CRC for Rail Innovation

Paper 9: Technology and Commercialisation Developments
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Table of Contents

List of Figures and Tables ........................................................................................................... iv

Executive Summary ..................................................................................................................... v

1. Introduction ................................................................................................................................. 1

2. New Freight Technologies .......................................................................................................... 2
   2.1. Rolling Stock .......................................................................................................................... 2
       2.1.1. Introduction ..................................................................................................................... 2
       2.1.2. Overarching Issues ......................................................................................................... 2
       2.1.3. Power and Propulsion Technologies ............................................................................. 3
       2.1.4. Other Technologies ........................................................................................................ 3
   2.2. Track Design, Construction and Maintenance ...................................................................... 5
       2.2.1. Rail Technologies .......................................................................................................... 5
       2.2.2. Other Design Features .................................................................................................. 6
       2.2.3. Track Maintenance ........................................................................................................ 6
   2.3. Control Technologies ........................................................................................................... 7
       2.3.1. Network Traffic Control ............................................................................................... 7
       2.3.2. Freight Manager Control .............................................................................................. 7

3. The Impact of New Freight Technologies ................................................................................. 9
   3.1. The Impact on Greenhouse Gas Emissions ......................................................................... 9
       3.1.1. Increased Load Factors .................................................................................................. 9
       3.1.2. Increased Energy Efficiency .......................................................................................... 9
       3.1.3. Operational Improvements ........................................................................................... 9
       3.1.4. Reduced Emissions Intensity ......................................................................................... 10
       3.1.5. Overall Impact ............................................................................................................... 10
   3.2. The Impact on the Competitiveness of Rail as a Transport Mode .................................... 11
       3.2.1. Reduction in Costs ........................................................................................................ 11
       3.2.2. Increased Speed ........................................................................................................... 12
       3.2.3. Greater Reliability ......................................................................................................... 12
       3.2.4. Other Aspects of Competitiveness .............................................................................. 12
   3.3. Timelines for New Technologies .......................................................................................... 13

4. Passenger Rail Technologies ..................................................................................................... 14
   4.1. Rolling Stock ........................................................................................................................ 14
   4.2. Power and Propulsion Technologies .................................................................................. 14
       4.2.1. Urban Electrified ............................................................................................................ 14
       4.2.2. Regional and Interstate: Diesel ...................................................................................... 14
   4.3. Railway Wheel-set ................................................................................................................ 15
   4.4. Train Configuration .............................................................................................................. 15
4.5. Other Factors ................................................................................................................... 16

4.6. Capacity ............................................................................................................................. 16

4.7. High-speed Inter-city Rail ................................................................................................. 16

4.8. Light Rail ........................................................................................................................... 18

5. The Impact of New Passenger Transport Technologies ...................................................... 20

5.1. The Impact on Greenhouse Gas Emissions ...................................................................... 20
  5.1.1. Increased Passenger Occupancy .................................................................................. 20
  5.1.2. Increased Energy Efficiency ......................................................................................... 20
  5.1.3. Operational Improvements ......................................................................................... 20
  5.1.4. Reduced Emissions Intensity ..................................................................................... 21
  5.1.5. Overall Impact ........................................................................................................... 21

5.2. The Impact on the Competitiveness of Rail as a Transport Mode .................................... 22
  5.2.1. Increased Capacity ...................................................................................................... 22
  5.2.2. Reduction in Costs ...................................................................................................... 22
  5.2.3. Speed .......................................................................................................................... 23
  5.2.4. Reliability ................................................................................................................... 23
  5.2.5. Safety .......................................................................................................................... 23
  5.2.6. Comfort ...................................................................................................................... 23
  5.2.7. Summary: Timelines .................................................................................................. 23

6. Conclusion ............................................................................................................................ 25

7. References ........................................................................................................................... 26
List of Figures and Tables

Table 9.1 Projections of the emissions intensity of freight modes in Australia, GCO₂-e/tkm ......................... 10
Table 9.2 Projections of the emissions intensity of passenger transport modes in Australia, GCO₂-e/pkm.. 21
Executive Summary

Current developments of both passenger and freight vehicles show that a major thrust of future development effort will be to make vehicles lighter and increase the usable volume. In addition to the obvious measures of exploiting new materials and manufacturing processes and intelligent use of the payload space, a major contribution can be made by the suspension and drive. The suspension and drive will be 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.

This range of both emerging and existing rail technologies are available to substantially reduce greenhouse gas emissions and reduce costs, increase speed and achieve greater reliability. For freight, a combination of improved load factors, energy efficiency and operational improvements could reduce greenhouse gas emissions from 20 GCO₂ equiv. per tkm to 14.8 GCO₂ equiv. per tkm between 2005 and 2020. For passenger rail transport the adoption of a similar range of new and emerging technologies is expected to reduce greenhouse gas emissions from 139 GCO₂ equiv. per pkm to 77.9 GCO₂ equiv. per pkm.

This paper provides an outline of the major emerging rail technologies and considers their impact on greenhouse gas emissions and the competitiveness of rail.

The pace of technological change in railway rolling stock is fairly slow because railway rolling stock has a long life. Vehicle/track interaction has been a key aspect of contemporary technological research. This research has focused on such factors as assessing the curving performance and dynamic response of vehicles, selecting vehicle components that take account of the dynamic response of track structures, developing wheel impact monitoring systems, identifying maintenance requirements, structural integrity testing and modelling, assessing the wear behaviour of wheel/rail materials, design of modified wheel profiles and other aspects of wheel architecture and bogies.

Continuing technological development is making available more powerful and energy efficient diesel engines and electric motors, more effective power converters, and introducing regenerative braking as a means of supplementing the supply of electricity from on-board generators.

The railway wheel-set is undergoing a broad range of developments. Improvements in the configuration of the bogie have facilitated high-speed intercity railways and could support other developments, including long-distance freight. For mechanical braking systems, a much more effective control of wheel-slip is available through digital systems, and electric brake actuation will become established as an alternative to pneumatic systems. Advances in materials technology could be utilised to reduce the weight of locomotives and wagons (bodies, bogies and components), with the objective of increasing energy efficiency through reduced weight and greater usable volume, increase component life and decrease maintenance and therefore cost.

The main components of rail track technology are:

- rail materials;
- rail profiling and corrugation control;
- rail welding performance;
- sleeper components; and
- ballast, sub-ballast and formation characteristics.

Train Protection and Control Systems (TPC) is one of the most important potential 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. A new generation of control technology is already changing long-established practices in railway operations. Combining electronic interlocking with advanced computerised control systems provides the basis for automation of traffic management on the railway. An extension of such technology facilitates multi-media communication of traffic information to customers.
The movement of freight and the management of that movement is a key aspect of logistics. Logistics is only effective when there is an adequate supply of information about what is happening at each point in the supply chain, and when available alternatives are well known and understood. The improvements in information technology therefore make increasingly sophisticated logistics management possible.

Advances in freight rail technologies can increase the average laden factors for rail freight. The ways in which this increase in laden factors could be accomplished are the following. 1) Advances in logistics systems associated with new control technologies that can increase average load factors by (i) reducing empty running, and (ii) increasing the proportion of movements undertaken with optimal load levels. 2) Increased load factors for both larger trucks and for rail freight occurring as a result of the development of intermodal facilities. This follows earlier trends in the United States, whereby intermodal freight developments benefited rail freight and increased its average load factor. 3) Advanced urban freight systems facilitating greater use of intermodal terminals and hence increased load factors for both larger trucks and for rail freight.

A wide variety of new technologies could raise energy efficiency. Engine technologies alone could reduce energy consumption by 5% to 2020, 20% to 2030 and 35% to 2050, although limitations in the Australian rail network limit the supply and use of these in Australia. More efficient diesel engines and electric motors are now available and will be further developed. Hybrid engines and possibly electrification and fuel-cell-powered engines could also make a contribution in time.

The major way that freight rail can contribute to the reduction in GHG emissions in the short-to-medium-term is by increasing its competitiveness against more emissions-intensive forms of freight transport. The most obvious opportunity exists in diverting long-distance freight from trucking to rail. At present, a shift of one tkm of freight from articulated trucks to rail would save 40.2g of GHG emissions.

