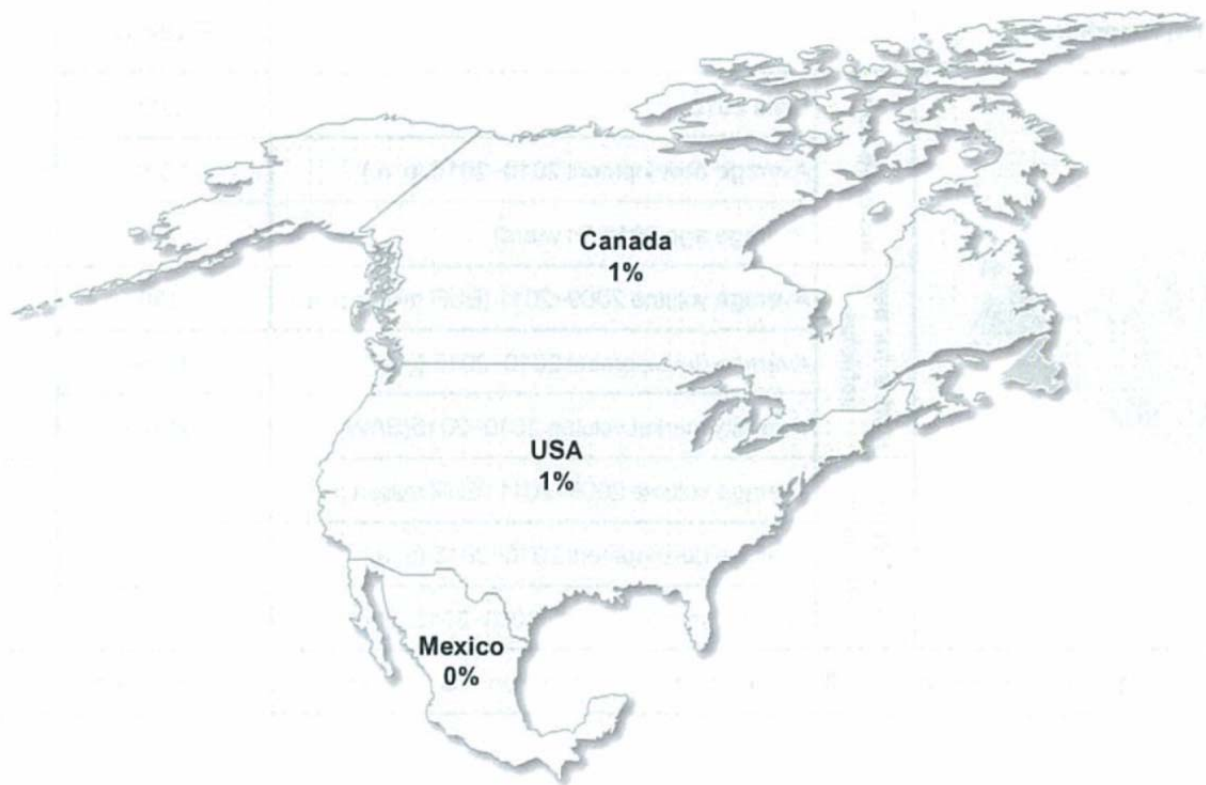


Figure 6: Rail Electrification in North America and Mexico (SCI Verkehr, 2011)

Table 2 below lists some of the orders for electric locomotives in North America.

Table 2: Market development in North America

Country	Type	No of locomotives	Power [kW]	Delivery	Comment
USA	ACS-64	70	6000	2013–2015	Amtrak awarded Siemens a contract to the value of EUR 337 million (USD 468 million) to replace the north-east corridor fleet. The first locomotives are set to be delivered in February 2013.
USA	ALP- 45DP	10	5300	2011–2012	New Jersey Transit ordered ten more ALP-45DP electric locomotives and spare parts amounting to EUR 51.4 million from Bombardier Transit.
CDN	ALP- 45DP	20	5300	2011–2012	Bombardier Transportation will supply 20 hybrid locomotives to L'Agence Métropolitain de Transport in Montreal which can be operated on all the networks of AMT, only parts of which are electrified.
USA	ALP-45DP	26	5300	2010-2011	NJ Transit ordered 26 hybrid locomotives from Bombardier Transportation which can be operated with alternating current and diesel

4.3.3 Africa

Very few countries in Africa have electrified rail networks. The degree of electrification is only 14% overall, with South Africa a notable exception with 43% of its network electrified². To put this in context, 70% of Africa's freight transport occurs in South Africa; with the transport of coal and iron ore dominating rail operations. On the African continent, only South Africa, with a fleet of 2000 electric locomotives, possesses a market for electric locomotives. In addition, South Africa is the only country that operates mixed traction (diesel and electric locomotives in the same consist) on the ore line³.

In South Africa, Transnet Freight Rail (TFR) recorded a 10% increase in rail freight in the year to July 2010 aided by strong growth in export coal and iron-ore traffic. This is helping to drive a \$US 26bn investment programme in South African railways. The major locomotive acquisitions plans are

² The high degree of electrification in South Africa can be traced back to the Apartheid era, when South Africa, with no oil reserves of their own but with an abundance of coal, were subject to international oil embargoes.

³ The rationale behind operating both electric and diesel locomotives in the same consist on the ore line was driven by a combination of a lack of electric locomotives and an electric overhead system in need of an upgrade.

detailed in section 2.2 and 2.3. Large volume orders can be expected in the long term in South Africa with plans to renew 10% of the freight wagon fleet in the coming years (SCI Verkehr, 2011). Electric locomotives were also delivered to Morocco by Alstom, showing further demand in the region for electric locomotives.

