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Post-Carbon Australian Options for Railway Locomotives:

(or what industry can do when it can no-longer afford diesel.)

Folio: 1:t9 Technical Material

Note: *Readers of this Technical Folio are assumed to have previously read as well as understood Folio:g Germinal Material!*

Numerous instances of drafts for this project where initially released on the net for public comment as **PCAL_dfX.pdf.** *This new restructured set of documents can be found at:-*

http://www.auzgnosis.com/pgs/auzloco.htm

Any and all feedback to the author via email (as above) is most appreciated. Thanks.

NOTE: The author is sympathetic with the Open Source movement. Thus proposal to include Post-Carbon Auz Railway Locomotive Options (or parts of) in Open Source strategies of software development and dissemination may receive favourably consideration.

2nd. Preamble.

As explained in the **Executive Summary** [See Germinal Material (1st folio in set)] this collection of papers are proffered as a "Plan B" for when the BAU [Business As Usual] approach comes unstuck faced with unexpected feedbacks between challenges of Climate Change compounded by Peak Oil in a Post Carbon world. While this first paper [Germinal Material] was aimed at a general readership, this and other remaining documents are of a more technical nature. The expectation being that any reader of this or latter documents will already posses the required level of knowledge to understand the complexities in the content of a given paper. Due to the breadth of material envisaged as possibly comprising the final collection it is unlikely that any single individual will be familiar with all the nuances raised by these investigations. *That said, and granted as dull or obtuse as the more technically minded reader may view the first Folio:g, it is assumed that readers of this Technical Material will be au fait with the preceding* ***Germinal Material*** *Folio:g.*

Objectives of Project.

1. Emphasise the conveniently neglected compounding commercial and logistical challenges that come to light when the implications of Climate Change to an evolving Post Carbon world are re-framed by the insights garnered from the Peak Oil discourse.
2. *Addressed in* 1st folio: Germinal Material: {Reappraise historical trends of the broad sociological structuring function engendered in choice of power sources within the evolution of an industrial society.}
3. Explore carbon neutral options for long-distance land transportation.
4. If plausible, investigate (non-domestic) industrial scale engine-types to be exclusively fuelled by outputs from renewable power sources.

Outline.

The double whammy of the unfolding Peak-Oil crisis simultaneously as Climate-Change ever worsen pose complex, intertwined challenges for humanity in the 21st Century and beyond.

This second paper (in the series) focuses on the particular difficulties to be faced by heavy-rail, so heralding an in-depth technical examination of options for railway locomotives.

Housekeeping.

World Wide Web URLs [web addresses] have been included as links to more detail background if the reader requires such. Not as any implied endorsement (of quality or completeness,) Wikipedia will be cited in many instance, primarily for the simplicity of the treatment, combined with list of good links to more rigorous sources. However few website frequently cited here-in; www.douglas-self.com for documenting of past technologies, www.5at.co.uk and www.martynbane.co.uk for knowledge of 2nd generation steam locomotives I'd unreservedly endorse. All the web addresses were verified and correct at the time of publication.

Technical units ideally will follow the **International System of Units** (abbreviated **SI** from *Système international d'unités*). However older units may be quoted as required by old formulas.

Legals & Personal.

As detailed on my company website: [http://www.auzgnosis.com/pgs/thinkin.htm] this document like other similar works via AuzGnosis is distributed as-is. ***AuzGnosis supplies ideas, with No Guarantee or Warranty. You are totally responsible for your own judgement as to the ideas' plausibility, suitability and desirability, thence any utilization and implementation, you may, or may not, undertake.***

Personally my resume and other such things can be found on my AuzGnosis website.

W. Shawn Gray

Part 5: Rail-History's Lessons.

IF: THEN: SKIP.

A pass-ticket for readers who are not particularly fascinated by railway traction, while being willing to accept that (in the following section's analysis I rationally explore why) past rail solution and

business as usual strategies will not be sustainable or sufficient after the horror bites of Climate Change reinforced with Peak-Oil. Such reader may here safely skip (over the tedious dry justific-ation) ahead to **Parts 6 & 7** where I first elaborate the challenge in reference to areas so far not discussed, before proceeding to sketch some innovative rail-power options that if implemented in-time may aid in addressing the forth-coming trials and challenges.
However if upon jumping ahead to these unorthodox proposals they strike one as too weird or crack-pot, then unfortunately you will need to retrace your steps to here. So you then may wade through intervening analysis drawing-out histories insightful lesson from the saga of railway loco-motive evolution.

Railway Motive Power Options.

Variety and Limitations.

As outlined in [Germinal Material Folio section] 'Options on Transportation Difficulties.' relocalizations in conjunction with the necessity to optimise operational responses with diverse, or exotic energy sources will engender a variety of niche solutions. Railways while better placed to successfully adapt to the challenges of the Post-Carbon World, will likewise not be able to forever cling to past fossil fuelled workhorses. Rather than a single network-wide choice; steam, electric or diesel being a common motive-power regime across a whole operation, different fuel and power options will more than likely be pressed into service to intimately match different task; switching / shunting, urban transit, local freight, mixed services (goods + passengers), heavy freight, express freight, long distance freight, urban passenger, interurban passenger, overnight passenger, interstate passenger, dry inland operations, mountain operations and coastal operations.

Caveat on Hindsight.

Before straining to see into a carbon challenged future, it is advisable to quickly recall some of the lessons of history, so as to avoid repeating the mistakes of the past. However such a review must be parenthesised within the technical limitations of their day. Just because something may have failed in a past context, that does not automatically mean it has no future. With the application of more advanced materials, techniques and technologies, cautiously tempered with wisdom of hindsight of past failure, the once dud idea may yet be reborn a future stand-out solution.

Power + Transmission

As locomotives became more powerful throughout the 19th century, the difficulty of effectively (as and when required) being able to deliver all that new power smoothly to the rails grew as a major concern among engineers of the day. Besides the occasional spinning of the wheels when the power is applied faster than friction will facilitate traction, the phenomena know as the **Hammer Blow** daily taxed the rail infrastructure upon which steam-engines rode.   The power output from a steam piston is not uniform over the whole cycle of rotation. The adverse effect of this pulsing of power is then amplified by the not insignificant reciprocating mass of connect rods and such, which combine to regularly throw punches of force, 'Hammer Blows' through the underlying rail infrastructure.

For innovators of locomotives other than steam, how to even get the sort of power that melted gear-boxes from fast spinning diesel, electrical or turbine engines to the wheels was not all that obvious at first. Example being the first German diesel locomotive compressed air to pump 'steam-like' pistons and connecting rods.[http://www.douglas-self.com/MUSEUM/LOCOLOCO/diesair/diesair.htm]

Mechanical Transmission

Beside pistons with connecting rods, other direct mechanical connections include: gears, chain or belt drives. All incurring power loss via extra friction in the drive-train, along with higher maintenance needs than piston connecting rod combination. Diesel-mechanical locomotives while being more energy efficient than diesel-electrics are restricted to models for shutting (switching) duties, as higher powers of larger locomotives have yet to be successfully realized via mechanical transmissions.

Hydraulic Transmission

These transmission utilize oil within one or more **torque converter(s)** [http://en.wikipedia.org/wiki/Torque_converter] to transfer power directly from the engine to the wheels. German diesel-hydraulic locomotives being the most exemplary implementation. While they seem to require more exacting attention than comparable diesel-electrics, the diesel-hydraulic loco exhibit superior power to weight ratios against the heavier diesel-electrics.

Electrical Transmission

Given the complementary paring in an electric system of generator / alternator via flimsy wires with batteries and motors conceptually (at least) electric transmission hold-out the promise of clean flexible implementations. So much so that as early as 1890 the French inventor J. J. Heilmann patented then built a few Steam-electric locomotives.[http://www.douglas-self.com/MUSEUM/LOCOLOCO/heilmann/heilmann.htm] There after many adventurous steam locomotives, most steam or gas turbines locomotives along with the vast majority of diesel locomotives have employed electric transmissions, of one variety or another.

Locomotive Traction Frames to Bogies.

How much traction a locomotive achieves is proportional to the extent a locomotive's weight is directed to the rails through powered axles. Historically steam-locomotives had an engine (cylinder + piston + valve gears + rods) affixed directly to each sides of the locomotive's frame. This arrangement often resulted in the need for additional non-powered axles (leading) in-front of the, or trailing behind the larger driving wheels. Such non-powered axles effectively squandered that part of the locomotive's traction potential not carried by the driving wheels. While non-powered leading, trailing, axles or bogies were a common feature of steam locomotives, both early types of electric locomotive and diesel locomotive also followed similar arrangements.

The development of electric power bogies changed everything, for now it was possible that all sizes of electric or diesel locomotives (not just small switchers) to be full traction locomotives. Rail-motors of the 1930 also saw the development steam power bogies. The quest for full traction of large steam engine is what inspired Oliver Vaughan Snell Bulleid's experimental Leader class locomotive [See 'S.R Leader class and C.I.E. CC1:' below].

Best Option; Bigger or More?

Historically steam-engines required a separate two-man crew (driver & fireman) to operate each locomotive. Automatic stokers and engine control telemetry technology being more recent innovations. Thus within the rail steam culture a 'bigger is better' mentality gained pre-eminence, culminating in the infamous Big Boy Mallet designs of the USA. The short-coming of the 'bigger is better' mind-set where thrown into sharp relief by the arrival diesel-locomotives with multi-unit control capabilities. [See Germinal Material Folio section 'Manpower versus Fuel Costs.']. So rather than having a fleet of steam locomotives of assorted power rating that needed to be matched with particular tasks, a diesel or electric rail-operator only needed numerous identical engines that could be strung together to sum to the power rating needed for a particular task, that at the end of which the locos could once again be mixed then matched in most efficient combination for the next scheduled task.

However despite all the additional flexibility of multi-unit operations, from an engine / energy efficiency stand-point there maybe still a role for singularly large locomotives as demonstrated by experiments such as the Union Pacific's **UP#8080** Coal-Gas Turbine-Electric behemoth [see below].

Steam Locomotives.

Having grown-up in an era when steam locomotives where still a daily feature of the railway operations of my childhood, I initially overlooked including any explanation of what steam-engines where. So for those readers unfamiliar with the workings of steam-engines see the *21st Century Vision of Steam Traction* team's explanation '**How the Steam Engine of the Locomotive Works**' [http://straction.wordpress.com/how-the-steam-engine-of-the-locomotive-works/ or http://en.wikipedia.org/wiki/Steam_engine]

Despite steam-train enthusiast's hankering for a bygone era, after the rise of diesel traction there was negligible justification for any previous return of steam-power. That was until the Arab Oil Embargo / Seventies Oil Shock gave the world a stark lesson concerning the strategic importance and vulnerability of dwindling oil reserves. In the 1970's the National Zimbabwe Railways reversed their dieselization with reintroduction of steam-power Garratts, some of which are still in operations today despite a second wave of dieselization.

Even now, with the exception of odd stand-out specimens cited below {LVM800}, any broad-brush argument for reciprocating steam-locomotives (especially in Australia and other warm climes) is a nostalgic delusion.

The Coal fired past.

As marvellous as early advances of steam railways would have been in the Victorian era, fuel efficient they definitely were not. Even as late as the 1930s squandering up-to 90% of a fuels' energy potential was not uncommon, puffing up the chimney as waste heat! Unfortunately the external combustion of solid fuel in old fashion furnaces of vintage steam locos, by necessity devours sizeable chuck of the total energy input just to perpetuate adequate flue draft to maintain sufficient heat under the boiler! Not a great thermodynamic configuration. But on the plus side the robust simplicity of this external combustion arrangement (unlike diesel's legendarily narrow fuel specifications) spurred the initial development of industrial engine technology by accepting anything that would burn as a potential fuel.

Visionaries for the New Generations of Steam.

Jules T. Anatole Mallet (1837~1919)

[http://en.wikipedia.org/wiki/Anatole_Mallet] In 1781 Arthur Woolf invented compound steam engine thermal efficient innovations that reused what was previously wasted steam to drive further pistons. As patented in 1805 *Woolf high pressure compound engine* was a massive stationary industrial unit. Over the century the technology was adapted to other situations like the big triple expansion marine engines common in 1880s shipping. However squeezing compound engines onto the wheels of a railway frame was an elusive dream for many till 1874 when Anatole Mallet patented in the first successful compound system for a railway steam locomotive. Famously Anatole's articulated Mallet locomotive configuration featured such Compound Cylinders. Unfortunately later American locomotive builders of monster (such as the Big-Boys) that had (non-compounded) "simple steam engines", insisted on still tagging these locomotives "Mallets" as they were articulated in the same fashion as Anatole's original patent.

André Chapelon (1892~1978)

[http://en.wikipedia.org/wiki/André_Chapelon] Was the French engineer that moved the design of steam engines from a formerly ad hoc art-form of trial and error, to a more rigorous scientific methodology. For a time André's legacy bequeathed France with the most (around 12%) efficient everyday railway steam locomotives, many of which where compound engine configurations.

Ing. L.D.Porta (1922~2003)

Achieving efficiency over 18% for steam rail-locomotives the student Porta surpassed his master André Chapelon (who Porta studied under). [http://www.martynbane.co.uk/modernsteam/ldp/ldp.htm] Livio Dante Porta the celebrated Argentinean steam engineer, is responsible for many technical innovations reigniting interest generally in the possibilities of steam power. While not limited to steam engines his more famous inventions include:-

- Gas Producer Combustion System (cleaner more complete burning of fuel).
- Lempor Theory (improved exhaust extraction manifold)
- Porta Boiler Water Treatment
- Adhesion Aids / High Adhesion Wheel Profile
- Axial Flow Char Separator

Porta classified the development of steam locomotives into four generation as:-

Generation Zero - the bulk of historical reciprocating steam locomotives built up to the 1920s.

First Generation Steam [FGS] - the masterpieces of traditional reciprocating steam locomotives, designed in the inter-war period. Draw-bar thermal efficiency up to about 7%.

Second Generation Steam [SGS] - new designs incorporating the best proven modern steam locomotive technology resulting in typical draw-bar thermal efficiency 15%.

Third Generation Steam [TGS] - totally new formats requiring considerable research and development to achieve - typical draw-bar thermal efficiency 25%.

There are numerous significant locomotive, design, modification and construction projects that Porta worked on in his lifetime, three worth special mention here are:-

Argentina:

The Peron years major rebuild of a metre gauge locomotive, (ex- FC* Central Córdoba class B22 4-6-2 No.2011). It was both the test-bed and display platform for many of Porta's ground breaking improvements. [http://www.martynbane.co.uk/modernsteam/ldp/argentina/arg.htm]

ACE3000:

This project entailed Porta's involvement (in the eventually still-born effort) by the American Coal Enterprises for the development of a prototype *TGS locomotive*. [http://www.trainweb.org/tusp/ult.html & http://www.freepatentsonline.com/4425763.html]

Prometheus Project LVM800:

A Standard Gauge 3 cylinder Porta-type Compound 0-6-2t (tank-engine). One of the last projects that Porta had been involved when he died in 2003 this little engine, could yet prove to be very important for the future of at least the Australian Sugar Cane industry in a post-carbon world. A very practical little work-a-day *SGS locomotive*. With highly-efficient burning of carbon neutral biomass (like sugar-cane waste) this design would easily beat any competition using more expensive fossil fuel, or some other synthetic fossil-fuel replacement. [http://www.martynbane.co.uk/modernsteam/ldp/lvm/lvm800.htm]

Roger Waller (1952~)

52 NT 8055:

A ground-up rebuild applying the lessons of Porta et al. This time Roger Waller was working with the famed Swiss Locomotive and Machine Works (SLM). They rebuilt '52 1649' an old (1942~43) 2-10 German 'Kriegslok' (Wartime) steam-locomotive. Converted to burn light oil with many other improvements, now numbered '52 8055' it hauls Orient Express coaches in Switzerland.

DLM

During a corporate restructure of SLM, Waller with others brought SLM's former steam-works to create form DLM ('Dampflokomotiv und Maschinenfabrik' = Steam Locomotive and Machine Works). DLM now has SGS locomotives designs for sale in the company catalogue. [http://www.dlm-ag.ch]

David Wardale ( )

[http://www.martynbane.co.uk/modernsteam/dw/dwhome.htm]

The Red Devil *SAR Class 26 3450*:

During my early study of Peak Oil transport issues it was the C standing for steam-condensing that brought South African Railway [SAR] to my notice. Condensers allowed the SAR 25C locomotive to operate effectively hauling the like of South Africa's famous Blue Train across the hot dry deserts. David Wardale's major upgrading of a standard SAR 25NC (Non Condensing) locomotive to his famous SGS locomotive (officially named the "L.D.Porta" but affectionately known as) the Red Devil, proving the performance potential and technical feasibility of Wardale's and Porta's vision for a steam renaissance.

The Red Devil and other tales from the age of steam. **by David Wardale**

ISBN No. 978-1-90935-01-0

Recently re-published by Camden Miniature Steam Services, David Wardale's technical blow by blow reminiscences is a must read book.

5AT:

[http://www.5at.co.uk/] The dream of David Wardale with other engineers and steam enthusiast to build (with private and commercial funding) from the ground up a *SGS locomotive* re-interpretation of the concept that formerly was British Railway Standard 5MT class. Featuring some innovative material refinements to diminish the hammer blow, they have remained faithful to time honoured practices rather than risk all by experimenting with untested innovations. [*http://5at.co.uk/index.php/faqs/valve-gear-questions/hammer-blow.html*] The aim being to clearly demonstrate that a modern steam engine can both function commercially as well as, in every-day operational sense be the equal of their particular allotted task, as any other contemporary rail-locomotive traction alternative for that particular niche. Unfortunately in the current European economic climate, despite the technological consolidation of Porta & Wardale, et al's work that the project promised to demonstrate as live steam operations for modern audiences, funding (sufficient to proceed) was unattainable.

Coalition for Sustainable Rail [CSR].

