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COMMERCIAL SUSTAINABILITY VIA ENVIRONMENTAL IMPROVEMENTS – TECHNICAL AND TRAINING CHALLENGES

Summary: Commercial viability is the primary concern in the operation of any business, and heritage railways are no exception. If volunteer labour is used, fuel costs account for an even bigger percentage of overall cost than in an ordinary commercial railway company. To say it in plain English, both commercial and heritage railway operators usually don't give a damn about environmental issues unless there are heavy protests from neighbours, usually concerning noise (commercial rail freight operators) and black smoke (heritage railways). Railways, truckers, shipping companies, and airlines all are only interested in cost reduction and consider environmental improvements as a nasty and – above all – costly obligation inflicted upon them by politicians. The one message of this talk is: **Environmental improvements cut down fuel and maintenance costs – they are one way to achieve commercial viability!** However, there are quite a few technical and training challenges that have to be met.

1. Compliance with environmental regulations as a precondition for the reopening of a railway as a heritage or tourist line

As an overreaction to past environmental abuses, it has become extremely difficult to reopen any industrial complex, no matter whether it is a factory, a mine, or a railway. In Germany, a project that might disturb the mating practices of some toads is a sufficient reason for green extremists to enter into lengthy litigation against it – this is no joke!

Right after the wall between East and West Germany had come down, Magdeburg Regional Headquarters of Deutsche Reichsbahn decided to reopen the Mt. Brocken line for tourist traffic. This metre-gauge line had been closed in 1961 due to its proximity to the West German border. In 1990, the present author did a first study on the environmental impact of different forms of tourist traffic up Mt. Brocken. Comparing bus traffic with diesel railcars and steam-hauled passenger trains (both coal and oil-burning 2-10-2 tank locomotives were considered), this study showed that coal-burning steam locomotives were least hazardous to the environment because in case of an accident, no diesel fuel or heating oil would contaminate the drinking water reserves in the area.[1] Due to frequent rainfalls in the area, the line-side fire hazard is practically zero.

Since 1990, further research - quite a bit of which was carried out by the present author - has revealed the following facts:

- The Stephensonian boiler is to date the most efficient vessel for the purpose of evaporating water ever invented.[2]
- Zero carbon footprint operation is relatively easily possible due to the wide range of fuels that can be used in principle.

- External combustion (as in a steam locomotive firebox) of both coal and oil does not produce any PM10 soot.[3]

Plate 1: 99 7237-3, a post-war 2-10-2 T, hauling a Mt. Brocken-bound passenger train between Eisfelder Talmühle and Schierke on April 6, 2007. Photograph: R. W. Serchinger.

2. Environmental improvements – opportunities and challenges

How do heritage and tourist railways assess the importance of environmental problems? After the 2009 FEDECRAIL conference in Luxemburg, FEDECRAIL's newly founded Environmental Working Group (EWG) carried out a Europe-wide survey on the matter:

FEDECRAIL Environmental Working Group (EWG)
European questionnaire: Survey results as at 22nd April 2010[4]

Total Number 'C' class railways	**274**
Total number of survey replies	**74**
European-wide response rate	**27 %**

The seven issues - in order of importance:

Most important	**1)**	**Air quality**
	2)	**Line-side fires**
	3)	**Vegetation control**
	4)	**Wastes disposal**
	5)	**Noise pollution**
	6)	**Ground water contamination**
Least important	**7)**	**Burning fossil fuel**

Air quality ranked #1 because of the many neighbour complaints we are quite familiar with.

The benefits and opportunities of environmental improvements are:

- Lower total expenditure on fuel.
- Shorter set-up times.
- Reduced maintenance costs.
- Reduced waste disposal costs.
- Avoidance of line-side fires.
- Avoidance of fines for not complying with environmental regulations.
- Fewer neighbour complaints.
- Improved public image.
- Possibility to raise funds from environmental programs.

But there are also challenges:

- Convincing traditionalists of the necessity of change.
- Training of both volunteer and paid staff so that they understand and put into practice new operating methods.
- Development of new technologies and components.
- Necessity to raise funds to cover the first cost of locomotive and infrastructure conversions.

How can the goal of better financial performance via environmental improvements be achieved in principle?

- New or heavily modernized steam locomotives using the latest technology ("modern steam").
- Adopting the very best working methods of old steam days plus minor low-cost modifications.

