QLD COMPETITION AUTHORITY

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September 17, 2012

John Hall
Chief Executive Officer
Queensland Competition Authority
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Dear Mr Hall,

Sustainable Electric Traction Pricing – Draft Amending Access Undertaking (DAAU)

Bombardier Transportation has reviewed the Queensland Competition Authority's ("QCA") draft determination regarding QR Network's DAAU for Sustainable Electric Traction Pricing and we have a number of comments that we would like the QCA to consider when composing your final determination.

1. State-of-the-art electric locomotive technology

1.1. Development of locomotive propulsion systems

The previous 20 years have demonstrated a renewed emphasis on the continuous development and improvement of power electronics, resulting in the demonstrated superiority of power electronics and widespread utilisation of asynchronous traction motor (AC) propulsion on all types of locomotives.

This is best demonstrated by the Swiss Loco 2000s. During the 1990s, the Swiss Loco 2000s were the first mainline locomotives to utilise the high voltage 4,500V gate turn-off (GTO) power switching semi-conductors. This innovation made it possible for Bombardier to install a power at the wheels of up to 7,000kW (9,380hp) on a four-axle locomotive, i.e. 1,750 kW (2,345 hp) per powered axle.

Soon after the development of the Loco 2000, the WAP-5 and WAG-9 locomotives were developed simultaneously and are equipped with this propulsion technology. The power conversion concepts and circuit topologies used on these Indian Railway locomotives are now an industry standard for locomotives running under AC catenaries (15 kV, 16.7Hz and 25 kV and 50Hz respectively).

Further technological developments were located in the semi-conductor switching devices - changing from the GTO-thyristor to the IGBT-transistor. This new device allows more compact converter designs, lower weight and higher overall power efficiency. Today, AC propulsion technology is used on practically all new high power locomotives, even on multi-system locomotives which operate on all four major European catenaries, i.e. 25 kVAC, 15 kVAC, 1.5 kVDC and 3 kVDC respectively.

1.2. Latest electric locomotive development – The TRAXX Platform

The TRAXX locomotive platform was developed as a standard locomotive family to meet the new requirements of train operators on today's liberalised trans-European rail network. The TRAXX platform is derived originally from the large series of >400 German freight locomotives BR 185. To date, more than 1,600 TRAXX locomotives have been sold and more than 1,400 units are in revenue service. The TRAXX locomotives have been adapted to the European infrastructure and have four axles with 21- 22 tons per axle. They are used for both freight and passenger services, hauling heavy 3,300 tonne train loads from Germany to over the Swiss Alps on 27‰ (1:37) to Italy, see photo 1. Further, these locomotives have lately proven their hauling capability with by starting trains with more than 3,700 tons on 6 ‰ (1:167) grades with a single locomotive.

The typical traction concept for freight in Europe is to use a single four-axle electric locomotive with the heaviest possible train load. Due to congestion with heavy traffic, the mandatory line speeds given by the network are typically between 80-120 km/h. This necessitates the requirement for a high power at the wheels of 5,600 kW (7,500 hp). These freight trains connect important hubs and operate increasingly long hauls of up to 1,000 km and more. They operate on typically fixed time schedules.

A further development over the last years has been to install a small diesel engine into the electric locomotives. This is the case with the new generation TRAXX AC3 which was first exhibited at the Transport Logistic fair in Munich, May 2011. This electric loco can operate on non-electric tracks and provides seamless operations between terminals – eliminating the need of diesel shunting locos and further increasing the efficiency of electric traction.

Future developments in Europe will further reduce the need of diesel locomotives, e.g. with the increased usage of high power batteries starting 2020 to overcome non-electrified sections of the network. Corresponding initiatives have been taken by the Germany State Railways, which will officially be announced at Innotrans, Berlin Sept. 2012, as part of their long-term Eco Rail project.

1.3. Newest electric locomotives for heavy haul freight

Electric locomotives provide an effective solution to heavy-haul operations where high tractive effort and high traction power is required. Typical examples are in South Africa (Coal Link and OREX), Australia (Queensland Railways coal trains), Russia, India and China. China is currently experiencing a massive electrification with 25 kVAC catenary with heavy investments in new electric locomotives with power levels of 9.6 MW for 6-axle CoCo and 10 MW for 2xBoBo locomotives – both locomotive types for heavy-haul operations. In India it has been decided to electrify both new freight corridors, Kolkata to New Delhi and Mumbai to New Delhi, for electric locomotives to haul heavy bulk and intermodal trains.