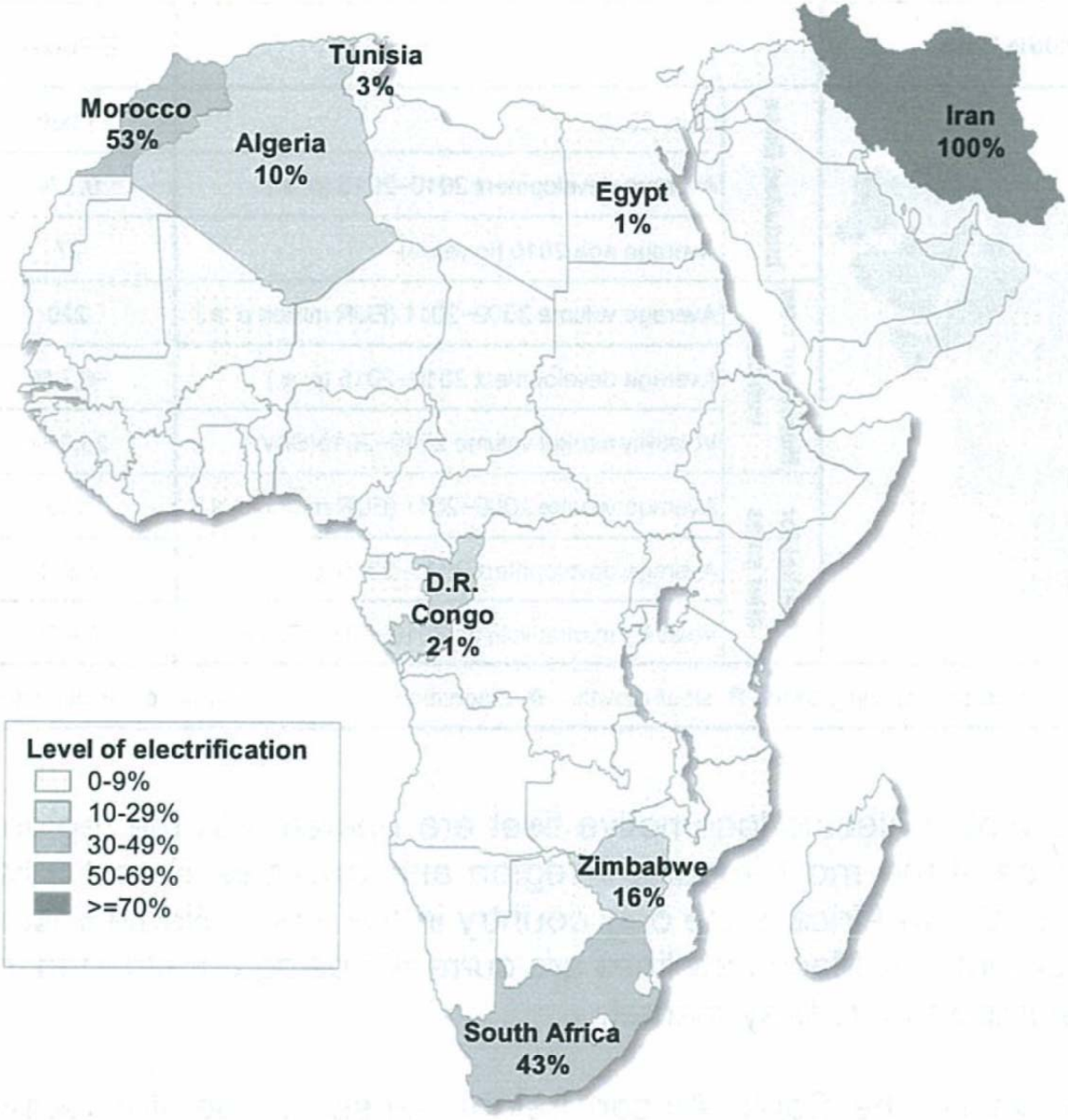


Figure 7: Rail electrification in Africa and Middle East (SCI Verkehr, 2011)

4.3.4 Australia

Rail locomotive market development in Australia is limited due to low levels of electrification infrastructure. Examples of demand for electric locomotives include the award of a contract to Siemens by BHP Billiton Mitsubishi Alliance (BMA) to supply 13 AC traction electric locomotives. QR National (previously part of the larger Queensland Rail) and Pacific National are the other rail operators which use electric locomotives in Australia.

Electrification in the passenger market includes Victoria's \$270m Sunbury Electrification project and \$400m electrification program for Adelaide's rail network in South Australia.

Market analysts SCI Verkehr predict that increasing transport demand, as well as fleet refurbishments and new product platforms will spur an average worldwide growth rate in electric locomotives of around 6% per year up to 2015.

4.4 Heavy Haul Locomotives in South Africa

4.4.1 Diesel locomotives

South Africa operates three different rail gauges - 1067mm, 600mm (rarely used) and 1438mm gauge (Transnet, 2008). Around 22,500 of route kilometres is owned by Transnet Ltd and the freight division, Transnet Freight Rail, haul 180 million tonnes annually consisting of coal, iron ore, manganese, and general freight. Transnet Freight Rail have an operating fleet of more than 3000 active locomotives and 76,000 wagons.

Between May 1981 and 1982, South African Railways (Spoornet) placed one hundred Class 37-000 EMD GT26M2C diesel-electric locomotives in service and after these locomotives were commissioned, the national carrier was not proposing to invest in new diesel-electric locomotives before 2009; nearly three decades later. Electro-Motive Diesel Inc. and Transnet Rail Engineering delivered the first new freight locomotive class 39-200 (GT26CU-3) to Transnet Freight Rail in 2009. (Electro Motive Diesel Media Release, 2009). The remaining 50 locomotives were assembled at the workshops of Transnet Rail Engineering in east Pretoria. Localisation of the production of the locomotive was a key part of the program and announcements have been made in 2012 that EMD is looking at an assembly plant for locomotives in South Africa for the wider market.

In December 2009, General Electric announced a landmark contract with Transnet Ltd to supply Transnet Freight Rail with 143 GE model class 43-000 C30ACi locomotives. According to the contract, ten of the locomotives will be manufactured in Erie and Grove City, USA and 133 will be assembled locally at Transnet Rail Engineering's site in South Africa with kits provided by GE Transportation. The first two locomotives were delivered in February 2011, all 133 locomotives are planned to be in revenue service by the first quarter of 2013 ((GE, 2011). Recently Transnet has also invited tenders for 465 new diesel locomotives.

Table 3: Market development in diesel locomotive in South Africa

Country	Type	Number of locomotives	Power[kW]	Delivery	Comment
South Africa	Diesel Locomotive	143	2200	2013	Transnet press release. Supplier-GE
South Africa	Diesel Locomotive	465	-	2013-2019	Transnet to launch tender, General Freight Division (Anon., 2012)

4.4.2 Electric locomotives

South Africa's most ambitious procurement program for electric locomotive is currently underway, with 55% of Transnet's fleet of 2,100 electric locomotives (now more than 35 years old) planned for replacement. The strategy is intended to decrease the average age of the fleet to less than 20 years by 2025.

The MARS and VENUS consortiums of Mitsui & Co and two African manufacturers, Simbambene Trade & Services Holdings and African Sky Innovative Solutions have been contracted to supply a total of 120 electric locomotives (SCI Verkehr, 2011). In 2011, Mitsui received an order to supply an additional 32 electric locomotives, the electrical systems for these locomotives are being provided by Toshiba, while the bodies are being procured from a local rolling stock manufacturer in South Africa. Table 3 highlights some of Transnet Freight Rail's future plans for electric locomotive acquisition from 2013-2019.

Table 4: Electric locomotive market development in South Africa

Country	Type	Number of locomotives	Power [kW]	Delivery	Comment
South Africa	Dual Voltage	Tender invited for 599	-	<ul style="list-style-type: none"> • First 65 units in 2015 • 130 units delivered each year between 2016 and 2018 • Final 144 entering service in 2019. 	Transnet to launch tender, General Freight Division (IRJ, July 2012). Contract awarded to CSR (Railway Gazette, September 2012)
South Africa	Class 19E-Dual Voltage	112	3000	2013-2019	Richards Bay Coal Line (IRJ, July 2012)
South Africa	Class 15E, 50kV ac	23	4500	2013-2019	Sishen - Saldanha iron-ore corridor (IRJ, July 2012).

4.5 International trade


Nearly 6,200 electric locomotives have been manufactured in the past five years. Two-thirds of these electric locomotives are provided by three global manufacturers –

- Alstom,
- Siemens, and
- Bombardier.

