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# **New Zealand Rail**

**Guest-edited by**

**Brian McCammon of the 5AT Project.**

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with a focus on sustainable energy use and development.

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## **SAB 88 EDITORIAL**

**by Guest Editor, Brian McCammon**

The SAB is normally concerned with the New Zealand environment. However, the focus of this issue is rail transport as a sustainable option against other transport modes so that we need to widen our attention to include a more global viewpoint. There is no distinctly New Zealand form of transport system which deals exclusively with transport problems peculiar to New Zealand. Transport is ubiquitous and the systems which have evolved are essentially the same throughout the world. In practical terms there are only four modes; rail, road, aviation and merchant shipping. Even such matters as the day-to-day administration of these different systems are essentially the same across the world. Thus, this issue of the Bulletin will present a more global perspective than usual.

It is difficult to believe that we can sustain our civilisation without some system of transport. What will the world look like in, say 50 years time? Governments, the business communities and ordinary people themselves are not going to willingly give up the Business-as-Usual scenario until circumstances force the issue. In 50 years time there will be no oil left, coal will be in serious decline and gas will be long finished. Of necessity, the human race will have had to turn to biomass and the renewables for its energy or face the bleak alternative of energy rationing and nobody knows how, or even if, this could be implemented.

It is doubtful, if in this suggested time-frame, the world would have the financial resources available to fully make the switch to renewables but even if we could, what would the impact be on rail transport? Renewables are, in practical terms, only satisfactory as a source of energy for electric power. To couple an electric generating system to mobile transport requires an extensive grid of overhead lines, switchyards, transformers and the other infrastructure which goes with this technology. This would be a huge commitment, both in monetary and energy terms.

It may be that the Heavy Duty Diesel engines which power the current generation of diesel fuelled locomotives can be modified to operate on B100 biodiesel in the future and it is to be hoped that this happens soon. Without a successful culmination to the experiments on this problem, the diesel locomotive fleets will be grounded until an alternative fuel is developed but whatever fuel it turns out to be, it will not have the almost magical properties of diesel. I am not aware of any fuel which can match diesel across all its properties.

All forms of transport machinery suffer energy losses and railway locomotives are no exception to this but it is equally true of trucks, aircraft, merchant ships or even a bicycle. As far as steam and diesel locomotives are concerned, they have to carry their own fuel and water supplies with them and when the fuel is burnt in these machines, some form of pollution is produced from their exhaust systems. The conventional wisdom would have it that in comparison, electric locomotives are practically pollution free. They certainly can be but only if the electric power generated to drive

them comes from carbon free generating systems such as hydro, nuclear reactors or windmills and even there a net energy analysis will bring to the surface some unexpected and unpleasant surprises. Unfortunately, 86% of the electric energy currently generated in the world comes from generators fired with fossil fuels and with the majority of that coming from coal. Coal fired thermal plants have an average emission factor of 265 kgCO<sub>2</sub>/GJ, one of the highest of all the energy conversion processes. This makes electric rail traction a suspect transport option for the future.

And then there is the infrastructure; without tracks, freight wagons and passenger coaches, electrical overhead lines where appropriate, signalling systems and the multitude of other tasks there can be no railway.

New Zealand, as with the rest of the world, suffers from all these problems. No transport system is ideal but, of them all, rail systems suffer the least, in spite of the inflexibility of having to use fixed rail corridors with the resulting problem of the "last mile" delivery. However, we had this problem long before we had diesel trucks so we may have to solve it yet again.

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***About the Author:***

***Brian McCammon*** is a retired telecommunications engineer, living in Dunedin, New Zealand, who since his retirement has become involved with various aspects of the road and rail transport industries including research into both fossil and alternative fuels suitable for these technologies.

## **WHEN THE OIL IS GONE: A FUTURE VISION FOR RAIL**

**By Jamie Keyte**

### **1. Introduction:**

To those who pay attention to such topics, it is clear that with unprecedented rates of consumption, dwindling reserves and increasing prices the days of petroleum fuelled transport are numbered. This article takes a speculative view of how the energy crisis might impact on the future of rail transport.

Firstly it is important to note that all that is written here regards the future. The author does not possess powers of foresight any better than the next person. This is simply one Engineer's view of how our future transport systems might evolve. It does not take account of the unpredictable nature of the world's financial situation, political upheaval, natural disaster, the inability of politicians (and the world at large) to see common sense and, of course, mankind's greed.

The picture painted in the following sections is based on the UK situation. There will be some parallels to other world transport systems, but the extent of the changes will depend on the local conditions.

### **2. When the Oil is Gone...**

Various sources suggest that Peak Oil is past and that in about 20 years time oil reserves will have depleted to such an extent that demand (at today's levels) will far outstrip supply. As the majority of the world's transport networks (in their current form) are absolutely dependent on oil there will clearly be some significant changes ahead.

It would seem likely that as reserves diminish governments will prioritize who, or what gets to use the oil. The Military, emergency services, food production, manufacture using oil as feedstock and other essential functions will take precedence over personal transport. Transport powered by internal combustion engines may simply become unviable due to the scarcity of fuel and its increasing cost.

It is also reasonable to predict that the way that society is organized will become very localized. This applies as much to the way individuals lead their lives as the production of goods. It will simply not be possible to ship vast tonnages of goods around the globe to satisfy consumer demand.

Of all of the transport systems railways seem best positioned to weather the storm. They will become pivotal to the success of the economy in the future. This is because the railways (in principle) can operate without dependence on oil and have done so in the past.

### **3. Transport Energy Options**

The cost and availability of oil based fuels will virtually preclude its use for widespread personal and commercial transport. Its use will be confined to specialist transport applications (military, emergency services, etc.) for which its use is essential. So what energy alternatives are available?

1. Biofuels which are sufficiently highly refined as to replace petroleum products may be limited in application. The EROEI (Energy Returned on Energy Invested) of some biofuels is marginal,

although those derived from algae appear to have good potential. Fuels based on crops are also grown on land suitable for food production, of which the latter will obviously take priority. The problem is that there simply may not be sufficient land to grow crops to replace the enormous quantities of oil currently consumed. Biomass cannot currently be used for transport use except in external combustion engines of which steam engines and Stirling engines are the best known.

2. Hydrogen. As of yet a process has not been developed which requires less energy to produce and store hydrogen than can be got back from the fuel (i.e. a negative EROEI). Until this issue is overcome hydrogen is simply not a viable fuel as there are better (and safer) ways of capturing and storing energy.
3. Renewable energy. This variously covers wind, wave, tidal, solar and geothermal energy. The processes either captures solar energy (directly or indirectly) or draws upon energy stored within the Earth (as kinetic energy or heat). They are most usefully captured as electricity or heat. The key issue here is that it is difficult to apply this energy to transport use. The two possible exceptions are water borne sailing craft and the solar powered cars that race across Australia.

For renewable energy to be viable for transport a means of storing and recovering energy is required. Some options are discussed in the following points.

1. Battery powered vehicles have been around for a long time, however range is limited and to increase it (by adding more batteries) reduces payload. Battery technology will no doubt improve, but a step change in performance will be required before they can seriously be considered for anything other than local transport.

As transport accounts for a significant proportion of world energy use then a corresponding increase in base load electricity generation will be needed to meet this additional demand. Resources of the metals required to make batteries may be as limited as fossil fuels.

2. Capacitors have developed considerably in the last few years. Super capacitors are now used on some hybrid vehicles in place of batteries. Total practical energy storage is still considerably less than batteries.
3. Heat storage has yet to find widespread use, however with modern thermal insulators there could be potential applications. It is relatively easy to convert electrical energy to heat. The two most likely options for converting heat back to mechanical work are the steam engine and the Stirling engine.
4. Pressure potential energy storage. Once again this is an old technology; fireless steam locomotives have been in use for many years in industrial use. Very hot pressurized water is pumped into a storage vessel and is used to drive an otherwise conventional steam engine. Obviously a ready source of hot water is required and once again range is limited. Pressure can also be stored hydraulically (large and heavy) or as a gas (entails wastage of significant energy as heat as the gas is compressed), neither of which is particularly suitable for transport.

5. Kinetic energy storage. Most commonly the flywheel is used. Kinetic energy storage is not very dense and is best suited to short term storage/recovery. There is a rail based vehicle (Parry People Mover) which uses flywheel energy storage for traction. The flywheel is charged at the stations.

One key factor of all stored energy systems is that they are not self regenerating. In the context of rail operations if you run out of energy on the open track you are stuck! Therefore stored energy transport can only be operated realistically at a range much lower than the theoretical maximum.

Given the state of the above technologies it seems likely that steam traction could well have a role to play in the operation of tomorrows railways for the following reasons.

1. The technology exists and is proven.
2. Steam can burn relatively unrefined biomass, waste products or coal.
3. It is improbable that any of the alternative technologies could reach a stage of maturity sufficient to justify widespread use in the timescale available.

#### **4. From Where Will Come the Energy?**

It appears that there may be an opportunity for steam to return to the railways principally because there may not be an alternative. However, the future of steam is far from assured. The coal shortages will be hot on the heels of the oil shortages. As other transport modes tend towards electric based technologies (e.g. battery power) the base load power demand will increase dramatically. Unless the production of renewable energy sources increases substantially much of the demand will have to be met by coal powered plant. Nuclear power is facing a similar (though slightly longer term) shortage of fuel and the timescales for constructing these plants are comparatively lengthy.

Possibly there will be 20 years (or so) breathing space to "Peak Coal" which could be used to develop alternative fuels. For biomass to be a viable fuel it will need to be burnt with minimal refining to maximize the EROEI. Wood looks like a possible alternative as it can be grown on land unsuitable for crops. The by-products of other processes (e.g. straw from wheat production or bagasse) could also be considered. Another possibility requiring further research is the combustion of glycerin which is a waste product of bio-diesel manufacture.

In short, it is far from clear how steam of the future will be fuelled. In principle, the steam locomotive has the potential to burn a wide variety of fuels and coal appears to most viable in the short term.

#### **5. Electrification**

Without doubt most European railways, metros and light rail systems, existing and new, will be electrified in the future. However, large sections of many rail networks are not electrified and traffic levels dictate that they never will be. This is especially true in the USA and other countries where the distances are great. Electrification is time consuming and costly to install. To keep networks operating alternative traction will have to be considered over the non-electrified route mileage.

## 6. Private Transport

With the demise of the motor car it is likely that (rather than adopting a wholly public transport approach) the population will be forced to use stored energy vehicles. These will derive their energy from renewable electricity sources and store it in batteries, capacitors, thermal masses, or whatever technology becomes available. Such vehicles would be fine for local transport, but as with all devices where energy is stored, mass and size have an important influence on range. For longer range journeys there are two options:

1. Use the train for the whole journey with walk/bike/bus for the “last mile”.
2. Drive the stored energy vehicle onto the train. This solution actually exists in the form of the Channel Tunnel Shuttle. The stored energy vehicles could recharge whilst in transit and passengers would retain their, all important, privacy.



*Fig.1. Le Shuttle, Channel Tunnel drive on – drive off service*

## 7. Commercial Transport

Given that commercial and private transport will be governed by similar constraints it is likely that goods will be moved in a similar manner. Goods will be taken to the rail head by stored energy road vehicles. The train will be used for most of the journey and stored energy vehicles used for the “last mile”.

Wagonload freight will probably be carried in intermodal containers as used today. Part wagon load freight could well be transported in wheeled trolleys or pallets. The other alternative is that commercial vehicles are also able to use roll on – roll off services, at the expense of transporting unnecessary mass about the country. Trainload freight, long the preserve of the railways, will probably remain substantially unchanged.

## 8. Trunk Routes

Rail trunk routes will be electrified. It is possible a high speed network of trunk routes will evolve for the use of passenger and shuttle services. These will be segregated from the existing network as the speeds will be incompatible with most secondary services. Also the additional loading gauge required for intermodal traffic probably makes most existing routes unsuitable.

With the existing main lines freed from the requirements of high speed travel, they would be left to handle the normal freight and secondary passenger services.

Railway operations may well become centred around strategic hubs connected by high speed electrified links. At each hub would be marshalling yards for freight as well as links for passenger traffic to the main urban centers.