As with freight rail technology, the overarching issues in passenger rail technology are focused on improving vehicle/track interaction, reducing vehicle mass while increasing usable volume, and introducing the intelligent train. The focus in the first case is on reducing maintenance. Passenger train mass can be reduced through better bogie dynamics, simpler suspension and less-massive components. The intelligent train will be designed to monitor rail infrastructure and the performance of passenger rolling stock.

Improvements in electric motors and the associated power electronics will reinforce the trend to wheel or hub motors over a wide range of applications. For mechanical braking systems, a much more effective control of wheelslip is available through digital systems, and electric brake actuation will become established as an alternative to pneumatic systems.

The railway wheel-set is also undergoing a range of new developments. Improvements in the configuration of the bogie have facilitated high-speed intercity railways and could support other developments. State-of-the-art technologies include bogies with reduced mass, active secondary suspensions, and improved wheel profile.

The modern articulated train configuration might be replaced with a semi-trailer configuration. The advantages of semi-trailer vehicles could be greater capacity (up 15%), reduced weight (down 10%), increased accessibility to passengers (thereby saving time on boarding and disembarkation), increased gangways and reduced energy use.

High speed rail (HSR) is typically defined as steel-wheel-on-rail operation with cruise speeds exceeding 200 km/h. HSR trips of less than three hours can provide a very attractive alternative to air travel, as the journeys to airports and the process of going through check-in and security screening can make the total travel time longer than HSR. Recent experience in Europe and Japan shows the average energy consumption per pkm of HSR is generally in the range of one-third to one-fifth that of aeroplane and car energy use per pkm.

A range of both emerging and existing rail technologies are available to substantially reduce greenhouse gas emissions and reduce costs, increase speed and achieve greater reliability. For freight a combination of improved load factors, energy efficiency and operational improvements could reduce greenhouse gas
emissions from 20 GCO₂ equiv. per tkm to 14.8 GCO₂ equiv. per tkm between 2005 and 2020. For passenger rail transport, the adoption of a similar range of new and emerging technologies is expected to reduce greenhouse gas emissions from 139 GCO₂ equiv. per pkm to 77.9 GCO₂ equiv. per pkm.
1. Introduction

This paper provides an outline of the major emerging rail technologies and considers their impact on greenhouse gas emissions and the competitiveness of rail. Some of the technologies discussed may not be suitable for deployment in certain sectors of the rail industry in Australia. For example, product tracking cannot yet be used for bulk freight, technology risk might be too great where the technology has not been proven for Australian conditions, and there may be operational reasons for which a given technology cannot be deployed over part of a fleet. It is beyond the scope of this paper to undertake an assessment of the relevance of a particular technology for a specified market in Australia.

The paper firstly considers these issues for freight and then passenger rail transport.
2. **New Freight Technologies**

2.1. **Rolling Stock**

2.1.1. **Introduction**

The pace of technological change in railway rolling stock is fairly slow because railway rolling stock generally has a long physical and financial life. Locomotives are typically rebuilt many times. The relatively slow turnover of both locomotives and freight cars has slowed the penetration of energy-efficient technologies into the railroad freight system (OTA, 1994; Wickens, 1993). This slow turnover has related to the modest growth in demand for rail freight for many decades because of its displacement by trucks for much non-bulk freight. In addition, in the Australian case, the existing rail infrastructure (particularly the specifications of bridges and tunnels) limits the deployment of the contemporary freight locomotive, which has become too large and weighty for much of the current rail infrastructure. As a consequence, choices are limited and expensive modifications are required for new locomotives sourced internationally to meet the constraints of local infrastructure.

The future situation in the medium-term looks like being significantly different from the situation in the previous decades. Capacity requirements are rising with the export requirements for bulk freight, higher oil prices are having a bigger impact on the cost of trucking than on rail freight thereby boosting rail’s competitiveness for some types of freight, and climate change policies may, in the longer run, add to the strength of demand for rail freight. Fuel cost pressures, while less than those facing trucking, will still need to be met, and carbon emissions reduced. The sector will be looking at major changes in rail infrastructure and new rolling stock with high energy efficiency and low mass and low-track impact to meet these cost and environmental challenges.

2.1.2. **Overarching Issues**

Rolling stock, track, vehicle/track interaction and signalling have been key aspects of contemporary technological research. This research has focused on such factors as assessing the curving performance and dynamic response of vehicles, selecting vehicle components that take account of the dynamic response of track structures, developing wheel impact monitoring systems, identifying maintenance requirements, structural integrity testing and modelling, assessing the wear behaviour of wheel/rail materials, design of modified wheel profiles and other aspects of wheel architecture and bogies (IRT, 2008).

Current developments of both passenger and freight vehicles show that a major thrust of future development effort will be to make vehicles lighter and increase the usable volume. In addition to the obvious measures of exploiting new materials and manufacturing processes and intelligent use of the payload space, a major contribution can be made by the suspension and drive. The suspension and drive will be 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 (IRT, 2008).

The third overarching issue will be the rise of the intelligent train. This train will be capable of monitoring its own condition and that of the infrastructure that it uses (Randall, 2007). This leads to automated and semi-automated Train Protection and Control (TPC) systems that can either advise the driver of maximum speeds given traffic conditions on the network, automatically slow the train to take account of other train traffic, or ultimately result in automated driverless trains as, for instance, in the Copenhagen Metro (Marotta, 2005).
2.1.3. Power and Propulsion Technologies

The conventional diesel-electric engine that forms the workhorse of Australia’s rail freight system consists of a diesel engine that powers a generator, electricity converters and inverters, and an electric motor that drives the wheels. Continuing technological development is making available more powerful and energy efficient diesel engines and electric motors, more effective power converters, and introducing regenerative braking as a means of supplementing the supply of electricity from on-board generators. Further improvement in the near-term can be expected as microprocessor control becomes more sophisticated and more refined models of engine behaviour are derived, including the phased operation of multiple generators. Alternative fuels could be used, with biodiesel being incorporated as a blend with conventional diesel. Compressed Natural Gas (CNG) gas-turbine locomotives may have a future. While there are significant short-term constraints on Australian freight rail taking full advantage of these emerging technologies, in the medium-term, appropriate investments in rail infrastructure should facilitate a major upgrading of our freight rolling stock.

In the medium-to-long-term a number of technological developments are possible. They include:

1. Further refinements of regenerative braking systems with intelligent control.
2. Greater consumption of biofuels in the overall fuel blend and the substitution of second-generation biofuels for first-generation fuels. These second-generation biofuels will have much lower life-cycle emissions intensity than first generation biofuels.
3. The use of energy storage technologies such as new types of batteries or flywheels in a hybrid diesel-electric power configuration in which the energy storage device feeds electricity into the system as an alternative to the diesel-fuelled generator, particularly in relation to idling and acceleration requirements. This development has already begun with respect to passenger rail, but much more powerful energy storage systems are required for long-haul freight vehicles. The Economist (2008) indicates the exciting potential for new battery technologies that has been recently unlocked.
4. Fuel-cell powered locomotives. These are being trialled for passenger rail, but are some way off for freight at this stage.
5. Electrification has obvious attractions for railways since the prime mover is not carried by the vehicle and a power/mass ratio better by a factor of up to 3 is obtained. Electric traction enables faster speeds and provides additional power for short periods more easily than the diesel-electric locomotive. Of course, electrification requires intensive use to justify the higher infrastructure cost, and, from a climate change point of view, is best justified when sources of power become more environmentally sustainable.

2.1.4. Other Technologies

Railway Wheel-set

The railway wheel-set is undergoing a broad range of developments. Improvements in the configuration of the bogie have facilitated high-speed intercity railways and could support other developments, including long-distance freight. Moreover, body-steered bogies, in which the wheel-sets are steered by means of linkages actuated by the car body, reconciles the fundamental conflict between steering and stability associated with the use of the coned railway wheel-set. There has been increasing interest in the application of single wheeled suspensions, where the two-
axle bogie is replaced by a single axle, enabling good laden/tare mass ratios, low mass per passenger and better utilisation of the structural clearance gauge to be achieved. In active guidance, wheels are steered by actuators in response to measurements of vehicle position with respect to track. If active steering is adopted, it is not necessary to rely on the coning of the wheels for guidance, thus allowing axles to be dispensed with (IRT, 2008).