These two approaches and their respective opportunities and challenges will be looked at in more detail in the next two paragraphs.

3. "Modern steam"

The "Modern Steam" concept for tourist railways was introduced by Roger Waller of Swiss Locomotive and Machine Works (SLM). It called for light-weight, thermally efficient, easy-to-maintain-and-operate, environmentally friendly, one-man-operated new steam locomotives. Roger Waller was able to find three customers in Switzerland and Austria for his brand-new H 2/3 rack tank design for the 800 mm and 1000 mm gauges.[5, 6]

- 3 prototype H 2/3 locomotives were delivered in 1992.
- 5 series H 2/3 locomotives were delivered in 1996.

These locomotives were designed to burn #2 (extra light) heating oil as used in domestic heating. They outperformed their diesel competitor Hm 2/2, especially environmentally:

- CO emissions: – 79 %.
- NO_x emissions: – 89 %.[7]

Operating costs were the same because the tax on #2 heating oil was much lower than on diesel fuel, thus compensating for the lower thermal efficiency of the steam locomotive. These locomotives proved in daily service that a modern high-tech steam locomotive reaches 50 % of the fuel efficiency of a corresponding modern diesel locomotive, thus making steam a viable commercial option if the steam locomotive fuel costs no more than half as much as diesel fuel per unit of lower calorific value.

Plate 2: Series H 2/3 rack tank steam locomotive at Brienz Station on September 5, 2007.

Plate 3: Series H 2/3 rack tank steam locomotive and its diesel competitor Hm 2/2 at Brienzer Rothorn Station on September 5, 2007. Photographs: R. W. Serchinger.

Starting in late 2008, the present author converted Zillertalbahn #5, an Austrian 1930-built 760 mm-gauge (2’6”) superheated 0-6-2 tank engine, to his proprietary SePhys oil-firing system. This conversion which also included a new blast pipe and a new superheater doubled the (thermodynamic) fuel efficiency in regular operation, eliminated neighbour complaints and the fire risk, and saved 2 man-hours each day of operation. On average over all crews and round-trips, 665 litres of tax-exempted diesel fuel at a price of 478.80 EUR delivered on site substituted for 1.6 tonnes of hard coal at 480.00 EUR delivered on site. Staff competence (and thus prior training!) is a crucial factor, though. The best crew, using a steady 30% cut-off on the whole trip, burnt 550 litres, whereas the worst, running in full gear all the time (even at top speed!), used up 990 litres in the same service!

Plate 4: Zillertalbahn #5 is being refueled at the diesel locomotive fueling station, using standard diesel locomotive bayonet tank filler neck fittings. Jenbach, October 27, 2010. Photograph: R. W. Serchinger.

However, after the end of the 2011 tourist train season, the Austrian government announced the discontinuation of the diesel fuel tax exemption for railways from January 1st, 2013 onwards. Therefore, cheap alternative fuels have a high priority on the agenda again. In order to be able to use a variety of liquid fuels (whichever are the best value at any given time), the SePhys oil-firing system is made exclusively from stainless steels, employs only FAME-resistant (biodiesel-proof) seals and gaskets, and incorporates both an electric and steam tank-heating system.