## 9. Secondary Routes and Branch Lines

Many of these will remain non-electrified simply because the level of traffic will remain modest. Whether closed routes will be reopened depends on the range of the stored energy vehicles feeding the railhead. The secondary routes may become the domain of a new generation of steam locomotives. It is possible that there will be greater use of bi-modal stock (such as the Class 325s in the UK) where they can be loco hauled for parts of the journey and use electricity for the remainder.

## 10. Potential Steam Locomotive and Traffic Types

It is envisaged that the above traffic requirements could be satisfied by three basic locomotive types. All would embody the most advanced state of the art steam technology<sup>1</sup>:

1. 2ATT. Of the same basic proportions as the BR Standard 2MT tank. This would be capable of handling short range traffic (<50km) up to approximately 200 tons. Traffic would include local passenger services and freight between population centers and the hubs.



*Fig.2. BR Standard 2MT Tank – Basis of the 2ATT*

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<sup>1</sup> Details of the proposed 5AT (Advanced Traction) can be found on [www.5at.co.uk](http://www.5at.co.uk). The basic principles embodied in the 5AT can be applied to a variety of locomotive designs. The AT technology has all been tried and tested in some form. There are no radical new technologies - simply sound application of the best known engineering practices. The resulting machine is twice as efficient as traditional steam.

2. 5AT: This loco would be capable of handling inter-regional traffic (50km – 200 km) on secondary routes where electrification is not viable. Train weights, both passenger and freight, would be up to approximately 500 tons. The general performance and technical specification of a locomotive of this type have been defined by the 5AT Group – see footnote.



Fig.3. BR Standard 5MT – Basis of the 5AT

3. Freight AT. This loco would be suitable for trainload freight. The size of the locomotive would be matched to the intended traffic and local operating conditions. Trains might be between 500 and 5000 tons.



Fig.4. An EAR Bayer Garratt – Basis of a Freight AT?

If possible locos should be designed with alternative fuel types in mind. Unlike the 5AT in its present form the emphasis will be on economy rather than performance.

## **11. International Travel**

On the whole it is reasonable to expect journey times to suffer. With the demise of conventional air travel, most trans-European passenger travel will be by extension of the high speed rail links. Outside Europe it is hard to see how intercontinental travel will develop without enormous investment in infrastructure.

Trans Atlantic travel will be a whole different problem. Air travel, even by airship, is likely to be limited simply because helium is also a finite resource (currently it is only found naturally in certain rock structures). Here we might see the return of sailing ships; the fastest trans-Atlantic sailing record stands at about 5 days. Scaled up sea-borne freight is also likely to make greater use of sail power. It is possible that an alternative auxiliary power source (solar power, or maybe steam) will be needed to maintain something like regular voyage duration.



*Fig.5. The Multihull Groupama 3. At time of writing it had just set out on an attempt on the 4 days 4 hours transatlantic sailing record – technology to be scaled up?*

## **12. The Rest of the World**

The scenario outlined above is based around UK conditions. Most of the scenario will probably apply to European railways, where the use of electrification will become increasingly widespread. Transcontinental railways face a whole different set of circumstances. In the US in particular there is a heavy dependence on diesel for long haul rail services. Once again steam would appear to offer the only viable alternative when one considers the US's (allegedly) vast coal reserves.

## **13. Conclusion**

Taking an objective view, steam traction could have a role to play on tomorrow's railways. The technology already exists to bring steam back in a modern form with very little development. The

inherent flexibility of the steam locomotive allows it to operate on a variety of fuels, many of which could be waste products or carbon neutral. Objections on grounds of poor efficiency are valid; however two points should be borne in mind:

1. Electric traction, where the electricity comes from coal fired plant, has overall efficiencies not dissimilar to modern steam (about 13% to 16%).
2. Development of the steam locomotive is far from its peak. A mere fraction of the investment that has been made in developing internal combustion engines would produce substantial improvements to the steam locomotive.

The biggest obstacle is not technology – it is the clouded perception of an oil dependent world.

Jamie Keyte  
29<sup>th</sup> July 2009

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***About the Author:***

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## THE ROLE OF RAIL IN A SUSTAINABLE TRANSPORT SYSTEM FOR NEW ZEALAND

Paul McGimpsey

Recent research, commissioned by the New Zealand Transport Agency, focused on how rail could be better utilised to improve the sustainability of New Zealand's transport system. The research involved a review of international literature, an analysis of the policy and legislative environment for rail in New Zealand and interviews with a number of key stakeholders.

This article briefly covers some of the key findings in relation to energy use and discusses some of the more practical issues that were raised regarding the potential for increased use of our rail system<sup>1</sup>.



Figure 1: New Zealand's rail network

## New Zealand's rail system

The operating environment for rail in New Zealand is complex and has undergone many changes since the first tracks were laid in the late 1870s. This has included a period of full and partial privatisation of some aspects of the system over the last 15 years. More recently, significant changes occurred in July 2008 when rail service operations were re-purchased by the government, meaning that virtually all components of the rail system are once again owned and operated by the government<sup>2</sup>. The rail system is now owned and operated by a single State-owned enterprise known as KiwiRail Group. One of the key reasons for the re-purchase was to improve the contribution of rail to creating a sustainable transport system for New Zealand<sup>3</sup>.

New Zealand's rail network consists of approximately 4,000km of tracks with the majority of the network dedicated to freight. As Figure 1 shows there are three main long distance passenger routes: Auckland to Wellington; Christchurch to Greymouth; and Christchurch to Picton. Auckland and Wellington both have metropolitan passenger systems.

## What sustainability benefits does rail offer?

Rail has a number of advantages over other modes from a sustainability perspective. This is primarily in relation to the lower energy use and increased energy diversity in comparison to road transport and the implications of this in terms of energy security and greenhouse gas emissions. Further benefits are the smaller land area required for rail transport compared to road and the comparatively long lifespan of rail infrastructure, including rolling stock.

## Moving freight

The movement of freight accounts for 43% of energy used in New Zealand's transport system. The modal split of the national freight task is shown in Table 1.

**Table 1: New Zealand's freight movement characteristics<sup>4</sup>**

Mode	Total tonne-km moved	Percentage of total tonne-km	Average journey length
Road	18.6 billion	70%	90km
Rail	4 billion	15%	280km
Coastal shipping	4 billion	15%	1,000km

Rail freight, which comprises 15% of total tonne-kilometres, tends to be dominated by large, bulky commodities such as logs, coal and dairy products.

The total amount of freight moved around New Zealand is predicted to increase about 2.2 times from its current level by 2040. As well as economic growth, an international trend towards the rationalisation of ports is likely to increase the demand for inter-regional freight movement. This would see a total of approximately 58.5 billion tonne-kilometres being moved by 2040. One of the objectives of the New Zealand Transport Strategy (NZTS) is to have 25% of all freight (on a tonne-

kilometre basis) transported by rail by 2040. This would see an increase in rail freight volumes of approximately three times from current levels.

Stakeholders agreed that increased use of the rail network for freight movement represents the greatest opportunity for rail to improve its contribution to New Zealand's transport system. Several sustainability benefits were cited, including:

the displacement of greenhouse gas emissions from higher emitting modes;

a reduced reliance on imported energy sources;

better utilisation of existing network capacity from transport infrastructure, reducing the need for new infrastructure;

reduced congestion from heavy road traffic, easing pressure on the road network.

Two main issues relating to increased use of the rail network for freight movement were raised. The first was the performance of the network in terms of journey times, reliability of service and a trend towards increased freight dimensions and weights. The widely acknowledged lack of investment in the rail network under private ownership means that the network is not performing as well as it could be. This reduces the competitiveness of rail compared to road in terms of journey times. Consequently, this makes it hard for rail to compete, particularly for highly time-sensitive freight. Similarly, the trend towards larger freight dimensions and weights presents challenges for the rail network. Tunnels and bridges can act as physical barriers to larger freight dimensions and weights. Rail tracks are also rated to safely carry a certain weight, known as axle loads, which can present a further constraint. A significant programme of works to address these constraints is underway. These works should see an improvement in the performance of the network in terms of journey times, reliability and network capacity, improving its attractiveness to potential freight customers.

The second key issue for rail freight was the feasibility of using rail for potential freight users. Currently, rail is only used in significant capacity by about six companies. This is because of the limited coverage of the network and because many potential customers do not have high enough freight volumes to justify investing in rail. Improving the feasibility of using rail for potential freight customers will be vital to achieving the 25% target set in the NZTS. Facilitating this could include the increased use of rail sidings and branch lines to improve access to the network. A trend towards centralised processing and distribution centres in many industries presents a clear opportunity for rail to meet the demand for reliable connections between these centres and ports. It was suggested by some stakeholders that central government could take a greater role in facilitating this by providing financial assistance in the form of loans or subsidies to industries, and local government presenting strong business cases.

### **Moving people**

The widespread view of stakeholders in relation to passenger transport was that the significant investment in passenger rail in Auckland and Wellington in recent years is long overdue and is very necessary. It was noted that maximising the benefits of these upgrades is also reliant on factors outside the rail system, such as the land use planning policies of local authorities. A further issue raised was the need to encourage the use of passenger rail in both centres by upgrading railway

stations. Particular aspects to consider include the perception of safety of rail users, mixed uses in and around stations, and the integration of stations with the surrounding urban area and with other transport modes.

Opportunities for further development of passenger rail beyond Auckland and Wellington were discussed, with two locales widely regarded as warranting further investigation: the 'golden triangle' between Auckland, Hamilton and Tauranga, and a rail system connecting the commuter towns in the Canterbury region. With the exception of these two cases, the prevailing view was that into the foreseeable future, long distance passenger rail would be unlikely to be a viable alternative to road and air travel due to the higher costs and longer journey times of rail over longer distances. However, all stakeholders did recognise the value of the key tourist routes such as the TranzAlpine and various heritage operations.

### Energy use and supply

The energy efficiency of rail and the diversity in the source of this energy is one of rail's greatest benefits. Rail is typically about four times more energy efficient than road transport (as shown in Table 2) and has correspondingly lower greenhouse gas emissions.

**Table 2: Energy use of various modes<sup>5</sup>**

Mode	Energy use
<b>Freight movement (W-h/tonne-km)</b>	
Road freight	810
Rail freight	200
Coastal shipping	100
<b>Personal transport (W-h/passenger-km)</b>	
Car	540
Bus	220
Rail - Urban metropolitan (Wellington data only)	90
Rail – Overall (including long distance)	440

In addition to proportionally lower energy use compared to road-based transport, rail offers the ability to operate on alternative energy sources which can further reduce emissions. The most common alternative energy source is electricity, but bio-fuels can also be used. While Wellington's rail system is fully electrified and Auckland's system is moving towards electrification, the majority of the network is not electrified with the notable exception of the North Island Main Trunk Line from Palmerston North to Te Rapa.

Electrification of rail lines is expensive and the dominant view of stakeholders was that in the immediate term, money potentially spent on electrification would be better spent on addressing some of the issues with the performance of the network outlined previously in order to encourage increase use of rail for freight. Due to rail's proportionally lower emissions, it was believed that achieving a modal shift from higher emitting modes would produce a greater net reduction in emissions rather than focusing on lowering rail's own emissions through electrification.

In the longer term it was noted that it would be entirely feasible for the entire rail system to be powered by renewably generated electricity with very minimal greenhouse gas emissions. Bio-fuels would also be a feasible energy source although the long-term sustainability of bio-fuels is still under question. Hydrogen also presents a possible future energy source although hydrogen fuelled rail systems are still in the development stages in Europe and Japan.

Although energy use and greenhouse gas emissions provide some of the most compelling reasons for increasing the use of rail, they do not rank as high priorities for most transport users. As such, the focus for rail in the immediate term must be on improving the service it offers to existing and potential users. This will encourage a modal displacement from higher emitting modes. Once network improvements have been undertaken and rail usage has increased, conversion to alternative energy sources such as electricity, bio-fuels or hydrogen could be considered.

