# “A Case for Steam”

## Steam Traction -
## still a viable alternative to diesel and electric traction

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Version 6

# Acknowledgements

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# “A Case for Steam”

## Justification for the adoption of steam traction where circumstances favour its use.

## 1 Synopsis

A proposal has been put forward for the purchase of reconditioned steam locomotives from China for use on a major coal transportation project in Indonesia.

Project funding agencies may be sceptical about the viability and economical justification of using “old fashioned” steam locomotives on a modern transportation project so long after steam was displaced by electric and diesel traction on most of the world’s railways.

This paper shows that steam has been superseded in many instances on the basis of less-than-sound economic justification, and it presents a strong case for the ongoing viability of steam traction where circumstances favour its use. The paper draws its deductions on the following observations:

- Availability of heavy-haul reconditioned steam locos from China (Section 4);
- Better reliability and lower fuel costs for steam traction compared to diesel, in published Chinese government statistics (Appendix 1);
- Large potential for enhancing performance of old steam loco designs (Section 5).
- Continued use of steam on many railways serving China’s coal mines (where fuel is cheap), notwithstanding government’s “steam extinction” policies (Sections 4 and 6);

A cost comparison between steam, “modern steam”, diesel and electric traction for coal haulage in Indonesia (based on Chinese data) is presented in Appendix 3 of this paper. Whilst the cost assumptions used in the comparison may warrant some refinement, the cost differences that have been derived for each form of traction are substantial enough to allow the firm conclusion to be drawn that for this particular railway project, steam traction will be the most cost-efficient option.

## 2 Background

Steam traction was developed in the first half of the 19th century and became universal traction for rail haulage for the next 100 years. The steam engine was arguably the most important invention in evolution of the modern industrial world. Accepted wisdom is that steam technology reached its peak in the 1930s whereafter it was superseded by more efficient technologies in the form of diesel and electric traction. Steam traction was phased out in the USA in the 1950s and in Western Europe in the 1960s & ‘70s. China was steam’s main bastion, steam traction having been displaced from the national rail system as recently 1999.

Steam traction continues in commercial “industrial” operation in a few locations. Most are in China, where it is active on several local railways serving coal-mining operations as well as on narrow gauge and industrial railways. Until late 2005, steam continued to haul all heavy traffic on the severely graded sections of a major semi-private (government joint-venture) freight line in Inner Mongolia when it was displaced by redundant diesels from the national rail system to conform to the central government’s “steam ban” policies, even though the railway’s operating department acknowledged that its steam fleet was less costly to operate than the new diesels.

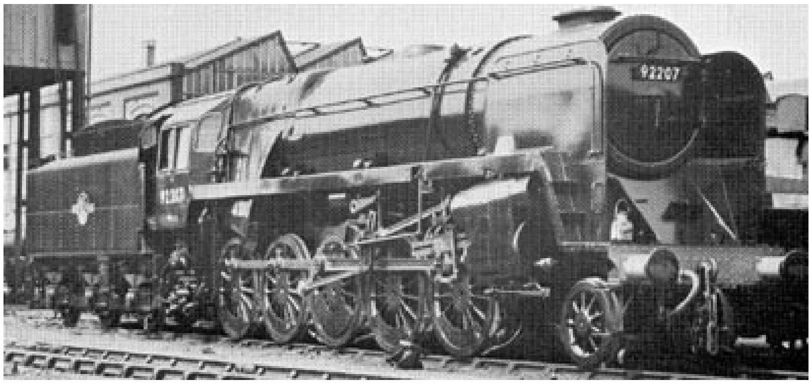
Commercial steam operations have also continued in a few other countries such as Cuba and Indonesia where it is (or was) used for hauling sugar cane during the harvest season. Steam has recently returned to the rails in Zimbabwe for economic reasons, where it is being used for the haulage of commuter trains, and there are moves afoot to bring steam back to the rails of Argentina for the haulage of coal. Apart from these isolated instances, steam activity on today’s railways is limited to tourist operations capitalizing on the fact that steam continues to generate a strong attraction to the general public.

## 3 “Modern Traction” Policies – Was Steam fairly treated?

***The New York Central Railroad’s 6000 h.p. Niagara Class locomotives***
*These were built to operate the 928 mile route from New York Chicago. The class averaged 26,000 miles per month, operating at speeds up to 100 mph and were cheaper to operate than diesels.*

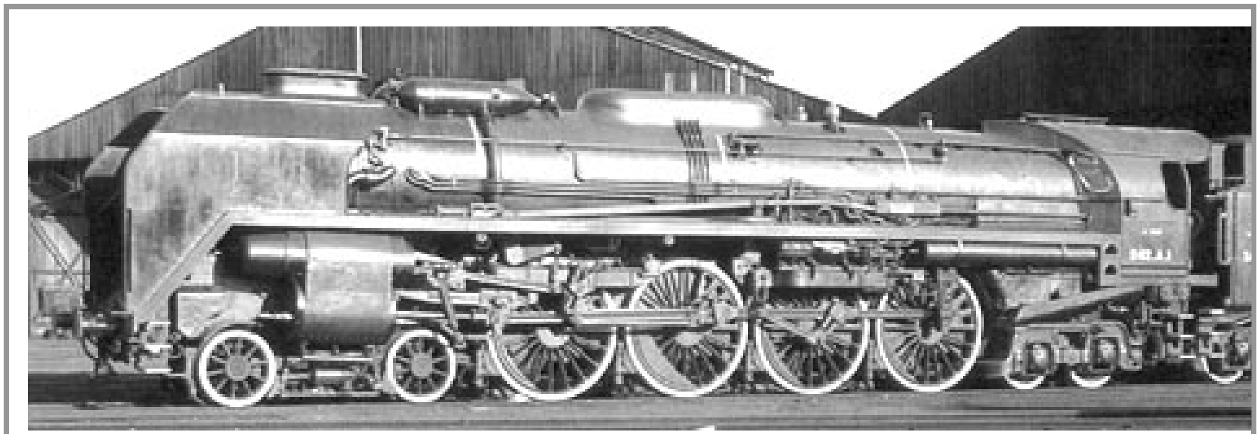
In the 1940s, the USA began what was to become a worldwide fashion for replacing steam with diesel, when large automotive corporations saw commercial opportunities for selling their products to the rail industry. The steam locomotive builders of the day were no match for General Motors in terms of spending capacity on technical research and marketing. Despite some astonishing demonstrations of speed and reliability by contemporary steam locos, railway companies throughout the continent were quickly won over by the modern and stylish image of the new diesels that were being marketed at the time.