On December 13, 2011, crude ester, a residue of biodiesel production, was tried out as a fuel on #5. This experimental run showed that both the fuel preheating system and the SePhys burner lances were able to handle this fuel in principle; however, the fuel delivered to Zillertalbahn for the test was not quite up to the specs given by the manufacturer. It contained a brown liquid phase which burnt well from a preheating temperature of 40 °C onwards (in line with the specs) and a black muddy phase which was sprayed unburnt through the burner flame to the firebox walls (centrifugal separation by the burner swirl) even at a fuel preheating temperature of 71 °C (not in line with the specs). After the fuel supplier had donated another 1000 l of the crude ester fuel – this time without black mud from the bottom of the reactor tank – a new test was carried out on September 5, 2012. The fuel used was a blend of 68 % crude ester and 32 % diesel fuel. It could be shown that the crude ester fuel mixes homogeneously with diesel fuel. While the kinematic viscosity of diesel fuel is in the 2 to 4.5 mm^2/s range at 40 °C, the BP C 16 – 12 crude ester fuel has a kinematic viscosity of 22 mm^2/s at the same temperature. The blend was reckoned to have a kinematic viscosity of 16 mm^2/s at 40 °C, the upper viscosity limit of the SePhys burners in their unmodified form. The blended fuel was heated up to 40 °C electrically overnight. Fuel temperature was measured in the fuel supply pipe right after the tank shut-off valve. Igniting the burners and heating up the locomotive the next morning (using compressed air as atomizing medium in the beginning) gave no problems. As lead engine of a double header on a heavy regular tourist train, #5 performed well but at reduced power output because of the lower calorific value of the blend in comparison to diesel fuel. Fuel temperature out on the line was varied between 42 °C and 74 °C by adjusting the steam supply to the tank heater. The optimum fuel temperature for the blend was found to be in the 50 °C to 60 °C range, corresponding to a 63 °C to 70 °C range for a 100 % crude ester fuel, for which the minimum preheat temperature would be 57 °C. Smokeless combustion was easily achieved. The crude ester stems from a biodiesel production based on used vegetable fats. However, French-fry smells are produced only when the load burners are ignited. Due to the higher viscosity of the fuel, fuel flow fluctuations were damped, resulting in even lower noise levels than usual. **The results obtained clearly show that a zero-carbon-footprint steam locomotive using a cheap residue fuel made from waste vegetable fat is feasible.**

Development work will continue with the 44 0225-1 EO (Eco Optimized) project in mind. This locomotive is an ex-DR (East German) 2-10-0 3-cylinder standard gauge freight loco on which the ultimate goal is a "green" oil-firing system for practically all liquid fuels so that the operator (the Danish Rent-a-Lok company) can switch to whichever fuel is cheapest. This is very important for the **financial** sustainability of the railways which for most of them is a bigger problem than ecological sustainability!

“There is no limit to abuse” – this famous Porta quote unfortunately also holds true for the heritage railway scene. Loco abuse by ignorant staff not only increases fuel costs but also causes unscheduled costly repairs. As Zillertalbahn #5 is equipped with poppet valves, the superheater of the locomotive had been designed for a superheat temperature of 450 °C. Some firemen used the load burners at high power for extended periods of time at standstill of the locomotive, resulting in burnt superheater element return bends. The head of the Zillertalbahn workshop told me: “Foolproof is not enough – you must make the loco idiotproof!” The superheater elements were shortened by 500 mm, bringing the maximum superheat temperature down to 400 °C, resulting in a 10 % increase in fuel consumption. Some other simplifications in the handling of the loco made #5 in fact almost idiotproof. Nevertheless, the overall thermodynamic efficiency in regular operation was still twice as high as with the original coal-firing (a factor of 2.3 was the maximum achieved before the final alterations). Thus the commercial optimum proved to be a compromise between thermodynamics (saving fuel) and adaptation of the system to the prevailing minimum competence of footplate staff (avoiding repairs caused by incompetent handling of the loco). “The more you know, the less you need” – this proverb of the Australian Aborigines holds true for locomotive operation, too!

4. Best working methods of old steam days plus minor low-cost modifications

The vast majority of all extant serviceable steam locomotives burn hard coal. Coal quality and competence of firemen are the two most important aspects of achieving environmentally friendly and economical operation of coal burning steam locomotives. For reasons of both environmental protection and safeguarding against excessive corrosion, only the best low sulphur locomotive coal should be used. If coal with the right percentage of volatile matter is not available, an appropriate mixture of two kinds of coal can give equally good results. It makes a big difference whether you use bad coal with a sulphur content of 4 % and a heat content of only 27.8 MJ/kg or good coal with as little as 0.6 % sulphur and a heat content of 31.4 MJ/kg: Burning the bad coal means 7.5 times more SO_2 emitted into the environment and a correspondingly higher corrosion of the firebox, superheater elements etc. - the use of cheap coal just does not pay! As part of his work for FEDECRAIL, the present author developed the below

Specifications for environmentally friendly steam locomotive coal:[8]