#### **What are the barriers to increasing the use of rail?**

In addition to many of the issues regarding the physical aspects of the rail system, it was also found that institutional arrangements can be barriers to increased use of rail. Historically, rail has sat outside the wider land transport sector and has been viewed as a discrete industry rather than as a component of a wider transport system. Most stakeholders believed that this isolation and insularity, with its origins in the days of the Railways Department, has been detrimental to the development of the rail system. Closely associated with this is how the rail system is funded, which has been largely separate from the rest of the transport sector<sup>6</sup>. Many stakeholders pointed out that one of the biggest barriers to developing a sustainable transport system is that many aspects of sustainability are not adequately factored into transport funding processes. This means that many of the sustainability benefits of rail previously discussed are essentially ignored. As a result, transport users are presented with a distorted pricing regime where they do not face the true cost of their transport choices. Debates about the level of subsidisation of various modes are politically contentious and fiercely debated but it is clear that we do not yet have a transport system that accurately reflects the true cost of our transport choices. Until we move closer toward this elusive goal, there will be little incentive for individuals and companies to make transport choices that are genuinely cost-effective and sustainable. The inclusion of the transport sector in the emissions trading scheme will price in greenhouse gas emissions, but there will still be other externalities that will not be adequately taken into account under current arrangements.

#### **Conclusions**

Rail has a number of potential benefits to assist in achieving a sustainable transport system for New Zealand. The rail system is an important national asset that is currently under-utilised. For a country so economically dependent on exports and so reliant on imported energy sources for transport, our rail system represents a major opportunity. With comparatively modest levels of investment, the

contribution of rail to the New Zealand transport system, to reducing our greenhouse gas emissions and to the national economy, could be significantly enhanced.

Rail faces a number of serious challenges if it is to fulfil this potential. It must respond better to the spatial and temporal needs of transport users in order to increase its attractiveness. This will only be achieved by continuing the investment in the network that has occurred over the past five years. At a time when government and private sector expenditure is under considerable pressure, the key for rail will be its ability to clearly articulate and demonstrate the benefits, both environmental and economic, that it can provide.

### **Notes and references**

1. *The full report, titled Promoting sustainability in New Zealand's rail system, is available to download at [www.landtransport.govt.nz/research/reports](http://www.landtransport.govt.nz/research/reports). The material contained in the report is the output of research and should not be construed in any way as policy adopted by the NZ Transport Agency but may be used in the formulation of future policy.*
2. *The exception to this is the Auckland metropolitan passenger service operated by Veolia under contract from ARTA and a number of heritage railway operations.*
3. *New Zealand Government. 2008. Rail buy back marks new sustainable era for transport. New Zealand Government Press Release: 5 May 2008. Wellington.*
4. *Based on data from National Freight Demands Study (Richard Paling Consulting 2008) with some rounding of values. It should be noted that the figure of 15% on tonne-kilometres for rail differs from the figure of 18% used in the NZTS.*
5. *Ministry of Transport. 2005. National Rail Strategy to 2015. Wellington: Ministry of Transport. 26pp.*
6. *State Services Commission. 2007. Next steps in the land transport sector review. Wellington: State Services Commission. 68pp.*

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### **About the author**

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## RAIL AS A SUSTAINABLE MODE OF TRANSPORT

Dr. Murray King - Sept 2009

Rail can help the country's drive to sustainability, because it can transport goods and passengers with less impact on natural resources than some other modes. It uses less fuel, less land, and has less noise and other impacts than road transport, for example. Shipping's use of resources is even less than rail's, because its pathway is provided entirely naturally, and because it can carry very large volumes. But each has its niche; shipping cannot reach all the places rail can, and rail is faster than shipping; and at the same time rail cannot reach all the places road can, and road can be faster than rail. The debate about sustainability will boil down to how the modes using fewer resources can help sustainability by carrying a greater proportion of the total transport task than at present. Trade-offs will be required, especially over speed of transit.

### Fuel efficiency

Rail's fuel advantage, often expressed as being four times more energy efficient than road (on a per tonne kilometre basis), arises from its ability to carry large loads in relation to the tare weight, and from the low rolling resistance of the steel wheel on the steel rail. Recently announced plans to increase the legal loads for trucks will narrow the gap for the first point, but cannot replace the second. EECA fuel consumption figures (combined with National Freight Demands Study tonne-kilometre data) suggest a six to one ratio, but that will include lighter trucks, not strictly comparable with rail.



*Darryl Bond, KiwiRail*

Meanwhile rail continues to improve its fuel efficiency. Locomotive engineers are trained to drive in ways that limit fuel consumption (with a 9% saving on one route). Recent developments in computerised traction control have increased the potential weight of trains up hills by up to 30%.

The new locomotives now ordered from China will feature higher power and substantially improved fuel efficiency.

With its superior fuel efficiency over road, rail will be able to make better use of supplies of oil as they become scarcer. If supplies become seriously scarce, rail has the advantage of being able to run independently of oil, on current proven technology.

### **Independence from fossil fuels**

One of the problems in reducing greenhouse gases is the high proportion that transport generates. It is particularly difficult to convert transport from its dependence on fossil fuels. But rail is an exception, because it is adaptable in terms of fuel type used, much more adaptable than road. It can in effect run on any form of fuel, through its ability to be electrified, using already proven technology.

Thus it can be said that trains can run on nuclear, wind, hydro, geothermal, solar, tide and wave power. They can do this because rail is a guided mode of transport, on a defined network, and the power can be readily transmitted to the vehicle. Road transport, with the limited exception of trolley buses, cannot achieve this, and has to rely on storage (batteries) to use electricity. That technology is still largely in the early stages of development, and confined to cars and some buses, not trucks. Electric propulsion is unlikely to be developed for trucks for some time.

### **Benefits of electrification**

Electrified railways use less energy, and have few emissions. Even when a fossil fuel is burnt to provide the power, it can be done in larger, more specialist, and more controlled equipment than a mobile engine. In New Zealand, about 70% of power is from renewable sources anyway, and the goal is to push this proportion higher (to 90%). Electrified railways are quieter as well. In terms of energy efficiency, they can also be better than diesel hauled railways, even after transmission losses. Diesel locomotives are in fact mobile powerhouses, since the diesel engine typically drives a generator which produces electricity to drive the actual motors that do the work of making it move. It does so, however, at thermal efficiencies (20-30%) well below those achievable in a modern power station (over 50%).

Even if electricity comes from fossil fuels, it can improve the fuel efficiency of trains. Simulations for a report on extension of electrification for Ontrack last year showed that electric locomotives on the Auckland – Hamilton route would be three times as efficient in their use of energy than diesel; measured in MJ/tonne kilometre. If all the power had been generated by fossil fuels, that would drop to 1.3 times, but still be a positive gain. Of course, the high proportion of renewables in New Zealand electricity generation means such an extreme position is unlikely. The fuel saving converts directly into a greenhouse gas saving too – the same study calculated that 28,000 tonnes of CO<sub>2</sub> equivalent would be saved annually by electrifying the whole Auckland – Mt Maunganui route, assuming 15% non-renewables in the generation mix. This compares well with initiatives proposed in the 2007 *Energy Efficiency and Conservation Strategy*, but at \$15/t was only worth \$437,000 pa.



*KiwiRail*

Electric locomotives can be more powerful than diesel ones, but in practice they can be equalised by using more diesel locomotives on a train. However, electric locomotives are lighter for a given power, because they do not have to carry the diesel engine, the power generator, and the fuel, unlike diesels. This reduced weight is valuable for environmental reasons, since the locomotive hauls less of its own weight and thus uses less fuel. Electric locomotive acceleration is better, and they can also be faster. Energy otherwise dissipated in braking can be fed back to other trains or into the national grid. Electric locomotives are simpler to maintain than diesels.

### **Costs of Electrification**

But electrification comes at a cost. Providing the network of transmission, substations, masts, and contact wires, and altering signalling to make it unaffected by the heavy traction current, costs about \$5 million per kilometre for double track, and \$3 million for single track. Works to improve clearances and significant infrastructure works would be extra. This means that the savings from cheaper fuel and using less of it are well outweighed by the capital cost of setting the system up, unless the traffic is very dense or there are steep grades or long tunnels. In rail commuter passenger service the quicker acceleration, linked with the lesser noise and lower emissions, makes electrification a viable option for the more densely trafficked routes.

In New Zealand, outside the Auckland commuter routes, the only route where further electrification might be viable is through the Otira Tunnel. This route's capacity is reduced by the time taken to clear fumes from the tunnel, and because it is a short section, the costs of electrifying it would be limited. Even so, it would cost about \$50m, and the capacity limit with diesel locomotives and ventilation fans has not yet been reached.

The most densely used routes for freight, road and rail, are in the Auckland-Waikato-Bay of Plenty "golden triangle". That is also where most growth in freight traffic is expected. The Ontrack study last year showed that the principal benefit of electrifying the railways on the Auckland-Mt Maunganui route would be fuel savings, followed by time and carbon savings. Benefits only totalled \$9m a year, compared with the capital cost of \$860m (excluding any new locomotives). Even with a low 5% discount rate, the benefits would have to be about \$50m a year to break even. As well, since the report was written electrification costs have risen 25%, and new, more powerful and more fuel-efficient diesel locomotives have been ordered. It does appear that until fuel or carbon prices rise substantially, the most sustainable way of running the railway is with diesel locomotives.

### **Other fuels**

That said, there are experiments being conducted with other fuels for locomotives and railcars elsewhere in the world. The principal contender is hydrogen, and such vehicles have been established as practicable operationally in the US and Europe. It can be burnt directly in a modified conventional engine, or used via fuel cells. The real issue for them is that hydrogen is not an energy source, but an energy carrier; the actual energy used in its creation is usually electricity, and in its turn the sources used to produce the electricity. Using on-board hydrogen is much less energy efficient than using straight electricity. Hydrogen is much less energy dense than diesel, so hydrogen locomotives would have reduced range or bigger tanks, and site storage would have to be larger. Hydrogen also raises safety issues. Since rail can use electricity directly, the use of hydrogen in rail vehicles will boil down to the relative expense of generating it, transporting it, and storing it, against the capital cost of electrifying the railway. A UK study has suggested regular use of hydrogen for transport is a long way off, even for road vehicles.

Hybrid locomotives have also been demonstrated to be feasible. Like a hybrid car, these store energy generated by braking and re-use it. Like the car, they make more efficient use of fossil fuels, but still rely on them as their energy source. Locomotives can also run on bio-diesel, either 100% or blended with mineral diesel. A New Zealand experiment running a 5% blend in two standard diesel locomotives was successful, but there were issues in maintaining supplies.

### **Rail uses simple natural materials**

Rail also makes use of natural and simple materials in forming its roadway. It is made of crushed stone ballast, timber or concrete sleepers, and steel rails. Track typically lasts for a very long time, contributing to sustainability through that longevity. A hardwood sleeper (not used much now, but still available from sustainably managed forests) lasts over 30 years (some 80 year olds still exist), a plantation softwood one 35 years, and a concrete one possibly as long as 80 years. Concrete and ballast are locally produced products, unlike asphalt. Rail life depends on its location and wear, but rails over 90 years old are still in use on branch lines in New Zealand, and probably older in sidings. On the other hand rails in curves on heavily used routes might only last 8-12 years before being taken out and reused in a less demanding role - for another 50 years. Of the original steel, over 90 % remains when the rail is worn out for railway use. It is then readily recycled.



*KiwiRail*



*KiwiRail*

Rail wagons are principally steel, and are designed to minimise the weight and thus the use of steel. They too are recycled when worn out, which can be 35-40 years after being built.

### **Efficient use of land**

Rail also makes efficient use of land. Its narrow corridor has very high capacity for hauling passengers or freight. According to the OECD rail uses only 4% of total land for transport. Figures in Beca Carter's *Promoting Sustainability in NZ's Rail System* (NZTA Research Report 370) show a railway can carry 10 times the people that a motorway lane can. Freight capacity is influenced by the signalling system, grades, and terminal capacity, but on a typical double track in New Zealand a train could be run every 6 minutes, hauling 2000t of freight. The actual railway occupies only about 5m of the land; there may also be an access track; the rest is in vegetation, often providing refuges and corridors for wildlife.