The remaining one third of the electric locomotives is supplied by Chinese manufacturers who have intensified their market share with recent export activities to Kazakhstan, Uzbekistan, and Iran. Transnet Freight Rail has recently awarded a contract to Chinese manufacturer CSR to supply electric locomotives (Railway Gazette International, 2012)

An increasing trend of localisation is evident in Eastern Europe and South Africa. South African orders are awarded on the basis of technology transfer and localisation of content in the order of 55%-65%. EMD has declared intentions of producing locomotives in South Africa to cater to the wider African market. Business Today in South Africa reported that Transnet-built diesel-electric GE locomotives meet 80% of the requirements of QR National and could potentially be one of the world's international suppliers (Smith, 2012)

North America, comprising a standard gauge (1435mm) network, with different safety standards and two dominant locomotive players, GE and EMD, can be considered a closed market and differs greatly in terms of structure and requirements from the market in continental Europe. Generally, locomotives are produced domestically in North America and this also applies to the sale of locomotives to operators in South Africa and Australia with the exception of electric locomotives in Australia.



Siemens are presently the sole supplier of electric locomotives into the Australian market with overseas production provided from their Munich (Germany) facility. Siemens has supplied 3800 class locomotives to QR National and 7100 class locomotives to Pacific National. These locomotives are customised to meet specific requirements of rail operation in Australia and are different to their standard product.

The major suppliers of diesel-electric locomotives in Australian market are EDI Downer and UGL Rail. These manufacturers cater to a broad range of differing requirements within the Australian market – a market which constitutes 9 different gauges, and more than 650 design differences in rolling stock design (Nye, 2012) . There is a push by the Australian rail industry to standardise rail products using RISSB (Rail Industry Safety and Standards Board) national standards driving greater standardisation, lower unit costs, and interoperability between different systems to harmonise the rail industry and make the asset attractive for similar gauge networks.


Currently, the major barrier to the import of standard ‘off the shelf’ locomotives from overseas markets such as South Africa or China are non-compliance with Australian standards including quality, safety, and network specific requirements. The first set of overseas-produced locomotives was acquired by SCT logistics in 2012 from CSR Ziyand (Rail Express, 2012). These locomotives are proposed for use on east-west transcontinental services, and feature customisation to suit Australian requirements such as isolated cab, bogie configuration, and design solutions to minimise noise and vibration. The locomotives were built to Australian standards and comply with Australian rail codes (Rail Express, 2012) .

Not surprisingly, differences in quality, design standards, and safety requirements impose additional costs for locomotives manufactured for the Australian market. Locomotives manufactured overseas comply with international equivalent standards that are comparable to Australian standards but with minor differences e.g. electrical safety, wheel steel, etc. Some rail operators also demand compliance with an additional layer of organisational specific quality requirements that may reduce the attractiveness or viability of importing ‘off the shelf’ standard locomotives from the overseas market.

As can be seen, the locomotives supplied to the Australian rail market are vastly different to the standard product offering. As such the possibility of locomotives being readily produced in one country and exported to another country has its own set of challenges. The transport costs by sea freight add to the capital cost of the locomotives; however due to cheaper overseas labours cost in China the landed cost for new locomotive is still attractive. Shipping a locomotive from Europe is expected to cost in the order of USD200,000 to USD250,000 per unit, including quarantine costs (Private communication, F. H. Bertling Pty Ltd, Sep 2012). Air freight cost for importing locomotives is an option, albeit very expensive at approximately USD1.5 to USD1.6m or USD1.8 to USD1.9m per unit from the Europe or US respectively to Australia. (Private communication, Ruslan International, Sep 2012). The advent of overseas manufacturers in the Australian diesel-electric locomotive market like CSR opens the door for further competition in the Australian domestic market.

4.6 Second-hand market for locomotives

Currently only two freight rail operators in Australia (QR National and Pacific National) and one in New Zealand (KiwiRail) operate electric locomotives. 90% of the total electric fleet in the Australia/Pacific region is operated by QR National and the locomotives are exclusively operated in freight transport. The majority of the currently operated electric locomotives were procured in the 1980s; small quantities were put into operation in the 1990s and the beginning of the 2000s. The average age of this electric locomotive fleet is around 19 years (SCI Verkehr, 2011) .



QR National electric locomotives procured in the mid 1980's have recently been refurbished in a major overhaul program and have been redeployed back into the coal network as 3551 class locomotives. This also includes 3900 class locomotives that have been rebadged as 3551 class locomotives. Transnet Freight Rail (South Africa) operate a dual-mode narrow gauge railway line with consists powered by electric and diesel-electric locomotives. This might be viewed as a potential market for second hand electric locomotives.

The market for second-hand electric locomotives is limited within Australia but recent media reports indicate that 33 retired diesel-electric locomotives from QR National are destined for Transnet Rail Engineering in South Africa for rehabilitation with an eye for further sale in the wider African market (Batwell, 2012). Narrow gauge (1067/1065mm) railways are common in Africa, where great distances, challenging terrain and low funding have made the narrow gauge solution attractive. African countries using narrow gauge, sometimes referred to as Cape gauge (1065mm), include Angola, Botswana, Congo, Ghana, Mozambique, Namibia, Nigeria, Sudan, Zambia and Zimbabwe. Narrow gauge network also exists in Asia in countries such as Indonesia, China and presents a market for second hand diesel locomotives.

Rebuilding locomotives may add a further 15-20 years of service life and many rail operators in Australia deploy this strategy to extract more service life. The QR National 3100 class was rebuilt as 3700 class electric locomotives; some locomotives in TasRail were rebuilt to a different class. Instances of isolated second hand sales to Vietnam, Senegal are also noted but volume of sales is very low.

With increased infrastructure spending in Africa and new mining operations commencing in West Africa, demand for railway is greater than ever before. This emerging African market presents new opportunities for sale of rolling stock and railway products.

Global market for electric locomotives is predominantly concentrated in Western Europe, Asia and the former Soviet Union accounting for almost 84% of the market share. Australia/Asia Pacific and Africa/Middle East account for 10% of the global electric locomotive share. It is expected that 38% of the global market supply of electric locomotives will be consumed in Asia with China, India and South Korea leading the way

South Africa has the highest degree of electrification in Africa with 43% of its network electrified and has recently placed a USD \$400 million order with CSR to supply electric locomotives. South Africa is looking to invest \$US 26bn in South African railways and major acquisition of locomotives are planned in future.

5. Relative efficiency of electric traction

5.1 Technical efficiency

The dynamics of the rail industry within a carbon restricted Australian economy raises a multitude of factors that are critical for delivering an efficient, economic, and maximum capacity railway. The major factors are:

- Capex and Opex evaluation to provide ‘whole of life’ costs
- Efficient use of infrastructure and rolling stock to provide the best possible return on investment
- Total cost to market and time taken in transit
- Reliability of service
- Impact on environment

The total cost of ownership analysis as demonstrated in the QR National business model, constitutes an inherent advantage for electric traction over diesel traction for a service life of 30 years. With recent advancements in technology, initial capital costs for overhead electrification in some cases⁴ has fallen by over 30% since 2004 reducing the costs further for electrification (Winder, 2011).

5.1.1 Power


On a power to weight analysis, electric locomotion is considerably more efficient than diesel locomotion. This characteristic is important when considering bridge loadings, track damage, infrastructure condition, and maximum allowable speed. Further, it is possible to achieve much higher overall horsepower in a similarly sized electric locomotive than in a diesel locomotive. Electric locomotives can deliver as much as 2½ times the tractive power output of an equivalent diesel locomotive (Sheehan, et al., 2009).

Electric locomotives can be designed to consume DC or AC power; either through an overhead contact system (OCS) and collected by a vehicle borne pantograph or through a ground-level third rail system and collected by a suspension mounted shoe. DC systems can directly feed the collected power into the traction motor controllers. AC systems require a large and heavy transformer and rectifier to change the input power into more usable power.