Responding to the specific needs of the LKAB iron ore mines in northern Sweden, a new six-axle electric locomotive "IORE" was developed to haul 8,600 ton train loads on steep 11 ‰ (gradient) (1:91) uphill grades at speeds of minimum 35 km/h. Further, the locomotive demonstrated a high regeneration capability on downhill grades with braking energy feeding back into the catenary. Typically, the energy savings amount to 20 % of the absorbed energy. This IORE locomotive has a double Co'Co' configuration with a power at the wheel of 2x5'400 kW (14,470 hp) and is the most powerful and most modern electric heavy-haul locomotive in operation worldwide to date, see photo 3. It is equipped with the same propulsion concepts as the TRAXX locomotives, however, adapted to the Co'Co' configuration and to axle loads which can be ballasted from 25 to 30 tonnes.

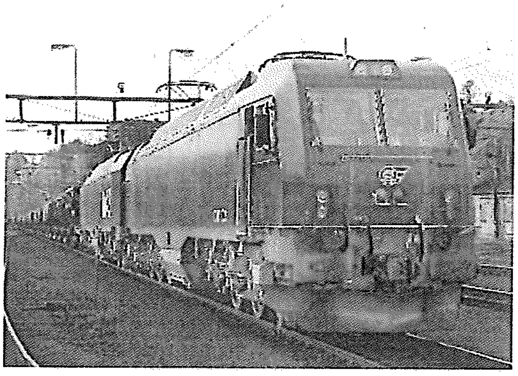

Photo 1 (top): TRAXX AC locomotives (BR 185) of DB Schenker Rail, Germany.

Photo 2 (middle): TRAXX AC3 locomotive with a small diesel engine for last Mile operation, eliminating the need of diesel shunting locos on non-electrified tracks, e.g. into terminals.

Photo 3 (bottom): IORE locomotives of LKAB in northern Sweden

2. Comparison of electric and diesel traction

2.1. General considerations

Electric traction was developed to obtain higher traction power at the wheels compared to locomotives with thermal engines. Although the development of electric locomotives ceased in North America during the 1970s, electric traction continued to be pursued vigorously in Europe. As such, this technology is not currently available in North America and operators source their requirements for electric locomotives from other markets, as demonstrated by the recent acquisition and delivery of the ALP 46 electric locomotive to New Jersey Transit and the dual-powered ALP-45DP (an electric locomotive which can operate also with diesel engines on non-electrified lines) to New Jersey Transit and AMT, Montreal.

The power efficiencies typically generated along the power supply chain are reflected below (Table 1):

Table 1. Power source and power efficiency	**Electric traction**	**Diesel traction**
Energy sources	Coal, gas, hydro, nuclear, oil, …	Oil
Thermal efficiency (approx): a) Combined cycle power plant b) Combined cycle power plant with waste heat utilization	 a) 60% b) 85%	 -- --
Electric generation and transmission	High efficiency	
Diesel engine thermal efficiency	--	Max 40%
Loco power conversion efficiency (average)	85 – 87%	83-84%
Overall efficiency	**higher**	**Lower**
Energy savings by power regeneration of braking energy: a) Flat countries (average) b) Mountainous countries (average)	 a) 5 – 7% b) 20 – 30%	Very low, only to the auxiliaries of the locomotive

Table 1: Power source and power efficiency

Power supply - electric locomotives. The power source for electric locomotives is comprised mostly of hydro, nuclear and thermal (oil, coal, gas) power plants. The incremental need of additional electric power for electric locomotives on freight corridors must be compared to the incremental power efficiency to supply this power. Modern combined cycle plants have a high thermal efficiency of up to 60% and up to 85% when combined with waste heat utilisation. Power plant electric generation and transmission for 25 kVAC catenaries have in general low power losses. The average power efficiency of the locomotive itself is typically between 85 – 87% depending on its specific design. Upon braking, energy is fed back to the catenary, and ultimately the grid, and can be used by other locomotives or other consumers on the grid. Energy savings by regeneration are typically in the range of between five to seven per cent in a flat country (Finland) and between 20 to 30 per cent in a mountainous country (Switzerland). A detailed analysis made in 2000 of the Coal Link in South Africa (24 hour simulation of all trains) for the line Ermelo – Richards Bay showed a total potential of energy savings of >30%.

