February 20, 2023
Public Comments of Benjamin G. Kaldunski
TO: Dane County Department of Waste & Renewables
RE: Madison Sustainability Campus Local Government Meeting

I am a Madison resident and graduate of the UW-Madison Nelson Institute with a keen interest in supporting the development of a circular economy through innovative technology deployment. The plans for Dane County and the City of Madison to develop the **Sustainability Campus** is admirable, ambitious, and ripe for beneficial collaboration with a variety of partners. My comments provide an overview of several promising technologies that could be incorporated into the Sustainability Campus design process in support of Madison's goal to achieve 100% Renewables and **Net Zero Carbon by 2030**.

The three technologies I would like to present for consideration are:

1. Hydrothermal Carbonization (HTC) bioreactors deployed in several European countries by the **Spanish firm Ingelia Spa**, which convert multiple forms of organic waste into a net zero carbon solid biofuel with energy content similar to lignite coal (8,600-10,300 Btu/lb);
2. Advanced steam boiler and engine technology developed by **Mackwell Locomotive Co**., of New Zealand that use waste biomass (or Ingelia biocoal) as carbon neutral fuel for farm tractors, waste collection trucks, street sweepers, snow plows and other fleet vehicles;
3. Modular combined heat and power (CHP) units developed by **Uniflow Power Ltd**., of Australia that utilize a wide variety of carbon neutral biomass feedstocks as fuel for a high efficiency steam engine capable of producing electricity, heat, hot water, distilled water and mechanical power;

I will describe each of the three technologies listed above in greater detail beginning with the HTC bioreactor developed by Ingelia. The modular HTC reactors have been undergoing development since 2007 and have now been deployed at commercial scale in Belgium, Italy, Spain, and the UK. The bioreactors are capable of processing a wide variety of organic waste feedstocks including agricultural waste (plant and animal), food waste, pulp and paper byproducts, and even municipal wastewater sludge. Each reactor measures approximately 4' square and 40' tall with a maximum inflow capacity of 770 lb/hour (dry), and output of 440 lb/hour. Ingelia bioreactors could be installed at the Sustainability Campus to process agricultural waste from local farms and/or food waste from UW-Madison cafeterias, restaurants, and other food service companies in the greater Madison area. These waste streams would be diverted from landfills and converted into a net zero carbon biofuel.

Notably, Ingelia's HTC bioreactors can process biosolids leftover from anaerobic digestion. They could be paired with Dane County's existing **community manure digester** facilities to generate additional value-added products. MMSD could also utilize the Ingelia bioreactors to process biosolids leftover from the anaerobic digestion process at the **Nine Springs WWTP**, This could be especially valuable during winter months when the MMSD's Metrogro fertilizer product must be stored onsite rather than distributed to local farms. MMSD could utilize the Ingelia bioreactors to produce solid biofuel for use in process heating, or municipal fleet vehicles. A commercial scale project using ten Ingelia HTC bioreactors cost 27.3 million Euros (about $30.2 million USD). Ten bioreactors would be able to produce ~19,310 tons of solid biofuel whose energy content of about 350,000 MMBtu is equivalent to ~2.5 million gallons of diesel worth $7.5 million assuming $3/gallon. The 10-reactor system was shown to have a payback period of 5.3 years (see **IEA Report**), compared to 15-20 years for solar photovoltaic systems. Producing net zero carbon biofuel from organic waste is directly aligned with Madison's goal to achieve 100% renewable energy and net zero carbon emissions by 2030.

Figure 1: Summary of HTC Demonstration Project

Solid biofuel produced from waste biomass and other organic feedstocks could then be used to power advanced steam boilers/engines in both mobile and stationary applications. Steam power may be considered a defunct and obsolete technology from the 19th century, but startup companies like Mackwell Locomotive Co., and Uniflow Power Ltd., have developed remarkably efficient and versatile prototypes well suited for use at the Sustainability Campus. Most importantly, modern steam engines can use many types of solid biomass, liquid biofuels, and traditional petroleum-based fuels instead of being limited to a single fuel source . They are relatively simple with fewer moving parts compared to internal combustion engines, and do not require the use of rare earth metals vital to the lithium-ion batteries used in hybrid or all-electric vehicles. In short, use of advanced steam technology for municipal fleet vehicles like garbage trucks, street sweepers, and snow plows, would transform waste streams with disposal costs into a net zero carbon fuel to reduce gasoline/diesel costs and dependency on foreign suppliers. The Sustainability Campus could serve as the fueling and maintenance hub for advanced steam fleet vehicles powered by locally produced biofuel.

For example, the **Mackwell AgLoco** utilizes a two-cylinder steam engine rated at 150HP and 5,800 lb-ft of torque with a towing capacity of 66,000 lbs. At that towing capacity, the AgLoco has an estimated range of 128 miles using 1,100 lbs. of solid fuel (equivalent to about 80-85 gallons of diesel assuming 137,000 Btu/gallon and 10,000 Btu/lb of solid biofuel). Cummins diesel engines commonly used in city buses are rated at 200-350HP and 500-1,000 ft-lbs or torque. The Mackwell AgLoco boiler and steam engine could be adapted to better suit the needs of on-road fleet vehicles to improve fuel and water economy. In fact, **Madison resident Charles Keen** built a modern steam-powered automobile in the early 1960's whose 4-cylinder 100 cubic inch engine was rated at 130HP and 2,500 lb-ft of torque with fuel economy of 10-15 miles per gallon (or about 1.2 miles per lb of solid biofuel). The ultra-high torque provided by steam engines at low RPM is ideal for slower speed operations like snow plowing and waste collection/hauling by City and County fleet services. Lastly, the ultra-efficient combustion of solid biofuel results in zero smoke emissions and lower air pollution than diesel engines (**Advanced Steam**).

Another leader in advanced steam technology is Uniflow Power Ltd., whose modular CHP units are based on Australian engineer **Ted Pritchard** who developed a steam automobile in the 1960's. Pritchard's 25 cubic inch steam engines were rated at 45HP and 340 lb-ft of torque with fuel economy of 20-25 miles per gallon (or about 1.5-2 miles per lb of solid biofuel). Water use of just 170 miles per gallon was achieved by utilizing the existing automobile radiator as a condenser to capture exhaust steam for re-use in the closed-loop system. Most impressive, the Pritchard steam generator and engine were capable of meeting 1990's era emissions standards when it was tested by major U.S. automakers in the early 1970's. While the steam automobile never went in production, Pritchard continued to develop his design into the S5000 engine (Steam 5,000 Watt) whose patents serve as the basis for Uniflow Power's modular CHP units. These CHP units could be used at the Sustainability Campus as the primary source of electricity, steam, and hot water for waste handling equipment and buildings. Larger models for commercial/industrial applications could be developed in the future as part of a demonstration project based at the Sustainability Campus with support from UW-Madison Engineering and the **Great Lakes Bioenergy Research Center**.

Madison's commitment to zero waste and 100% renewable energy goals, as well as the long history of public/private partnerships involving UW-Madison and other public agencies present the ideal conditions for demonstration and deployment of HTC bioreactors to produce fuel for advanced steam boilers/engines being developed by Mackwell, Uniflow Power, and others. I would love for Madison and Dane County to achieve their ambitious sustainability goals through partnerships with these firms, or other companies offering similar technological solutions to our environmental challenges. The in flux of federal funding from the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA) could also be leveraged to support innovative partnerships to deploy the technologies summarized above.

Federal programs that appear well suited for supporting technology demonstration projects at the Sustainability Campus include the following:

- U.S. EPA Solid Waste Infrastructure & Recycling Grants Program (**website**)
- Section 11403 State Carbon Reduction Program (**website**)
- Section 11511 Emerging Alternative Fuel Vehicle Study (**website**)
- Section 11401 Community Alternative Fuel Infrastructure Grants (**website**)

Thank you for providing the opportunity to submit comments on this important project. I look forward to continued engagement with Dane County and the City of Madison Sustainability Committee.

Sincerely,
Ben Kaldunski
Madison Resident

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16. Virtual Tour of the Nine Springs Wastewater Treatment Plant. Accessed at https://storymaps.arcgis.com/stories/424038e10de64a4884d915d95a3b1fb5

List of Attachments:

1. IEA Bioenergy White Paper on Ingelia HTC Technology (2021)
2. NEWAPP Final Report Summary of Ingelia HTC Reactor Demonstration Project (2016)
3. Mackwell Locomotive Co., AgLoco Technical Specifications Brochure
4. Pritchard Steam Engine History & Patents (basis for the Uniflow Power Ltd., Cobber CHP Unit)
5. Keen Manufacturing Company Brochure (1961)
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ATTACHMENT 1

Hydorthermal Carbonization (HTC):

Valorisation of organic waste and sludges for hydrochar production and biofertilizers

IEA Bioenergy: Task 36

October 2021

Hydrothermal Carbonization (HTC):

Valorisation of organic waste and sludges for hydrochar production of biofertilizers

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Index

PREFACE

This is the second of a case study compilation to explore lessons on material and energy valorisation of waste within the framework of IEA Bioenergy Task 36. The set of case studies will be published during 2021 covering social and public acceptance aspects, barriers in Waste-to-Energy (WtE) implementation, success stories for decentralized solutions, and integration of WtE within material and/or nutrient recovery. The purpose of these case studies is to showcase examples from which countries can get inspiration and support in implementing suitable policies and solutions in the waste/resource management and WtE sector that would facilitate their transition towards circularity.

IEA Bioenergy Task 36, working on the topic 'Material and Energy Valorisation of Waste in a Circular Economy', seeks to raise public awareness of sustainable energy generation from biomass residues and waste fractions including MSW as well as to increase technical information dissemination. As outlined in the 3-year work programme, Task 36 seeks to understand what role energy from waste and material recycling can have in a circular economy and identify technical and non-technical barriers and opportunities needed to achieve this vision.

See http://task36.ieabioenergy.com/ for links to the work performed by IEA Bioenergy Task 36.

SUMMARY

Hydrothemal Carbonization (HTC) technology has demonstrated to successfully convert biowaste and sludge – which are input feedstocks - into high quality hydrochar, sometimes considered to be a more valuable product than biochar materials. Several HTC industrial plants operate in Europe. Ingelia, an HTC technology developer, operates its own industrial HTC plant in Valencia (Spain) since 2010, CPL Industries Ltd operates an HTC Plant in the UK which was commissioned in 2018 and a third plant is under construction in Belgium, expected to start operations in 2021. Ingelia HTC technology has been proven at commercial scale, reaching TRL9.

The HTC process acts as an acceleration of the natural coal formation process, working at moderate pressure and temperature (20 bar and 210 ºC for the Ingelia process), allowing the dehydration of the organic matter and increasing the C-content up to 60 wt.%. By means of HTC, feedstock with high moisture content converts into a coal-like product called hydrochar. The Ingelia HTC technology includes separation equipment for impurities that are present in the waste such as sands, stones, pieces of metals or glass. However, there are some inorganic components in the carbon structure, such as Ca, K, or P, that can be reduced by specific washing and chemical post-treatment steps. As a result of the HTC process, most of the carbon content of different wet organic waste streams is concentrated and retained within the obtained hydrochar.

HTC process represents a solution for the valorisation of biowaste streams, while generating a carbon-based solid fraction, hydrochar, that can be used as an energy source, a soil ameliorant, or as a feedstock to produce bioproducts. The hydrochar is chemically stable and storable, preventing the emission of methane if the feedstock would be landfilled. The moisture present in the feedstock condensates after the HTC process, and solubilises elements like N, P, K, etc. These elements represent a liquid biofertilizer that potentially can be used as a substitution of chemical fertilizers. The HTC process provides a source of renewable carbon whose properties can be adapted to its final application. The hydrochar can undergo specific post-treatment to reduce the content of specific nutrients to the limits accepted in the industry and energy sector, or to modify moisture content and density (by palletisation or briquetting) with the aim of delivering a product that can be sold as a natural resource for fossil coal substitution.

A life cycle assessment was carried out to determine the potential environmental impacts (global warming, freshwater eutrophication, and terrestrial acidification) of a large-scale HTC plant processing 78 000 ton of wet biowaste and sludge per year in Italy. The analysis highlighted three major contributors to overall environmental impacts; electricity and thermal energy used in the process, CO_2 produced in the process, and the organic content in the waste streams impacting the environment when applied to land. The analysis shows that there is potential for improving the environmental performance of the HTC process by optimising energy use and using greener sources of energy.

BACKGROUND

It is estimated that 139 Mton of biowaste and more that 10 Mton of sewage sludge are generated in EU every year [1]. Biowaste includes food and garden waste in mixed municipal solid waste (MSW), and waste from the food and drink industry. The biowaste can be separated at origin or collected in the mixed waste fraction. The waste handling options for the biowaste range from anaerobic digestion and composting, incineration, and landfilling. In the EU, biowaste usually constitutes 35 wt.% of the total mixed waste, but ranges from 18 wt.% up to 60 wt.%, and an important part of it is treated by the less preferable options in the waste hierarchy. On average, 41 % of MSW is landfilled[2] while for some Member States (e.g., Poland and Lithuania) this percentage exceeds 90 %. The amount of sewage sludge landfilled in Europe in 2017 was 282 kton. These figures show that there is still room for further improvement of management of some major waste streams, especially as there is an increasing drive to move towards more 'circular' approaches to waste management.

Coal is steadily leaving the energy market in many developed economies due to a combination of environmental policies and competition with increasingly cost-competitive renewable energies. The International Energy Agency (IEA) recently published the World Energy Outlook 2019[3], drawing up three scenarios for the world coal consumption until 2040. In the Sustainable Development Scenario, industrial coal use decreases, but coal remains as an important fuel, reflecting the difficulty and high costs of finding substitutes for coal in the industrial processes. Coal remains the backbone of the iron and steel industry and cement sub-sectors, and its use in the chemical sub-sector keeps increasing, particularly in China. In the Sustainable Development Scenario, industrial coal consumption is estimated to be 844 Mton. Hydrochar can provide a great opportunity to replace fossil coal as it offers a carbon-designed adapted chemical composition to the customer needs, CO_2 free (carbon neutral) and available in the local market.

Table 1. Hydrochar average chemical composition and properties. daf: dry and ash free; db:dry basis

C (% daf)	H (% daf)	N (% daf)	S (% daf)	Moisture (%)	Ash (% dry)	Volatile (% db)	Fixed C (% db)
60	6	1.5	0.1-0.3	<9	>10	65	25

The table below (Table 2) shows the industrial analysis of pulverized coal comparing the hydrochar with different types of coal[i4].

All the reported hydrochar examples showed beneficial characteristics for usage in blast furnace (BFs), like a low sulphur content, which increases the quality of pig iron and steel, a low ignition point, and a good flammability. Some critical aspects have been identified in the ash content, ranging from 6 % of orange peel hydrochar, to 13% of green waste hydrochar, and grindability, lower than 60 for organic waste hydrochar. Grindability, ash content and ash melting point have been identified to be critical aspects. Orange peel hydrochar have been identified as the highest quality material, capable to increasing the steel quality if mixed with fossil coal. The mixing approach of hydrochar and fossil coal is representing an attractive opportunity for the application of HTC to the steel sector. The process allows to produce bio-coal by using different types of residues at the same time and at different percentages, so that the content of ashes can be controlled whether by mixing the original feedstocks or the hydrochar produced from different feedstocks. A 100 % replacement of pulverized fossil coal

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[1] IEA (2019), World Energy Outlook 2019, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2019
[2] Eurostat, Municipal Waste 2008
[3] IEA (2019), World Energy Outlook 2019, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2019
[4] 4 EUBCE 2018 Evaluation of utilising Ingelia hydrochar produced from organic residues for Blast Furnaces Injection

in blast furnaces could be achievable only upgrading the Ingelia bio-coal into a material with higher fixed C content, e.g. by slow pyrolysis.

Table 2. EUBCE 2018 Evaluation of utilising Ingelia hydrochar produced from organic residues for Blast Furnaces Injection

Sample	C (% db)	H (db %)	N (db %)	S (db %)	Moisture (db %)	Volatile (% db)	Ash (% db)	Fixed C (% dry)	O (% db)
Lingyuan anthracite	77.38	3.61	0.86	0.90	0.84	13.21	15.02	70.93	1.35
Shenhua bituminous coal	65.12	4.05	0.92	0.34	5.05	35.88	8.58	49.49	15.94
Hydrochar from green waste	50.94	4.95	1.43	0.38	2.58	57.82	15.97	23.63	23.75
Hydrochar from organic fraction	58.61	6.72	2.24	0.31	2.11	68.76	12.88	16.25	17.13
Hydrochar from orange peel	58.06	5.08	1.56	0.166	3.51	59.66	6.18	30.65	25.45

Energy facilities and industries from different sectors have shown interest in using hydrochar as raw material for substituting coal or as biofuel in the energy sector. However, the average ash and volatile carbon content (Table 1) needs to be reduced in order to increase the quality of the final product. Research and trials carried out by Ingelia showed that it is possible to transform the hydrochar into a high-quality carbon-based material, similar to coking coal (classified as a critical raw material according to the 2020 CRM list of EC[5]), by applying post-treatment to the hydrochar for ash separation and thermal treatment to increase the fixed carbon content.

A by-product of the HTC process is a liquid biofertilizer, containing soluble alkali elements and highly assimilable nutrients. Research carried out in cooperation with IVIA (the public Institute for Agricultural Research in Valencia, Spain) and technology institute AINIA (Valencia, Spain), showed that the HTC liquid phase can be considered as an enriched effluent increasing plant growth, acting as a biofertilizer or for feeding Anaerobic Digestion (AD) plants, generating biogas. Due to the HTC process conditions, this liquid biofertilizer is free from microorganism or bacteria. Heavy metals present in the feedstock are retained in the hydrochar. After some enrichment steps, a suitable concentration of nutrients can be achieved, and the liquid phase represents a potential commercial biofertilizer.

WASTE SOURCE AND LOGISTICS

Heterogeneous waste streams with a high moisture content can be difficult to store and manage without a specific treatment. In addition, decomposition or fermentation generates CO_2 and CH_4 emissions into the atmosphere. HTC provides a solution for converting these waste streams into stable and valuable products. Many kinds of organic waste streams can be used in the HTC process to produce bio-carbon and biofertilizers. As an example, waste streams shown in Figure 1 have been tested at Ingelia industrial plant. HTC can be also a solution for biowaste streams with high content of plastics (up to -15 % on dry base) that cannot undergo composting.

[5] https://ec.europa.eu/docsroom/documents/42849

Figure 1. Waste feedstocks used in the Ingelia HTC process. From left to right: compost out of specification (30% wt. moisture); green waste (50% wt. moisture) and digestate (85% wt. moisture).

The waste stream valorised through the HTC process can vary in moisture content and/or heterogeneity both in particle size and composition (particle size with up to 10 cm is possible to be introduced in the HTC process). Waste streams with up to 88% humidity content have been tested successfully. HTC avoids landfilling of organic waste which often have associated long distance transportation. Results of some trials performed in Ingelia's HTC industrial plant that have been presented in conferences in this topic are presented below:

1. HTC 2017 (Queen Mary University of London)[6]

An industrial trial to recover hydrochar from biowaste was presented in 2017 in London at the HTC international conference. A biowaste with 75 % moisture content was transformed into a 4 % moisture hydrochar. The thermal energy consumption of the process was 2.2 GJ/ton of waste (dry) and the electricity consumption was 148 KWh/ton of waste (dry) (Figure 2).

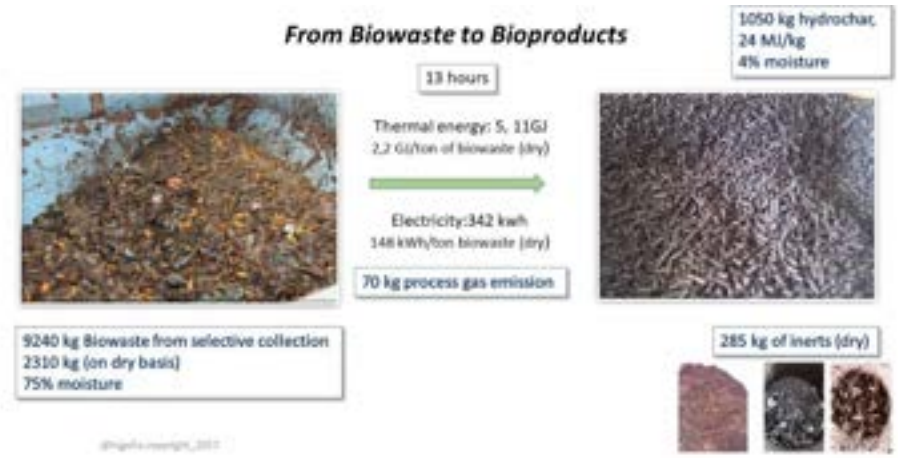

Figure 2. From biowaste to hydrochar – Example of a trial

2. VDI Conference 2017 in Copenhagen[7]

An industrial trial with sewage sludge (80 % moisture content) was presented in 2017 in

[6] https://www.sems.qmul.ac.uk/events/htc2017/programme/
[7] https://www.vdi-wissensforum.de/

Copenhagen at the VDI International Conference. 624 kg of hydrochar were obtained from 9 000kg of sewage sludge with thermal energy consumption of 1.6 GJ/ton of sludge (Figure 3).

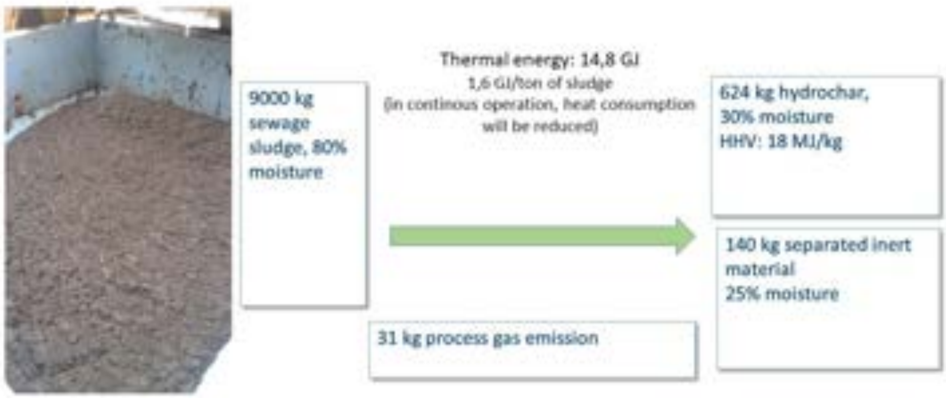

Figure 3. From Sewage sludge to biocharmaterials

3. Jernkontoret 2019 (Stockholm)[8]

A trial using paper sludge as feedstock was performed in Ingelia´s plant in 2019 with the following comparison between hydrochar and paper sludge:

Figure 4. From paper sludge to hydrochar

Table 3. Comparison of the composition of the paper sludge used as feedstock and the char obtained in a trial performed at Ingelia in 2019. Db: dry basis; daf: dry and ash free.

	Moisture (%)	Volatile (% db)	Volatile (% db)	Fixed C (% db)	C (% daf)	S (% daf)
Paper sludge	68.8	64.9	23.1	12	55.3	0.22
Ingelia char	7.5	66.5	16.4	17.1	64.4	0.29

[8] https://www.swerim.se/en/calendar/a-fossil-free-society-what-role-can-the-industrial-symbiosis-play

Due to the speed of the HTC processes and the modularity of Ingelia's process, the plants are upscaled by increasing the number of reactors and they can be installed close to the waste source without odour problems. CO_2 emissions are reduced due to shorter transports of waste, and fossil coal, avoidance of methane emissions and carbon recovery from waste. Following the recommendations of the IPCC (Intergovernmental Panel on Climate Change) for the calculation of CO_2, total $CO_{2\text{-eq}}$ avoided emissions per ton of hydrochar due to activities related to coal mining, waste landfilled, and fossil fuel substitution are estimated to be from 6.5 to 8.4 tons of $CO_{2\text{-eq}}$/ton of hydrochar.

TECHNICAL ASPECTS

HTC process represents a solution for the valorisation of biowaste streams, while generating a carbon-based solid fraction, hydrochar, that can be used as an energy source, a soil ameliorant, or as a feedstock to produce bioproducts. The hydrochar is produced at low temperatures (200—230 ºC) and moderate pressure (20—30 bar) in subcritical water conditions from a wide range of organic residuals. During the HTC process the carbon content concentrates over 60 % (dry and free of ash) in solid products. The residual is transformed into aqueous phase containing the soluble elements. Since the process temperature is around 200 ºC, no problematic compounds are formed in during the process.

Prior to the HTC treatment, the feedstock needs to be grinded and passed through a trommel to remove materials larger than 8 cm. It is also convenient to install a metal separator to avoid large metal parts reaching the process. Another convenient pre-treatment would be the separation of stones and other hard materials that can cause abrasion and equipment degradation.

Figure 5. Ingelia HTC plant

By means of post-treatment processes, small pieces of glass, stones, metals, and other inert materials that have passed through the process are separated. The separation of inert in the post-treatment is done in liquid phase. The ash content in the final solid product obtained in the tests carried out by Ingelia is > 10 %, and the moisture content < 9 %. According to these results, the hydrochar is suitable for combustion in industrial boilers and for biobased raw materials, substituting coal for the industries. Industrial boilers usually have ash extraction facilities and particle separation cyclones.

Recent combustion tests using hydrochar as biofuel have been carried out in industrial boilers with satisfactory results in terms of emissions, without slag formation and with high performance and combustion stability. The use of hydrochar as biofuel supports the substitution of fossil fuels and the reduction of the impact from the emissions derived from the transport of the HTC feedstocks. However, as circular economy principles become more embedded, the 'linear' pathways of combustion for power generation are being superseded by the desire to use waste streams as manufacturing and other feedstocks. Hydrochar, therefore, in addition to be used as biofuel, is gaining more interest as a feedstock for gasification and manufacture of bioproducts, absorbents, soil amendments.

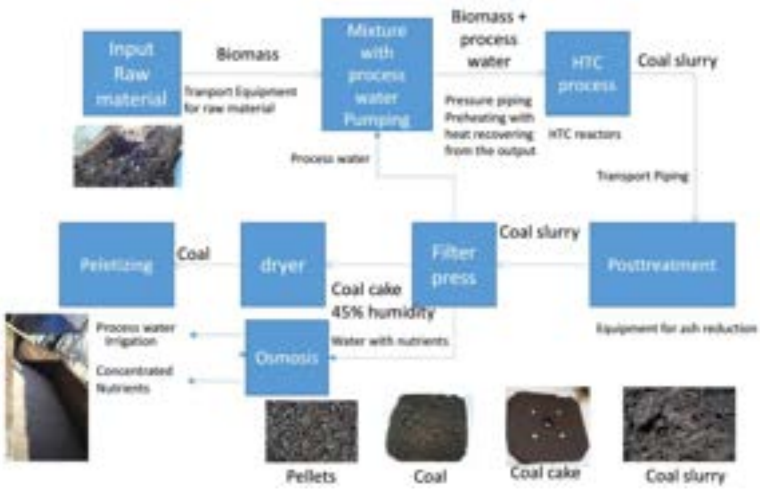

Figure 6. Ingelia HTC Technology flow diagram

In case of heavy metals in the feedstock, they remain mainly in the ash of the hydrochar. That is the case for phosphorus (another critical raw material) that can be extracted by acid leaching techniques, reducing the ash content, and generating an additional raw material for market applications.