Hence, DC powered rolling stock is typically lighter and simpler, but AC powered rolling stock currently offers greater tractive efforts. The net benefit is that AC locomotives provide higher overall train acceleration, speed, and system capacity. When hauling heavy loads up hills, electric units can make better use of their short-time rating by drawing more power from the overhead supply and thus climb the hill faster. Diesel units are limited to the power of the engine installed. Thus, where a track route involves much hill climbing, then faster timetables (and hence greater slot utilisation) can be run with electric units than with diesel units of similar nominal power.

Light electric locomotives suffer from adhesion limitations – the wheels are prone to spin on slippery rail. Locomotives are typically overpowered at low speeds and cannot realize the full benefit of their nominal horsepower ratings. The greatest benefit is achieved at the mid and high speeds, where it can help trains achieve the posted track speeds more quickly, recover from local slowdowns and generally maintain posted speeds more consistently (Metrolinx, 2010). With electric propulsion, further energy

⁴ Peter Winder from O'Donnell Griffin appears to refer to Victoria's Watergardens to Sunbury electrification project.



savings can be achieved by implementing “Coasting” as the driving strategy (Karim & Tariq Shallwani, 2010). Coasting is recommended for areas where the trains stop frequently as this optimises energy efficiency and reduces noise.

5.1.2 Noise

Electric locomotives are typically quieter as compared to diesel-electric locomotives as they do not carry an internal prime-mover in the form of a diesel engine and instead rely on energy supplied by an off-car electrified traction power supply and distribution system. There is no exhaust noise and less mechanical noise as there are far fewer moving parts. Fewer moving parts add to the reliability of electric locomotives in comparison to diesel locomotives. A study done by Toronto Transit agency, Metrolinx, Canada, suggests that electric locomotives have a better reliability performance than diesel-electric locomotives.

Statutory Australian state and federal noise regulations must be met and complied with by the rail operator in relation to locomotive noise performance. Metrolinx also conducted a study on the noise levels from locomotives and found the noise from electric locomotive to be five to ten decibels lower than from diesel-electric (Karim & Tariq Shallwani, 2010). Electric traction, by virtue of the reasons described, has advantages over diesel traction as it has a smaller impact via reduced noise levels.

5.1.3 Emissions

About 75% of the worldwide diesel electric market is operating under some form of local emission regulation. Emission standards were introduced in the US in 1997 and the United States lead the world in terms of the toughest and most restrictive regulatory environment for locomotives. International Union of Railways introduced emission standards in 2002, the EU in 2004, and they are anticipated to be introduced to Canada in 2012 (Environ, 2012). GE recently revealed its next generation of diesel-electric ‘Evolution’ locomotives that meets the stringent requirements of the US Environmental Protection Agency’s (EPA) “Tier 4” emission standards⁵, which calls for the single-largest emission reduction in the tiered program’s timeline.

Australia currently has no air emission limits for new or re-manufactured locomotives nor are substantive programs in place addressing air emissions from in-service locomotives. With increased coal outputs, freight movements, and an ageing locomotive fleet, emissions are bound to increase. More than 80% of diesel-electric locomotives in the Australian rail industry operate on emission standard performance that can be classified as ‘Pre-Tier 0’ and 0.3% of the fleet meet the requirements of ‘Tier 2’ emission standards (Environ, 2012).

The Australian Railway Association (ARA), together with the Australian Rail Industry Corporation (ARIC), recently undertook a review to guarantee the improvement of rail’s environmental performance. The report, “Environmental Solutions for Freight Rail” has developed a plan of action to partner with the Australian Federal Government to address the higher emissions from the ageing fleet of locomotives and put the rail industry in line with international performance on emissions (Australian Railway Association Inc., 2011). Rail customers increasingly seek information on greenhouse performance in their supply chain and operators with a low level of environmental impact for the task undertaken can potentially have a knock-on effect in increased business.

Even taking into consideration that the electric energy necessary to provide the electric locomotive traction is derived from a coal or oil fired power station, it has been estimated that electric locomotion

⁵ Tier 4 is the most stringent emissions standard. The ‘Tiers’ refer to the allowable levels of emissions.

typically emits 20% and 35% less carbon per passenger mile than a diesel train (Rail Safety and Standards Board, 2007). In a carbon-constrained industry this is going to become a critical issue in the delivery of heavy haul services. In a “Well to Wheel”⁶ fuel efficiency analysis between diesel and electric traction, not surprisingly the highest efficiency and lowest emission was achieved in the United States with electrification when electricity is produced with low and non-carbon sources such as hydro, renewables and natural gas. Efficiency for electric traction was found to be slightly higher than diesel traction on a “Well to Wheel” basis with higher emissions for diesel traction (Hoffrichter, et al., 2012).

Figure 8 shows the well to wheel efficiencies and emissions for electric, diesel and hydrogen traction systems with electricity generation data from 2008.

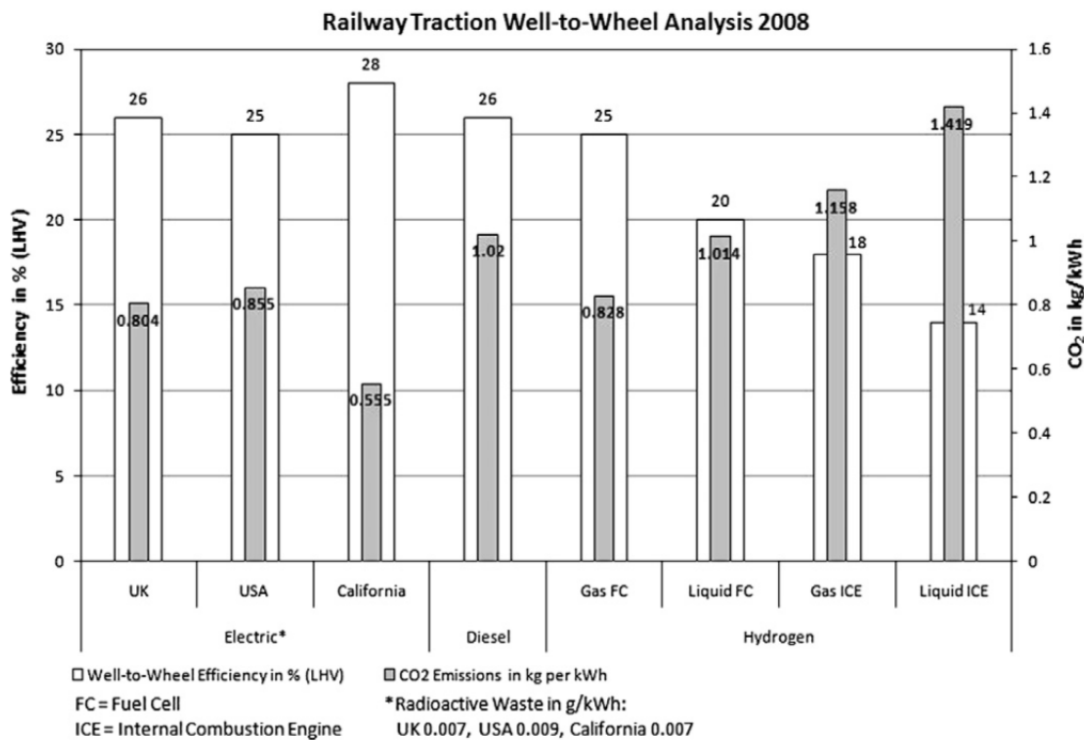


Figure 8: Railway traction well to wheel analysis based on low heating value⁷ (Hoffrichter, et al., 2012)

⁶ A Well to Wheel (WTW) analysis includes the energy use and greenhouse gas emissions at every stage of the process from the original source (well) to energy delivery at the wheels (wheel). It is split into two stages – the well-to-tank (WTT) or fuel cycle stage, and the tank-to-wheel (TTW) or vehicle efficiency stage – allowing the comparison of vehicle drive trains powered by the same fuel.