[http://www.csrail.org/] along with the University of Minnesota. They state their mission as to; "*Develop the world's cleanest, most powerful higher-speed passenger locomotive, proving the viability of biocoal and modern steam technology.*" Following David Wardale's strategy of recreating a SAR 25NC as the "Red Devil", the CSR likewise have their eyes set on a ATSF 3463 selected as their test bed locomotive for (a reversible) conversion to (USA's first example of) a Second Generation Steam [SGS].

But as beneficial as the 5AT and this project promise to be for the colder climes of Europe and North America, I personally do not see much relevance from them for the parched dry Australia's Post-Carbon challenges.

Dead-ends Historical or Technical.

By the 1920s the short-comings of traditional (FGS) steam engines where obvious to many railway workers. But the logical fixes stubbornly refused to give much satisfaction, being rather a series of blind alleys and technological conundrums.

Steam Turbines.

See detailed discussion in Turbine Locomotives section [below].

Geared Locomotives.

[http://en.wikipedia.org/wiki/Geared_steam_locomotive] Where a tailored solution to tasks (industrial, mills, mines and forestry operations) demanding high-torque at slow speeds. With effectively a single fixed 'gearing' ratio this was beyond what the traditional of rod and piston configuration could provide. With the design constraint of slow speeds geared locomotives sidestepped the 'hammer blow' problem on light and /or unballasted track. [http://www.gearedsteam.com/]

High Pressure Steam

The theoretical thermal efficiency of any heat engine is directly beholden to differences between the minimum and maximum temperatures of the engine's inputs and outputs. [http://en.wikipedia.org/wiki/Heat_engine] The apparent simplest way to increase a steam engines performance was to raise the temperature, thence pressure of the steam entering into the cylinder to perform useful work. Whilst many country experimented with High Pressure Steam engines between the Twenties and the Fifties, none were satisfactory either being too expensive, difficult to keep running, or just downright dangerous. Normal boiler pressures were 200 to 250 psi (1.4 to 1.7 MPa). Operating over 350 psi being considered High Pressure locomotives, with some special constructions reaching over 1,500 psi (10.3 MPa). [http://www.douglas-self.com/MUSEUM/LOCOLOCO/hptech.htm] Skipping the voyeuristic distraction, what is of most interest to us now are the technical obstacles. To get water to high pressure steam demands a lot of heat, just often more than the stoker and fuel could continually deliver. The devilish combination of high temperatures and high pressure was beyond strength to weight parameters of materials at the time. Lastly, but most significant was the unappealing chemistry of water and container in such hellish conditions. Using distilled water temporarily reduced undesirable reactions like scaling, but inevitably the operating demands would eventually contaminate the working-fluid with the feared downside.

Lost Dreams etcetera.

The following either faded-away because of limitations of the technology along with materials available in their day. Lost with the historical dislocations like the Depression and Second World War disrupting a dreams evolution or sadly victims of market juggernauts out of step with the flow history and ecological imperative. Good ideas in the wrong place or at the wrong time.

Drawing-board ensnared Coal-fired Dreams.

Beside the [above] ACE3000 project there has been other proposals (especially in the USA) for a return coal-fired steam locomotives to modern railway networks. [http://www.trainweb.org/tusp/21_cent.html]

Steam Motors.

Rather than a large piston shared by coupled driving wheels, steam motors feature one or more cylinders directly matched to their own axle. So steam motors promised smoother rides along with an end to the hammer blow issue. They featured on revolutionary European express passenger engines over the 1930s & 40s [http://www.douglas-self.com/MUSEUM/LOCOLOCO/steamotor/steamotor.htm].

Less glamorous but more relevant are the intriguing metre gauge creations dispatched to Société National des Chemins de Fer en Colombe, Columbia (South America) in 1934 (during Abner Doble consultancy at the company) from the Sentinel Waggon Works Ltd of Shrewsbury, England. A high-pressure locomotive running on steam-motor power bogies feed by a Woolnough water-tube type boiler. [http://www.douglas-self.com/MUSEUM/LOCOLOCO/colombia/colombia.htm]

Sir Nigel Gresley's Hush Hush: Mainline Water Tube Boiler Express.

Water tubes boilers common in the maritime context offer superior heat transfer performance. In 1924 inspired by the Sentinel Waggon Works success with water tubes boilers, Sir Nigel Gresley designed two squashed Yarrow marine boilers in series for his secretive "Hush Hush" engine experiments. By 1929 official tagged LNER W1 No. 10000, the high pressure compound locomotive never fulfilled all the designers' and operator's expectations. In the quest for greater efficiency the theoretical advantages of high pressure steam tempted many a railway company, unfortunately such innovations comes with their own handful of regular gremlins. [See the above section 'High Pressure Steam' *under the heading* 'Dead-ends Historical or Technical'] Hush Hush with no marked performance advantage over simpler traditional locomotives of the day was eventually refitted with a standard fire tube boiler onto the 4-6-4 wheel-base. Thereafter the salvaged squashed Yarrow boilers provided many years of exemplary service as a stationary boilers.

Oliver Vaughan Snell Bulleid (1882 ~ 1970)

[http://www.bulleidlocos.org.uk/(S(thofntvmw2kge2meo3s5spuh))/_ovs/ovsbBiography.aspx] The innovative English engineer crafted steam locomotives such as the iconic Merchant Navy class or the practical Q1 class 0-6-0 at (UK's) Southern Railway. Sadly later steam creations were not as successful.

S.R Leader class and C.I.E. CC1:

[http://www.semgonline.com/steam/leader_01.html] Arguably the most controversial locomotive ever built in England [see below section 'Steam-motor power bogies under Boxy Carriage-work'] After being involved in the introduction of diesel locomotive to British railways this adventurous engineer bravely tried to re-imagine coal burning steam locomotive so as to have all the operational advantages of the electric or diesel locomotives running at the time on the British rail-network. An unconventional tank-engine riding a-top two six-wheeled reciprocating steam bogies, configured with a cab at each end and the fireman stuck in a hole half way along one side, Bulleid had inadvertently merged the saddest aspects of British diesel aesthetics with the most troublesome quirks of steam power and tank-engines. Bulleid did later perfect his concept in Ireland as the CC1 peat-burning prototype/ experiment on the Córas Iompair Éireann [http://www.bulleidlocos.org.uk/(S(4duuz1darc3gkjddkknt41a2))/_oth/cc1_itb.aspx]

Abner Doble (1890 ~1961)

Abner Doble is probably best know for his pioneering work with small steam engine design used to great fanfare in early automobiles. [http://en.wikipedia.org/wiki/Abner_Doble] In 1930 Abner left the USA for *A&G Price Ltd.* (the builders of some innovative geared locomotives for logging railways) in New Zealand. Moving on in 1932 to *Sentinel Waggon Works,* Shrewsbury, England. Staying four years working on steam lorries and locomotives Abner influence was inspiring. See 'Steam Motors.' [above]

Edward Pritchard (1930~2007)

While the above visionaries where working with railway-power Ted was quietly revolutionising steam power's future where-ever that may be; on the road trucks and cars [http://www.youtube.com/watch?v=LJq2Hc_mXFI] at sea, on the farm or down a mine. Combining his Vee-Twin uniflow steam-engine, with a mono tube steam-generator (instead of cumbersome pressurised boiler) in a condensing circuit. Ted created a thermal efficient, powerful, compact steam-power, distinguished with negligible water consumption.

[http://wayback.archive.org/web/20080710063739/http://www.pritchardpower.com/Ted_Pritchard.html & http://web.archive.org/web/20020523193230/http://prsteam.inventdata.com.au/] For many a future transport niche Ted's steam innovations many yet be the most feasible alternatives when contemporary petrol or diesel is but a faded memory. Ted's 2001 paper (on a couple of future-steam websites) "**Brief case for an investigation to be made into the suitability of modern steam locomotive production in areas with heavy production capability"** is a collection of imaginative suggestions and observation for future steam locomotives such as putting one V-twin Uniflow engine on each driving axle via bevel gears. Such arrangement would weigh only half that of the electric final-drive motors in current railway usage.

Fireless Locomotives.

[http://www.trainweb.org/oldtimetrains/industrial/steam/westinghouse.htm]
Reciprocating piston locomotives used in situations where naked flames or smoke where unwelcome such as; food processor, chemical factories, coal mines, along with other underground railways. Unlike a traditional steam engines gaining their power by burning some fuel under the on-board boiler to a working pressure for the piston, the Fireless locomotive had a reservoir charged with either steam or compressed air that was consumed by the piston as useful work was undertaken. Prior to reliable battery technology and efficient electric engines, such small (four or six little driving-wheel configuration) fireless and pneumatic locomotives occupied a critical transport role in industry of the day.

Steam Charges.

[http://en.wikipedia.org/wiki/Fireless_locomotive]

Compressed Air.

[http://www.douglas-self.com/MUSEUM/TRANSPORT/comprair/comprair.htm] The two major former USA builders (both companies have since closed) of such pneumatic locomotives where Porter and Heisler (of geared locomotive fame). While these locomotives were analogous to their steam siblings air is not steam, thus there were significant differences with fine details like temperatures, clearances and choice of materials.

Current Revival and Future.

Normally one would have expected fireless and pneumatic locomotives to have remained a quaint historical footnote, had it not been for the challenges of the Post-Carbon Age. As the real price of energy escalates, every extra conversion step (with its associated inefficiency losses) between the original source form of energy and the final useful work to be done, becomes increasingly costly and unattractive.

The Canadian engineer and railroad researcher Harry Valentine has written extensively about his musing for plausible future options. Typical pieces being (found duplicated on numerous websites) titled *Researching The Ultimate Fireless Steam Locomotive Parts1-4* [http://www.internationalsteam.co.uk/trains/newsteam/modern35.htm & modern38.htm, modern39.htm, modern48.htm] and other things like *Proposals for a Heat Accumulator Fireless Steam Engine* [http://www.internationalsteam.co.uk/trains/newsteam/modern49.htm as well as modern27, modern28]

Solar Thermal.

A good example was the proposal for a Solar Steam Train project, in Sacramento, California, U.S.A. Rather than squandering a seizable portion of the sun's radiated heat and light endeavouring to capture the energy directly as electricity via photovoltaic cells, they are instead building solar-thermal power facility. This allows the thermal storage of previously captured energy on-site for demand periods later when the sun is not shining. Such storage of large quantities of electricity being something much more difficult to accomplish, the stored heat can then be astutely converted to electricity as demands dictates.

Not falling for the habitual trap of unthinkingly converting all incoming solar energy straight to electricity is the most saleable output. This project has asked in what form could energy be most efficiently utilized for various task. For transport some quickly perceived that fireless steam engine could more directly make use of the stored heat, thus avoiding inefficiency losses of transforming the energy into intermediate modes before eventually facilitating the desired transportation task.

But even where the source is as electric power, thermal energy storage has an advantage over traditional electric-batteries. Railway applications will require many long deep discharge and recharge cycles. No existing electric-battery technologies come even close to the number of charging cycles possible with thermal-batteries.

The down-side of this arrangement is the severely limited range, nothing much beyond shutting / switching tasks, or amusement rides is feasible with just stored steam, or compressed air, as neither approach provides sufficient energy density (with plausible size storage containers) required for more demanding (harder / longer / heavier) tasks.

Cryogenic Liquid Gas.

A somewhat counter-intuitive alternative to the Steam-charged Fireless locomotive is one where a Cryogenic Liquid Gas is the applied storage medium. [http://en.wikipedia.org/wiki/Cryogenic_energy_storage]. As the concepts involved here are central to the functioning of many of 'Candidate Solution' in 'Part 6: Exploring Solution Spaces' [below] it is worth pausing here for a moment to tease out some of those details. Cryogenic is very very cold temperatures below −150 °C, 123 K or −238 °F. Temperatures so low that chemicals that normally exist (in our everyday experience) as gases have condensed into their liquid state. Containers of such cryogenic liquid gases maybe easier for the moment to think of as cold bottles of e*xtremely* compressed gas, thus Liquid Air is just *Extremely* Compressed Air! A transfer of energy is needed to occur for the phase change of any substance as they move from one physical state to the next; gas freezing to liquid, solid melting to liquid etc. Such as the addition of sufficient heat to water that the water boils to steam. Just as boiling water raises steam to drive a steam-engine, so heating say liquid air expands it to a high pressure air as used in a pneumatic locomotive [see 'Compressed Air' above] Experiments of using Liquid Nitrogen to power a automobiles have also been tried. [http://wayback.archive.org/web/20080309161030/http://www.aa.washington.edu/AERP/cryocar/Papers/sae98.pdf & http://en.wikipedia.org/wiki/Liquid_nitrogen_vehicle] The main disadvantage experienced being the need for a large heat-exchange, coincidentally exactly the same function that the boiler of a traditional steam-engine performs.

Electric Locomotives.

Mains-power.

Mains/grid electric-power is supplied from some remote traditional power-station, either by the familiar overhead catenary wires, or 'live third-rail' found on many urban underground mass-transit systems. It will be very advantageous in the Post-Carbon world that the supply of exactly the required amount of ready to use electric power to wheel traction-motors, is achievable without necessitating the extra weight penalty of lugging generating machinery with cumbersome low power-density fuel for the train. While as much as 85% of the power from the electric grid is applied to the rail as useful work, it must be remembered that the overall energy efficiency of such electric railway cannot be greater than the efficiency that the power-station generators are feeding the grid at!

Battery.

Modern electric-motors feed from batteries are the technology that in most cases superseded pneumatic fireless locomotives. While the technology is very useful in coal-mines and other industrial situations, the power demand in main-line railways operations a generally too high for long battery runs. Some operators do use batteries for short-hops over breaks of supply (such as old tunnels with insufficient clearance to run overhead lines through) between mains-powers legs of a journey   For readers who consider fuel-cells as some-sort of hydrogen battery see Hydrogen section [below].

Regenerative Braking.

With this technique the electric motor is harnessed as a brake. This is possible because electric generators and electric motors are substantially the same device. With a generator some power-source rapidly rotates 'turns of wire' through a magnetic field inducing an electric current in the output wires. The electric motor works the opposite way, in that current passing through motor's wiring affords it to do some work. Without feeding any power to the electric motor engage the wheels to mechanically turn the engine over. With the engine connected to some load (like a flat battery), turning the motor over will send a charge to the battery. As the 'Conservation of Energy' Law instructs, the energy charging the battery has to come from the mechanical work, in the case of braking a train the moment of the train is being absorbed, thus 'braking' / slowing the train.

Turbine Locomotives.

Steam Turbines.

mechanical transmission.

By 1920 steam turbines had all but monopolized stationary and maritime steam power. Turbines being of simpler design, easier to upkeep thence more reliable, with a much improved thermodynamic efficiency compared to the troublesome reciprocating masses of rods and pistons. Alas on the railways big steam turbines just refused to work as dreamed. Of the many different attempts at steam turbine locomotives only a few non-condensing standard pressure design could be called any sort of a success for the short lives they had. The Swedish TGOJ, which inspired the LMS Turbomotive 6202, lastly the Pennsylvania Railroad class S2 Turbine Loco number 6200.

The high efficiency of turbines only come at full load, when the steam turbine is venting into a near vacuum. The vagaries of a normal daily locomotive operations, with frequent stopping then starts frustrates any engineering requirement to guarantee continual working at full load. While more elegant in design, hot fast spinning steam turbines proved very fragile exposed to the large sudden jolts of railway work. Lastly you cannot run a turbine in reverse, so a separate dedicated turbine is needed just for reversing as ships (without variable pitch propellers) must have. If all that were not enough problems in the quest for improved efficiency many steam turbine experiments were also high pressure units with all the trouble canvassed above. [http://www.skyrocket.de/locomotive/turbines.htm]

electric transmission.

The idea of marring a steam-turbine with an electric generator to create a turbo-electric-steam-locomotive [TESL] is very seductive. Attractive from both a thermodynamic perspective as well as for the mechanical simplicity, many fans see the TESL as the ideal configuration for resurrection of steam-traction in the twenty first century. Even Ing. L.D.Porta with the ACE3000 project patent "US4425763" for the revolutionary compounded reciprocating steam locomotive, included a TESL configuration as an alternative layout. This was probably done on the basis of the North American Railroad industry's past enthusiasm for the TESL experiments; Union Pacific's two General Electric built 2+C-C+2 TESLs, Chesapeake and Ohio Railway's three 2-C1+2-C1-B coal-fired steam turbine-electric locomotives scrapped after only three years (primarily passed being repaired), Norfolk & Western Railway C+C-C+C Jawn Henry. The puzzling aspect of all this being that despite the many prototypes and unsuccessful experiments even today the TESL is still an extremely popular unfulfilled dream.

Oil Gas Turbines.

While Gas Turbines have a very attractive power-to-weight ratios, their primary disadvantage is that they have a lower thermal efficiency than diesels particularly when not fully loaded. Thus as oil prices rise gas turbines become rapidly less appealing as they become ever more uneconomical.

mechanical transmission.

Interesting things but no major success. [http://en.wikipedia.org/wiki/Gas_turbine_locomotive].

electric transmission.

The most successfully turbine locomotives where the Gas Turbines-Electric Locomotives (or GTEL) type. [http://en.wikipedia.org/wiki/Gas_turbine-electric_locomotive]
The stand-out examples being:

- **Swiss Federal Railway's, Am 4/6**, 1.6 MW Brown Boveri turbine a gas turbine-electric locomotive, delivered 1941/42, with the unusual wheel arrangement of 1A-Bo-A1.
- (French National Railways) **SNCF's Turbotrain** gas-turbine trains.
- (Canadian National Railways) **CN Turbos** operating on Toronto-Montreal route from 1968 and 1982.
- Starting in the 1950s Union Pacific had a lot of success with turbine-powered freight locomotives, like their 2nd generation **UP 62 Veranda.**

Coal Gas Turbines Electrics.