Once the diesel fashion had been established in North America, the rest of the world followed suit. Whilst coming a decade later in Western Europe, the tide of change was as rapid and unseemly as it had been in the USA. Thousands of modern and perfectly functional steam locomotives, many of them no more than 5 years old, were summarily discarded and replaced by “modern” diesels that all too frequently failed to live up to expectations.



***The British Railways' '9F' was the last steam loco class designed and built in the UK.***
*Designed to haul heavy freight trains, they proved equally capable of handling fast expresses at speeds of up to 90 mph. They were one of the most versatile classes of locomotives ever built.*
*251 were built, the last in 1960. All were withdrawn by 1968, many after no more than 5 years' service.*

One of the most brilliant of all locomotive engineers was a Frenchman by the name of André Chapelon who produced some of the most advanced and efficient steam locomotives. His crowning achievement was the famous No 242A1 which generated over 5,500 hp in its cylinders, almost as much as the Niagaras (mentioned above) despite being little more than half their weight. In fact, 242A1 produced the second highest power-to-weight ration achieved by any steam locomotive to date (the highest being another smaller Chapelon locomotive). The locomotive proved to be an embarrassment to French railway authorities who hastily redesigned a new class of electric locomotive so that it would outperform 242A1, which was thereupon withdrawn from service and quietly scrapped.



***Chapelon's 5,500 ihp 242A1 of the late 1940s***
*This locomotive outperformed diesels and electric locomotives of its day*

It is well accepted that railway authorities made little attempt to cost-justify their "modernization policies", because in most cases such attempts would have been counterproductive. Certainly their decisions to scrap near-new and perfectly serviceable steam locomotives and to replace them with untried diesels, could never have been justified by rational analysis and were frequently proved wrong by events. Decisions to "modernize" were greatly motivated by railway managers and/or governments wanting to present an up-to-date image to the world. Other factors no doubt added impetus – including expectations of improved working conditions for staff and a reduction in smoke emissions in cities – but there can be little doubt that the desire for a modern image was the most often the main incentive for change in those days.

It is pertinent to quote Col. K. Cantlie who offered the following response to a paper by Ing. L.D. Porta titled "Steam Locomotive Development in Argentina" that was presented to a meeting of the Institution of Locomotive Engineers in Manchester in 1969. His observations were prescient and relevant to this discussion:

"Diesels were forced on the Third World by propaganda and financial incentives, yet in many countries there was a chronic shortage of skilled diesel and electric fitters because they could always get better paid jobs in garages and power houses once the railways had trained them. As a result the maintenance standards of diesel locomotives fell, failures increased and there was a fall in availability. Then there was the vexed question of spare parts. Overseas railways with well equipped workshops could make nearly all the spares for their steam locomotives, but they could not make the numerous and sophisticated spare parts for diesel engines, for even British railway jibbed at making such spares. The largest manufacturer of diesel locos had given out the slogan to the Third World: "The steam locomotive is relic of colonialism - abolish it and you are free." The very contrary was the truth. Once an Overseas railway had obtained diesel locomotives, it was shackled to the manufacturer for the life of the locomotives. This was not only very irksome to nationalistic sentiment in the emerging countries, but most of them had great difficulty in getting allotments from their Governments of scarce foreign exchange to pay for such spares. Previously it was believed that these difficulties were temporary, but they are, if anything, growing worse."

## 4 Cost Comparisons between Steam and Diesel

As a consequence of the hasty manner in which steam traction was displaced from the railways of the world, there is a dearth of contemporary evidence either to disprove or to support the view that steam traction remained an economically viable means of rail traction. Some studies were however conducted and it is instructive to summarize those that come to hand:

- A cost comparison carried out in the USA in 1946[1] showed that availability and monthly mileages for steam locomotives were 90% that of diesels, and that the cost of operating a relatively inefficient[2] 6000 hp steam loco was $1.22 per mile, while that of a 4000 hp (twin unit) diesel was $1.11 and a triple-unit 6000 hp diesel was $1.48. A 5000-hp electric cost $1.15 excluding any allowance for the maintenance cost of the power generation or distribution equipment.

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[1] Kiefer "A Practical Evaluation of Railroad Locomotive Power", 1947

[2] The costs were taken for the Niagara Class locos. Had they been taken from Chapelon's much more efficient 242A1, they would have been substantially lower.

- A detailed cost study produced by an investigative committee within South African Railways (SAR) in 1983 (operating in a country with vast coal reserves and no indigenous oil) established that the (then) existing fleet of 1950s steam locomotives were less expensive to operate than its expanding diesel fleet. The report also acknowledged that significant further cost savings could be achieved by modernizing the steam fleet along the lines of David Wardale's "Red Devil", a rebuild of a Class 25 locomotive which had demonstrated a 60% increase in power and a 30% reduction in specific fuel consumption over the original 1950s German design[3]. SAR ignored the report and continued with its dieselisation policy despite the fact that it would make their railway dependent on imported oil. Like Chapelon's 242A1, the Red Devil became an embarrassment to a railway authority that was determined to rid itself of steam.

***Wardale's 3,300 kW (4,500 iHP) Class 26 "Red Devil" of the mid-1980s***

*This was a modernized version of the South African Railways' 1067mm gauge Class 25 incorporating technology developed by Argentinean engineer L.D. Porta. The locomotive showed a 60% power increase and 25% fuel saving compared to the original design. A 100mph demonstration was not allowed by SAR, already embarrassed enough by its performance.*

- A paper presented to the Institution of Mechanical Engineers in 2003[4] demonstrated that a fleet of modern (21st century technology) steam locomotives operating on mountain (tourist) railways in Switzerland and Austria are not only cheaper than diesel railcars, but attract more tourists and haul higher payloads.

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[3] Wardale D.; Red Devil and Other Tales from the Age of Steam pp 345-351

[4] Waller R.; Modern Steam – An Economic and Environmental Alternative to Diesel Traction, presented to the Institution of Mechanical Engineers Feb 2003.

