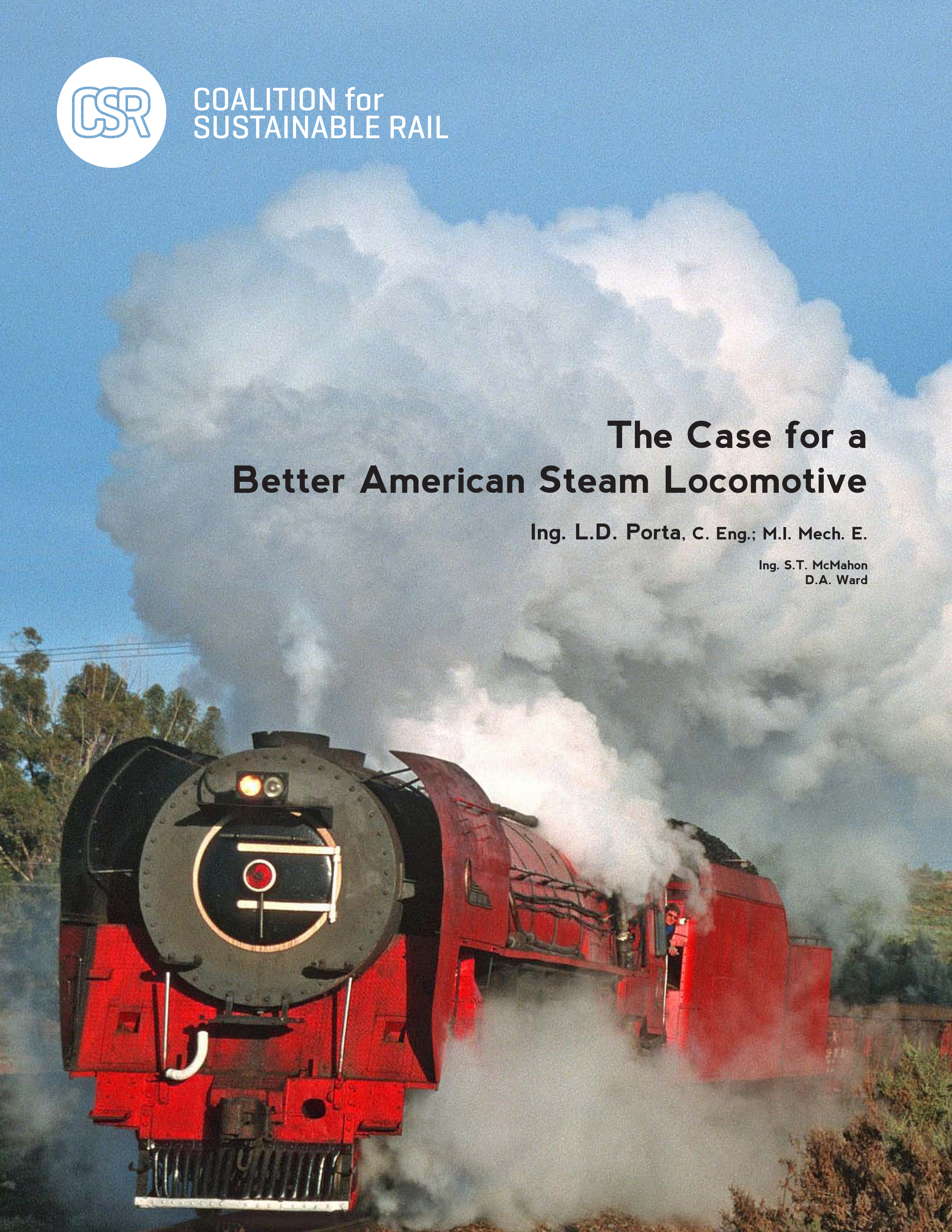
COALITION for
SUSTAINABLE RAIL



The Case for a Better American Steam Locomotive

Ing. L.D. Porta, C. Eng.; M.I. Mech. E.

Ing. S.T. McMahon
D.A. Ward

About the Coalition for Sustainable Rail

The Coalition for Sustainable Rail (CSR) is dedicated to the refinement of solid biofuel technologies for use in the world's first carbon-neutral higher speed locomotive. Our team is a combination of the research prowess of the University of Minnesota with the technical expertise of Sustainable Rail International (SRI), a 501c(3) nonprofit dedicated to the research and development of modern steam locomotives. A scientific and educational organization, CSR's mission is to advance biofuel research and production; to research and develop sustainable railroad locomotives; to promulgate associated sustainable technologies; and to support and conduct non-partisan educational and informational activities to increase awareness of sustainable railroad locomotives.

About CSR's White Paper Program

Working in conjunction with the University of Minnesota (U of M), the Porta Family Foundation, and other not-for-profit rail and biomass research organizations, CSR's White Paper Program is bringing scholarly works pertinent to biofuel, modern steam locomotive and transportation research into the public discourse.