The organic content of the excess liquid phase can be easily used as a feed for biogas production by anaerobic digestion, before being discharged. The option of recovering fertilizers from process water, especially potassium and nitrogen, can also be a possible alternative. As the process takes place at low temperature, no nitrogenated aromatics are formed.

Figure 7. Hydrochar obtained in the HTC Ingelia process

An advantage of using HTC process compared to other small scale waste handling processes is the significant decrease in odours and the amount of air that needs to be treated. Once the biomass has entered in the pumping system, the emissions are minimal and easy to manage. Since the HTC process takes place in liquid, only the thermal drying step, included in the post-treatment, implies an air flow that requires a particle removal treatment.

The economic feasibility of the HTC process with organic fraction is obtained by a combination between the biowaste gate fee and the sale of the solid bioproduct obtained.

ECONOMIC ASPECTS

The cost for an HTC plant with treatment capacity of 78 000 tons/year of biowaste (70 % moisture ctent) and production of 15 400 tons/year of hydrochar is shown in the table below. The investment includes a turnkey HTC plant and the post-treatment units. Assuming a market price for the hydrochar of 180 €/ton and tipping fee of 50 €/ton, the project Internal rate of return (IRR) is 18.7%, CAPEX: 351 €/ton of waste; OPEX: 20 €/ton of waste, which is in the range of market drivers.

Since the plant is modular, the treatment capacity can be adapted to the feedstock availability or the needs for local supply of hydrochar, reducing unnecessary transports of waste and products.

The plant can also be installed next to an AD plant or composting facilities providing a solution for the organic residues (digestate or off-spec compost) generated from these processes. In addition, the process water could be reutilized to feed the AD process.

Table 4. Summary of the economic aspects of a Ingela HTC plant

HTC Plant for organic waste 70 % moisture	
Size	10 reactors
Area	5 600 m^2
Investment	27 343 800 €
Wet feedstock processed	78 000 ton/year
Hydrochar produced	15 378 ton/year
Liquid fertilized produced	47 720 m^3/year
Operating costs	
Operating Costs	1 540 505 €/year
O&M	1 269 454 €/year
Technical Service	218 750 €/year
General Expenses	52 300 €/year
Incomes	
Hydrochar sales	6 668 126 €/year
Tipping fee for waste	2 768126 €/year
EBITDA	5 127 622 €/year
Simple Payback	5.3 years

ENVIRONMENTAL ASPECTS

HTC processes take place in a water solution. As the reaction is exothermic, low thermal energy is required and the process is very flexible admitting a wide range of feedstocks regardless of humidity and heterogeneity.

By recovering carbon molecules from organic wastes and sludges, a reduction of methane emissions that, otherwise, would occur during decomposition in landfill is realized. In addition, when the hydrochar replaces fossil coal, the emissions associated with coal use as well as coal mining activities are avoided. Estimations on global emissions of coal mine methane (CMM) were around 40 Mton in 2018, equal to around 1 200 Mton of CO_2-eq. In 2018 the global coal production was 5 566 Mton. Based on these figures, it can be assumed that 0.22 ton CO_2-eq/ton coal were emitted due to liberation of methane contained in coal seams (mining emissions).

Following the World Bank report on waste management, 1.6 billion tons CO_2-eq greenhouse gas emissions were generated from solid waste treatment and disposal in 2016[9]. This is driven primarily by disposing of waste in open dumps and landfills without and without landfill gas collection systems. Food waste accounts for nearly 50% of emissions. Almost 2 billion tons of waste were generated in 2016, of which 44 % was food and green waste. 800 Mtons of CO_2-eq emissions are attributable to landfilling of 887.5 Mtons of waste, which means that approximately the disposal of one ton of waste is responsible for 0,9 tons of CO_2-eq emissions. The conversion ratio from waste to hydrochar, assuming 70 % of humidity in the waste, is 0.18 tons of hydrochar/ton of waste, so that we can calculate that 4.9 ton of CO_2-eq are avoided in non-controlled landfills per ton of hydrochar produced.

Methane emissions from organic waste when deposited in controlled landfills as in most cases in Europe are estimated following the method from the IPCC report[10]. Methane emissions depend on several factors: the waste composition, the management method, and climatic conditions.

The CO_2-eq avoided emissions due to activities related to coal mining, waste landfilled, and fossil fuel substitution are estimated in the table below.

Table 5. CO_2-eq avoided emissions

CO_2-eq avoided emissions	
Average humidity of waste	70 %
Hydorchar produced	0.18 ton/year
CO_2-eq avoided	6.54 – 8.32 CO_2-eq ton/year

The use of the process water for replacement of chemical fertilizers (NP and NPK) will have a positive impact in the CO_2 calculations as well as a reduction of methane consumption for their production. According to the EC report "*Fertilizers in EU*" dated June 2019, producing 1 ton of UREA takes 696 Nm^3 of Methane. However, to make an exact calculation of the impact on the emissions, a life cycle assessment is foreseen with specific assumptions for each project.

[9] World Bank report on waste management
[10] https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_1_CH4_Solid_Waste.pdf

POLICY ASPECTS

The following EU policies support the construction of HTC Plants:

- EU Circular Economy Action Plan[11]
- Waste framework directive[12]
- Waste landfilling
- Sewage Sludge directive 86/278/EEC
- EU climate action[13]

Ingelia has worked hard to certify and standardize the hydrochar according to EU legislation. So far, the hydrochar from green waste, agricultural waste and food waste has been included in the Technical Specification of ISO 17225-8[14]. Currently, national standardization bodies are working on it for it to be adopted in different countries. Also the Joint Research Centre, based on the work of the Strubias group, on Sept.2019 made a publication titled "*Technical proposals for selected new fertilising materials under the Fertilising Products Regulation (Regulation (EU) 2019/1009" where HTC process and hydrochar have been requested to be added respectively, as permitted core process and new component material category (CMC ZZ (pyrolysis & gasification materials)), also opening the possibility to use sewage sludge as input (new Product Function Categories (*PFCs*) of* EU *fertilising products).*

Additionally, Ingelia has already initiated the REACH procedure with the European Chemical Agency, to ensure a safe product for commercialization. In Italy, Ingelia obtained positive feedback from the Environment Protection Agency, demonstrating that the HTC plant capacity to turn organic wastes and sludges into hydrochar, usable for different scopes, such as energy or soil conditioning. Two plants are in operation with biowaste as feedstock, one in Spain and one in the UK and a third plant is under construction in Belgium with biowaste as feedstock.

SOCIAL ASPECTS

Besides enabling energy and carbon recovery from wastes there are further advantages derived from the HTC process:

- Water is also generated in the HTC process originating from the biowaste humidity. After the micro- and nanofiltration process a liquid fertilizer is generated that potentially could be reused for agriculture.
- Fertilizer companies will reduce their CO_2 emissions by incorporating the biofertilizers produced in the plants, so that an improved ecosystem will be created around each project.
- Job creation for plants operation will be created. Around 8 people are required to operate a plant of 10 reactors.

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[11] https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf
[12] https://ec.europa.eu/environment/waste/framework/
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015PC0594 and https://ec.europa.eu/clima/policies/eu-climate-action_en

[14] https://www.iso.org/standard/71915.html

- A beneficial impact on the local economy will be created around the plants' location, due to supply of materials, spare parts and maintenance.

LIFE CYCLE ASSESSMENT

Description of the case study

The aim of this task was to carry out a life cycle assessment (LCA) to assess the environmental impacts of a large-scale HTC plant for conversion of biowaste and sludge (i.e., green waste, food waste, organic fraction of MSW, and digestate) to high quality hydrochar in Italy. The processing capacity of this plant was assumed to process 78 000 ton of wet biowaste per year. The LCA results are intended to identify the environmental impacts/benefits of different biowaste based hydrochar pellets at a large-scale plant in Italy. This LCA study was carried out in accordance with ISO Standards[15,16], and has been internally reviewed. The details of the study, results and conclusions are outlined in the following sections.

Goal and Scope

The functional unit (FU) is defined as one ton of dry biowaste treated by the HTC plant. The selection of this FU in line with other published LCA studies on waste management[17,18], and allows comparison with other waste management processes. The potential environmental impacts are expressed according to this unit.

The specification of the geographical boundaries is an important aspect in LCA as location can influence factors such as biowaste composition, technology type (including waste recovery), and the electricity gid mix. This LCA analysis is based on Italy where possible. The scope of the study is limited to the HTC plant and assumed to be located near to the AD or composting facilities to avoid unnecessary transport of feedstock. Moreover, providing a solution for the reutilisation of digestate and water within the process.

Description of the system studied

The study represents a 'gate-to-gate' LCA and as such the system boundary includes processes from raw material pumping to the operation of the HTC to disposal of waste stream. The aspects of the life cycle considered are resource extraction (for all materials and energy inputs) and operation of the HTC plant. The HTC process includes pumping of feedstock into the reactor, drying and pelletizing, and disposal of post treated ash and treated water. It is important to note that the analysis does not consider upstream impacts from the production of feedstock, hence the 'zero burden assumption' is used which suggests that the waste carries none of the upstream burdens into the waste treatment site. This approach is in line with other published studies which assess the

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[15] ISO, *ISO 14040:2006 – Environmental management – life cycle assessment – principles and framework. 2006.*

[16] ISO, *ISO 14044:2006 – Environmental management – Life cycle assessment – requirements and guidelines. 2006.*

[17] Cherubini, F., S. Bargigli, and S. Ulgiati, *Life cycle assessment (LCA) of waste management strategies: landfilling, sorting plant and incineration.* Energy, 2009. 34(12): p. 2116-2123.

[18] Owsianiak, M., Ryberg, M.W., Renz, M., Hitzl, M. and Hauschild, M.Z., 2016, *Environmental performance of hydrothermal carbonization of four wet biomass wase streams at industry-relevant scales.* ACS Sustainable Chemistry & Engineering, 4(12), pp: 6783-6791.

environmental impacts of waste management systems[18,19,20]. The products of the HTC plant are hydrochar pellets, process waste (treated and reused) and ash (landfilled). The system boundary is shown in Figure 8.

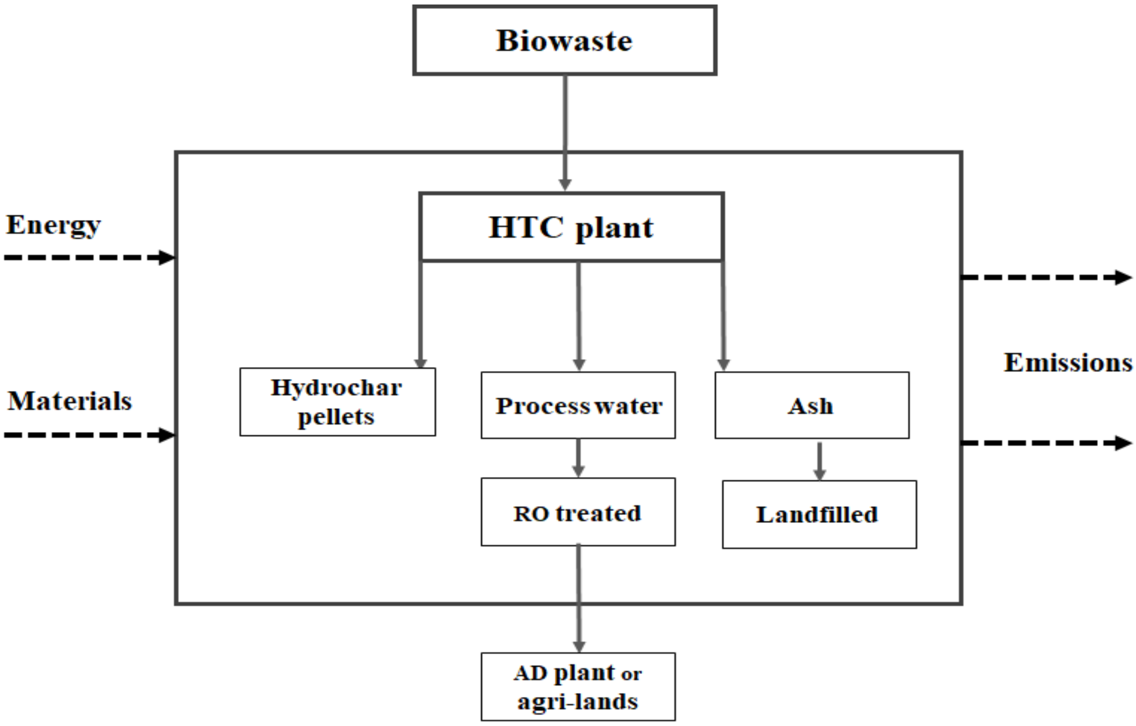

Figure 8. System Diagram

Life Cycle Inventory

The Life Cycle Inventory (LCI) consists of the data collection associated with the different process stages. The data inventory compiled for this LCA study consists mainly of data specific mostly to Italy. When specific data were not available, data were based on average European data. Foreground data for the HTC was adopted from Owsianiak et al[21] and scaled to the industrial level and represented in Table 6. Life Cycle Inventory per functional unit (one ton of biowaste). Electricity production in Italy was obtained from Ecoinvent data which contains data on the electrical grid fuel mix from 2017[22]. The thermal energy production and use in the study was considered at an industrial scale using the

[19] Eriksson, O., et al., *Municipal solid waste management from a systems perspective*. Journal of Cleaner Productions, 20005. 13(3): p. 241-252.
[20] Fruergaard, T., T. Astrupo, and T. Ekvall, *Energy use and recovery in waste management and implications for accounting of greenhouse gases and global warming contributions*. Waste Management & Research, 2009. 27(8): p. 724-737.
[21] Owsianiak, M., Ryberg, M.W., Renz, M., Hitzl, M. and Hauschild, M.Z., 2016. *Environmental performance of hydrothermal carbonization of four wet biomass waste streams at industry-relevant scales*. ACS Sustainable Chemistry & Engineering, 4(12), pp.6783-6791.
[22] Ecoinvent, T., T. Astrup, and T. Ekvall, *Energy use and recovery in waste management and implications for accounting of greenhouse gasses and global warming contributions*. Waste Management & Research, 2009. 27(8): p. 724-737.

feedstock softwood chips from forest burned in a furnace of 1,000 kW capacity with Europe as geographical location. Reverse osmosis (RO) data set (global) with 8-inches spiral wound modules SW30HR-380 and 35.3 m^2 of active surface per module was used in the analysis for process water treatment and obtained from the Ecoinvent database[20]. The ash landfilling was analysed using dataset "process-specific burdens, residual material landfill" available in the Coinvents database. This process considers inorganic landfill for polluted inorganic wastes with carbon content below 5 %.

Table 6. Life Cycle Inventory per functional unit (one ton of biowaste)[23]

Inputs & Outputs	Units	Green Waste	Food Waste	Organic fraction of MSW	Digestate
Inputs					
Waste	ton dw	1	1	1	1
Moisture content	%	45	84	34	59
Electricity for pumping	kWh	0.003	0.003	0.003	0.003
Thermal Energy	kWh	611.1	611.1	611.1	611.1
Electricity for drying & pelletizing	kWh	40	40	40	40
Electricity for reverse osmosis	kWh	0.540	0.370	0.620	0.560
Outputs					
Raw hydrochar	ton dw	0.590	0.370	0.720	0.560
Cleaned hydrochar pellets	ton dw	0.54	0.37	0.62	0.56
Process waster	ton	0.5597	0.8543	0.4714	0.6678
Ash	ton	0-0703	0.0179	0.1011	0.0597
N in waste stream	ton	0.0011	0.0017	0.0008	0.0013
P in waste stream	ton	0.0001	0.0001	0	0.0001
Inputs & Outputs	**Units**	**Green Waste**	**Food Waste**	**Organic fraction of MSW**	**Digestate**
K in waste stream	ton	0.0002	0.0008	0.0005	0.0009
Carbon dioxide (CO_2)	ton	0.0624	0.0434	0.0257	0.0118
Carbon monoxide (CO)	ton	0	0.0006	0.0004	0.0006
Hydrogen (H_2)	ton	0	0.0001	0.0009	0

[23] Owsianiak, M., Ryberg, M.W., Renz, M., Hitzl, M. and Hauschild, M.Z., 2016. *Environmental performance of hydrothermal carbonization of four wet biomass waste streams at industry-relevant scales*. ACS Sustainable Chemistry & Engineering, 4(12), pp.6783-6791.

Life Cycle Impact Assessment

Environmental impacts considered include terrestrial acidification (TA) expressed in kg SO_2-equivalents, freshwater eutrophication (EP) expressed in kg PO4-equivalents, and global warming potential (GWP) expressed in kg CO_2-equivalents. ReCiPe 2016 Midpoint (H) methodology[24] was used in characterising the environmental impacts.

Results

Table 7. Life cycle impacts for processing of 1 ton of biowaste to hydrocar pellets shows the results of the impact assessment for different biowaste conversion to hydrocar at an HTC plant with 78 000 ton per annum capacity. The table shows the impacts per ton of biowaste treated, with major contributing factors (CO2/phosphates, electricity, and thermal energy) highlighted across the study. HTC of 1 ton of biowaste causes total global warming (GW) emissions in the range of 73 to 110 kg CO_2-eq, acidifying emissions of 0.355 to 0.511 kg SO_2-eq, and eutrophying emissions of 0.020 to 0.102 kg P-eq. With highest global warming (GW), freshwater eutrophication (FE) and terrestrial acidification (TA) for treating green waste (110.4 kg CO_2-eq), food waste (0.102 kg P-eq) and digestate (0.511 kg SO_2-eq), respectively. The higher GW, FE and TE values within the study were mainly due to the higher levels of CO2 released in the process and the presence of organic contents in the waste streams. The higher NPK contents in the waste streams of green, food waste and digestate waste makes it nutritionally rich process and leading to higher eutrophication emissions. The electricity usage is the prime contributor to GW in for MSW and digestate feedstocks. The terrestrial acidification (TA) across all the processes was mainly due to emissions involved in the resource extraction and production of electricity and heat.

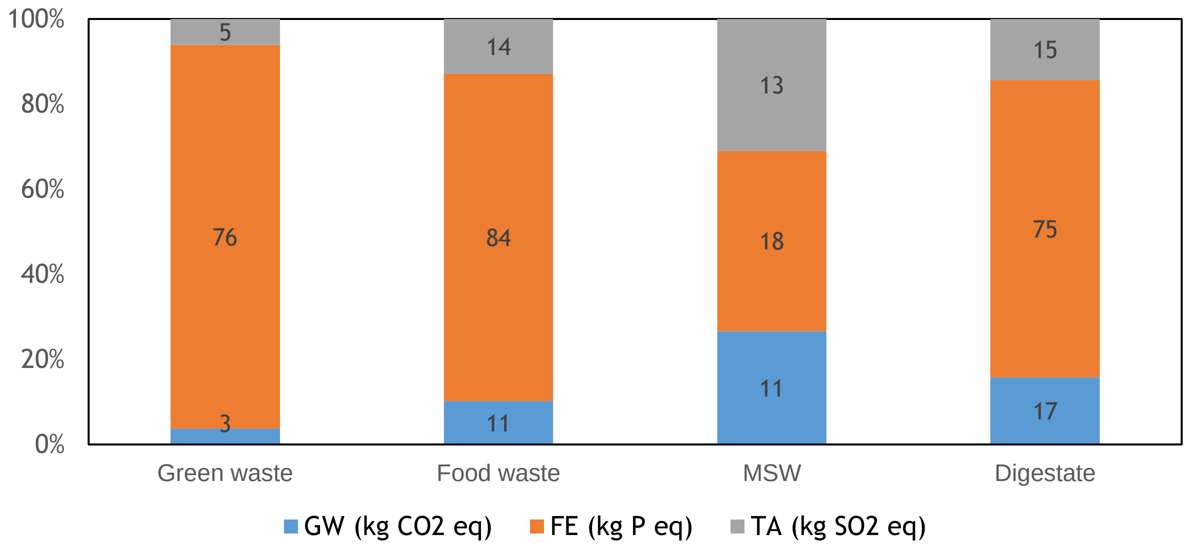

Figure 9. Avoided emissions by reusing the wastewater stream for agri-land

Table 7 shows that freshwater eutrophication (FE) is highly affected in all the waste conversion

[24] Huijbregts, M.A., Steinmann, Z.J., Elshout, P.M., Stam, G., Verones, F., Vieria, M., Zijp, M., Hollander, A. and van Zelm, R., 2017. *ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level*. The International Journal of Life Cycle Assessment, 22(2), pp. 138-147.

processes except MSW, where all three impacts were almost equally avoided. Reusing the process water, and displacement of NPK-based fertilisers in the field would reduce the eutrophication emissions in the current process significantly, ranging from a 17.62 to 76.10% reduction depending on the feedstocks. The higher range of avoided FE emissions can be attributed to the presence of nutritionally rich (NPK contents) in the process water stream (Table 1). Whereas GW and TA impacts are reduced to a lesser extent, however, have a more significant impact in the HTC process with MSW as feedstock.

Table 8 demonstrates the comparative impacts associated with HTC technology utilising different resources across various geographical locations. The aim of this comparative analysis was to ascertain the impacts of HTC technology if it was operating in different parts of the world. It is evident in Table 7 that energy consumption esp. electricity is one of the major contributing elements that can be linked directly to the impacts of the system. Therefore, considering the average electricity grid mix from different countries would provide an estimation of emissions that would facilitate the stakeholders to strategically plan the establishment of HTC plant in future in a particular location or country by keeping environmental sustainability in mind.

The LCA analysis revealed that the GWP and TA were higher for the HTC technology when South Africa (SA) is the place of operation, whereas FE was higher in case of Australia (AU). Higher GWP and TA can be attributed to the source of production of electricity in SA i.e., primarily coal which accounts for 88.8% of the total electricity produced in the country. Whereas FE was dominating in AU electricity grid mix due to its higher phosphate emissions (68 times) involved in electricity production than SA based electricity. However, Norway (NO) was found to be best in terms of impacts as the primary energy for electricity production is 98% renewable leading to lower emissions in comparison to other countries fossil dominating electricity production Moreover the hierarchy of the impacts with respective to the countries analysed i.e., from higher to lower values is also shown in the bottom of the Table 8.

Table 7. Life cycle impacts for processing of 1 ton of biowaste to hydrocar pellets

Biowaste	Green Waste				MSW				
Impacts	**CO_2/phosphates**	**Electricity**	**Thermal Energy**	**Total**	**Impacts**	**CO_2/phosphates**	**Electricity**	**Thermal Energy**	**Total**
GWP (kg CO_2-eq)	62.436	37.94	9.81	110.44	**GWP (kg CO_2-eq)**	25.68	37.79	9.82	73.61
FE (kg P-eq)	0.05461	0.01	0.0038	0.073	**FE (kg P-eq)**	0.0018	0.0145	0.0038	0.0202
TA (kg SO_2-eq)	----	0.18	0.17	0.356	**TA (kg SO_2-eq)**	----	0.18	0.172	0.35

Biowaste	Food Waste				Digestate				
Impacts	**CO_2/phosphates**	**Electricity**	**Thermal Energy**	**Total**	**Impacts**	**CO_2/phosphates**	**Electricity**	**Thermal Energy**	**Total**
GWP (kg CO_2-eq)	43.45	40.10	9.82	93.87	**GWP (kg CO_2-eq)**	11.80	54.68	14.12	80.87
FE (kg P-eq)	0.083	0.015	0.0038	0.10	**FE (kg P-eq)**	0.065	0.021	0.0055	0.092
TA (kg SO_2-eq)	----	0.19	0.172	0.36	**TA (kg SO_2-eq)**	----	0.26	0.248	0.511

Impact category	Unit	Incineration	Sodium hydroxide	Quicklime	Chemicals organic	Chemicals inorganic	Light fuel oil	Electricity	Incineration on plant	Residues Disposal	Total
Global warming	kg CO_2-eq	917.46	6.47	15.22	2.63	3.09	3.68	36.48	3.42	1.15	989.59
Acidification	kg SO_2-eq	0.69	0.03	0.01	0.01	0.03	0.01	0.08	0.01	0.01	0.87
Eutrophication	kg PO_4-eq	0.11	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.16

Table 8. Environmental impacts of HTC system with different source feedstock and across various geographical locations

Impacts	Global warming potential (GWP kg CO_2 eq)				Fresh water eutrophication (FE, kg P eq)				Terrestrial Acidification (TA, kg SO_2 eq)			
Waste	***Green waste***	***Food waste***	***MWS***	***Digestate***	***Green waste***	***Food waste***	***MWS***	***Digestate***	***Green waste***	***Food waste***	***MWS***	***Digestate***
Country												
Italy (IT)	110.444	93.87	73.61	80.87	0.073	0.102	0.020	0.092	0.356	0.36	0.35	0.51
Ireland (IE)	124.039	108.23	87.14	100.47	0.017	0.018	0.017	0.025	0.34	0.36	0.34	0.49
South Africa (SA)	187.623	174.90	150.53	192.07	0.084	0.088	0.083	0.12	1.21	1.27	1.21	1.74
Australia (AU)	170.771	157.09	133.75	167.78	0.15	0.16	0.152	0.22	0.49	0.50	0.49	0.70
Norway (NO)	75.551	56.99	38.85	30.58	0.0061	0.0062	0.0061	0.0088	0.18	0.18	0.18	0.26
Sweden (SE)	77.231	58.77	40.52	33.01	0.0073	0.0075	0.0073	0.011	0.195	0.19	0.19	0.28
United states (US)	146.114	131.02	109.18	132.24	0.0771	0.081	0.077	0.11	0.366	0.37	0.36	0.52
GWP: *SA>AU>US>IE>IT>SE>NO*; **FE:** *AU>SA>US>IT>IE>SE>NO*; **TE:** *SA>AU>US>IT>IE>SE>NO*												

LESSONS LEARNED / RECOMMENDATIONS

HTC process offers a unique way to recover materials from organic wastes and sludges which are otherwise difficult and expensive to be valorised. This novel technology has been developed at industrial scale during the last 10 years and represents a very stable and simple process which simulates an accelerated process similar to the natural formation of coal. The products generated within the HTC plants can be adapted to the industry's requirements by applying further post-treatments enabling the industries to substitute fossil coal, reducing the CO_2 emissions and encouraging circular economy.

