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Paper 8: Powering Rail: Electrification and Emissions Intensity

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Table of Contents

Executive Summary

In other papers in this series, it is argued that, when operated in an efficient manner and at adequate scale, there are substantial economic and social benefits in rail transport relative to road transport (see Papers 2 and 5). The economic benefits are of course dependent on an appropriate context of use, including the density of transport demand, the distance of travel, and the technology used. In many contexts, the most efficient form of rail transport is fully-electrified rail and, if powered by electricity generated from renewable sources, rail can become a virtually zero emissions transport mode. In practice, electrified rail in Australia does not fully achieve these potential emissions benefits since it is primarily powered by coal-based electricity and, in some cases, has low loading factors and employs older technologies.

Rail is typically a more energy-efficient form of transport than road, with lower energy use per passenger kilometre or per tonne kilometre. Rail's energy intensity can be reduced further by a range of measures, from lighter and more advanced vehicles and improved vehicle/track interactions to more efficient engines and regenerative braking. In the long term, rail offers the possibility of virtually zero emissions transport, that is, if rail transport is fully electrified and powered by electricity from renewable sources.

This paper briefly examines a range of issues concerning the possible future role of low-emissions rail transport in the Australian transport system. The paper is introductory only, and it is recognised that much more work needs to be done to explore fully the costs and benefits involved in electrified rail powered by renewable sources.

The Competitive Position of Electrified Rail

Operational advantages. One advantage of electrification is greater tractive power output. Electric locomotives can deliver as much as 2½ times the tractive power output of an equivalent diesel locomotive. Electric traction is particularly efficient for ascending gradients. Electric traction also means that it is possible to further increase efficiency through regenerative braking. A reduction of 15-20% in the energy required to move electric passenger trains can be achieved through regenerative braking, while diesel-hybrid battery technology has shown fuel savings of 20% in trials in Japan (RSSB 2007a). In general, electric trains are simpler and cheaper to maintain.

Local environment benefits but increased accident rates. Electric trains are environmentally cleaner than diesel ones, especially at fully-enclosed stations, where complex waste extractions systems need to be installed. But there is also the possibility of a higher accident risk with electric rather than diesel trains in view of the live power line.

Lower fuel and other operating costs, but high capital costs. Electric trains generally have lower operations and maintenance costs than diesel ones. In principle, as oil prices rise and the cost of carbon comes to be fully reflected in fuel costs, electric rail will offer significant savings in fuel and other operating costs. For some freight applications, the benefit of lower fuel costs could be increased as a result of time-of-day pricing through the electricity grid. But the capital costs of electrification are high, although they vary greatly with the conditions. Electric locomotives are more expensive than diesel ones to purchase. In some case, however, there can be savings in capital costs since fewer electric locomotives may be need to pull a given volume of freight.

Lower greenhouse gas emissions. Electric traction can generate lower greenhouse gas emissions than diesel traction in many contexts, even when electricity is generated from coal. One key issue is passenger numbers. If the electrified service carries a passenger load near to optimal levels, its energy efficiency will be higher than for cars or diesel rail services.

Importance of market size and network issues. Given the scale of the capital infrastructure costs, electrification requires significant traffic volumes if these costs are to be recouped. Thus electrification is best applied to whole, coherent network segments in a coordinated way, and should not be adopted piecemeal.

The Existing Pattern of Electrification in Australia

At the present time, rail systems in all of the major cities are electrified, but only in Queensland are there major electrified routes in non-urban areas. Queensland Rail has about 1000 kms of electrified track, including the line from Brisbane to Rockhampton, and the coal routes of central Queensland. The major new electrified passenger line in recent years has been the Perth to Mandurah railway, and some extensions to electrified lines are planned for Melbourne. Both Victoria and NSW have withdrawn electric locomotives from regional lines over the past two decades. In both cases, this seems to reflect problems with incorporating electric locomotives into a predominantly diesel network, together with low fuel costs.

Options for Further Examination

Four options to increase the use of low-emissions electrified rail in the Australian transport system seem worthy of further analysis:

The ARTC track. Considerable work is underway on ARTC's network and has been supported by a $1.2 billion injection of equity into the ARTC under the Government's Nation Building announcement on 12 December 2008. Given the network issues involved, the case for including electrification in the rebuilding process should be given urgent consideration. Time-of-day pricing could offer substantial cost savings to operators (and returns to the ARTC), while electrified track and some renewable power generation to feed could offer substantial benefits to regional communities.