UP#8080 Union Pacific's home-built 18 axle three unit monster. Blowing the expanding gas from burning pulverized coal directly into the turbine was extremely powerful. Though the resulting high-speed fine-ash made Swiss-cheese of the turbine blades.
[http://en.wikipedia.org/wiki/Union_Pacific_GTELs]

Diesel Locomotives.

As historically subsidised by cheap mineral-oil derived diesel-fuel, the diesel locomotive despite some non-trivial short-comings was in its day the best fit for the job. 60% of the world railways currently are diesel operation (the remainder primarily being electric, with a slim fraction as the odd steam display or tourist line marking up the total).

Diesel locomotives unlike steam locomotives must have a transmission between the engine/motor and the wheels, for a diesel engine has to continue turning-over, running even when the locomotive is stationary. Thus all diesel locomotives should be considered as a hybrid of the diesel engine and what ever type of transmission is involved in getting the power to the rail. The three types diesels where previously outlined in the section 'Power + Transmission' [above] Diesel-mechanical locomotives, diesel-hydraulic locomotives and [DEL] diesel-electric locomotives . The generic popular ambiguous term "diesel loco" is more than likely actually a DEL.

Advantages.

- ✓ At ~30% a greater thermal efficiency than FGS steam trains on ~6%, or even ~15% of SGS trains. Thus in-terms of fuel energy potential diesels are more efficient than 1st and 2nd generation steam traction.
- ✓ Without the steam locomotive's clouds of smoke and steam there was a misplaced public perception that diesel were cleaner.
- ✓ Track infrastructure was spared the impost of steam's hammer-blows.
- ✓ Operating conditions were safer and more desirable for crew.
- ✓ Diesels with their ability to be topped-up via a fuel-tanker anywhere, did not demand the

extensive dedicated track-side support systems of water-tanks and coaling stops required for steam-train operations.

- ✓ Diesels could be coupled together so as to allow a single crew to drive multiple unit [MU] locomotives as if they where a single locomotive. MU operation effectively modularised the scheduling of hauling power among a railway's diesel fleet.
- ✓ The dieselisation of railways also cut crew requirements by 50-70%.
- ✓ Diesel engines did not require daily low-skilled manpower intensive maintenance, like de-ashing of the firebox etc. between every major outing.
- ✓ Historically railways' steam locomotive fleets consisted of a numerous specialised locomotives acquired for a variety particular roles. Freed of hours tied-up unavailable in the daily low-skilled steam-engine maintenance combined along with the extract flexibility of MU scheduling, railways upon swapping to full diesel operation found they were meeting all their commercial obligation with <u>only a third the number (diesels) locomotives</u> than historically demanded by steam operations.
- ✓ But the killer blow (as identified by W. Withuhn in his Trains Magazine [June 1974] article 'Did we scrap steam too soon?') was:- *"... the diesel's premier advantage is its ability to deliver close to its rated horsepower at almost any train speed, not just one"* Contrast this with the steam-engine which can only deliver their maximum horsepower at their maximum speed!

Short-comings.

- × At 30%~35% energy efficiency markedly lower than total/system energy efficiency for electric traction from hydro and other renewable power-generating capacity.
- × When diesels smoke is not deliberately cleaned (with regenerative particulate filters) the 'sub-10-micro' carbon black particles in diesel smoke actually posses a greater health risk than modern clean burning steam locomotives.
- × Diesel technology necessitates a lot higher precision with tolerances of 0.0025 mm (1/10,000th of an inch) compared to steam's 0.25 mm (1/100th of an inch). This dramatically increases the cost of new locomotive acquisition, despite diesel parts being more suitable for mass production.
- × As with all internal combustion [IC] engines the very design parameters of the diesel engine are inextricably circumscribed by the fuel they burn. Thus with regard to the composition, purity and mix of the fuel that may be used in a particular locomotive even small variations could render a diesel locomotive inoperable, posing serve risk to continuation of a diesel fleet during times of uncertain oil supplies. By stark contrast to this unnerving commercial predicament, external combustion engines such as steam-engines are readily adaptable (with minimal low-techs adjustment) to a vast array of (time-honoured along with non-expected) fuel options.
- × Diesel engines historically have had difficulty operating in the thin air of high altitudes such as in the Andes.
- × Diesel engines' constant power over their whole speed-range renders them effectively under-powered when the physics of high-speed (beyond 50km/h) necessitates more power for; accelerating to, or maintaining higher speeds, especially when faced by obstacle such as rising grades or loss of rail adhesion due to wet weather.

Hydrogen.

Hydrogen as Fuel [See Germinal Material Folio section 'Renewable & Alternative Energy'] highlights many of the distinctive problems Hydrogen entails. Hydrogen is near impossible to effectively transport by road transport (the Australian technology roadmap [below] limits modelling to a two hour round trip by road from production point to final retail outlet) or pipelines much beyond hundred miles (160.9 km) from the point of production. The standard solution is to just use electric power (delivered by grid) to crack water [H_2O] into hydrogen and oxygen where and when you need it. Unfortunately for arid Australia water is one thing often unattainable most of the time in many places across the continent Hydrogen also has a marked performance penalty (50-60% that of with diesel-fuel) it will be possible with minor modification (as for other gassy hydrocarbons) to directly fuel diesel engines from liquid hydrogen, thereby extending the life of the significant capital investment represented in existing diesel locomotive fleets globally. In such light I was bemused by Hydrogen rail-fans' jingo that *Hydrogen is to Diesel, what Diesel was to Steam*. Hydrogen is an 'Energy Transfer Medium' NOT a raw-fuel.

For the overly rosy Australian road-map shackled as it is to fossil fuels vision see [http://archive.coag.gov.au/reports/docs/hydrogen_technology_roadmap.pdf].

Fuel-cells (aka Hydrail).

Fuel-cells are a class of technologies that allow the transformation of the chemical energy of some input fuel to electricity without the historical losses of mechanical generation. [http://en.wikipedia.org/wiki/Fuel_cell] Here we be concentrating on the case of hydrogen gas into the fuel-cell for electricity out. In the rail-transport industry this hydrogen to electricity via fuel-cell is also called Hydrail. (As this highly popular path of fuel-cells are more akin to batteries than anything normally designated as an engine, I had initially considered including hydrogen fuel-cells trains under Electric for that reason.) Beyond a few Asian examples of road-buses fuel-cells being re-jigged as rail-motor-buses. There appears to be two (one in the USA and other in Europe) main government industry collations pushing fuel-cells for use on railways.

Yard Switcher.

The Fuelcell Propulsion Institute of Colorado USA, set-up in 1996 to promote industrial fuel-cell applications, with projects for the mining industry and railways. December 2008 they released a prototype fuelcell-hybrid switcher [http://www.fuelcellpropulsion.org/Rail/Websites/Switcher.htm] locomotive. From concept to roll-out the switcher was realized with a budget around US$4.45M.

EU Hydrogen Train Project.

An Europe wide consortium lead by Hydrogen Innovation and Research Centre in Denmark are aiming to run a hydrogen fuel-cell passenger train on the Vemb-Lemvig-Thyborøn (VLTJ) Railway. [http://www.greenhydrogen.dk/Default.aspx?ID=338&Print=tree&Printerfriendly=2] In 2003 estimating at least ten years work to develop a hydrogen locomotive by 2015-2025 (when oil may no-longer be viable for railways), €75,000 has so-far been earmarked for the 'Conceptual Phase' [see section 'Strategy:Phases' in Germinal Material Folio] of this project. By 2020 they are aiming to first retro-fit an existing two-car rail-bus set as hydrogen train test-rig. Next they will roll that experience into a HYSTRATOR train, {an operational re-gigging of an existing coach-production to a hydrogen train} then finally into a HYVATOR train {ground up purpose built} optimised hydrogen train. These trains will source their hydrogen via electrolysis with electricity from extensive wind-farms in that part of Scandinavia.

Obstacles found so far include:

- Life expectancy of fuel-cell has to be increased from the auto-manufactures 5,000 hours to at least 20,000 for railways.
- Fuel-cells and related components have to be enhanced so as to reliably cope with the higher

demands encountered in railway operations.

- By 2020 the consortium estimate that a fuel-cell hydrogen train will cost an extra 5%~15% than a comparable diesel outfit.

Hybrid Locomotives.

To address rising petrol prices (a symptom of Peak Oil) along with demands for better mileages (remedial action on air pollution and Greenhouse Gasses loads) the automotive industry has introduced hybrid vehicles featuring petrol + electric motor combinations for the family car. Likewise North American railroad locomotive builders have introduced diesel-engines + electric hybrid locomotives. Such diesel-engine component can be fuelled with diesel-oil, natural-gas, or some synthetic diesoline alternative, so at this moment these hybrid locomotives strictly speaking are not hydrogen fuelled engines. However as hydrogen gas will eventual fuel the vast majority of diesel engines these hybrid locomotives best sit here in this future technology survey.

Green Goats.

First diesel-electric yard-switcher (shunter) with a significant on-board bank of lead-acid batteries. Built by RailPower Technologies Corp. Quebec,Canada. they *claim 40-60% fuel savings, 80-90% reduction in NOx and particulate emissions*. Exciting a development that some may view this, with specified operating environment -30° ~ 40°C ambient temperature, Australia would be just too hot for year-round operation of the Green Goats.

General Electric.

May 2007 GE introduced their 4,400 hp Evolution Hybrid diesel-electric prototype that is capable of (regenerative braking) recycling thermal energy as stored power in innovative on-board batteries. GE are targeting the prototype to reduce fuel usage and emissions by 10% against most freight locomotives in use today.

This follows on from April 2006, out-of the USA DOE (Department of Energy) a peer review paper, Heavy Vehicle Systems Optimization: 21st. Century Locomotive Technology (locomotive system tasks) [http://www1.eere.energy.gov/vehiclesandfuels/pdfs/hvso_2006/22_salasoo.pdf].

Misjudgements.

For the sake of intellectual completeness a heading under which outliers maybe explored. For while the following options are (at a superficial level) technically feasible they do not stand up to broader more rigours investigation.

Atomic Locomotives.

The populist fantasy of the post-war optimism, atomic locomotives are not an option for serious consideration any longer. With the success of atomic powered submarines, it seemed logical that atomic-power would follow the same adoption path from submarines to railway locomotives taken half a century earlier by diesel engine technology. Initial ideas (evidence numerous patents) revolved around the atomic-steam engines with the atomic pile as a direct replacement of the traditional firebox.

The most detailed concept came from the University of Utah in 1954 as the X-12 project of Professor Lyle B. Borst and his team. Basically a diesel-electric configuration with the atomic reactor replacing the diesel generator as done in nuclear powered submarines. [http://brainmindinstrev.blogspot.com.au/2012/03/project-x-12-borsts-imaginary-nuclear.html & in German http://de.wikipedia.org/wiki/X-12_(Lokomotive)] The phenomenal weight of the designed reactor along with projected cost of the locomotive simply made the investigation commercial non-viable.

"straw-man" **Cryo-Hydrogen Reciprocating Compressing.**

Rather than using Liquid Nitrogen [as explored below in "Candidate Engine Configurations"] for the working-fluid use Liquid Hydrogen in the same fashion, while also burning some of the gaseous form as the heat-source fuel. An obvious concern with this option is the wisdom or safety of hydrogen as a working-fluid in cylinders. Additionally don't forget the many distinctive problems already noted under the heading 'Hydrogen as Fuel' [See Germinal Material Folio section 'Renewable & Alternative Energy']. The particular benefit in considering this 'straw-man' would be the total efficiency of such external combustion quasi-steam locomotive compared to the total efficiency (Hydrogen production source to power at the rails) of other hydrogen locomotive systems; fuel-cells with electric-motors, internal combustion (modified former diesel motors), or even hydrogen feed gas-turbine rigs. Hydrogen feed gas-turbine rigs may yet be a viable alternative in some operational contexts outside of Australia, but as such are beyond the scope of this investigation.

Part 6: Exploring Solution Spaces.

Before getting too far into our quest's solution space it is advisable to do a quick refresher of physic relevant constants and promises. Thus enamoured by an enhanced perspective it is intended to recap the links betwixt the challenge to the options at hand.

Thermodynamics and Kin.

Newton's laws of motion.

[http://en.wikipedia.org/wiki/Newton's_laws_of_motion & http://en.wikipedia.org/wiki/Classical_mechanics]

1# ***The velocity of a body remains constant unless the body is acted upon by an external force.*** In other-words ***Everybody persists in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed.***

2# ***The change of momentum of a body is proportional to the impulse impressed on the body, and happens along the straight line on which that impulse is impressed.***

3# ***To every action there is always an equal and opposite reaction: or the forces of two bodies on each other are always equal and are directed in opposite directions***

James Watt *(1736 – 1819).*

Prior to the end of the 18th century much of what passed for as engineering was more an ad-lib craft-work underpinned by a few rudimentary calculations. The professional discipline of Engineering along with functional steam-engines are children of the Industrial Revolution. The great Scottish inventor James Watt being regarded by many as the father of modern mechanical engineering. With universities then undertaking the education of engineers, the profession gradually began to annex methodologies with philosophies to ratchet-up the effectiveness of their prior rigour with materials. It is to these often over-looked thence forgotten theoretical under-pinnings we should now digress. {***Author's Apology:*** *The former placing of the section in the paper was somewhat problematic as the dry theoretical contents' relevance for here only became apparent as the paper's arguments progress. Any reader would more than likely choose to skip over most of that section, despite being cross referenced with increasing frequency as the paper develops from here-in, so for ease of reading the section was relegated to the Appendixes at the end of the document* } [See **Part 2: Issues of Philosophy and Design.** in Germinal Material Folio]

Laws of Thermodynamics.

As the long traditional detailed expression of the Laws are on the web, [http://en.wikipedia.org/wiki/Laws_of_thermodynamics] for now I believe simpler characterisation [http://en.wikipedia.org/wiki/Ginsberg's_Theorem] is more useful for the current purposes. So for a more casual expression of the four laws of thermodynamics we can say:

0# **You must play the game**; (restatement of Zeroth Law of Thermodynamics)
[http://en.wikipedia.org/wiki/Zeroth_Law_of_Thermodynamics]

1# **You cannot win**; (restatement of First law of thermodynamics)
[http://en.wikipedia.org/wiki/First_law_of_thermodynamics]

Energy can be neither created nor destroyed. It can only change forms.

All claims to any sort of *Perpetual Motion Machines* are struck-out by the Laws of Thermodynamics most stumbling at the First Law demand for *conservation of energy* over the total system.

2# **You cannot break even**; (restatement of Second law of thermodynamics) [http://en.wikipedia.org/wiki/Second_law_of_thermodynamics]

3# **You will always lose**. (restatement of Third law of thermodynamics)
[http://en.wikipedia.org/wiki/Third_law_of_thermodynamics]

Myths About thence Delusions Thereof.

The 1st Law of Thermodynamics is also formally stated as ***"For a thermodynamic cycle the net heat supplied to the system equals the net work done by the system"***. Often misinterpreted as (the demonstratively false belief) that no more work is obtainable from a valid thermodynamic device than that exclusively provided by the fuel consumed. A solar hot-water heater does not require any pre-processed / pre-packaged fuel supply to heat the water, rather the hot-water is obtained by capturing the sun's natural bounty.

Efficiency and the Carnot Cycle.

[http://en.wikipedia.org/wiki/Carnot_cycle & http://en.wikipedia.org/wiki/Carnot_heat_engine] The 19th century Nicolas Léonard Sadi Carnot a French military engineer conceived the first successful theoretical understanding of the physics of the heat-engine. Beside the Carnot Cycle as method of analysing any device's use of some energy input in the quest of useful work, he also facilitated the comparisons of how "efficient" a device was in converting the energy supplied into desired work. Which neatly brings us to one of the most misrepresented or distorted attributes of transportation (and electric power generation) "engine efficiency" (the other offender being deliberate under-reporting of humanity's contribution of greenhouse gas to the atmosphere). Advertisers and the media love to trumpet the efficiency of one design versus another, so that efficiency equates to what is the most meritorious option. When comparing like with like, say rescue helicopters, then low fuel consumption of the most efficient engine is indeed worth noting. But nowadays, even as ever more so as abundant supplies of sweet crude oil diminish while carbon pollution cost weigh heavier by the day, it is foolishly naive to quarantine energy efficiency issues to the last device on some long supply chain. The ecological soundness or otherwise of over-night recharged electric cars is a well known case in point. It is not so much how energy efficient the electric car is, but rather how environmental sound and energy efficient is the household's electricity power supply (a renewable power generator? or a dirty old coal fired power station?) with which the car was recharged? [http://www.theage.com.au/victoria/electric-cars-make-more-emissions-unless-greenpowered-20121203-2ar3x.html] {A clear explanations with worked examples can be found in '*Efficiency of Energy Conversion*' *Chapter4* of the on-line-text-book posted by Professor Ljubisa R. Radovic, at Pennsylvania State College of Earth and Mineral Sciences [http://www.ems.psu.edu/~radovic/matsc101.html]}. Additional to the compounding inefficiency ~ efficiency of the whole fuel supply chain, care needs to be taken to include all auxiliaries mandatory to the engines operation. The 'Green Goats' [above] overheating problem (in warm climates) is readily redressed by always-on air-conditioning of the massive battery banks, but the significant energy cost of that strategy must be included in any locomotive energy efficiency comparisons. So to accurately assess the comparative merits of different transport modes, or vehicle options, the old *Efficiency of Energy* debate needs recasting in terms of the Carbon Release Imposts per useful output (expressed in some standard units). In the absence that such a Carbon Release Imposts is defined, a crude workaround would be to {discount /} ignore the Energy Efficiency of any preceding links (of the long supply chain) that are free of Carbon pollution. Applying that to our rail transport question when comparing an oil burning diesel train to an electric train supplied exclusively from a renewable energy source, while the diesel's energy efficiency is to be determined over the whole supply chain, for the carbon imposts free electric train only the last step need be considered. Unfortunately that simplistic approach soon fails when the comparison complexity increases. Take for example the decision of how to bring sugar cane from t he fields to the mill. The most ecological sound and practical solution would be a 3 Cylinder Porta-type Compound 0-6-2t steam-engine burning cane waste as per the Prometheus Project LVM800 [above], even if compared against trucks or trains burning hydrogen liberated from water by electrolysis feed with electricity generated from renewable sources. That is because while the last step for the hydrogen engine is a fuel-cell with a high energy efficiency that ignores the all the practical complication of using hydrogen as an energy transfer medium (and economic cost) versus the negative opportunity cost of using what is a carbon neutral waste product into the historical validated technology of small steam-engines.