Environmental authorisations for HTC plants should be as simple as possible in order to shorten the time to market of this new and interesting process to valorise organic waste. A coordinating group of experts could give general advice to public administrations in order to simplify the procedures.

ATTACHMENT 2

New technological applications for wet biomass waste stream products

Reporting

Project Information

NEWAPP

Grant agreement ID: 605178

Closed project

Start date
1 November 2013

End date
30 April 2016

Funded under
FP7-SME

Overall budget
€ 2 580 061,78

EU contribution
€ 1 756 000

Coordinated by
EUROPEAN BIOMASS INDUSTRY ASSOCIATION
Belgium

Final Report Summary - NEWAPP (New technological applications for wet biomass waste stream products)

Executive Summary:
1. Executive summary (1 page)
Approximately 120 to 140 million tonnes of bio-waste are produced every year in the EU [1]. This corresponds to almost 300kg of bio-waste produced per EU citizen per year. From these, a substantial amount is organic waste. These, also called wet biomass waste streams, (i.e. wet agricultural residues, wet municipal waste such as foliage, grass or food waste), are abundantly available in Europe, while their disposal and recycling becomes increasingly difficult as energy efficient, environmentally sound and economically viable processes hardly exist.
NEWAPP aims at developing an alternative cost- and resource-efficient and environmentally sound way of dealing with wet biomass waste through HTC technology.

The existing treatment methods for these streams are mainly incineration or landfilling, 67% of the waste is disposed of in these ways. A small amount is composted, digested anaerobically or used as animal fodder. However, the most used methods are not the best: landfilling not only takes up more and more valuable land space, it also causes air, water and soil pollution, discharging carbon dioxide (CO_2) and methane (CH_4) into the atmosphere and chemicals and pesticides into the earth and groundwater. This, in turn, is harmful to human health, as well as to environment.
In parallel to the growing amount of biowaste there is a fast growing demand for new raw materials worldwide. Applications such as chemical separation, water purification, catalysis, energy conversion and storage, bio imaging, fertilization and soil remediation and fuels are based on high value products and secondary raw materials demanded by our current technological growth and society. These products have several aspects in common: they are scarce, expensive, located in very concrete regions of the world and carbon based. The concept behind NEWAPP is that wet biomass can be a resource more than a waste, and does not need to be disposed of in the costly and inefficient way it is nowadays. The alternative, which NEWAPP introduces, is to create a continuous system which will allow to recover carbon in an energy efficient for tailor made HTC (Hydrothermal carbonization) products way. NEWAPP will focus on green waste, agricultural waste, municipal solid waste, waste from food processing industry and waste from markets for running the HTC process and exploring the possibility to obtain high-value carbon products.
NEWAPP will gather international researchers, industrial associations and SME's from different European countries in its thirty months lifecycle to assess the requirements and constraints of SME-AGs in the reuse of wet biomass with HTC, analyse the potentials of the different wet biomass streams for using them for HTC, perform intensive testing with this innovative system technology for heat recovery and efficiency for tailor made HTC products launch a standardization process for the two most promising waste streams to prove their viability for commercial applications.
Project Context and Objectives:
HTC consists in applying high temperatures and pressures to biomass in the presence of water, which results in two main products: a coal-like product (hydrochar) and water-soluble products. This process allows converting different biomass streams, such as waste, into fuels and other substances of industrial interest.
There is a clear need to develop new technological pathways for reuse that are economically attractive and environmentally sound at the same time. Promising technologies such as hydrothermal carbonisation show high potentials but so far only very few commercial units have been present on the market. Up to now there have been some experiments done with municipal solid wastes at lab scale aiming to take and separate carbon in order to get high value products through the HTC process. Different products can be obtained from this process, such as active carbon, electrodes, fertilizers, etc. NEWAPP will focus on green waste, agricultural waste, municipal solid waste, waste from food processing industry and waste from markets for running the HTC process and exploring the possibility to obtain high-value carbon products. In 2011, EU-27 imported these products for a value of 22.666.570.073 €, while it exported for a value of 1.917.542.097 €, 12 times less. At the same time, EU generates yearly 80.000.000 tons of wet biowaste that can be effectively recycled to carbon materials by means of HTC. Based on this it can be concluded that EU industry has a need for carbon products, as fuel and as raw material.
This existing technology requires however, of several improvements in order to be ready to be used at the large scale as a reuse alternative for wet biomass. Pre- and post-treatment, are critical points for HTC, and pose questions not yet answered for a widespread implementation. The adequate mix of different kinds of wet biomass and the fine-tuning of the systems required for reaching high efficiencies are is still a

hindrance for HTC at the industrial scale.
NEWAPP has gathered international researchers, industrial associations and SME's from different European countries in its thirty months lifecycle to (1) assess the requirements and constraints of SME-AGs in the reuse of wet biomass with HTC, (2) analyse the potentials of the different wet biomass streams for using them for HTC, (3) perform intensive testing with this innovative system technology for heat recovery and efficiency for tailor made HTC products (4) launch a standardization process for the two most promising waste streams to prove their viability for commercial applications.
The developments in NEWAPP have targeted the upgrade of turning waste into new resources using HTC process and have paved the way to provide economically attractive and environmentally friendly alternatives to utilisation of wet biomass, allowing European SME-AGs to advise their SME members to use the optimal utilisation technologies for their specific needs. The companies from the biomass and waste sectors usually belong to at least one sector-specific association. It is from these that new technologies are introduced in the sector and standards and codes of practice are set. As NEWAPP aims at making a broad impact in these sectors, the scheme of research for SME Associations has been chosen by the three SME-AGs leading the consortium, two of them Europe-wide associations (EUBIA and ACR+) and one of them working at the national level (BSVE, Germany).
Increasing amounts of urban organic waste and farm organic residues are produced and often landfilled or burnt in Europe. The total annual amount of bio-waste in the EU is estimated at 76.5 - 102 Mt food and garden waste included in mixed municipal solid waste and up to 37 Mt from the food and drink industry. In addition, annually around 700 Mt of agriculture wastes are produced within the EU, which represents a high load for farmers due to the numerous problems they face handling them.
This consortium has aimed to combine the above and increase the amount of bio-waste diverted from landfill and burning into high value products that can be used as fuel, activated carbons for water treatment, soil remediation, carbon sequestration schemes and other applications. This requires the transformation of urban organic waste and farm organic waste from a costly disposal process into an income-generating activity.
In Europe there is a surplus of organic waste of municipal and agricultural origin. The material was, and in many countries still is, discarded in landfills or, for some agricultural wastes, burned in the field. Both practices are no longer acceptable in a modern European context and European targets for reduction have been set (EC, 2008).
Bio-waste is a putrescible, generally wet waste. There are two major streams – green waste from parks, gardens, and kitchen waste. The former includes usually 50-60% water and more wood (lignocelluloses and cellulose); the latter contains no wood but up to 80% water. Currently, the data collected under the Waste Statistics Regulation is not of sufficient detail on a country by country basis to relate to the definition of biowaste launched in COM(2008) 811 final (EC 2008, EC 2002). However, for the European Waste Code (EWC) for animal and vegetal wastes, which also includes manure and the like, European wide data is available.

Waste reduction initiatives have been active for the past decades, but their impact is not large enough to solve the waste disposal problem. In parallel, the demand for energy has increased in the EU-27 countries, as well as the need to use renewable energies. The EU has set a target of 20% of energy from renewable and an increase of 20% in energy efficiency by 2020, which will not be met only through brand new development (i.e. installation of solar fields). Taking existing resources, like waste, and using their potential achieves success faster while promoting innovation in already mature sectors. The impact of this innovation is much higher in terms of revenues and employment, because it strengthens the existing industrial fabric. NEWAPP is composed by national and international SME-AGs that acknowledge the potential of HTC treatment of wet biomass and its reuse for energy, and have the means to spread these innovations to a large number of SMEs at European level.

To achieve this, the consortium has focused on:
Developing a new technical utilisation pathway for turning biowaste into high value products. Hydrothermal carbonisation is a technology that already exists. However, a suitable solution for its up-scaling, energy consumption optimization or technology costs not yet been developed, despite the huge potential it represents. Additionally, the knowledge on what products can be obtained by what exact biowaste is very limited. The starting point of NEWAPP will be to address the existing technological barriers that these heterogeneous waste streams pose for our technologies and to assess the conditions that need to be met for the successful implementation of HTC.
Exploring what different products can be obtained from the selected waste streams after the HTC process. HTC carbon can be further upgraded to high-value materials by physical and/or chemical speratation methods for more sustainable applications than simply burning. By a purely thermal treatment it can be split into two parts – fixed carbon together with the inorganic matter and volatile part. Up to present the volatile part has not been separated and characterized. The fixed carbon together with the inorganic content is the lower value part that can be used for energy valorization or studied as fertilizer for crop plants. As the volatile part is ash-free and has a more homogeneous composition with a very low lignin derived content, its separation will be a possibility to obtain purified HTC material suitable for specialised applications.
Standardization. The results achieved will enable the partners to the first st of standards for HTC products to be distributed to through the participating SME-AGs to their members. The focus will be on achieving a large implementation, ensuring products with properly quantified relevant calorific value. The need to meet quality and safety standards will stimulate the waste management industry to improve the bio-waste treatment process and will thus lead to technological development. No coherent set of product norms dealing with sufficiently detailed end user needs and environmental and human safety standards has been proposed yet.
Techniques for added value. This consortium will develop and introduce several techniques for the application of the products of HTC with increased added value for energy purposes, farmers (as soil amendment) and other industrial uses, such the creation of activated carbons and nanostructured materials.
The above focuses will create a virtuous cycle which will increase mutually beneficial interactions between urban and rural areas. It will create new opportunities for the waste and related industry and it will reduce the negative carbon and nutrient footprint of cities. It will also enhance the environmental sustainability of energy production while simultaneously contributing to climate change mitigation.
Technical objectives
- Turning 20% of the presently disposed biowaste into high-value carbon products
- Finding and testing the 5 most appropriate wet biomass waste streams for obtaining different products – green waste, agricultural waste, municipal solid waste, waste from food processing industry.
- To develop a suitable, practical and scalable HTC carbon separation procedure
- To improve the potential for producing more high-value carbon products by optimized pre- and post treatment of biomass

- Defining the 4 most valuable carbon products that can be obtained with HTC, their production methods, potential applications, and market opportunities
- A full characterization of the effects of different wet biomass streams in the HTC reactor, as well as the products obtained, creating standards for high-value HTC products

Economic objectives:
- To reduce the HTC carbon product costs by 10%
- To develop an upgrading process for wet biomass which is 25% more cost efficient than existing disposal and treatment procedures
- To target a market of 10 000t of biowaste to carbon products (approx. 1.5M €)
- To substitute 20% of the currently imported carbon products with HTC carbon upgraded ones
- To strengthen the waste-to-enegy sector, increasing the amount of waste treated with technologies for the production of energy
- To create a business plan for the implemetation of the technologies developed in the project
- To define a set of quality standards for the use of wet biomass that will enable the producers and the energy industry to build reliable business

Social and environmental objectives:
- Increase SMEs and farmers´ knowledge, acceptance, and practices of new methods for biowaste reuse
Reduce negative environmental impacts (soil contamination) of improper waste disposal and reuse
- Protect/increase employment in the agricultural sector
- Reduce citizen´s health risks associated with improper application of waste disposal and application to agriculture
- Inform about and help meet current legislations/guidelines, present novel and efficient solutions for treatment and reuse of waste to policy makers/legal representative and last but not least help harmonize these efforts on a European scale.

The partners behind NEWAPP are convinced that it is by taking action at the association level that the results obtained by a project like this will reach the highest impact level in all EU Member states. The two international associations in the consortium have the means to disseminate the results, especially the standards and implementation decision tool, to a large number of national associations and SMEs. A similar scheme is ensured by the national association BSVE acting in Germany, which aims at achieving an uptake of these results in at least a 35% of the SMEs it represents.

Project Results:
The work performed in the first period focused on the selection of the biomass waste streams that would be dealt with, their characterization and the assessment of their potential. The partners dealt also with the description of the marketable products to be obtained from HTC, and the definition of the characteristics these have to comply with in order to be competitive in the current markets. Once the waste streams were selected, their HTC processing started in the pilot plant in Náquera, Spain. The purchase, building and commissioning of new equipment required in WPs 2, 3 and 4 resulted in a stop in this phase and a delay in the technical development of the project.

This delay was overcome in the second project period. The partners worked in the improvement of the coal obtained, specifically in the reduction of inorganic and halogen content, with positive results. In WP3 the partners studied the different fractions obtained and their applications. The hydrochar obtained was separated successfully into two parts: a solid one and a viscous liquid. The viscous liquid obtained was

further evaluated for its use as liquid fuel. A direct use as drop-in diesel fuel cannot be recommended but its use as a refinery feedstock would definitely be feasible.
A second application the solid product fraction was the preparation of battery electrodes. However, although the surface area stipulated in the DoW of 350 m2/g was obtained, the whole composition with an elevated inorganic content made the material unsuitable for this application. Therefore, an alternative higher value application for which the ash content could be tolerated was chosen: the use as adsorbent for waste water treatment, as a substitute for active carbons. Furthermore, the potential of hydrochar for soil amelioration if hydrochar can be a suitable substitute for the biochar that is currently used in soil amelioration products was studied. The results were in line with existing literature, and indicate some negative effect in plant growth. The exact reason for that, and possible solutions have been identified (i.e. co-composting), but this would require a longer testing period, beyond the time available in NEWAPP.
Once results were obtained in this respect, the work shifted towards the technology assessment, LCA, and the development of a suitable business plan, as well as the quality standards for the reuse of waste biomass. The connections of the partners in the consortium with standardization bodies that are working on standards for HTC allowed them to share information and harmonise NEWAPP's results with ongoing initiatives, which will render these result much more useful in this nascent industry.
Demonstration workshops were held at the Ingelia plant throughout the second period. In order to achieve a higher demonstration impact, workshops were also held remotely, using audiovisual material and HTC-coal samples to demonstrate the process. As a result of these activities, new HTC plants are planned to be built by Ingelia in the coming years (i.e. in Italy).

Finally, the RTD partners prepared training materials and gave training to the SMEs and associations in the project. As a means of achieving a long-lasting transfer of the project results, the partners prepared a handbook on the main activities and results of the project. In this way, NEWAPP has published the first long and comprehensive publication, and made it available for free at the website.

All partners contributed to the dissemination of the project's objectives, and NEWAPP has been present in six international scientific conferences and has appeared in local, regional and national media of the countries represented in the consortium.

• Result 1: New waste biomass reuse technologies based on HTC developed and tested
The work performed in WPs 1 to 4, especially 2 and 3, will render new ways to valorise waste, focusing on the use of waste streams selected by the SME-AG and SME partners in the project and the technological improvements described in WPs 2 and 3.
This result has been achieved in the successful completion of WPs 2 and 3. The project has developed new knowledge about the characteristics and uses of HTC coal, both indicating feasible uses and identifying others that are not directly achievable in with the substrates used. The impact of this result goes beyond the pure academic success, to devising new ways to deal with specific waste biomass streams.
• Result 2: Quality standards for the reuse of wet biomass waste streams
Defined in D 4.2 they will comprise the range for a variety of parameters that the biomass products must have in order to comply with the conditions from the industry for their use: maximum, minimum and optimum, for example for Cl- content, calorific value, etc. As a variety of uses will have been studied in WPS 1-4 (energy, soil amendments, water quality, etc), D4.2 will include the assessment of the industry requirements and real performance values obtained at the lab or prototype tests.

This result has been fully achieved. Furthermore, the NEWAPP standards have been presented to ISO, to be considered in the the ISO 238 technical committee for the elaboration of standard EN ISO 17225-8. In this sense, NEWAPP has maximized its impact and provided a long-lasting effect in future standards.

• Result 3: Decision tool for the implementation of wet biomass reuse technologies
The completion of WPs 4 and 5 will entail the achievement of result 3: the information gathered along these tasks will allow the RTDs to complete a decision tool for the SME-AGs, their members and the SME partners to choose what waste streams can be treated best with HTC, and what products are the most appropriate for their markets.
The work carried out throughout the project has led to the successful completion of this result. The knowledge generated after treatment of different biomass waste streams, their analysis and further consideration of LCA and business plan will enable municipalities to consider HTC as a viable option for waste treatment. This approach has already born fruits in the most recent agreements at Ingelia for establishing new plants in Italy.
• Result 4: HTC carbon products developed
Result 4 deals with the carbon products developed, and the processes used how to obtain them, as well as their commercial exploitation. This result is directly linked with the work in WPs 1 to 5.
The work performed in WPs 1,2 and 3, which was later demonstrated to relevant stakeholders has led to the achievement of this result. As described in WP3, NEWAPP has generated new knowledge on the products that can be obtained from waste biomass and their market placement.
• Result 5: Cost-benefit analysis
This result will be comprised in Deliverable D 4.1 result of task 4.3 and it will give the end- users potential calculations of inputs required for a theoretical HTC system for the products studied in the project, investments required for the implementation and selling prices.

This result has been achieved, and is a valuable tool for the relevant stakeholders to decide on the installation of an HTC plant. This will enable an easier and broader implementation of HTC.

S&T work that led to the achievement of the project’s results:
Work package 1: Characterization of wet biomass waste streams and definition of end-user requirements
Task 1.1 Screening of suitable wet biomass waste streams
The aim of Task 1.1 was to screen the available wet biomass waste streams on a European level both in qualitative and quantitative terms under consideration of their economic relevance.
It was originally planned to send out questionnaires to relevant stakeholders to obtain the required data. Based on unsatisfactory experiences the consortium had made with questionnaires in previous projects it was decided to use the Statistical Institute of the European Union (EUROSTAT) databank to obtain the data and to crosslink the data with the data on waste generating sectors from NACE-2. The results of the questionnaire were used to fill information gaps afterwards. Moreover the literature study and the chemical analyses conducted in Task 1.2 were taken into account.
Four criteria were established to identify suitable wet biomass waste streams:
1) The waste must be or contain an organic fraction
2) It must be available in sufficient volume
3) It must not have a suitable application as secondary raw material yet

4) It must be suitable for HTC with respect to composition

In the beginning ttz identified 13 waste stream categories containing carbon in the EUROSTAT database (e.g. wood wastes, vegetal wastes, animal faeces, urine and manure, household and similar wastes, different types of sludge, etc.) which were reduced to five categories after the application of the four criteria stated above. In a workshop conducted in the kick-off meeting questionnaires were developed for each of these waste stream categories and sent out to the respective actors, i.e. municipalities, waste managers, water treatment plant operators and digestion plant operators. The Associations participating in the project had an important role in the distribution of the questionnaire: for ACR+, Mr Jean-Jacques Dohogne and Ms Françoise Bonnet gave important input to develop the questionnaire to gather information on which types of wet biomass are of utmost interest for treatment and in which season, in task 1.1. In the same task, Ms Cristina Mestre Martinez and Ms Lisa Labriga conducted comprehensive dissemination activities to spread the questionnaire amongst the members of ACR+ and to motivate them to fill them in. This included mass mailings, articles in the weekly Newsletter of ACR+ plus personal mailings and calls to some members, in the months February – April 2014. EUBIA disseminated the project to its members in order to get information regarding most interesting waste biomass streams to process in HTC. In addition, EUBIA participated to the dissemination of the questionnaire to about 40 contacts of municipalities. Bvse participated in the discussion on the characterization of biomass within NEWAPP on the knowledge of characterization of biowaste from the requirements of national und European legal framework, i.e. European Waste Framework Directive, EU 1774/2002 and EU 1069/2009, and in Germany, i.e. the Bioabfallverordnung, the Klärschlammverordnung, the Düngemittelverordnung, the Düngegesetz and the Düngeverordnung. Bvse provided an overview on the biomass streams in Germany accordingly to waste flows and agriculture origin was given. Hence, first suggestions for the selection of suitable biomass streams for HTC processing on the knowledge of main biomass waste flows in Germany were performed. Dr. Thomas Probst, from bvse: took part in the discussion of various biomass streams in Europe, which could be suitable for HTC processing. He also participated in the evaluation of conventional biomass processing in Europe, as well as in the discussion of the data available from national and European statistics, bvse contributed significantly to the identification on the restrictions of processing various biowaste flows for hygienic reasons and their transport requirements to the processing plant. The SMEs Terra Preata and Ingelia supported the rest of the partners in the discussions that led to D 1.1 the preparation of the questionnaires and their distribution among their network of contacts. Ingelia also provided the boundary conditions for the waste streams to be successfully processed with HTC.

After analysing the data obtained from the questionnaires and considering the data obtained in the literature studies and practical biomass analyses of Task 1.2 five biomass waste streams were selected that were identified to be most suitable as feedstock for the HTC process and will be further considered in NEWAPP:

1) Sewage sludge from domestic wastewater treatment plants
2) Digestate from the biogas production
3) Biomass from garden prunings
4) The organic fraction of municipal solid waste (OFMSW)
5) Vegetable waste from markets and similar waste

DTU contributed to task 1.1 in the identification of companies, municipalities and institutions dealing with one of the identified waste streams (i.e. organic household waste) in Europe, distributed questionnaire to them, and analysed their responses. Additionally, Mr. Morten Ryberg identified and collected literature data to complement results from questionnaire analysis. Both results are included in D1.1. Mr. Mikolaj

Owsianiak gave an important input to D1.1 by describing the methodology used to screen wet biomass waste streams in Europe suitable for HTC.
As a common result of Task 1.1 and Task 1.2 detailed information in terms of the availability and the chemical properties of all five selected biomass waste streams was compiled and first conclusions on how to process them were drawn. All the information obtained in Tasks 1.1 and 1.2 can be found in Deliverable D1.1 “Screening and chemical analysis of suitable wet biomass waste streams” which was submitted to the Commission on June 30th, 2014.

Task 1.2 Chemical analysis of wet biomass

Task 1.2 completed the work performed in task 1.1. First, to obtain relevant and representative Europe wide results a statistical review was conducted using the Statistical Institute of the European Union (EUROSTAT) databank. After a short evaluation, further information was been retrieved by cross linking the data with the data on waste generating sectors from NACE-2. Then, data have been further completed by a questionnaire survey, carrying out analysis and literature research.
Evaluation of the data was done after all steps and decisions were made when possible depending on the available data. Four criteria were established. The first one was a very soft one which was only applied (criterion 1 in Figure 1) to get the widest range of waste stream categories that are or contain organic fraction. Three further additional criteria were established which were applied in each evaluation step: (i) it must be produced in sufficient volume; (ii) it must not have a suitable application as secondary raw material yet, and (iii) it must be suitable for HTC with respect to composition.
CSIC carried out literature surveys for data on chemical properties of food waste, garden prunings, green waste, the organic fraction of municipal solid waste, sewage sludge and digestate from biogas production plants. CSIC carried out all analysis summarized in D1.1. The biomass was obtained from sewage sludge, digestate, green waste/prunings and OFMSW. These analysis involved analysis of humidity, pH (if applicable), elemental analysis (CHNS), ash content, lignocellulosic composition, and lignine and hollocelulose among others. Higher heating value was determined at CSIC in Zaragoza.
The final conclusion was the selection of the following five biomass waste streams for the trial in WP2 and further considering in the project:

- sewage sludge
- digestate residue from biogas production
- green waste/garden prunings
- OFMSW
- food market waste/vegetable waste

Task 1.3 Identification of marketable products, definition of end-user product requirements

The aim of Task 1.3 was the identification and quantification of the most interesting carbon products that can be produced from HTC carbon and to determine the characteristics and quality parameters that the produced HTC carbon must comply with.
During the preparation of the project proposal, a literature study was conducted to identify products and applications where HTC carbon has shown suitability on a laboratory scale. These products and applications comprised solid fuel, coke, battery electrodes, soil remediation products such as peat or charcoal, activated carbon, catalysers, liquid fuel, carbon sequestration, carbon fuel cells and hydrogen storage.A market study was conducted for all products and applications in order to obtain information on specifications and requirements of the raw carbon (physical properties, applicable standards, existing alternatives and current market price), on the European market size and on the main sectors demanding

the products and applications. Based on the results of the market study the following five products with the best market potential have been identified and will be further considered in the NEWAPP project: Solid fuel, liquid fuel, peat, charcoal (and coke).

The SMEs and Associations contributed with relevant data: bvse coordinated the writing and contributed with information about the European markets, and Ingelia and Terra Preta contributed with their existing knowledge of the market for HTC products. CSIC participated in the preparation of deliverable D1.2. CSIC composed the chapters on coke, catalyser and liquid fuel. Mr. Morten Ryberg from DTU identified marketable products for carbon sequestration, carbon fuel cells and hydrogen storage and defined their end-user requirements and requirements to the char. This is included in Deliverable 1.2.

All the information obtained in Task 1.3 can be found in Deliverable D1.2 “Report on marketable products and requirements of the desired end products” which was submitted to the Commission on February 24th, 2014.

Work package 2: Obtaining HTC carbon from seleted waste streams and post-treatments developed for improved products

Task 2.1 Processing of the five selected biomass streams at industrial scale

The need to install a new boiler at the Ingelia plant in order to perform the work foreseen in WP3 and 4 with the best results entailed a delay in this work package already in the first period. The work in the second period focused in completing the processing of the biomass streams and collecting the data necessary for fulfilling the objectives set or this and subsequent tasks. This task started during the first reporting period and continued during the second. The major part of the pilot plant trials was carried out during second reporting period, including a second trial on the organic fraction of municipal solid waste (BO+), sewage sludge (BS), bell pepper residues (BF+) and orange peel waste (BF) as food wastes, a second trial on green waste (BG+) and a second trial on digestate (BD). CSIC-ITQ contributed to this task by analyzing the raw material employed in the trial in the same way as during the first reporting period. The analyses include humidity content, ash content, volatile content, fixed carbon content, elemental analysis (CHNS), ash composition by ICP-OES (Na, K, Mg, Ca, Si, Al, Ti, Mn, Fe and P), holocellulose content and lignin content). For the feedstocks BO+, BD and BS also heavy metals (As, Cd, Cr, Co, Cu, Pb, Mo, Ni, Se, Zn and B) were determined in the ashes by ICP-OES. Higher heating values were measured at the Carbonchemistry Institute of the CSIC in Zaragoza. According to the wet biomasses defined in the previous work package, Ingelia, with the support of ttz, EUBIA, bvse and ACR+ designed the tests to be performed in their HTC plant located in Náquera, as well as designed the improvements and modifications to be done in the HTC plant in order to adapt the pre-treatment of biomass (initially designed for vegetable residues).

CSIC-ITQ was in charge of collecting the results of this task and compiling them in Deliverable 2.1 “Analysis of HTC carbon samples”, which was sent to the EC on 15th January 2016. The long delay in this submission was due to the delay in the restart of the plant operation as described in the first periodic report.