⁷ Low heating value (LHV) refers to useful calorific value in real world conditions. The approach of using the LHV in WTW comparisons is widely adopted and recommended by Wang (1999), the Department for Environment, Food and Rural Affairs (Defra), as well as the Department of Energy and Climate Change (DECC) (Hoffrichter, et al., 2012).

5.2 Operational efficiency

Studies confirm that one of the major benefits of electrification is the lower operational cost of an electric railway as opposed to a diesel railway (Metrolinx, 2010). The main operational cost benefits are likely to be fuel savings and rolling stock maintenance, with lesser cost savings from crew costs and possibly from improved asset utilisation (Metrolinx, 2010). Electric trains have a high power-to-weight ratio compared with diesel vehicles, which carry their own power sources on board e.g. diesel engine, alternator, and fuel tank. On average, fuel costs tend to be lower for electric vehicles, but if electricity is generated from conventionally expensive energy sources, then the overall operational expenditure could be higher.

Uses of regenerative braking in electric trains further reduces energy demands, noise levels, and wear on mechanical brakes because kinetic energy is recovered and converted to electrical energy without friction. While regenerative braking is possible on diesel-powered trains, electrified trains typically have better regenerative braking performance because energy can be recovered from more powered axles. This electricity can supply in-train loads, such as heating, ventilation and air conditioning (HVAC), lighting, and low voltage power. Excess power can be fed back into the distribution system (OCS or third rail), if that system can accept and use the excess power. Significant advances in energy storage devices have been made such as batteries, ultra-capacitors, and flywheels to collect excess power when it's available and feed it back into the system when required. Some devices can be fitted onto locomotives or can be installed in the form of wayside storage besides tracks.

Assuming a diesel fuel cost of 75 cents per litre⁸, the equivalent cost of 2.93 kW hours of electricity at an assumed rate of \$45 per MWH is less than a fifth of the cost of diesel traction (see Appendix A for equivalence calculations). High upfront capital costs for electrification are offset by reduced daily maintenance activities that typically consist of remote monitoring of the power utility and overhead wires. According to an electrification study done by Toronto Transit agency, Metrolinx, Canada for their entire rail system, the average annual maintenance cost for a diesel locomotive (Tier 4) is estimated to be C\$287,740 whilst an electric locomotive is estimated at C\$247,038 (Metrolinx, 2010). This includes material and labour costs for a 30 year service life. The table below provides a comparison of above-rail operational and maintenance cost between a typical diesel-electric and electric locomotive operation for an assumed 20 mtpa rail system of say 300 km, assuming different input values for diesel and electricity:


Table 5: Comparison of Above Rail Cost per 1000 gross tonne-kilometre (000's GTKM)

Cost	Diesel Operation		Electric Operation	
	\$0.75 per litre	\$2.0 per litre	\$45 per MWH	\$160 per MWH
\$/000's GTKM	3.11	8.23	0.57	1.95

With the use of regenerative braking, and system electrical usage can be further reduced by 5%-20%. Given that electricity costs (as output costs) tend to be more stable than oil prices (as input costs), the operation of an electrified system can be profitable in a foreseeable time after the infrastructure costs have been incurred. Several studies, including a comprehensive U.K. report (Network Rail, 2009), outlined the following benefits of electrification in relation to long-term costs:

- 50% reduction in rolling stock operating costs.

⁸ Current cost to rail operators net of diesel fuel rebate

- 
- 15% reduction in infrastructure operating costs such as track maintenance due to light-weight trains causing less track damage.
 - 3% increase in rolling stock availability
 - 22% reduction in vehicle leasing costs.

Given the fluctuations in diesel fuel prices and dependence on foreign markets for oil, volatility of uncontrollable factors must be taken into account while calculating the operational costs for diesel traction.

Electric locomotives, with a higher power to weight ratio, can deliver as much as 2½ times more tractive power output than an equivalent diesel locomotive with lesser track damage. Thus electric units with higher speed and better acceleration can provide faster timetables and greater slot utilisation increasing the capacity in the system.

Electric locomotives are more reliable; five to ten decibels quieter than diesel and at the rolling stock level do not emit greenhouse gases. In a 'Well to Wheel' study done in the UK and US, electric traction was found to emit 20% less CO₂ than diesel traction with similar efficiencies.

The major benefit of electric traction as opposed to diesel traction is the lower operational cost- likely to be fuel savings and rolling stock maintenance expenses. Use of regenerative braking in electric trains further reduces energy demands and can provide a saving of 5%-20%. Studies from Network rail, UK (2009) detail the major benefits of electrification in relation to long term costs such as:

- ***50% reduction in rolling stock operating costs.***
- ***15% reduction in infrastructure operating costs due to light-weight trains causing less track damage.***
- ***3% increase in rolling stock availability.***
- ***22% reduction in vehicle leasing costs.***



6. Technological development opportunities for electric traction

An important feature of the electric traction supply chain is that the energy can be sourced from various sources of energy—coal/gas-powered stations, hydro, nuclear or alternative/renewable sources of energy. At present, renewable energy contributes around 7% to Australia's electricity generation, with 4.7% sourced from hydroelectricity. Renewable energy production increased at an average rate of 2% a year in the five years from 2003–04 to 2008–09. In 2008–09, renewable energy production increased by 6%. While still a small contributor, solar electricity experienced the strongest growth in 2008–09, increasing by 40% (arguably from a very low base) (Department of Resources, Energy and Tourism, 2011).

A range of policy measures have been introduced in Australia to support the uptake and development of renewable energy. These measures include the Australian Government's Renewable Energy Target (RET). The expanded RET began on 1 January 2010, committing the Australian Government to a target of 20 per cent of Australia's electricity supply coming from renewable energy sources by 2020 (Department of Resources, Energy and Tourism, 2011).


As we can see from above statistics, the grid-connected electricity generation industry reduces emissions by developing large scale renewable energy sources, the advantage of electric trains over diesel trains will increase.

Other proposed technical advances for heavy-rail traction drives are to use high voltage power switches in innovative configurations to eliminate the need for heavy and expensive transformers in future heavy-rail traction drives operating directly from 25-kV AC catenary supplies. This has the potential to reduce the weight of the locomotive and reduce maintenance costs (Stemmler, 2000).

Recent advancements in AC traction technology for diesel-electric locomotives have led to the achievement of performance benefits of AC traction previously only evident on electrified 25kV AC networks. There are minor technical advantages for enhanced inverter operating characteristics and efficiency for diesel-electric locomotives as opposed to electrics with field control of synchronous alternator making it possible to adjust the DC link voltage supplied to the traction inverters more conveniently than in the catenary supply units (Jahns & Blasko, 2001).