Electrification. The cost of electrification is typically small compared to the total investment of new railway lines and is typically only five per cent of the total investment costs. It is even much lower if complex infrastructure is required, for example, bridges and tunnels. Catenary wires are very durable and can average ten Mio locomotive passings or more for freight operations. The life of electrification infrastructure, for example, substations, is in the range of fifty to a hundred years. In addition, the maintenance costs of modern catenary systems are relatively low. The amortisation of new electrification (infrastructure) on well-frequented (high demand) lines is considerably shorter, than diesel. Furthermore, diesel fuel costs are increasing on average and are already considerably higher than electric energy on a per transported gross tonne per km basis. In Europe simulations show that a heavy freight train operating between Munich and Hamburg has twice the costs for fuel in case of running with diesel locomotives in comparison to the energy costs whilst running with electric locomotives. Further, the national security of energy supply must be taken into consideration.

Power supply – diesel locomotives. In stark contrast to the above, the thermal efficiency of a modern locomotive diesel engine is approximately 40% in best case. This value is obtained by reviewing the impact of new technologies such as high power density (via high turbocharger boost), high turbocharger efficiencies, direct fuel injection with electronic timing control and high compression ratio and low thermal and mechanical losses. The resulting power at the shaft of the diesel engine is then converted to traction power at the wheels. On the Bombardier TRAXX DE this conversion efficiency is approx 84%. In general, the conversion efficiency on a diesel-electric locomotive is lower compared to an electric locomotive due to the high cooling power needed to dissipate the diesel engine heat.

Diesel emissions. The diesel engine has critical issues of noise, vibrations and exhaust emissions particularly when it operates in highly populated areas. For these reasons, national and international standards are specifying a massive reduction of their emissions of NOx, CO, HC and particle matter. European Authorities have developed the EU Stage IIIB which is by legislation compulsory starting 2012. These new limits require new and more expensive diesel engine technologies, e.g. SCR or ERG. Due to the increased costs of such large low emission railway engines, Bombardier has introduced a paradigm shift by replacing large diesel engines with multiple smaller industrial engines. The first high power multi-engine diesel locomotive fulfilling the Stage IIIB exhaust emission requirement in Europe is the TRAXX DEME which is revealed to the public for the first time at the Innotrans, Berlin Sept. 2012.

Double stack operation. In order to improve the efficiency of train operations, locomotives must haul heavy trains and increasingly bulky intermodal trains. In the latter case, double stack trains greatly improve the competitiveness of the railway. As demonstrated in figure 4a, double stack trains are also possible with electric traction and are currently in operation under the catenaries of the North-East Corridor in America. As reflected in figure 4b, the pantographs of the modern ALP 46 of New Jersey Transit are adjusted to this high catenary. Also, in China, double stack container trains operate under 25 kVAC catenaries. The introduction of double stack trains on electrified dedicated freight corridors will depend on operational considerations, for example, maximum speed and operation on feeder lines to the freight corridor. Potentially, high reaching pantographs can also be installed on existing electric locomotives.

Photo 4a (top): Operation of trains with double stack containers under catenary on the North-East Corridor, USA.

Photo 4b (bottom): ALP 46 electric locomotive operating under high catenary on the North-East Corridor, USA.

Electric locomotives – high power capability. The greatest advantage of electric traction is the much higher available power at the wheels. Comparatively, due to the heavy diesel combustion engine, the power for the diesel locomotive is much lower than on an electric locomotive for a given axle load. This may be seen in the comparison between the diesel-electric TRAXX DE with the electric TRAXX AC locomotive. Therefore we are able to discern that the TRAXX DE is one of the most powerful diesel four-axle locomotive available in its weight class of 84 tonnes. This locomotive has a significantly higher output power per weight than typical American diesel engines, even with lower exhaust emission standards. As reflected in the table below (table 2), the electric TRAXX locomotive is three times more powerful than the comparable diesel locomotive.