Task 2.2 Analysis of HTC carbon samples

CSIC-ITQ analyzed the solid products obtained from the trials carried out in task 2.1. These analyses were coordinated with TTZ in order to obtain the required data for subsequent work packages. CSIC-ITQ analyzed all samples provided by Ingelia. The analyses included humidity content, ash content, volatile content, fixed carbon content, elemental analysis (CHNS), ash composition by ICP-OES (Na, K, Mg, Ca, Si, Al, Ti, Mn, Fe and P). During this reporting period for almost all trials and conditions heavy metal contents (As, Cd, Cr, Co, Cu, Pb, Mo, Ni, Se, Zn and B) were determined in the ashes by ICP-OES. Higher heating value and chloride and fluoride content were measured at the Carbonchemistry Institute of the CSIC in Zaragoza.The determination of the heavy metal content was estimated, in coordination with TTZ and the other NEWAPP partners, to be strongly required although this work was not specified in the DoW. Therefore, budget shifts within the RTD activities from travel costs to personnel and consumables were necessary. All information acquired with task 2.2 was summarized in deliverable D2.1.

Task 2.3 Improvement of HTC solid fuel by reduction of inorganic content

During the second period, CSIC-ITQ, Ingelia and ttz completed the work in this task, and Ingelia prepared Deliverable 2.2.

Decreasing of the ash content of hydrochar has been the focus of this work. The experiments preformed on the AT1 hydrochar sample were adapted from the Ultra Clean Coal (UCC) process. The selected consisted in a caustic digestion at 225 ºC followed by an acid treatment. There are numerous combinations for setting up the alkali-acid treatment as well as numerous different coal types all having specific ash contents. It is not feasible to do experimental work on all combinations and ash contents. To save experimental work, the developed model allows for comparison of different scenarios with different alkali-acid leaching setups. The model can be readily used to optimize alkali-acid cleaning of hydrochar, as it predicts that final ash content of a hydrochar should be < 5 wt%, which is within range of measured values.

In the experiments it was confirmed that this process can be adapted and applied to hydrochar and the required limit of a maximum ash content of 5 wt% as demanded by milestone MS2 was met. The temperature for the first, alkaline treatment was above the process temperature of the HTC process and this high temperature was responsible for advanced carbonization. However, the high temperature would involve higher energy costs of the process which is undesired. Therefore, lower temperatures for the first step were also studied. In this case silicon was not extracted efficiently. This was in accordance with the prediction from the model elaborated from literature data. Therefore, it was concluded that the two-step ash treatment is a valuable procedure for producing low-ash hydrochar for high-value applications. However, for the use as solid fuel, the procedure had to be simplified. Therefore, a single step treatment was designed and evaluated.

As summary it can be stated that the UCC process applied to hydrochar is an efficient method for reducing the ash content to below 5% as demanded by milestone MS2. Interestingly, the carbon content (on a dry and ash-free basis) was further increased.

Figure 1. Diagram of the general procedure 1 for the ash reduction adapted from the Clean Coal Process.

Single step ash treatment

A single step ash treatment (GP-2) was developed consisting in a treatment with sulphuric acid, subsequent filtration for hydrochar recovery and washing. It was found that with a reaction temperature of 100 ºC and a reaction time of 2 h the ash content was lowered to below 2 wt%. With this result milestone MS2 was reached which demanded an ash content of below 5 wt% of the treatment. The treatment was especially efficient for the removal of calcium and phosphorous. It was further found that an efficient ash reduction involves a penalty on the mass balance. This means that approximately one third of the hydrochar was lost when the low ash content was achieved. This has clearly a negative impact on the process economics in the case that the low ash has at least a 50% higher value than the initial high-ash hydrochar. Sulphuric acid might be substituted by hydrochloric acid which showed also an interesting potential. However, for this acid reaction conditions have to be still optimized further. A further critical point is that washing procedure after the treatment. A relatively high amount was needed for efficient ash reduction. This might be recovered by means of the inverse osmosis unit incorporated into the pilot plant during the NEWAPP project. As a limitation of the present procedure it has to be stated that it can only be applied to low silicon (and low aluminium) hydrochars since both elements are not removed during the treatment with an acid.

The existing ash reduction unit at the prototype was used and optimized during the NEWAPP trials. Additionally two different chemical processes were studied on laboratory scale (see first reporting period). With both processes MS2 was reached, i.e. ash content was reduced to below 5%. CSIC-ITQ compiled the results in deliverable D2.2.

Task 2.4 Improvement of HTC solid fuel by reduction of halogen content

The work in this task continued in the second period from the preliminary literature review performed by CSIC and DTU to the development of procedures for the reduction of the halogen content.

CSIC-ITQ, with support from INGELIA and ttz, designed two different procedures and evaluated them at lab scale. The first one was the treatment with an alkaline solution with the aim to substitute halide anions by hydroxide anions described in the DoW. The second procedure was derived from a control experiment when the hydrochar was treated only with washing water and from a literature survey. Hence, with the alkaline solution and the neutral water the chloride content was decreased. Then a second study was carried out to confirm the possibility to use only water for the treatment. During this study all produced samples met the requirement of milestone MS3. With these satisfying results CSIC-ITQ designed the implantation at the pilot plant together with Ingelia. The most straightforward incorporation was the washing step in the filter press after removal of the process water. The corresponding trials were carried out at Ingelia’s pilot plant and supervised and analyzed by CSIC-ITQ. However, a final proof for the efficiency of the procedure could not be obtained. The hydrochar produced when the experiment was run had already a low chlorine content, already fulfilling the established values, so that it could not be further decreased.

Work package 3: Post-processing of HTC carbon for high-technological applications: bio-diesel and electrodes

Task 3.1 Separation of HTC carbon into two or more fractions

Based on preliminary tests, CSIC-ITQ and ttz selected the following separation method for hydrochar: in a down-flow reactor with a porous plate in the heating zone hydrochar was treated at different temperatures passing a nitrogen flow down flow producing three products: thermally treated hydrochar, a condensed liquid and a gaseous effluent. All three products were collected and analyzed. The amount of each product was quantified in function of the temperature of the treatment and the time of the treatment. In this study CSIC-ITQ could show that this treatment was suitable to eliminate the volatile content from the hydrochar and to enrich the fixed carbon and ash content. On the other hand not all the volatiles were lost and part could be recovered as a viscous liquid. The gas consisted mainly of carbon dioxide and had no value for further uses. Perhaps, it might be used for energetic valorization in a potential industrial application for generating the heat for the thermal treatment.

For the production of solid and liquid on a larger scale (kg scale) CSIC-ITQ designed a different apparatus since a straightforward up-scaling of the down flow method was not possible. With this apparatus several kg of solid were obtained whereas the yield of liquid was lower. With respect of the solid the quantity produced was sufficient for other Tasks of the project. Contrarily, for the liquid several down-flow reactions had to be carried out to accumulate the amount required for the hydrogenation reactions of Task 3.2. CSIC-ITQ analyzed the surface area of the solid and showed that after the treatment it was much higher (approx. 300 m2/g). CSIC-ITQ showed that the higher heating value is increased by approx. 20% for the treated solid.

The thermal treatment was not carried out for the ten samples as specified in the DoW. Table 24 of deliverable D2.1 showed that all the regular hydrochar samples (with exception of the ones which were separated in the post-process treatment due to a high ash content) had a very similar volatile content (55 to 68%) and, therefore, it was concluded that results of the thermal treatment should be very similar. It was preferred instead to focus on the characterization of the products and on up-scaling. Hence, thermal treatments were mainly carried out with hydrochar samples derived from green waste and from orange peel waste.

As a summary it can be stated that hydrochar was separated successfully into two parts: a solid one and a viscous liquid. CSIC-ITQ compiled all the results obtained with the thermal treatment in a chapter which was included in deliverable D3.1.

Task 3.2 Upgrading of HTC carbon fractions to products of commercial interest

In the DoW it was proposed to develop two marketable products from the fractions obtained in Task 3.1. Since the results of the separation were not completely predictable some deviation from the initial working plan occurred.

bvse performed an overview of products generated by the various techniques, e.g. composting, biogas plants, substitute fuel, bio-diesel, applied for biomass conversion. In addition technologies and techniques applied therefore were screened and shown to the NEWAPP partners. Also the qualities of the conversion products were presented. Hence, an insight on the costs of biomass collection, transport and processing were given. At least, the actual prices of secondaries generated from bio-waste conversion were given. This knowledge is the basis to enhance commercial interest.

EUBIA screened the average composition required for the commercialization of the char as feedstock to be applied for a wide range of end use. Among the most relevant markets, EUBIA studied the char application potentials as fuel, soil conditioner and activated carbon source. Additionally, EUBIA studied the present market potentials and the main barriers of char application as soil conditioner, fuel, activated carbon and c source in metal industry

The viscous liquid obtained was further evaluated for its use as liquid fuel. For doing so, CSIC-ITQ hydrogenated the liquid in an autoclave after removal of the water contained. In this first experiment it was observed that the catalytic activity ceased very rapidly. It was assumed that this was due to coke deposition, the latter evidenced by thermogravimetric analysis of the catalyst. In two further trial CSIC-ITQ distilled the viscous liquid prior to the hydrogenation. This measure improved the hydrogenation result and two highly deoxygenated liquids were obtained. Oxygen content and lower heating value were determined at the Carbonchemistry Institute of the CSIC in Zaragoza. As a result of the hydrogenations it can be stated that the chemical process improved considerably the flow properties of the liquid. A direct use as drop-in diesel fuel cannot be recommended but its use as a refinery feedstock. A high nitrogen content, which has its origin in the plant raw material employed for the HTC process, makes it less suitable for the direct use but it should be possible to reduce this nitrogen content in an oil refinery. Hence, using the liquid as feed in the refinery it is separated into different refinery flows according to their physical properties. CSIC-ITQ determined a yield of 5 wt% for the hydrogenated liquid with respect to dry hydrochar after water elimination, distillation and hydrogenation.

A second application for a product fraction of Task 3.1 in this case for the solid product, was proposed in

the DoW, i.e. the preparation of battery electrodes. However, although the surface area stipulated in the DoW of 350 m2/g was obtained, the whole composition with an elevated inorganic content made the material unsuitable for this application. Therefore, an alternative higher value application was chosen for which the ash content could be tolerated and this was the application as adsorbent for waste water treatment, as a substitute for active carbons. CSIC-ITQ selected methylene blue as a model compound of a colorant contaminant. In laboratory experiments, CSIC-ITQ showed that this was a potential application the thermally treated hydrochar. However, a control experiment showed that pristine hydrochar had an even higher affinity to the colorant. This was unexpected since pristine hydrochar has a very low surface area. Therefore, it can be concluded from this study, apart from the fact that hydrochar has an interesting potential as adsorbent, hydrochar possesses particular properties due to its polar surface involving many oxygen functionalities. This has not been foreseen in the DoW and opens up a wide area for the application as alternative adsorbent to active carbons.
In Task 3.2 it has been demonstrated that thermally treated hydrochar may be used as adsorbent for waste water purification. This has been shown with methylene blue as a model compound for colorant contaminants. In Task 3.1 one of the samples employed in the adsorption study was prepared on kg scale. Therewith it can be concluded that MS6 has been achieved.

CSIC-ITQ compiled all the results obtained with the hydrogenation and the adsorption experiment in a chapter on Task 3.2 which was included in deliverable D3.1 prepared by ttz.
Task 3.3 Hydrochar soil application and process water quality
3.3.1 Hydrochar soil application
This task was planned in order to assess the potentials of hydrochar for soil amelioration, i.e. to answer the question if hydrochar can be a suitable substitute for the biochar that is currently used in soil amelioration products. The work performed under this task was divided into two main parts: a large series of tests conducted in 2015 and a smaller series of tests conducted in 2016. All the work was performed by TTZ, with contributions from TP.
The work began with a comprehensive literature study, e.g. on the scientific basics of soil amelioration with char and on the state of the art in research on soil amelioration with hydrochar in particular. On this basis, the research needs were identified and a research plan was developed, which was confirmed by TP.
EUBIA has a strong interest in biofertilizers sector and dedicated strong attention to the hydrochar potential application as soil conditioner. EUBIA staff contributed to assess the potentials of the hydrochar for soil amelioration and also to define the potential post processing activities which will be needed to upgrade the product into a higher value biochar.
The tests conducted comprised germination and plant growth rates, nutrient and water storage capacities, the compliance with widely accepted biochar standards, and others. In order to confirm the test results, some of the tests were repeated by TP in a smaller series. In the end, the results of all tests were collected and compared to the available literature and conclusions were drawn. All results of this first series of tests can be found in Deliverable D3.1.The first series of tests conducted in 2015 for the analysis of the effects of hydrochar on the growth of plants delivered negative results: plants of all 3 tested species grew best in substrates containing no hydrochar at all, while increasing concentrations of hydrochar increasingly inhibited plant growth. These observations were confirmed by various further studies. However, some of these studies stated that the negative effects of hydrochar on plant growth could be removed by thoroughly washing the char, incubating it with compost of exposing it to weather for some time (e.g. Busch et al. 2013). Since one of the hydrochar samples was available both untreated and exposed to the weather for a

year, it was decided to conduct a second series of tests to compare the effects of the two char varieties on plant growth.

The germination and plant growth tests were conducted in exactly the same way as the first series of tests was conducted in 2015 (compare D3.1) with the only differences in the tested char samples. In the first series of tests, 5 different hydrochar samples (made from different feedstock) and 1 biochar sample were used, while in the second series 2 varieties of the same hydrochar sample were used, 1 left standing outside exposed to the weather for a year, while the other one was kept inside protected from all potential influences. All seeds were planted on March 30th, 2016. The germination tests were finished 2 weeks later; the plant growth tests were finished 4 weeks later.

Germination rate

Lactuca sativa reached the highest germination rates of all 3 species. Between 45 (90 %) and 48 (96 %) of all planted seeds germinated. There were no significant differences between the germination rates in the different hydrochar varieties and concentrations (Table 1, Figure 1).

Avena sativa reached the lowest germination rates of all 3 species. Between 21 (42 %) and 30 (60 %) of all planted seeds germinated. Germination rates were, on average, slightly higher in the "treated" hydrochar samples, while the char concentrations did not have an effect on the germination rate (Table 1, Figure 2).

Raphanus sativus reached intermediate germination rates. Between 36 (72 %) and 45 (90 %) of all planted seeds germinated. There were no significant differences between the germination rates in the different hydrochar varieties and concentrations (Table 1, Figure 3).

In summary, it can be stated, that the germination rate of all 3 seed species was neither influenced by the hydrochar variety nor by the char concentration., except for small effects of the hydrochar variety observed for Avena sativa.

The observations made clearly indicate that hydrochar does not have significant effects on the germination rates of seeds. Germination rates were very similar for all char concentrations and for both hydrochar varieties. However, germination rates of Avena sativa seeds were slightly lower in substrates containing untreated char. An explanation could be that there are substances in the hydrochar that can influence the germination rates, but the concentrations of these substances were too low to have stronger effects on the germination rates.

Growth rate

Concerning Lactuca sativa, there were significant differences in the biomass production between the 2 char varieties and the 6 char concentrations. The by far highest biomass production was reached in substrates containing no char at all (9.6 g per 10 plants), while already very low char concentrations of only 1.25 % substantially reduced the biomass production (2.2 and 2.6 g per 10 plants). Biomass production at low char concentrations (1.25 % and 2.5 %) was higher for the untreated (not exposed to weather) hydrochar variety, while at higher char concentrations (5-20 %) the biomass production was higher for the treated (exposed to weather) variety. Higher concentrations (5 % or more) of untreated char almost completely inhibited growth.

Concerning Avena sativa, there were significant differences in the biomass production between the 2 char varieties and the 6 char concentrations. The by far highest biomass production was reached in substrates containing no char at all (4.9 g per 10 plants), while already very low char concentrations of only 1.25 % substantially reduced the biomass production (1.6 and 2.1 g per 10 plants). Biomass production at low char concentrations (1.25 % and 2.5 %) was higher for the untreated hydrochar variety, while at higher char concentrations (5-20 %) the biomass production was higher for the treated variety. Higher concentrations (5 % or more) of untreated char significantly inhibited growth.

Concerning Raphanus sativus, there were significant differences in the biomass production between the 2 char varieties and the 6 char concentrations. The highest biomass production was reached in substrates containing no char at all (4.6 g per 10 plants), while already very low char concentrations of only 1.25 % substantially reduced the biomass production (2.3 and 2.5 g per 10 plants). Biomass production at low char concentrations (1.25 % and 2.5 %) was higher for the untreated hydrochar variety, while at higher char concentrations (5-20 %) the biomass production was higher for the treated variety. Higher concentrations (5 % or more) of untreated char significantly inhibited growth

In summary, it can be stated, that the biomass production of all 3 plant species was by far highest for substrates containing no char at all, while already low char concentrations substantially reduced the biomass production. Effects of growth inhibition were observed for all 3 species for substrates containing 5 % or more of untreated char, while for treated char this effect was not observed. The negative effects of the char on the biomass production were highest for Lactuca sativa and lowest for Raphanus sativus.

The fact that the biomass production of all 3 species was highest in substrates containing no char at all clearly indicates that hydrochar does have strong negative effects on the plant growth, even at very low concentrations of only 1.25 %.

The observed differences in the biomass production between the treated and the untreated hydrochar at char concentrations of 5 % or more confirm that the exposure of the char to weather does reduce negative effects on the plant growth.

These results confirm the observations made in similar studies (e.g. Busch et al. 2013). Hydrochar seems to contain substances that negatively affect the growth of plants. These substances still need to be identified, since the most common substances with a toxic potential (heavy metals, dioxins, furans, PAHs and PCBs) were not responsible (compare D3.1). It was moreover confirmed that the exposure of hydrochar to weather for a certain time reduces the negative effects on plant growth, probably caused by the degradation of the toxic substances.

CSIC-ITQ supported TTZ and TP in this task by analyzing samples and facilitating information on the hydrochar contributing in this way to the interpretation of the obtained results by these NEWAPP partners.

The results of this sub-ask were compiled by ttz in Deliverable 3.1 “Post processing of HTC carbon for high-technological applications”, submitted on March 30th 2016. The reason for this delayed submission is the overall delay in obtaining the carbon samples and the climatic conditions to carry out the germination and growth tests.

3.3.2 HTC process water quality

The main goal of this sub-task was to evaluate the process water quality and its potential re-use and valorization options. The HTC process itself, i.e. the conversion of wet biomass streams into a HTC carbon, does not consume water; in contrast, it produces water by chemical dehydration.

Other steps in the process do however involve the consumption of water, as the production of steam for the heating of the reactor or the halogen reduction post-process. Therefore, water is consumed by the operation of the HTC plant and excess process water is produced, which needs to be handled, re-used and or disposed. While the DoW considered the possibility of identifying organic compounds such as acetic acid, aromatics, aldehydes and furanic and phenolic compounds that could be extracted and valorised, the experience acquired since the proposal preparation from Ingelia and ITQ-CSIC show that the concentration of such components, if found, would be too low for a viable and profitable recovery.

Hence the excess process water is submitted to an aerobic treatment in order to decompose unstable process intermediates and achieve a pH above 6. Remaining organic compounds are mainly humic compounds, which could be considered beneficial for agricultural soils. Process water has also been analysed for presence of potential pollutants in the frame of this task.
ttz was in charge of the analysis of the water, and the appraisal of the data received against current legislation and scientific literature for finding out the most adequate use. Due to incompliance with the current regulation, direct application of process water in agricultural fields is not possible. The application of diluted process water would allow to compile with the regulations. The balance of nutrients provided does not fulfill the needs of the studied crops, meaning additional fertilizers would be needed for some compounds, mainly N and P. Hence, the attractiveness of the agricultural use of HTC process water seem to be more on the reclaimed use of the water in water-scarce regions, than in its nutrient composition.

Since the first application to explore for the process water is fertigation in agricultural fields, persistent organic pollutants (POP) were selected, since they will have the highest environmental and health hazard.Literature on POPs in the potential feedstocks was screened, as to identify pollutants that could come into the system with the feedstock. This literature search included El-Sahawi et al (2010), K.T. Semple et at (2001), Rogers (1996), Paxéus (1995), Düring and Gäth (2002), Palmu (2011), Wang et al (2010), ADEME (1995) as well as the Stockhold Convention (2001). The following families of POCs were selected:

-Clorophenols and chlorobenzenes
-PAHs and Clorinated PAHs
-PCBs.
-Clorinated PAHs
-Dioxines
-Pesticides

From the 677 POCs that were analysed, only 8 were detected in the process water sample, mainly chlorophenols. This is consistent with the literature, which had already identified phenols formation in HTC. Although the chemistry of the reaction is not totally known, chlorophenols formation could be linked to the relatively high Cl content in green waste. The obtained results have been crossed checked with the pollutants analysed in the hydrochar in the frame of Chapter 3, finding no correlation. Further research is needed to confirm is these identified pollutants generally occur in HTC, if they come in with the biomass feedstock of if they are formed in the HTC process. Other authors suggest that organic pollutants are degraded through HTC (Weiner et all 2013).

The results of this sub-ask were compiled by ttz in Deliverable 3.1 “Post processing of HTC carbon for high-technological applications”, submitted on March 30th 2016. The reason for this delayed submission is the overall delay in obtaining the carbon samples and the climatic conditions to carry out the germination and growth tests.
Work package 4: Technology assessment and business plan development
Task 4.1 Life Cycle Assessment and cost-benefit analysis
Task leader: DTU
Mr. Mikolaj Owsianiak, from DTU expanded the LCA model, in agreement with Ingelia and ACR+, by: (i)

assessing environmental performance of HTC at full commercial scale with 2 and 4 reactors (in addition to pilot scale operation with 1 reactor that was promised in the DoW); (ii) adding LCA-based comparison of HTC with alternative waste treatment options, including anaerobic digestion, incineration and ladfilling (in addition to compositing that was promised in the DoW). In addition, Mr. Mikolaj Owsianiak contributed to cost-benefit analysis of hydrochar used as soil conditioner. Mr. Morten Ryberg from DTU contributed to the comparison of HTC with alternative waste treament options by interpreting resuts and identifying environemntal hot-spots in respective treatment technologies. The resources to cover the aforementioned tasks are those assigned originally to WP3, and it was agreed between TTZ and DTU that tasks originally assigned to DTU in WP3 will be covered by TTZ.
Mr. Mikolaj Owsianiak finalized the LCA model of hydrochar used as soil conditioner for carbon sequestration. (Note that most of the work in WP4 was carried out in RP1).
CSIC-ITQ collaborated actively in the life cycle assessment and the cost benefit analysis. CSIC-ITQ provided all required data on the NEWAPP trial related to chemical analysis. In particular CSIC-ITQ carried out detailed analysis on the gaseous effluents and confirmed the presence of furan in this effluent. LCA had attributed a negative impact in one of the impact categories. As a consequence, the HTC process was improved by conducting the effluents to the boiler combusting the furan and eliminating this emission.
Bvse collaborated win the discussion of various suggestions made from the participants of NEWAPP due to the Life Cycle Assessment, LCA, of HTC-hydrochar were performed. A special of NEWAPP was the processing of bio-sludges, rich in water contents. LCAs of various biomasses were reviewedFrom ACR+, Mr Dohogne, Ms Bonnet, Ms Labriga, and Ms Spasova gave significant input to this task by discussing the results obtained with DTU and by suggesting to also comparing HTC to other Waste Management options.
EUBIA monitored the LCA and cost benefits analysis results, providing a review of the achieved goals and comparing them with the present technologies currently used for organic waste treatment in Europe.
Task 4.2 Definition of quality standards for innovative technologies for the reuse of waste biomass
ttz, with the support from the rest of the partners, compiled and prepared the quality standards. From the several potential products studied in NEWAPP project, the most promising has been found to be solid fuel. To support the use of HTC carbon as a solid fuel, they focus on a proposal for a new product standard in Europe. Other working groups are working in standards applicable for to HTC solid fuels, and hence synergies have been sought for to maximize the outreach and relevance of the results and work developed in NEWAPP in this task.

As background, the International Organisation for Standardisation (ISO) Technical committee 238 (ISO/TC 238) has started to draft an international product standard for torrefied pellets and briquettes made from woody and non-woody (herbaceous, fruit and aquatic biomass) in February 2013. The European and International Standard will be developed in parallel, hence the standard will be published in Europe as EN ISO 17225-8 “Graded thermally treated and densified biomass fuels”. Thermal treatment includes processes such as torrefaction, steam treatment (explosion pulping), hydrothermal carbonization and charring, all of which represent different exposure to heat, oxygen, steam and water. Hence, this standard will be the reference for solid fuel HTC products. In order to ensure that all findings from NEWAPP project reflect in the standard, D 4.2 includes the definitions and quality tables that reflect the project’s research and results, required for a successful marketability of the obtained high quality NEWAPP products. Data and results from NEWAPP have been provided to the German standardization body contact point, Daniela Thrän from DBFZ, and the ISO 238 working group contact point Eija

Alakangas from VVT (Finland), and the Spanish contact point at AENOR. INGELIA participating in AENOR's ISO standardization committee TC238 in Work Group 2, this document has been presented in the last committee meeting in April 2016 in Kuala Lumpur.

CSIC-ITQ collaborated actively to the completion of this task. CSIC-ITQ also contributed by providing regular analyses data. CSIC-ITQ searched for laboratories specialized in the analysis of contaminants and sent samples for analysis. CSIC-ITQ carried out analysis on hydrochar and process water (e.g. heavy metals) to acquire necessary information for the quality standards. The corresponding analyses were not foreseen in the DoW and, therefore, a budget shift from the prototype to consumables within RTD activities of CSIC-ITQ was required.

ACR+ and bvse participated actively in the discussion of suggestions concerning the definition of quality standards for innovative bio-technologies. In addition, the evaluation of chemical parameters, which limit the use of biomass in biosphere was discussed. Since a special of NEWAPP was the processing of bio-sludges rich in water contents, it was found, that the main parameters of concern were the halogen contents, i.e. bromine and chlorine, as well as the heavy metal contents. Legal standards are settled in the European Waste Framework Directive, EU 1774/2002 and EU 1069/2009. In Germany, legal framework is settled in the Bioabfallverordnung, the Klärschlammverordnung, the Düngemittelverordnung, the Düngegesetz and the Düngeverordnung. Furthermore, the evaluation of HTC-hydrochar – short-term, medium-term and long-term was discussed. Here, positive results for water retention capacity and water storage by biaohar and hydrochar were obtained. Moreover, first results HTC-char application show no negative influence on N2O-emissions. Furthermore, positive effects were expected from biochar and hydrochar, which include CO2 minimizing energy production, soil amendment and C-sequestration. Up to now, some studies on the soil amendment properties of HTC-char showed negative effects of plant growing.