Recapping Post Carbon Rail Transport Challenges.

- "*The whole 'switching to alternatives' position becomes more bizarre when it is realized there are no alternatives that match oil's unique mix of appeals. All the so-called 'alternate energy' solutions are niche answers for a small handful (from a mind-boggling large collection) of technical problems to be faced in a post-carbon world.*" 'Response Deficit' [above] Whatever new fuel or engine technologies maybe seen as possible solutions they are not going to available when need if the years of prototyping and development are not completed before hand, in other-words without investment in an economic era where the "*immediate*" justification does not exist (because oil supply troubles are yet to happen) there will not be sufficient time left for developing answers when the crisis arrives. Even if some miracle fuel is concocted along with successfully prototyping of required vehicle technology, it will be a next-to-useless mirage if the required infrastructure has not also been rolled-out so that it is there when society needs it.
- The decline of cheap oil supplies will trigger a modal shift (in reverse of the last half century's trend) from roads back to rail. "*From a time when double digit horsepower rating where impressive, railways where ever about maximising business results ... Steel wheels onto steel rails have a very low rolling resistance thence friction penalty. With minimal grip between vehicles and rail-surface inclines by necessity have been engineered long and shallow, thus requiring minimal energy to continue travelling along."* 'Railways aka Railroads.' [above] With need again for rail access where road-transport previously sufficed low volume branch-lines and tramways will again be a component for any land transport strategy.
- Where demand / traffic volumes are sufficient to underpin the additional catenary supply infrastructure electric traction will be the first choice for railways throughout this new century.
- Very High Speed passenger service will continue to follow current best practice as exclusively dedicated electric traction corridors. 'Fast Trains' [above]
- Hybrid locomotives, battery and hydrogen fuel-cell models are already starting to fill short-distance light duty niches in the cooler wetter climes of Europe and North America, [See 'Hydrogen' above] but it is unlikely that this technology will be robust enough for more demanding and heavier operational requirements.
- In the cooler wetter climes of Eurasia and North America (with the required carbon-offsets) SGS and TGS (that is designs incorporating; Modern / Advanced Steam Technologies [http://en.wikipedia.org/wiki/Advanced_steam_technology & http://5at.co.uk/index.php/modern-steam-2/principles-of-modern-steam.html]) locomotives will return to fill the gap left by liquid hydrocarbons demise. In the favourable niches, such as the Tran-Siberian Railway I am hard-pressed to see what else they would be able to practically deploy once the Post-Carbon era gets well under-way. Same goes for great stretches of Canada or parts of South America and Africa.
- Beside the work for the 5AT [above] There is 'Roger Waller' [above] at DLM ('Dampflokomotiv und Maschinenfabrik' = Steam Locomotive and Machine Works) with 2nd generation steam locomotives for sale in the company catalogue. [http://www.dlm-ag.ch/en/locomotives]. Also further proposal from L.D. Potra's [see below]
- 'Pyrolysis Oil aka Bio-oil' [above] is a carbon-neutral liquid fuel readily derived from organic wastes. Utterly unsuitable for internal combustion engines (diesel locomotives) having an

octane rating of practically zero, it is a sustainable fuel source for external combustion as in 2nd and 3rd Generation steam locomotives.

- As good as the last few points answers are for cold wet climes there currently exists no parallel answers for hot dry climes such as Australia, central Asian deserts, South Africa, Bolivia etc. That operational need is the identified gap this research paper will now attempt to go someway towards find one or more suitable remedies for.

Candidate Solution Mandatory Features /Requirements.

Carbon Neutral.

After facility and plant construction, all proposed option are at least Carbon Neutral, if not Zero Carbon at operational level.

Powered from Renewable Source.

Utilizing biomass waste (such as sewage etc.) the Pyrolysis Oil in this context is tagged as a renewable resource. All the other option use renewable energy sources via the associated power / recharge stations.

Avoids use of Mineral Resources in Scarce Supply.

Such as the rare metal catalysts required by hydrogen fuel-cells. Or unethical supplies such as Blood Tantalum.

Employs All Applicable Mechanical and Thermal Advances for Modern Steam.

See discussion 'Mechanical and Thermal Advances for Modern Steam' [below].

No or Low Water Consumption.

Higher efficiency steam mechanics with steam re-compression technology (such as used by the Red Devil and Ted Pritchard's motors) should mean all steam-locomotives envisaged here will be substantially more water efficient than previous steam locomotives used in Australia. Whereas the Cryogenic Liquid Nitrogen options uses no water.

Mechanical and Thermal Advances for Modern Steam

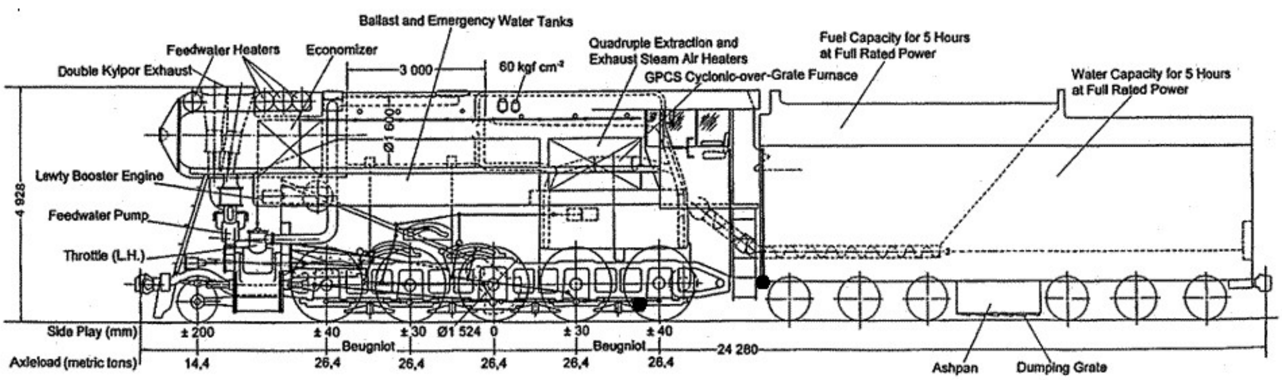
As romantic an object of nostalgia as steam locomotives from the end of the nineteenth century to the 1920's may be, that **Generation Zero** [classification per 'Ing. L.D.Porta' above] were woefully inefficient in consumption of both fuel and water. George Stephenson's (1825/ two hundred year old) classical format was puffing nearly 90% of the fuels energy potential up the chimney as waste heat. Picturesque as that maybe the results was a draw-bar thermal efficiency of barely 7%! No surprise then that nowadays the public image of steam locomotive is smoky inefficiency relics of a bygone age.

Spurred by the obvious deficiency of **Generation Zero Steam** the twentieth century was witness to many insightful refinements and bold innovations characteristic of this FGS (1st Generation Steam). Unfortunately these developments historically were deployed in an ad-hoc, piecemeal fashion. The **SGS** and **TGS** (2nd & 3rd Generation Steam) are those designs reaping the accumulative rewards of all the advances integrated together, draw-bar thermal efficiency up to 25%.

Nowadays with harsh commercial conditions combined with serious environmental threats [See Germinal Material Folio 'Part 1: Challenges thence Ramifications.'] it would be foolhardy to once again populate any railway with 1st Generation Steam locomotives. Ignoring the occasional "*historical replica*" it is therefore fairly certain that any new "*steam*" locomotives built will deploy all the applicable 2nd and 3rd Generation Steam refinements in their design, construction thence operational careers.

In wetter climates (than Australia's harsh interior) where (with the prerequisite carbon offset) energy dense fuel (rock oil or coal) is still affordable and available then 3rd generation steam locomotive

such as L.D. Porta described at the 14th Pan American Railway Congress at Lima (Peru, November 1978) could be soon be common. For further information see the web-page "*Third Generation Steam for North America. A 6000hp Triple Expansion Compound 2-10-0*" .
[http://www.martynbane.co.uk/modernsteam/ldp/usa1978/usa1978.html]



[©Estate of L.D.Porta]

In addition to previously highlighted; roller bearings, Porta's adhesion aid for driving wheel, etc. there are a lot other innovations such as; Scullin Double Disc Wheel Centre, Nathan type of Fusible Drop Plug, Franklin Radial Tender Buffer. (Good lists with links of such can be found on web.) [http://www.martynbane.co.uk/modernsteam/tech/mstech.htm] All that aside when looking at building a locomotive there have been major improvements in the properties of materials, thence choices flowing from advance in physics, chemistry and material science over recent decades.

Questing Thermal Efficiency Gains.

While identifying the reasons for the poor thermodynamic performance of 1st generation steam engines where fairly obvious, discovery of satisfactory solutions has proven far more elusive. In a strict technical sense "engine" is not a readily interchangeable alternative word for "locomotive". For the "engine" is that part of the locomotive that extract useful work from the energy laden working-fluid feed to the "engine" from the boiler. So on a traditional steam locomotive the "engine" is the sum of: (one on each side) a pair of piston and cylinders, their valves and valve gear with the reciprocating motion. Alternatively if piston and cylinders are replaced by a turbine, then the engine could be the turbine plus associated controls along with whatever direct transmission gets the power to the wheels.

Thus in the quest for thermal efficiency the design then control of the piston and cylinders became the focus of enquiry. The longer opportunity the working-fluid has for release of the energy entrusted to it, the more energy efficient the engine performance is. If the steam is only partly expanded before being dumped to the atmosphere via the chimney, one is squandering a significant chunk of the energy the furnace and boiler have laboured to imbue the working-fluid with. Entangled there-in is a second complication, for as the working-fluid's expansion (inside the cylinder) does useful work the kinetic energy of the growing volume of vapour falls. A relentless cycle of heating (the cylinder casing along with) values and ports up as hot working-fluid enters the cylinder, followed quickly by the energy depleted vapours escaping cooling that which moments before was just heated is from a thermodynamic perspective a rather dumb design. Coming from different aspects (maximising expansion or concerns about temperature variation) of the challenge the two historical responses where typically implemented in isolation of each other.

Compounding.

Is the technique of letting the steam partially expand in one cylinder, before expelling it to one or more additional cylinders to complete the full expansion. [http://en.wikipedia.org/wiki/Compound_engine & http://en.wikipedia.org/wiki/Compound_locomotive] Invented by the Cornish engineer **Arthur Woolf** (1766 - 1837) refined to near perfection for locomotives by 'André Chapelon (1892~1978)' [above]. The downside of compounding was that it need more skilled train drivers to fully reap a given locomotive's designed potential.

Uniflow Cylinder.

[http://en.wikipedia.org/wiki/Uniflow_steam_engine] While thermodynamically alluring with dedicated ports for steam entry only at each end a cylinder and steam always exiting the cylinder by larger central portal exposed as the piston head passes by. Unfortunately metal expands when it is heated so in operation the ends swell while the centre contracts leading to a lack of steam tightness or jammed pistons or both. But the results can be magnificent when crafted in the hands of master like 'Ing. L.D.Porta (1922~2003)' and 'Edward Pritchard (1930~2007)' [above]

Boiler Architectures {Conventional Water to Steam}.

Traditional (Heat) Fire Tube Boiler.

Historically for railway locomotives the fire tube boiler was the most practical approach in getting the working-fluid from the liquid phase to the gaseous phase. A fire tube boiler is a large cylindrical tank with an array of opened end tubes passing all the way through from back to front of the tank. In operation the tank is filled with water (the working-fluid), then the heat from the fire in the grate along with the smoke are drawn via the draft through the tubes then out the chimney. In this way the thermal energy released by the (external) combustion of the fuel on the grate, is absorbed by the working-fluid through the walls of the fire tubes as the hot gasses are passing by. While simple and practical for the era of the design's conception it was far from an ideal heat transfer mechanism. Beyond the many innovations of Porta et al, the theoretical further improvement in heat transfer rates that maybe gained by reducing the diameters of the fire tubes is negated by the accompanying reduction in flue draft, in turn smothering the fire thence the amount of heat obtainable! Added to that would be a marked increase in the difficulty of cleaning the fire tubes of tar and soot deposits.
High-pressure 300 psi and above locomotive designs favoured Water Tube Boilers [following]. As historically (that is to say with technology of the day, prior 1950s) 300psi was/is about the upper safe operating limit for a fire-tube boiler in a steam locomotive.

Traditional (Working-Fluid) Water Tube Boiler.

The alternate water tubes approach is more common in shipping where accommodating a tall boiler is of little concern, especially given this marine variant superior heat transfer performance. Sir Nigel Gresley's secretive “Hush Hush” high pressure compound locomotive never lived up to the builder's hopes. [See above 'Sir Nigel Gresley's Hush Hush: Mainline Water Tube Boiler Express.'] But Sentinel Waggon Work's success with small water tubes boilers and other developers' deployment of "steam generators" (a more specialized water-tube configuration) speak to the Working-fluid Tube Boiler being the most promising avenue to explore for cryogenic boilers.

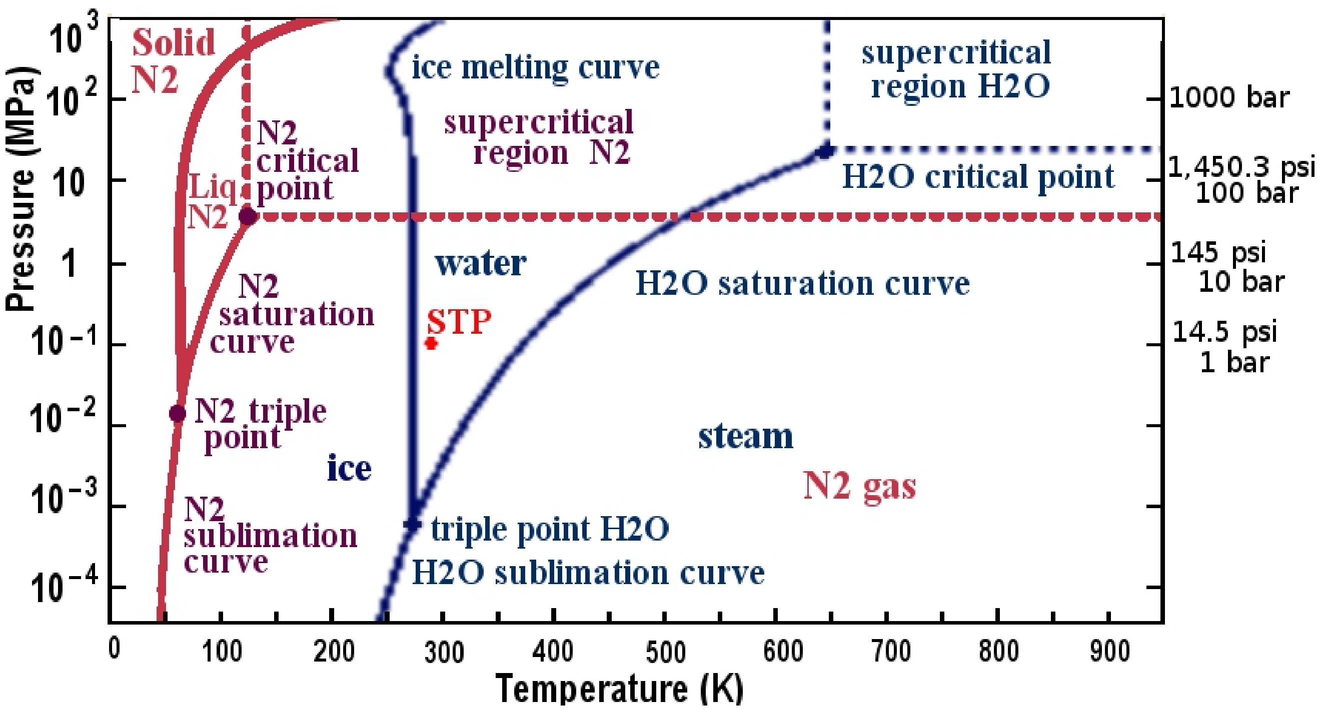
Advantages in Cryogenic Liquids as Working-Fluid

Greater thermodynamic design potential closer to ambient environment.

Kinetic Energy Reclamation.

As discussed in ‘Regenerative Braking.’ [above] for ‘Electric Locomotives.’ some electric motors, when acting as generator maybe used for brakes on electric passenger trains. Unfortunately for freight trains along with our cryo-liquid locomotives the options are a tad more convoluted.
A critical aspect to reclamation of energy during braking operations is that it must be reclaimed

from ALL surfaces deployed to slow the train. In the case of electric traction on railways (as well as for electric road vehicles) each electric motor coupled to their respective wheel(s) becomes a brake as soon as the motor is switched; from the power supply, to some electrical load (any system hungry for electrical power like a battery requiring recharge). But the symmetry of the same unit(s) being totally responsible for accelerating then decelerating the whole vehicle is rarely to be encountered in non-electric railway transportation (the obvious exception being rail-cars/buses). Ignoring electric trains (along with diesel-electric locomotives feeding trailing electric motor-cars) all other trains have a locomotive which provides all the power to accelerate train, but the brakes on each of the hauled carriages (along with the brakes on the locomotive) must be engaged to safely bring the train to a halt.
While not unheard of the situation of the lone locomotive pushing a long train from behind is only orthodox procedure for short distances, or in an emergency. {Historically in the steam-era "helper" locomotives where sometimes assigned to aid trains with a little extra push up steep banks or inclines.} Conventionally the locomotive is at the head the train, pulling the carriages following. So hauling the train the locomotive out-front will supply all the power needed to accelerate the mass of the whole train to whatever momentum it achieves. But while the brakes on the locomotive will stop the locomotive's movement, the following carriages are still obliged to obey the laws of physics [see above 'Newton's laws of motion'].
Proportional to each carriage's individual mass as a fraction of the mass of the entire train each following carriage has accumulated their own share of the train's momentum. Thus when the locomotive applies its' own brakes the remaining non-braked carriages will endeavour to continue racing forward per each carriages individual momentum. If such a scenario where to play out from a very slow speed on straight level track then with luck the couplings and buffers should absorb much of the momentum. The remaining kinetic energy is dissipated as; the supposed stationary locomotive receiving a shove from behind, the accompanying cacophony of screeches and bangs. Failing to apply what brakes a carriage has, or worse still carriages with-out functioning brakes will inevitably result in derailment (if not catastrophe) once; the train's speed increases, the track curves, or an incline is encountered.