*Darryl Bond, KiwiRail*

### **Conclusion**

Rail can contribute substantially to a sustainable future, by doing what it is now doing, but better. There are as well opportunities for further contributions by changes in motive power that might be sensible sometime in the future, depending on the prices of diesel and carbon. Rail could play an even bigger role in promoting sustainability by carrying more, especially more freight. Its option value as a mode that can continue in times of scarce oil supplies should be recognised. But the current transport policy settings favour road transport, as the mode that has the greatest share of the overall transport task in New Zealand, and little recognition is given to rail's current and potential contribution to sustainability.

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### **About the Author:**

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## HOW GREEN ARE OUR TRAINS?

By Brian Beer

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In these days of Global Warming and energy conservation, terms such as 'Carbon Footprint' and 'Green Credentials' are becoming more and more important. Facing up to the realities of modern-day living, ex-British Rail engineer, BRIAN BEER, takes a hard and unsentimental look at the thermal efficiencies of Britain's trains and assesses how rail travel compares with other forms of Inter-City transport.



All forms of transport suffer energy losses and all fuel-burning ones produce some form of pollution. In less enlightened times, wastages and inefficiencies weren't considered too big a problem, but in today's age of serious environmental issues, they are rapidly becoming unacceptable.

All mankind's energy-producing machines, with the exception of the water wheel and the wind turbine, are what are known as heat engines and they are surprisingly inefficient at converting fuel into actual work. In fact, most primary machinery is regrettably more effective at heating up the world's atmosphere and producing unwanted gases such as carbon dioxide (CO<sub>2</sub>).

The ratio of work produced compared with the potential energy in the fuel is known as 'thermal efficiency' and to show how effective different machines are, we need to know the level of their efficiency as well as the amount of chemical by-products ('greenhouse gases') they produce.

**Poor progress:** Expressed as a percentage figure, thermal efficiency gives an interesting insight into Man's relatively poor progress in producing an efficient form of motive power from the various fuels he has had at his disposal since the dawn of the Industrial Revolution more than 200 years ago.

A practical example of this can be demonstrated by studying historic locomotives like Stephenson's *Rocket*. In the 1830s, *Rocket*, propelled by wet steam from a fire tube boiler, had a practical thermal efficiency of just seven per cent, in other words, for every 100 shovels of coal thrown into its firebox during a journey, only seven did any useful work hauling the train. The other 93 were wasted as gas and heat losses warming up the surrounding atmosphere.



*Previous page and above: A stark contrast in locations as a Class 37 runs through a verdant rainbow-graced valley while a Class 373 'Eurostar' passes the four chimneys of former Battersea Power Station.*

In the days of plentiful cheap coal supplies, thermal efficiency was not considered a major issue, but after the Second World War, coal prices and labour costs began to rise rapidly. Suddenly, thermal efficiency became an important factor to the then British Transport Commission when considering future developments for the UK's rail network.

The 1955 Modernisation Act was implemented to provide a more competitive and efficient railway. Developments with diesel and electric traction in other countries had shown what was possible and it was clear to the BTC that more efficient traction must be procured.

Main line electrification was expensive and required extensive civil engineering, so initially BR opted for what was intended to be a 'stop-gap' measure of diesel traction. However, with the exception of a few specialised locos for Commonwealth and UK markets, British industry had at that time little experience of main line diesel locomotive production and, in retrospect, 'buying off the shelf' from the highly-developed American market would have been the answer to BR's dreams. But, in exercising caution and bowing to political pressures, the BTC allowed home-based industries to unleash a whole gambit of traction solutions to replace the reliable steam locomotive. After that unhappy early experience, diesel power (especially the diesel-electric version) eventually evolved into an impressive motive power source.

Electric traction has had a less precarious history, but, interestingly, is not necessarily the most cost-effective, environmentally-clean or thermally efficient. This statement may surprise many enthusiasts, but the following examination of advantages and disadvantages of the various forms of traction will, I hope, provide a satisfactory explanation.

**Electric traction:** 'Pure' electric traction is powerful, easily controllable and commercially sensible for both high density inter-city main line traffic and commuter services. It is limited only by the network's supply capacity and the tractive effort of the motive power.

Its disadvantages, however, are the low thermal inefficiency of the power station producing the electricity in the first place and the fact that the energy supply has to be transmitted considerable distances through contact rails or catenary systems, which results in substantial losses.

The majority of Britain's National Grid power stations are less than 40 per cent thermally efficient and it stands to reason that the thermal efficiency of a train cannot exceed that of the power station supplying its current. Most power stations are fossil fuel-based (coal, oil or gas fired) producing high levels of greenhouse gases. It has been calculated that another eight per cent is lost in transmission through power lines, transformers and associated equipment before the current enters the locomotive or train itself – which then loses a further three to four per cent converting electric power to mechanical traction at the wheels. This all brings the combined thermal efficiency of electric trains down to around 28 per cent.

This is still considerably higher than steam, of course, but electrification also entails high installation costs, particularly overhead systems, not to mention bridge lifting/rebuilding etc. for safety clearances. Lower voltage contact-rail systems, such as in the south-east of England, are less expensive from a capital cost point of view, but require frequent booster sub-stations, which increase the cost per mile.

So, while electric power provides clean traction on the railway itself, it is not as clean as it might first appear to the public.



Keen to show their 'green' credentials, the French have gone one better than others and adorned some of their locomotives with slogans such as "This locomotive respects your environment", noted on No 172160 in 2005.

**Diesel-electric traction:** Such locos and units have the advantage of carrying their own small 'power station' around with them, although they generally lack the acceleration power and haulage capacity of a pure electric. At optimum revolutions per minute (r.p.m.), an average modern diesel loco engine has a thermal efficiency of around 38 per cent - but due to the engine having to drive a generator, which in turn provides electricity for the traction motors, the overall thermal efficiency drops to around 32 per cent. This means that around 68 per cent of the diesel fuel is wasted heating up the atmosphere with exhaust gases containing high levels of CO<sub>2</sub> and other pollutants. The loco also has to carry around its own fuel supply, adding to the weight, which thus reduces drawbar power output.



*Diesel-electric Type 5 No 60066 John Logie Baird climbs towards Shap with a Jarrow Stanlow rake of petroleum tanks on Aug 13 1994. Such images illustrate two of the most controversial aspects dealt with in the main text – the UK's continuing heavy reliance on oil fuel, much of it imported; and the widespread use of diesel traction on electrified routes. DAVE McALONE.*

The new generation of long-distance 125mph diesel-electric multiple units we now have in Britain (e.g. 'Voyagers') have a thermal efficiency of around 33 per cent, but the biggest problem with today's new generation of long-distance DEMUs is that their increased power output, for greater speed and acceleration, has increased the tare weight of each vehicle.

This means they are no more (and in some cases less) energy-efficient than the older generation of diesel inter-city trains. In fact, recent studies have shown that a 30-year-old HST with two power cars

has a better fuel economy performance per seat mile than many of the newer express multiple units.

This questions the logic of producing 100mph-plus diesel trains with distributed traction, which carry fewer passengers per vehicle at a considerable increase in fuel consumption.

**Diesel-hydraulic power:** This has the highest thermal efficiency of all traction systems as it can achieve an overall 37 per cent.

This is because there are no losses involved converting mechanical energy into electric energy and then back into mechanical energy again for traction, as there are with diesel-electrics. The main losses are in the diesel engine and expensive torque converter, which takes all the punishment during train starts and acceleration of heavy loads.

The Western Region of BR took the hydraulic path in the 1960s with the 'Warships' and 'Westerns' and found them powerful locomotives capable of exerting a high drawbar pull, but on a practical level, they proved expensive to run with high maintenance costs per unit mile and inferior reliability compared with diesel-electrics. Stanier and Gresley would have loved them on the heavy trains of the 1930s and '40s, but by 1977 they had all been withdrawn.

**Diesel-mechanical traction:** Originally conceived as a lower cost option for commuter services, this system uses (in DMUs) an under-bodied diesel engine with a mechanical drive powering the wheels via a fluid clutch, gearbox and prop-shaft. It has generally been used on lighter trains, such as railcars and multiple units, but conventionally positioned engines also power many shunting locomotives.

The thermal efficiency is around 35 per cent - slightly better than diesel-electric power as there is no energy conversion involved and only slight transmission losses in the fluid clutch drive and gearbox. As with all diesel traction, the exhaust gases do contain high levels of CO<sub>2</sub> and other pollutants.

**Gas-turbine traction:** The late-1940s and '50s saw experiments with locomotives carrying gas-turbine generating sets, providing traction through direct current motors (BR Nos. 18000 and 18100, for example). The turbine effectively replaces the diesel engine as a power source and is geared to a generator to provide electric current for the traction motors.



*Diesel-Hydraulic: The Western Region alone among BR Divisions opted for hydraulic transmission which came out on top in our survey with a thermal efficiency of 37% but proved expensive to run and maintain. In this May 1964 scene, 'Warship' No D852 Tenacious comes off the sea wall and approaches Teignmouth. A.E.COPE COLOUR-RAIL DE376.*



*Diesel-mechanical: Class124 Trans-Pennine DMU at Manchester Victoria East Jct en-route to Hull April 1961. J.DAVENPORT/COLOUR-RAIL DE935.*

The exception to this configuration in Britain was loco No. GT3, which used a Stanier 'Black Five' steam chassis and was mechanically driven through torque converters and gearing.



*Gas Turbine: Brown-Boveri 2,450hp A1A-A1A No. 18000 which worked in Britain for several years from 1950, mainly on the Western Region, and is now preserved at Crewe Heritage Centre*

The advantage of the gas-turbine engine is its high power-to-weight ratio, being much lighter than the diesel. Its major disadvantage, apart from its higher manufacturing cost, is that it does not achieve its maximum thermal efficiency until it is at 100 per cent power output. Even then, its maximum is only around 35 per cent for the turbine (30 per cent after conversion to electric power).

Gas-turbines do not possess the flat power/fuel consumption curve of a diesel engine and the thermal efficiency drops rapidly when the power output is reduced.

A typical locomotive's duty cycle is, of course, a varying one, with many accelerations and decelerations due to station stops and signal pauses etc. This means that the fuel consumption per unit mile is extremely high with gas-turbine power, which explains why it has proved unsuitable for normal train haulage. It did briefly re-emerge in the 1970s on Britain's Advanced Passenger Train (APT-E) and France's TGV prototypes (the reason being the concept of continuous high-speed running over long distances with minimal stops), but it was eventually killed off in the fuel/ energy crisis of that period.

The pollution and CO<sub>2</sub> levels in the turbine exhaust are high and more difficult to control or filter than diesel exhausts, although it must be said that modern developments can now utilise waste heat from the turbine exhaust to produce steam, which is then used to power a second turbine. This has dramatically improved thermal efficiencies in these combined cycle engines and figures of over 60 per cent have been claimed.

Consequently, there could be a promising future for this technology on the railways after all.

**How train travel compares:** The foregoing may not have made particularly pleasant bedtime reading for most enthusiasts, but the good news is that rail travel is generally more energy-efficient and carries a lower carbon footprint per passenger per mile than any other form of powered public transport - as long as the trains are reasonably full.

Poorly-patronised trains are not energy-efficient or cost-effective and consume almost as much fuel and produce approximately the same level of pollution as a full train.

For example, an average full diesel-hauled express train carrying 500 passengers would use 4.54 litres of fuel per mile, giving an economy of 110 miles per passenger per litre. If the same train ran with only 200 passengers on board, it would use 4.2 litres per mile, so the figure would drop to 47.6 miles per passenger per litre, which is worse in energy efficiency than a motorway express super-coach carrying a 50 per cent passenger load and averaging over 52 miles per passenger litre. So, for rail networks to sustain their lower energy and pollution profiles, they must be well patronised (which thankfully, many do seem to be at the moment).

Tracked guidance systems allow trains to run at higher speeds in greater safety and comfort than other forms of land transport, but the quest for ever higher speeds has an environmental cost.