Hybrid locomotives are an emerging alternative to diesel engine or electricity provided through a connection to the electric grid (third rails or overhead lines) and utilizes stored energy from batteries. GE report that their engineers are designing a Hybrid diesel-electric locomotive that will capture the energy dissipated during braking and store it in a series of sophisticated batteries. That stored energy can be used by the crew on demand—reducing fuel consumption by as much as 15% and emissions by as much as 50% compared to most of the freight locomotives in use today (GE Transportation, 2011). This technology may also be applicable to electric locomotives in the future.

On-board energy storage devices are being investigated; it may take the form of batteries, flywheels and super-capacitors. Trials have also been conducted for on-board flywheel storage and Alstom ran an experimental diesel train Lirex in 2002 that used flywheel to accelerate trains from station. While on-board technology is still to be mastered, stationary storage is more mature and flywheel storage was first trialled in London Underground and local trains in Cologne in 2001 (Jackson, 2001). Ureco manufacture 100kWh flywheels and the first commercial system was implemented in New York State Transit Authority. Pentadyne Energy Corporation installed the flywheel storage system in NYC, Paris



and Lyon stations (www.railway-technology.com, n.d.). An electrified network provides more opportunities for energy savings as stationary flywheel storage technology is more advanced as compared to batteries and super-capacitors.

With the Australian Government's Renewable Energy Target (RET) expanding to 20% from the current 7% by 2020, the grid-connected electricity generation industry reduces emissions by developing large scale renewable energy sources. This will reduce the greenhouse gas emissions for electric traction and the advantage of electric trains over diesel trains will increase.

With the proposed developments in solid state electronics that may replace the heavy transformers in electric locomotive, advancements in on-board energy storage devices and the application of wayside flywheel energy storage offers advantages for electric traction to further reduce operating costs.

7. Supply chain risk


7.1 Impact of peak oil production and dislocation

A more significant impact on the supply chain is the continued, uninterrupted supply of energy. Traction choice options between diesel and electric locomotive traction is largely based on consideration of relative capital costs. Long term forecasts predict increasing demand for transportation fuel owing to increased freight transportation. In a report produced by Australia's CSIRO, 'Fuel for Thought', it is stated that if there is a near-term peak in international oil production and Australia is seen to be more vulnerable due to its relatively high fuel use and declining domestic reserves (CSIRO, 2008).

"Peak Oil" is defined as "the point in time when oil production reaches its annual maximum rate, after which the annual production rate declines each year" (CSIRO, 2008). Numerous studies over the years have pointed to different projected dates for peaking of world conventional production of mineral oil but there is uncertainty as to when it will happen. There is no disagreement though that mineral oil reserves are finite and the oil embargo in 1974 compelled certain countries like India and the Netherlands to adopt electrification of rail on a massive scale. The majority of the studies reviewed for this paper estimate peak of world mineral oil production clustered between 2004 and 2020. Table 5 shows projection for world oil production peaking, according to several studies (Hirsch, et al., 2005).

Table 6: Projections of world oil production peaking

Projected Date	Source	Year study was undertaken
2006-2007	Bakhitari	2004
2007-2009	Simmons	2003
After 2007	Skrebowski	2004
Before 2009	Deffeyes	2003
Before 2010	Goodstein	2004
Around 2010	Campbell	2003
After 2010	World Energy Council	2003
2010-2020	Laherrere	2003
2016	EIA (Nominal)	2000
After 2020	CERA	2004
2025 or later	Shell	2003
No visible Peak	Lynch	2003



Peaking of world production of mineral oil presents rail operators with an unprecedented risk management problem. With Australia's dependence on oil based fuels for freight transport and increased reliance on overseas markets for oil supply, any shortfall in the international supply will increase the price of fuel oil dramatically. In the event of peak oil, transport intensive activities such as mining would be most vulnerable and an oil-dependent freight network will be constrained in the movement of coal from pit to port. With primary global energy demand to increase by 50% by 2030 and demand for coal predicted to rise to supply energy for the developing economies, electrified rail network has strategic advantages over oil based transportation. Any increase in international demand for coal can be met in an electrified rail network that may otherwise face disruption in a peak oil situation on oil based transport network. In the future scenario of world oil production decline, the costs of preparing too early has to be weighed against the cost of not being ready on time.

The status quo in oil supply chain is being rapidly impacted by a variety of forces; international energy outlook 2011 predicts the demand for liquid fuels in transport sector will grow more rapidly than in any other sector. This presents critical supply and demand issues and in "constrained supply", regardless of the cause of disruption, will profoundly affect economic, environmental, energy and national security realities (Drake, et al., 2009).

7.2 Benefits of an electrified system


An electrified rail system has a significant long term advantage in dealing with issues such as the shortage of supply of a particular fuel source. This is because the electrified network is provided for by electricity from power stations that can be coal fired (as many are currently in Queensland), gas, hydro, or nuclear. Future shortages in one or the other fuel sources will drive investments in other power stations, or conversion of existing power stations.

A diesel network on the other hand relies on the continued supply of diesel fuel for the operation of the trains. Any disruption to the supply, made more possible as a result of the peak oil situation, will have significant impact on the continued supply of coal from the Blackwater and Goonyella Systems to the world market.

7.3 Alignment of risks

The provision of coal-fired power supply to the electric overhead in the Blackwater and Goonyella Systems is necessary to support export of coal to satisfy global demand for coal in overseas (coal-fired) power stations. It is highly improbable that a situation might arise whereby the continuation of coal fired power to these rail systems is replaced with alternative fuel sources unless this is accompanied by similar market changes in the end market of the coal being transported on these systems, the ultimate objective of the rail systems in question.

This alignment of risk is a significant advantage compared with the risk associated with the supply of diesel fuel for the locomotive fleet. In fact, a heightened risk of diesel fuel supply interruption is more likely to occur in a high cost energy market, when the demand for other sources of energy including coal is also high. In some instances, overseas power stations reliant on oil as their fuel source will need to revert to alternative fuel sources including coal. A conversion of oil-fired power station to coal-fired is technically feasible.



In the event of a continued disruption of the supply of fuel oil, the demand for coal is likely to be strong. This will not bide well for a diesel powered coal supply chain servicing the coal export market. The inability to service the market at such lucrative times is likely to be very costly to the coal export industry. An electrified supply chain would in that situation have a significant competitive advantage and is likely able to gain market share from other supply chains.

Majority of peak oil studies referred to for this report indicate that the oil peak will occur between 2004-2020.

With Australia's dependence on imported oil, any disruptions to the oil supply chain has the potential to increase the cost of oil dramatically thereby jeopardising the feasibility of oil based rail freight transport.

International energy outlook 2011 predicts the demand for liquid fuels in transport sector will grow more rapidly than in any other sector. This presents critical supply and demand issues and in "constrained supply", regardless of the cause of disruption, will profoundly affect economic, environmental, energy and national security realities.

An electrified rail system has a significant long term advantage because the electrified network is provided for by electricity from power stations that can be coal fired (as many are currently in Queensland), gas, hydro, or nuclear. Future shortages in one or the other fuel sources will drive investments in other power stations, or conversion of existing power stations.