Acknowledgements

CSR would like to thank Alejandro Porta, son of Ing. L.D. Porta, for sharing enthusaism for his father's work in providing CSR access to the Porta Family Foundation Archives. CSR would also like to thank its supporters, who provide the funding necessary to keep this nimble organization moving forward and who believe in the reality of modern, sustainable steam locomotion.

Cover Photo - *Modified South African Railways 4-8-4 number 3450, affectionately known as the "Red Devil," hauls a freight train many years after engineer David Wardale's departure from the railroad. - Trevor Staats Photo*

The Case for a Better American Steam Locomotive

Ing. L.D. Porta, C. Eng.; M.I. Mech. E.

Commentary: Ing. S.T. McMahon, D.A. Ward

Foreword

Originally written in the mid-1970's, at the height of the Arab Oil Embargo, this paper is a logical response to two, mid-1960's articles published in TRAINS Magazine regarding French and U.S. steam locomotive development. Its author, Livio Dante Porta, was the original founder of modern steam locomotive development; a practitioner, engineer, educator and pioneer dedicated to the application of thermodynamics to the robust armature of the steam locomotive. He is very accurately described in his 2003, *Guardian* obituary:

> *A theoretician, and author of around 200 scientific and technical papers, Porta was as down to earth as the steam locomotive itself.... Porta's great contribution to steam technology was what his disciples call his "holistic method of design," a scientifically based steam locomotive had to be a machine that took into account not just its own, streamlined internal workings, but ecological, social and economic concerns, too.*

To the reader of this never-before-published article, it is important to note that the general principles outlined herein have been proven on projects around the globe. Most well-known, though still obscure to many, is the work Porta, and my fellow colleague David Wardale, undertook in South Africa on SAR Class 26, No. 3450 named "L.D. PORTA" and subsequently nicknamed the "Red Devil" by maintenance and operating staff (pictured on the cover in a photograph by Trevor Staats).

Through application of the Gas Producer Combustion System, Lempor Exhaust, better internal streamlining of steam passages, larger steam chest and a whole list of improvements, Porta and Wardale proved, in clearest of terms, that a steam locomotive which conforms to the principles of Thermodynamics can outperform diesel-electric locomotives. The numbers mentioned in this paper, including a 40% reduction in coal consumption, 40% increase in horsepower and decreased maintenance costs, were all quantified a decade after its writing with the "Red Devil."

Thirty years have passed since that great experiment, and forty since this paper was penned. The push towards carbon-neutral biofuel production and need for higher-speed, high horsepower locomotives to propel intercity passenger trains has revitalized the need to investigate modern steam locomotion. The University of Minnesota, working in collaboration with the Coalition for Sustainable Rail, is pursuing such a development. More details on that may be found in the *Afterword* of this paper.

The modern steam locomotive is a powerful, yet simple, tool that can be used to usher in a new era of clean, efficient transportation and energy development. This paper begins to speak to the strengths and shortcomings of traditional U.S. steam development, and how a redesign can produce outstanding results.

Ing. Shaun T. McMahon
Director of Engineering

Summary:

TRAINS readers will have studied the "Case for the French Steam Locomotive" and the reply "The Case for the American Steam Locomotive," but neither of these soliloquies considered the possibility of uniting the best of both, of improving the best American designs, or stating the possibilities of a fully developed steam locomotive technology incorporating all the progress of the last thirty years.

For the past twenty years, almost the only voice in the wilderness pointing out the realities of comparative motive power costs in the U.S. has been that of eminent consulting engineer Harry Farnsworth Brown, who showed that average overall operating costs of diesel main line operation on Class I railroads had achieved no saving over those with modern steam power due to excessively high capital charges, combined with the very short economic life of major components. The validity of the case, which has so well been argued by Mr. Brown in his papers to learned societies in the U.S.A. and Great Britain, has now been enhanced by the serious effects of the oil crisis.

The U.S. transportation system relies 99% for fuel on scarce oil, much of which is imported and subject to political uncertainties. We can expect that railroads will be given a greater share of total transportation requirements on account of their higher efficiency as energy users, but the coal burning steam locomotive offers a dramatic solution: it needs no oil!

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1. Introduction

The readers of TRAINS will remember two articles, the first entitled "The Case for the French Steam Locomotive,"[1] and the second "The Case for the American Steam Locomotive,"[2] which was in the form of a reply to the first. To the author, both of them seemed like a "talk between the deaf", or as two monologues, because each enthusiastically put forward the best side of their respective cases. The first one did not offer any constructive proposals in the sense of taking that which was the good from French locomotive developments and which could have made an important contribution to American design; whilst the second article had the same, but in the reverse direction. The author feels that a positive step could be taken by starting from the premise that much can be gained if such mental attitudes were revised, whilst pointing out that the French engineers had already studied and appreciated the best of American locomotive practice, and had thus taken their shape in the interchange of ideas.[3]

The seriousness of the oil crisis has lead many people to question of whether it was sensible to scrap non-oil-burning transportation motive power, and a lot of *mea culpa* surely are being cried in secret. But time does not stand still and there is no alternative but to look ahead. The opportunity has come to explore in full what really can be achieved with the best conventional steam locomotive design. Nothing is to be lost in this exercise, whilst other people prepare to spend billions of dollars searching for alternatives to diesel motive power.

