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 19th and early 20th 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?

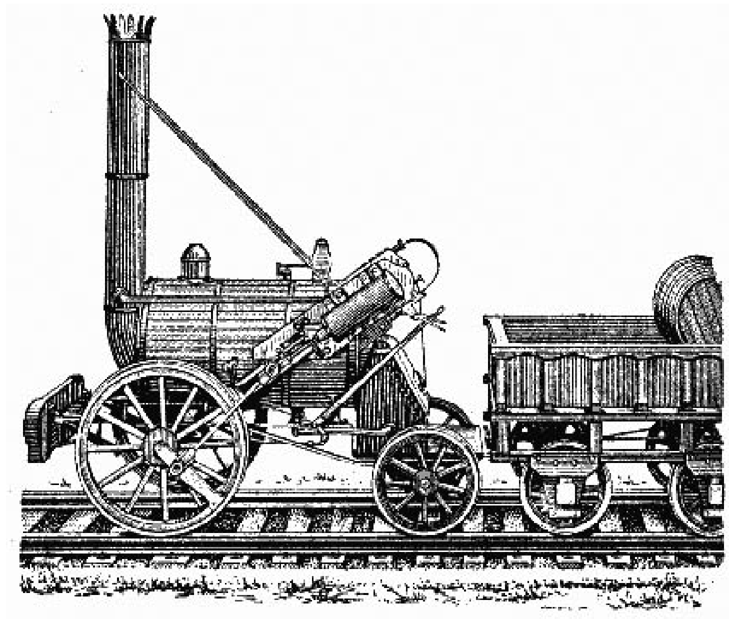
This paper describes the history of steam traction and the reasons behind its rapid displacement in the mid-20th century by "modern traction". It goes on to describe the potential for further development of steam traction technology and the possible roles that steam traction might be able to perform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

Background – outline history steam traction and its demise

From the beginning of time until the mid-18th 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-17th 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 19th 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-20th century adopted the basic design principles that Stephenson incorporated into his Rocket. These can be summarised as follows:



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

- 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).

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 Carnot's theorem. However at the turn of the 20th 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 CO_2 emissions – a latter-day issue that did not concern decision-makers in the 1950s.

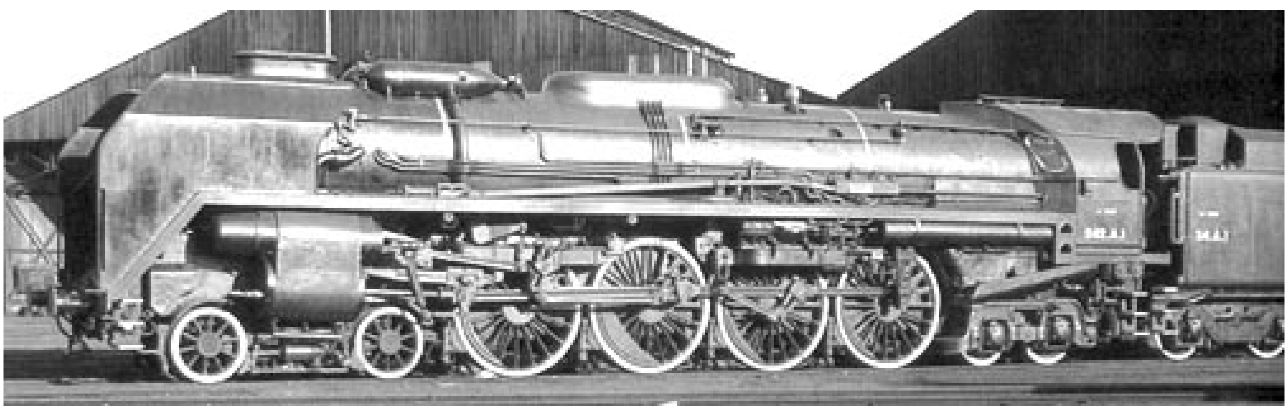
Other disadvantages that were (and still are) claimed against steam traction but which are more easily challenged, include:

- 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 locomotives.



Chapelon's 242A1 of the late 1940s
Capable of delivering 5,500 indicated horsepower, it outperformed all diesel and electric locomotives of its day

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.

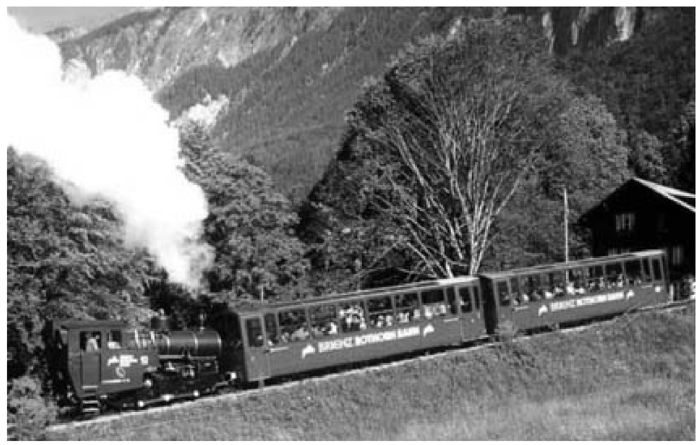
Wardale's 3,300 kW (4,500 hp) South African Railways Class 26 "Red Devil" – capable of 160 km/h performance if it had been allowed.