Aerodynamic drag increases with the square of the velocity - therefore very high speed trains have to be streamlined to bring their drag factor down. Even with its streamlined profile, however, a Eurostar travelling at 186mph consumes more than three times the energy of an ordinary inter-city train travelling at 100, as the power requirement for the reduced journey time is proportional to the velocity cubed.

It follows therefore that the extra energy required for high speeds reduces the miles per passenger per kWh by the same factor. That would be a problem if high-speed rail was being compared with other forms of land transport - but Eurostars and TGVs are designed to compete with inter-city airline traffic, and therefore do so more energy efficiently on short-haul journeys (i.e. around 500 miles) ... producing a much lower 'carbon footprint' to boot, particularly in countries like France which have an 80 per cent nuclear power station generation base.

To try to operate trains at such speeds using *only* fossilised fuel as an energy source at the power station stage would be uneconomic and produce higher levels of carbon dioxide.

#### **Train travel comparisons with road-passengers vehicles:**

- A modern motorway coach can attain 97 miles per passenger per litre of fuel, when fully loaded at 70mph.



*The High Speed Train (HST) has been one of Britain's success stories. Here the prototype, No 252001, stands alongside the gas-turbine powered Advanced Passenger Train prototype APT-E at Swindon in the early 1970s.*

- A modern diesel car can attain 40 miles per passenger per litre with four passengers, on a motorway cruising at 70mph.
- A modern aircraft can achieve around 23 miles per passenger per litre in flight - but these figures are improving.
- A diesel loco-hauled train carrying 500 passengers can achieve 110 miles per passenger per litre.

It must be remembered however that these figures are calculated for a train travelling at 100mph, whereas the road vehicle consumptions are for 70mph. The loco-hauled train has an energy efficiency 12 per cent or so better at 100mph than the motorway coach at 70mph, but must be well patronised to achieve those levels.

TGV derivatives consume much more power to enable them to achieve their shorter journey times, which reduces their energy economy to an *equivalent* of around 40 miles per passenger per litre of diesel fuel - again with a full train.

Due to the exponential rise in air resistance, running trains at speeds greater than 186mph entails very high power consumption, which explains the recent greater use of Duplex (double-decked) TGVs on the Continent.

This law of diminishing returns renders operational ground speeds above 230mph uneconomic with conventional rail technology. It is also a limiting factor for all ground transport systems (even linear motor propulsion hover trains) operating at or around sea level, due to the dense air creating high drag.

Train bogies, consume as much as 20 to 30 per cent of the power at high speed, hence the preference for articulated bogies and suspension - which also enables a reduction of 40 per cent in total bogie weight as well as reducing drag.

A further 10 to 15 per cent of the aerodynamic drag with electric traction at very high speeds is due to the current collection system and, as explained in our layman's guide to pantographs (March issue), pantographs cause increased contact wire vibration and wave propagation at those speeds. This exacerbates energy loss due to poor electrical contact and arcing.

It also needs to be said that trains, in the UK particularly, are subject to ever more stringent health & safety regulations concerning crashworthiness and disability facilities, which some other transport modes do not have to comply with. These regulations increase the weight (and therefore reduce the efficiency) of each vehicle, although they do ensure that rail travel is by far the most comfortable and safe mode of transport.

In conclusion, rail traction has made notable advances in motive power thermal efficiency since the 1950s, but over the last decade has lost some ground because competitors such as the private car, the heavy goods vehicle and the road coach have improved their fuel efficiencies significantly. In addition, airlines enjoy generous fuel tax concessions that do not apply to other forms of transport.

**The future:** Trains need to have better fuel efficiency, employing lighter vehicles, with greater passenger/ luggage capacity and more efficient traction.

Manufactures need to embrace new technologies such as lighter permanent magnet motors, energy saving & storage systems; for diesel traction - more fuel efficient low pollution engines, and combined cycle power systems utilising waste heat energy. These are all considerably more achievable via separate locomotives or power cars than via distributed power throughout a rake.

Looking at the overall picture for electric traction, the greatest losses are at the generation/supply end, so better, more thermally efficient, electricity power generation is needed, from whatever energy source can be made environmentally acceptable and cost-effective. Nuclear fission-generated electricity is free of CO<sub>2</sub> production, but its thermal efficiency is below 40 per cent and its long-term usage costs are high, both financially and environmentally. Therefore I strongly feel it is essential that the potential of tidal hydro-power, from schemes like the Severn barrier, should be seriously investigated by the Government.

It is clear that fossilised fuel will continue to be essential as a power generating source for some years to come. Britain still has large coal reserves and major progress has been made in clean coal gasification, CO<sub>2</sub> capture and fluidised bed generation technologies. All should be considered, if only for the sake of Britain's national energy security.

Even if power stations can be made more efficient, the provision of electricity for traction is not fully utilised in the UK, with many parts of the main line system remaining unwired. We have the ludicrous situation of many diesel-powered expresses leaving the capital (King's Cross is a good case in point) and running under wires for 60 per cent or more of their journey. Many of these do so simply to complete the remainder of their journey on non-electrified routes. Far too many freight trains are also diesel-hauled under wires.

In conclusion, railways need to be progressively energy-conscious in the future or they will lose their environmental and cost advantages, resulting in higher fares ... and that will reverse the rising popularity trend the industry has seen in recent times.

For the sake of the industry and future generations, it is vital that we achieve a reduction in greenhouse gases and improve total system thermal efficiency.

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***About the Author:***

***Brian Beer*** is an electrical engineer who spent most of his early working life in the coal mining, heavy electrical and communications industries. Until his retirement he spent 23 years as a Rail Vehicle Testing Engineer with British Rail Research in Derby UK.

## **COULD THERE BE A PLACE FOR STEAM TRACTION FOR RAIL TRANSPORT IN A “SUSTAINABLE ENERGY” WORLD?**

**By Chris Newman**

### **Introduction**

Steam power was at the forefront of the Industrial Revolution, and it created the means of traction that triggered the massive development of rail transport throughout the world in the 19<sup>th</sup> and early 20<sup>th</sup> century. However 125 years after George Stephenson created his famous “Rocket”, steam traction found itself being rapidly displaced by “modern traction” in the form of more efficient diesel and electric powered locomotives. But was steam traction really obsolete at the time of its demise? Does it have a potential for development that could be exploited for use in a fossil fuel-depleted world?

This paper describes the history of steam traction and the reasons behind its rapid displacement in the mid-20<sup>th</sup> century by “modern traction”. It goes on to describe the potential for further development of steam traction technology and the possible roles that steam traction might be able to perform in a world dependent on renewable energy.

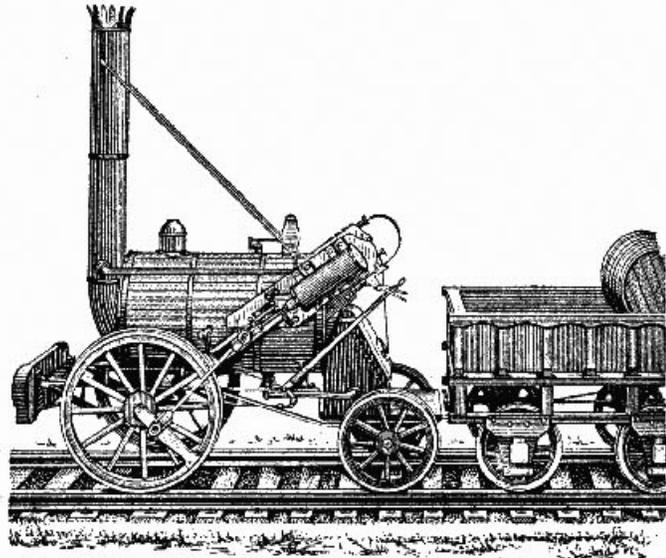
### **Background – outline history steam traction and its demise**

From the beginning of time until the mid-18<sup>th</sup> century, the human race lived in close harmony with its environment. Technology had advanced as far as wind and water power for pumping and milling operations but the only power available for transport was from animal and man-power. A revolution in transportation nevertheless began in the mid-17<sup>th</sup> century with the construction of canals throughout Britain and to a lesser extent Europe which dramatically reduced the cost and time for the transportation of goods. Passenger transport was nevertheless limited to the horse-drawn coach which was both expensive, tedious, uncomfortable and hazardous, with the result that the mobility of most people was extremely limited.

This timeless world was changed dramatically and irreversibly by the development of “steam power” beginning with the “atmospheric engine” of Thomas Newcomen in 1712 which revolutionized the pumping of water from mines and allowed mine depths to be increased. The father of the steam engine was James Watt whose engines derived their power from steam pressure rather than steam condensation (as Newcomen’s had), however it was a Cornishman by the name of Richard Trevithick who, at the turn of the 19<sup>th</sup> century, developed Watt’s ideas through the application of higher steam pressure and by mounting his engine on a wheeled frame to make the first steam-powered vehicles. He went on build the world’s first rail-mounted engine which was demonstrated as a novelty in London in 1808. George Stephenson built the first truly “industrial” locomotive for the Stockton & Darlington Railway in 1825, and named it “Locomotion”. His more famous “Rocket” was built in 1829 to operate on the Liverpool and Manchester Railway – the world’s first passenger railway which Stephenson himself had been responsible for building.

With very few exceptions, all steam locomotives built between 1829 and the “end of steam” in the mid-20<sup>th</sup> century adopted the basic design principles that Stephenson incorporated into his Rocket. These can be summarised as follows:

- Horizontal boiler with multiple fire-tubes connecting between a smokebox at the front and firebox at the back;
- Self regulating steam production by means of exhaust steam passing through a “venturi” system inside the smokebox to draw combustion-air through the fire-grate;
- Steam flow to the cylinders controlled through a valve system allowing reversing and “expansive working” at speed;
- Double acting pistons with direct drive through connecting rods to the driving axle;
- Two-man control , one driving and one “firing” with controls located inside a “cab” mounted at firebox end of locomotive;
- Fuel and water carried in a separate wagon mounted behind the cab (with the exception of “tank locomotives” where the fuel was carried in a “bunker” mounted at the rear end of the locomotive’s frames and water was carried in a tank or tanks beside or above the boiler).



*Stephenson's "Rocket" built for the Manchester and Liverpool Railway (1829)*

Improvements in steam loco performance and efficiency over the next 125 years were largely achieved through increases in size (which of itself increases efficiency) and detailed improvements in design. Apart from “compounding” which involves expansion of the steam through high and low-pressure cylinders, only one significant scientific/engineering development was applied to steam traction over that time in the form of steam superheating through which the temperature of steam is increased above its saturation temperature (boiling point) thereby increasing thermal efficiency in accordance with Carnot’s theorem. However at the turn of the 20<sup>th</sup> century, thermodynamics was a new science, and even by mid-century it seems to have been little understood by decision-makers in the railway engineering world (with the exception of France) with the result that even the last designs of steam locomotive remained relatively inefficient machines.

Very few locomotives were built that deviated from the “Stephensonian model”, the main exceptions being isolated examples incorporating turbine-drive, high pressure water-tube boilers and occasionally a combination of both. One notable exception was the Leader class developed by O.V. Bullied of the Southern Railway in Great Britain in which he attempted to leap-frog steam technology to compete directly with “modern traction” by mounting drivers’ cabs at both ends, and by providing power to all six axles which he mounted in two “bogie” frames. The experiment was a dismal failure largely due to the incorporation of too many novel and untried ideas.



***Leader Class Steam Loco (1949)***  
*– too many novel and untried ideas*

#### **Why was steam traction displaced so rapidly by “modern traction”?**

In retrospect, the displacement of steam traction with diesel (and to a lesser extent electric) traction seems both inevitable and well justified. However the benefits of the change-over were not quite so obvious at the time as illustrated by some contemporary articles and technical papers that questioned the financial wisdom of scrapping vast numbers of newly-built steam locomotives and replacing them with new and unproven machines. Indeed, it was a common sight in the UK in the 1960s to see steam locomotives standing-in for failed diesels.