Braking Waste Heat Reclamation.

As the cryogenic liquid is markedly colder than the ambient environment let alone the temperature of waste-heat from hot loaded brakes, usable work effecting energy typical squandered as waste heat could be scrubbed from brakes to raise the cryogenic working-fluid to pressure for powering of the engine. How that maybe achieved is a question for later investigation.

Re-compression to Reclaim Energy.

To the extent that there is sufficient previously expanded Nitrogen immediately available within the appropriate locomotives systems, re-compression could be used reclaim energy normally squandered in any braking operation of the locomotive. Recalling Newtonian physics whatever amount of energy is expended acceleration some mass to a particular velocity, then the same amount of energy must be expended / liberated to bring that mass to a stop.

Contamination of Working-Fluid via Reuse.

One bug-bear of recycling and reuse of water and steam in traditional steam-engines, is the concentrating of various contaminates present in the system such as lubricants. While this snag has been effectively solved for steam operations, it may yet prove insurmountable in the case of cryogenic Working-Fluids, thus limiting designs to single pass configurations.

Working-fluid Trade-offs.

Terminology.

For clarity words newly crafted or re-purposed (from another language or tradition) in italics.

<table>
<tr><th>Functionality</th><th>Steam</th><th>Fireless steam</th><th>Pneumatic</th><th>Cryogenic Vapour</th></tr>
<tr><td>Exhaust Collection Site</td><td>Smoke-box</td><td colspan="2">Not applicable</td><td>Fume Cabinet</td></tr>
<tr><td>Exhaust Energy Recapture</td><td>Water Preheater</td><td>-</td><td>Re-heater</td><td>Swirl</td></tr>
<tr><td>Engine + Drive</td><td colspan="4">Cylinders, Pistons, Valves & Valve-gear</td></tr>
<tr><td>Pressure Routing Store</td><td>Steam-chest</td><td>Steam-dome</td><td rowspan="2">Reservoir</td><td>Vapour-chest</td></tr>
<tr><td>Pressure Accumulation</td><td>Steam-dome</td><td>Reservoir</td><td rowspan="2">Kettle</td></tr>
<tr><td>Pressure Source</td><td>Boiler</td><td colspan="2">EXTERNAL</td></tr>
<tr><td>Heat-exchanges</td><td>Tubes &
Super-heater</td><td>-</td><td>Re-heater</td><td rowspan="2">Heat-exchanges,
Tubes, Radiators &
Collectors</td></tr>
<tr><td>Heating Site</td><td>Firebox</td><td colspan="2" rowspan="5">Not applicable</td></tr>
<tr><td>Thermal Energy Vector(s)</td><td>Burning Fuel</td><td>SOLAR + Reclaimed,
&/or
Chemical reactions.</td></tr>
<tr><td>Heating Fuel Storage</td><td>Bunker/Tender</td><td>Hotbox</td></tr>
<tr><td>Working-fluid Storage</td><td>Gin / Tender</td><td>Cryogin</td></tr>
<tr><td>Woking-fluid Recovery</td><td>Steam-condenser</td><td>Regenerative Braking</td></tr>
</table>

<u>Challenges of Working with Cryogenic Liquid Gas.</u>

Many of the proposals necessitate utilizing cryogenic working-fluids at high pressures, this raises a collection of issues that will need to be addressed during future investigation.

Material Concerns.

Lowering the operational temperature window below that required by steam technology reduces the risks of material failure associated with high temperatures; bending, stretching, fatigue, softening, with parts melting or welding in extreme cases. Cryogenics however have their own set of challenges; brittleness of many materials at low temperatures would exclude usage on railways notorious for regular jolts of intense longitudinal shocks. The magnitude and frequency of shocks experienced in regular railway (or other usage scenarios like mining) service needs to be quantified and qualified so that material operating parameters maybe specified with allowances included for relevant safety margins and engineering tolerance. While the usual railway engineer choices of steel perform poorly in cryogenic situations, stainless-steel, aluminium, nickel, copper along with many alloys of those metals are sufficient for the task of future locomotives. Reactivity of different materials at low/cryogenic temperatures is another troublesome issue, especially in the case of Hydrogen [http://en.wikipedia.org/wiki/Hydrogen_embrittlement].

Atmospheric Moisture Condensation and Icing.

The constituent parts of the Earth's blanket of air are normally only of concern to atmospheric scientist. When designing for devices operating at cryogenic temperatures any moisture content of the air becomes a critical issue. Most people only become concerned about the moisture content of the air when it is absent, extremely dry air parching the breather. Normally the moisture content of air will range from a not insignificant level to very high. Moisture that will rapidly condense / precipitate, yea even instantly freeze when passing over sufficient cold surfaces. Such below (water) freezing surfaces could be abundantly profuse in the internals of any devices operating at cryogenic temperatures. While the draining of water condensation from moist air is more a nuisance issue, any occurrence of icing is a major concern to the structural integrity of the design, along with the thermodynamic efficiency of the engine. The structural challenge of water freezing arising from the forces entailed in the volume expansion as water moves from a liquid to solid state. Thus surfaces in risk of temperatures below 1°C should all be located away from ambient air flows. If passing air is unavoidable such subfreezing points should be situated on flat or lazy-turning convex surfaces so that any ice or water can freely fall off the locomotive without risking hazardous accumulations. .

Optimal Efficacy Point.

How extensive an issues the 'Material Concerns' [immediately above] could be, is a flexible quantity. For as while storing a gas in a liquid state guarantees the highest attainable density for transportation it does not necessarily follow that such low temperatures are the ideal operating setting for the working-fluid's (which includes the gaseous state of same) peak effectiveness. As previously stated in 'High Pressure Steam' [section above]:-

The theoretical thermal efficiency of any heat engine is directly beholden to differences between the minimum and maximum temperatures of the engines inputs and outputs.

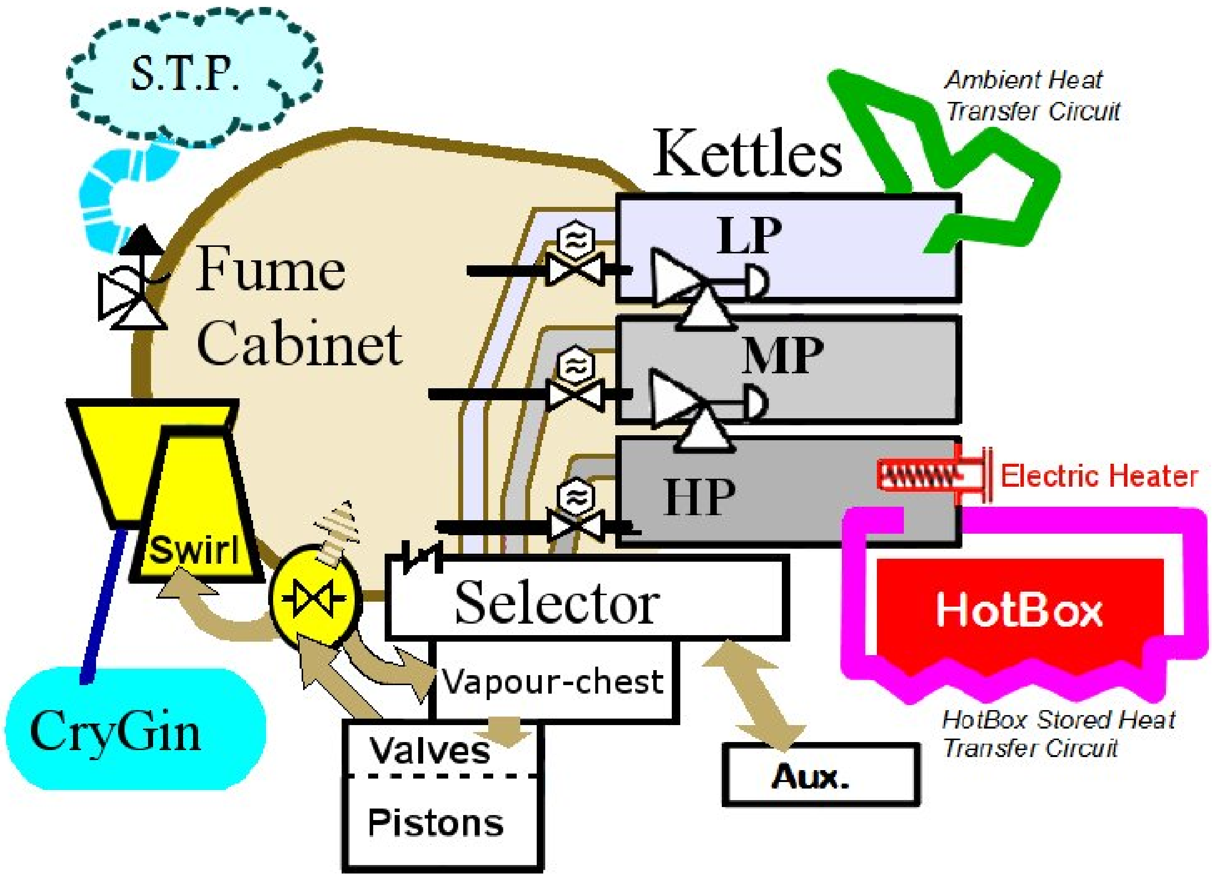
So a question for early resolution is if there maybe some point warmer than -195.79°C (77.36 K, -320.33°F, the Boiling Point of Liquid Nitrogen @ 1 atm.) where the reduced material complexity (flowing from not having to be engineered for such extreme cold) will justify some loss of potential theoretical thermal efficiency in deploying Nitrogen as the working-fluid. Alternatively (personally I believe there maybe) is there some design configuration whereby the working-fluid could be rapidly raised from the extreme cold of the liquid states without necessitating the bulk of the locomotive's components having to deal with such extreme cold operating temperatures.

Boiler as Pressure Reserve.

While moving along to cryogenic liquid/gas boilers sidesteps many of the scaling and corrosion concerns associated with water as a working-fluid, the lower temperatures coupled with higher expansion rates raise other less familiar challenges. Conventional boilers (especially fire tube and to a lesser degree water tube) have one significant attribute that must not be overlooked. Unlike (following) instantaneous techniques for transforming the working-fluid to a gaseous state, once laboriously charged or brought up-to operating temperature (by extension operating pressure also) traditional boilers provide a pressure reserve that can be drawn on whenever the temporary demand of the cylinders exceeds the fluctuating input of the stoker. For options reliant on the cryogenic working-fluid being heated by ambient temperature air this reserve or head of pressure provided by the boiler may yet prove critical to any success for said options.

Cryogenic Boiling Other Concerns.

How much ambient energy can be taken up by the cryogenic working-fluid being heated by ambient temperature air flowing (or blown) through or around the tubes, so then deployed as useful work by-way of the rapid expansion the heat starved working-fluid is the critical hurdle for such locomotive strategies. While the external surfaces of the locomotive offer many opportunities to absorb ambient heat energy, in designing such specialised treatments care must be exercised not to adversely impact the wind / air drag of the vehicles body.



<u>Cryogenic Swirls and Kettles Options.</u>

Initially I conceived of these two classes of components as *Expanders* and *Reservoirs.* However an unacceptable level of ambiguity from semantic cross-talk soon arose. '*Expander*' is too easily misconstrued as a functional enhancements of the traditional turbo-expander the very thing not included in this class of devices. Likewise the term '*Reservoir*' is misleading as it only relates to one aspect (an optional one at that) of what is a more complex entity. For while *Reservoir* captures the storage attributes of this class (such as '*tank*' would), it recalls nothing of heating potential envisaged for this class of devices.

Apparatus for Boiling Liquid Cryo-Gasses.

[Technical considerations detailed in Confidential Folio section 'Cryogenic Boiler Things'.]

Air Heat Tube Boiler or Air Fluid Tube Boiler

As direct analogues of traditional steam engines both these configurations have value for exploration in thought experiments. However for the reasons explained in **Atmospheric Moisture**

Condensation and Icing section [above] such an approach would be very challenging to implement if not utterly impractical. [Solution Confidential Folio section 'Staggered Air Boiler']

Instantaneous Liquid to Gas Approaches

- Continuous Flash Boiler (aka steam generator) ,
- Discrete Flash Boiler (pulsed injector)
- Direct to Cylinder Liquid Injectors,
- Turbo-Expander

Swirls.

To-date I have identified three possible technical lineages that such Swirls may follow:-

1. **Blasted.**
2. **Impeller.**
3. **Cyclonic.**

Kettles.

Reservoirs with Matrix Heat Exchanges

Similar in concept to conventional heat-exchangers of the Spiral or Shell-and-tube style, but with insulated holding reservoirs inter-connected via heat-exchanges rather than adjacent boiler tubing.

1. **Staggered Air Boiler**
    - Pea-pod
    - Babushka Dolls
    - Nautilus shell fractional segment.
    - Flower-head
2. **Fractal Membrane**

Vapour-chest.

With the evolution of the fume-cabinet the vapour-chest has become an optional component for some designs consistent with the operational requirements, size and complexity of a particular cryogenic vapour engine. For small engines where space is paramount to dispense with any vapour-chest in favour of the directly supplying the cylinders from the selector appears perfectly logical. However in the case of larger locomotives the insertion of a vapour-chest betwixt the cylinder ports and the selector overhead may prove to be an unavoidable consideration.

Gates, Valves et-al.

In the context of machinery being defined in these documents, “Gates” should be understood as a cluster at least one valve with either; some control device such as an actuator, or additional valves. Akin to functioning of logic gates in computer hardware, all the gates referred to in these writing do perform or are necessary for logic function activity within the machine, that is to say the locomotive.

Valves of Cylinders.

Similar in operation to traditional steam or pneumatic piston engines the locomotives “valve-gear” will facilitate the orderly sequential opening and closing of the cylinders’ valves directing the vaporized working-fluid into the cylinders then in turn exhaust of the processed vapours [fumes] escaping from those same cylinders. Most latter-day traditional steam locomotives configuration employed either poppet or piston forms of vales for this function. While the combination of rotating cams coupled with poppet valves provides a highly flexible arrangement of cut-off timings, the superior ‘steam-tightness’ of piston valves (as demonstrated by many of the previously cited heroic engineers advanced steam design) in all likelihood would be the better option for working with the smaller (by comparison to water) N_2 molecules at possibly higher pressures than historical steam locomotives.

Rep Gate.

While traditional steam locomotives where coasting, drifting and running down inclines there is no reason in physics to squander precious steam reservoirs pushing idle pistons back and forth in the cylinders. To prevent the idle cylinders from functioning like brakes, specialized valves such as “Trofimov valves” (that re-circulate exhaust steam back to input ports) or “sniffing valves” (that by allowing air to enter the steam power circuit so avoiding any vacuum arising in the cylinders to behave as a break on the engines momentum.

As the envisaged cryogenic vapour engine does not require, nor allow the interaction, nor intake of ambient atmosphere at any point. It is effectively a closed circulation system, venting depleted working gas only on an as-needs protocol. Thus sniffing valves are definitely not an option, while the complexity a Trofimov valve can be side-stepped. A simple selectable diversion gate (butterfly valve) inserted in the cylinders’ output-manifold so redirecting the cylinder exhaust away from the swirl directly to the fume cabinet (whence the cylinder input is being taken from) accomplishes the circulator flow that of Trofimov valve’s complexity provides in steam-engines.

The Selector.

Functionally the “Selector” is to the operation of the envisaged cryogenic vapour engine akin to what a “router” is to any communications network, or a "mixing-desk" is to a recording studio / or sound-system. As initially conceived this component was indeed a router bi-directionally switching cylinder input sources and exhaust destinations. But such a router concept rapidly degenerated into a plumber’s nightmare when Porta’s edict of internal streamlining was considered.

The ‘router concept’ was broken down into two separate independent components; the “Selector” switching (engine) cylinder intake sources, while the “Fume-wall” automatically open and closed the most appropriate destination kettle for a given swirl exhaust pressure. This solution to the internal streamlining dilemma delivered a simplification bonus in regards to both operational demands and mechanical architectural configuration.

NOTE: Likewise where any auxiliary cannot be directly be supplied from a particular (or dedicated) kettle it will either have access to the output of a dedicated selector for it alone, or a feed from the generalised selector feeding any remaining auxiliaries.

Mechanical speaking the selector is a bank of remotely controlled gates. Each “Selector Gate” consisting of an actuator with associated control valve, for reason of strength and compactness most probable types of valves will be; rotator-valves, or poppet-valves.

Selector Operational Decision Tree.