EUBIA contributed to this task by identifying the most interesting quality standards for the integration of char as fuel in the EU market. In particular, EUBIA also investigated the present potentials of new standardisation programmes for the application of biochar and hydrochar as soil conditioner in different EU countries. The standardization bodies included in EUBIA study are ASTM, CEN, ISO.

Task 4.3 Business plan and patent research for the implementation of reuse options for wet waste biomass

ttz carried out a preliminary analysis of different business models related to waste treatment with HTC. After the initial considerations and after presenting and discussing them with the rest of the partners, it was agreed with all SMEs and associations to focus on the case of a municipality with a population of 60,000 using HTC as the mean to treat their waste. This decision was made after discussing with Ingelia their experience in the field and recent business developments. Additional information was provided by ACR+ and bvse. A municipality in Europe with this population produces annually, in average, 225 kg of wet biomass per capita. There are some technologies currently treating these wastes, mainly incineration and composting which have some problems: high costs, waste of energy (incineration), low profit, and huge amount of areas needed (compost). HTC represents a better and more efficient way to treat these residues, which follows the circular and green economy, as well as the European energy and environmental policies.

The business plan includes the simulation of the performance of a 4-reactor HTC plant with a capacity of 21,840 tons of wet bio-waste per year. The plant is estimated will have a lifetime expectancy of 20 years. During this 20 years of operation, it will treat not only the whole wastes from the municipality but also, for

some periods of time, the residues from the neighbouring small municipalities. Treating a total of approximately 450,000 tons of wet biomass including parks and gardens, markets wastes, kitchen residues, digestate, and the organic fraction of municipal solid waste.
The payback year of the 4-reactor HTC plant is achieved in the 5.5 year. After that each year has an EBITDA of 856,945 euros per year. Having a total profit, during the 20 years, of almost 5 million euros.
The business plan compares HTC treatment with other six technologies for the treatment of these wastes: incineration, composting and anaerobic digestion, among others, as these are the most widespread technologies and therefore, HTC's direct competitors. It also shows the comparison between different fuels for domestic heat stoves. EUBIA reviewed the business plan and contributed to its implementation by providing information and data on the present market situation and competing technologies currently in place in Europe. Business plan results have been used by EUBIA to assess the potential market development of the Industrial HTC technology investigated by NEWAPP project.
CSIC-ITQ collaborated actively in the discussion of the business plan and provided required information on the technical data.
Johannes Schräder and Dr. Thomas Probst, from bvse was in charge of carrying out the patent search in various databases. These were the German Patent Office (DEPATISnet), the European Patent Office (EPO), the US Patent and Trademark Office (USPTO) as well as the Google Patent Search. The patent search, here search terms were „hydrothermal carbonisation", „hydrothermal carbonization", „hydrochar" and „vapothermal carbonization", revealed a total amount of 150 patents concerning hydrothermal carbonization. Vapothermal carbonization, an HTC-similar process, revealed only one strike. The patents were classified in the six different categories, listed in the NEWAPP proposal. Furthermore, various charts to show the results of the patent search were created and discussed. However, it has to be pointed out, that there are various definitions of the terms „hydrochar" and „biochar". Hence, a further search query with the term "biochar" revealed a total amount of over 700 patents. These biochar patents were not included in the patent search. Ingelia, Terra Preta and EUBIA revised the deliverable draft and contributed with their knowledge of the sectors to cover all relevant results. The results were compiled and analysed and collected in deliverable 4.3 "Update on the patent situation".
Work package 5: Demonstration of project results
Task 5.1: Long term demonstration and adaptation
Task leader: ACR+, EUBIA
Ingelia carried out the long-term demonstration of HTC in the operation of the pilot plant, and maintains its Náquera pilot plant in operation as a showcase for municipal green waste. Ingelia's plant is receiving visits from different stakeholders and organization to show and demonstrate the application of HTC process.Ingelia is arranging Ingelia contunes at the date of writing, to operate the pilot plant and offer the opportunity of arranging visits to interested stakeholders as continuing demonstration efforts beyond the project energy sector for combustion and gasification, in collaboration with WPS, a brokerage consultancy with expertise in this sector.
EUBIA supported the demonstration activity by fostering members and stakeholders from different EU regions to visit the plant during its continuous operational activity in order to show the reliability of the technology for large amount of wet biomass processing. At ACR+, Ms Bonnet, Ms Labriga, and Ms Spasova supported the RTD partners for the long term analysis of the potential of HTC biomass treatment and HTC carbon sequestration. Ms Labriga and Ms Spasova furthermore helped Ingelia and ITQ in organising visits of interested stakeholders to the test site, such as the site visit that was combined with the second workshop, held on 6 March 2015 in Valencia. bvse supported the task advertising the events

among their members.
DTU contributed to the demonstration workshops providing additional information on the work performd in previous WPs: Mr. Mikolaj Owsianiak contributed to the assessment of long-term performance of the HTC technology by providing sets of recommendations for the technology developers on how to optimize the technology further in the context of environmental performance when the technology is scaled up to the full commercial scale in the long-term and (ii) recommendations on how optimize environmental performance of HTC carbon when used as either solid fuel or soil conditioner with carbon sequestration value. In addition, Mr. Owsianiak identified environmental improvement potentials of the technology by highlighting the need for avoiding of potentially toxic emissions from the HTC reactor, minimizing the use of energy as one of the most important parameters determine the overall sustainability performance of the technology.
ttz followed the same strategy, providing information of the performance of HTC coal as a soil amendment and, later in the project, about the business model developed for municipalities using HTC as a means to treat their waste. CSIC-ITQ supported Ingelia at the on-site demonstration events and in meetings with interested stakeholders.
Task 5.2: Demonstration workshops
Ingelia hosted the demonstration workshops at the pilot plant, scheduling the plant operation and providing the attendees with all necessary explanations.
CSIC-ITQ participated actively in five demonstration workshops. Four of them were open to the general public: two in Valencia, one in Lucca, Italy and one in Vienna (EUBCE). CSIC-ITQ co-organized the two workshops in Valencia together with Ingelia. The venues were the campus of the Polytechnic University of Valencia (UPV) near to the CSIC-ITQ building, for initial explanations and discussions, and the Ingelia pilot plant in Náquera. Furthermore, CSIC-ITQ organized a special course for Master students of the UPV including a plant visit.
EUBIA co-organized and participated in three demonstration workshops, presenting the project and contributing to train stakeholders regarding the current framework of organic material valorisation in Europe. Additionally, EUBIA contributed to the dissemination and organization of the workshops by contacting more than 2000 persons including researchers, SMEs representatives and authorities.From ACR+, Ms Labriga and Ms Voltz, co-organised several of the demonstration workshops in the course of the project. The workshops held were:
- Workshop 1: Valencia/Náquera (ES), 13 November 2014
- Workshop 2: Valencia/Náquera (ES), 6 March 2015
- Workshop 3: Lucca (IT), 26 March 2015
- Workshop 4: Vienna (AT), 4 June 2015
- Workshop 5: Valencia/Náquera (ES), 9 March 2016
- Workshop 6: Brussels (BE), 12 April 2016
- Workshop 7: Berlin (DE), 14 April 2016
- Workshop 8: Copertino (IT), 29 April 2016

All details on these demonstration workshops can be found in D5.1 Assessment of overall long-term performance and demonstration workshops, prepared by ACR+ and submitted on 29.04.2016.

Potential Impact:
The project NEWAPP has had as a focal point strengthening the competitiveness of the participating SME-AGs active in the bio-waste treatment sector in Europe. The introduction of novel and cost-effective

technology in this sector will capture the attention of European SMEs who have a leading role in the bio-waste treatment market. The European bio-waste handling market is nowadays experiencing a great challenge due to the numerous EC directives restricting the ways bio-waste is disposed. The demand for innovative and cost-effective ways for reuse rises every year. However, waste and managers lack adequate and innovative technologies for efficient bio-waste reuses allowing for the production of high-value products with steady quality.
HTC as a bio-waste management and recycling technology will have a positive impact on bio-waste producers and handlers as they will clearly benefit from:
• higher cost efficiency due to the HTC system and the savings in which it results
• securing the efficient wet bio-waste stream disposal through HTC and producing high-value products after HTC carbon sequestration process
• meeting present and future regulatory requirements set by the EC waste disposal and handling directives
Another SME group that was anticipated would benefit from HTC are the producers of relevant high-value products (Li/Na batteries, electrodes, etc.). These SMEs will be able to make commercial use of the generated know-how. However, as it has been seen through the work in the project, these aspects of HTC need to be further researched and optimized before reaching their full market potential. All SME IAGs have high interest in the development of the HTC bio-waste treatment technology as well as on the HTC carbon sequestration process and the possibility of having high-value carbon products and their immediate market implementation. HTC has proven to be a valuable tool also for municipalities and agriculture: the main producers of wet biomass waste streams can benefit from the technology that will turn these wastes into a product that can be directly used at the same premises as energy carrier.
Economic Impact for SME-AG beneficiaries and their members:
After 30 months of work, the SME-AGs EUBIA, bvse and ACR+ are the owners of the property rights for the developed high-value carbon products, the optimization of HTC and the standards generated in the project. The efforts spent in training have resulted in a group of professionals trained in the insights of a novel technology that has a huge potential in the coming years. All consortium partners will profit from the knowledge gained about possible risks or optimisation/decision paths to the developed in the work plan technology. Those will guide future technology optimizations and implementations, plus direct market applications of existing technologies in their most suitable fields. Additionally, NEWAPP results will support and contribute for expanding international guidelines on safe and efficient wet bio-waste streams reuse in the European waste sector.
As the work plan of NEWAPP is focusing only on the 5 most promising waste streams for running the HTC process and obtaining high-value carbon products afterwards, further demonstration will be essential to verify the economics of the technology and to expand even further the consumer’s acceptance. It is already anticipated that after the completion of the project the participating associations will keep the exploitation of project results demonstration to their members via different programs. In addition, the partners have cooperated in establishing permanent links to continue the training beyond the project‘s lifetime, as in the booklet, which is available to the general public for free. As a measure of the interest generated by this result, it has been downloaded 181 times in the 17 days it has been available, since its upload to the preparation of the present report. The partners anticipate it will have a great impact in the waste management sector, including academia.

The European sectors and markets addressed by NEWAPP
HTC has the potential to impact a large number of sectors. From producers of these wastes to managers

and end-users, the benefits would affect a large number of European SMEs while providing a solution to a pressing environmental problem shared by all Member States.
Results obtained in the proyect are ready to be implemented under real-life conditions. Indeed, the work carried out in the project, together with the large efforts carried out by Ingelia, have resulted in new compromises and contracts to build new HTC plants in Italy, a first step that illustrates hpw suitable this technology is, and how relevan was NEWAPP from themoment of its conception.
HTC has the advantage that its products will not require a reorientation of existing businesses, as the developed blueprints for waste streams provided by NEWAPP are scalable. Furthermore, NEWAPP addresses several steps in the waste value chain as it takes in consideration producers and managers, keeping the perspective of delivering an innovative product that is competitive in the current market.

One of the results obtained has been the development of a set of quality standards for innovative technologies for the reuse of waste biomass. The biomass sector is nowadays hindered by the heterogeneity of the raw materials and technologies. This yields a great range of qualities in the final products obtained, and an insecure market. The quality standards will allow the end users to have a competitive advantage for the beneficiaries and their members against other competitors.
Furthermore, based on its innovative features, it is expected that the NEWAPP technology has an enormous potential for the European waste sector addressed. Implementing the results provided will allow European farmers to improve the way bio-waste is handled which will ultimately lead to a substantial reduction in waste disposal costs, producing of new high-value carbon products, and thus higher revenues for them. NEWAPP has in this area also reached results beyond the foreseen at the proposal preparation, and has collaborated actively with the ISO task in charge for a standard on HTC and torrefaction products. The impact of this is huge, as it means that the recommendations developed during the project are currently being considered tob e included in the next ISO standard.

Impact of in its NEWAPP SME-AG and SME participants
EUBIA, as the main European association of biomass producers, has as a duty to its members to provide frequent updates on the State-of-the-Art of biomass transformation, and HTC is, as it has been demonstrated in NEWAPP, a technology with a great potential in this area. EUBIA has been able to enlarge its existing work on biochar, build its capacities and establish themselves firmly in the HTC scene. This has resulted in an increase in members, attracted by the work in the project and therefore, an increase in revenues.
The impact of NEWAPP in ACR+ has been building the capacity of its staff in HTC as a waste treatment, which will be transmitted to their members: mayors and municipalities commited to achieving higher sustainability in european cities. In this sense, ACR+ has been actively pursuing the training of this group of stakeholders already during the project, which have led to several of their members considering HTC as an option for their waste disposal. The business plan prepared in the project will be further used for this purpose, due to the fact that the SME AGs own also the files and calculators used by the RTDs for the preparation of this result.
For bvse, participating in the project will have the impact of staying at the forefront of technological developments. This is especially important, as Germany hosts already a vibrant HTC sector, and their knowledge has already attracted new members. Having participated in the projcet gives bvse an advantage also for their members, similar to that achieved by EUBIA. It is anticipated that bvse will continue training its members in the results of NEWAPP after its completion.

For Terra Preta, NEWAPP has provided important insight on a potential ally and competitor: HTC coal is regarded as a potential substitute for biochar. The knowledge gained by Terra Preta in the project will enable them better decision-making with regard to theis product catalogue and ingredients used in their products and their marketing strategy. Although the project has demonstrated that „raw“ HTC coal could have adverse effects on planth growth, with an adequate post-treatment it would be a suitable and cheaper substitute of biochar.
Finally, Ingelia has been the host of the project's pilot plant and has received first-hand training by the RTDs on the different parts of the HTC process as they have been dealt with in the project. During the project, and as a result of its engagement, Ingelia has expanded its operations Europe-wide greatly, with new plants planned in Italy, and promising developments in other EU countries and beyond. In this sense, NEWAPP has exceeded the expectations of knowledge transfer and increase in revenues. Specifically, the results obtained in those WPs dealing with the process and the plant have opened new business pathways (re-use of the water, pelletizing) for Ingelia that were not reachable before the project started.
Main dissemination activities:
NEWAPP has implemented a powerful dissemination strategy in which the obtained knowledge is transferred directly from RTDs to SME-AGs and from SME-AGs to SMEs and end-users. The SME-AGs within NEWAPP have an overall potential dissemination range of more than 10 000 end-users. BVSE alone is one of the biggest German associations on waste management and recycling. ACR+ and EUBIA belong to the most important professional international organizations which additionally extends the project range Europe-wide. The work plan prepared for NEWAPP comprises a dissemination strategy under WP7, which ensures effective transfer and exploitation of progress, results and knowledge gained within the project, beyond the training workshops for SME-AGs and their members (part of WP6).
The success of NEWAPP, being a project for SME associations is strongly dependent on well-coordinated dissemination and exploitation activities. The individual dissemination activities aim at achieving the best possible spreading of the project results and to establish cooperation among local municipalities, researchers and technical SMEs.
The project's dissemination activities have focused on fostering the implementation of the new NEWAPP system among companies in the waste sector – both within existing facilities aiming to optimise their processes and new systems with the latest state-of-the-art.

Activities and target groups:
In order to assure appropriate dissemination during and after its duration, raise awareness and assure the continuity of the achievements beyond, the dissemination strategy considers the following target groups:

・Companies working in the solid waste sector, which could improve the efficiency of their processes by the implementation of the new NEWAPP technology
・Municipalities, the end user and clients of these companies
・General public: Given the role played by public opinion concerning waste, it is important to consider the general public as a target group of the NEWAPP plan, raising awareness of advantages of the NEWAPP technology in relation to
・Researchers, aiming at the exchange of knowledge and results to achieve a faster development of the technology
・Standardization agencies and initiatives, working already in including HTC coal in their norms. The efforts have been focused in this case in aligning the NEWAPP standards with future standards

The dissemination activities undertaken during the project aim at ensuring that the results are disseminated as swiftly as possible, with EUBIA being responsible for assuring that they are compatible with the protection of intellectual property rights, confidentiality obligations and the legitimate interests of the SMEs and SME associations.
The general dissemination instruments for the presentation of the project activities and expected results include:

• a web page, http://NEWAPP-project.eu

• a project handout

• Press releases published in generalist media
• Appearances in radio or television outlets

The specific dissemination activities consist of the following activities:

• Including the project in the websites and/or newsletters of the partners

• Advertisement of the project at the SMEs and via institutions supporting the activities of this sector such as chambers of commerce, the relevant ministry of enterprise, as well as any industrial association they might belong to
• Promotion on specialised trade fairs
• Publications in specialised magazines, according to the SME's business, market and target groups.
• Scientific publications: The RTD performers will submit any scientific paper prepared on the work performed in the project to the SMEs, and will request their consent to publication before its submission for review.

The following sentence has been added to all publications developed under NEWAPP, as well as the project's website: "The research leading to these results has received funding from the European Union's Seventh Framework Programme managed by RES – Research Executive Agency (FP7/2007-2013 under grant agreement n° 605178"

Dissemination policy

The partners in the consortium have identified dissemination activities as necessary for the successful completion of the project, and have sought not only participating in events such as conferences and fairs, but also to present the project to their business partners. These contacts are not reflected in the tables for dissemination events due to their informal nature.

Even though dissemination of the project objectives and results is an objective for the partners, each beneficiary is aware of the restrictions in terms of disclosing confidential foreground.

Dissemination activities including but not restricted to publications and presentations shall be governed by

Article II.30 of the Grant Agreement. In the case of a party objecting a publication has to show that its legitimate interests will suffer disproportionately great harm and shall include a request for necessary modifications.

In order to avoid conflict, a party may not publish foreground or background of another party, even if such foreground or background is amalgamated with the party's foreground, without the other party's prior approval. Any data which is to remain secret should be cleared labelled as confidential. Parties agree to abide by the default notice period foreseen in the grant agreement to communicate their planned dissemination activities with a notice at least 45 days prior along with sufficient information about the intended dissemination.
In the final meeting the partners have agreed on continuing the dissemination activities once the project is over, both attending to events (fairs, conferences) where the results of the project can be showcased, and meetings at the Ingelia plant, where the prototype can be used in demonstration workshops and meetings. The booklet, available online, will be promoted as a high-quality and long-lasting training and dissemination tool after the project ends.

• Scientific publications:
• ENVIRONMENTAL PERFORMANCE OF HYDROTHERMAL CARBONIZATION OF FOUR WET BIOMASS WASTE STREAMS AT PILOT- AND FULL-COMMERCIAL SCALE
Mikolaj Owsianiak, Morten Ryberg, Michael Renz, Martin Hitzl, Michael Hauschild
• LIFE-CYCLE BASED EVALUATION OF HYDROCHAR APPLICATION TO SOIL AS A POTENTIAL CARBON SEQUESTRATION AND STORAGE TECHNOLOGY
Mikolaj Owsianiak, Jennifer Brooks, Alexis Laurent
• LIFE-CYCLE BASED COMPARISON OF HYDROTHERMAL CARBONIZATION OF FOUR WET BIOMASS WASTE STREAMS WITH ALTERNATIVE TREATMENT OPTIONS
Mikolaj Owsianiak, Morten Ryberg
• Fuel and chemicals from wet lignocelulosic biomass waste streams by hydrothermal carbonization
Pedro Burguete et. Al. Green Chemistry, 2016, 8. P.1051-1060
• Hydrothermal carbonization (HTC) for valorizaiton of food waste. M. Renz et al, presentation at the 3rd International Symposium on Green Chemistry, May 3-7 2015 La Rochelle, France
• Production of a solid fuel from garden prunings, food waste, OFMSW, digestate and sewage sludge on pilot plat scale, M. Renz et. Al, oral presentation at the 23rd European Biomass Conference and Exhibition
• Poster presentation at the Green and Sustainable Chemistry Conference, Berlin, Germany, 03/06/2016–06/06/2016
• NEWAPP, estudio de la valorización de residuos alimentarios a través de carbonización hidrotermal (HTC), Retema: Revista técnica de medio ambiente, ISSN 1130-9881, Año nº 27, Nº 179, 2014, págs. 6-7

Expected exploitation:
The partners started discussing the need for patenting the results obtained from the end of the test season until the end of the project. In the discussion about IPR issues in the final meeting, all SMEs agreed on the following points, as collected in the final meeting's minutes:
The partners in the consortium have identified dissemination activities as necessary for the successful completion of the project, and have sought not only participating in events such as conferences and fairs, but also to present the project to their business partners. These contacts are not reflected in the tables for

dissemination events due to their informal nature.

Even though dissemination of the project objectives and results is an objective for the partners, each beneficiary is aware of the restrictions in terms of disclosing confidential foreground.

The partners will not pursue any joint protection action (patent).

Dissemination activities including but not restricted to publications and presentations shall be governed by Article II.30 of the Grant Agreement. In the case of a party objecting a publication has to show that its legitimate interests will suffer disproportionately great harm and shall include a request for necessary modifications. In order to avoid conflict, a party may not publish foreground or background of another party, even if such foreground or background is amalgamated with the party's foreground, without the other party's prior approval. Any data which is to remain secret should be cleared labelled as confidential. Parties agree to abide by the default notice period foreseen in the grant agreement to communicate their planned dissemination activities with a notice at least 45 days prior along with sufficient information about the intended dissemination.

In the final meeting the partners have agreed on continuing the dissemination activities once the project is over, both attending to events (fairs, conferences) where the results of the project can be showcased, and meetings at Lempe, where the prototype can be used in demonstration workshops and meetings.
A session of the final meeting was dedicated to future dissemination events, and the partners have prepared a list of events where the objectives and results of the project can be explained to potential clients. A preliminary list of actions and comprises the references below:

- Integration of the booklet in existing training programs at the SME-AGs
- Presentation of the booklet at the EUBCE conference in Amsterdam in June 2016
- 5. Mitteleuropäische Biomassekonferenz, Graz, Austria, January 2017
- 2nd World Bioenergy Congress and Expo, Madrid, Spain , June 2017
- Conference on Energy efficiency and Renewable Energy, April 2016 ,Sofia, Bulgaria
- 2nd Euro Global Summit and Expo on Biomass, Brussels, Belgium, August 2017
- Presentations at fairs (IFAT, TERRATEC, etc)

The RTDs have also expressed their compromise to further dissemination using the basic materials prepared during the project (leaflets, PowerPoint presentation)

List of Websites:
www.newapp-project.eu

European Biomass Industry Association
Rond Point Schuman, 6
B-1040 Brussels
administration@eubia.org
www.eubia.org

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Last update: 7 October 2016

Record number: 189826

Permalink: https://cordis.europa.eu/project/id/605178/reporting

ATTACHMENT 3

AgLoco® 150 Initial Technical Specifications[1]

Engine	
Rated power, kW (hp)	112 (150)
Max. power, kW (hp)	152 (204)
Crankshaft torque, N·m	7,920
Rated crankshaft speed, rpm	400
Cylinder bore, mm (in)	178 (7.00)
Stroke, mm (in)	275 (10.8)
Cylinders	2
Cycle	Regenerative Simple Expansion
Steam pressure, MPa (psi)	2.14 (310)
Steam temperature, °C (°F)	400 (752)
Transmission	
Speeds	2
Road gear, km/h (mph)	40 (25)
Field gear, km/h (mph)	20 (12.5)
Drive	
2WD	Standard
4WD	Optional
Hydraulics (Optional)	
Type	Closed centre, load sensing
Flow, L/min	120
Selective control valves	6
Power beyond	Optional
Wheels & Tyres	
Front	540/65R28
Rear	650/65R38
Capacities	
Rated towing capacity on 12% gradient, kg (lb)	30,000 (66,000)
Range with rated load in tow, km (mi.)	204 (128)
Bunker, solid biofuel (wood chip), kg (lb)	500 (1,100)
Feed tanks, water, L (gal)	2,000 (528)
Time between refuelling at 48% load factor[2], h	4
Cab	
Fully enclosed, air-cycle air conditioning (HFC free)	Standard
Open canopy	Optional
Dimensions	
Wheelbase, mm (in)	3,100 (122)
Width x height x length, mm	2,490 x 3,300 x 6,100
Ground clearance, mm (in)	500 (19.7)
Shipping weight, kg	4,000
Operating weight, full supplies, kg	6,500
Power Take-Off (Optional)	
Location	Front & rear
Drive	Independent v-twin engine
Speeds, rpm	0-1000 (Variable speed)
Max. power, kW (hp)	112 (150)
3 Point Hitch (Optional)	
Front	Optional
Rear	Optional
Category, front/rear	IIIN/II, IIIN or III
Max. lift capacity at hooks, front/rear, kg	4,000/6,500
Brakes	
Engine (dynamic service brake)	Counter-pressure steam brake
Engine (service)	Hydraulic flywheel disc brake
Rear axle	Independent hydraulic drum brakes
Front axle	Hydraulic drum brakes
Pneumatic trailer brake	Optional
Hydraulic trailer brake	Optional
Suspension	
Front axle	Hydro-pneumatic, double wishbone
Steering	
Type	Hydrostatic
Turning radius, m (ft)	4.7 (15.4)
Autosteer	Optional
Various	
ISOBUS ready	Optional

[1] All specifications are subject to change.
[2] California Air Resources Board, *Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower*, California, 2018.

Powerful, Practical & Resilient

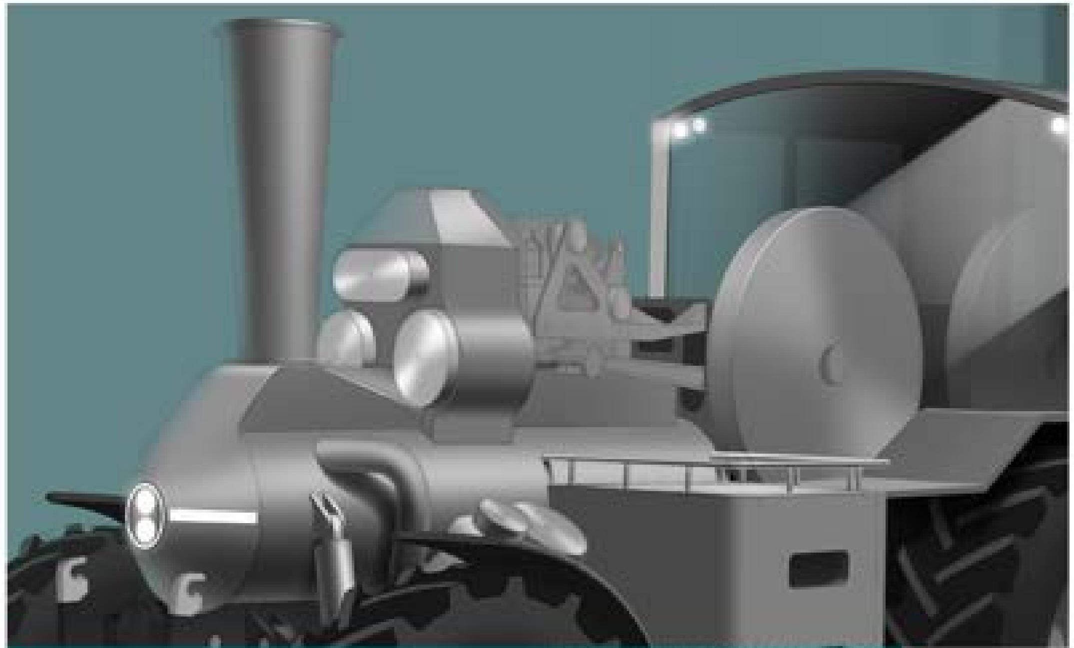
AGLOCO® 150

THE FUTURE OF TRACTION

agloco.co.nz - info@agloco.co.nz - +64 3 669 3366

150 Horsepower

10x the torque of a diesel engine



No excuses...