Technologies for the preventive maintenance of rolling stock are available. Condition monitoring systems focus on wheel heat as a diagnostic parameter. This approach identifies problems before failed axle bearings or frozen brakes cause damage to the wheel-set, track, or contribute to derailment. Acoustic signature monitoring involves the automated interpretation of noise produced by moving train wheels for the diagnosis of a variety of mechanical defects (SKM, 2004).

**Braking Systems**

For mechanical braking systems, a much more effective control of wheel-slip is available through digital systems, and electric brake actuation will become established as an alternative to pneumatic systems. The parallel improvement in actuators used in active suspension and brake control systems could lead to the all-electric vehicle with all the simplification that this represents. The integration of steering, drive and ride would provide an intelligent wheel, which would become the major building block in future vehicle design. However, when these braking technologies are deployed they need to be across the whole fleet since operators cannot have a mix of electric and pneumatic brakes on one train.

**Other Technological Possibilities**

Advances in materials technology could be utilised to reduce the weight of locomotives and wagons (bodies, bogies, and components) with the objective of increasing energy efficiency through reduced weight and greater usable volume, increase component life, and decrease maintenance and therefore cost. This should be treated as a whole system (railway rolling stock and rail infrastructure) issue. The materials of interest include the steels used in the manufacture of wheels and vehicle body construction (IRT, 2008; Goodall, 2007). The weight of rolling stock can also be reduced by replacing existing mechanical control systems with electronic fly-by-wire systems (Copper, 2007).

New configurations for wagons are another possibility. A new wagon design from Finland maximises volume. Another possibility is the self-loading container train which has been in use internationally since the early 1990s. Finally, short freight trains (Freight Multiple Units) possess the acceleration and speed characteristics of passenger trains and provide less reliance on full train payloads, thereby allowing for more responsive delivery scheduling (SKM, 2004).

There is also some possibility of increasing energy efficiency through reducing the aerodynamic drag experienced by moving trains. Aerodynamic drag is an increasing function of speed and a decreasing function of train length. Increasing length will reduce the energy consumption per wagon. Of course, longer trains require more freight to be economically operated. Drag can also be reduced through better aerodynamic profiling of locomotives and, possibly, the use of airbags between wagons.
The energy use associated with the operation of accessory equipment is of relatively small importance in freight transport;\(^1\) but innovations adopted in relation to road vehicles could be used with respect to mobile air-conditioning and lighting.

2.2. Track Design, Construction and Maintenance

2.2.1. Rail Technologies

The main components of rail track technology are:

- rail materials;
- rail profiling and corrugation control;
- rail welding performance;
- sleeper components; and
- ballast, sub-ballast and formation characteristics.

In the past, track-related research has concentrated on the durability of rails, with a focus on rail corrugation and rail wear. Advances in materials technology have enabled the development of both steel alloys and head-hardened rails that are suitable for heavy haul traffic, such as that required in the transport of iron ore.

At present, the focus on ameliorating rail deterioration has shifted to rolling contact fatigue damage. The development of improved wheel and rail profiles has led to markedly reduced contact at the gauge corners of the rail and, consequently, significant reduction in rates of wear and defect generation. Research on rails and welds has developed models to predict critical stress locations and mechanical testing to determine failure modes. This information, in combination with vehicle/track interaction characteristics, has been used to determine the most cost-effective rail selection. Detailed analysis of track geometry data has provided the means for assessing track behaviour and different track components (IRT, 2008).

Research into the development and assessment of new materials can increase component life and reduce cost. The materials of interest include the steel used in the manufacture of rails, rail welding, bridges and sleepers; cast iron used in rail fastening systems; polymers used for rail pads; rail and wheel lubricants; and the rock used for ballast. Traditional timber sleepers are now being displaced by low-profile concrete sleepers and plastic sleepers.

Randall (2007) notes that tracks are now being redesigned to better match train dynamics. This involves such factors as better control of track position, much tighter tolerances, improved drainage, and improved performance. Finally, water-based lubrication is being applied under a computerised system after the locomotive drive wheels. This can reduce fuel consumption by an average of 7.5% and rail and wheel maintenance and replacement costs by as much as 25%, in addition to reducing noise (SKM, 2004).

Except perhaps for the Pilbara railways, which are regarded as some of the world’s best, Australia starts a long way behind the world’s-best rail track technology. Big investments are required to plug the gap and then take advantage of the expanding technological frontier.

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\(^1\) Although electronic engine controls, including the greater use of fly-by-wire systems to replace mechanical systems, could change this.
2.2.2. Other Design Features

Railways have certain natural advantages in their effect on the environment. But environmental standards are becoming increasingly more stringent in response to the expectations and concerns of the public. For a new line land-take is small compared with a motorway, which has a lower capacity. The most severe environmental impact of trains is that caused by noise and vibration. The most effective form of control at present is to install barriers alongside the track. Much can be done to improve vehicle design and features such as bogies with better steering, wheel-sets with resilient inserts and bogies with skirts can be expected to become more common.

Finally, the design of railway bridges and an ongoing assessment of their performance is an important aspect of rail infrastructure development and operation. This will become an important issue in Australian rail infrastructure. Assessment procedures include inspection of bridge structures, measurement of axle load distributions, strains within bridge structures and the derivation of dynamic amplification factors. There are two main objectives for this research:

- accurate estimation of bridge capacity and remaining life; and
- implementation of higher axle loads.

The implementation of higher axle loads with a larger kinematic envelope (outline size of the train) would allow the purchase of USA standard rolling stock. This would decrease acquisition times, decrease cost, increase the payload per train and allow the quick introduction of more efficient rolling stock.

2.2.3. Track Maintenance

On railways that are increasingly subjected to commercial pressures not only must track maintenance costs be minimised but also disturbance to train services must be avoided. There is a high degree of mechanisation of track maintenance and the machines used are becoming increasingly productive. An example of current technology is the Dynamic Track Stabiliser, which enables track renewal overnight with restitution of full-speed operation the next morning. In addition, combined technical and economic modelling of track component deterioration has resulted in recommended rail replacement strategies which, in turn, have led to reduced system costs. This approach has been extended to the provision of a detailed track maintenance planning tool that takes into consideration the effects of rail and track maintenance activities, rail and wheel wear, rail fatigue defects and fuel costs to give an overall minimum operating cost to the railway system. Monash’s Institute of Railway Technology has developed an automated condition monitoring system for railways. It has been used by BHP Billiton on its Iron Ore Rail Road in Western Australia (IRT, 2008). SKM (2004) notes a number of asset maintenance and monitoring systems, including asset maintenance analysis, remote asset condition monitoring, wayside condition monitoring, and in-train condition monitoring.

Artificial intelligence, expert systems and robotics together with diagnostic systems and condition monitoring are converging technologies likely to create significant synergy in the next two decades. With the computerisation of the measurement and analysis of track defects, the development of mathematical models of track response to the loads applied by trains and the application of robotics to track maintenance, completely automated track maintenance systems have become possible.
2.3. **Control Technologies**

2.3.1. **Network Traffic Control**

Improving traffic control of trains, such as through Train Control and Protection systems, 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.

A new generation of control technology is already changing long established practices in railway operations. Combining electronic interlocking with advanced computerised control systems provides the basis for automation of traffic management on the railway. An extension of such technology facilitates multimedia communication of traffic information to customers. Such systems would ultimately combine operational control including the monitoring and correction of real-time performance, such as energy use, and the allocation of resources in terms of vehicles, infrastructure and staff. These systems would embrace on-board signalling and train control with automatic vehicle identification and continuous track-to-train communication. The final logical step would be the automation of train driving and driverless trains, which is already occurring in many countries (Marrotta 2005).

Progress will not be confined to the provision of better hardware. A significant feature of the control centre of the future is that it provides an opportunity to unify the planning, the monitoring and the control of operations in one consistent set of software. The full exploitation of expert systems will avoid the rigidity of algorithmic methods and enable the incorporation of human expertise and experience.