***1996-built High Efficiency "Second Generation" Steam Locomotive***
*designed and built for the Brienz Rothorn tourist railway in Switzerland by DLM. The railway purchased five of these locomotives after discovering that they not only attract more tourists, but outperform and are cheaper to operate than diesel railcars.*

- Figures from China Rail[5] (the Chinese national railway system) show that right until the end of its existence on their system, steam's fuel costs were less than those for diesels, and its reliability higher. There can be little doubt that China's steam elimination policy was not based on economic considerations but on the desire to rid the country of a technology that was thought to present a "third-world" image. Elimination of steam from urban areas was also aimed at reducing the appalling levels of pollution in many Chinese cities.

The above examples cover a long period of time and give broad evidence to demonstrate that steam was not (and is not) the outmoded and uneconomical technology that it was claimed to be when railway policy-makers attempted to justify their intentions to replace it. In the case of the last example in China, figures taken from the country's national statistics prove conclusively that steam was not superseded on the grounds of technological or cost failings.

Haulage of coal trains in Indonesia where coal is cheap and plentiful (and available "on the doorstep" from the coal mine) presents an obvious instance where steam ought to be a clear winner both in terms of fuel costs and overall operating costs, particularly when suitable "as-new" reconditioned high powered locomotives can be procured at very low

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[5] See Appendix 1

cost from China[6]. A comparison of estimated costs for the use of electric, diesel and steam traction on this Indonesian coal railway, based on China National Railways fuel and power consumption data, is presented in Appendix 3 of this paper. It will be noted that steam shows an estimated cost per tonne-km of coal hauled that is around **half that of diesel** (based on Indonesian diesel fuel costs as reported in March 2006) and at least 35% lower than electric traction even when excluding the substantial cost of electrical infrastructure maintenance.

**Note:** In considering commonly-used arguments against the use of steam, one must be aware that one of steam's great strengths is also one of its great weaknesses: a steam engine will continue to operate under the worst of maintenance conditions that would be impossible for the operation of a diesel. In consequence, steam locomotives tend to be run under the worst operating and maintenance conditions, and are then condemned for being unreliable and inefficient. Equally unfairly, most comparisons between steam and diesel compared the performance of newly built diesel locomotives of modern design with that of run-down steam locos of antiquated design.

# 5 Operational Comparisons between Steam and Diesel

As mentioned above, comparisons between steam and diesel locomotives tend to be distorted by comparing old steam locomotives with new diesels. Furthermore, diesel technology has benefited from decades (and many millions of dollars) of research and development effort, whereas steam development largely ceased after 1950.

Ongoing development of steam has however continued, mostly at the hands of one person - a brilliant Argentinean engineer by the name of L.D. Porta[7] who built on Chapelon's work and became the mentor of the engineers who today carry on the task of advancing steam technology and implementing improvements to new and existing steam locomotives.

Porta was responsible for the development of a number of new technological breakthroughs that have had an enormous impact on the ability of "modern steam" to operate efficiently and economically in today's world. Some of these advances are described in outline in the next section of this paper. The fact that modern steam suffers from some disadvantages compared to diesel and electric traction is a reflection on the lack of investment in development and refinement of the technology rather than a limitation of the technology itself. Some perceived disadvantages might include:

- **Higher manning levels**: Two locomotive crewmen are normally needed to operate a steam locomotive. However double manning brings with it safety benefits (two pairs of eyes watching the signals), and is not a significant consideration in countries where labour costs are low (for instance in China where diesel locomotives continue to be double-manned as was its steam fleet).

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[6] Fully reconditioned 3000hp QJ locomotives can currently be purchased ex-works in "as-new" condition, for approximately $US 300,000 (FOB cost).

[7] Porta died in 2003 leaving a legacy of knowledge that is currently being put into practice on the "5AT" project, through which it is proposed to construct a new high performance "second generation" steam locomotive incorporating many of the advanced design features developed by Porta. This modest sized locomotive will weigh only 80 tonnes, but will generate 3500 hp and be capable of running at speeds up to 125 mph (200 kph). See www.5at.co.uk.

- **Multiple working**: Operation of several locomotives coupled together and operated by a single crew in the front engine is not currently possible with steam. However whilst this might reduce steam's operational flexibility in some situations, it does not necessarily make steam uncompetitive or impractical for modern railway operations (much of which do not require the use of multiple-locomotives).
- **Greater skill levels:** Steam locomotives currently require a higher level of skill by their operators than diesels. However this is not necessarily a disadvantage in a world where the opportunities for people to take pride in their work skills are declining.
- **Optimum operation in forward direction**: Certainly most steam locomotives perform better and are safer to operate when they are run in the forward direction. However provided turning facilities are available at each end of a line (e.g. a turning loop, "triangle" or turntable) this is not a problem. In the case of coal transportation, it is normal for trains to travel around a "balloon loop" at each end of the line to allow loading and unloading "on the run", thereby avoiding delays from train reversing or locomotive run-around. In this way locomotives always operate in the forward direction. In any case, at the low speeds likely on a coal haulage line, reverse running would not present a problem, should it be necessary to do so.
- **Pollution**: Steam locomotives do emit particulates (as smoke), but so do diesels. However, when correctly operated with good fuel, steam locomotive emissions can be significantly less toxic than diesel fumes, a large part of the exhaust being water vapour. When fitted with a gas producer combustion system (see next

***White steam from Chinese QJ Class locomotive***

*Chinese steam locomotives are renowned for producing little visible smoke even though much of the coal they consume is of small size and poor quality.*

section) locomotive emissions are significantly lower than with a normal firebox[8]. In the case of oil-fired steam locomotives, it has been demonstrated that CO and $NO_x$ emissions can be substantially lower than those from diesels[9].

- **Carbon Emissions**: $CO_2$ emissions from steam locomotives will inevitably be higher than those from diesels whenever coal is burned simply because coal has a higher carbon content than oil. Even when burning oil, steam locomotives' $CO_2$ emissions will be higher than diesels' until technical advancement allows steam's thermal efficiency to rise to the level now achieved by diesel locomotives.
- **Image:** whilst it is undeniable that dirty and run down steam locomotives can present a bad image, the converse is just as true – steam locomotives are intrinsically beautiful machines that have attracted people's admiration since they were first built. A well-kept fleet of steam locomotives can be an enormous source of pride as is the case on all tourist railways that operate them. In the case of industrial railways, they can generate tourist revenues for the railway and for local communities.