- 10 minutes to reach full pressure
- Reduces fuel costs by up to 90%
- 4 hour range at an average 48% load
- Refuel in less than 10 minutes
- Front and rear 112kW PTOs
- Front three point hitch
- Haul 30 tonnes
- 4wd optional
- Self feeding fuel system
- Spacious and air conditioned cab
- Autosteer option

"The AgLoco® 150 is a significant investment in your future..."

... A future of self reliance, where you grow your own regenerative fuel and put it to work.

The 150 is powered by solid biofuels such as cord wood, wood-chip, wood pellets and crop residues.

Fuel it yourself
Fix it yourself

The 150 is both durable and simple to repair, using basic farm workshop equipment, hand machined parts and locally available skills.

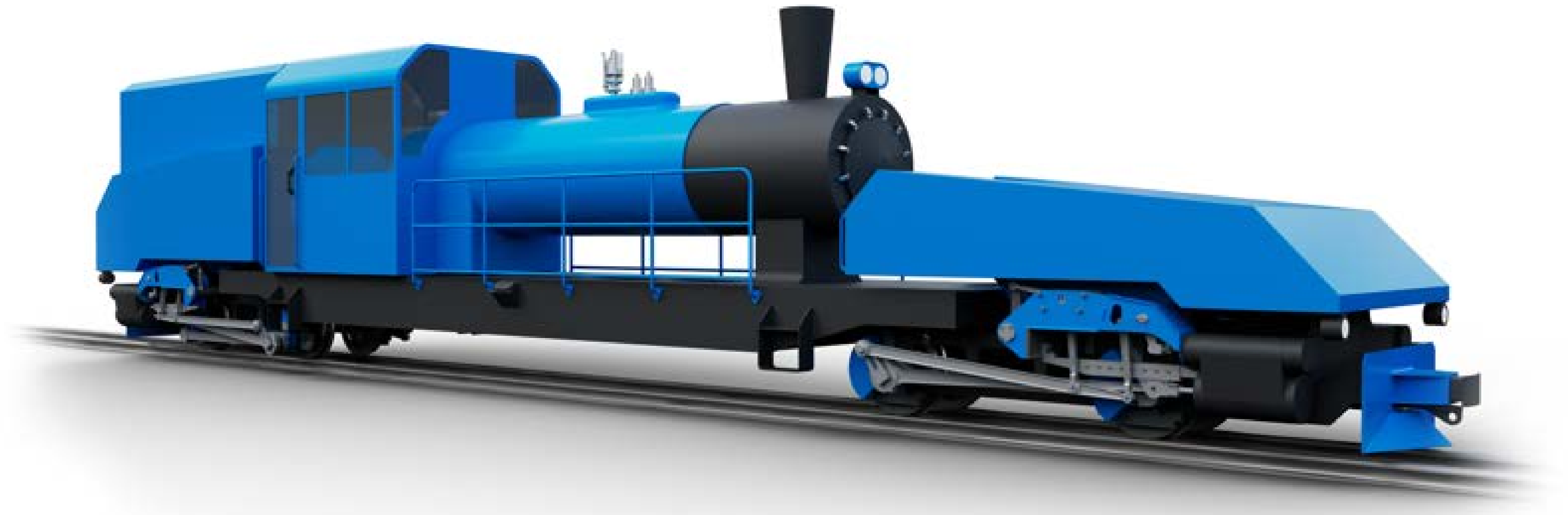
Regenerative carbon cycles
Complete combustion
Future resilience

As solid biofuel is produced, carbon dioxide is captured and stored.

The 150's advanced steam boiler technology utilises complete combustion resulting in a highly efficient, clean, spark and smoke free combustion.

The next round of solid biofuel growth simply recaptures emissions released during combustion.

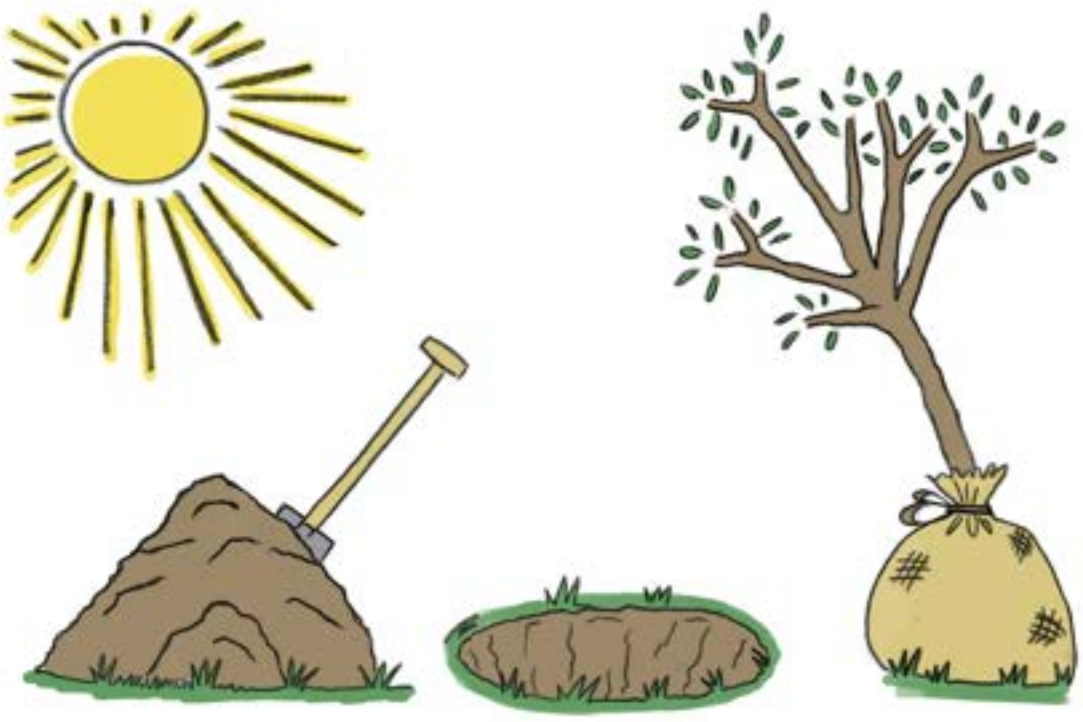
Mackwell Locomotive Co.



ZEROLOCO™ 400

SELF-SUFFICIENT TRANSPORT

mackwelloco.com - info@mackwelloco.com - +64 3 669 8607

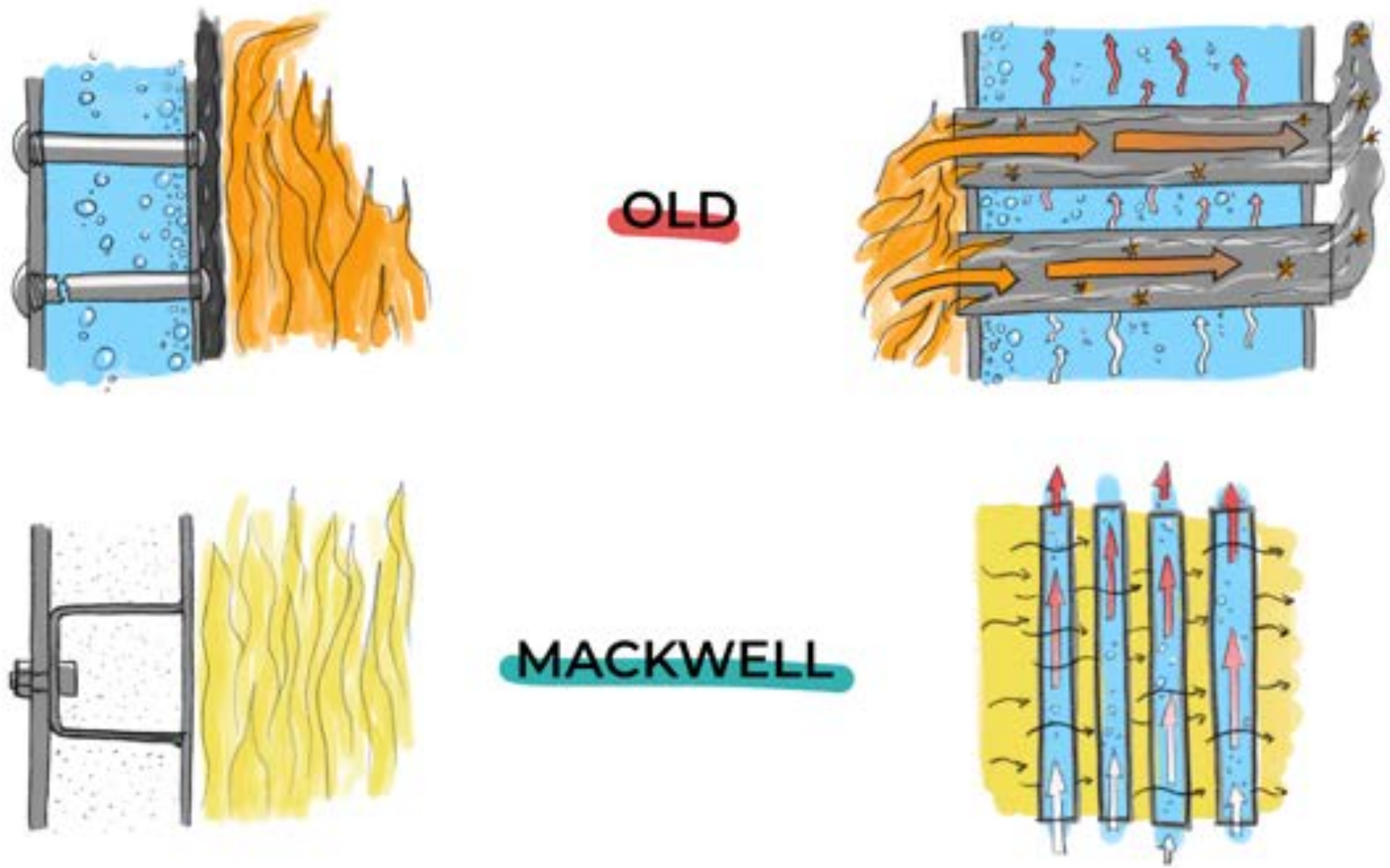


We believe energy for transport must be affordable, for everyone.

Affordability is not just about money. **Environmental impact**, **energy availability** and **community resilience** are equally important.

Solar energy, **captured and stored** by nature as **solid biofuel**, will provide affordable energy for transport.

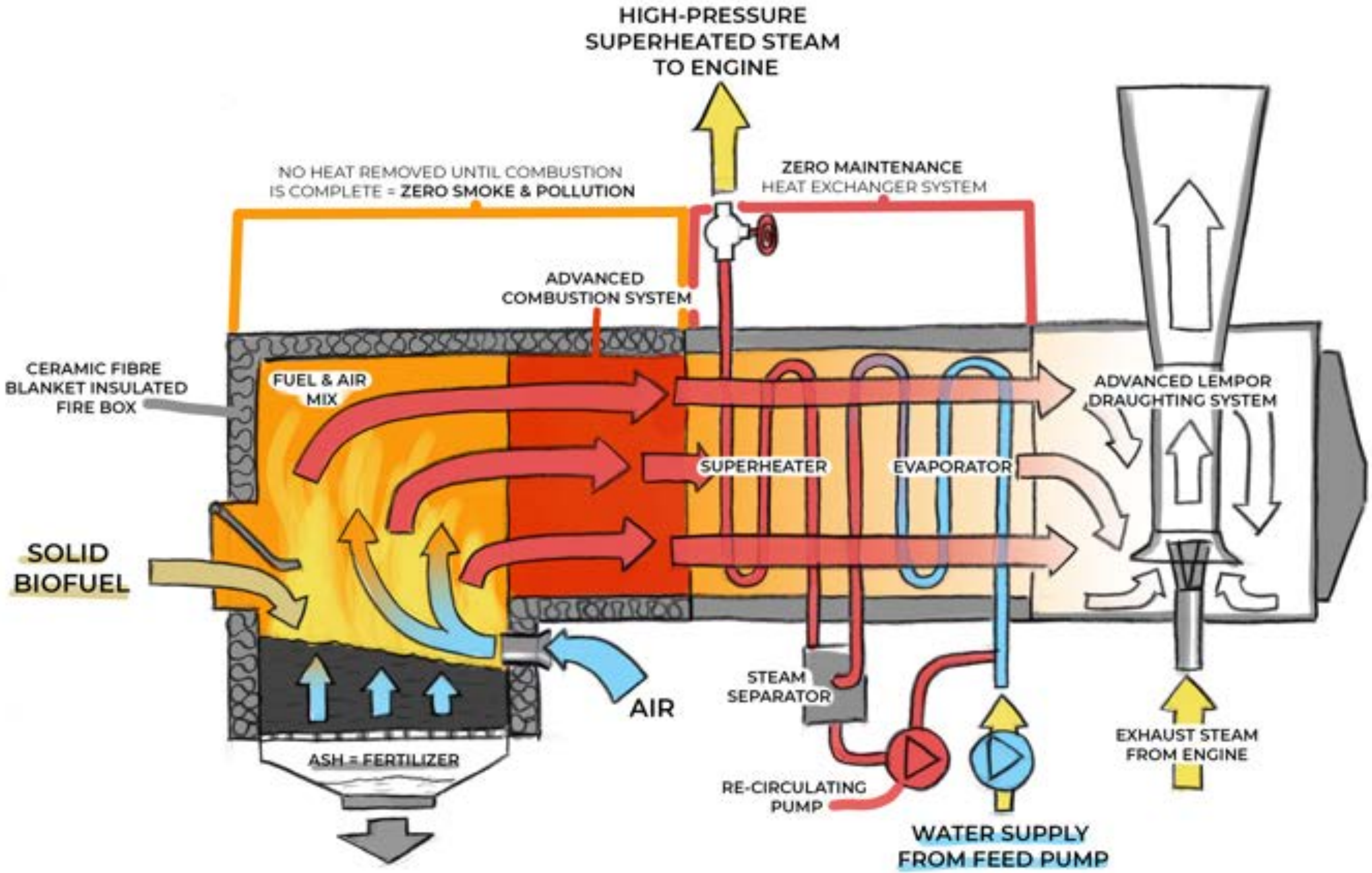
Advanced steam locomotives use solid biofuel responsibly by transporting loads on **highly efficient railway systems**, using raw solid biofuel directly and requiring few resources to build and maintain.



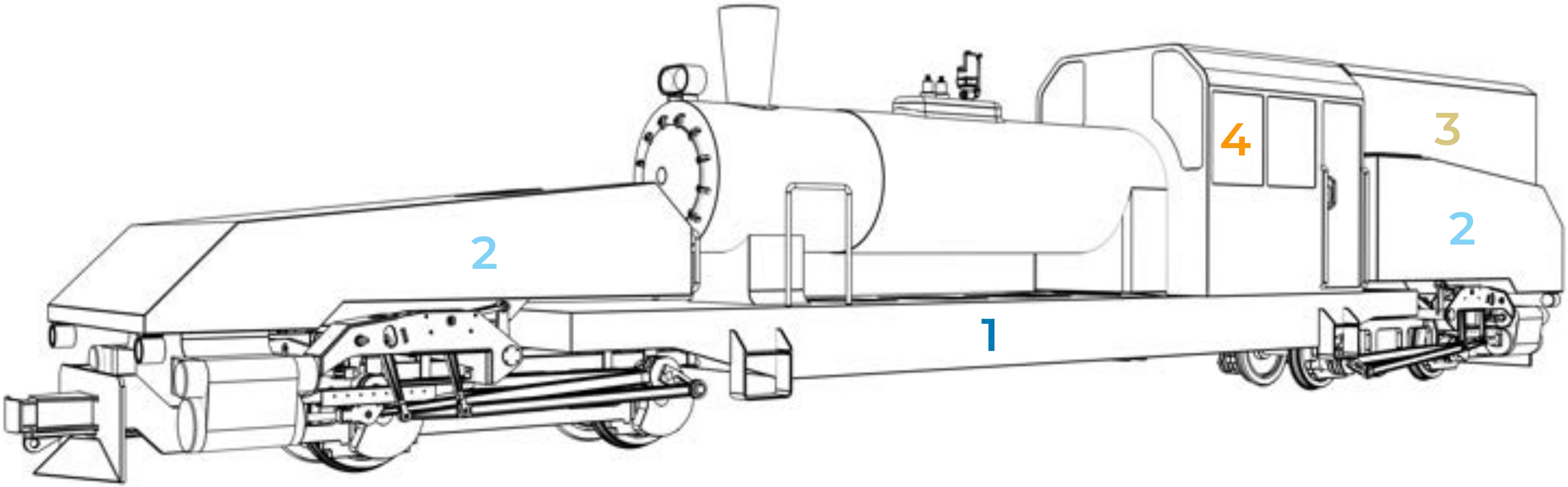
Two key principles underpin the Mackwell boiler technology:

1. **No heat is removed until combustion is complete.**
2. **Fast-moving water is heated inside small robust tubes.**

We have reinvented the locomotive boiler, **eliminating the sparks** and **smoke** that traditional boilers emit when fed solid biofuel.



Mackwell Locomotive Co’s advanced steam boiler technology



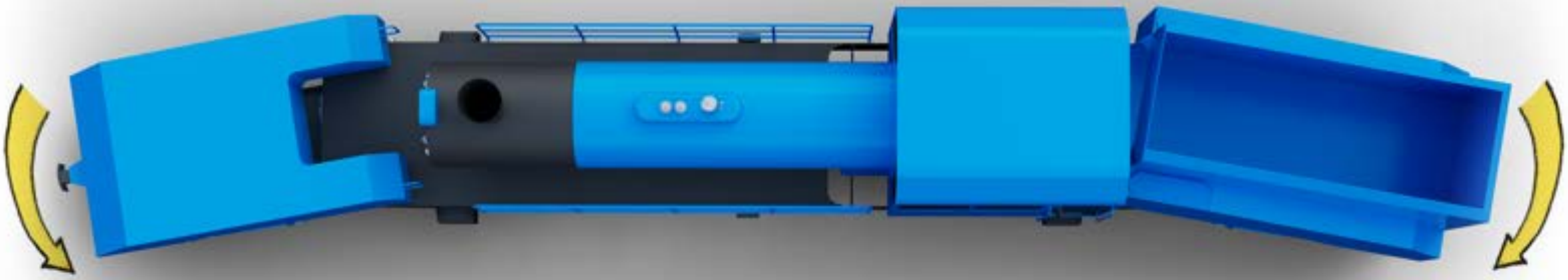
ZeroLoco™ combines Mackwell boiler technology with a highly successful articulated locomotive concept and state of the art mechanical design.

1 The long **articulated wheelbase** ensures an extremely stable ride allowing the ZeroLoco™ to glide around the tightest curves and climb steep grades. The **high power-to-weight** ratio of ZeroLoco™ gives **maximum drawbar power** with the minimum of steel. ZeroLoco™ is designed for **bi-directional operation**, no turning facilities are necessary.

2 **Large water capacity** is provided beyond typical service requirements, allowing the **locomotive's weight** to be **actively adjusted** to accommodate sections of lightly laid track.

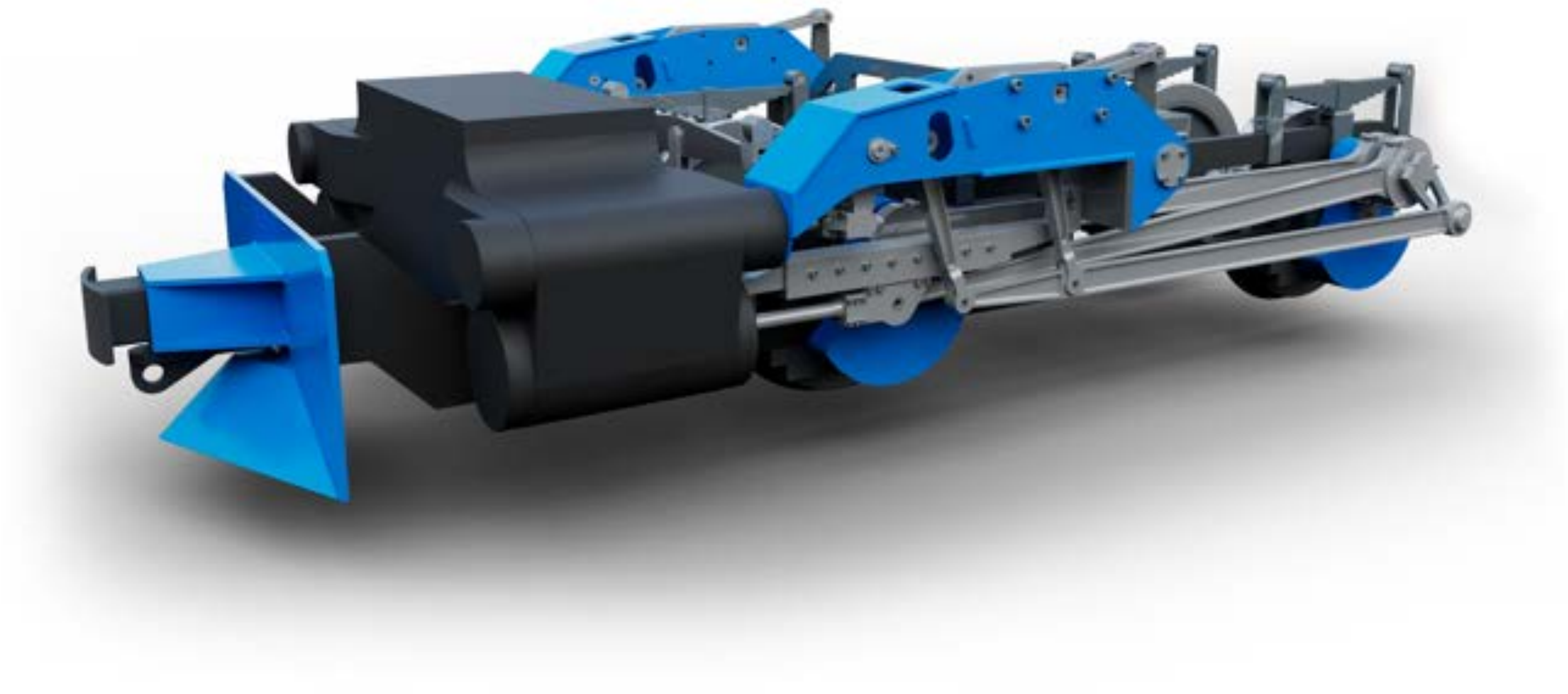
3 **Fuel bunker capacity** is large to enable the use of the **lowest-cost grades of solid biofuel** without compromising the **useful range** of the locomotive

4 An enclosed, **climate controlled cab** is provided, eliminating the hot working conditions experienced on traditional steam locomotives. **Air suspended seats** are fitted to minimise operator fatigue. **Facilities** are provided for using the heat of the boiler to **prepare hot beverages and cook food**.



The ZeroLoco is **articulated** on a highly successful pattern invented in 1908 by Herbert William Garratt. On curves, Garratt's invention results in the locomotive's **centre of gravity** moving inwards, aiding **stability**, especially on **narrow gauge** lines.

Supplies of solid biofuel and water **are carried by the driving wheels**, improving **adhesion**. The ZeroLoco's design **distributes its weight** over a long length, **reducing bridge stress.**



Tightly sealed **lightweight pistons** convert **superheated steam** into kinetic energy to haul trains. Piston thrust is transferred through **rolling element bearings** and **alloy steel rods** to crankpins on each axle.

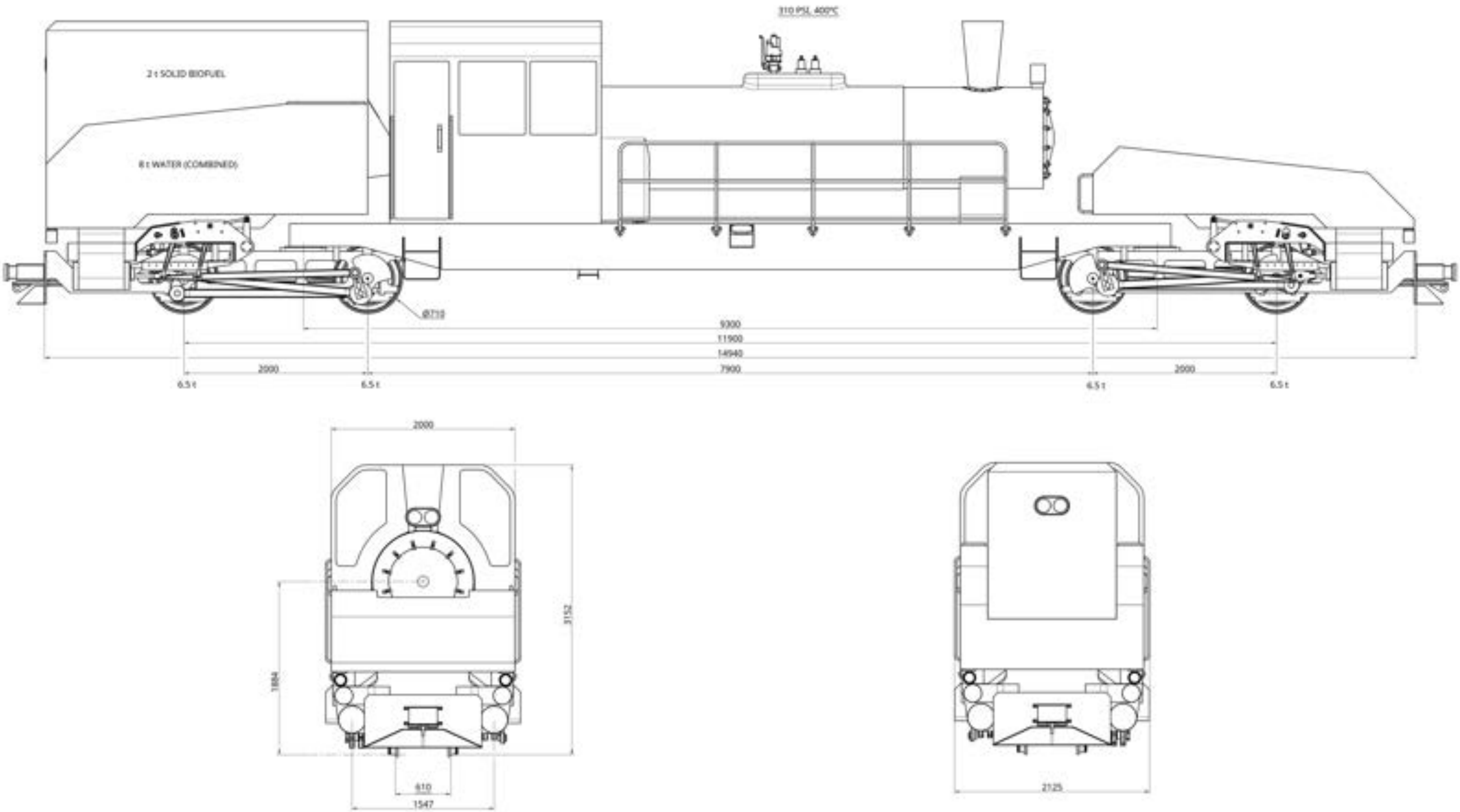
A simple mechanism named **Southern valve gear** controls the direction and power output of the locomotive. Being external, the moving parts of the transmission are simple and time effective to maintain.