Notwithstanding, there is no denying that steam traction even in its heyday carried significant impediments that were substantially overcome through the introduction of diesel traction. These can be summarized as follows:

- Low thermal efficiency - rarely more than 6% compared to (perhaps) 15 to 20% for modern traction at the time;
- Obvious smoke pollution (a big issue in urban areas) compared to less obvious emissions from diesel traction and electricity generation;
- Need for frequent servicing stops, especially for fuel and water replenishment;
- 2-man operation compared to single-manning for modern traction;
- Low haulage capacity due to limited adhesion associated with non-driven axles, whereas all axles are driven on modern traction;
- Unidirectional operation requiring locos to be turned (except in the case of tank and Garratt type locomotives) compared to bi-directional operation for modern traction.

To these can be added high CO2 emissions – a latter-day issue that did not concern decision-makers in the 1950s.

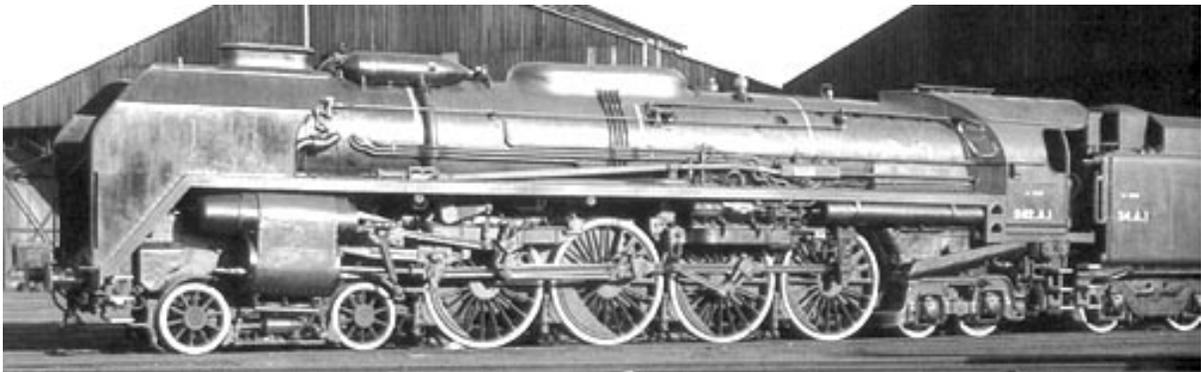
Other disadvantages that were (and still are) claimed against steam traction but which are more easily challenged, include:

- High maintenance costs;
- Low reliability;
- Low availability;
- Inability to maintain high speeds in service.

These latter items can largely be refuted by both example and argument. Generally though, there were sound reasons for the replacement of steam traction with diesel and electric traction, though the indecent speed and extraordinary cost of the change-over were of questionable justification.

#### **Was steam traction fully developed? Is there room for future development?**

Unknown even to most steam enthusiasts let alone the wider world, a few dedicated engineers have continued the development of steam traction throughout most of the 40 or 50 years since steam's demise in most of the world. A French engineer named **André Chapelon** pioneered a number of important advances in the 1930s, demonstrating how the application of thermodynamic theories could transform the performance of steam locomotives, and achieving what were then astonishing levels of performance and efficiency through the extensive rebuilding of poorly performing



***Chapelon's 242A1 of the late 1940s***

*Capable of delivering 5,500 indicated horsepower, it outperformed all diesel and electric locomotives of its day locomotives.*

In the early 1950s Chapelon prepared several new high performance designs of locomotive that were intended to meet the speed and haulage needs of the newly nationalized French railway system, however none were constructed before the government decided to pursue an electrification policy (associated with its decision to focus on nuclear-powered electricity production) which involved the rapid displacement of its fleet of steam locomotives.

At around the same time a young Argentinean engineer named **Livio Dante Porta** began a career that was to see him take over the reins of steam development when Chapelon retired at the end of

the decade. Porta applied Chapelon's principles to the rebuilding of an old locomotive that was given the name "Argentina" in celebration of the supposed achievements of the Peron government. In trials, the locomotive equaled the highest thermal efficiency figures that Chapelon had achieved in France and established Porta's reputation as an outstanding locomotive engineer – a reputation that he upheld for 50 years until his death in 2003.

Like Chapelon, Porta's was never able to build a new locomotive that incorporated all his ideas and theories. Nevertheless, his achievements in developing old designs were astonishing, and can be summarized under the following broad headings:

- Improved thermal efficiency through improved design and the application of thermodynamic principles;
- Improved steaming rates through the application of fluid flow theories in the design of exhaust systems;
- Improvements in water treatment such that boiler maintenance costs can be practically eliminated (ordinarily boiler repair is the highest cost item in loco maintenance).
- Dramatic reduction of wear rates in valves, pistons, cylinders and other components through the application of principles of tribology through improved lubrication;
- Elimination of steam leakage through improved detail design;
- Improved adhesion through detail design and changed maintenance practices;

Porta achieved notable success in the modifications he made to a fleet of diminutive coal-haulage locomotives operating in Southern Patagonia through relatively minor modifications, increasing their haulage capacity by over 50% and halving their maintenance costs. He went on to achieve similar or greater improvements in several countries in South America and the Caribbean and prepared designs for highly advanced locomotives that have as yet never been built.

Porta also inspired and guided the work of English engineer David Wardale who achieved great successes with two steam locomotive rebuilds in South Africa, one of which – the iconic "Red Devil" as it became known – achieved a 60% increase in power output and 25% reduction in coal consumption compared to original (and relatively advanced) original German design.



*Wardale's 3,300 kW (4,500 hp) South African Railways Class 26 "Red Devil" – capable of 160 km/h performance if it had been allowed.*

It is clearly evident from the above examples that steam traction was capable of significant development at the time of its demise. It should also be noted that almost all developments cited above were low-budget projects, and some

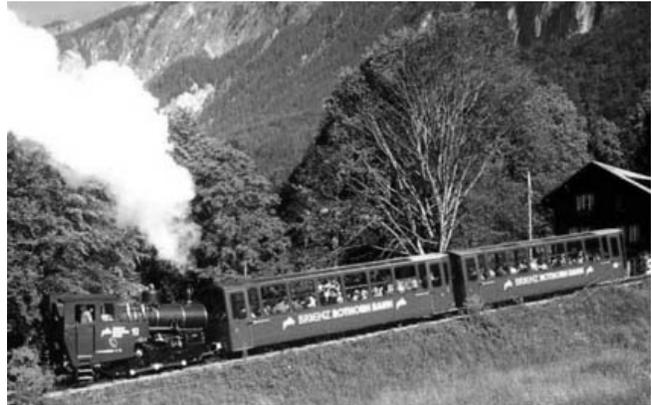
did not even have official sanction. Thus it may be deduced that given the huge investments that have been applied to the development of diesel and electric traction and the huge advances that have been made in the intervening 50 years, it is reasonable to assume that had the same investment been made in the development of steam traction, a similar scale of improvement might have been achieved.

Porta was firmly of the view that given sufficient development funding, steam traction could achieve a drawbar thermal efficiency close to 25%, which itself is close that that of modern diesel traction today and equal to or better than electric traction when powered by traditional coal-fired power stations. Such gains would be achieved through the use of much higher steam pressures and temperatures, and through highly expansive compound working of the steam.

### Current and Future Developments in Steam Traction

The death of Porta in 2003 was a blow to the small fraternity of engineers who are engaged in the ongoing development of steam power for rail traction. However their work continues across many parts of the world. These practitioners include:

- **Roger Waller** of DLM in Switzerland (see <http://www.dlm-ag.ch/index.php>): In the 1990s DLM constructed two fleets of oil-fired “Modern Steam” locomotives incorporating many of Porta’s principles for operating on mountain “rack” railways in Switzerland and Austria. The locomotives compete with diesel locomotives and they not only attract more visitors but produce less toxic emissions and are more cost-efficient on a “per passenger-km” measurement. DLM has also installed a steam engine into one of Lake Lucerne’s passenger ferry fleet with good economic results both in terms of passengers carried and overall cost of operation. The company now has plans in place for a new design of modern steam locomotive for hauling tourist trains on near-disused branch lines in Germany for the purpose of increasing passenger numbers and returning profitability to the lines.



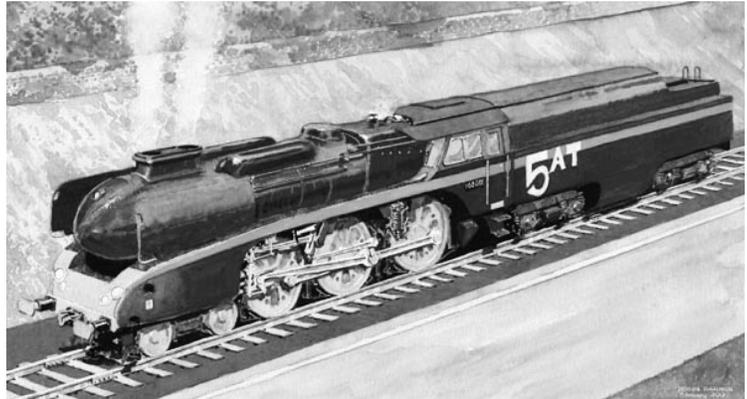
*Modern Steam rack Loco built by DLM in mid 1990s, operating on the Brienz Rothorn mountain railway in*

- **Phil Girdlestone** of Girdlestone & Associates based in South Africa (see <http://www.pgrail.co.za/>): Phil specializes in the design and construction of modern steam locomotives incorporating Porta’s principles. Whilst most of his locomotives have been supplied to narrow gauge tourist lines, he has undertaken major rebuilds of standard gauge locomotives in Australia and Russia.
- **Shaun McMahon**: Shaun currently lives in Argentina where he has worked on modernizing the locomotives fleet on the FAF tourist railway in Ushuaia and on plans to rehabilitate the RFIRT coal transportation railway in Patagonia. Shaun worked with Porta for many years and is therefore more familiar with Porta’s ideas and principles than most other engineers.

- **Nigel Day:** An expert on locomotive drafting who is currently working in the USA, improving the performance of locomotives on tourist railways.
- **Ian Screepton** and **Ian Gaylor** in the UK are both applying Porta's principles to improve the performance of locomotives on miniature and narrow gauge tourist railways.

In addition there are several groups and businesses that are pursuing the development of steam power, such as:

- **5AT Project** being planned by a team of engineers and other professionals (see [www.5at.co.uk](http://www.5at.co.uk)): This UK-based project was established in 2001 for the purpose of incorporating Porta's design principles into a new high-speed locomotive for hauling tourist trains in the UK and Europe. The "Fundamental Design Calculations" for the locomotive were completed by David Wardale (of "Red Devil" fame) in 2004 which demonstrate that the locomotive will be capable of meeting the defined performance criteria – viz:



*Impression of the 5AT locomotive (by artist Robin Barnes).*

- max speed of 200 km/h (125 mph);
- continuous operating speed of 180 km/h (113 mph);
- continuous power output of 1890 kW (2535 hp) at the draw-bar at 180 km/h;
- drawbar thermal efficiency at maximum drawbar power output approx 11.4%.

[Note: An efficiency of 11.4% is very high when delivering very high power and trailing a large tender of the same nominal weight as the engine itself. By comparison with the best level achieved with simple expansion locomotives in former times, the BR Class 7MT 4-6-2's at maximum evaporation, generating 17.3 indicated kW per ton of engine weight, gave a drawbar thermal efficiency of 7.7%, and the BR Class 5MT, at its maximum of 17.0 indicated kW per ton of engine weight, gave 6.8% efficiency.]

Very high levels of reliability are expected from the locomotive and very low maintenance costs even compared to "modern traction".

- **Spilling Energy System GmbH** (see <http://www.spilling.de/english/index.php>): An old company that has been manufacturing steam engines for over 100 years. It now specializes in stationary (reciprocating and turbine) steam engines for small and medium-sized power plants and "combined heat and power" generators. However its power units might be fitted into railway vehicles perhaps to create a steam-electric power unit.
- **The Vapor Locomotive Company** (see <http://vaporlocomotive.com/>): A newly established company in the USA which has procured the old stock, tooling and drawings from the old Skinner Engine Company for the purpose of rehabilitating old engines of this type and

manufacturing new ones. Skinner steam engines were widely used in marine applications, but could be adapted for railway use.