Officials from the Pennsylvania Railroad stand beside prototype 4-4-4-4, T1-class locomotive number 6110, in this roster shot, taken in 1942. *- Wikimedia Commons Photo*

2. The glorious past and its shortcomings

Many pages of TRAINS are full of descriptions and photographs of efficient looking steam locomotives pulling endless rakes of cars on high speed passenger trains, and indeed there was a glorious time in which people were quite happy to enjoy the sensation of peace and safety induced by the iron horse in front. There are a lot of reasons behind her popularity as shown by the un-declining interest in the pages of this magazine. Yet in spite of all those golden years of scream, we must be conscious that those magnificent performances were carried out within a poor framework of thermodynamic efficiency. Six out of ten photographs show a solid black column of smoke ejected (with a tremendous amount of unutilized kinetic energy thrown to waste), ten feet away from a small stack. Power, huge power, was obtained not by extracting every bit available from a decent theoretical thermodynamic cycle, but by burning inefficiently mountains of coal carried on enormous tenders.

Whilst American engineers did understood the meaning of increasing the overall efficiency by enlarging the upper limits of the theoretical steam cycle, namely higher steam pressures / temperatures and feed water heating, they failed to realize, in full, the importance of the lower limit-exhaust back pressure, which, for example, absorbed about 1,400 h.p. in the Pennsylvania T1 [SHOWN ABOVE] at full power, equating to about one fifth of the total power of the locomotive.

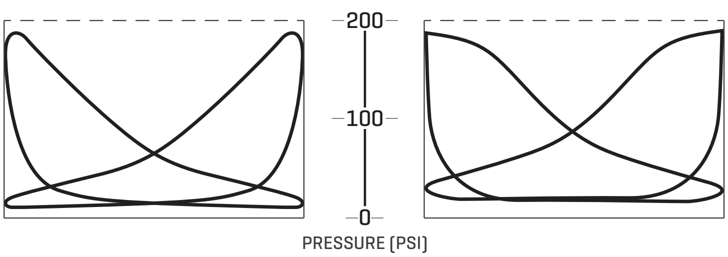
To save a pound of back pressure is worth an increase of thirty pounds in boiler pressure. Yet nobody has been able to assess all the mishaps resultant from the unfortunate work of Young[4] on exhaust design, which lead to the poor proportions, high back pressures and heavy blast characteristic of American locomotives: which certainly did not have the best drafting arrangements in the world! (Fig. 2 - Page 8)

Internal streamlining, the magic key to French locomotive designer Andre' Chapelon's techniques was introduced too late and imperfectly understood. The highest boiler pressures were wasted in poor piston valves, small steam passages and unnecessary throttling. Fig. 1 shows a typical indicator card of the well known K 4s. Specific steam consumption was not as low as it could have been at full power and so enormous boilers were required to produce the steam required, thus entailing unnecessary carrying wheels and weight, a heavy coal bill and showers of sparks making an unwanted cinder carpet of the right of the way. The poor drafting arrangements could not be improved to give smokeless combustion and a free steaming boiler; no one will say that such a state of affairs was conducive to efficient operation!

Briefly, the following equation was not fully understood:

$$\textbf{Maximum Power Produced} = \frac{\textbf{Maximum Steam Produced}}{\textbf{Specific Steam Consumption}}$$

Fig. 1 - Indicator Diagrams, PRR K4s



Test - 4033 Year - 1915	Test - 904 Year - 1940
2350 I.H.P.	3790 I.H.P.
36.7% Cut-off	34% Cut-off
66 mph	66 mph
PISTON VALVES	FRANKLIN GEAR

An ALCo-built 141R in a typical "roster" shot.- Wikimedia Commons

While the importance of the numerator was appreciated, that of the denominator was not, nor was the interrelation between the two. To that point, the following list outlines additional common omissions of U.S. locomotive designers:

- The size of the firebox's grate as the most important feature of the boiler was seldom recognized at all, and its lesson misunderstood. Consequently the best qualities of coal were nearly always insisted upon, thus imposing limitations and a higher fuel bill.

- Cylinder insulation was a bare minimum, perhaps just to comply with the conscience: this huge piece of ironmongery was cooled by a gallant air stream, and re-heated at every start. Engineers seemed to forget that, as a heat engine, the steam locomotive has to work in a hostile environment in which intermittent operation was inherent.

- The blower! It was as inefficient as it could be, and used and abused as much as possible. How much air was unnecessarily heated in oil burning engines when standing by?

- Compounding's virtues were not fully realized in the US, and the failure to appreciate that poor internal streamlining, particularly between the high pressure and low pressure cylinders, was the cause of poor results obtained when higher speeds were sought.