2.3.2. **Freight Manager Control**

A second aspect of control technology pertinent to rail freight is freight manager control. The movement of freight and the management of that movement is a key aspect of logistics. Logistics is only effective when there is an adequate supply of information about what is happening at each point in the supply chain, and when available alternatives are well known and understood. The improvements in information technology therefore make increasingly sophisticated logistics management possible. Of prime importance has been the development of barcoding systems that enable goods to be tracked and real-time data to be compiled. The modern electronic equivalent is by radio frequency identification devices (RFID), which allows electronic detection and interrogation of information regarding wagons, containers, pallets, boxes or products. Developments in mobile communication technology and various means to exchange data with vehicles have substantial impacts to structured processes, in particular, acquisition of data from moving vehicles and freights. With the further development and deployment of mobile communication technology, it will become possible to obtain dynamic data of freight and fleet and to grasp the overall perspectives of freight movements on a real-time basis. Other ICT developments of major significance include e-commerce, supply chain-related e-business solutions, digital delivery and B2C e-commerce.

A range of information systems are being deployed through the logistics system, including vehicle routing and scheduling systems that optimize vehicle use, track and trace systems, freight matching, and vehicle booking systems.

The Australian rail freight operator, Pacific National, is developing a fully-integrated freight control system (FCS) that uses GPS, satellite communications and track-side data readers to plan and control a range of business operations from the deployment of wagons and locomotives to fuel consumption, crew rosters and
maintenance schedules. It also offers customers the convenience of online freight booking via its Freight Web, automated monitoring of terminal operations and online freight monitoring across the network.

ICT technologies are also being utilised to improve train management. There are in-cab advice systems for improving timekeeping and reducing energy consumption on long haul trains (SKM 2004).

Non-ICT technological change has also offered new solutions to logistical problems. The standardisation of container sizes and the development of groupage services is an important example. Improvements in equipment for intermodal transport, including modified truck trailers, train wagons and lifting equipment have also been important. Improved efficiency in the intermodality of transport has been of vital importance in enabling the globalisation of supply chains (this topic is covered in the next section of the paper). The use of longer trains with higher axle mass limits has complemented these technologies in improving logistical efficiency.
3. The Impact of New Freight Technologies

3.1. The Impact on Greenhouse Gas Emissions

3.1.1. Increased Load Factors

Advances in freight rail technologies can increase the average laden factors for rail freight. A rough assessment of the potential savings in energy and emissions from increased laden factors would be 6% by 2020, 10% by 2030 and 15% by 2050 (Jolley, 2008). The ways in which this increase in laden factors could be accomplished are:

1. Advances in logistics systems associated with new control technologies that can increase average load factors by (i) reducing empty running, and (ii) increasing the proportion of movements undertaken with optimal load levels.
2. Increased load factors for both larger trucks and for rail freight occurring as a result of the development of intermodal facilities. This follows earlier trends in the United States whereby intermodal freight developments benefited rail freight and increased its average load factor.
3. Advanced urban freight systems facilitating greater use of intermodal terminals and hence increased load factors for both larger trucks and for rail freight.

3.1.2. Increased Energy Efficiency

A wide variety of new technologies could raise the energy efficiency (i.e., reduce energy consumption and emissions) of rail freight by 18% to 2020, 39% to 2030 and 55% to 2050 (Jolley 2008). Engine technologies alone could reduce energy consumption by 5% to 2020, 20% to 2030 and 35% to 2050. More efficient diesel engines and electric motors are now available and will be further developed, and eventually hybrid engines and possibly electrification and fuel-cell-powered engines could make a contribution. Further improvements in energy efficiency could be gained through microprocessor controls on engines (a net 2% gain after allowing for the offsetting extra energy consumption associated with the increased use of electronics for all purposes). Universal energy recovery from regenerative braking could reduce energy consumption by as much as 15% by 2030.

Weight reductions for rolling stock could be achieved by exploiting new materials and manufacturing processes, improving the design of the wheel-set, and moving towards fly-by-wire control systems. Gains of around 4% in energy efficiency could be secured by this means up to 2050. Design changes that result in reduced aerodynamic drag could result in gains of 2% in energy efficiency in the long run. Improved track design including the adoption of rail lubrication techniques could result in the average performance of freight services getting nearer to the most energy-efficient performance, with gains of up to 12% in the long run.

3.1.3. Operational Improvements

Operational improvements could yield energy economies of 4% to 2020, 12% to 2020 and 20% to 2050. Three factors could contribute to such results:

1. High-technology rail maintenance (perhaps resulting in 5% long-run efficiency improvements), which would reduce the incidence of stoppages and enforced slowing of traffic.
2. Traffic decongestion could lead to 10% long-run efficiency increases. This could occur as a result of improved network traffic control of trains, with improved intermodal freight systems also contributing to decongestion.

3. Remote driver operation technologies could add another 8% in efficiency improvements in the long run to operational performance.

3.1.4. Reduced Emissions Intensity

The above factors indicate the means by which the adoption of new technologies could reduce the energy consumption of freight rail. All things being equal, these reductions will flow through to a proportionate cut in the GHG emissions arising from the operation of freight rail in Australia. But in addition to the reductions in GHG emissions associated with reduced energy intensity, GHG emissions per unit of energy consumption for freight rail will also be reduced in the long run by more than 35%. This would occur as a consequence of:

1. The substitution of biodiesel for diesel as a fuel will lower emissions. This may occur with the development of second-generation biodiesel after 2020, although there remain considerable uncertainties about the likely development path for biodiesel.

2. The extension of electrification of parts of the freight rail network may be possibility in the very long run. This would coincide with the expected major reduction in the emissions intensity of electricity production in Australia. The introduction of advanced urban freight systems drawing on electricity would also represent a substitution of electricity for oil-based fuels.

3. Zero-emissions hydrogen-powered fuel cells may be possible in the very long run.

4. Hybrid locomotives are able to reduce fuel consumption through regenerative braking.

3.1.5. Overall Impact

Table 9.1 summarises the possible overall impact on GHG emissions per tkm of technological and organisational changes on public freight rail, along with comparisons with private freight rail and articulated trucks.

| Table 9.1 Projections of the emissions intensity of freight modes in Australia, GCO₂-e/ktm |
|----------------------------------|-------|-------|-------|-------|
| Public Freight Rail              | 2005  | 2020  | 2030  | 2050  |
| With improved loading factors    | 20.0  | 18.8  | 18.0  | 17.0  |
| Plus energy efficiency improvements | 20.0  | 15.4  | 11.0  | 7.7   |
| Plus operational improvements    | 20.0  | 14.8  | 9.7   | 6.1   |
| Plus Fuel Shifts                 | 20.0  | 13.6  | 7.5   | 3.9   |
| Private Freight Rail             | 5.4   | 3.3   | 1.8   | 1.2   |
| Articulated Trucks               | 60.2  | 47.2  | 35.7  | 19.1  |

The combination of improved loading factors, energy efficiency improvements, operational improvements and fuel shifts could reduce GHG emissions per tkm for public freight rail from the current level of 20.0g to 13.6g in 2020 and 3.9g by 2050. Similarly, the already low emissions rate of 5.4g for private freight rail could fall to 1.2g by 2050. By way of comparison, technological and organisational changes could reduce the corresponding emissions rate for articulated trucks (the main form of competition between rail and road for freight movements) from 60.2g in 2005 to 19.1g in 2050. Without major technological changes in the rail sector, rail freight could lose its environmental advantage over road freight in the very long run.
3.2. The Impact on the Competitiveness of Rail as a Transport Mode

The best way that freight rail can contribute to reducing GHG emissions in the short-to-medium-term is by increasing its competitiveness against more emissions-intensive forms of freight transport. The most obvious opportunity exists in diverting long-distance freight from trucking to rail. At present, a shift of one tkm of freight from articulated trucks to rail would save 40.2g of GHG emissions. In the very long run, there is significant potential for emissions reductions in trucking, but technological progress in rail should ensure a sizeable gap in emissions-intensity between trucking and freight rail will persist. As a result, environmental pressures for continuing modal shift in freight will continue. The following sub-section of this paper outlines the way in which change in the rail sector can boost its competitiveness as a freight mode.

3.2.1. Reduction in Costs

Technological and other innovations can facilitate a reduction in the costs of freight rail, thereby boosting its competitiveness with other transport modes. There are five ways in which this might occur.