4-axle	Axle load	Length	Diesel engine	Power at wheel
TRAXX AC	21t	18.9m	----	5'600 kW / 7'500 hp
TRAXX DE	21t	18.9m	2'200 kW / 2'950 hp	1'840 kW / 2'465 hp

Table 2: Comparative table

In addition, electric locomotives are rated by their power at the wheel, whilst diesel locomotives are typically rated by the diesel engine power. Therefore, the power at the wheels of diesel locomotives is substantially lower than their rated powers published.

Adhesion. The maximum possible tractive effort of both electric and diesel locomotives is dependent on many factors, for example:

1. *Axle load and axle configuration (four- and six-axle)*
2. *Wheel / rail running quality*
    - Wheel guidance, e.g. avoiding lateral slip
    - Load transfer, which can be minimized by appropriate bogie design
    - Wheel material, allowing optimal wheel surface conditioning
3. *Torque control schemes*
    - Bogie or single-axle control
    - Control schemes, allowing wheel surface conditioning without excessive wheel slip
    - True speed measurement

Considering the above design influences, a very high adhesion coefficient of >40% is able to be reached at ideal conditions (perfectly aligned and dry tracks). More importantly however, is the ability to obtain a high adhesion at real operating track conditions, i.e. with contaminated track surfaces (rust, dampness, leaves or non-perfectly aligned track geometry). The Flexifloat bogies of the WAG-9 and TRAXX locos allow axle loads of between 20 to 30 tonnes and have excellent ride quality even at non-optimal tracks. Additionally, the TRAXX locomotives have novel control schemes that can clean contaminated tracks and therefore raise the adhesion coefficient from one wheel set to the next. Considering the influence of the wheel-track interaction, the four-axle locomotive has a slight advantage against the six-axle locomotive with regards to adhesion.

Remote operation. Both electric and diesel locomotives are used today in remote operation with communication either by cable or radio. This is best demonstrated by Locotrol - used on electric trains at Queensland Rail. In addition, the Loco 2000 was equipped with Locotrol for operation over the Swiss Alps. For various reasons, for example lower overall cost even when using an additional driver, Locotrol is no longer used in Switzerland.

2.2. Characteristics of electric and diesel locomotives in comparison

In the following evaluation, various electric and diesel locomotives are compared for the following train loads on freight corridors:

a) Train load of 6,000 tons on 5‰ (1:200) grade

b) Train load of 7,200 tons on 5‰ (1:200) grade

The locomotives types are:

a) TRAXX AC: This is the standard four-axle locomotive as used in Europe for freight on 25 and 15 kVAC respectively. It has 5,600 kW (7'500 hp) at the wheels, 300 kN starting TE and weighs 84 tonnes (21t/axle). This corresponds to an adhesion coefficient of $\mu = 0.36$.

b) TRAXX AC-H: This is a potential derivative of the above four-axle locomotive, however, is ballasted to 30t/axle. Based on the same adhesion coefficient the starting TE is set at max 429 kN.

c) IORE: This is the locomotive used on the iron ore line in northern Sweden. Each six-axle section has a power at the wheels of 5,400 kW (7,235 hp), 600 kN starting TE and weighs 180 tons (30t/axle). It uses the same Flexifloat bogie concept as the WAG-9. In comparison to a two-axle bogie, it attains on the average a slightly lower adhesion coefficient due to increased load transfer and increased lateral wheel slip in curves due to the longer wheel base. The max. adhesion coefficient used is $\mu = 0.34$.

d) WAG-9: This is the six-axle freight locomotive of the Indian Railways. It has a power at the wheels of 4,500 kW (6,000 hp), 460 kN starting TE and weighs 123 tons (20.5t/axle). This results to a maximum adhesion coefficient of $\mu = 0.38$.

e) TRAXX DE: This is the four-axle diesel-electric locomotive of the TRAXX platform with a 2,950hp (2,200 kW) engine power. It has 1,840 kW (2,465 hp) at the wheel, 270 kN starting TE and weighs 84 tons (21t/axle). This corresponds to an adhesion coefficient $\mu = 0.33$. Principally, this locomotive has the same adhesion capability as the electric TRAXX locomotives; however, an overall design optimum was found with a slightly lower TE. Note: Starting 2012 the TRAXX DE is replace by the TRAXX DEME to meet the new European Stage IIIB exhaust emission requirements.