Whilst the above list of shortcomings could be enlarged even further, we must state the other side of the case:

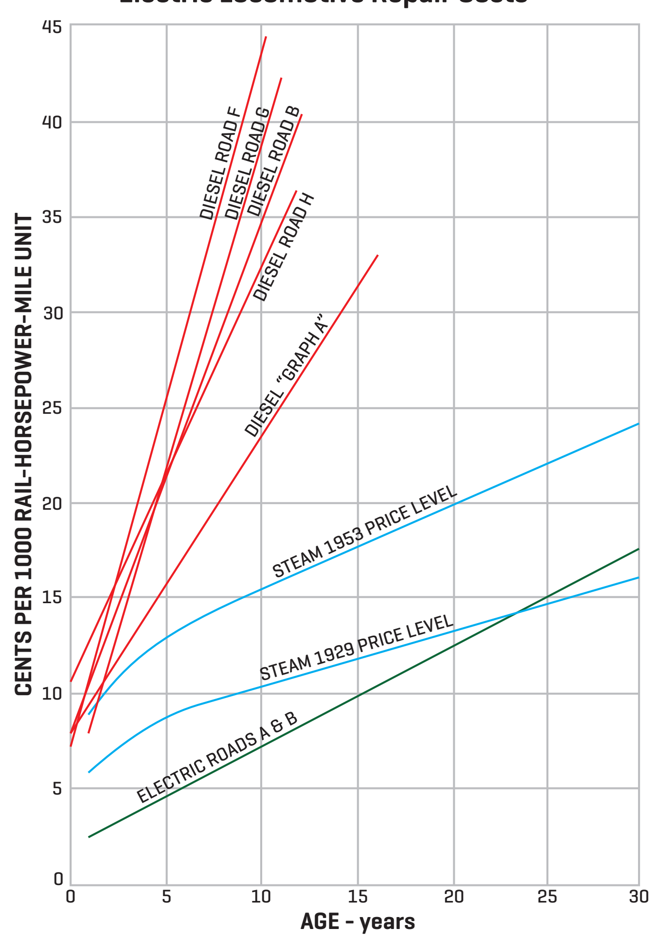
American engines were mechanically sound, most reliable and capable of almost continuous operation, getting the most out of their capital investment in terms of ton miles per day. An excellent example of this is the American 141 R's [ABOVE] operating in France. They were the last steamers to be retired, a high tribute to their reliability in view of their undeniably heavy fuel consumption. To the writer who has worked with engines coming from many prestigious locomotive building companies, there is nothing like the American design for rugged construction and reliability.

3. Harry Farnsworth (H.F.) Brown logical motive power cost analyses.

Probably few Americans have heard of one of the most important pieces of evidence of the steam locomotive in the diesel-steam comparison, "Economic Results of Diesel Electric Motive Power on the Railways of the United States of America," a study produced by H.F. Brown, an electrical engineer from New Haven.[5]

His case, based on an exhaustive study of motive power operating costs for the retention of steam power in coal burning areas of the U.S., was given in papers in the U.S. and England. It was deemed important enough a research study that the President of EMD crossed the ocean and went to London to attend its presentation.

Comparison of Steam, Diesel, and Electric Locomotive Repair Costs



Taken from *Economic Results of Diesel Electric Motive Power on the Railways of the United States of America* by, H.F. Brown, Ph.D., the graph above places steam, diesel and electric locomotive maintenance costs on a level playing field, using 1953 price levels.

Mr. Brown's paper made a considerable impact in Great Britain, but it unfortunately came too late to reverse British decisions on dieselization.

H.F. Brown was not an enthusiast, but an electrical consulting engineer. He realized the shortcomings of a so-called electrical locomotive which carried its own costly prime mover, and calculated the data included in Appendix 1. An updating of Mr. Brown's calculations to 1967 showed a similar result.

Thus, Mr. Brown showed what could be expected from U.S.A. railways if operated by modern steam power, and with further developments in design of steam power, these could be improved considerably.

Union Pacific "Big Boy" number 4019 takes a train of Pacific Fruit Express cars through Echo Canyon, Utah, smoke included. - UP Photo / Wikimedia Commons