The Pilbara mining network. Given the likely future cost of diesel fuel, including the cost of carbon, there may be a case for electrifying this 1000 km railway and powering it by gas or gas/renewal energy sources. While this would be primarily a commercial decision, it may be influenced by appropriate public policy settings.

Urban rail systems. Rapid rail passenger growth is occurring in many Australian cities, in part because many are looking for cleaner methods of travel. This advantage of rail could be enhanced if operators purchased RECs to ensure that urban rail was low emissions. Such action could assist the renewables industry in the State in question.

The Queensland rail network. QR has led the way in electrification in recent years, and the issue of reducing the emissions intensity of the power used in that network is now an important one.

1. The Role of Electrification and Renewable Energy

Rail is typically a more energy efficient form of transport per unit than road, with lower energy use per passenger kilometre or per tonne kilometre. This presupposes an appropriate context for rail use, primarily based on density of transport demand and distance of travel. As discussed in other supporting papers, rail's energy intensity can be reduced further by a range of measures. But rail's current lower energy intensity means that even if both road and rail are powered primarily by fossil fuels (that is, by petroleum or coal-based electricity) rail has a lower emissions intensity. But one of the advantages of rail is that it offers the possibility of virtually zero-emissions transport, that is, when rail transport consists of fully-electrified rail powered by electricity generated from renewable sources. In France, for example, about 80% of electricity is generated from sustainable sources and there is a nationwide grid of electrified rail transport, with an official objective of complete electrification within 20 years. This provides France with an efficient, low-emissions component of its overall transport system, with rail transport accounting for only 0.63% of all transport's CO_2 emissions (SNCF 2009).

Here, we review briefly some of the issues concerning the possible future role of low-emissions rail transport in the Australian transport system, while recognising that these are major issues that require much more detailed attention than is possible here.

1.1. Cleaner Rail with the Existing Fuel Mix

Current trends in both passenger and freight vehicles show that a major thrust of the future development effort will be to make vehicles lighter and increase their usable volume. In addition to the obvious measures of exploiting new materials and manufacturing processes, together with intelligent use of the payload space, a major contribution can be made by improvements to the suspension and drive. The suspension and drive will become more compact and lighter, provide good ride quality with lighter car bodies, cope with larger variations of tare to laden mass, and maximise the use of structural clearance gauge. (See Papers 6, 7 and 9 in this series.)

Other likely initiatives include improvements to vehicle/track interaction, more powerful and energy efficient diesel engines and electric motors, more effective power converters, and the introduction of regenerative braking as a means of supplementing the supply of electricity from on-board generators. Train Protection and Control Systems (TPC) will be one of the most important initiatives. Improving traffic control of trains can increase infrastructure network capacity by allowing more trains to run on the tracks without compromising safety, and reduce fuel usage through trains not being required to stop as frequently.

The pace of implementation of this technological change in railway rolling stock is fairly slow because railway rolling stock generally has a long life. In addition, Australian railway rolling stock needs to be custom built to make it smaller and lighter owing to the limitations of the Australian rail network. This limits the adoption of new technology, increases its costs, and significantly delays the implementation of existing more efficient technology. However, with the correct policy settings, this range of both emerging and existing rail technologies could be brought forward to substantially reduce energy use, and hence greenhouse gas emissions for a given fuel mix, and also reduce costs, increase speed and achieve greater reliability. Based on the detailed discussion of freight options in Papers 6 and 9, it is likely that for freight a combination of improved load factors, energy efficiency and operational improvements could reduce greenhouse gas emissions per tkm by 25% by 2020 for the existing fuel mix. For passenger rail, the material in Papers 7 and 9 suggests that a larger reduction is possible, with emissions per pkm in passenger rail down by as much as 40% by 2020.

1.2. The Competitive Position of Electrified Rail

For some time, rail systems in Australia have been either diesel powered or powered by electric traction, with substantial technological changes continuing to be made in diesel locomotive technologies.

Operational advantages. One advantage of electrification is greater tractive power output. Electric locomotives can deliver as much as 2½ times the tractive power output of an equivalent diesel. Electric traction is particularly efficient for ascending gradients, and can generally provide faster acceleration than that of trains using diesel power. Electric traction also means it is possible to further increase efficiency through regenerative braking. A reduction of 15-20% in the energy required to move electric passenger trains can be achieved through regenerative braking, and diesel-hybrid battery technology has shown fuel savings of 20% in trials in Japan (RSSB 2007a). In general, electric trains are simpler and cheaper to maintain. For passengers, the advantages of electric traction include less vibration and smoother, quieter journeys.