f) DE-4400 hp: This is a potential six-axle diesel locomotive with a 4,400 hp engine based on the design concepts of the TRAXX DE, however, extended to a Co'Co' locomotive. It has 2,750 kW (3,685 hp) at the wheel, 500 kN starting TE and weighs 150 tons (25t/axle). For comparison, the same Flexiloat bogie is assumed as the IORE locomotive, thus the adhesion coefficient is $\mu = 0.34$. This locomotive overall performance is slightly higher than the Euro 4000 of Vossloh which has a 4,258 hp engine.

g) DE-6000 hp: This is a potential six-axle diesel locomotive similar to the above DE-4'400 hp, however, it contains a 6,000 hp engine. It has 3,745 kW (5,029 hp) at the wheel, 600 kN starting TE and weighs 180 tons (30t/axle).

The locomotive data is listed in the below Table 3.

Table 3		TRAXX AC	TRAXX AC-H	IORE	WAG-9	TRAXX DE	DE-4400hp	DE-6000hp
Configuration		Bo'Bo'	Bo'Bo'	Co'Co'	Co'Co'	Bo'Bo'	Co'Co'	Co'Co'
Axles		4	4	6	6	4	6	6
Axle load	tons	21	30	30	20.5	21	25	30
Mass	tons	84	120	180	123	84	150	180
Diesel power	kW hp	-- --	-- --	-- --	-- --	2'200 2'950	3'285 4'400	4'478 6'000
Length	m	18.9	18.9	22.9	20.562	18.9	~22	~23
Power at wheel rim	kW hp	5'600 7'500	5'600 7'500	5'400 7'235	4'500 6'000	1'840 2'465	2'750 3'685	3'745 5'029
Power at wheel per axle	kW hp	1'400 1'876	1'400 1'876	900 1'206	750 1'005	460 616	458 614	624 836
Power at wheel per locomotive weight	kW/t hp/t	67 89	47 63	30 40	37 49	22 29	18 25	21 28
Starting tractive effort	kN	300	429	600	460	270	500	600
Max. adhesion coefficient	μ	0.36	0.36	0.34	0.38	0.33	0.34	0.34

Table 3. Locomotive data

In the following chapter the performance of these locomotives for the above defined trains is demonstrated and a comparison is provided.

3. Locomotive hauling performance in comparison

The tractive effort diagrams of all types are depicted in figure 1, together with the train resistance curves for the loads of up to 6,000 and 7,200 tons respectively. These train resistance curves should be considered to be an average, as mixed freight trains could have higher values and dedicated high performance freight cars (Scheffel bogies in South Africa) have lower values. It is evident that only the electric and diesel locomotives with high TE can haul the trains. However, using two locomotives in multiple operations, see figure 2, all of the above locomotives can haul the trains at different maximum speeds. This depends on the available power at the wheels. The highest speed is obtained by the electric locomotives due to their high power capability.