• Type of coal	Bituminous hard coal
• Lump size (for hand-firing)	80 – 120 mm or 50 – 80 mm
• Water (in mass-% of the crude coal)	$\leq$ 5 %
• Ash (in mass-% of the crude coal)	$\leq$ 6 %
• Sulphur (in mass-% of the anhydrous substance)	$\leq$ 1 %
• Volatile constituents (in mass-% of the anhydrous and ash-free substance)	19 – 28 %
• Lower calorific value (of the crude coal)	> 28 MJ/kg
• Ash fusion temperature (T_B)	> 1300 °C
• Iron (of the anhydrous substance) (when air is lacking, Fe_2SiO_4 and FeO are formed and lower the melting point of the ash)	$\leq$ 5500 mg/kg
• Mercury (boiling point = 357 °C) (of the anhydrous substance)	$\leq$ 0.2 mg/kg
• Cadmium (boiling point = 767 °C) (of the anhydrous substance)	$\leq$ 0.6 mg/kg

Polish locomotive coal as sold in continental Europe is usually better than the above specs require; however, its content of volatile matter is in the 30 – 33 % range. Old coal-fired steam locomotives of proven design with well aligned blastpipe and smokestack usually have smokeless combustion **if fired properly**. Good training of firemen and their willingness to do a good job is therefore of crucial importance. Generally, to fire little and often is better than to put in a lot at long intervals. The latter method increases coal consumption by up to 20 % and CO-emissions by a factor of at least 10 as measurements carried out on Achenseebahn #1 showed in 2007. East German Reichsbahn found that black smoke at standstill increases the coal consumption by 3.6 kg per minute and square metre of grate area![9]

The Chinese firing practice for smoke avoidance was described in the present author's talk at the 2009 Congress in Australia.[10] It is very suitable for long distance runs, whereas the alternative Harz Narrow Gauge Railways' ring fire method outlined below works better on stopping passenger trains in densely populated areas. When leaving a station, the amount of coal shovelled into the centre of the fire is reduced so that almost all of this coal will have been burnt when the train reaches the next station. The ring of burning coal along the firebox walls is maintained at normal height. Thus smoke can be almost completely avoided at stations and their usually densely populated neighbourhood. The ring fire method also helps to minimize incidence of fractured stays.

Both combustion and fuel efficiency can be improved by the fitting of a modern exhaust system such as the LemPor-exhaust[11] or the Giesl-ejector.[12] Especially former East German (DR) and Austrian (ÖBB) steam locomotives that once had Giesl-ejectors should be re-equipped with this highly efficient system. Locomotives that never had a Giesl-ejector can be equipped with the LemPor-exhaust (4 de Laval-nozzles plus a round diffusor smokestack); the original outer appearance can thus be preserved to a great extent. Even the simplest modification of the front end, the replacement of the standard blastpipe by a single big de Laval-nozzle and a downward extension of the smokestack to just above the de Laval-nozzle gives good results. Generally, a modification to the exhaust system is not very costly and can be done in the running shed. In addition to the well-known front end alterations, other low-cost modifications are possible and make good sense.

Low-cost standard conversion procedure for classical coal-fired steam locomotives to reduce both smoke and spark emissions:

- **Inverted steel arch or extended brick arch over two thirds of the firebox length**.
- **Deflector plate** over the firehole plus **secondary air inlet(s) in the firedoor**.
- **Alteration** of existing ashpan **air inlets**.
- **Additional** ashpan **air inlets** if necessary.
- Heat-resistant stainless steel **grid or wire mesh over all air inlets**.
- **Spark arrestor** made from the same wire mesh **fully encloses space between blastpipe and chimney**.
- **Mesh width 5 mm x 5 mm**, wire diameter 2 mm (legal requirement = 6 mm x 6 mm for hard coal).
- **Total line-side fire protection** can be achieved if **mesh width** is **2 mm x 2 mm for hard coal** and **1.7 mm x 1.7 mm for lignite**, respectively.[13]
- **Modified front end** (Giesl, LemPor etc.).

Plate 5: Inverted steel arch and deflector plate. Achenseebahn #1, experimental set-up with secondary air inlet in the firedoor, Jenbach, June 7, 2008. On a test run, this arrangement boosted fuel efficiency under full load by some 22 %! Photograph: R. W. Serchinger.