Local environment benefits, but increased accident rates. Electric trains are environmentally cleaner than diesel, especially at fully enclosed stations, where complex waste extractions systems need to be installed for diesel engines. Taking a life-cycle analysis into account, electric traction also has the advantage of almost completely eliminating emissions of carbon monoxide and hydrocarbon particles, and has a smaller impact via noise levels. But there is also the possibility of a higher accident risk with electric rather than diesel trains as a result of the live power line.

Lower fuel and other operating costs, but high capital costs. In principle, as oil prices rise and the cost of carbon comes to be fully reflected in fuel costs, electric rail will offer significant savings in fuel and other operating costs. For some freight applications, the benefit of lower fuel costs could be increased as a result of time-of-day pricing through the electricity grid. In such applications, much of the traffic can take place overnight, in periods of low electricity demand, and hence low electricity prices.

But the capital costs are high. The cost of electrifying existing lines is substantial, although costs vary markedly with conditions and whether the electrification is part of a greenfield project or the electrification of an existing line. A 2007 report by the UK Rail Safety and Standards Board (RSSB 2007) found that the cost to electrify an existing route was £550,000 to £650,000 (A$1.2-1.4 million) per single track kilometre, but higher estimates have been cited in Australia. Electric locomotives are more expensive than diesel ones, but in some case there can be savings in capital costs since fewer electric locomotives may be needed to pull a given volume of freight.

Lower greenhouse gas emissions. Electric traction can generate lower greenhouse gas emissions than diesel traction, and in many contexts, even when electricity is generated from coal. If an electrified passenger service carries a passenger load near to optimal levels, its energy efficiency will be significantly higher than for cars or diesel rail services. The RSSB study found that, in the UK, electric traction produced 20% less CO2 emissions than diesel traction per vehicle-km, and that this was likely to rise to 25% by 2020 (RSSB 2007b). But the relative level of emissions will clearly differ greatly depending on the nature of power generation in any given country.

Importance of market size and network issues. Given the scale of the capital infrastructure costs, electrification requires significant traffic volumes if these costs are to be recouped. In addition, there are important network coordination issues, which means that operators may need incentives to switch to electric locomotives, while uniform electrification standards are also necessary. These issues of scale and network coherence thus affect the competitive position of electrified rail, and electrification needs to be applied to whole, coherent network segments in a coordinated way, and cannot be adopted piecemeal.

1.3. The Existing Pattern of Electrification in Australia

At the present time, rail systems in all of the major cities are electrified, but only in Queensland are there major electrified routes in non-urban areas. QR operates about 1000 kilometres of electrified track, including the line from Brisbane to Rockhampton, and the coal routes of central Queensland. The major new electrified passenger line in recent years has been the Perth to Mandurah railway, and some extensions to electrified lines are planned for Melbourne. Both Victoria and NSW have withdrawn electric locomotives from regional lines over the past two decades. In both cases, this seemed to reflect problems with incorporating electric locomotives into a predominantly diesel network, together with low fuel costs at the time of the decision.

1.4. The Role of Renewables in Powering Rail

Two factors influence the potential for the use of renewable energy sources to power rail. One is the fact that rail demand for electricity is intermittent over the full 24 hours of any day, and the other is that it is often located in remote or regional areas. This means that power must normally be provided through a grid, although stand-alone generation systems may be viable for large, remote rail networks if the time-of-day issues can be addressed (e.g., by combined systems involving solar and gas power). It would also be possible for dedicated renewable power systems to be connected to the grid, and hence both buy from and sell to the grid.

Several different type of railway traction electric power system configurations are in use in different parts of the world. The choice of the system depends on the train service requirements, such as commuter rail, freight rail, light rail, train loads, and the electric utility power supply. The railway electrification load is one of the most difficult kinds of load to be fed by an electric utility and presents a challenge both for the railway company and the utility. For the utility, it requires over-sized substation facilities and may result in power quality deterioration for its other customers. These utility challenges have been met using different methods for the different railway electrification system configurations. Some countries have used low frequency (15-20 Hz) railway electrification systems to maximize the efficiency and reduce costs, while the others have maintained the 50/60 Hz frequency and have developed high-voltage innovative designs to meet these challenges. With modern power electronics, technology is available for frequency conversion and the high-power quality demanded by utility power customers. As a result, low-frequency systems could be an increasingly viable option that has the potential to provide an affordable and desirable railway electrification systems (Bhargava, 1999).

Another approach to ensuring that electricity used by electrified railways is effectively renewable is to purchase Green Power or Renewable Energy Certificates. Green Power is nationally accredited to ensure that electricity accredited by Green Power is renewable and beyond business as usual, and is considered further below.