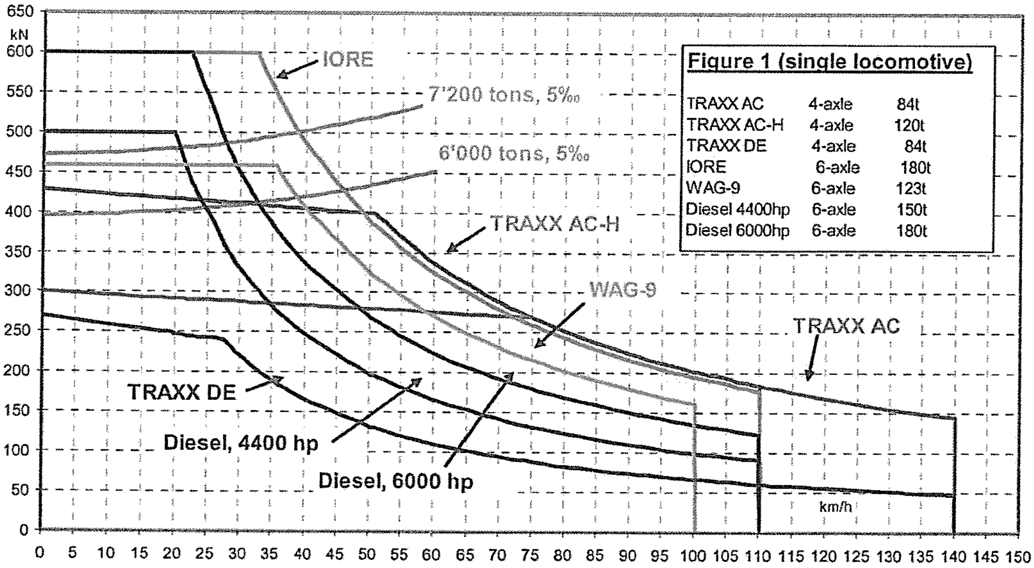

Figure 1: Tractive effort versus speed for a single locomotive.

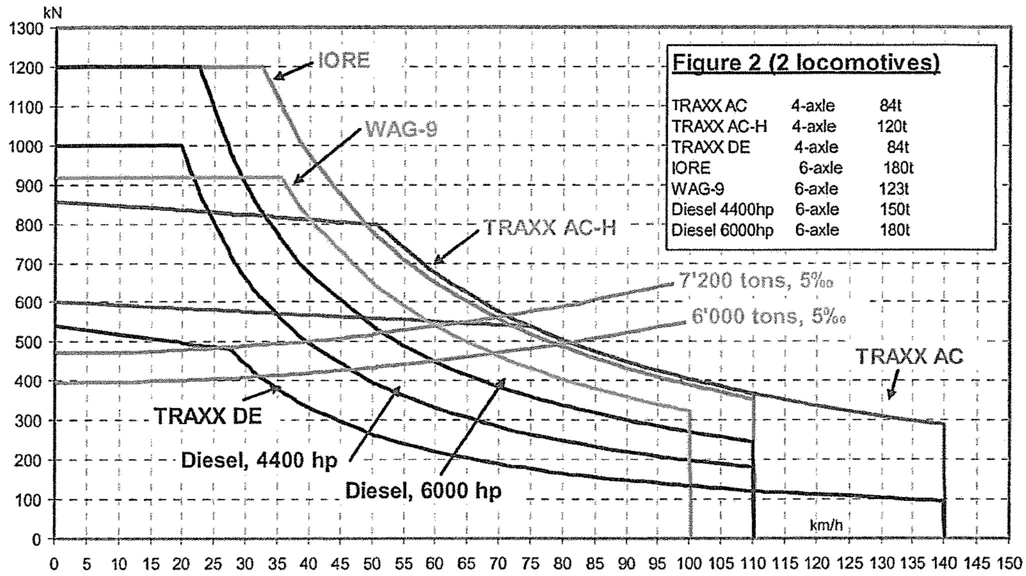

Figure 2: *Tractive effort versus speed for two locomotives in multiple.*

The situation changes significantly, however, when the specified trains must operate at a higher speed of 100 km/h. Here, a high power at the wheels is needed, i.e. minimum 16 MW and 19 MW for the train loads of 6,000 and 7,200 tons respectively. Correspondingly, for the 7,200t train the smallest number of locomotives, i.e. four units, is obtained with electric TRAXX AC (and IORE) locomotives as is shown in figure 3. Further, the DE-6000 hp locomotive requires a minimum of six units, see figure 4.