1. Many of the new rolling stock technologies will have the effect of increasing the capital costs of rolling stock in the short-to-medium term. However, operating costs per tonne km will be reduced by increased energy efficiency, reduced maintenance requirements (particularly on tracks and wheels, but also in the less complex nature of the new generation of engines and motors, and the adoption of preventive maintenance techniques for rolling stock), and increased flexibility in the tare to laden mass, including gains associated with new wagon designs.

2. New track technologies could result in reduced interruptions to freight movements because of track defects. Increased life for track and track components associated with these technologies would help to spread capital costs and also reduce maintenance costs. Track improvements can also reduce rolling stock operational costs and potentially improve effectiveness (e.g., increased capacity with higher axle loads).

3. The adoption of advanced network traffic controls can reduce the fuel costs of the freight operator and improve the utilisation of vehicles and staff and thereby reduce both the variable and fixed cost of operations. Improved logistics facilitate economies in both fuel costs and the cost of equipment through more efficient vehicle operation.

4. Increased modal choice associated with the development of intermodal freight facilities will tend to reduce freight rates. Intermodal transport facilities will increase the integration of rail into the logistics network.

5. Infrastructure costs for advanced urban freight systems are high and uncertain. Operating costs could be reduced because of automated transport (reduced labour costs), and greater throughput from the ports allowing for economies of scale in intermodal and rail freight systems.

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2 This is based on the existing average emissions rates. Strictly speaking, it should be based on marginal rates, which are more difficult to calculate. For very small shifts in freight volumes, the marginal changes in emissions would be slight in both modes with loading factors changing more than traffic volumes. The use of averages is a more useful approximation for large intermodal shifts.
3.2.2. Increased Speed

A second means of achieving increased competitiveness is through measures that increase the average speed of rail freight services. This can occur in five different ways.

1. New engine technologies and improved vehicle/track interaction will permit higher speeds, which adds to the competitiveness of rail, although increased speed could eat into the environmental advantages gained in energy efficiency.

2. Average rail freight speeds would be boosted by more consistent track conditions as a consequence of new track technologies.

3. Advanced network traffic controls can reduce stoppages and thereby increase average speeds.

4. The development of intermodal freight facilities could result in a reduction in the transit time through the supply chain.

5. The adoption of advanced urban freight systems could result in faster cargo movements through the system.

3.2.3. Greater Reliability

A third aspect of improved competitiveness is advances towards greater reliability in freight services. These could occur as a consequence of:

1. New rolling stock technologies that reduce the disruption associated with faults in rolling stock or track infrastructure.

2. Improved track conditions increasing the reliability of services.

3. More advanced track maintenance methods resulting in quicker restitution of damaged track.

4. Advanced network traffic controls that increase the reliability of maintaining schedules of freight operation.

5. The provision of state-of-the-art intermodal freight facilities that result in a general improvement in the quality of rail freight services.

6. Advanced urban freight systems resulting in increased reliability.

3.2.4. Other Aspects of Competitiveness

Other aspects of improved competitiveness for freight rail would be:

1. Increased operational flexibility as a consequence of operating short freight trains in certain locations.

2. Improvements in track and control technologies and the introduction of new urban freight systems increasing safety.

3. Security increased by separating inspection from the port area.

4. The development of facilities for intermodal freight increasing the overall energy efficiency of the transport system and improving opportunities for freight rail.

5. The adoption of advanced urban freight systems would reduce congestion on existing modes and hence emissions related to such congestion.
6. Advanced urban freight systems would facilitate the increased competitiveness of long-distance rail for freight by improving the scope for transporting long-distance from intermodal terminal to intermodal terminal.

3.3. Timelines for New Technologies

The timelines for the development and diffusion of new rail technologies are summarised below.

The Diffusion of Existing State-of-the-Art Technologies

1. The introduction of current state-of-the-art technology in diesel engines and electric motors, railway wheel-sets and braking systems.

2. The diffusion of improved wheel and rail profiles, better methods of selecting rails and other components, advanced bridge design and the increased mechanisation of maintenance.

3. The adoption of the new generation of network traffic control technology and advanced technologies in logistics.


Near-term Innovation and Medium-term Adoption of New Technologies

1. Microprocessor control on engines, full adoption of regenerative braking, the use of biofuel blends, advances in bogie design, and materials technology.


3. The adoption of next-generation network traffic controls and logistics technologies.

4. Incremental change in intermodal freight facilities.

Medium-Term Innovation and Longer-Term Diffusion

1. The introduction of hybrid engines, active steering, second-generation biofuels, advanced materials technology in rolling stock and change of the rail network to allow the off-the-shelf purchase of US rollingstock.

2. Re-design of track technologies in the light of further information. Completely automated track maintenance systems and algorithms for preventive maintenance.

3. Investments in major projects such as the North-South inland railway.

The Very Long Run

1. Fuel-cell powered locomotives.

2. Advanced urban freight systems deployed in the Port of Melbourne to metro intermodal centres, and the Port of Botany to Sydney intermodal centres.
4. Passenger Rail Technologies

4.1. Rolling Stock

The modern passenger train contains the following vehicle sub-systems: car body; car body fittings; bogies and running gear; power system; propulsion; auxiliary systems; braking system; interiors; on board vehicle control; passenger information system; communications systems; cabling and cabinets; door system; heating, ventilation and air-conditioning system (HVAC); tilt system; lighting; and coupler. The main aspects of desirable technological change in passenger railway equipment involve suspension and drive, power and energy, communications and information, track, and track environment.

As with freight rail technology, the overarching issues in technology are improving vehicle/track interaction, reducing vehicle mass while increasing usable volume, and introducing the intelligent train. The focus in the first case is on reducing maintenance. Passenger train mass can be reduced through better bogie dynamics, simpler suspension and less-massive components. The intelligent rain will be designed to monitor rail infrastructure and the performance of passenger rolling stock (Randall, 2007).

4.2. Power and Propulsion Technologies

4.2.1. Urban Electrified

The application of high power gate turn-off devices has made three-phase drives cost-effective, while developments in control technology have made it possible to control AC motors as effectively as the DC machines that they are replacing. The greater simplicity and the lower mass and volume of the AC motor gives more design freedom for innovation in running gear, quite apart from the major benefits in terms of controlling the tractive effort. Possible improvements in electric motors and the associated power electronics will reinforce the trend to wheel or hub motors over a wide range of applications.

For mechanical braking systems, a much more effective control of wheelslip is available through digital systems, and electric brake actuation will become established as an alternative to pneumatic systems. The parallel improvement in actuators used in active suspension and brake control systems could lead to the all electric vehicle with all the simplification that this represents. The integration of steering, drive and ride would provide an intelligent wheel, which would become the major building block in future vehicle design.

4.2.2. Regional and Interstate: Diesel

As we have seen with respect to rail freight, the technology of diesel engines has been improving, while regenerative braking has been introduced. Regenerative braking is destined to be adopted in all electric and diesel-electric trains.

JR East & Hitachi Ltd introduced the world’s first hybrid rail passenger car, which entered service on August 1, 2007 in Japan, and on September 30, 2007 in Britain. It has relevance for the non-electrified passenger rail systems in Australia. The conventional diesel-electric locomotive has been modified to include a battery system alongside the diesel generator. The battery supplies power to auxiliary functions at station stops and at the departure for the station. Power is supplied by both the diesel generator and batteries for acceleration, and regenerative power from braking is stored in batteries. Test results from the 2003-06 period indicated that this locomotive provides 20% savings in fuel and a 50% cut in harmful emissions, as well as reducing engine costs.

JR East & Hitachi Ltd are also trialling a fuel-cell-powered hybrid railcar. In a world first, running tests commenced on April 15, 2007. The diesel engine/electric
generator link has been removed together with stores of diesel fuel and replaced with fuel cells and hydrogen tanks. Its perceived advantages are the replacement of diesel engines and oil-based fuel, the provision of an alternative to further electrification, operational flexibility and, eventually, zero-carbon emissions (Cooper, 2007).