	Expanding	**Free & Idle**	**Compressing**	**Re-jigging**
@ Cylinder Ports				
Input OPEN	0%	0%	0 % .	0%
Input CLOSE	5% ~ 75%	50%	100 % .	5% ~ 75%
Exhaust OPEN	5% ~ 75%	50%	0% ~ 45%	0% ~ 95%
Exhaust CLOSE	100%	100%	45% ~ 99%	5% ~ 100%
Rep Gate destinations with ...				
Vapour-chest	Swirl Injector	Vapour-chest	*Optionally* On / Off	Swirl Injector
NO vapour-chest	Swirl Injector	Fume-wall	*Optionally* On / Off	Swirl Injector
CAPTURE @ Fume-wall Gates				
to Kettles	Automatic	Closed	Automatic	Automatic
RELEASE by Selector from ...				
	Kettles	Vapour-chest or Fume Cabinet	***Kettles*** or Fume Cabinet	***Kettles*** or Fume Cabinet

The Fume-wall.

For the cryogenic vapour locomotive the name fume-cabinet was lifted from a machine-translation of *"boîte à fume"* (the French terminology for smokebox). Following traditional steam locomotive layout at the back of the smokebox the front of a fire-tube boiler is designated as the tubeplate. Analogously in the cryogenic vapour layout, at the back of the fume-cabinet, the fume-wall is situated in the same structural location (that the tubeplate is found in the traditional steam layout). But unlike the single vertical surface of the traditional tubeplate, the fume-wall (most likely) will be the bumpy sum of the contours of a stack of small diameter pressure-vessel. Each pressure vessel has an outlet pipe running to the selectors' inputs and a single access gate allowing the ingress of the desired pressured fumes into the kettle behind from the common supply space of the fume-cabinet. Each fume-wall is an interlinked combination of control valves that only open to allow fumes in the desired pressure range to enter the kettle if those in the kettle happen at that instance to be of a lower (in range) pressure. Diaphragm-vales being the mostly likely valve type for this functionality.

Candidate Engine Configurations

<u>Water > Steam.</u>

+ Pyrolysis Oil.

A 2nd generation steam engine burning oil derived from carbon neutral recycled organic-waste. This option is only a minuscule step from current best practice. Outside of the 5AT originals design constraint built as they were on the current operational practices with high energy density fuels, it still is possible to fire such 2nd generation steam locomotive with Pyrolysis Oil. However a lower density fuel adversely impacts the locomotive's range and /or payload as Brian McCammon kindly detailed in correspondence:-

> "*The 5AT tender is designed to have a fuel tank capacity of 7 tonnes of petrodiesel fuel. This has a density of 0.865 so that the fuel tank will have a volume of 8.4 cubic metres. This volume of petrodiesel fuel will give a fuel range under representative mainline service*

conditions of 940 km. The water tank will have a volume of 46.3 cubic metres giving a water range under the same conditions of 620 km.

Once you start reducing the energy density of the fuel you are compromising the range. The tender cannot be made any larger because then it will not fit on the modern turntables in the UK and Europe. Extra water and fuel could be carried on trailing wagons but then the payload of the train has to be reduced so it may not be economic to run a train with reduced load. Wood pellets have about the same energy density as pyrolysis oil, about 18 MJ/kg, and I worked out the ranges using a tender of the same length. This came out at a fuel range of 620 km but the water range dropped to 508 km. ..."

As well while yet to be trialled not a new idea see *"Proposals for a Modern Steam Locomotive Design"* [http://www.internationalsteam.co.uk/trains/newsteam/modern46.htm] this candidate does provide opportunity for one significant thermodynamic modification to be explored. Rather than squandering precious heat up a chimney to draw draft from burning typical solid fuels, the Pyrolysis Oil fire maybe fan-forced from the cab end.

+ Thermal Batteries.

Some of the on-line storage options being implemented for renewable energy power stations (solar-thermal particularly) are various techniques for stockpiling a store of heat while the sun-shines. Then after sunset those same reserves can be drawn-upon to raise steam to spin turbines connected to electric generators. These same thermal-storage techniques can be incorporated in movable containers that could be deployed as giant thermal batteries “HotBoxes” for quickly switching in and out of locomotives, much like loading a standard shipping-container onto a flat-car. This container strategy is detailed in 'Rapid Provisioning' [above], then implications explored further in' Appendix 1: Pencil Chimeras' under the heading 'Real-world Benchmarks' [below].

Ambient Air + Electrical Batteries + Cryogenic Liquid.

While a simple leap of imagination from the old steam locomotive templates it poses the most tricky of engineering problems. Use an electric-fan to force ambient temperature air through; a fire-tube boiler (as in a 1st generation steam-engine), or a heat-exchange (per a traditional Fireless Pneumatic triple-expansion Locomotive). A gas (air, CO_2, Nitrogen etc.) is condensed at low temperatures to a cryogenic liquid. Functionally the cryogenic liquid substitutes for the previous working-fluid; of compressed air in Pneumatic Loco case, or for water in the steam-engine's case. The major difficulty with such a system is during high humidity or wet weather, any moisture (water) freezing would at least compromise the engine efficiency. But beside a predicable breakdown could trigger catastrophic rupturing of the (high) pressure cryogenic liquid systems.

Cryogenic Liquid Nitrogen Gas.

As all the following options (in part of their operations at least) necessitate vaporising the cryogenic liquid for use at higher temperatures thence pressures, Nitrogen being the less reactive candidate was initially the only gas considered.

+ Pyrolysis Oil

Substituting liquid nitrogen (instead of water) as the working-fluid it is similar to ***Water > Steam + Pyrolysis Oil*** [as above].

+ Thermal Batteries

Like ***Water > Steam + Thermal Batteries*** [as above] but substituting liquid nitrogen instead of water. The most significant advantage of combining Thermal Batteries with Liquid Nitrogen is that one effectively doubles the amount of energy available which maybe deployed in powering the locomotive.

+ Thermal Batteries & Heat Transfer Mediums.

Much the same as previous option ***Cryogenic Liquid Nitrogen Gas + Thermal Batteries*** [immediately above] but the Thermal Batteries have been augmented with the deployment of a circulating high temperature fluid such as liquid sodium, or some mix of salts, being employed to move heat from the battery into the boiler. This is the same sort arrangement used in geothermal power stations. A more flexible design as it separates the need for co-location, the thermal battery's stored energy such that it can also be directly drained off by the working-fluid, instead the continually circulating hot liquid charge acts as a movable intermediary alternately depleted by the working-fluid in one spot, before being recharged in another places by passing through the thermal battery's stored energy then going around again and again. This strategy can also be effectively extended to movement of ambient temperature energy in another circuit.

Compound Reciprocating, Compressing Cryogenic Schematic.

The schematic [a few pages above] is an early (and as such by no measure debugged) sketch roughing out how the various warming vectors for a cryogenic working-fluid could interface. This plausible configuration features three isolated pressure zone, boiler compartments interrelated to various in-put thence altered out-put pressure of working-fluid vapours as they work throughout the compound piston regime.

Mountain Leaper Specialist Configurations.

Local historical impetus.

The urban sprawl of Sydney and beyond, South to Wollongong and North to the Hunter is (for the most part) serviced by standard gauge railway network feed by a 1500 V DC overhead catenary supply. Primarily to haul coal to the coast from the mines around Bowenfels in 1950s electrification was extended over the Blue Mountains to the mines. As one set of mines were worked out and others came on-stream diesel locos took-over hauling the coal trains beyond Lithgow where the electrification now terminates. Then in 1996 with the break-up of the NSW Government Railways as separate corporations, access to the catenary electricity infrastructure imposed charges higher than the diesel fuel cost for the same amount of work. That combined with the nuances of locomotive changes lead to (then more economical) diesel units running the full trips, while the electric locomotives where decommissioned. But in a Post-Carbon age all this logic will flip once again. However in this particular case, (especially with a predicable loss of coal train traffic) demand will be too patchy (intermittent) to justify the extension of electrification as-is beyond Lithgow. Then of my initial solutions I originally said "*Lastly was a couple of misbegotten matches to very specific local requirements.* "

Catenary Electricity Feed Locomotives

With the flips to common sense that come with the Post-Carbon age transport challenges, extension of railway electrification will at first seem like a perfect fit for renewable electricity generation alternatives. Unfortunately the business case for electric traction is not such a simple decision. The cost of the electric catenary infrastructure establishment then on going maintenance and operation are not insubstantial. Without frequent regular train operations to amortise the cost over dreams of the electric supply are just not sustainable.

So for the cases such as Sydney to Bathurst over the Blue Mountains the most promising option will be specialised dual-power locomotives, that while primarily electric-units can undertake pre-determined forays beyond the end of the electrification supply. Development of such dual-power locomotives combined with strategically located short spurts of catenary infrastructure, would finally free railway schedulers from the logistic quandary of excessive (to normal running) muscle required to get trains up steep grades. In the bygone days of steam operations such extra muscle was supplied by "helper engines" permanent stationed and crewed at the bottom of such troublesome grades (obviously an expensive answer in terms of manpower and plant sitting idle between their helpful jaunts). The multi-unit control of diesel locomotive allowed for a slightly better (if still wastefully costly) answer to annoying geographical humps. Railway operators now address the need for extra muscle by including additional 'slave' locomotive units in such challenged trains make-up. While this addresses the steam era man-power wastage the operator now has to lug the dead-weight of the idle slave for the remainder of the entire journey. But with dual-power locomotives the extra power needed could be drawn down from the catenary infrastructure to feed existing traction motors temporarily boosting the locomotives muscle up the incline.

As I laboured to point out in the earlier section 'Turbines Locomotives' [above] I have serious reservations about the general wisdom of turbines in railway locomotives, as most previous experiments have failed. What success there where seemed to be limited to close matching of turbine capacity to specialized tasks, fast Swiss and French express trains, or the extra heavy Southern Pacific freight trains (in the USA). Just the same two roles that need to be address in time over the Great Dividing range; heavy freight-trains, along with express passenger trains to Bathurst 84 kilometres past Lithgow. So here are few more (restrictive and specialized) locomotive options proposal targets.

Electric Boosted SGS.

During World War 2 when the supply of coal was unreliable, so the Swiss Federal Railways augmented some of their regular 0-6-0 steam tank-engines to be able to also operate from the plentiful electric supply where it was available.
http://www.douglas-self.com/MUSEUM/LOCOLOCO/swisselec/swisselc.htm Now as to if (in a post-carbon world) it could makes more sense to feed steam from a external combustion boiler directly to pistons driving the wheels, or instead add more complexity via a turbine plus generator to electric traction motor drive chain? is for now an unresolved possibility. Actual case by case operational context (class and mix of traffic) along with logistic geography (the terrain with grades of track in the gaps between electrified infrastructure) will undoubtedly dictate the individual conclusion of such debates. That said this Swiss oddity of an electric fired steam locomotive may yet inspire a practical solution to one of the many troublesome niches that will come to dog post-carbon transport planners.

Grid and Battery Cryo-Turbine Electric Locos.

As a variation on the theme, follow the trail blazed by the GE Evolution Hybrid diesel-electric prototype [above] that is capable of recycling energy as stored power in innovative on-board batteries, then drawing from those same batteries to drive conventional bogey mounted electric traction motors. Then instead of an oil burning diesel, swap in cryogenic liquid gas, heated via ambient temperature transfer unit and electrical radiators to rapidly expanded highly compressed gas before blowing into a typical turbine generator combo. Augment all that with a direct catenary pick-up from any overhead supply where it exists, to both drive the locomotive and / or top-up the batteries as needed.

Pyrolysis Oil + Grid and Battery Cryo-Turbine Electric Locos.

The same concept as ***Grid and Battery Cryo-Turbine Electric Locos*** [immediately above] with the addition of a Pyrolysis Oil supply to further heat the expanding gas from the cryogenic liquid during passage to the turbine.

Locomotive Proposals' Technical Ramifications.

Relative Merits of Candidate Solutions

While the various locomotive options have been outlined in a sequence consistent with the unfolding of the documents concerns, such ordering bears no reflection as to the practicality, desirability, feasibility, usefulness of all the competing locomotive development paths. The following orderings being just a few of the different ranking criteria that will need to be considered after more in-depth analysis of the various technological details. NOTE: The follow orderings are only for a subset of *Candidate Solutions*. For the sake of simplicity specialized solution such as the 'Mountain Leaper' [above], along with minor variations in configuration have been omitted from the following orderings. Taken in concert these orderings provide informative predictors as to the timeliness in the candidate selection for a particular operational task.

Envisaged Degree of Technical Difficulty

This ordering is a good indicator of how long (relative to the others) each of the candidate technologies may take to mature from the lab to commercial deployment. In other words without prudent preparatory research (before Peak-Oil & Climate Change's inevitable impacts) this ordering points to the likelihood that a candidate technology could / would be deployed at short notice.

Ordered: Easiest to Most Challenging:-

1. Water > Steam + Pyrolysis Oil.
1. Cryogenic Liquid Nitrogen Gas + High Pressure Hot Fluid.
2. Ambient Air + Electrical Batteries + Cryogenic Liquid.
3. Water > Steam + Thermal Batteries.
4. Cryogenic Liquid Nitrogen Gas + Pyrolysis Oil.
5. Cryogenic Liquid Nitrogen Gas + Thermal Batteries & High Pressure Hot Fluids.
6. Cryogenic Liquid Nitrogen Gas + Thermal Batteries.
7. Reciprocating, Compressing Cryo-Hydrogen.

Envisaged Maximum Range

Remembering that a Post-Carbon will-be characterised by fuels of much lower energy density and operational utility than has been enjoyed in the recent past. The major impact of low density fuels on rail transportation will be shorter distance between fuel-stops, or the necessity to carry larger quantities of fuel will reduce the payload capacity available for the journey.

***Ordered: Longest to Shortest Range* (**Ignoring for the moment extensions gained from Reclamation Braking**):-**

1. Cryogenic Liquid Nitrogen Gas + Pyrolysis Oil.
1. Reciprocating, Compressing Cryo-Hydrogen.
2. Water > Steam + Pyrolysis Oil.
3. Cryogenic Liquid Nitrogen Gas + Thermal Batteries & Heat Transfer Mediums.
4. Cryogenic Liquid Nitrogen Gas + Thermal Batteries.
5. Water > Steam + Thermal Batteries.
6. Cryogenic Liquid Nitrogen Gas + High Pressure Hot Fluid.
7. Ambient Air + Electrical Batteries + Cryogenic Liquid.

Potential Flexibility of Option

Ordered: Potentially Most Adaptable to Least Adaptable:-

1. Cryogenic Liquid Nitrogen Gas + Thermal Batteries & Heat Transfer Mediums.
1. Cryogenic Liquid Nitrogen Gas + Thermal Batteries.
2. Water > Steam + Pyrolysis Oil.
3. Cryogenic Liquid Nitrogen Gas + Pyrolysis Oil.
4. Water > Steam + Thermal Batteries.
5. Cryogenic Liquid Nitrogen Gas + High Pressure Hot Fluid.
6. Reciprocating, Compressing Cryo-Hydrogen.
7. Ambient Air + Electrical Batteries + Cryogenic Liquid.

Envisaged Operational Complexity

Ordered: Simplest to Difficult:-

1. Water > Steam + Pyrolysis Oil
1. Cryogenic Liquid Nitrogen Gas + High Pressure Hot Fluid.

2. Ambient Air + Electrical Batteries + Cryogenic Liquid.
3. Cryogenic Liquid Nitrogen Gas + Pyrolysis Oil
4. Water > Steam + Thermal Batteries
5. Cryogenic Liquid Nitrogen Gas + Thermal Batteries
6. Cryogenic Liquid Nitrogen Gas + Thermal Batteries and Heat Transfer Mediums.
7. Reciprocating, Compressing Cryo-Hydrogen.

Refuelling from Renewable Energy

Locations

With the obvious exception of the Water > Steam + Pyrolysis Oil case [following] all the other proposed options require one or more Renewable Energy Refuelling Stations. Despite this project being originally inspired by the once proposed Sacramento Solar Steam Train project the solution-space is not restricted in relevance to only those facilities employing Solar-Thermal technologies [http://en.wikipedia.org/wiki/Concentrating_solar_power]. While the Solar-Thermal configuration is the most geographically unrestricted along with direct engineering vector for the capture thermal energy it is not the only one. Locations where the hot-rock resources exist, Geothermal power is another direct thermal resource.

Besides the thermal sourced options, all renewable energy electricity mains-grid power stations that have a need to store power will more than likely use some form of heat storage repository, thus making them suitable to recharge thermal-batteries or heat hot-liquid charges. Conversely all renewable power sources can also be augmented with liquid Nitrogen condensing facilities as a negative-heat storage repository. [See headings 'Solar Thermal' & 'Cryogenic Liquid Gas' above] It is conceivable that a locomotive could take on both liquid Nitrogen, along with a hot-liquid charge or thermal battery replacement at a single recharge station. However excluding operations that commence and terminate at the same depot single station recharge is not necessary, especially given schedule load and local topography both mediums may not be deplete at the same rate, as was the historical case of steam-traction's coaling stations and water-towers, taking on more water about twice as often as re-coaling was needed.

Rapid Provisioning

Energy dense liquid hydrocarbons like 42.3 MJ/L of Diesel fuel is nearly double 25.3 MJ/L Propane / LPG, far ahead all other more space hungry alternatives. Both 200 bar (202.65 atm., 20.53 MPa) compressed natural gas, or liquid hydrogen having about 10 MJ/L, needing four times more space than same amount of energy in diesel. But as the investigation of this theme began with a handful of energy densities ten times more disheartening, being typically less than 1 MJ/L for compressed air and competing electrical battery technologies, tedious frequent refilling was an obvious show stopper. My grandson's battery toy-car was the inspiration that what was required was some sort of high-speed automated battery exchange that would impede a train's trip no-longer than a typical passenger stop (under a minute or so). Think big; recharge brick / block akin to the size of a shipping container, automatically swapped on then off the locomotive by (laser guided, overhead gantry crane) robots. [See "Mechanics of Rapid Provisioning" section in Confidential Technical Detail Folio]

Cryogins and Hotboxes.