However, steam locomotives offers several distinct advantages compared to diesels, which are not generally known:

- **Ability to burn coal and other indigenous fuels**: In a world faced with rising oil prices and declining production, the ability to burn indigenous fuels gives steam locomotives a distinct advantage. For instance, in the late 1990s Porta produced a new steam locomotive design to operate in the Cuban sugar industry and which would have burned bagasse – a by-product from the sugar mills. Steam continues to operate in China (another oil-deficient country) on lines connecting coal mines to power stations where fuel is plentiful, cheap and locally available. It would make similarly good economic sense to operate steam locomotives on coal transportation duties in Indonesia.
- **Environmental benefits:** in addition to reducing in toxic emissions (as mentioned above), the "external combustion" that occurs in a steam locomotive's firebox (as compared to "internal combustion" in a diesel engine) enables the burning of a multiplicity of fuels, including biomass-type carbon-recyclable fuels. Large steam locomotives in Mozambique and Angola used to burn eucalypt wood purposely grown in plantations beside the railway, providing a carbon-neutral fuel source,
- **Robustness:** as intimated above, steam locomotives will operate in and under the worst physical conditions such as would be intolerable for diesel locomotives. Notwithstanding, like all machines, they do operate much more efficiently reliably if they are well maintained and kept in peak condition. It was not unusual for steam locomotives to remain in operation for 100 years – an unimaginable lifespan for a diesel locomotive.
- **Maintainability:** Steam locomotive technology is relatively simple and within the competence of even the most primitive railway operations. As with fuel, spare

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[8] Government research is currently being conducted in Argentina aimed at further reductions in steam locomotive emissions and raising thermal efficiency *[source – S. McMahon 13 April 04]*.

[9] Waller R.; Modern Steam – An Economic and Environmental Alternative to Diesel Traction

parts can be produced locally at low cost without the need for expensive imports. Most railways have had to turn over responsibility for maintenance of their diesel fleets to specialist companies (very often the locomotives' suppliers), thereby losing control of the work and of costs, and losing the skills to handle it in-house (see Col. Cantlie's comments in Section 4 above).

## 6 Scope for Improving Steam's Performance

As mentioned earlier, diesel traction has benefited from five decades of massive investment in research and development by big corporations. In that time, steam has benefited from the dedicated attentions of virtually one person – the Argentinean engineer, L.D. Porta – who dedicated his life to the scientific understanding and advancement of the technology[10].

Porta's achievements are prodigious. The massive improvements in performance, economy, downtime and maintenance that can be achieved through the adoption of his work have been well demonstrated by Porta himself, and by several of his "disciples" particularly in Argentina, South Africa, and Switzerland. There is abundance evidence that the performance of practically any 'FGS' locomotive can be substantially enhanced through the incorporation of "Porta improvements".

Examples of **some** of the improvements that can be implemented are listed below:

- **Improved combustion** through the use of a "Gas Producer Combustion System" (GPCS): this significantly reduces carry-over of coal particles from the fire (i.e. limited spark throwing) thereby reducing coal consumption and pollution levels, and increasing thermal efficiency. It also prevents ash clinkering. Cost: medium to high[11].
- **Improved exhaust system design** will significantly improve both combustion and cylinder efficiency. Cost of modifications: low to modest.
- **Enlarged steam pipes and steam chests** can significantly improve cylinder efficiency and overall thermal efficiency. Cost: modest to medium.
- **Efficient feed water heating** will improve boiler efficiency. Cost of modifications: modest to medium.
- **Simple and effective water treatment** will massively reduce boiler maintenance (the most expensive part of steam locomotive operation), increased boiler component life, and substantially reduce "down-time" for washing out of the boiler. High boiler efficiency maintained due to guaranteed rates of heat transfer. Chemicals used are safe and the system was specifically developed for "third world" usage without high levels of technical training. Cost of implementing: low.

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[10] "Steam Locomotive Development in Argentina - Its Contribution to the Future of Railway Technology in the Under Developed Countries". Read before Inst. Loco. Engineers, Manchester 7 March 1969

[11] It is meaningless to offer estimates of costs for modifications, since actual costs will depend on the locomotives involved, the design of the modifications, and the country where the modification work is done. A range of comparative cost indications is offered ranging from "low" representing perhaps a few hundred dollars, to "high" representing some tens of thousands of dollars.

- **Increased superheat temperatures** will significantly improve thermal efficiency. Costs: modest to medium.
- **Improved valves and valve liners** can significantly improve cylinder efficiency. Costs: medium to high.
- **Improved cylinders and pistons** giving minimum clearance volume can significantly improve cylinder efficiency. Costs: medium to high.
- **Improved insulation** can substantially reduce heat losses and improve thermal efficiency. Cost: modest to medium.
- **Modified piston rod packings** can substantially reduce steam losses and maintenance costs. Cost: low to modest.
- **Improved lubrication** is necessary to cater for higher steam temperatures, and improved design can reduce oil consumption. “Single point” lubrication systems reduce labour costs. Costs: modest to medium.
- **Roller bearings** to reduce friction losses and maintenance costs. Cost: modest to high (depending on which bearings are replaced.)
- **Improved tyre profiles** can substantially improve rail adhesion and reduce tyre wear. Cost: low.
- **Regular wheel reprofiling** can significantly reduce tyre wear and (thus) maintenance costs. Cost: modest.
- **Improved sanding equipment** can significantly improve rail adhesion. Cost: modest to medium.
- **Rail cleaning (with steam)** can significantly increase adhesion for traction by eliminating rail contamination. Cost: low.
- **Rail washing** (to remove sand behind the locomotive) can significantly reduce rail friction on long trains by removing sand and contaminants from railhead. Cost: low.

Most of these ideas were adopted by David Wardale on his “Red Devil” conversion in South Africa and are described in detail in his book “Red Devil and Other Tales from the Age of Steam”. As indicated before, this locomotive achieved a 60% increase in power output and a 25% reduction in fuel consumption compared to the original German design.

In addition to the above mechanical improvements, there is vast scope for the development of electronic controls and monitoring systems to improve the operation and performance of Third Generation Steam locomotives.

# 7 The Steam Option for Indonesian Coal Transportation Project

Whilst steam locomotives that were designed in the 1950s are thermally inefficient, they remain a practical and cost-effective solution for rail operations in many situations. They should not be discounted simply because they are old-fashioned. The alternative of a “modern steam” design offers even greater benefits in terms of increased thermal efficiency, lower maintenance and operating costs, and reduced emissions.

Several instances have been quoted of successful and economical use of steam locomotives on non-tourist commercial railway operations, most notably today on several railways serving coal-mining operations in Northeast China[12]. Steam remains a viable and vibrant option, and as shown in Appendix 3 of this paper is almost certain to offer the most economic solution for the operation of a dedicated coal transportation railway in Indonesia with an abundant fuel source on hand.