4.3. Railway Wheel-set

The railway wheel-set (comprising bogies, suspension, wheel-set systems and auxiliaries) is also undergoing a range of new developments. Improvements in the configuration of the bogie have facilitated high-speed intercity railways and could support other developments. State-of-the-art technologies include bogies with reduced mass, active secondary suspensions, and improved wheel profile. Future possibilities comprise active steering, composite bogie frames, composite wheel-sets, bogie-less configurations and alternatives to pneumatics (Goodall, 2007). While these developments would increase the cost of vehicles, track impact, energy consumption and emissions would be greatly reduced, and a smoother and more comfortable ride would be provided for passengers.

There has been increasing interest in the application of single-wheeled suspensions, where the two-axle bogie is replaced by a single axle, thereby enabling good laden/tare mass ratios, low mass per passenger and better utilisation of the structural clearance gauge to be achieved. Active suspensions in the form of tilting body systems are now established in railway service, and other forms of active suspensions may well be exploited. In active guidance, wheels are steered by actuators in response to measurements of vehicle position with respect to track. If active steering is adopted, it is not necessary to rely on the coning of the wheels for guidance and the axles can be dispensed with.

4.4. Train Configuration

The technologies employed in car body sub-system are developing. The main elements in the car body sub-system are the body shell, underframe, floor, crash structure and windows. Most of the material in a car body is there to make it sufficiently rigid. The technology to save weight has already been developed, but is costly. Current technologies being deployed include lighter-weight structures and crash zones and high-integrity windows. Future possibilities include lightweight composite bodies and double-decker bodies. While increasing vehicle cost, these changes would reduce track impact, energy consumption and emissions (Goodall, 2007).

New stock on the London Underground now include regenerative braking, flexible frame bogies, improved suspension, wider gangways, saloon air-conditioning, electric sliding double-doors, and full audio-visual information systems.

Neil (2007) suggests that the modern articulated train configuration might be replaced with a semi-trailer configuration. The advantages of semi-trailer vehicles could be greater capacity (up 15%), reduced weight (down 10%), increased accessibility to passengers (thereby saving time on boarding and disembarkation), increased gangways, and reduced energy use. Development time and capital spending would be increased, but operating costs reduced. Manufacturers are developing concepts but commercial versions are not yet in place.

Neil (2007) also argues that new rail car designs can improve the passenger interface through improvements in accessibility, safety, signage, emergency facilities, emergency lighting levels, saloon ambience (with respect to lighting, temperature, comfort and noise) and personal space. Displays of real-time information at stations and on trains are improving in quality. Advances in the technologies used in fare collection can also add to

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3 In active steering, wheelsets are steered by means of linkages actuated by the car body.
customer convenience. Finally, passengers can look forward to having high-speed Internet access on-board in the future.

4.5. Other Factors

Part of the vision for new energy efficient passenger trains is the design of lightweight but high-capacity trains. For some countries, such as the United Kingdom, this would mean a reversal of a tendency for trains to become heavier. The impact of lighter weight trains would be to reduce energy consumption and therefore GHG emissions. In addition, it would also reduce the impact on rail track, fatigue load and hence track maintenance.

At present, the control systems on trains are estimated to weigh about 4 tonnes per train. In the next generation of technology, mechanical control systems will be replaced by electronic fly-by-wire systems (Cooper, 2007) (as pioneered in the aerospace industry).

As power and propulsion systems become more regenerative and efficient, kinetic energy (proportional to mass, and hence train length) becomes a progressively smaller contributor to consumed energy, and energy use becomes dominated by aerodynamic drag. Increased train length will always reduce the energy consumption per seat, but aerodynamic drag can be reduced by the better profiling of car bodies (Goodall, 2007). Improvements in the operation of accessory systems on passenger trains are possible. These include changes in HVAC systems, better thermal insulation, more energy-efficient lighting, and reduced idling (Randall, 2007).

In the long term, consideration is likely to be given to Remote Train Operation (RTO) or ‘manned driverless’ trains. RTO is being approached through incremental steps. The first step – auto-reversing – is being assessed in some countries. The principal rolling stock requirements for RTO are intelligent door control, high train system reliability, enhanced communication facilities, remote recovery, and back-up manual driving controls.

Automatic Train Protection (ATP) interfaces the signalling system of railways and transmits relevant data to the train. It can supervise actual train speed and location against the movement authority generated by the signalling system and apply brakes automatically if the driver fails to respond to movement authority limits.

4.6. Capacity

To accompany technological change, there is a case for the extension of network coverage, capacity and frequency (OECD 1997). In the case of Australia, this involves extending electrified rail passenger routes into major suburban areas not presently covered (a process that will be encouraged by increasing population densities in many of these areas), investing in infrastructure improvements that increase the quality of regional train services (as in the case of recent initiatives in Victoria), and improving interstate rail services. In the latter case, there is the longer-run possibility of developing an electrified Very Fast Train service between Melbourne and Sydney and, eventually, Sydney to Brisbane.

4.7. High-speed Inter-city Rail

High speed rail (HSR) is typically defined as steel-wheel-on-rail operation with cruise speeds exceeding 200 km/h. At present, HSR systems exist in Europe, Japan and other parts of Asia as well as the east coast of the United States. HSR trips of less than three hours can provide a very attractive alternative to air travel, as the journeys to airports and the process of going through check-in and security screening can make the total travel time longer than HSR. For the International Energy Agency’s BLUE scenario, HSR becomes an attractive option since: a) it can provide passenger service at lower average energy intensities than air or car travel (per passenger km), and b) the electricity used will be generated primarily by zero-carbon sources after 2030.
Though the energy intensity of HSR varies with operating conditions and passenger load factors, recent experience in Europe and Japan shows the average energy consumption per pkm of HSR is generally in the range of one-third to one-fifth that of aeroplane and car energy use per pkm. CO₂ emissions are also dependent on the source of electricity generation. Clearly, with zero CO₂ generation, the total CO₂ emissions of rail systems are near zero (apart from factors such as construction of the trains and track systems themselves, and fossil energy used to heat stations).

A key consideration for HSR construction is the niche it serves. As mentioned, HSR can be competitive with air travel up to at least three hours of HSR travel, or 700 to 800 kilometres. The recent announcement of a new generation of HSR technology promises even greater speeds and applicable distances. However, HSR is not especially advantageous for journeys less than 200km, as conventional rail systems achieve nearly the same overall time performance at much lower cost.

Costs of HSR construction vary significantly from country to country on account of differences in land costs, labour costs, financing methods and topography. The costs per kilometre of rail systems can range from around US$10 million to over US$100 million.

Many HSR lines are currently being proposed and planned around the world. However, their rate of construction is far slower than announced plans would suggest. Europe leads with 2000 km of high-speed lines in operation, and with another 4000 km planned for construction by 2020. China is expected to build 3000 km of high-speed railways within 15 years. Argentina has recently announced plans to build a 700km line from Buenos Aires to Córdoba, which would be the first high-speed line in Latin America. Many other countries are planning HSR lines, including Brazil, Morocco, Saudi Arabia, Iran, Israel, Turkey, Portugal, Russia, Malaysia (along with Singapore), Pakistan, and Vietnam (IEA, 2008).

Four new HSR lines are due to be launched in Europe within a year, with trains running up to 320km/h. International passenger-rail services in Europe will be opened up to competition from January 2010. This could lead to a dramatic liberalisation of Europe’s railways, akin to that of its airlines. Concerns over climate change, hassles at overcrowded airports, delayed flights and congested roads have conspired with better high-speed rail technology to make the train an increasingly attractive alternative and an especially green one: a full high-speed electric train emits between a tenth and a quarter of the carbon dioxide of a plane.

How successful will the new high-speed lines be at taking business away from airlines? If airlines had to pay the same taxes train operators do, namely value-added tax and a tax on fuel, a big shift in passenger numbers would be more likely. High-speed rail has other advantages over airlines: added comfort and the ability to walk about, eat in a dining car, work online or use a mobile phone, and avoiding endless queues and security checks. Railways have to compete in other respects. Booking and yield management systems need to improve (although SNCF has an airline-type system that is competitive). However, airlines are reckoned, in general, to be 15 years ahead of railways regarding the way in which they manage their businesses. As with multiple freight modes, coordinated airline-rail ticketing and transfers are a possibility and are being trialled by Deutsche Bahn. Travel experts note that, on six-hour journeys, rail is typically winning more than 60% of the leisure market from airlines. The same is happening with business travellers on four-hour journeys (Economist, 2007).