The ZeroLoco can be quickly **reversed without stopping** and **dynamic counter-pressure braking** is provided to minimise brake wear.

ZeroLoco™ 400 Technical Specifications[1]

Propulsion	
Max. wheel rim power, kW (hp)	298 (400)
Wheel rim tractive effort, kN (lbf)	49 (11,000)
Rated speed, km/h (mph)	60 (40)
Cylinder bore, mm (in)	170 (6.7)
Stroke, mm (in)	355 (14)
Cylinders	Four
Cycle	Regenerative Simple Expansion
Steam pressure, MPa (psi)	2.14 (310)
Steam temperature, °C (°F)	400 (752)
Grate area, m^2 (ft^2)	0.99 (10.7)
Valve gear	Southern
Driver diameter, mm (in)	710 (28)
Capacities	
Load capacity on a 1.5% gradient, tonnes (tons)	240 (265)
Load capacity on the level, tonnes (tons)	1120 (1230)
Typical range with rated load in tow, km (mi.)	300 (190)
Bunker, solid biofuel (hog fuel etc.), m^3 (ft^3)	8 (283)
Feed tanks, water, L (gal)	8,000 (2110)
Comfort	
Cooling	Air-cycle air conditioning (HFC free)
Heating	Steam heat
Seating	Air suspended, fully adjustable
Ride stability	Long flexible wheelbase with hydraulic stabilisers
Amenities	Provision for cooking on boiler & preparing hot drinks
Dimensions	
Wheel arrangement	0-4-0+0-4-0
Rigid wheelbase, mm (in)	2,000 (78.7)
Overall wheelbase, mm (in)	11,900 (469)
Width x height x length, mm (in)	2,130 x 3,150 x 14,900 (83.7 x 124 x 588)
Max. axle load, tonnes (tons)	6.5 (7.2)
Min. axle load, tonnes (tons)	4 (4.4)
Shipping weight, tonnes (tons)	16 (17.6)
Operating weight, full supplies, tonnes (tons)	26 (28.7)
Adhesion aids	Air sanding, steam rail head conditioning
Gauge, mm (ft)	610 (2.0)
Brakes	
Engine (dynamic service brake)	Counter-pressure steam brake
Engine (service)	Air, clasp brakes acting on all wheel treads
Engine (park)	Spring apply, air release
Train	Automatic air or to suit operator
Various	
Minimum curve radius, m (chains) degrees	27 (1.33) 65
Drawgear	To suit operator

[1] All specifications are subject to change.



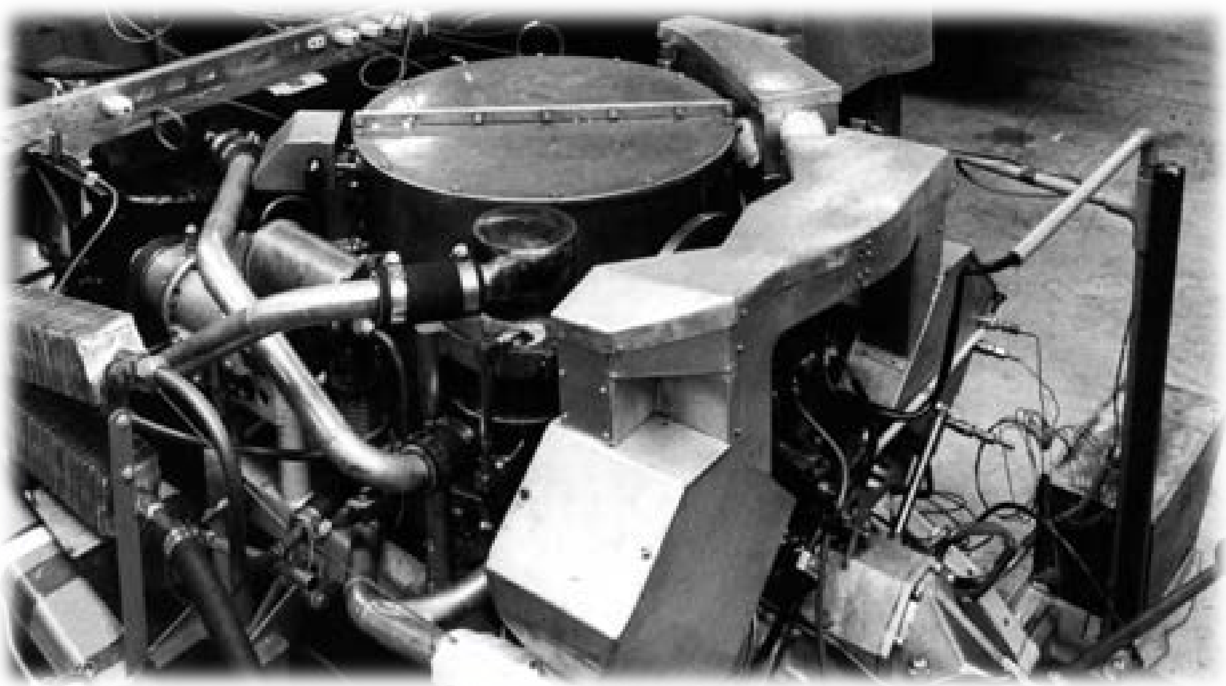
GENERAL ARRANGEMENT
ZEROLOCO™ 400-610

THE FUTURE IS NOT BUSINESS AS USUAL...

ATTACHMENT 4

Pritchard Steam Power System – Basis for Uniflow Power Ltd. Cobber CHP Unit

Available at http://www.virtualsteamcarmuseum.org/makers/pritchard_steam_power_pty_ltd.html

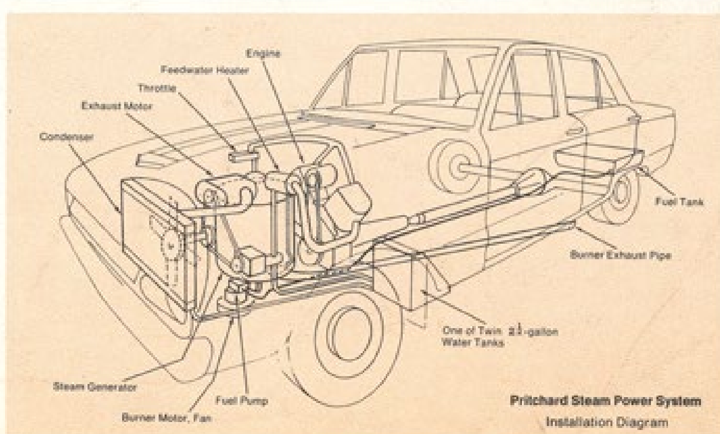


PRITCHARD
STEAM CAR

Australia's Own Design

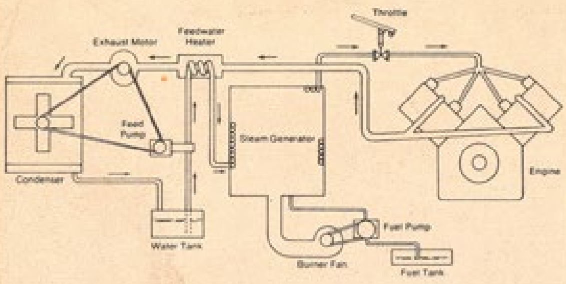
Pritchard Steam Car being airlifted to U.S.A. for special auto industry demonstrations November 1972.

The Installation Diagram shows the steam generator located centrally under the bonnet. The vee twin engine, behind the steam generator, drives the rear wheels through the propeller shaft. No gearbox is required.
The exhaust motor, mounted above the steam generator, drives the condenser fan and feedpumps positioned towards the front of the under-bonnet space.



Pritchard Steam Power System
Installation Diagram

Pritchard Steam Power Pty. Ltd.



Pritchard Steam Power System Schematic Diagram

Schematic Diagram

Capacity of the WATER TANKS located at the rear wells of the two front mudguards is 5 gallons. A FEED PUMP lifts water from the storage tanks to a FEED-WATER HEATER, where the water is pre-heated before entering the monotube STEAM GENERATOR. High-pressure steam is supplied from the generator to the uniflow ENGINE, the amount of steam being regulated by the THROTTLE.

Exhaust steam from the engine is utilized to drive the EXHAUST MOTOR, which powers both the feed pump and the condenser fan. Exhaust steam is condensed in an automotive-type radiator, which serves as the CONDENSER. The resulting condensate is returned to the water tanks by gravity, thereby completing the cycle.

Fuel and air are supplied to the BURNER MOTOR by an electrically driven FUEL PUMP and BURNER FAN. Fuel currently being used in the FUEL TANK is ordinary household kerosene.

SPECIFICATIONS

Engine type	Two cylinder 90^{0} vee, double-acting full Uniflow. Self starting, reversible, provides emergency braking.
Cylinder Bore	2.3/8" (60 mm)
Piston Stroke	2 in (51 mm)
Displacement	17.6 cub. in. (288 cc)
Maximum Speed	4000 r.p.m.
Maximum Torques	360 lb. ft. Late cut-off (for starting) 240 lb. ft. Medium cut-off (low speeds) 160 lb. ft. Early cut-off (normal running)
Horsepower	36/40
Lubrication	Crankcase — all roller and ball bearing — splash. Cylinders — mechanical pump.
Steam Generator type	"Monotube". ("Once — through") No pressure vessels.
Water content	4 pints.
Casing size	15 in. dia. (38 cm) by 16¼ in. high (42 cm)
Control	Automatic by temperature, pressure and built-in proportioning controls.
Steam pressure	1400 p.s.i. — Burner off. 1200 p.s.i. Burner on
Burner type	Cold starting from "ignition" key, pressure atomising.
Combustion chamber	Gas turbine type.
Power Unit Seals	All non-adjustable.

PERFORMANCE

AT PRESENT STAGE OF DEVELOPMENT

Starting up time	1 — 2 minutes
Cruising speed	60 m.p.h.
Fuel tests at 40, 50, 60 m.p.h.	19.6 m.p.g. (kerosene)
Water consumption	40/50 m.p.g.

POLLUTION COMPARISON

Pritchard Steam Car	Burner "Steady State"
Petrol Car	Typical uncontrolled engine.

	Petrol Car	Pritchard Steam Car
Carbon Monoxide	0.5 to 7%	0.013%
Hydrocarbons. Parts per million	200 to 3000	Less than 1
Nitrous Oxide. Parts per million	500 to 1000	115
Lead Compounds	Yes	None

THE COMPANY

PRITCHARD STEAM POWER PTY LTD an Australian controlled Company was formed to develop modern steam power units primarily for automobiles. The result is the compact steam power unit at present fitted to an early Ford Falcon body. The cover shows this car on its way to the United States where 24 demonstration runs were given to interested bodies.

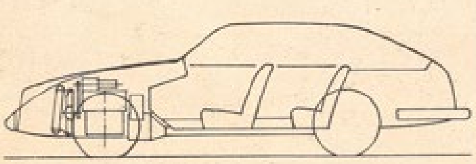
It is known that a steam car produces little smog. It does not require a gearbox. What else, then, is required for a modern steam car?

One answer is that a compact steam power unit must be used. (Boot space must not be taken up by the components of the power plant.) Only a small amount of water should be carried in the steam generator. We have made much needed break throughs in the control of pressures and temperatures in a tiny steam generator containing only 4 pints of water. It should be noted that this type of steam generator is not subject to inspection by boiler authorities.

A special feature of our design is the use of exhaust driven auxiliaries which assist in obtaining fuel consumption competitive with modern petrol-engined vehicles. The use of low grade fuel confers additional economy. Until recently, development work was carried out in a small factory at Caulfield. Operations have now been transferred to a centre at Bayswater. Here, three advanced units are to be made and subjected to intensive testing.

A production batch will then be made available for sale to the public. Your further enquiry regarding the development of this engine is invited.

Modern Steam Power for the Car of the Future



The Pritchard Steam Power Unit is a long-life, low pollution type. The engine has low mechanical drag. These are ideal characteristics in an engine for a car of the future, with low fuel consumption taking advantage of advanced body design.

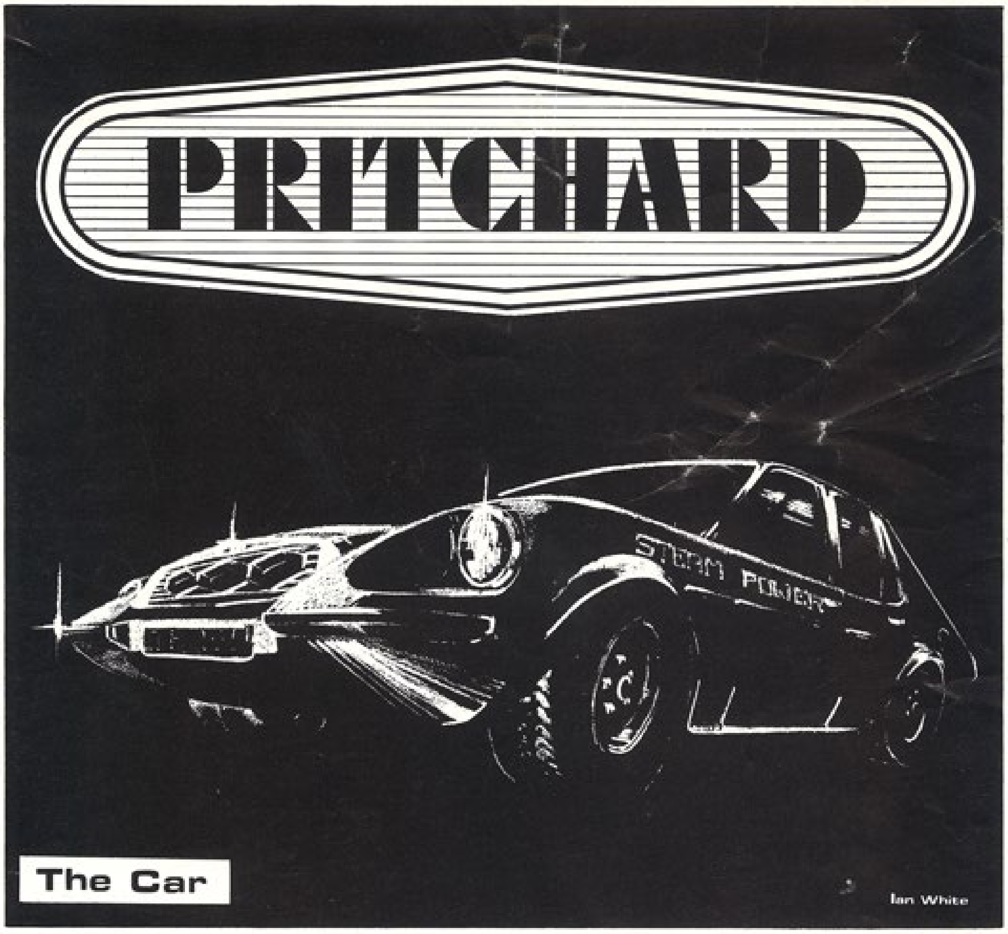
Energy Crisis Steam engine burner fuel is of a wide "cut" or distillation range. This means greater flexibility in the operation of the oil refinery enabling the best possible useage of the available crude oil.

In the event of a petroleum oil shortage, fuel used can be other liquid, gaseous, solid fuel or fuels derived from solid fuels.

There is no "octane" ("pinging" or "detonation") requirement for the steam engine fuel. There is no need for high volatility. (A safety feature). There are possibilities with shale oil, and solar energy crops such as eucalyptus, peanut oil, wood and wheat.

Pritchard Steam Power PTY. LTD.

Unit II 176 Canterbury Road, Bayswater Vic. 3153 **Phone: 729 3766**



The Company

PRITCHARD STEAM POWER PTY. LTD. is an Australian controlled Company formed to develop modern steam power units primarily for cars.
Patents have been issued in a number of countries on such subjects as — steam generator, burner control and engine improvements.
Mr. Pritchard has presented two papers to the Society of Automotive Engineers describing his work to date. These are —

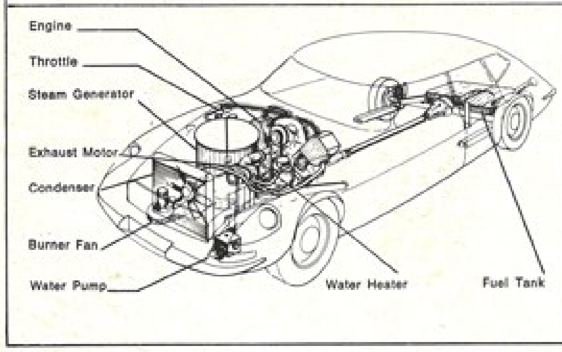
(1) "The Steam Car — Fact and Fantasy", See "SAE-Australasia", Sept.-Oct. 1971 (Winner of Hartnett Award for "An outstanding contribution to Automotive knowledge or Practice")and
(2) "Progress on the Pritchard Steam Car", See "SAE-Australasia", July-Aug. 1974.

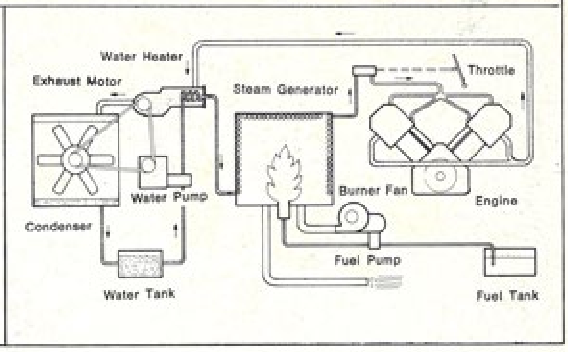
Three power units of improved design are being built at the Bendigo Ordnance Factory. One is to be mounted in the PRITCHARD aerodynamic car body, one for dynamometer testing and the other is a spare. After the test programme on these engines we will be ready to produce a pre-production batch of power units and cars for sale to interested persons.

PRITCHARD STEAM POWER PTY LTD

Factory 11, No.176 Canterbury Road Bayswater Vic. 3153 Phone: 729 3766

MODERN STEAM POWER - The answer to today's Energy and Pollution problems





GENERAL LAYOUT **PRITCHARD STEAM POWER SYSTEM** **SCHEMATIC DIAGRAM**

Features demonstrating superiority of the PRITCHARD power unit over current internal combustion engines.

*** Multi-fuel capability:** Alcohol from sugar cane, "Grown crop" oils, or petroleum based liquid fuels can be used. Economic use of solid fuels is being investigated for stationary and marine applications.

*** Environment:**
(a) **Pollution** is virtually non existent. Fuels do not need to be leaded.
(b) **Noise.** Steam has always been noted for its quietness in operation, and the PRITCHARD power unit is no exception. This is most essential for trucks, buses, construction and agricultural equipment. Many plant operators and farmers have had their hearing affected by noisy machinery.

*** Safety:**
(a) **Reluctant Flammability.** Fuels used in the PRITCHARD power unit do not need to be highly volatile. This is a great advantage in marine applications, where spilt or leaked petrol can collect in bilges and causes explosions.
(b) **Collision.** The Steam Generator consists of coiled tubing, which, in a heavy front end collision acts as an impact absorbing crushable structure; unlike the rigid cast iron cylinder block of an internal combustion engine. There are no pressure vessels to cause explosions.
(c) **Elimination of "Runaway" danger.** In the event of brake failure, the reverse torque of the Steam Engine can easily halt the vehicle. This is an important advantage for all vehicles, especially buses and trucks.

*** Generally:** The engine is self starting and reversible. High torque from the relatively small engine eliminates the need for a manual gearbox and clutch, or automatic transmission. Easy manoeuvering and driving is thus obtained. Low engine friction loss — about one-sixth of a petrol engine — enables development in conjunction with low drag car bodies toward further increases in fuel economy.

*** Summing up:** **The PRITCHARD is a very safe, low pollution, multi-fuel power unit. It has characteristics most desirable for use in automotive, marine, construction and agricultural machinery; and stationary applications such as sawmilling and electric power generation.**

SPECIFICATIONS — CAR ENGINE

ENGINE:

Type	Two cylinder 90° vee, double acting full Uniflow. Self starting, reversible, provides emergency braking.
Cylinder Bore	66 mm.
Piston Stroke	60 mm.
Displacement	410 cc.
Max. r.p.m.	4000.
Max. torques	Late cut-off (for starting)(500 lb.ft.) 678 Nm. Medium cut-off (low speed)(340 lb.ft.) 461 Nm. Early cut-off (normal running) (225 lb.ft.) 305 Nm.
Power	33.5 kw (45 H.P.).
Lubrication	Crankcase — all ball and roller bearings — splash. Cylinders — mechanical pump.

STEAM GENERATOR:

Type	Monotube ("Once-through").
Water Content	2.2 litres.
Casing Size	410 mm dia. x 470 mm high.
Controls	Automatic by temperature, pressure and built-in proportional controls.
Steam Pressure	9646 k Pa (1400 p.s.i.). Burner off. 8268 k Pa (1200 p.s.i.). Burner on.

BURNER:

Type	Cold starting from "ignition" key, pressure atomising.
Combustion Chamber	Gas turbine type.

(**Note:** *Specifications are subject to change without notice.*)

*Figures subject to confirmation by testing programme.

POLLUTION COMPARISON

PRITCHARD Steam Car.... Burner "Steady state"
Petrol Car ....Typical uncontrolled engine.

Exhaust Emission	Petrol Car	PRITCHARD Steam Car
Carbon Monoxide	0.5 to 7%	0.013%
Hydrocarbons (parts per million)	200 to 3000	Less than 1
Nitrous Oxide (parts per million)	500 to 1000	115
Lead compounds	Yes	None

Note: *PRITCHARD steam car passed pollution requirements easily for Australian 1976 standards in test on 21st May, 1974.*

PERFORMANCE DATA. PRITCHARD STEAM POWERED UNITS

Parameter	*Early Truck 5 Ton*	*Experimental Car. 6 Passenger.*	• *New Car 6 Passenger*
Cruising Speed	64 kph (40 mph)	104kph (65 mph	136kph (85 mph)
Fuel Consumption (kerosene)	28-47 L/100kmz (6-10 mpg)	11-14 L/100km (20-25 mpg)	9-11 L100km (25-30 mpg)
Water Consumption	28 L/100km (10 mpg)	to 1.66 L/100km (170 mpg)	Negligible (semi-sealed)
Start up time	4 minutes	1½ minutes	45/50 seconds
Acceleration	Good	Capable of improvement	Good

PRITCHARD STEAM POWER PTY LTD

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(LA3) THOUSAND OAKS, Cal., Dec 14--STEAM AUTO ENGINE UNVEILED--Edward Pritchard, an Australian inventor, shows off his steam automobile engine in a demonstration Thursday in Thousand Oaks, Cal. Pritchard, who built the system into a Ford Falcon , said he's driven the car up to 60 miles per hour and says the engine could meet pollution emission standards set up for 1975. (AP Wirephoto)(rhs51410stf-dfs) 1972

Pritchard Steam Car – Drive Article (2022)

Available at https://www.drive.com.au/caradvice/the-australian-designed-car-built-to-steamroll-the-establishment/

You could be forgiven for not knowing of The Pritchard, an obscure, yet ambitious automotive marque founded by a Melbourne-based engineer, who'd go on to have his 'steamer' air freighted to Detroit to show it to the 'big boys'. Mad about steam engines from an early age when he and his father used to build them for fun, Edward 'Ted' Pritchard was a well-credentialed mechanical engineer and visionary. A Fellow of Melbourne's Technical College (now the Royal Melbourne Institute of Technology) and a member of the Institute of Engineers Australia, he believed that steam could power anything and do so economically. To prove his beliefs, he set about commercialising a steam power unit for use in everything from the agricultural to automotive sectors.

A labour of love for Ted and his father, the self-named, designed and engineered Pritchard Steam Power System was, in essence, a steam crate motor that could be retrofitted, or engineered from the outset as a primary power source for any machine requiring motive force. To demonstrate the flexibility, compact size, and practicality of the steamer, Ted decided to fit it to a 1963 XM Ford Falcon.

Over four years, Pritchard refined the drivetrain and packaging to suit the Falcon, with the final steamer featuring a 288cc, 90-degree, V-twin which developed approximately 40 horsepower and a mighty 360Nm of torque, with peak revs reached at 4000rpm. This was enough to return a fuel efficiency of 9.4 litres per 100km. Compare that for a moment to the standard six-cylinder XM Falcon – which would consume close to 15 litres of fuel per 100km – and you start to understand why the Pritchard had potential.

The Pritchard also had fewer moving parts, could run on any type of combustible fuel from cooking oil to kerosene, and weighed less than its combustion-powered contemporary. Most interesting was the fact that the car did not need a transmission as the engine could be thrown into reverse at the flick of the column-mounted shifter for immediate 'reverse-torque,' or as Ted called it an additional 'safety device.' The car was also self-starting, featured a closed-loop boiler, made use of the standard Falcon radiator as a condenser and could cruise at 120km/h.

By 1967, Ted and his 'Green Stripe' XM – named for the green centre stripe Pritchard fitted to the vehicle – were ready to undertake proof on concept and field trials. Conducted around Melbourne, Pritchard's field trials were described as 'convincing' by the media of the time. So widespread was the interest in the 'steam-powered car' that several news networks covered the vehicle trial at the time.