This strategy of standard swappable recharge modules akin to shipping containers, also delivers advantages in the modularisation of both locomotive production as well as the refuelling points design and construction. (For clarity) I intend to call the standardized HOT recharge bricks “Hotboxes” to distinguish them from other more tightly coupled thermal battery configurations.

Likewise let us name the standardized COLD recharge bricks “Cryogins” being short for Cryogenic Liquefied Working-Fluid Gins (recalling that a “Gin” is an additional water tender as historically used in this country. [see below 'Traditional Tender Locos + or −.']).

The cryogin concept also neatly avoids some of the main safety and engineering drawbacks to using cryogenic liquid gases as transport working-fluids or fuels. Being able to swap the cryogin in and out, without any need for manual handling to refill tanks, sidesteps freezing and asphyxiation risk normal posed for refuelling staff.

Module Sizing.

Originally [see 'Real-world Benchmarks' below] standard inter-modal freight shipping containers, where envisaged as the template for this role. But preliminary sketching of possible locomotive side elevation quick highlighted a clash between deck height over driving wheels dimension versus low deck height needed to accommodate boxy containers with clearance stipulated in Australian Railway Loading Gauges. 20 foot inter-modal shipping containers or standard RACE containers dimension are not ideal. Some other swappable recharge module standard, with a top semi-circle end-on view so as to better fit the loading gauge silhouette will need to be developed. Ideal whatever recharge module standard is defined should fit within the dimension limits of one of the existing variations of inter-modal shipping container standards. That is to say (maybe with additional packing, spacing scaffolding) the standard recharge module could meet, then be handled as if it was any other normal shipping container in the context of regular shipping (say from point of manufacture to power-station prior to priming charge / provision investment loading.

Fundamental Considerations; Operational and Cultural.

Before delving too deeply into the relative merits of the competing locomotive alternatives, there remains a few pragmatic determinants that need to be raised for discussion.

The Locomotive's Job Requirements.

While this seems rather obvious, there are two interlocking hidden questions.
1# Is the locomotive for ; passenger, freight, mixed or other services? mainline or branch line work?
2# In the future what and how will rail transportation be used?

Determination of Leading Dimensions.

In E.A. Phillipson seminal tome "*Steam Locomotive Design: Data and Formulæ*" first published 1936 {reprinted by Camden Miniature Steam Services © 2004}, Phillipson lists then examines the many (often overlooked) determining factors impinging on the design of a new locomotive. Such as :- Climatic Conditions, Water supply and quality, Fuel, Civil Engineering Limitations, Rail Gauge, Loading Gauge, Gradients and Curves, Permanent Way, Mechanical Engineering Restriction, Conditions imposed by Traffic Department, Legal Stipulation, Wheel Adhesion, Resistances, Engine Performance Expectation. Phillipson then explores these ramifications in his Chapter IV. *Cardinal Points of Design*.

Part 7: Scoping Proposals.

Locomotive Design Considerations.

Anticipated Factors Impinging on Candidate Locomotives.

- Climatic Conditions:
- Water supply and quality:
- Fuel:
- Civil Engineering Limitations:
- Rail Gauge:
- Loading Gauge:
- Gradients and Curves:
- Permanent Way:
- Mechanical Engineering Restriction:
- Conditions imposed by Traffic Department:
- Legal Stipulation:
- Wheel Adhesion:
- Resistances:
- Engine Performance Expectation:
- Tenders, Tanks, Articulates, Power-Units and Trailers:

The designers of steam-locomotives were faced with a non-trivial choice between the pros and cons of tank-engines versus those of locomotives pulling a tender. This choice is somewhat spurious because excluding optimisation for direction of operation the total weight of engine plus the load or unloaded tender, is the same as an engine converted to a tank engine load or unloaded (for the same quantity of provisions). Common to all non-grid mains-electric locomotives is the need to carry a supply of consumable material to fuel the engine, steam-locomotives must additionally carry a large quantity of bulky weighty water from which to raise steam as the engines working-fluid. Originally as steam-engines burnt cumbersome solid fuels like wood, coal or coke, necessitating that the fuel supply had to be stored as close as possible to the firebox-door, to facilitate the fireman's efficient stoking of the grate. So from the earliest day of steam-traction there arose the convention of attaching an open truck immediately behind the locomotive to carry supplies of water and fuel, which in time evolved into a specialised tender.

Traditional Tender Locos + or −.

As the majority of tender locomotives where unable to run tender first at speed (over 45mph ~ 72.4 kph), the integrated design of the steam-locomotive with a trailing tenders inflicted a single direction running practices upon railways, necessitating the network complications of wyes or turntables, with which to rotate troublesome only forward running direction tendered steam-locomotives. Due to the diminishing quantities of fuel and water consumed over a journey, the tender's weight accordingly decreases. Because the tender's dimensions are not restricted to those of the engine-frame (as with tank-engines) the tender can be optimally sized to operational needs. One such operational need specific to this paper's concerns is the inclusion of steam to water re-condensing units on tenders intend for operations in dry climates. Also some trains pulled extra water in water gins specialized water only tenders. The NSWGR [New South Wales Government Railways (Australia)] bogie water gins carried 7,000 gallon (UK) / 31,822 litres, while the smaller four wheel water-gins 2,000 ga (UK) / 9,092 litres.

Cab-Forward Oil Burning Steamers.

In the design of some steam-engines when solid coal was replaced by liquid oil as the fuel, there no-longer was a need for the cabin to be at the engine's rear-end adjacent to the trailing tender. The most famous examples being the big Southern Pacific Railroad AC-12 class of 4-8-8-2 cab-forward locomotives. Cab-forwards where so arranged to overcome operational challenges like smoke entering the cabin when running in long tunnels. Despite liquid fuel freeing designers from the need to place the cab adjacent to the tender, inexplicably (to the best of my knowledge) the builders of the day failed to exploit this new freedom with any configurations that facilitated the tender being attached to either end of engine, so by enabling bi-directional running of such enhanced tendered locomotives, with the engine continuing to pull the tender irrespective of which direction the engine was nominally facing!

Tank Locos + or −.

Meanwhile tank locomotives with their water and fuel storage included on the same frame as the boiler and rest of the engine easily undertook bi-directional operation. Unfortunately incorporating fuel bunkers along with water tanks on the engine-frame's already limited space restricts the supply capacity of same (water and fuel). The unfixed shifting weight of input-stores (water and fuel) on the engine-frame increases the tank-locomotive's instability. Conversely including the weight of consumable stores on the engine-frame (even if ever-so temporarily) also increases (often small) tank-engines tractive effort (by comparison to what it would be for the equivalent tender configuration). But as tank-engines get larger such increased weight often leads to problems with network axle loading limits.

Steam-motor power bogies under Boxy Carriage-work.

Easily the most infamous example being the (the British) Southern Railway's 0-6-0 + 0-6-0 "**Leader**" class of O.V.S. Bulleid [see section Oliver Vaughan Snell Bulleid (1882 ~ 1970) above]. While Bulleid did later perfected his concept as a peat-burning prototype in Ireland, the unsuccessful SR Leader where scrapped before ever entering regular service. History attests that Beyer-Garratts 'Articulated Steam Locomotives' [see below] such as the (New South Wales, Government Railways in Australia) N.S.W.G.R. AD60s proved to be a more elegant, easier to maintain solution for a similar functional niche to that Oliver Bulleid's Leader had aspired to fill.

Articulated Steam Locomotives.

Many of the limitations of tender or tank locomotives have be partially addressed among various articulated engine configurations such as the common:- Mallet, Meyer, Garratt, Fairlie and Union-Garratt configurations, along with the less-common French inspired:- Golwé and Du Bousquet configurations.

Power-Units and Trailers.

With electric traction, petrol and diesel motors a configuration that has proved very popular for passenger transportation, particularly in the context of mass-transport systems, is the stringing together carriage-sets. Each 'carriage-set' consist of an omnibus like power-unit paired with (typically one) non-powered trailer. However for non-urban operation power-car specifications trend to larger more powerful units with reduced passenger seating capacity offset by more trailer-cars per power-unit. The culmination of this trend being the common push-pull long-distance passenger express configuration. Two streamlined dedicated locomotives are placed facing outwards at either end of the short line of passenger carriages (some of which may feature powered bogies). This pair of power-units are so inter-linked to respond as if a single larger conventional locomotive, but without the operational difficulties of having to rotate a single direction locomotive or re-sort train carriages at the end of one journey before undertaking the next journey from the terminus.

Appendix 1: Pencil Chimeras.

To tease out some more issues as well as gaining a sense of the relative potential performance of the various proffered locomotive options a cluster of little thought experiments. But a few assumptions are needed first so that any comparison is as free as possible from the inevitable complications of variations in design due to optimising for a selected combination of working-fluid with heating medium. However as the assumptions and input data are refined the results in due process will become more accurate, till the point when they maybe directly compared with currently operating locomotive types.

Self-limiting Calculation.

Fortunately some of the comparative figures we may wish to determine, require only minimal data. Assuming linear relationship, where only one item / variable is different between contending proposed locomotives with all else (other involved aspects) being equivalent, then the relativity of said variable will have a proportional direct effect on the results being compared. See Operational Range [Below].

Real-world Benchmarks.

So that our assumption are not totally divorced from reality we need some historical examples that can act starting points or templates that the various chimera's may be abstracted from. The ideal situation would have been to discover the same class of steam locomotive implemented as a four cylinder compound tendered steam engine as well as in a Garratt or Fairlie or such tank layout. Unsurprisingly no such animal could be found. However a small collection of roughly equivalent era locomotives (around World War II) do give us something to feasibly extrapolate from. Included are New South Wales Government Railways (NSWGR), Pennsylvania Railroad (PRR), French National Railway (SNCF) and Belgium National Railway (SNCB) examples:-

PLM / C.F.Algeria 231-132BT
(French) **Société Franco-Belge** built {**4-6-2 + 2-6-4**} streamlined Beyer-Garratt used extensively in Algeria.

NSWGR AC38
Early{4-6-4 + 4-6-4} concept for streamlined express Garratt based on the 231-132BT.

NSWGR C38
The{**4-6-2**} express tendered locomotive that actually went into service on NSWGR. Most famously the streamlined 3801. (Only the first five delivered where streamlined, the rest being more traditionally utilitarian).

NSWGR AD60
The only Beyer-Garratt {**4-8-4+4-8-4**}deployed on the NSWGR network (as well as being built under licence by same).

PRR T-1
Pennsylvania Railroad's {**4-4-4-4**} compound streamlined express tendered locomotives. A simply gigantic steam engine at 15ft 10 high, then 122ft 9¾ long!

SNCB 12
The most successful **4-4-2** steam locomotive the Belgium National Railway's class 12.

While gathering real-world data the other item that we must consider following the modularity of the design philosophy is the dimensions along with limits of the standard inter-modal freight shipping containers. It should be noted from the table [immediately following] that while the sizes of the containers may vary the maximum gross mass remains static at 66,139 lb or 30,400 kg. The net load of the containers actually decreasing while the size of the container increases as the physically larger container weighs more empty than any smaller kin.

		20′ container	40′ container
		metric	metric
external dimensions	**length**	6.096 m	12.192 m
	width	2.438 m	2.438 m
	height	2.591 m	2.591 m
interior dimensions	**length**	5.758 m	12.032 m
	width	2.352 m	2.352 m
	height	2.385 m	2.385 m
volume		33.1 m³	67.5 m³
maximum gross mass		30,400 kg	30,400 kg
empty weight		2,200 kg	3,800 kg
net load		28,200 kg	26,600 kg

[*from* http://en.wikipedia.org/wiki/Intermodal_freight_shipping_container]

Weights as **tonne-force**, **metric ton-force**, **megagram-force**, or **megapond** (**Mp**) are 1000 kilograms-force

Locomotive various Data Source		**231-132BT C.F.Algerian**	**AD60 NSWGR**	**C38 NSWGR**	**Class T1 PRR**	**Class 12 SNCB**
First Bldg. Year		1934	1952	1943	1942	1939
Gauge		Standard	Standard	Standard	Standard	Standard
	mm	1435	1435	1435	1435	1435
	ft	4 8½”	4 8½”	4 8½”	4 8½”	4 8½”
Wheel Arrangement		4-6-2+2-6-4	4-8-4+4-8-4	4-6-2	4-4-4-4	4-4-2
		(2 C1)(1 C2) h4t	(2 D2)(2 D2) h4t	2 C1 h2	2 BB2 h4	2 B1 h2
Length (over all)	mm	29,432	33,121	23,279	37,430	21,190
(over all)	ft. in.	96 ft. 6⅞ in.	108 ft. 8 in.	76 ft. 4½ in.	122 ft 9¾ in	69 ft. 6¼ in.
Tender	mm	*not applicable for Garratts*			4,400	3,000
(less tender)	mm				*33,030*	*18,190*
Height					15' 10 (4.83 m)	
Max Boiler Diameter	ft. in.	6' 10 3/4	(2209 mm) 7' 3			
Leading Wheel Ø	mm	1,000	914		914	900
	in.		36		36	
Driving Wheel Ø	mm	1,800	1,397	1,753	2,032	2,100
	in.	71	55	69	80	82¾
Trailing Wheel Ø	mm	1200	914		1,067	1,262
	in.		36		42	
Cylinder Ø	mm	490	489	546	476	480
	in.	19¼	19.25	21½	18.75	18⅞
Piston Stroke	mm	660	660	660	660	720
Bore	in.	26	26	26	26	28⅜
Max. Speed (Design)	km/h				193	140
Max.(achieved) Speed	km/h	131			209	165
Max. Axle Loading	Mp	18,4	16 / 18	23,2	32.5 t	23,6
	Tons	18.2 (18.5 tonnes)	16		71,680 lb	
Weight on drivers	Mp	(111.0 tonnes)	128	68.5 t.	127.0 t	45.8 t.
(Adhesive Weight)	lb.	241000		150000	279910	101000
Weight (total)	Mp	216 Mp	269	205 t.	432.7 t.	148
	lb.	47500		451000	954000	
when in steam	tons			201		
when in steam	kg			204000		
Working order (Tons)		212.6 (216.0tonnes)	260		Loco. weight	
sans tender	t.	*not applicable for Garratts*			227.8	89.5
sans tender	lb.				502,200	188,500
Tender weight	kg			14,224		
Empty: t		*not applicable for Garratts*			89.5	
Empty: lb					197,400	
Loaded: t					200.7	
Loaded: lb					442,500	
Tender type					180 P 84	

Tabled continued on next page......

Locomotive various Data Source		231-132BT C.F.Algerian	AD60 NSWGR	C38 NSWGR	Class T1 PRR	Class 12 SNCB
Fuel		Coal	Coal	Coal	Coal	Coal
	lb	24,000	(14224 kg)	31,500	85,200	17,500
	t	(11 tonnes)10.8	14 tons	14.5	38.6	8
Water	m^3	30	(42075 lt)	37	72.5	24
	imp gal	6,600	9,350	8,100	16,000	5,800
	gal US	7,900		9,700	19,200	6,300
Boiler Pressure	MPa	20 hpz/bar	1.378	1.69	2.07	
kp/cm^2 kg/cm^2		20		17.25	21.2	18
	psi	284	200	245	300	256
Grate Area	m^2	5.4	5.9	4.4	8.5	3.7
	sq ft	58.1	63.5	47	92	39.8
Heat'n surface:	sq ft	220	238		490	
Firebox	m2		21.89		45.5	
Heating Tubes area.	sq. ft.	2574	2792	142 tubes		
dia. each	in.		(l.) 13 ft. 6½"	2¼		
	mm		(length) 4127	51.7		
Heating Flues area.			50	36 flues		
dia. each	mm		(5½") 139	139		
Heating Surface Area	m^2	260	281.8	243	391	161
	sq ft	2,794		2,614	4,209	1,729
Superheater Area			50 element	36 element		
	m^2	91	69.8	70.2	131.9	63
	sq ft	975	750	755	1430	678
TOTAL Heating	m^2	350.26		313.2	523.9	
Surface Area	ft^2			3,369	5,639	
Power Transmission		Rods	Rods	Rods	Rods	Rods
Power	hpi	3,000			6,552	
	kW	*2238.8*			*4889.55*	
Tractive Effort	Mp	29.38	23.8	16.12	29.35	11.86
	kN		264.92	161.02	259.3	
	kg	29,920		16,425	29,300	12,079
	lb	65,960	59,560	36,200	64,700	26,620
	lbf			36,200	58,300	
(@75% BP)	lb	58,200	52,700			

Preliminary Assumptions:

The appearance, wheel arrangement, overall size or shape of our Chimera Locomotive for the moment is inconsequential. But to aid the reader's imagination, think of sometime similar to the mainline locomotives currently running on standard gauge (or things close to that like Irish Broad Gauge) networks. Or provisionally fantasise a Garratt similarly proportioned to the 231-132BT [above] with working-fluid and heating medium constrained by container standards as explained in 'Consumables, Quantity and Results' [below].

Number of Cylinders.

While the rudimentary two cylinder arrangement would seem an obvious starting point, given the inefficiency (except for uniflow cylinders) of such a layout it would be a rather unlikely choice for any future post-carbon mainline locomotive. From a thermal perspective something like the 'Prometheus Project LVM800' [see earlier above] a conventional three compound cylinders would be a more desirable arrangement. Even better still are four cylinder configurations, where cylinders may take steam (/boiled working-fluid) at common or dispersed pressures facilitated by varying piston intake cut-off settings. So for our exercise let our chimera have a four cylinder architecture, be that Garratt, Fairlie, Mallet or whatever has no significance to our experiment.

Heating Area, Operating Pressures and Cylinder Volumes.

Problematically for our earlier stabs at these thought experiments, much of the technical potentials and limitations are simply unknown (having yet to be deduced by rigorous scientific experimentation), at such an early point in the development of the Post-Carbon Loco concept.

Chief among our unknowns are questions related to heating area required for practical pressure out of the boilers designs for the proposed contending designs. So whatever pressures will be thence the prescribed Cylinder Volumes for the moment at best is random reasonably sounding figure plucked out of thin air. {*Pun intended*}.