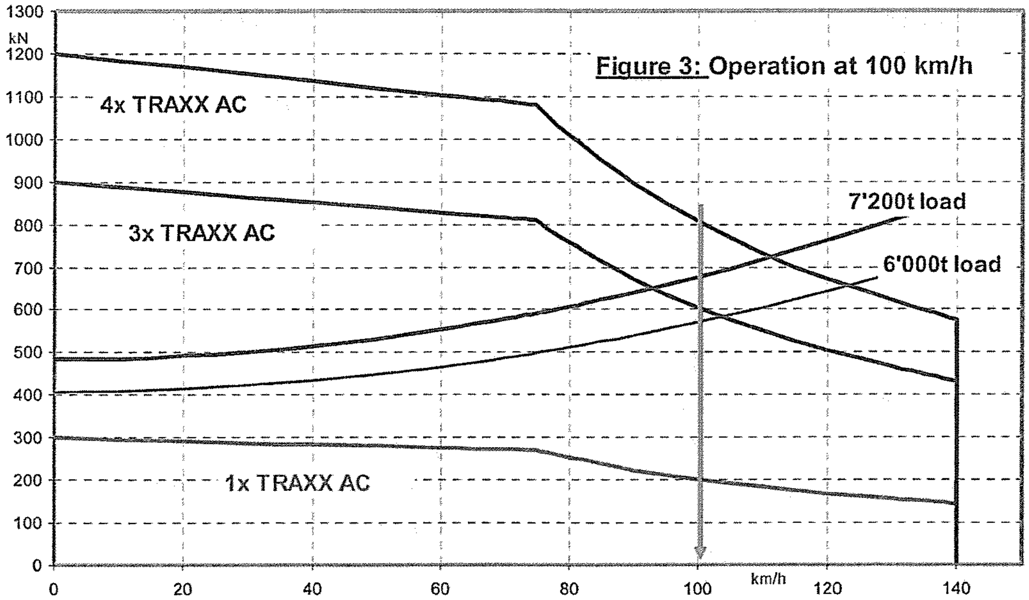

Figure 3: *Three TRAXX AC locos can haul the 6,000 ton train load on 5‰ (1:200) at 100 km/h. Four TRAXX AC locos are ample for the 7,200 ton train load.*

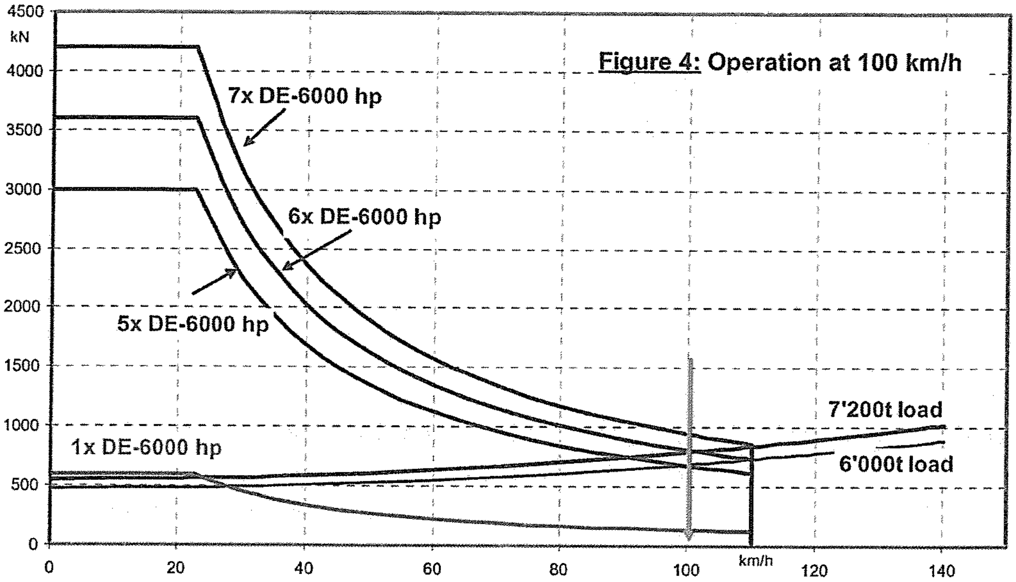

***Figure 4:** A minimum of 5 DE-6000 hp are needed for the 6'000 ton and minimum 6 DE-6000 hp are needed for the 7'200 ton train load on 5‰ (1:200) at 100 km/h.*

The results of the analysis are given in Table 4:

		TRAXX AC	TRAXX AC-H	IORE	WAG-9	TRAXX DE	DE-4400hp	DE-6000hp
Maximum speed with a single locomotive on 5‰								
Max speed with 6'000t	Km/h	--	(30)	45	38	--	25	32
Max speed with 7'200t	Km/h	--	--	38	--	--	(20)	28
Maximum speed with two locomotive on 5‰								
Max speed with 6'000t	Km/h	80	80	78	68	32	46	59
Max speed with 7'200t	Km/h	60	70	68	60	25	39	52
Operation at 100 km/h on 5‰								
6'000t	**locos**	**3**	**3**	**4**	**4**	**10**	**7**	**5**
Mass locos/train load	ratio	4.2%	6%	12%	8.2%	14%	18%	15%
Length locos/length load	ratio	6%	6%	9%	8%	19%	15%	12%
Powered axles	axles	12	12	24	24	40	42	30
7'200t	**locos**	**4**	**4**	**4**	**5**	**11**	**8**	**6**
Mass locos/train	ratio	4.7%	6.7%	10%	8.5%	13%	17%	15%
Length locos/length load	ratio	8%	8%	9%	10%	21%	18%	14%
Powered axles	axles	16	16	24	30	44	48	36