The Sydney-Melbourne route provides a test case for the prospects of high-speed rail in Australia. The economic equation is becoming more favourable with high oil prices and congestion at Sydney airport. Potential traffic volumes are quite high by international standards. Climate change policies and, in particular, the way in which emissions trading works, will be an important factor influencing the overall economics of Sydney-Melbourne fast rail.
4.8. **Light Rail**

Light rail is a form of urban rail public transportation that generally has a lower capacity and lower speed than heavy rail and metro systems. The term is used to refer to modern streetcar/tram systems with rapid transit-style features that usually use electric rail cars operating mostly in private rights-of-way separated from other traffic but sometimes, if necessary, mixed with other traffic in city streets.

Light rail as we know it today was first created in mainland Europe from the 1970s as street tramways were upgraded with new rolling stock and segregated alignments. In the 1990s new technology was introduced to provide low-floor trams with step-free entrances only 350mm above rail level. By building up kerbs slightly to match this height each stop, trams have been made fully accessible.

There has been a great deal of change in light rail technology over recent years. The changes include the following.

*Reduced power consumption.* Lower energy use has been attained through the development of more efficient motors, better electronic controls, regenerative braking, and the use of lighter weight car bodies. This helps reduce operating costs and improves the environmental footprint of light rail.

*Faster acceleration.* Improvements in electric motors, including the development of more powerful magnetic materials, and the development of advanced electronic controls for them, have enable faster average speed to be attained and reduced trip times.

*Wheel-mounted motors.* This is a relatively new alternative to conventional systems. With this technology, the axles are driven by motors via reduction gears and flexible couplings. The major advantage is that the bulk of the motors and drive couplings under the vehicle floors is eliminated, thereby enabling floors to be lowered. Another advantage is reduced torque transmission loss and thus lower power consumption. In addition, it results in both reduced maintenance costs and lower noise output.

*Lower floors.* Low floor vehicles have been made possible by the development of wheels that are individually powered, thereby eliminating the need for bulky central motors and axles. Lower floors make entry and exit easier, faster and safer, especially for people with disabilities. They also reduce dwell time, thereby contributing to faster overall speed.

*Lighter weight car bodies.* Aluminium alloys and composite materials can provide high strength while greatly reducing weight as compared to steel. The result is a substantial savings in energy consumption without sacrificing safety.

*Greater safety.* Safety standards for light rail have been enhanced by the development of stronger vehicles, the elimination of steps, and thus use of CCTV cameras for vehicle operators to monitor the closing of doors and road traffic behind the vehicle.

*Traffic signal priority.* Low-cost electronic devices allow street traffic signals to give priority to approaching rail vehicles in intersections where rail vehicles run in streets or in street-medians. This contributes to overall speed.

*Alternative power.* Methods of powering vehicles for locations for which erecting overhead electrification is not economical or practical include diesel engines, batteries, fuel cells and flywheels. Progress has been made in all of these. Diesel is still the most practical and has recently seen much progress, including reduced fuel consumption, lower exhaust emissions, reduced noise output, faster acceleration, increased passenger capacity and simplified maintenance. Fuel cells could become practical in some situations within a few years. At least one company is offering lightweight transit vehicles that are powered by flywheels recharged during station stops. Moreover, research is also being undertaken on ultra-light rail transit vehicles that are powered by solar energy.
Greater passenger capacity. This has been made possible by the development of longer, articulated vehicles for use in place of trains consisting of separate cars. Articulation allows vehicles to negotiate much sharper curves than could non-articulated vehicles of the same length, and it allows what would otherwise be wasted space between individual cars to be used effectively. Advantages of increase train capacity include less crowding, reduced station dwell times and greater productivity for vehicle operators.

Improved fare collection. Advances in electronics and computer technology have made automatic ticket machines and other automatic payment systems easier to use, more reliable, more versatile, and less expensive. The result is greater rider convenience (machines can provide change, accept credit cards and issue different types of passes) and the elimination of collection of fares on board.

Increased security. Advances in electronics and software have greatly reduced the cost and improved the efficiency of monitoring vehicles, stations and the right-of-way for nuisances, dangerous conditions and criminal activity.

Real-time information. The display of real-time information for both vehicle operators and passengers is being made possible through advances in electronics, communications and computer technologies, including the availability of large, low-cost LCD displays in stations and vehicles showing such data as the next station, arrival times, times required between stations, delays, etc.

Computer-friendly. It is becoming increasingly practical to provide transit users with high-speed Internet access both in vehicles and in stations as a result of improvements in wireless-fidelity (Wi-Fi) technology (Eastside Rail Now! 2007).

Light rail systems have the advantage, in the Australian context, of being attuned to medium-density urban centres. Their major disadvantage stems from low operational efficiencies when they share traffic with road systems – traffic congestion leads to low energy efficiencies and unreliability with respect to operating schedules, in addition to safety issues. Where services operate on a separate right-of-way, these disadvantages are reduced, although more frequent stops still imply lower energy efficiency and slower speeds.

As Table 9.2 indicates, the average emissions-intensity of light rail is actually higher than that for passenger vehicles. The existing light rail system is most strongly developed in Victoria, where the emissions-intensity of electricity supplies is particularly high. Lower emissions-intensity sources of electricity would enable light rail to become competitive against passenger motor vehicles so far as emissions-intensity was concerned. The adoption of state-of-the-art technologies and separate rights-of-way would further strengthen the case for light rail services in Australia.
5. The Impact of New Passenger Transport Technologies

5.1. The Impact on Greenhouse Gas Emissions

5.1.1. Increased Passenger Occupancy

The current surge in demand for urban heavy passenger rail services has increased average passenger occupancy per km travelled, with a consequent benefit to energy consumption per pkm and GHG emissions per pkm. In some areas of service, this trend had led to serious overcrowding, which could have harmful consequences for the long-run patronage of rail services. However, it is possible that a more permanent increase of 20% in average passenger occupancy rates could be sustained for urban heavy rail services. Operational improvements in booking and yield management systems could result in a 10% increase in non-urban passenger rail occupancy rates in the long run.

5.1.2. Increased Energy Efficiency

A wide variety of new technologies could raise the energy efficiency (i.e., reduce energy consumption and emissions) of passenger rail by 27% to 2020, 39% to 2030 and 54% to 2050. Engine technologies alone could reduce energy consumption by 10% to 2020, 20% to 2030 and 30% to 2050. More efficient power and propulsion systems are delivering major benefits. The latest Japanese passenger trains are delivering energy consumption reductions that range from 49% at steady speeds to 32% with increased acceleration. For non-urban passenger rail, energy efficiency would be boosted by improved diesel technology, the introduction of new hybrid trains, and the possible launch of hydrogen fuel cell motors. Energy recovery from braking would yield 15% energy savings, most of which could be realised by 2020.

Advanced electronics leading to intelligent control of auxiliary power, and HVAC systems along with more efficient LED lighting could secure improvements in energy efficiency of 6% in the long run. Weight reduction could contribute a reduction in energy consumption of 4% in the long run. Mass per seat in European passenger rail is currently 670 kg/seat, with the potential to reach 470 kg/seat.\(^4\) Aerodynamic design could lead to further energy savings of 2%. Track design improvements can also increase the energy efficiency of actual train operations, with potential improvements of up to 12% in energy efficiency.

Energy efficiency in light rail could be boosted by reduced power consumption from new technology motors, electronic controls, regenerative braking, lighter weight car bodies, and wheel-mounted motors.

5.1.3. Operational Improvements

Operational improvements could yield energy economies of 4% to 2020, 12% to 2020 and 20% to 2050. Three factors could contribute to:

1. High-technology rail maintenance (perhaps resulting in 5% long-run efficiency improvements), which would reduce the incidence of stoppages and enforced slowing of traffic. Better track conditions imply average performance of freight services approaching the most energy-efficient performance.

2. Traffic decongestion could lead to 10% long-run efficiency increases. This could occur as a result of improved network traffic control of trains. Improved network

\(^4\) However, in the short run, recently introduced passenger rolling stock has greater weight than earlier cars.
traffic control of trains can reduce fuel usage by requiring trains not to stop as frequently.