Large and powerful (3000 hp) QJ Class steam locomotives of high reliability, relatively modern design and late construction, continue to be overhauled in China and are available for purchase in as-new condition at prices far below what might be paid for an equivalent diesel locomotives. Alternatively, new “modern steam” locomotives can be designed and built to meet specific performance targets, for instance by a specialist firm such as DLM in Switzerland[13] – their significantly higher capital cost being offset by substantially reduced operating and maintenance costs[14].

With respect to the Chinese QJ locomotives, these were the mainstay of long-haul heavy freight haulage all over China for most of 40 years, so it can be assumed that they would be suited to haulage of coal trains in Indonesia. This is confirmed by performance data for these locomotives which show that each locomotive should be able to handle 4000 tonne trains on lightly graded tracks[15].

As indicated earlier, there is conclusive evidence from China that steam traction (much of which was in the form of QJ locomotives) was cheaper to operate **and** was more reliable than diesel traction throughout the 15 years that China’s national rail system converted from steam to diesel operation (see Appendix 1).

There is no doubt that the performance of QJ locomotives could be significantly enhanced by modernizing their design using Porta’s technology, along the lines demonstrated by Wardale on his Red Devil locomotive in South Africa. In fact, Wardale was engaged by the Chinese Ministry of Railways in 1987 to implement improvements to the design of the QJ locomotive class which was then expected to continue in production into the foreseeable future. Wardale’s book describes in detail the modifications that he designed and the improvements in performance that he expected the modified locomotives to achieve.

Unfortunately the Chinese government changed its traction policies in favour of dieselization before the modifications could be trialled; nevertheless Wardale’s work demonstrates the scale of improvement that might be achieved by modifying a fleet of QJ locomotives in accordance with Porta’s principles. This however is a subject requiring detailed analysis, and is too complex to be dealt with here.

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[12] A good example is the Jixi railway that transports coal (and mine workers) from several mines in central Heilongjiang. It is operated by a fleet of about 25 steam locomotives.

[13] See www.dlm.ag

[14] See Appendix 3

[15] See Appendix 2

# 8 Conclusion

There is ample evidence to demonstrate that steam is an option that remains worthy of consideration in many circumstances, and most particularly on coal haulage projects and in developing countries such as Indonesia. In such circumstances, the steam option not only offers lower capital costs than both the diesel and electric alternatives, but operation and maintenance costs are likely to be significantly lower as well, and more so if “modern steam” designs are adopted.

Furthermore there is bountiful evidence that great potential exists to improve the performance of “old” steam traction by the implementation of relatively modest low-cost improvements such as those described in this paper.

# Appendix 1 - Comparative Figures: Steam vs Diesel from China Rail.

| Year | Available Loco Per Day | | Train Gross Ton-kilometers | | Loco Failures per $10^6$ t-km | | Year average energy consumption per $10^6$ t-km | | Unit Price of fuel | | Unit Price of traction | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (sets) | | ($10^6$ t-km) | | (failures per $10^6$ ton-km) | | Kg | | (RMB) | | (RMB/ $10^6$ t-km) | |
| | Steam | Diesel | Steam | Diesel | Steam | Diesel | Steam | Diesel | Steam | Diesel | Steam | Diesel |
| 1987 | 5317 | 3282 | 770,009 | 750,090 | 3.0 | 11.0 | 11090 | 2590 | 200 | 3050 | 2218 | 7900 |
| 1995 | 3061 | 6224.2 | 268,998 | 1,495,365 | 3.4 | 16.8 | 13740 | 2430 | 200 | 3050 | 2748 | 7412 |
| 1999 | 1013 | 7825.6 | 32,475 | 1,682,046 | 0 | 13.1 | 20660 | 2620 | 200 | 3050 | 4132 | 7991 |
| 2003 | - | 8585.5 | - | 1,384,996 | - | 7.0 | - | 2540 | 200 | 3050 | - | 7747 |

*Figures supplied through China National Railways, Mar 2004.*

**Note:** *The above figures are taken from the official statistics of the operation department of China's National Railway, which have been published by State authorities. It may be noted that the figures do not include contemporary fuel costs; 2003 costs have therefore been inserted for comparative purposes only.*

# Appendix 2 – Performance Data for Chinese QJ Locomotives

| Performance Data for Chinese QJ Steam Locomotives | | | |
|---|---|---|---|
| 1 | Weight of Loco in working order (t) | | 133.8 |
| 2 | Wheel Arrangement | | 2-10-2 |
| 3 | Axle Loads | Leading Axle (t) | 13.40 |
| | | Driving Axle (t) | 20.10 |
| | | Trailing Axle (t) | 19.90 |
| 4 | Tender | Weight in working order (t) | 119.70 |
| | | Weight empty (t) | 48.2 |
| | | Coal Capacity (t) | 21.5 |
| | | Water Capacity (t) | 50 |
| 5 | Gross Weight of Loco and Tender in working order (t) | | 254.73 |
| 6 | Total Length of Loco and Tender (m) | | 29.181 |
| 10 | Working Pressure of Boiler (kPa) | | 1500 |
| 7 | Design Speed (kph) | | 85 |
| 8 | Nominal Wheel-rim Power at 70 kph (kW) | | 2191.8 |
| 9 | Starting Tractive Effort (kN) | | 326.2 |

**Summary of QJ Performance Capacity on Straight Track**
hauling wagons fitted with roller bearing axle-boxes,
using figures for starting and rolling resistance provided by China Rail

| Straight Line Gradient | No of Wagons | Gross Train Weight Tonnes | Max Constant Speed kph |
|---|---|---|---|
| Level | 98 | 8036 | 60 |
| 0.1% (1 in 1000) | 76 | 6232 | 50 |
| 0.5% (1 in 200) | 39 | 3116 | 40 |
| 1% (1 in 100) | 23 | 1886 | 20* |

* Note: Actual performance of QJ locomotives in good condition may exceed the above figures. David Wardale records an occasion of a QJ locomotive in slightly modified condition hauling 4,100 tonnes up a grade of 0.7% at a speed of 25 kph[16].