1.5. Options for Further Examination

Four options to increase the use of low-emissions electrified rail in the Australian transport system are worthy of further analysis.

The ARTC track. Considerable work is underway to upgrade the ARTC track, and this has been supported by a A$1.2 billion injection of equity into the ARTC under the Government's Nation Building announcement on 12 December 2008. Given the network issues involved, the case for including electrification in the rebuilding process should be given urgent consideration. Time-of-day pricing could offer substantial cost savings to operators (and returns to the ARTC), while electrified track and some renewable power generation to feed into the grid could offer substantial benefits to regional communities.

The Pilbara mining network. Given the likely future cost of diesel fuel, including the cost of carbon, there may be a case for electrifying this 1000 km railway and powering it by gas or gas/renewable energy sources. While this would be primarily a commercial decision, it may be influenced by appropriate public policy settings.

Urban rail systems. Rapid rail passenger growth is occurring in many Australian cities, in part because many are looking for cleaner methods of travel. This advantage could be enhanced if operators purchased Renewable Energy Certificates to ensure that urban rail was low emissions. Such action could assist the renewables industry in the state in question.

The Queensland rail network. QR has led the way in electrification in recent years, and the issue of reducing the emissions intensity of the power used in that network is now an important one.

2. Towards Renewable Energy Sources

Increased electrification of the rail system combined with an expansion of renewable electricity generation has the potential to achieve near-zero greenhouse gas emissions rail transport. The greenhouse impact of a switch from diesel fuel to electricity is dependent on the energy efficiency of the motors used and the greenhouse gas intensity of the electricity source used to power the rail transport. Determination of the greenhouse-gas impact of switching from diesel locomotives to electric trains would require a detailed assessment of existing locomotives and potential replacement locomotives. The geographical area in which electrification took place would be an important factor in the assessment since there is a significant variation in the greenhouse gas intensity of electricity generation from one region to another.

Ensuring that electricity used by railways is effectively renewable can be achieved by a variety means. The first and least likely is dedicated renewable electricity generation for powering the new electrified railway routes. While it may be possible to partially achieve dedicated renewable electricity, it is likely that electricity to power the railways will be mainly be drawn from an existing electricity grid. In this respect, the source of electricity transmitted and distributed to the electrified lines does not differentiate between renewable and non-renewable electrons.

It is possible that solar and wind power could be dedicated to providing power to a rail system. The technical feasibility of utilising solar and wind power in this way is location and time dependent. In addition, such an approach is likely to create distribution issues that may or not be readily resolved. Furthermore, if dedicated renewable energy was used to power rail transport, it would be important to structure arrangements with an electricity distributor that enable any excess power generated from renewable sources to be exported into the distribution system on an appropriate financial basis. The assessment of the technical feasibility of following this course action would also require specific detailed analysis.

The simplest approach to ensuring that electricity used by electrified railways is effectively renewable is to purchase Green Power or Renewable Energy Certificates. Green Power is a nationally accredited to ensure that electricity accredited by Green Power is renewable and beyond business as usual. By purchasing Green Power, the demand for renewable electricity generation is increased and investment in renewable electricity generation is stimulated. If the volume of Green Power equated to the volume of electricity used by the electric trains, the trains would effectively be using Green Power. In the absence of a Green Power purchase from the railway, the volume of renewable electricity generation would be lower. Another possible course of action open to the railways would be to purchase Renewable Energy Certificates (RECs) from new accredited renewable electricity generators. The RECs purchased would be voluntarily acquitted. As a consequence of this acquittal, it would be necessary for additional renewable electricity to be generated to ensure that the Mandatory Renewable Energy Target (MRET) was met.

An assessment of the economics of developing clean rail transport would involve an examination of the interaction of investment costs, electricity prices, green power prices and the financial benefit of introducing a climate neutral railway system under an emissions trading scheme. Many issues beyond electrification are also relevant to reducing emissions.

3. Conclusion

In the immediate future, the electrification of rail in Australia will largely involve extending the network of electrified passenger services in the major metropolitan areas (i.e., filling existing gaps and providing new routes in growing outer metropolitan areas), although some large-scale electrification developments are underway in Queensland. In the longer run, the case for inter-city high-speed electrified rail will potentially grow, given the potential volumes of passenger demand and changes in the relative prices of rail- versus airfares consequent upon climate change policies and oil price trends. Given the potential role that electrified, low-emissions rail could play in Australia's low emissions future, the five potentially opportunities cited above, and others, should be the subject of urgent and detailed examination.

4. References

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