Table 4: Advantages of electric over diesel traction

From the above it is evident that there are substantial advantages to utilising electric traction as opposed to diesel traction. The key results are demonstrated below:

1. **Higher speed:** Both the TRAXX AC with 21t axle load and the IORE locomotives with 30t axle load haul the 6,000 and 7,200 ton train loads at significantly higher speeds in double traction than two DE-6000 hp locomotives.
2. **Smaller number of locomotives for 100 km/h:** The TRAXX AC locomotive requires only three units for the 6,000 ton loads and four units for the 7,200 tons. The IORE requires four units. The DE-6000 hp needs five and six units respectively.

3. **Power utilization at 100 km/h:** The locomotive weight is a non-productive mass and should be kept as low as possible. For the TRAXX AC locomotives, the total locomotive weight is less than five per cent of the train load. The DE-6000 hp locomotives have a much higher weight of 15 per cent of the train load. Therefore, the power needed at the wheel of the DE-6000 hp to run the train (and pull its own unproductive weight) is approx 10 per cent higher than the TRAXX AC.
4. **Train length utilization at 100 km/h:** In the same way as above, the TRAXX AC locomotives add up to a train length of between six to eight per cent of the train load (assumed 1,000m length of train load). The DE-6000 hp locomotives add up to between 12 to 14 per cent of the train load length. Therefore, with a train length limited by the sidings, the TRAXX AC can haul approx six per cent longer train loads than the DE-6000 hp.
5. **Service and maintenance:** On a modern locomotive, service and maintenance costs are to a large extent determined by the mechanical parts that are subject to wear and tear. The state-of-the-art electric locomotive is a "solid-state" machine and, as such, has only few moving parts - primarily in the bogies. Therefore, the number of powered axles is an important indicator of required maintenance costs. The TRAXX AC requires only 12 and 16 powered axles to pull the 6,000 and 7,200 tonne train loads at 100 km/h respectively. The IORE needs 24 powered axles. The DE-6000 hp needs 30 and 36 powered axles respectively.
6. **Wheel life:** There are no inherent weight restrictions on the electric locomotives. Therefore, these locomotives are equipped with large wheels of 1,250mm diameter. In this way a long wheel life of more than 1'000'000 km is obtained at typical operations in Germany. On the other hand, diesel locomotives are critical in weight and size. This is one of the reasons why smaller wheels are used, which must be replaced more frequently. Wheel replacement adds significantly to maintenance costs.
7. **Track forces:** Whilst the TRAXX AC requires much fewer locomotives than the diesel alternatives, they also have a much lower axle load of 21t compared to the 30t with the DE-6000 hp. This greatly reduces wear and tear on wheels and tracks.
8. **WAG-9 versus the DE 4400/6000 hp:** As seen from table 2, the WAG-9 is more advantageous than the DE-4400 hp and the DE-6000 hp.
9. **High tractive effort:** If the objective is to have locomotives with high tractive effort, then a high axle load is needed. The electric locomotives TRAXX AC-H and IORE provide a high tractive effort with least amount of powered axles at a given speed.

4. Summary

It is evident that the choice of traction is primarily a question of overall system optimisation, taking all aspects of the railway system into account. Equally important is the perception of competitive market forces and future technological developments, given the long-term nature of rolling stock and infrastructure investments. Therefore, a holistic view of the total cost of operation is equally as important as achieving energy and environmental policy objectives. As AC locomotive propulsion technology is well established in Australia, there is an important opportunity to continue to leverage the opportunities presented by the higher performance characteristics of electric traction through continued investment and utilisation of dedicated heavy rail haulage corridors such as the Blackwater and Goonyella systems.

We trust that the QCA considers the issues and concerns raised above when composing your final determination.

Best regards,

[redacted]

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