A further step would be L. D. Porta's gas producer combustion system (GPCS).[14, 15] However, its original version is costly to install and – due to the sluggish response of the thick firebed – has drawbacks when loads vary frequently. Besides, the original GPCS gives optimum results only if the coal fired has the content of volatile matter the system was designed for. The all-fuel strategy described above for the case of oil-burning locomotives should also apply to the traditional coal-burning steam locomotive. Preliminary thought has been given to an all-solid-fuel system which is a development of Porta's GPCS – the variable gas producer combustion system (VGPCS). The ultimate goal here is to be able to burn scrap wood, sawdust briquettes, lignite, hard coal, and synthetic coals – whichever is cheapest at any given time – in one properly modified loco, again for **both financial and environmental sustainability.** Besides, the firebed is kept thinner under frequent load changes, thus responding more quickly. Unfortunately, there are no customers, no funds, and no sponsors for this project yet. Maybe the resurgence of coal mining in the UK will open up funding possibilities for HRA member railways and a joint project modifying a British coal burner.

Optimum cut-off on classical steam locomotives is in the 35 % to 25 % range. Lower cut-offs on unrebuilt locomotives do not increase fuel efficiency due to throttling of the steam but cause premature wear of bearings.

Obviously, the use of good coal, staff training, and simple modifications as outlined above can considerably lower the costs of coal-firing and help to avoid neighbour complaints about black smoke.

Coal ash can be disposed of by using or even selling it as a fertilizer for gardens provided there are no heavy metals in the coal. This was standard practice in Austria and parts of Germany still in the 1970s. It can also be used as a material for road construction. A chemical analysis of German coal from the General Blumenthal mine carried out in 1996 yielded its content of both harmful and harmless trace elements – the result vindicated the former practice.[16] Unfortunately, the General Blumenthal mine was closed. However, such an analysis could be carried out for the coal used by HRA member railways. Perhaps the UK suppliers might be helpful and do these analyses in their labs for free.

5. WATTRAIN fuel data base

In order to create a WATTRAIN steam locomotive fuel data base, the author kindly requests all heritage and tourist railways around the world to send him the specifications of the fuels they use, no matter whether coal, oil, or wood. Comments on the experiences with these fuels would also be greatly appreciated. Please email the specs to info@sephys.de !

Notes

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2. A. Giesl-Gieslingen: *Anatomie der Dampflokomotive* (Anatomy of the Steam Locomotive). Verlag Josef Otto Slezak, Wien (Vienna), 1986, on p. 40.

3. R. W. Serchinger: *Environmental Protection - What Can Be Done*. Paper presented on the 5th of February, 2011 at the "Annual General Meeting 2011" of the "Heritage Railway Association" (HRA), Swindon, UK, on slide 11.

4 Originally compiled by T. Tomkins (HRA).

5 R. M. Waller: "Neue Zahnrad-Dampflokomotiven H 2/3 - die attraktive und wirtschaftliche Alternative für Bergbahnen" (New rack steam locomotives H 2/3 - the attractive and economical alternative for mountain railways). *ZEV+DET Glasers Annalen* 117 (1993): 100–113.

6. R. W. Serchinger, R. M. Waller: "Modern steam locomotives – a comeback for economic and ecological reasons." *Railway Technical Review (RTR)* 2/3 1997: 45-46.

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9. J. Schwarze et alii: *Die Dampflokomotive* (The Steam Locomotive). Reprint of the Second Edition of 1965, TRANSPRESS, Berlin, 1993, in the appendix on p. 46.

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11. L. D. Porta: *Theory of the LemPor ejector as applied to produce draught on steam locomotives*. Unpublished paper, Buenos Aires, December 1974.

12. A. Giesl-Gieslingen: *Die Ära nach Gölsdorf* (The Era after Gölsdorf). Verlag Josef Otto Slezak, Wien (Vienna), 1981, on pp. 278-283.

13. Ibid., on p. 196.

14. L. D. Porta: "Steam Locomotive Development in Argentina - Its Contribution to the Future of Railway Technology in the under-developed Countries." *Journal of the Institution of Locomotive Engineers*, Vol. 59, London, 1969: 205-233.

15. D. Wardale: *The Red Devil and Other Tales from the Age of Steam*. Published by the author, Inverness, Scotland, First Edition, 1998, on pp. 78-92.

16. Reinhard W. Serchinger: *Dampflokomotiv-Emissionen auf der Achenseebahn. Messungen und Untersuchungen vom Oktober 2007 bis August 2008* (Steam locomotive emissions on the Lake Achen Railway. Measurements and investigations from October 2007 to August 2008). Paper prepared for "Verband Deutscher Museums- und Touristikeisenbahnen (VDMT)“ (Association of German Museum and Tourist Railways), München (Munich), August 2008, on p. 7.