An alignment of risk with electric traction is a significant advantage compared with the risks associated with the supply of diesel fuel for the locomotive fleet. In the event of a diesel supply interruption in a high cost energy market, the demand for coal is likely to be strong. An electrified supply chain would in that situation have a significant competitive advantage and is likely able to gain market share from other supply chains.

8. Concluding Comments

8.1 Market for electric locomotives

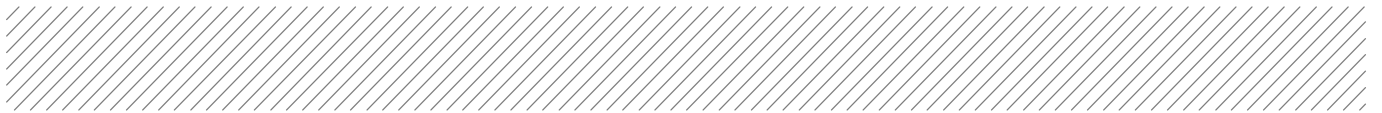
As mentioned in above, the market for new electric locomotives is influenced by six key drivers:

1. Fleet Structure (size of installed base)
2. Private Competition (deregulation of the rail freight transport market)
3. Transport Demand (transport volume)
4. Operational Requirements (to comply with changing operating environments)
5. Infrastructure (degree of electrification)
6. Life-cycle costs/technology trends (including operating costs)

The implications for QR Network's Blackwater and Goonyella Systems are summarised in the table below. The perceived positive implications for the electric hauled option are shown in green, and the negative implication shown in red.

Table 7: Impact on Blackwater and Goonyella systems

Key Driver	Blackwater System	Goonyella System
Fleet Structure (size of installed base)	A significant amount of diesel locomotives prevalent in the pool. Some mines cannot be serviced by electric locomotives (e.g. Rolleston and Minerva). Rolleston spur is proposed to be electrified.	Predominately electric locomotives, however with opening up of operations to Abbot Point will see proportion of diesels increase
Private Competition (deregulation of the rail freight transport market)	Above rail competition evident through Pacific National. Below rail main line under control of one entity.	
Transport Demand (transport volume)	Demand for rail expected to increase, however some of this may come from mines further afield, not (yet) connected to the electric overhead system.	Demand for rail expected to increase, however some of this will be diverted to Abbot Point.
Operational Requirements (to comply with changing operating environments)	Expectations of increased stringent emissions control expected to put pressure on diesel hauled operations.	



Key Driver	Blackwater System	Goonyella System
Infrastructure (degree of electrification)	Fully electrified, except for the spur line to Rolleston (Rolleston spur planned to be electrified), and the connection to Minerva (Currently railing small tonnes from the Springsure Branch).	Fully electrified, however connection with the Newlands System for operations to Abbot Point is not electrified.
Life-cycle costs/technology trends (including operating costs)	Recent significant investments in electric overhead sub-stations have increased the costs due to low utilisation. Overall, the case for electric trains is still positive if there are sufficient volumes and market share.	Most of the electric assets have been depreciated to some extent, reducing unit costs to users. Overall, the case for electric trains is very positive if sufficient volumes and market share continues.
Overall Comment	Generally positive for the Blackwater System, however due to the high installed base of diesel locomotives, recent new investments in assets, combined with low electric utilisation and current AT5 tariff structure, results in a challenging position for rail operators to bias electric over diesel locomotive.	Quite positive for the Goonyella System, however potential for erosion due to the diversion of traffic to Abbot Point.

8.2 Risk

The peak oil situation described in Section 7.1 above has the potential to be a threat to the coal supply chain powered by diesel fuel. The Blackwater and Goonyella Systems are in a unique position to capitalise on the potential situation if and when disruptions to the supply of diesel fuel threatens the continued operation of diesel hauled trains. In the future scenario of world oil production decline, the costs of preparing too early has to be weighed against the cost of not being ready on time.

Another risk lurking in the coal supply chain is the increase in emission regulation. North American and European locomotives already comply with much more stringent regulations. The application of more stringent measures will significantly impact on the current fleet of diesel locomotives.

Under the new Australian federal carbon tax laws, the power generation industry will progressively move to reduce emissions by developing renewable energy sources and rail electrification is poised to play an important role in the commercial, social and environmental “scenario”. Currently, the supply of diesel fuel for rail transport and mining is exempt from excise tax but this exemption can be withdrawn in future making the diesel traction an unattractive mode of rail freight transport with increased operational costs.

The present drive towards cleaner, more energy-efficient and more sustainable transport also applies to the heavy haul rail industry. With energy a major component of the operating costs, a more economical use of energy would be a distinct advantage.



8.3 A way forward for Queensland

The significant coal rail development in China illustrates what a centrally controlled development of a major supply chain can yield. The electrification of the Blackwater and Goonyella systems back in the 70's and 80's occurred under circumstances of partially central coordination/ownership under Queensland Government Railway. The advent of fractured ownership and open competition makes whole-of-supply chain decisions much more difficult: commercial contracts in place between various parties will all have to be renegotiated.

Notwithstanding these constraints, the desire remains to strive for lower whole-of-supply chain costs. The estimation of the Total Cost of Ownership undertaken by QR Network appears to suggest that the full electric option would yield a significant benefit for the entire supply chain. We do not dispute that. The difficulty is in getting to that position of full electric under the circumstances all the Blackwater system users find themselves.

One possible solution would involve commercialising the arbitrage position currently in existence but not able to be captured by QR Network through the regulatory regime. The possible solution involves the buying back of a significant number of diesel-electric locomotives currently operating in the Blackwater system and replacing them with electric locomotives to users of the system. This can be done through an operating lease. The net benefit is that existing users are no worse off, QR Network's risk of stranded electric assets is significantly reduced, and rail operators possibly have their balance sheets improved by taking assets off their balance sheet.

9. Bibliography

- Anon., 2012. *King and Sons*. [Online]
Available at: http://www.kingandsons.co.za/news_view.aspx?id=571
- Australian Railway Association Inc., 2011. *Environmental Solutions for Freight Rail*. [Online]
Available at: <http://www.ara.net.au/publications-list?sort=date&search=&issue=0&page=2>
- Batwell, J., 2012. *International Railway Journal*. [Online]
Available at: <http://www.railjournal.com/index.php/africa/qr-national-locomotives-shipped-to-south-africa.html>
- Clarke, J. & Cheung, R., 2012. *China Coal Sector Overview*, s.l.: BNP Paribus Securities.
- CSIRO, 2008. *Fuel For Thought: The future of transport fuels: challenges and opportunities*, Newcastle: s.n.
- Department of Resources, Energy and Tourism, 2011. *Energy in Australia*, Canberra: Australian Government.
- Drake, A., Bassi, A. M., Tennyson, E. L. & Herren, H. R., 2009. *Evaluating the Creation of a Parallel Non-Oil Transportation System in an Oil Constrained Future*. Washington, Transportation Research Board, p. 21.
- Electro Motive Diesel Media Release, 2009. *Electro Motive Diesel*. [Online]
Available at: http://www.emdiesels.com/emdweb/company/more/032609_GT26CU.html
- Environ, 2012. *Locomotive Emissions Project*, Sydney: s.n.
- GE Transportation, 2011. *GE Transportation*. [Online]
Available at: <http://www.getransportation.com/rail/rail-products/locomotives/hybrid-locomotive.html>
[Accessed 14 September 2012].
- GE, 2011. *GE Transportation*. [Online]
Available at: www.getransportation.com
- Hirsch, R. L., Bezdek, R. & Robert Wendling, 2005. *Peaking of World Oil Production: Impacts, Mitigation, & Risk Management*, s.l.: United States Government.
- Hoffrichter, A., Miller, A. R., Hillmansen, S. & Roberts, C., 2012. Well-to-wheel analysis for electric, diesel and hydrogen traction for railways. *Transportation Research*, pp. 28-34.
- Indian Railways Service of Mechanical Engineers, 1999. *Economies of Traction Diesel vs. Traction*, s.l.: s.n.
- Jackson, C., 2001. *Railway Gazette*. [Online]
Available at: <http://www.railwaygazette.com/news/single-view/view/high-speed-flywheels-cut-energy-bill.html>
[Accessed 14 September 2012].
- Jahns, M. T. & Blasko, V., 2001. *Recent Advances in Power Electronics Technology for Industrial and Traction Machine Drives*. s.l., PROCEEDINGS OF THE IEEE.
- Karim, D. M. & Tariq Shallwani, 2010. Toward a clean train policy: diesel versus electric. *The Journal of Policy Engagement*.