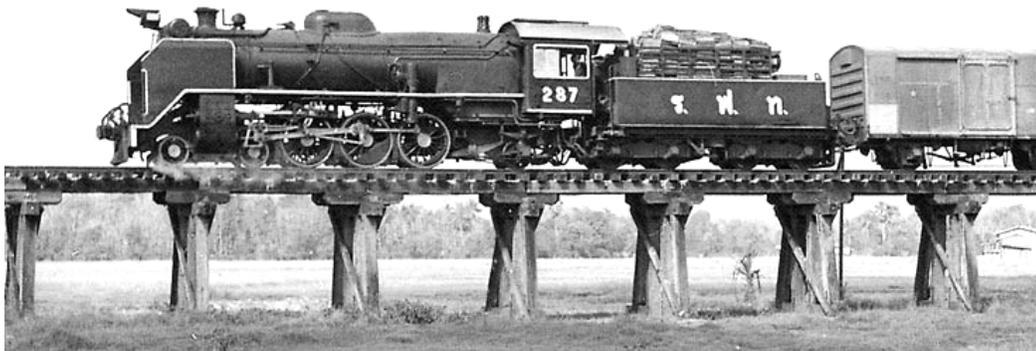
- **Pritchard Power Australia** (see <http://www.pritchardpower.com/>): This is a newly established company that plans to rehabilitate the technology developed by Ted Pritchard in Australia in the 1970s including the vee-twin steam engine that he developed for automotive use. Whilst having no application for rail traction at present, the establishment of the company was based on recognition of the potential advantages that steam power offers, particularly in the use of renewable fuels.

Finally, it should not be forgotten that “steam power” remains at the forefront of modern technology, driving almost all modern power stations and nuclear power plants. In fact most modern electric trains are (in most cases) driven by remotely-generated coal-fired “steam power”. The “failure” and replacement of steam locomotives was inevitable only because the technology was allowed to grow out-dated through lack of development. As such it became seen as dirty, inefficient, slow, unreliable and obsolete, particularly when compared to the clean, efficient and fashionable alternatives that the newly developed diesel and electric traction were able to offer.

#### **What can steam traction offer in a “renewable energy” world?**

Whilst even the most advanced steam locomotive designs envisaged by Porta would be unlikely to equal the thermal efficiency of modern diesel traction, this does not mean that there can be no role for steam traction on future rail systems. Independent studies conducted by Wardale in South Africa and Newman in Indonesia have shown conclusively that even 1950s steam traction can offer substantial cost savings where the cost of its fuel are low enough (as was the case with indigenous coal in the two studies mentioned), and that even greater savings can be achieved with “modern steam” traction.

But steam engines do not have to burn coal. Indeed one of their most attractive attributes is their ability to burn anything that is combustible including bio-mass waste products. There are many examples from the past of steam locomotives being fuelled with log timber including the USA where, until 1870 as forests were cleared, wood was the principle locomotive fuel. Wood was a principle locomotive fuel in Thailand also until the 1970s when forest depletion became an issue.



*State Railway of Thailand wood-burning locomotive*

Finnish State railways made much use of wood fuel on secondary lines until the 1960s, and even today wood-burning locomotives operate over electrified main lines when hauling excursion trains.

Other agricultural waste products have been used to power steam engines, rice husk being commonly used in South East Asia to produce the steam to power rice mills; and bagasse has been commonly burned to power steam engines that drive sugar mills. Bagasse has also been used to fuel small locomotives on sugar plantations, in the Philippines and Indonesia.

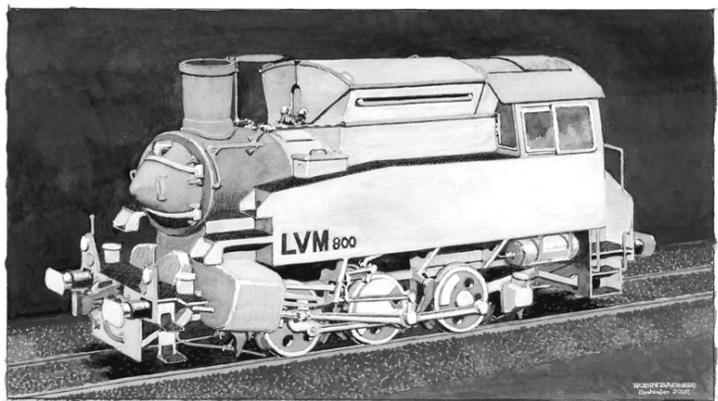
The main problem with biomass fuels for locomotive use is their relatively low heat content (calorific value) and low density compared to fossil fuels with the result that much larger volumes of fuel must be carried (and handled) in order to produce an equivalent amount of traction. Furthermore, because bio-mass fuels are lighter in weight than coal, they are more easily carried away by the flow of "combustion air" passing through the firebed. The use of a GPCS (gas producer combustion system) firebox in which only a small proportion of combustion air is passed through the fuel (most passing above the firebed), can significantly reduce particle carry-over and thus reduce fuel consumption.

A comparison between fuel types is presented below (courtesy Brian McCammon):

Comparison of Fuel Properties				
Fuel Type	Fuel	Calorific Value (MJ/kg)	Bulk Density (Kg/litre)	Ash Content (%)
Fossil Fuels (non-renewable)	Light Fuel Oil	43.7	0.913	0.02
	Petro-diesel	45.9	0.835	<0.01
	Coal	28	1.32	5
	LNG	61	0.41	<0.01
Bio-Fuels (renewable)	Kiln dried wood chips	16	0.25	4
	Wood pellets	18	0.7	0.75
	Wood briquettes	18	1.1	0.75
	Biodiesel	37	0.90	Not known

From these figures it is easy to estimate the additional weight and volume of fuel that a wood burning locomotive would need to carry to undertake the same work as an equivalent fossil fuel-burning steam loco. For instance, the weight of wood pellets carried would need to be 55% greater than that of coal, and the volume would need to be three times greater.

Notwithstanding these drawbacks, Porta was an early advocate of the development of steam locomotives for burning bio-fuels, and he undertook at least two projects to test out his theories, the first being the rebuilding in the late 1980s of a wood-burning locomotive in Paraguay which through simple modifications achieved a massive 70% reduction in fuel consumption.



Porta's LVM 800 – an impression by artist Robin Barnes

He subsequently developed a new design of loco – the 800 h.p. “LVM800” - with the specific purpose of using bagasse or other biomass as fuel (see <http://www.martynbane.co.uk/modernsteam/ldp/lvm/lvm800.htm>). This diminutive but powerful locomotive would have been revolutionary in demonstrating the capabilities of “green” steam traction, but even though the design is fully complete (including shop details), funding has never yet been found for the construction of a prototype machine.

John Johnston, a US engineer, is one who is putting into practice Porta’s principles in his miniature (7½” gauge) “Green Loco” project – see <http://www.greenloco.com/>.

### **Conclusion**

Whilst steam locomotives are generally regarded as items of only historical interest, it has been demonstrated by Porta and others that steam locomotive technology was never fully developed, and that with even modest and easily implemented improvements, the performance of old locomotive designs can be dramatically improved. Whilst no new design of locomotive has ever been built to incorporate all of Porta’s principles, it has been shown by engineering calculation that 100% efficiency improvements can be achieved through the application of existing technologies, and it can be predicted that 200% gains in efficiency might be possible through further development, thereby achieving levels of efficiency very close to that of modern traction.

However the singular advantage that steam traction offers is the ability to burn solid bio-waste as a fuel. Whilst such fuels are less energy-intensive than fossil fuels, they nevertheless generate heat which can be used to provide tractive power. Large numbers of early steam locomotives ran on wood fuel, and modern designs have been developed for the purpose of using biomass as their fuel source. There can be little doubt that future development of the technology could produce substantial improvements in performance and increased thermal efficiency.

Steam traction will never meet the all the future needs of the world’s railway systems. Bio-diesel will gradually displace fossil-diesel in the tanks of diesel locomotives, and biomass can be used to generate electricity to power electric locomotives. Nevertheless, the possibilities for steam traction should not be ignored and it is likely that commercial opportunities will arise for its use in locations where renewable bio-mass fuels are cheaper and more readily available than bio-diesel, and where the massive costs of railway electrification are not justified.

In an uncertain world of rapidly diminishing fossil fuel reserves and escalating prices, it will be wise if all possible options for powered transport are developed so as to ensure that the most appropriate and economic selections can be made from the limited choices that will then be available.

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### **About the Author:**

**Chris Newman** graduated as BSc.Eng. from Aberdeen University in 1967. He is a specialist in bulk materials handling and transportation, especially in grain industry developments in Australia and

*China. Latterly he has been responsible for conducting studies on the economics of rail traction options for coal haulage in Indonesia. Currently he resides in China.*

## **CONSIDERATIONS RELATING TO COSTS OF “SUSTAINABLE” RAILWAY TRACTION OPTIONS**

**By Chris Newman**

*(updated version of paper - see end note)*

**Introduction:** In September 2008 a paper was presented at the CORE2008 rail industry conference in Perth, Australia, that compared the cost of four rail traction options for the operation of a hypothetical 100km coal haulage railway in a developing country. The paper, titled “Feasibility of Steam Traction for Coal Transportation in Developing Countries”, compared the costs of operating four types of traction:

- Reconditioned 20 year old ex-China Railways steam locomotives of traditional design;
- New design of “Modern Steam” locomotive developing much higher thermal efficiency;
- Standard modern Chinese diesel traction;
- Standard modern Chinese electric traction.

The study compared the performance of each traction type to determine realistic haulage capacities for each, and then applied known or estimated costs (based on Chinese data) covering capital amortization, maintenance, labour, water and fuel. It concluded that within the assumed scenario of low labour costs and low-cost coal available directly from the mine mouth, both steam options offered very substantial cost savings compared to the diesel and electric alternatives.

A similar approach can be taken to compare the costs of “sustainable” traction options in a fossil-fuel deprived world, wherein biodiesel fuel might be used to fuel suitably modified diesel locomotives, where hydro, wind or carbon-sequestered coal-fired power stations might provide power to electric traction and where biomass (wood) products might be used to fuel high-efficiency “modern steam” locomotives.

With so many uncertainties and the need to rely on broad assumptions about future (and even present) costs, such predictions can offer no claim to accuracy. What they can do however is to initiate the development of a more meaningful costing model that could provide clearer insights into a range of possible future outcomes and thus highlight potentially useful avenues for technical development aimed at creating an environmentally sustainable railway industry.

**Sustainable Rail Traction:** Before ideas can be developed as to possible cost scenarios, it is necessary to define (as best as may be possible) what the term “sustainable rail traction” might cover. Two possible options spring immediately to mind - viz: (a) “environmentally sustainable”, in terms of not releasing CO<sub>2</sub> or other harmful substances, and (b) “energy sustainable” in terms of not relying on fossil or other “mined” fuel source. For instance, with 100% carbon capture, coal could be regarded as an “environmentally sustainable” fuel source whilst ever coal resources remain exploitable, whereas electricity supplied only from wind, water or geothermal sources could be regarded as “energy sustainable” in the longer term. Both require major advances in technology and/or capital investment which will inevitably result in substantial increases in the price of energy.

Energy is likely to represent the largest cost component of any rail traction system, however it should not be forgotten that a comprehensive analysis should include the environmental or energy

costs of manufacture as well as those associated with fuels for operation. Such costs might be similar for each form of traction unit and may therefore not weigh significantly in comparative terms, but it is questionable whether the energy inputs required to build the infrastructure associated with electric traction would be insignificant in comparison with steam or diesel traction. Such considerations fall outside the limited scope of this article, but should not be ignored in a more detailed analysis.

This article uses a simple methodology for comparing costs of traction alternatives. Much further work is required to refine both the costing methods and data before firm conclusions can be drawn. For instance (as noted above) no attempt is made to assess the energy costs of equipment manufacture, and the figures used for future sustainable energy costs are no more than crude guesstimates.