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:



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

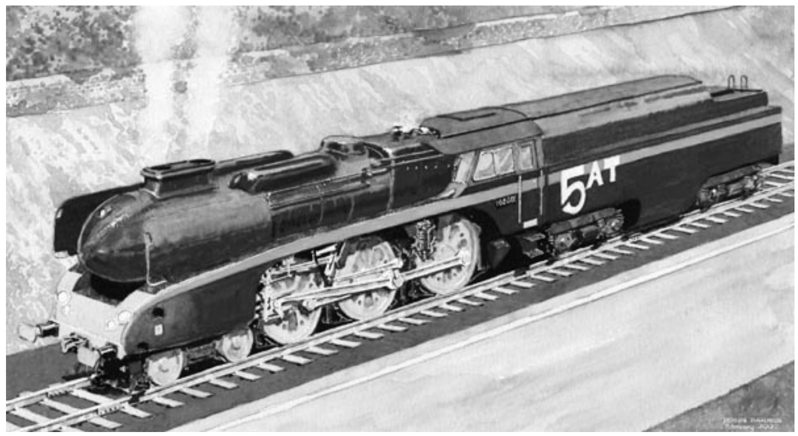
- **Roger Waller** of DLM in Switzerland (see http://www.dlm-ag.ch/index.php): In the 1990s DLM constructed two fleets of oil-fired "Modern Steam" locomotives incorporating many of Porta's principles for operating on mountain "rack" railways in Switzerland and Austria. The locomotives compete with diesel 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.
- **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 FACF 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 Screeton** 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): 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:
    - 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;
    - max thermal efficiency at optimum operating conditions approx 14.5%.

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



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

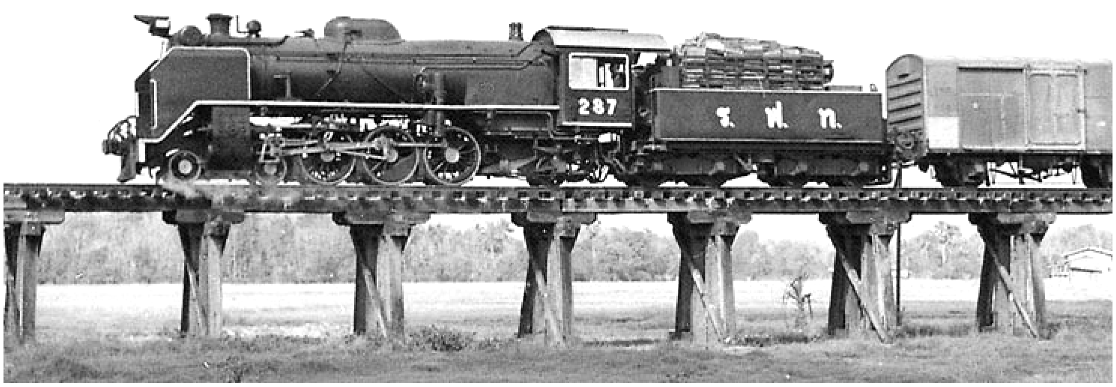
- **Spilling Energy System GmbH** (see http://www.spilling.de/english/index.php): An old company that has been manufacturing steam engines for over 100 years. It now specializes in stationary (reciprocating and turbine) steam engines for small and medium-sized power plants and "combined heat and power" 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.

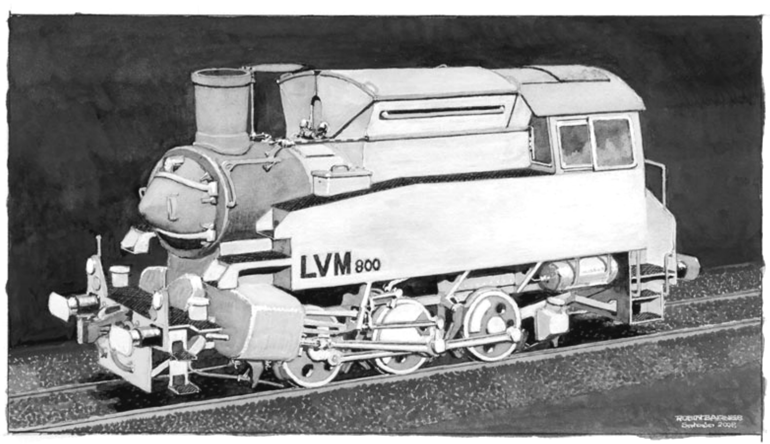
A comparison between fuel types is presented below (courtesy Brian McCammon):

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. 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



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

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.*