4. What could have been

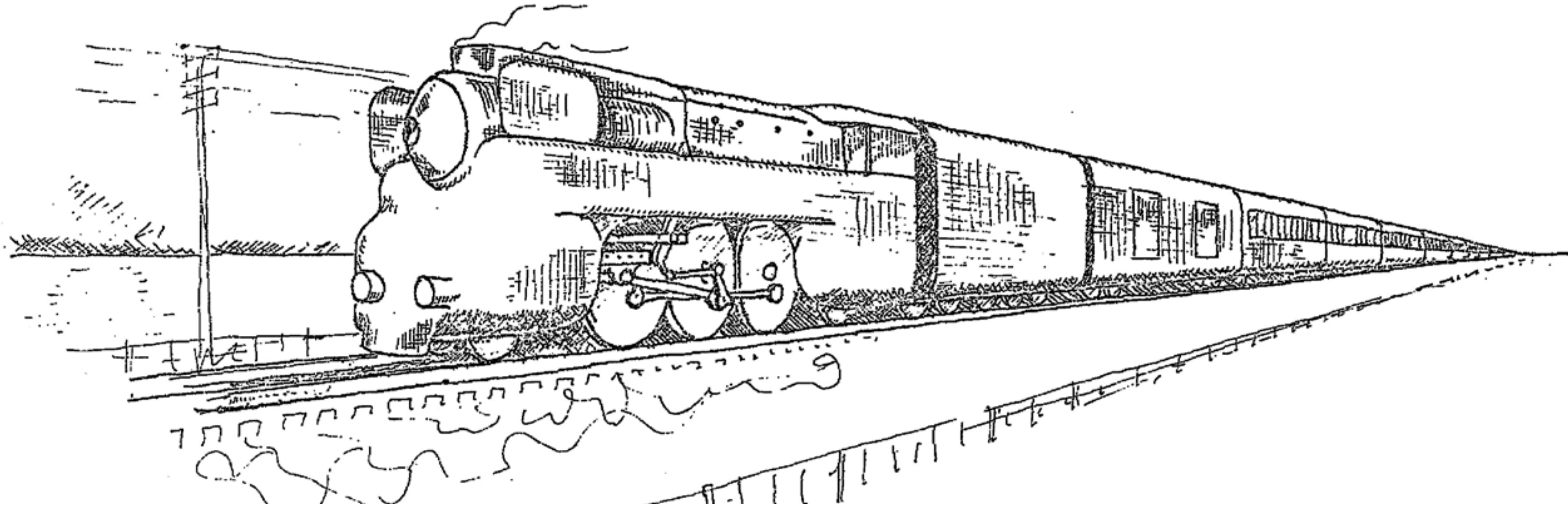
While fully respecting the technological traditions which have contributed to the wellbeing of the community it served with billions and trillions of tons transported over lengthy distances, it is interesting to carry out the exercise of exploring what could have been achieved by a modern American engine if properly "thermodynamized." Let us take as an example the Big Boy [ABOVE, RIGHT], which can be regarded as a high water mark of American steam locomotive engineering.

One of those locomotives could develop as much as 7,000 horsepower at the drawbar, its furnace eating 10 tons of coal per hour… with a thermodynamic efficiency of… 60% of what could have been possible!

The following are the most important non-structural design improvements:

- Adoption of the Kylechap, Giesel or Kylpor blast pipe to achieve a drastic reduction of back pressure down to 6 psi at maximum rate of working instead of about 25 psi. This along would increase the maximum power by about 1,500 h.p.!
- Substitution of the exhaust steam injector by a closed feedwater heater, giving a 130 degree Celsius feedwater.
- Adoption of air tight ashpan dampers to control the fuel consumption during standby.
- Adoption of the gas producer combustion system (GPCS).
- Adoption of an exhaust steam air preheater.
- Raising the steam temperature by throttling gas flow through the small tubes, thus diverting more hot gas through the superheater flues.
- Improving the steam tightness of superheater elements against the header.
- Thorough improvement of cylinder insulation.
- Substitution of multiple, narrow rings of "diesel quality and make" for existing wide rings on all valves and pistons.
- Minor, but significant, improvements to the internal streamlining of the piston valves.
- Slight alterations to the valve gear to give longer valve laps.
- Adoption of the "Precision" type of valve gear power reverse.
- A thorough enquiry into minor defects to be corrected.

It can be expected that the above, non-structural design improvements will raise the actual drawbar horsepower from 7,000 to 10,000 (a 40% increase), making an equivalent 13,000 diesel horsepower locomotive, while coal consumption could be cut down by some 40%. The GPCS would make the significant contribution of allowing such performance to be achieved with cheaper, "second class" coals whilst its high combustion efficiency will result in clean, non-polluting cinder-free exhaust.



5. What can be done

Whilst the above list shows sizeable improvements that would enhance the position of steam power in H.F. Brown's analysis, it still follows the basic layout of existing engines and therefore does not take full advantage of all the possibilities inherent in a brand new design. Improvements in the theoretical limits of the thermodynamic cycle can, of course, still be found without abandoning the extraordinarily successful "Stephensonian" constructional layout of the traditional steam locomotive, which has outlasted a lot of attempts to achieve progress through unconventional designs (such as those by Leoffler, Schmidt-Henschel, Krupp, Ljumstom, General Electric, Pennsy / LMS Tubomotives, Kitson Still, James Archibald and many others).

As a matter of fact, further improvements can be carried out – further than the Chapelon French designs – in the way the real engine's thermodynamic cycle approaches the already-improved theoretical cycle. This essentially involves the following points:

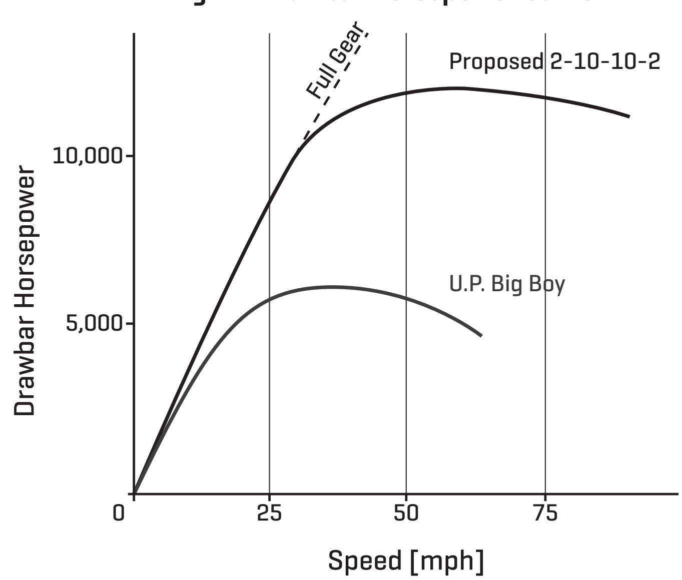
a) Internal streamlining carried out to the utmost so as to allow full advantages to be taken from compounding and highest volumetric horsepower obtained with modest piston thrusts.
b) Full consideration must be given to the fact that a steam locomotive is inherently an intermittent working machine.
c) The actual achievement of the most sophisticated technical development compatible with easy driving techniques.

The IMAGE ABOVE shows a proposed high speed design worked out for 125 mph timetables (not requiring, for example, any of the sophistications of the British Advanced Passenger Train [APT]), that could be built almost immediately and without recourse to still unknown technologies. The expected drawbar performance will be 4,000 horsepower for a 100 ton engine, and its coal consumption not greater than 50% of the best achievable with a postwar design.

Because of the cumulative effects of the various improvements, a low axle load results (about 40,000 lb). This, coupled with the low impact factor inherent in the exclusion of nose suspended motors, leads to a much required reduction in track maintenance.

Figure 2 [BELOW] gives an outline of a proposed Mallet incorporating roller bearings, capable of reaching 10,000 HP at the drawbar, but with a piston thrust (the Achilles heel of high American horsepower) of no more than 130,000 lbs, working on "second class coal" and requiring neither expensive nor critical materials.

Fig. 2 - Drawbar Horsepower Curve



6. Conclusions

The impact of the oil crisis upon U.S. transportation system has been shown to be a formidable one, since actually 99% of it depends on oil products. As a matter of fact, railroads will be entrusted by the community with a larger share of those duties, and it is difficult to imagine what can be the diesel lobby's arguments defending their selling policy which requires railways to operate on oil products, involving the whole nation in a major political effort to secure oil imports at ever-increasing cost.

While electrification will of course be invoked as an alternative, the people favoring it will probably ignore the possibilities with steam which they did not see and about which they can not be conversant. But if oil is already a scarce commodity, copper is just second to it, and it is good to remember that "copperless" electrification is still a dream.

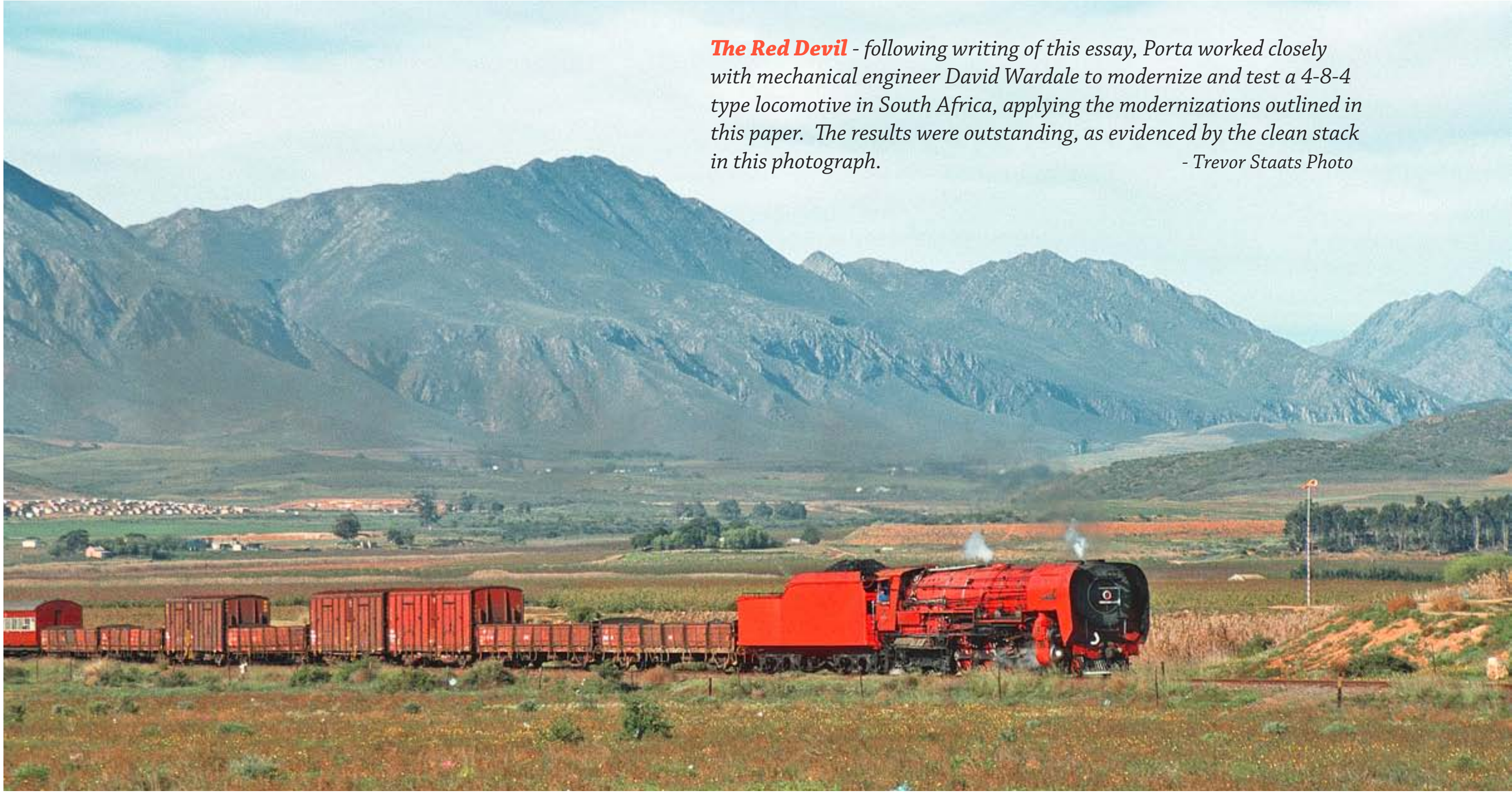
Heavy investments are the other inconvenience of electrification, which shows a dangerously rising tendency on rates of return on capital needed to amortize the capital first cost. The community is becoming steadily more aware of the effects of immobilizing money in static equipment, and this is shown by the clear trend of allocating capital investment solely on the schemes with the highest return.