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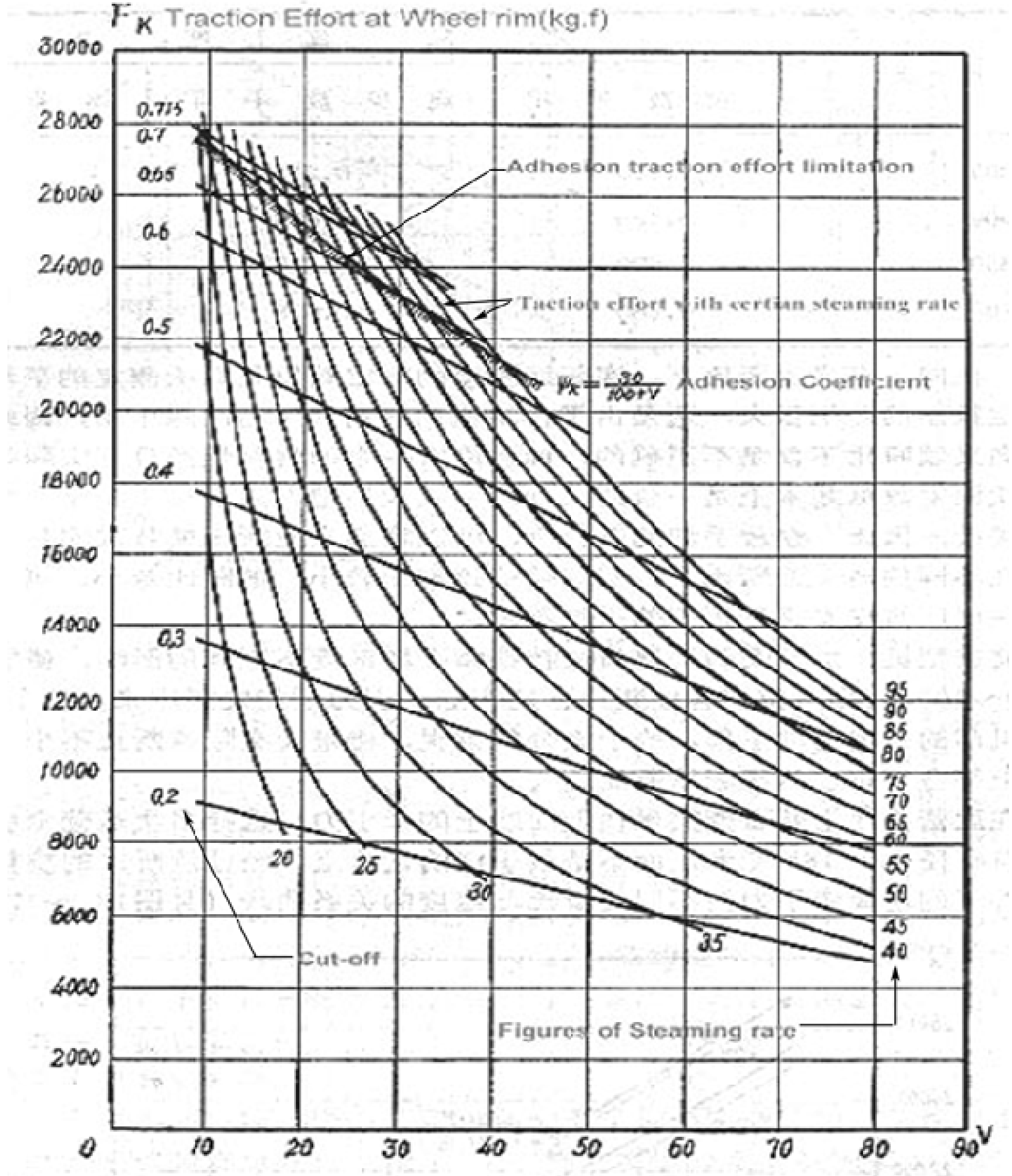
[16] Wardale D.; Red Devil and Other Tales from the Age of Steam p. 467

# Performance Curves for QJ Locomotives

(from Chinese National Railways)



The curves of traction effort at wheel rim to different steaming rate, cutoff and speed (V)

图17 轮周牵引力$F_K$按不同遮断比、不同供汽率与速度的关系曲线

# Appendix 3 - Comparative Cost Estimate between **Steam and Diesel Traction** on Proposed Coal Transportation Railway in Indonesia

The following cost estimates were prepared in March 2006 for a presentation to partners forming the consortium responsible for planning the Indonesian Coal Transportation Project.

1. **Fuel Consumption per Gross Tonne-km**: The following figures are copied directly from Appendix 1. The figures shown in **Red** are used for cost comparative purposes in subsequent calculation (under item 3 below).

| **Years** | **Available locos per day (Sets)** | | **Train Gross Ton-kilometers ($10^6$ t-km)** | | **Loco Failures per 106 t-km** | | **Av. Fuel Consumption per $10^6$ t-km (tonne)** | | **Unit Price of Fuel ($US/tonne)*** | | **Fuel Cost of Traction $US/$10^6$ t-km** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Steam** | **Diesel** | **Steam** | **Diesel** | **Steam** | **Diesel** | **Steam** | **Diesel** | **Steam** | **Diesel** | **Steam** | **Diesel** |
| 1987 | 5,317 | 3,282 | 770,009 | 750,090 | **3.0** | **11.0** | **11.09** | 2.59 | 24 | 367 | 267 | 951 |
| 1995 | 3,061 | 6,224 | 268,998 | 1,435,365 | **3.4** | **16.8** | 13.74 | 2.43 | 24 | 367 | 331 | 893 |
| 1999 | 1,013 | 7,825 | 32,475 | 1,682,046 | **0** | **13.1** | **20.66** | 2.62 | 24 | 367 | 497 | 962 |
| 2003 | - | 8,585 | - | 1,384,996 | **-** | **7.0** | - | **2.54** | 24 | 367 | - | 993 |

2. **Supplementary Fuel/Power costs per gross tonne-km of freight hauled in China**: The following data comes from a senior engineer in China National Railways. Figures shown in **Red** are used for cost comparative purposes in subsequent calculation (under item 3 below).

| | | |
|---|---|---|
| Average cost for normal electric railway construction, including infrastructure, contact wire, signalling system, stations and marshalling yards | >30 m RMB per km | >$3.75 m per km |
| Av Cost for Main Line Electrification | >3.4 m RMB per km | **>$425,000 per km** |
| 2001 Fuel Consumption – Steam | 19.5 tonnes per $10^6$ t-km | |
| 2001 Fuel Consumption – Diesel | 2.57 tonnes per $10^6$ t-km | |
| 2001 Power Consumption – Electric | **11310 kW-h per $10^6$ t-km** | |
| 2005 Cost – Diesel Fuel | 3970 RMB / tonne | $496 per tonne |
| 2005 Cost – Electric Power | 0.65 RMB/kW-h | **8.1 cents per kW-h** |

Note: the fuel consumption rates quoted for steam and diesel in 2001 are consistent with the figures given in the previous table.