**Cost Analysis Assumptions:** The methodology used to produce the cost comparisons for the CORE2008 paper was based around a conceptualized purpose-built single-use single-track coal haulage railway of specified length and configuration designed to deliver a predetermined annual throughput of coal. The costing model included detailed predictions of train size (based on the tractive capacity of each locomotive type) from which estimates of locomotive and rolling stock requirements could be made. An intensive 24 hour per day operating schedule for the line was also derived, which allowed detailed estimates to be made of locomotive utilization, annual mileages and maintenance requirements.

Fuel consumption estimates were made based on assumptions relating to thermal efficiency, calorific value of fuels etc, these estimates being calibrated with reasonable accuracy against known fuel consumption data. Capital costs and maintenance costs and frequencies were based on Chinese data for each type of traction excepting, of course, for the “modern steam” option for which no historic data exists. Costs for modern steam were therefore based on such information as was available from various sources, and where necessary through intelligent guesswork. Fuel (and electricity) costs were based on 2006 Chinese data.

The other cost items that were included in the calculations were labour costs (for operational purposes only) and water costs for steam traction only, including water treatment costs.

As stated above, both traditional and modern steam options produced the lowest overall costs by substantial margins, showing a 60% costs advantage over electric traction, and more surprisingly, a 200% cost advantage over diesel traction. These outcomes appeared to be robust insofar as large changes in input values changed only the magnitude of the cost differentials rather than their order.

Such dramatic cost advantages for steam traction arose from very low costs for both coal and labour available in a Third World coal-producing country. As might be expected, diesel and electric traction costs become much more competitive in a Developed World scenario where much higher costs apply to these items. Notwithstanding, in looking forward to a fossil fuel-depleted future, in which renewable transport fuels will become a necessity instead of an option, and where fuel costs are likely to rise dramatically, it behoves us to consider all “sustainable” options that might serve to keep trains moving and preserve something of the mobility that mankind has enjoyed since railways were first created 200 years ago.

Analyzing traction costs for a non-specific general merchandize railway system is more problematical than for a specific single-purpose single-commodity railway of known length and throughput. A simplified analysis is therefore proposed, in which comparative costs are derived in “NZ dollars per million net-tonne-km”, based on assumed values for average train weights, average length of journey, loco fleet size etc, in addition to a large number of cost assumptions.

For the purpose of the preliminary study that was prepared for this article, the following assumptions were made, based on estimates and (in some cases) assumptions of current costs.

<b>Assumptions for Comparing Loco-Hauled Rail Operations based on 2009 Costs</b>			
<b>Item</b>	<b>Modern Steam</b>	<b>Diesel</b>	<b>Electric</b>
Av distance travelled by each loco	200,000 km per year (approx 600 km per day) <sup>1</sup>		
Average train weight	1200 tonnes gross, 900 tonnes net <sup>1</sup>		
Locomotive fleet size	16 units <sup>1</sup>		
Average train journey length	200 km <sup>1</sup>		
Annual tonnage handled (assuming fully loaded journeys both ways)	14.4 million tonnes net (2,880 million net tonne-km)		
Percentage of single-line track	50% <sup>1</sup>		
Refuelling and servicing infrastructure cost	NZD 10 million (including watering facilities)	NZD 2.5 million	NZD 2.5 million
Capital costs for locomotives	NZD 6.0 million <sup>2</sup>	NZD 4.0 million <sup>3</sup>	NZD 4.0 million <sup>3</sup>
Life expectancy (for depreciation)	25 years	25 years	25 years
Electrical infrastructure costs			NZD 1.5 million per km per track <sup>4</sup>
Operating shifts per day	2	2	2
Loco crew per shift	2	1	1
Servicing crew per shift	0.5 per loco <sup>5</sup>	0.3 per loco <sup>6</sup>	0.5 per loco inc. lines-men <sup>7</sup>
Labour costs including overheads etc	NZD 60,000 per annum <sup>8</sup>	NZD 60,000 per annum <sup>8</sup>	NZD 60,000 per annum <sup>8</sup>
Water costs	NZD3.00 per tonne <sup>9</sup>	n/a	n/a
Water treatment costs	NZD 1.25 per tonne <sup>10</sup>	n/a	n/a
Net Calorific Value (NCV) of fuel	wood pellets: 18 MJ/kg = 4300 kcal/kg <sup>11</sup>	light fuel oil: 42.9 MJ/kg = 10,250 kcal/kg <sup>12</sup>	
Fuel costs	wood pellets NZD 300 per tonne	light fuel oil: NZD 1000/tonne	electricity NZD 0.10 per kWh
Carbon tax or sequestration costs applied to electrical supply costs	NZD 0 per tonne of CO2	NZD 0 per tonne of CO2	NZD 0 per tonne of CO2
Assumed thermal efficiency	12% <sup>13</sup>	25% <sup>14</sup>	73% (from point of supply) <sup>15</sup>
“Load Factor” to estimate average day-to-day thermal efficiency	55% <sup>16</sup>	55% <sup>16</sup>	55% <sup>16</sup>

Major Overhaul costs <sup>17</sup>	NZD 250,000 each 500,000km	NZD 400,000 each 700,000 km	NZD 500,000 each 1.2 million km
Minor Overhaul costs <sup>17</sup>	NZD 50,000 each 167,000 km	NZD 75,000 each 233,000 km	NZD 100,000 each 400,000 km
Regular Maintenance costs <sup>17</sup>	NZD 7,500 each 30 days	NZD 12,000 each 30,000 km	NZD 15,000 each 40,000 km
Maintenance cost of Electrical Infrastructure	n/a	n/a	4% of capital cost per annum
Spare locos needed to cover maintenance and breakdowns (calculated numbers)	15.8% over nominal requirement	12.1% over nominal requirement	9.8% over nominal requirement

**Notes:**

<sup>1</sup> These values are based on the assumption of a medium length freight haulage railway;

<sup>2</sup> Steam loco capital cost based on studies by 5AT Group – see [www.5at.co.uk](http://www.5at.co.uk);

<sup>3</sup> Diesel and electric loco capital costs based on price of UK Class 66 diesel freight loco;

<sup>4</sup> Electrical infrastructure cost extrapolated from 2001 Chinese cost data, viz: RMB 3.4 million per km. The assumed value of NZD 1.5 million per km is an under-estimate (refer Murray King’s paper (p 21) which gives a cost of NZ\$3 million/km for single track in New Zealand);

<sup>5</sup> A figure of 0.5 men per loco per shift is adopted for steam locomotive servicing – i.e. refuelling, watering, firebox and smokebox cleaning, mechanical checks etc.

<sup>6</sup> A figure of 0.3 men per loco per shift is adopted for diesel locomotive servicing – i.e. refuelling, mechanical checks etc.

<sup>7</sup> A figure of 0.5 men per loco per shift is adopted for electric locomotive servicing, including teams of linesmen looking after the electric power transmission system.

<sup>8</sup> Assumed labour costs (no firm data available)

<sup>9</sup> Assumed water costs (no firm data available)

<sup>10</sup> Estimated water treatment costs are based on information from Martyn Bane – see <http://www.portatreatment.com/>;

<sup>11</sup> The net calorific value for wood pellets (18 MJ/kg) is taken from “Review of Carbon Neutral Fuels with Potential Use in Modern Steam Locomotives” is as given by B. McCammon;

<sup>12</sup> The net calorific value for diesel and light fuel oil (42.9 MJ/kg) is as given by B. McCammon (23 Jul 09);

<sup>13</sup> The maximum drawbar thermal efficiency of modern steam traction is assumed to be 12%;

<sup>14</sup> The maximum drawbar thermal efficiency of diesel traction is assumed to be 25% based on a maximum crankshaft thermal efficiency of 35% (estimated by J. Keyte 23 Jul 09);

<sup>15</sup> The maximum drawbar efficiency of electric traction is assumed to be 73% (recommended by J. Keyte 22 Jul 2009) comparing output at the drawbar to energy input at the point of supply. This figure excludes power station and transmission losses;

<sup>16</sup> The “load factor” is applied to allow for locos operating at sub-optimal conditions. A 55% load factor has been selected to generate fuel consumption rates that are consistent with 1995 Chinese data (with allowance for improved efficiencies likely to be achieved by more modern designs).

<sup>17</sup> Maintenance costs and frequencies are based on Chinese data for diesel and electrical traction. Modern steam maintenance costs extrapolated from Chinese steam maintenance data.

Space does not permit a detailed description of the relatively simple methodology used to analyze these cost assumptions. For the purposes of this article it is sufficient to summarize the outputs of the analysis and to look briefly at their sensitivities to changes in input values.

Looking first at the outputs generated from the above-listed assumptions:

<b>Cost Comparisons for Loco-Hauled Rail Operations based on 2009 Costs</b>			
<b>Item</b>	<b>Modern Steam</b>	<b>Diesel</b>	<b>Electric</b>
Capital Costs per loco per km	NZD 1.31	NZD 0.83	NZD 8.33
Labour Costs per loco per km	NZD 1.50	NZD 0.78	NZD 0.90
Water Costs per loco per km	NZD 0.58	-	-
Fuel Costs per loco per km	NZD 3.88	NZD 2.60	NZD 1.06
Maintenance Costs per loco per km	NZD 1.20	NZD 1.29	NZD 3.54
<b>Total Cost per Loco per km</b>	<b>NZD 8.46</b>	<b>NZD 5.50</b>	<b>NZD 13.83</b>
<b>Total Cost per Loco per million net-tonne km</b>	<b>NZD 9,404</b>	<b>NZD 6,116</b>	<b>NZD 15,369</b>

The outputs confirm what should be expected – that the diesel option is the most cost-effective for this scenario. In a more heavily trafficked (suburban) scenario with (say) 100 locomotives operating over average distances of 50 km, the model confirms that (as might be expected) electric traction becomes the most cost-effective option.

Looking to the future however, perhaps to 2029 when “light fuel oil” (fossil diesel) may have been replaced by bio-diesel having a calorific value of only 8840 kcal/kg<sup>2</sup>; where liquid diesel and electricity prices have doubled (based on 2009 prices) but where wood products have risen only 50% (reflecting the much higher rate of energy return that wood products offer<sup>1</sup>); where electric power is further penalized with a \$50 per tonne carbon tax (or carbon sequestration cost); and where steam technology has advanced far enough to allow single-man crewing and capital costs similar to diesel and electric traction: the cost comparisons change significantly:

<b>Cost Comparisons for Loco-Hauled Rail Operations based on Hypothetical 2029 Costs</b>			
<b>Item</b>	<b>Modern Steam</b>	<b>Diesel</b>	<b>Electric</b>
Capital Costs per loco per km	NZD 0.83	NZD 0.83	NZD 8.33
Labour Costs per loco per km	NZD 0.90	NZD 0.78	NZD 0.90
Water Costs per loco per km	NZD 0.58	-	-
Fuel Costs per loco per km	NZD 5.82	NZD 6.04	NZD 2.13
Maintenance Costs per loco per km	NZD 1.20	NZD 1.29	NZD 3.54
<b>Total Cost per Loco per km</b>	<b>NZD 9.32</b>	<b>NZD 8.94</b>	<b>NZD 14.89</b>
<b>Total Cost per Loco per million net-tonne km</b>	<b>NZD 10,360</b>	<b>NZD 9,933</b>	<b>NZD 16,550</b>

<sup>2</sup> Figure taken from “Review of Carbon Neutral Fuels with Potential Use in Modern Steam Locomotives” - an unpublished paper by Brian McCammon.

In this scenario, wood-fired “modern steam” presents a potentially cost-competitive alternative to bio-diesel traction. Whilst the cost assumptions and methodology used in this study are somewhat crude, they do suggest that when looking forward to a world that will be searching for alternatives, the steam option should not be dismissed as summarily it was in the mid-20<sup>th</sup> century, and that more detailed costing studies may be warranted.

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**End Note:** This is an updated version of the paper published in the October edition of the Solar Action Bulletin No 88. It contains minor changes to the costing estimates.

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***About the Author:***

***Chris Newman*** graduated as BSc.Eng. from Aberdeen University in 1967. He is a specialist in bulk materials handling and transportation, especially in grain industry developments in Australia and China. Latterly he has been responsible for conducting studies on the economics of rail traction options for coal haulage in Indonesia. Currently he resides in China.