Have American railroads enough traffic intensity to justify all-out mainline electrification programs, or can this be justified economically only on a limited number of fairly-short sections carrying very dense traffic?

Really modern steam deserves at least to be given a fair evaluation if it can be applied within the most stringent parameters of thermodynamic efficiency, far removed from the fuel-wasting philosophy prevailing in the past. If it can be achieved by development of conventional technology, so much the better.

More or less lengthy arguments can be produced to prove the validity of the case, but there's just one cardinal point making any scheme a matter of "to be or not to be;" the will to succeed. No steam locomotive development, however technically advanced and commercially successful it could be, can become useful to the community unless the strong will and determination necessarily associated with any real progress is applied and sustained.

Therein lies the key to success or failure.



The Red Devil *- following writing of this essay, Porta worked closely with mechanical engineer David Wardale to modernize and test a 4-8-4 type locomotive in South Africa, applying the modernizations outlined in this paper. The results were outstanding, as evidenced by the clean stack in this photograph.* *- Trevor Staats Photo*

Appendix 1

Comparative costs of diesel operation versus operation with equivalent modern steam on basis of 1957 costs

	Diesel		Steam	
	Cost	Saving	Cost	Saving
Road Power				
Repairs:				
Diesel and equivalent steam	$ 377.4	-	$ 293.0	84.4
Other	51.6	-	51.6	-
Fuel:				
Diesel and equivalent steam	366.7	85.0	451.7	-
Other	23.2	-	23.2	-
Engine men	388.3	19.4	407.7	-
Engine house expense	104.2	22.3	126.5	-
Water	5.3	26.9	32.2	-
Lubricants	27.2	-	7.7	19.5
Other locomotive supplies	8.8	-	8.8	-
Total road locomotive expense	1,352.7	153.6	1,402.4	103.9
Net operating savings		49.7		-
Yard Power				
Repairs:				
Diesel and equivalent steam	76.0	-	52.8	23.2
Other	8.1	-	8.1	-
Fuel:				
Diesel and equivalent steam	40.5	77.5	118.0	-
Other	3.4	-	3.4	-
Engine men	242.7	-	242.7	-
Engine house expense	29.9	15.6	45.5	-
Water	1.1	18.7	19.8	-
Lubricants	4.4	-	3.1	1.3
Other locomotive supplies	2.2	-	2.2	-
Total yard locomotive expense	408.3	111.8	495.6	24.5
Net operating savings		87.3		-
Total expense, road and yard	1,761.0		1,898.0	
Total net operating savings		137.0		24.5
Investment				
Road locomotives	2,760.0	-	1,925.0	835.0
Yard locomotives	1,120.0	-	555.0	565.0
Total locomotives	3,880.0	-	2,480.0	1,400.0
Facilities (pro-rated 300 road, 100 yard)	400.0	-		400.0
Total investment	4,280.0		2,480.0	
Net saving in investment		-		1,800.0
Fixed charges				
Depreciation of equipment:				
Road	165.6	-	61.0	104.6
Yard	50.4	-	17.5	32.9
Interest on undepreciated equipment:				
Road	55.2	-	38.5	16.7
Yard	22.4	-	11.1	11.3
Total fixed charges, equipment	293.6	-	128.1	165.5
Total, all charges road	1,573.5	-	1,501.9	71.6
Total, all charges yard	481.1	43.1	524.2	-
Total, all charges yard and road	**$ 2,054.6**	**-**	**$ 2,026.1**	**$ 28.5**