3. **Fuel/ Power Consumption estimates** for four different traction types, hauling 20 million tonnes of coal per year (one way) and returning empty trains over 90 km railway based on China National Railway's data:

| **Traction Type** | **Electric (New Build)** | **Diesel (New Build)** | **Modern Steam (New Build)** | **Reconditioned QJ Steam** |
|---|---|---|---|---|
| Total Tonne-km (loaded) (x$10^6$) | 2,400 | 2,400 | 2,400 | 2,400 |
| Total Tonne-km (empty) (x$10^6$) | 600 | 600 | 600 | 600 |
| Total Tonne-km (x$10^6$) | 3,000 | 3,000 | 3,000 | 3,000 |
| Consumption t or kWh per $10^6$t-km | **11300** | **2.5** | **11** | **20** |
| Total Consumption t or kWh/year | 33.7m | 7,500 | 33,000 | 66,000 |
| Fuel/Power Cost per tonne or kWh | $0.08 | $700 | $20 | $20 |
| Total Fuel Cost per Year | **$2.70m** | **$5.25m** | **$0.66m** | **$1.32m** |

**Notes:**

(1) Taking into account the low calorific value of this particular Indonesian coal (between 5000 and 6000 kCal/kg), the worst CNR consumption figure has been used for estimating QJ consumption and since "modern steam" efficiency should be about twice that of old steam, the best CNR figure has been used for "new" steam.

(2) Average CNR figure has been used for diesel fuel consumption.

(3) The 2001 CNR figure has been used for electric train power consumption.

(4) The 2005 CNR figure has been used for electric power cost.

(5) Cost estimates in **Blue** are transferred to next table.

See over for Table 4

## 4. Cost Comparison between locomotive types to handle 20 million tonnes of coal per year over a dedicated 90 km coal-haulage railway in Indonesia:

| Traction Type | Electric (New Build) | Diesel (New Build) | Modern Steam (New Build) | Reconditioned Steam |
|---|---|---|---|---|
| Horsepower | 3000 kW | 3000 kW | 3000kW | 2200kW |
| Haulage Capacity Factor | 1.75 | 1.50 | 1.25 | 1.00 |
| Purchase Cost | $1.0 m | $1.0 m | $4.0 m | $0.4 m |
| No Locos Needed | 7 | 7 | 8 | 10 |
| Railway Electrification | $38.25 m | - | - | - |
| Total Investment | $45.25 m | $7.0 m | $32.0 m | $4.4 m |
| Life Expectancy | 25 years | 25 years | 25 years | 10 years |
| Annualized Cap Cost | $1.81 m | $0.28 m | $1.28 m | $0.44 m |
| Maintenance Cost estimate | $0.22 m | $0.35 m | $0.15 | $0.32 |
| Fuel/Power Cost estimate | **$2.70 m** | **$5.25 m** | **$0.66 m** | **$1.32** |
| Water Cost estimate | - | - | $0.46 m | $0.58 m |
| Labour Cost estimate | $0.20 m | $0.14 m | $0.32 m | $0.41 m |
| Total Cost per Year | $4.92 m | $5.98 m | $2.86 m | $3.05 |
| Cost per Tonne hauled | $0.25 | $0.30 | $0.14 | $0.15 |
| Cost per Million Tonne-km | $2,733 | $3,322 | $1,587 | $1,693 |

**Notes**: (1) The life expectancy of both modern and reconditioned steam is likely to be higher than the figures shown, hence the cost advantage of steam are likely to be greater than indicated;

(2) The cost of diesel fuel is likely to increase in the future whereas the cost of coal is likely to remain low, hence the cost diesel traction is likely to increase in comparison to steam and diesel;

(3) Labour costs have been estimated at $5,000 per year which is probably excessive for rural Indonesia. Using a lower figure would give steam a greater cost advantage;

(4) Labour hours have been based on 3 x 8 hour shifts per day, two man operation of steam locos plus five servicing crew; one man operation of diesels plus two servicing crew; and one man operation of electric locos plus six servicing crew per shift (including line maintenance staff).

(5) Maintenance costs for QJs are based on reliable information from China; those for electric, diesels and modern steam are “guestimates” and subject to amendment.

(6) Maintenance of the electrical power supply and cabling systems have **not** been included in the cost estimates for the electric traction alternative. Electrical maintenance costs are likely to be significant, especially in hot and humid climatic conditions.

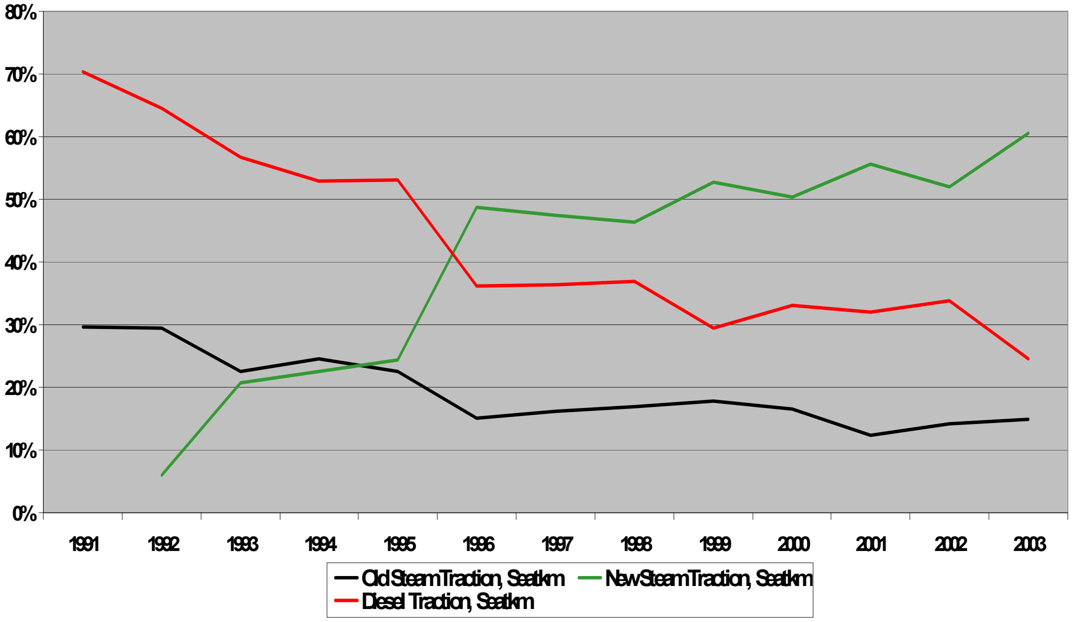
The figures suggest a substantial cost advantage for the use of steam traction, even a number of cost assumptions have been slanted to favour diesel and electric traction in order to avoid any suggestion of bias. The economic case for use of modern steam as against reconditioned QJ locomotives is not proven and requires more refinement to analyse accurately, however the figures suggest that further study is justified.