Stroke and Driver Diameter.

For the sake of simplicity where plausible we will set the stroke and driving wheel diameters identical across all contenders.

Consumables, Quantity and Results.

While fixing the mass of the working-fluid and heating medium would have greatly simplified the calculations, given the wide span of densities across the proposed fluids and mediums the implied volumes (for less dense subjects) became ludicrous. Likewise (tracking closer to traditional practice) the volumes could be fixed, but then the converse danger of excessively heavy-loads when dealing with dense consumables must be avoided. However for the moment (before venturing into highly detailed design considerations) this hiccup may be side-stepped by recalling our proposed modularity design principle. Thus both the maximum volume along with maximum weight can be constrained per the inter-modal freight shipping containers standards. So to begin with let us start with the most flexible for envisaged consumables supply role as the 20ft. container standard. Per those specifications our maximum volume is 1,169 ft^3 being 33.1 m^3 while the maximum weight of the 'consumables' load will constrained as the net load 61,289 lb, in metric 28,200 kg.

Inconveniently with regards to the working-fluids a couple of additional hazy assertions will be needed to coax these thought experiments to reconcilable conclusions. Per the historical operations of the traditional steam-engine, besides the allocation of water stowed (as close as plausible to ambient air temperature) in the tender for the anticipated journey, the engines boiler would be full of boiling water and steam sufficient to get the train rolling. This practice was necessary as it takes many hours (along with a none too small supply of fuel) to bring a boiler full of water to operational pressure from a cold start. To expedite the need for a steaming operating pressure full boiler at the start of a shift, most locomotive depots commonly charged cold engines from large stationary boilers. Thus to remove any bias from our comparison it must be assumed that the steam-engines start, with the boiler's working-fluid being raised to operational requirements from only the fuel represented by the heating-medium's allocation. I hasten to under-line such cold-starts are not something to be ever expected in an normal operating environments but purely a fiction for sake of a level playing-field in our thought experiment. At this point in the Post-Carbon Loco concept's evolution it is unclear exactly what the distribution status of the working-fluid to, thence within the cryo-liquid gas boiler (as an analogous terminology) will be implemented at commencement of each daily operations. So our second hazy assertion will be that of the total working-fluid allocation for the boiler accounts for half while the storage tanks house the remaining half.

Operational Range.

The operational range plausible for a given fuel type, at the most simplistic level is a self-limiting calculation. Starting with the obviously false assumption that all our candidate combinations would display the same engine efficiency it is possible to deduce the relative distance our locomotive will travel is directly proportional to the potential energy theoretically obtainable (by the envisaged means) from the heating medium. The volume of working-fluid required to support such a range can for the moment be dismissed as where critical the proposal are proffering various reclamation, recirculation technique that will-be assumed to more than suffice for what is needed. {Oh that the world was actually so obliging}.

	Inter-modal Shipping 20 foot Container Net Loads	Mass		Volume		Net Energy Load	Limit factor
		K20m =	28,200 kg	K20v =	33,100 L 33.1 m^3		
If Contents	**Energy density by**	MJ/kg	MJ	MJ/L	MJ	**MJ**	
	Diesel /domestic heating oil	45.8	1,291,560	42.3	1,400,130	1,291,560 Max	mass
	LPG propane	49.6	1,398,720	25.3	837,430	837,430	vol.
	Biodiesel oil (vegetable oil)	42.2	1,190,040	33	1,092,300	1,092,300	vol.
	Crude oil	41.87	1,180,734	37	1,224,700	1,180,734	mass
	coal Anthracite	32.5	916,500	72.4	2,396,440	916,500	mass
	coal Bituminous	24	676,800	20	662,000	662,000	vol.
	Wood (top end)	17	479,400			479,400	mass
	coal Lignite	14	394,800			394,800	mass
	Wood	6	169,200			169,200	mass
	Lithium ion battery (Top end)	0.72	20,304	1.9	62,890	20,304	mass
	Lithium ion battery	0.54	15,228	0.9	29,790	15,228	mass
	Lead acid battery (Top end)	0.11	3,102	0.17	5,627	3,102	mass
	Lead acid battery	0.09	2,538	0.14	4,634	2,538	mass

The preceding table gives a very quick comparison of the (hypothetical) Net Energy contents a fully loaded 20 foot Inter-modal Shipping Container. Hypothetical as no extra allowance has been made for the safe confinement nor safe transport of fuel beyond the little of a normal container's construction. Most importantly there is no consideration for the oxidising agents required by such energy liberating reactions.

Engine Weight, Tender or Tank.

Both Tender and Tank body-shapes of the same imaginary base-model engine are to be explored. For the moment we will ignore the energy and weight implication of assorted auxiliary devices such as; blower fans (for Pyrolysis Oil version), steam-condensers (where H2O is the working-fluid), or re-compressor (for cryo-liquid working-fluids). Therefore we can now assume that the total unladen weight of the tank-version (think Garratt) of our chimera is equivalent to the sum of the tendered engine (think Mallet) plus the paired tender.

Because the changing weight of fluids and fuel on-board affect the performance of tank-engines three instance; fully stocked (as at the commencement of a shift), utterly empty (as a theoretical end-point), then the mid-point between these extremes, will be calculated. Not forgetting that for each working-fluid and heating medium combination the tendered body-shape is to be reckoned. Lastly to furnish a juxtaposition in addition to the proposed locomotive options, a few traditional steam-engine fuels; wood, coal, bunker oil will be likewise accounted for.

1st. Experiment.

Settings.

Taken from the 231-132BT Algerian SNCF because of the clean metric dimensions.

[a] Number of Cylinders =4

[b] Cylinder Ø [Diameter] = 490 mm → Cylinder Radius = 245 mm
Cylinder r^2 = 60025 mm

[c] Piston Stroke [Bore] = 660 mm = Cylinder *h* [Height]

[d] ~~Cylinder Volume = 49.0 cm * 66.0 cm = 3234 cc = 3.234 litre = 0.003234 m³~~

Volume of a Cylinder = π r^2h = 3.1416 * 60025 mm * 660 mm = 124459196.4 mm^3

(1 mm^3 = 0.000000001 m^3) = 0.1244591964 m^3 = 0.12446 m^3

[e] Driving Wheel Ø = 1,800 mm

[f] Driver Circumference = 1.8 m * π = 1.8 * 3.1416 = 5.65488 m

[g] Working-Fluid Volume (20ft container) = 33.1 m^3/ kl

NOTE #g: *No allowance has been made here /yet for that volume which would be lost to the design requirements / restrictions associated with transport of cryogenic gases. The smaller volume within a suitable cylinder versus the rectilinear space within an empty container.*

[h] Expansion Ratio of Working-Fluid to STP = 1 to 694

[i] Boiler Pressure 20 kp/cm² (kgf/cm²)

= 20 * 98,066.5 Pa = 1961330 Pa

= 20 * 14.223 psi = 284.46 psi

= 20 * 0.96784 atm = 19.3568 atm.

Rational and Calculations.

I# Maximum Available Expanded Working-Fluid.

= Working-Fluid Volume [g] x (Expansion Ratio [h] less one for the STP {Standard Temperature and Pressure} working-fluid remaining in the cryogin at the end of operations)

NOTE I: *For this remainder to have been consumed would mean that the cryogin is left as a vacuum or that it has been filled with air, neither option being desirable as the locomotives are presently conceived. The astute reader will have noted that there is here no allowance made for the filling of the volume of the cryo-boiler nor all the associated internal piping of the engine. This is because such spaces will continue to contain WF at STP upon the conclusion of any scheduled operation. That is to say no allowance is needed as they are already full when a new cryogin is loaded.*

= 33.1 * (694 - 1) = 22,938.3 m^3

II# Full Strokes Supportable from Available Working-Fluid [WF] at STP.

= 22,938.3 / (0.12446 * 4) = 22938.3 / 0.49784 = 46075.64679415073 strokes

{BTW: the cylinder volume is multiplied by 4 as this locomotive has 4 cylinders on it.}

NOTE II: *This number is substantially less than what any locomotive would normally be able to attain, because operationally the working-fluid supply to the cylinder is "cut off" before the cylinder is fully filled. The work of the engine being obtained by the drop in pressure as the working-fluid expands in the cylinder after the supply has been interrupted.*

II# As steam cylinders do two strokes per revolution of the driving wheels.
Driving Wheel Revolutions to Consume all WF
at 1 atm. = 46075.64679415073 / 2 = 23037.82339707537

III# So if all the expanded working-fluid available at STP was to be pumped out via completely filling the cylinders the distance that could be traversed assuming a hypothetical ZERO SLIPPAGE (between the steel wheels and steel rails) per cryogin swap would be [f] Driver Circumference * [III] Driver Revolutions for all WF

= 0.00565488 km * 23037.82 = 130.2761075616 km

IV# Repeating the previous step at specified boiler pressure of 19.3568 atm, in other words full throttle flushing the working-fluid via cylinder full fills directly exhausted to atmosphere gives a miserable 130.2761075616 /19.3568 = 6.73025 km (per cryogin swap). In a normal operating environment (if mechanically plausible) no engine-driver would ever be so extravagantly wasteful!

NOTE V: *The extremely wild assumption here is that all the energy required to raise the cryogenic liquid gas used for the working-fluid to the ambient temperature can be sucked in a timely and elegant manner from the neighbouring environment immediate adjacent to the stationary or moving locomotive!! .*

V# The conventional operation of (external combustion or, prior pressurised working-fluids) reciprocating engine is to cut-off working-fluid supply such that the cylinder is only partially filled allowing the engine to convert to mechanical work the energy liberated by the pressurised working-fluid as it expands in the cylinder.

1st Exercise Conclusions.

Recognising the extra range that will be gained by implementing traditional cut-off (rather than the 100% cylinder fills) this 6.7 km while disappointing is not a disaster for this quest. Especially as this extremely rough experiment is without any investigation of impacts of rudimentary consideration of physics like momentum. An ALCO (American Locomotive Company) advertise of the day (ALCO being the North American distributor) noted that one of our benchmark locomotives achieved 75 mph when running at messily 4% cut-off. If the above experiment is recalculated at a 4% cut-off the rang between swaps becomes a respectable 167.5 km! Returning to missing consideration of physics the ALCO advertisement goes onto proclaim "*And, as an indication of its free running and low internal resistance , over 60 m.p.h. (light engine* [= no carriages attached]*) has been maintained for a distance of 5 km on practically level track with the steam shut off*"

2nd. Experiment.

Settings

from the C.F.Algerian 231-132BT so same calculation as **1st. Experiment [**above**]**

Number of Cylinders = 4

Cylinder Ø [Diameter] = 490 mm	Piston Stroke (Bore) = 660 mm
Cylinder Volume = 0.12446 m^3	[d] per 1st. Experiment calculations [above]
Driving Wheel Ø = 1,800 mm	Driving Circumference = 5.65488 m

[j] Cylindrical Volume = $\pi r^2 h$

[j] Overall Lengthen = 29,432 mm

[k] Maximum Boiler Diameter = 6' 10 3/4" (1,828.8 + 273.0500 mm)
= 2101.85 mm = 2.101 85 m

[l] Boiler r [Radius] = 1050.925

[m] r^2 = 1102500

Cautionary Warning.

Unfortunately the 'Real-world Benchmarks' table [above] is the only hard data I have to work with at the moment. I'm aware dimensioned drawing (of unknown quality) for the C.F.Algerian 231-132BT exist as enthusiast have built models of this locomotive, I have yet to source any. So in an effort to mitigate this difficulty I am going to resort to additionally including (clearly flagged) rubbery estimates deduced from photographs of the locomotive.

Rational and Calculations.

II# *approx* Boiler Length = 4500 mm = h

VI# *approx* Capacity of Boiler = $\pi r^2 h$ = 3.1416 * 1102500 * 4500
= 15586263000 mm^3 = 15.586263 m^3

VII# Working-Fluids [WF] Allocated Volume = 30 m^3

VIII# *estimate* Boiler WF Vol. ≈ [VIII]*50% = 7.793 m^3

IX# Ratio of Boiler to Storage Tanks Volumes for WF *approximation* =

[X]:([IX]-[X]) = 7.79 : (30 - 7.79) ≈ 8 : 22 = 4:11

2nd Exercise Conclusions.

The estimated 22 m³ storage for "water" (being steam-engine traditional) Working-Fluid is less than the 33.1 m³ conceptual limit of a *20 foot Inter-modal Shipping Container* template. As well it is reasonable to extrapolate that boiler along with engine workings, piping, etc. will account for around a further 8 m³ of WF during the engines commissioning and initialisation. This 8 m³ will also be indicative of the total internal volume of system's piping and containers where the WF would be expected to take up and or release thermal energy. However that spacial figure should not to be confused the surface area across which thermal energy will expected to pass.

3rd. Experiment.

Settings

again from the C.F.Algerian 231-132BT as in earlier Experiments [above]

[o] Coal 24,000 lb (* 0.453 592 37 = kg) = 10,886.21688 kg

NOTE 'o': *From the Energy Densities Table* [above and below] *we know that different types of coal have varying energy and density attributes:-*

Anthracite *is rated 32.5 MJ/kg & 72.4 MJ/L (L/1,000 = m³)*

Bituminous *is rated 24 MJ/kg & 20 MJ/L*

Those volume numbers while giving an absolute minimum space occupied are helpful, do not forget that even in a powered form any storage of a solid will include a some mandatory volume of air between the lumps of coal.

X# if Anthracite then MJ =10,886.21688 * 32.5 = 353,802.0486 MJ

XI# if Bituminous then MJ =10,886.21688 * 24 = 261269.20512 MJ

XII# Anthracite as 353,802.0486 MJ

L = 353802.0486 / 72.4 = 4886.768627071823 = 4.8868 m³

XIII# Bituminous as 261269.20512 MJ

L = 261269.20512 /20 = 13063.460256 = 13.06346 m³

XIV# Thus Heating Medium's volume range is 4.8868 to 13.06346 m³

XV# Heating resource used in the historical benchmark (assuming no lesser quality of coal was used) was between 353,802.0 to 261,269.2 MJ

3rd Exercise Conclusions.

As expected (due to the greater energy density of traditional hydrocarbon fuels) this estimated range 4.8868 to 13.06346 m³ would easily fit within the 33.1 m³ conceptual limit of a *20 foot Inter-modal Shipping Container* template. Especially given that the mandated 10,886 kg load of coal is well below 28,200 kg conceptual limit of a *20 foot Inter-modal Shipping Container* template.

As in traditional Stephenson implementation the WF of water bequeaths no energy input to the locomotive's outputted work the coal's chemical energy is the only energy input to the engine. Therefore it may be concluded that a practical work output (with the same thermodynamic efficiency) can be attained a total energy input with between 353,802.0 to 261,269.2 MJ. [XVII# above]

.... *{ yet to be expanded }*

4th. Experiment.

Settings

Weight of Engine and Frame alone = Mp 216 / 47500 lb

Appendix 2: Laws, Conventions, Rules of Thumb

Rubrics for Reciprocating Steam Locomotives

Sourced from E.A. Phillipson seminal tome Steam Locomotive Design: Data and Formulæ first published 1936 {reprinted by Camden Miniature Steam Services © 2004}

Diameter of Coupled (Driving) Wheels.

- "Tractive force exerted by a locomotive is in inverse proportion to the diameter of the coupled wheels."
- ".. an empirical rule which states that the diameter of the coupled wheels at the tread in inches, should equal the maximum speed at which the engine is required to run, in miles per hour. ... This rule implies a maximum rotational speed of 336 revolution per minute, … for design a ***maximum*** speed of 360 r.p.m. is generally assumed; .. some continental designs allow for the exceptional maximum of 420 r.p.m."

BUT: *504rpm as recommended by the American Association of Railroads (while also restated by both Porta and Wardale) the nominal maximum* ***continuous*** *operating speed of a locomotive* ***in mph*** *should be taken as the 1.5 times the wheel diameter measured in inches (which equates to around 8.5 Hz). Attested by Chris Newman's experience to be a very important point which applies equally to freight engines for them to develop maximum power output at relatively low speeds.*

Target km/h	Target mph	Locomotive {wheel layout according to White classification}	Drivers' Ø [mm]	Drivers' Ø [inches]	***Continuous*** *mph per Wardale.*	***Maximum*** *mph per Phillipson*	*European theoretical* ***maximum***	RECORDED mph { km/h}
80	49.7							
160.9	100			66.666		66.67		
180	113	5AT as designed	1880	74	113	74	92.5	
		4468 Mallard {4-6-2} LNER A4 Pacific	2032	80	120	80	100	125.88
200	124			82.666	124	82.67	103.33	
		Milwaukee Rail Road A Class Atlantic{4-4-2} and F7 Hudson {4-6-4}	2133.6	84	126	84	105	
		BORSIG 05-002 Deutsche ReichReichsbahncs-6-4 Baureihe 05		90.6	135.9	90.6	113.25	124.5 {200.4}
250	155			103.333	155	103.33	129.17	
350	217			144.67	217	144.67	180.83	

Wardale's nominal **maximum continuous operating speed** in mph ([*American Association of Railroads*] *AAR* std. for motion design) {504 r.p.m. which equates to around 8.5 Hz }
= 1.5 * Drivers' Ø [inches]. (Source = 5AT's "FDC.1.3b.pdf")
Phillipson's maximum mph {336 r.p.m. 5.6Hz} = Drivers' Ø [inches] @ Tread
European theoretical maximum mph {420 r.p.m. 7Hz} = 1.25 * Drivers' Ø [inches] @ Tread

NOTE: The above calculations have lazily treated the stated diameter of the drivers as being the diameter of those wheels measured at their tread, where in fact the wheel's actual diameter measured at the extreme of the flange would be a few inches more.

$C = 2\pi r$ $C=3.1416d$ $C=6.2832r$