(All figures in millions of dollars)

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Economic Results of diesel electromotive power on the railways of the United States of America by H.F. Brown, Ph.B., Fellow A.I.E,E.
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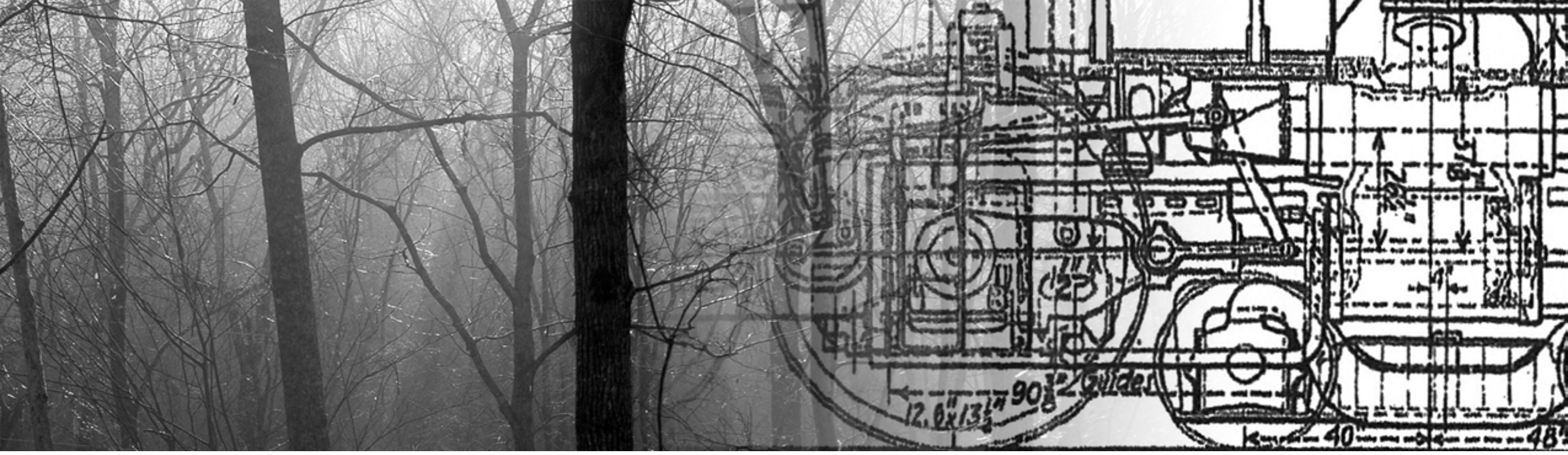

Afterword

"NOBODY KNOWS WHAT THEY DO NOT KNOW UNTIL THEY KNOW IT"

L.D. Porta used that phrase many times to describe his work ethic and his drive. The supporters and leaders of CSR share that affinity and enthusiasm, striving to bring *modern* steam back into the conversation of railroad motive power, but this time there's a twist: it's a clean, powerful and sustainable alternative.

CSR, working in collaboration with the University of Minnesota, is driving an interdisciplinary project focused on modern steam technology and solid biofuel refinement. Research collaborator *Natural Resources Research Institute* (NRRI), of the U of M, is a leader in producing a highly efficient to refine, solid biofuel known as "torrefied biomass." Made from solid plant matter (e.g. woodchips, corn stover, kudzu), torrefied biomass is made through heating of the aforementioned plant material in the absence of oxygen, driving off volatile gases and leaving a charred biofuel that repels water and can be easily briquetted. For all intents and purposes, however, this torrefied fuel has the same energy density and properties as coal, without the heavy metals, sulfur, ash content, moisture... and it is carbon neutral!

On the modern steam side, CSR acquired a 1937-built express passenger steam locomotive (No. 3463) from the Great Overland Station in Topeka, KS in pursuit of modernization and testing. The transfer of ownership was facilitated with the best interest of the locomotive in mind; following years of neglect, it was in dire need of attention. CSR will apply a similar, yet more in-depth modernization regimen to 3463 as was undertaken on the "Red Devil" and, although the locomotive will sport modernizations, it will be radically different from its former self in performance more so than form.

The crux of the project is to meld torrefied biomass and modern steam technology, creating what *Steam Railway* magazine coined a "Biofuel-powered Monster." The modified engine will break the world speed record, set in 1938, by traveling in excess of 130 miles per hour while burning torrefied biomass, in honor of which CSR has named this endeavor "Project 130." The ultimate goal of the project, however, is to prove the efficacy of the core technologies and develop a body of data from which to build a modern, computerized steam locomotive and advanced torrefied biomass facilities.

I welcome you to continue to monitor our website, www.csrail.org, for additional updates and further issuances of White Papers as they are "published" periodically, and I thank you for your interest!

Davidson A. Ward
President

CSR cosmetic stabilization crew on the front of 3463 following its repainting in May, 2012.

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