3. The use of energy efficient driving techniques such as accelerating and braking only once between stations plus the application of lower speed restrictions could boost energy efficiency by up to 5% in the short-medium term, traffic conditions permitting. Remote driver operation technologies could lead to an ultimate 8% in efficiency improvements in the long run to operational performance.

5.1.4. Reduced Emissions Intensity

In addition to the reductions in GHG emissions associated with reduced energy intensity, operational improvements, and higher passenger occupancy rates, GHG emissions per unit of energy consumption for freight rail will also be reduced in the long run by up to 80% as a consequence of fuel-related factors. The key areas of change would be:

1. The reduction in the emissions-intensity of electricity supplied to rail services.
2. Electrification of some previously non-electrified passenger rail services.
3. The use of biofuels in blends with diesel for non-electrified services.
4. Zero-emissions hydrogen-powered fuel cells may be possible in the very long run.

5.1.5. Overall Impact

Table 9.2 summarises the possible overall impact on GHG emissions per pkm of technological and organisational changes on urban heavy passenger rail, together with comparisons with non-urban passenger rail and light rail and non-rail passenger modes.

| Table 9.2 Projections of the emissions intensity of passenger transport modes in Australia, GCO₂-e/pkm |
|-------------------------------------------------|--------|--------|--------|--------|
| Urban Heavy Passenger Rail                     | 2005   | 2020   | 2030   | 2050   |
| With improved loading factors                 | 139.0  | 111.2  | 111.2  | 111.2  |
| Plus energy efficiency improvements            | 139.0  | 81.2   | 67.8   | 51.2   |
| Plus operational improvements                  | 139.0  | 77.9   | 59.7   | 40.9   |
| Plus Fuel Shifts                               | 139.0  | 55.9   | 23.3   | 8.5    |
| Non-Urban Passenger Rail                      | 65.0   | 40.1   | 22.6   | 10.7   |
| Light Rail                                     | 187.0  | 95.0   | 41.0   | 15.2   |
| Air Passengers                                 | 129.0  | 104.7  | 84.8   | 56.9   |
| Buses                                          | 87.0   | 68.7   | 51.7   | 24.3   |
| Passenger Motor Vehicles                       | 166.0  | 103.3  | 64.5   | 22.1   |

The combination of improved loading factors, energy efficiency improvements, operational improvements and fuel-related factors could reduce GHG emissions per tkm for urban heavy passenger rail from the current level of 139.0g to 55.9 in 2020 and 8.5g by 2050. The emissions rate of 65.0g for non-urban passenger rail could fall to 10.7g by 2050, and even light rail could drop from 187.0g to 15.2g. By way of comparison, technological and organisational changes could reduce the corresponding emissions rate for passenger motor vehicles from 166.0g to an eventual 22.1g, thus implying that urban heavy rail could extend its advantage in relation to GHG emissions against private vehicles. Similarly, non-urban passenger rail could significantly increase its environmental advantage over air transport.
5.2. **The Impact on the Competitiveness of Rail as a Transport Mode**

The major way that passenger rail can contribute to the reduction in GHG emissions in the short-to-medium-term is by increasing its competitiveness against more emissions-intensive forms of passenger transport. By far the biggest opportunity is to shift urban passenger transport from light-duty motor vehicles to urban heavy passenger rail. At present, a shift of one pkm of passenger traffic form cars to rail would save 27.0g of GHG emissions — less than the equivalent shift of a tkm of freight form trucks to rail, but still significant. This margin will increase in the medium term and persist into the long term. There are even bigger emissions savings in shifting passenger traffic from air to rail (64.0g per pkm at present). Noteworthy, too, is that the present environmental advantages possessed by buses is reversed in the medium- and long-term. The following sub-section of this paper outlines the way in which change in the rail sector can boost its competitiveness as a freight mode.

A shift of one tkm of freight from articulated trucks to rail would save 40.2g of GHG emissions.\(^5\) In the very long run, there is significant potential for emissions reductions in trucking. Despite this, technological progress in rail should ensure that a sizeable gap in emissions-intensity between trucking and freight rail persists, so environmental pressures for a modal shift in freight will continue.

5.2.1. **Increased Capacity**

The capacity of passenger rail transport can be increased for a given rail infrastructure through:

1. New car technology up 6% in capacity on current technology.
2. Semi-trailer vehicles providing up to 10-15% more capacity than enhanced conventional cars.
3. Dealing with increased capacity – platform management, four doors per side, train length, digital in-cab signalling.
4. Modern electronic Train Protection and Control (TPC) systems can also improve capacity, reliability and safety as well as reduce infrastructure and operating costs.

5.2.2. **Reduction in Costs**

The operational costs of passenger rail can be reduced in the following ways:

1. New track technologies could result in reduced interruptions to services because of track defects. Increased life for track and track components associated with these technologies helps to spread capital costs and also reduces maintenance costs.
2. The adoption of advanced network traffic controls can reduce the fuel costs of operators and improve the utilisation of vehicles and staff and thereby reduce both the variable and fixed cost of operations. Improved logistics facilitate economies in both fuel costs and the cost of equipment through more efficient vehicle operation.
3. Improved light rail vehicles requiring lower maintenance.

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\(^5\) This is based on the existing average emissions rates. Strictly speaking, it should be based on marginal rates, which are more difficult to calculate. For very small shifts in freight volumes, the marginal changes in emissions would be slight in both modes with loading factors changing more than traffic volumes. The use of averages is a more useful approximation for large intermodal shifts.
5.2.3. **Speed**

The average speed of passenger rail services can be increased in a number of ways. New passenger rolling stock have faster average speeds and acceleration.

1. Very fast rail may have long-term potential for intercity rail.
2. Light rail vehicles will have faster acceleration, faster exit and entry, and perhaps traffic-signal priority.
3. Average rail speeds would be boosted by more consistent track conditions as a consequence of new track technologies.
4. Advanced network traffic controls can reduce stoppages and thereby increase average speeds.

5.2.4. **Reliability**

The reliability of passenger rail services can be boosted.

1. Improved track conditions increase the reliability of services.
2. More advanced track maintenance methods result in quicker restitution of damaged track.
3. Advanced network traffic controls can increase the reliability of maintaining schedules of freight operation.

5.2.5. **Safety**

Passenger rail safety can be increased.

1. Improvements in security technology, such as through the use of CCV cameras.
2. Light rail: lower floors, easier entry and exit especially for people with disabilities. Stronger vehicles, increased security.
3. Improvements in track and control technologies, including the use of Automatic Train Protection, could increase safety.

5.2.6. **Comfort**

Comfort to rail passengers can be increased.

1. Minimised vibration.
2. Low noise.
3. Integrated tilt and active lateral suspension control may solve motion sickness issue.
4. Wi-Fi technology and Internet access.

5.2.7. **Summary: Timelines**

The timelines for technological changes in passenger rail are summarised below.

**Diffusion of New Technologies**

1. Improved rolling stock:
   - weight reduction;
   - track interface;
   - fly-by-wire technology;
   - active suspensions; and
   - hybrid engines.
2. The diffusion of improved wheel and rail profiles, better methods of selecting rails and other components, advanced bridge design and the increased mechanisation of maintenance.

3. The adoption of the new generation of network traffic control technology and advanced technologies in logistics.

**Current Innovation, Medium-term Diffusion**

1. Wheel or hub motors.
2. Fuel cell engines.
3. Active steering.
4. Semi-trailer configuration of cars.
5. High-speed Internet access on board.
7. Light rail innovations.
9. The adoption of next-generation network traffic controls and logistics technologies.

**Long-term Diffusion**

1. Remote train operation (RTO).
2. Re-design of track technologies in the light of further information. Completely automated track maintenance systems and algorithms for preventive maintenance.
6. Conclusion

A range of both emerging and existing rail technologies are available to reduce greenhouse gas emissions substantially and reduce costs, increase speed, and achieve greater reliability. For freight a combination of improved load factors, energy efficiency and operational improvements could reduce greenhouse gas emissions from 20 GCO₂ equiv. per tkm to 14.8 GCO₂ equiv. per tkm between 2005 and 2020. For passenger rail transport, the adoption of a similar range of new and emerging technologies is expected to reduce greenhouse gas emissions from 139 GCO₂ equiv. per pkm to 77.9 GCO₂ equiv. per pkm.
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