# Appendix 4 – Steam vs. Diesel Comparisons from DLM Switzerland

The following graphs are supplied supplied by Roger Waller of DLM, Switzerland, and show comparisons of usage, cost and performance between steam and diesel traction on Swiss and Austrian Tourist Railways. It is evident that DLM's "modern steam" locomotives have practically taken over the entire operation of the Schafberg Railway and a large proportion of operations on the Brienz Rothorn Railway, displacing both the old steam locos and diesel railcars

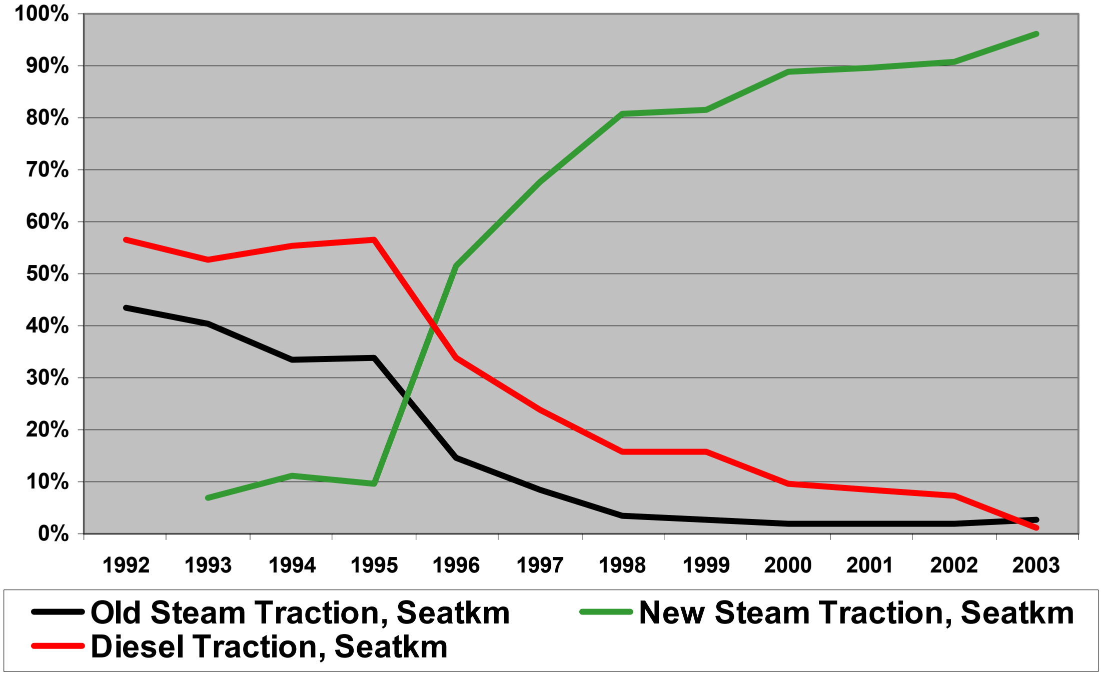
**Brienz Rothorn Railway:**

**Modal Split between Old Steam-, Diesel- and Modern Steam-Traction 1991-2003**

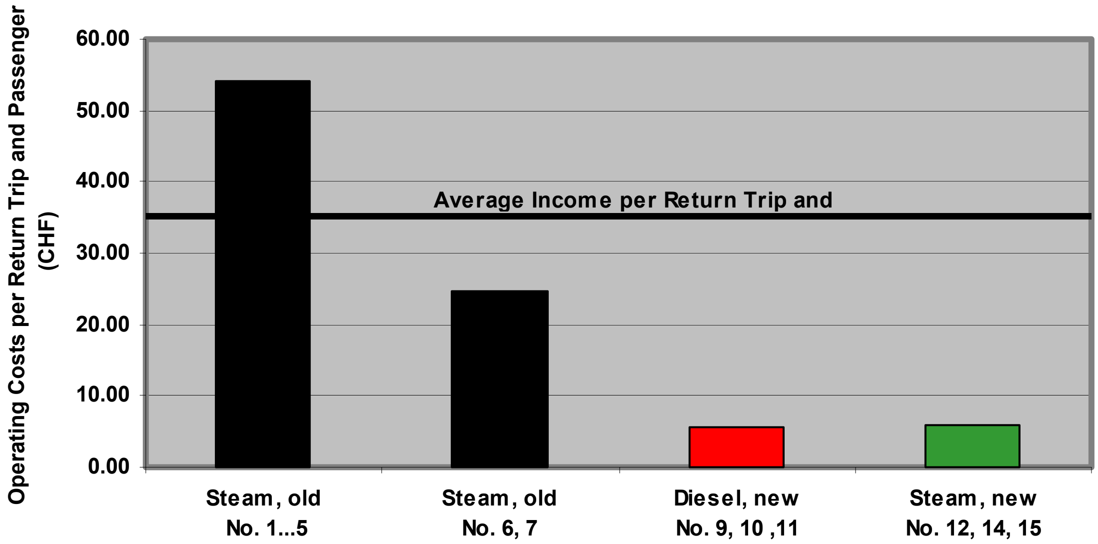


**Schafberg Railway:**

**Modal Split between Old Steam-, Diesel- and Modern Steam-Traction 1992-2003**



## Comparison of Direct Operating Costs
### of the Locomotives of the Brienz Rothorn Railway (1999)



## Comparison of Direct Operating Costs
### of the Locomotives of the Schafberg Railway (2000 to 2002)