Metrolinx, 2010. *Go Electrification*. [Online]

Available at: http://www.gostransit.com/electrification/en/current_study/updates.aspx

Network Rail, 2009. *Network RUS: Electrification*. [Online]

Available at:

http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CCAQFjAA&url=http%3A%2F%2Fwww.networkrail.co.uk%2Fnetworkrus_electrification.pdf&ei=9ilXUMH2POeviQfypYHoAQ&usq=AFQjCNGfVuc2LYM3PBI305IqC7Tb3-qNTw

Nye, B., 2012. *Australian Railway Association Update*. Newcastle, Informa.

People's Republic of China Ministry of Railways, 2011. *2011 Railway statistical bulletin*. [Online]

Available at: http://www.china-mor.gov.cn/zwzc/tjxx/tjgb/201204/t20120419_31155.html

[Accessed 24 September 2012].

Rail Express, 2012. *Rail Express*. [Online]

Available at: <http://www.railexpress.com.au/archive/2012/may/may-2nd-2012/top-stories/sct-welcomes-csr-locos>

Rail Safety and Standards Board, 2007. *Traction Energy Metrics*. [Online]

Available at: http://www.rssb.co.uk/SiteCollectionDocuments/pdf/reports/Research/T618_traction-energy-metrics_final.pdf?bcsi_scan_294638643E643F25=tfKRyM2bmEdFHCvZ+nsO9dV1IkVyAAAA/Z6+Qw==:1

[Accessed 14 September 2012].

Railway Gazette International, 2012. *Railway Gazette International*. [Online]

Available at: <http://www.railwaygazette.com/news/freight/single-view/view/csr-zhuzhou-wins-south-african-locomotive-order.html>

[Accessed 17 September 2012].

Schuchmann, T. & Wittke, K., 2012. Electric Locomotive Market Primed For Growth. *International Railway Journal*, March, p. 2.

SCI Verkehr, 2003. *Worldwide Rail Market*, Cologne: SCI Verkehr.

SCI Verkehr, 2011. *The World Market For Electric Locomotives*, Hamburg: SCI Verkehr.

Sheehan, P., Jolly, R. & Mountain, B., 2009. *Paper 8: Powering Rail: Electrification and Emissions Intensity*, Brisbane: s.n.

Smith, N., 2012. *Business Today*. [Online]

Available at: <http://www.bdlive.co.za/articles/2012/05/17/sa-poised-to-supply-australia-with-heavy-haul-locomotives>

Stemmler, H., 2000. *State of the art and future trends in high power electronics*. Tokyo, IEEEJ International Power Electronics Conference.

Transnet, 2008. *Railway Transportation in South Africa*, s.l.: s.n.

Winder, P., 2011. *Rail electrification's role in a carbon constrained future*. [Online]

Available at: <http://www.railexpress.com.au/archive/2011/july/july-20th-2011/other-top-stories/rail-electrification2019s-role-in-a-carbon-constrained-future>

www.railway-technology.com, n.d. [Online]

Available at: <http://www.railway-technology.com/contractors/electrification/pentadyne/>

[Accessed 16 September 2012].

Appendix A

Calculations

Energy equivalence between electricity and diesel

Table below represents efficiency chains for diesel and electric hauled trains

Diesel Traction		Electric Traction	
Stage	Efficiency %	Stage	Efficiency %
Oil Refining	93	Coal Refining	98
Fuel Handling and storage	96	Generation	32
Idling and Leakage	97	HV Transmission	98
Diesel engine including auxiliaries	37	132/25 kV Transformer	99
Loco traction equipment	75	25 KV System	98
Weight Penalty	78	Loco traction equipment	76

Source: *Well to wheel analysis for electric, diesel and hydrogen traction for railways, Hoffrichter et al, 2012*

To obtain equivalent energy consumption at the point of purchase for the railway operator, we have

$$\text{Diesel traction efficiency} = 0.96 \times 0.97 \times 0.37 \times 0.75 \times 0.78 \times 100 = 20.2\%$$

$$\text{Heat energy in one litre of fuel} = 38.6 \text{ MJ}$$

$$\text{Or } \frac{38.6 \times 10^6}{10^3 \times 3600} = 10.72 \text{ kWh}$$

$$\text{Energy available for traction} = \frac{10.72 \times 20.2}{100} = 2.16 \text{ kWh per litre}$$

$$\text{Electric traction efficiency} = 0.99 \times 0.98 \times 0.76 \times 100 = 73.7\%$$

To obtain 2.16 kWh output of electric traction we would require an input from the supply of

$$\frac{2.16}{73.7} \times 100 = 2.93 \text{ kWh}$$

For equivalent performance of trains working on the same schedule 1 litre of diesel fuel translates into 2.93 kWh of electric energy.

For a sample freight task of 6Mtpa over 250 km with empty wagons and a ruling grade of 1 in 80, a typical fuel consumption of 0.0041 litres per trailing gross ton km can be assumed.

Tare wagon - 21 tonnes

Gross weight - 106 tonnes

Net weight- 85 tonnes

Forward trip-

$$\frac{6,000,000}{85} \times 106 \text{ tonnes} = 7,482,353 \text{ tonnes}$$

Return trip-

$$\frac{6,000,000}{85} \times 21 \text{ tonnes} = 1,482,353 \text{ tonnes}$$

Total gross tonnage per annum = 8,964,706 tonnes (excluding weight of locomotives)

Fuel consumption per annum = 8,964,706 x 250 x .0041 = 9,188,124 litres and

Equivalent electricity consumption per annum = 9,188,124 x 2.93 = 27 GWh.



Aurecon Australia Pty Ltd

ABN 54 005 139 873

Level 14, 32 Turbot Street
Brisbane QLD 4000

Locked Bag 331
Brisbane QLD 4001
Australia

T +61 7 3173 8000

F +61 7 3173 8001

E brisbane@arecongroup.com

W arecongroup.com

Aurecon offices are located in:

Angola, Australia, Botswana, China,
Ethiopia, Hong Kong, Indonesia,
Lesotho, Libya, Malawi, Mozambique,
Namibia, New Zealand, Nigeria,
Philippines, Singapore, South Africa,
Swaziland, Tanzania, Thailand, Uganda,
United Arab Emirates, Vietnam.