Buoyed by enthusiasm from the successful trials, Ted refined his offering and by 1971 his 'Green Stripe' had attracted the attention of US auto manufacturers, who undertook extensive local testing in Australia. So impressed were the Americans, that in November of 1972, the car and its inventor set off for the United States. Landing in L.A., the company embarked on 24 demonstrations over three weeks to the likes of Ford, General Motors, American Motors and a host of other interested parties, with all leaving the events impressed according to the inventor.

Upon return to Australia, Ted was made aware that 'Green Stripe' was the cleanest vehicle ever evaluated by far, already surpassing the incoming 1975 US Emissions Regulations.

These forthcoming emissions standards, which we now know as Corporate Average Fuel Economy (CAFE) regulations, would see a slew of new emissions measures thrust onto American manufacturers – including Exhaust Gas Recirculation, recognition of NOx emissions and the adoption of catalytic converters. Pair this with the oil shock of 1973 and automakers moved quickly to clean up their act, in turn stifling interest in Pritchard's work.

Undeterred, Ted continued to refine his drivetrain and by 1974, interest had reignited in Pritchard's work, with Ted presenting the vehicle for further testing at Ford's Geelong testing facility. At first, Ford's engineers thought their testing equipment was mis-calibrated, so they reset the equipment, but the result was the same. Pritchard's drivetrain was able to meet emissions regulations that we would not see until 1999 – known as Euro 2 – but Ford passed on the tech once again.

It was by this time that media interest was again piqued, and the engineer-come-advocate appeared on the iconic Australian TV series Leyland Brothers World (if you don't know who they are, just Ask the Leyland Brothers) this time with the Falcon sans the green stripe. It is during this interview with Mal Leyland is told of a second-generation Pritchard steamer that is under development. That second vehicle was first shown to the public at the 1975 Melbourne International Auto Show as a model (below), debuting as the Advanced Pritchard Steam Car. So compelling was the proposition that the then Federal Minister for Manufacturing and Industry awarded a grant to Pritchard to build three prototypes.

Based on a 'restyled' Holden Torana donor vehicle, progress on the prototypes was slow and funds began to run out. To keep the program alive, Ted sold one of the original steam trucks he and his father worked on in the early days, but it was not enough. Fortunately, in July of 1977, State and Federal Governments injected further funds into the company just as it was on its knees. This cash lifeline was enough to finish the prototype drivetrains and get them to the bench testing phase, but again the program began to run behind schedule and was bleeding cash.

In short, by 1981 the company went broke and despite growing international interest in the powertrain, for both motive and stationary purposes, the company just didn't have the means to finish its development work. But Ted wasn't about to give up on his dream and passion. Finding work as a Lecturer at the Royal Melbourne Institute of Technology (RMIT) Ted taught the finer points of engineering and thermodynamics by day, and whiled away at his drawing desk by night investing five years and 6000 hours into his new S5000 steam engine – named so because of its ability to generate 5000 Watts of power.

Between 1992 and 2002 Ted Pritchard remained committed to his cause, lobbying governments and publishing articles on the advantages of steam power. By 2003, Pritchard Power Australia had been formed to further develop and license the S5000 power unit, but it was never to be. In 2006, with Ted now 77 years old, he signed the technology over to an Australian company that embarked on commercialising the engine, but he died before it was finished. Today, Pritchard's S5000 lives on via the Victorian-based company Uniflow Power which has developed the steamer into a consumable product dubbed the 'Cobbler'. Able to produce electricity, steam, hot water, distilled water and rotary mechanical power, the Cobbler is everything Ted Pritchard envisioned his powerplant could be.

Additional details on Pritchard Steam Engine Patents can be found at:
http://www.rexresearch.com/pritchardsteam/pritchard.html

ATTACHMENT 5

The Keen

Steam Car

This magnificent sports roadster achieves outstanding performance in almost complete silence.

THE KEEN STEAM CAR

NO SMOKE — NO DIRT — NO FUMES

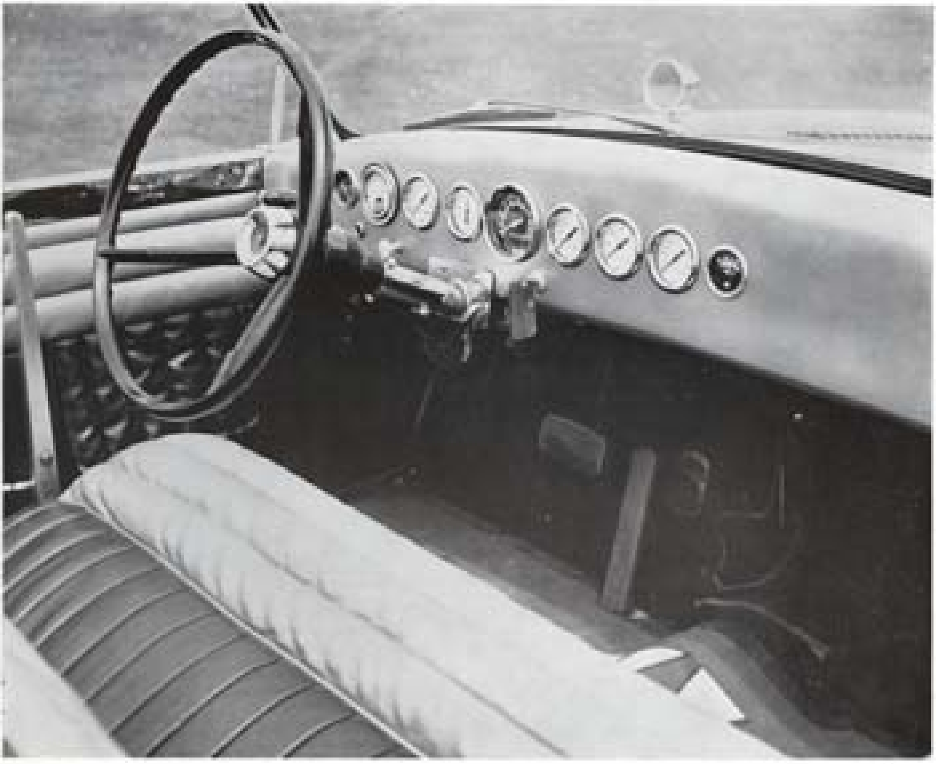
Starts at the turn of a switch — No gears — Silent travel.

Here is a magnificent bright red, very sleek sports car of rakish design, losing nothing by comparison with the most expensive and illustrious of that ilk. The exterior has twelve coats of rubbed down lacquer, and has beautiful magnesium wheels. Interior décor is in black and gold, the commodious cockpit having plenty of leg room and clean swept space. The impressive dashboard has a long array of gauges to inform the driver of what is going on, with the reversing lever at the left. If desired a foot pedal could be substituted for this lever.

Careful streamlining and beautiful finish combine to create distinction.

Performance.

A turn of the switch and the burner ignites with a slight puff. No smell and no smoke from oil fuel—lovely combustion. By my watch timing, steam pressure was raised and we moved away in just over one minute with full power available. When the power unit is warm, steam raising is practically instantaneous. We threaded our way through heavy city traffice and then out on



In charge of exciting power, the driver sits amid opulence.

With interior decor in contrasting black and gold surmounted by dove-grey panel which frames the instruments in neat array, the Keen displays excellent craftsmanship. Most of the intruments are of engineering interest only, being merely visual reminders of efficient automatic control.

From left to right are spotlight for instruments, water and fuel gauge, steam temperature guage, fuel oil pressure, steam pressure, speedometer, steam pressure at engine, engine oil pressure, exhaust steam pressure, ammeter. Below from left to right are signal light for feed water pumps, headlight switch, and windscreen wiper control beside steering column bracket.

Two pedal control is provided by the brake and throttle accelerator pedals.

to the open road. Owner-driver, designer Charles F. Keen let her out and we rolled at sixty and then at seventy, which was all traffic conditions would allow. No fuss and no trouble. The monotube steam generator and automatic controls provide the steam when the engine requires it, all the driver has to do in normal running is use the accelerator pedal and footbrake. To reverse, the engine rotation is reversed. There is no clutch or gearbox. Acceleration is brilliant, being best described by the remark: " . . . . **at the average stop lights I am across the intersection before most cars get started."**

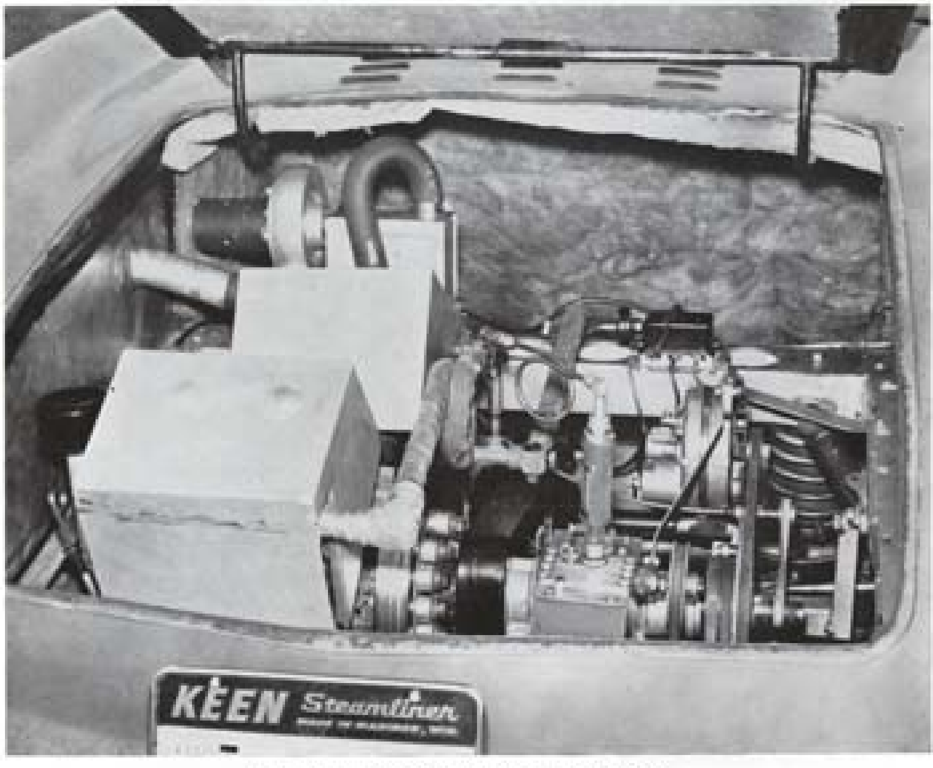
On a spurt, pressure once dropped to 800, but promptly came back, and the rest of the time remained quite steady at 1,000 to 1,200. This type of steam generator, being inherently safe from all fear of explosion is **not** subject to insurance cover or inspection. At 45-50 m.p.h., the burner was frequently automatically switched off due to excess steam pressure, very rarely due to excess steam temperature, which proves the worth of the automatic control system. There are two power settings—a low fire position, which gives about 85 m.p.h. top speed and the high fire with about 100 m.p.h. available.

Economy.

Cheap paraffin (kerosene) or furnace oil gives an economical 12—18 m.p.g. (10-15 m.p.g. American), depending on driving conditions, with improved economy envisaged for the future. Ordinary tap water is used and, with the steam condensed for re-use, the water tank need be only rarely filled.

Silence.

The engine and pumps are extremely quiet, comparing favourably with a perfectly tuned i.c. engine. On a sudden hard pull one is aware of a slight pulsation, but it is not very noticeable unless one is told to watch for it. There are several positions for variation of cut-off (which is the fraction of the piston's stroke during which steam is admitted to the cylinder). Engine drive coupling



The engine compartment under the rear deck.

The 4 cylinder uniflow expansion, single-acting engine is shown at left. Cylinders in this 90 deg. V. design are arranged in two banks of two each. There is direct drive to the rear axle, no clutch or gearbox being required. Freedom from vibration is ensured by a coupling incorporating twenty-four drive pins each surrounded by a rubber bush. With the engine installed transversely aft of the rear axle, the torque in forward direction tends to throw more weight on the rear wheels, thus counteracting wheel spin.

contains 24 drive pins each surrounded by rubber bushes to give smooth, silent transmission. When riding along at 25-30 m.p.h., it is impossible to know whether the burner is on or off.

Engine.

With four cylinders—the equivalent in power impulses of an eight cylinder i.c. engine, and 100 cub. in. (1,639 cc.) capacity, the compact V4 design gives 130 h.p., which can be increased if needed.

Steam distribution in the cylinders is on the uniflow principle, in which steam enters through a valve and exhausts through ports cut in the cylinder walls near the end of the stroke. Very high torque is available at very low r.p.m.,

The steam generator.

Nestling neatly under the bonnet (hood) is the highly efficient, oil-fired, automatically controlled steam producer, quite different from the cumbersome boilers of yesteryear.

so high that there was a danger of excessive wheel slip during acceleration. For this reason the engine is placed transversely **behind** the rear axle so that when power is applied going forward it throws more weight on the rear wheels, thus avoiding wheel spin. Also when the throttle (accelerator) is tromped on, the car hugs the road rather than creating a tendency for the front wheels to lift. That this arrangement is of great practical use is made evident by the ease with which the rear wheels can be made to spin when reversing.

Steam Generator.

Gone are the days of the bucket of coal, belching smoke, and greasy rag. Steam is generated automatically, without noise, smoke or troublesome fumes. Combustion is so good that there is none of the noxious odour associated with the diesel and, to a lesser extent, with the petrol (gas) engine.

Air and oil spray are blown into a totally enclosed combustion chamber at the top of the steam generator, and the hot gases give their heat to closely wound coils of immensely strong tube before being allowed to escape from an exhaust duct beneath the body of the car. Water is pumped into the coils of

The graceful lines give no indication of the smooth, silent steam power, with brilliant acceleration.

tube, turning to steam therein, which is admitted to the engine via a throttle valve operated by the accelerator pedal. Steam pressure is automatically controlled at a maximum of 1,200 lbs. per sq. in. by the action of a pressurestat, which switches the fire on and off to suit the engine's demand for steam, as controlled by the throttle. The normaliser allows a small spray of water to be admitted into the hot or superheater section of the coiled tube, cooling the steam before its exit to the engine and enabling the thermostat to maintain a steady steam temperature. The whole nestles unobtrusively under the bonnet (hood). This is a very light-weight, compact steam producer, not be be confused with a heavy, cumbersome boiler.

Starting is more simple and reliable than an i.c. car. You just turn a switch. There is no need to wait for the engine to fire. Within the minute stored power is available to make the car accelerate right up to maximum speed as fast as the tyres will allow, without a pause for gear changing.

A familiar car in Madison, U.S.A., is the Keen Steamliner, but nevertheless one which rarely fails to merit excited comment. Preliminary arrangements for eventual manufacture on a commercial scale are being made.

Enquiries should be directed to :—

THE KEEN MANUFACTURING COMPANY,

1602 GILSON STREET, MADISON 5, WISCONSIN, U.S.A.

Published by :—

"LIGHT STEAM POWER," KIRK MICHAEL, ISLE OF MAN, U.K.

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ATTACHMENT 6

Institution of
Mechanical Engineers

Railway Division

I MECH E

The Sir Seymour Biscoe Tritton Lecture

MODERN STEAM - AN ECONOMIC AND ENVIRONMENTAL ALTERNATIVE TO DIESEL TRACTION

ROGER WALLER, Dipl.-Eng.ETH

Lecture presented at the
Sir Seymour Biscoe Tritton Lecture
on Monday 3 February 2003 and Tuesday 4 February 2003

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MODERN STEAM - AN ECONOMIC AND ENVIRONMENTAL ALTERNATIVE TO DIESEL TRACTION

ROGER WALLER, Dipl.-Eng.ETH

1. INTRODUCTION

More than 30 years have elapsed since a paper on steam locomotive development was presented to the Institution of Locomotive Engineers. Whilst that paper [1] given by Mr. L. D. Porta in 1969 was directed to the traction requirements of the under-developed countries, this paper suggests a fresh look at *modern steam* as a potential alternative to diesel traction mainly in the first world. This strong statement is based on practical experiences gained over the last 11 years whereby *modern steam* traction has compared favourably with diesel traction.

Since 1969, steam traction has seen ups and downs, but the general tendency has been that of decline. However, during the oil crisis in the 1980's, steam power was reconsidered by many railways, recognising its inherent advantage in its ability to burn most types of fuel. Even in the USA, steam traction was seriously looked at, resulting in several ambitious projects including ACE 3000 [2]. When the oil price dropped again, these projects were terminated at an early stage of development. Nevertheless, several other projects have been realised in countries with abundant, cheap coal, amongst which was the rebuilding of 89 Garratt locomotives in Zimbabwe [3]. It incorporated the conversion of all axles to roller bearings, but otherwise the design was left unchanged. The rebuilt Garratts replaced diesel locomotives, saving oil and money.

In South Africa, steam locomotives were developed under the direction of David Wardale, who employed Porta's technology to rebuild 19D class light 4-8-2 No.2644 and 25NC class heavy 4-8-4 No.3450 [4]. The author has been involved in testing the latter. However this decision to leave the Swiss Locomotive and Machine Works to work on steam locomotive development was based on interest rather than intentions. Like most people I thought that steam locomotives were fascinating, but inefficient, polluting and old-fashioned. This attitude changed with the insight of an economic traction study done by the South African Railways in 1981 for the mainline from Kimberley to De Aar [5], whereby the 30 year old 25NC class steam locomotives proved to be more economical than both the newer 34 class diesel locomotives and the 7E electrics. The rebuilt No.25NC 3450 was the most economic of all. This unexpected result proved that steam locomotives were not a priori uneconomical, but it did not change the long-term traction policy of SAR. The drive to be "modern" was stronger than the aim to optimise the economics. Realising this meant that steam locomotive development has to be done in the first world, if it is to be seriously considered by normal commercial railways. Switzerland, with 99 % of its railway lines electrified, was certainly the most unlikely place for steam locomotive development and therefore ideal for the desired effect. With one steam railway only, the choice of where to propose modern steam locomotives was not too difficult!

At that time the only steam operated railway in Switzerland, the Brienz-Rothorn Railway, was about to purchase yet another diesel locomotive. Diesel traction had been introduced in 1973, when a solution had to be found to improve the economics and increase the traffic capacity. The old steam locomotives could no longer cope with the demand and were expensive to operate. In 1970 a traction committee therefore investigated alternatives, carefully looking at all traction modes. The recommendation was for diesel-hydrostatic locomotives and lightweight coaches. The first diesel locomotive No. 8 was not quite up to the expectations, but provided a basis for a much better version built in 1975. Locomotives No. 9 and 10 are capable of handling 112 passengers with a driver and a guard, whilst the old steam locomotives transport 48 to 80 passengers only and require a fireman.

Rolling Stock of the Brienz-Rothorn Railway from 1975 to 1986						
Engine No	Type	Built	Coaches	Seats	Train Crew	"Productivity"
1.. 5	Steam	1891/92	1	48	3	100 %
6, 7	Steam	1933/36	2	80	3	167 %
8	Diesel	1973	1	48	2	150 %
9, 10	Diesel	1975	2	112	2	350 %

Table 1: Rolling Stock of the Brienz-Rothorn Railway from 1975 to 1986. "Productivity" relates to the number of passengers per train crew member in relation to the oldest steam train.

This situation left the railway with a dilemma - most passengers wanted to ride in steam trains, but capacity and economics forced the railway to prefer diesel traction. The result was a continuous decline in the number of passengers that were actually transported by steam traction. Many passengers were dissatisfied and complained. The author thought it was time to present a better alternative and proposed modern steam locomotives that would be as economical as the diesels and as attractive in interest as the old steam locomotives. Fortunately the director of the Brienz-Rothorn Railway was interested, but it turned out to be more difficult to convince the management of the Swiss Locomotive and Machine Works to take up the production of steam locomotives again, which had been terminated in 1952. Indeed the first design proposal as well as the first meeting with the director of the Brienz-Rothorn Railway were done in spare time, with kind permission of SLM. Many internal discussions followed, but in the end the SLM management proposed to leave the decision to the results of market research. Six or more new rack steam locomotives would mean the go ahead. If the call was for less, the file on new steam locomotives would be closed for good.

The market research revealed a demand for no less than 15 new steam locomotives, more than anyone had expected. The Brienz-Rothorn Railway opted for two, the electrified (!) Montreux-Glion-Rochers-de-Naye Railway for one and the Austrian Federal Railway for 12, six each for the rack lines on the Schafberg and the Schneeberg.

2. SHORTCOMINGS OF OLD STEAM POWER

Most comparisons between steam, diesel and electric traction ignored a considerable age difference and were therefore neither balanced nor fair although it cannot be denied that old steam locomotives did indeed have shortcomings. These are still well known and therefore only briefly mentioned:

- High footplate staff costs due to the fireman
- High maintenance costs (on account of the old age or obsolete constructional practice)
- Low thermal efficiency resulting in high fuel consumption
- Smoke and air pollution due to incomplete combustion
- Risk of line side fires due to spark emission
- High stand-by losses due to lack of insulation of boiler, steam pipes and cylinders.
- Extensive servicing necessary for taking coal and water, preparing and cleaning the fire, emptying ashpan and smokebox, washing out the boiler
- No interchangeable parts

To overcome these shortcomings in order to compete against diesel and electric traction, a thorough analysis was done. It was found that the majority of deficiencies were dictated by the use of outdated technology and constructional practice. The conclusion was that employing modern technology would allow economical and clean steam traction.

3. ADVANTAGES OF MODERN STEAM POWER

New steam locomotives that are economically and ecologically competitive need to have the following advantages:

- One man operation
- Light oil firing with excellent combustion
- Higher thermal efficiency
- Full insulation of boiler, cylinder and steam pipes
- Quick start-up
- Minimum servicing requirements
- High mechanical efficiency
- No leakage of lubricating oil
- Interchangeable parts

It was soon clear that an entirely new design was needed to achieve all these technical improvements. Rebuilding of existing old rack steam locomotives would not be appropriate and was not even discussed. It was also clear that the entire train operation had to be looked at. The aim was to match the latest diesel locomotives of the Brienz-Rothorn Railway and to outperform the diesel railcars of the Schafberg Railway. This was by no means an easy task, as the last two diesel locomotives of the Brienz-Rothorn Railway performed exceptionally well and the railcars of the Schafberg Railway had given quite good service.

To improve the economics, more passengers must be carried with fewer personnel. This called for a new concept.

4. ECONOMICAL OPERATING CONCEPTS

The century-old track of the Brienz-Rothorn Railway restricts the train weight to 32 tons, which meant that an increase in the number of passengers required minimal weights of the locomotive and the coaches. The existing coaches were already of excellent lightweight construction, weighing 3.1 tons for 56 seats and 4.0 tons for 60 seats respectively. According to the Swiss norms, average passengers weigh 75 kg. The aim was to take the two heavier coaches with 120 passengers up the 1 in 4 inclines of the Brienz-Rothorn to outperform the diesel trains seating 112 passengers meant a service weight of a mere 15 tons for the engine. Compared to the latest steam locomotives of the Brienz-Rothorn Railway built in 1933 and in 1936, the weight of the new engines had to be reduced by 5 tons, whilst the power had to be increased considerably to attain the higher speed envisaged. This consequently required application of the principles of lightweight design and the use of new materials previously unknown in steam locomotive construction. Of course, lightweight design requires careful engineering and additional calculations. Table 2 shows a comparison of the weight per seat and proves the excellent relative position of the new rack steam trains. Only the last series of diesel locomotives of the Brienz-Rothorn Railway are slightly better in this respect. Railcars, either diesel or electric, have a much higher weight per seat, a fact that is not commonly realised. Less weight per seat also means reduced energy consumption, especially on mountain railways. The actual energy consumption per passenger round trip is much more important than a maximum efficiency achieved at a specific load on a test bed.

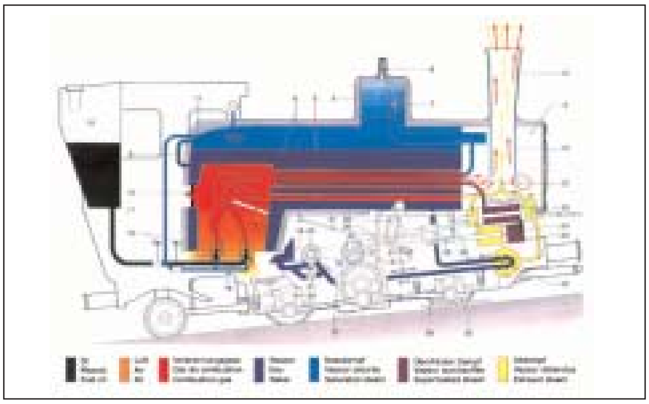
Comparison of the Weights per Seat on Rack Railways

Railway, max. Gradient Train	Train Weight	Seats No.	Seats Weight (per seat)
Brienz-Rothorn Railway, 250 ‰ (1 in 4)			
Diesel locomotive No. 9 - 11 + 2 SIG - Coaches	19'400	112	173
Steam locomotive No. 12, 14, 15 + 2 SIG - Coaches	21'200	112	189
ÖBB Schafberg Railway, 250 ‰ (1 in 4)			
Steam locomotive 999.201 – 204 + 2 ÖBB - Coaches	24'800	105	236
Diesel railcar 5099 001, 002	25'700	77	334
NÖSBB Schneeberg Railway, 200 ‰ (1 in 5)			
Steam locomotive 999.201 + 2 Bombardier - Coaches	23'800	110	216
Diesel No. 11 – 13 + 2 Coaches No. 21,22; 31, 32	32'150	120	268
Snowdon Mountain Railway, 200 ‰ (1 in 5)			
Diesel railcar No 21 - 23	15'250	41	372
Diesel locomotive No. 11 – 13 + 1 Coach No. 2 – 8, 10	25'200	56	450

Table 2: Comparison of the train weights per seat on rack railways. All weights are in kg. The number of seats on the diesel railcars 5099.001 and 002 have been reduced from 77 to 70 in 2001 for fire safety reasons.

5. TECHNICAL DESCRIPTION

As can be seen from figure 1, the basic layout of the new steam rack locomotives has remained classical, albeit with many design improvements.



The following is not a full technical description and is limited to the innovative features of the new rack steam locomotives:

5.1 One-Man Operation

The new steam locomotives are operated without a fireman, reducing footplate staff costs to the level of diesel and electric traction. One-man operation is facilitated by the fact that the trains are pushed. Consequently line observation when climbing is assured by the guard riding up front, leaving the driver to concentrate on his engine. When running downhill the driver has to observe the track ahead; on the other hand the boiler requires no attention then. Nevertheless various improvements ensure that the driver is not overtaxed with his dual responsibility of driving and firing:

- **Oil firing:** Compared with hand firing of coal, oil firing saves a lot of work. Moreover a newly developed compound governor enables the firing rate to be controlled with one hand.
- **Boiler feed pump:** There is a mechanically driven feed pump for feeding the boiler while in motion. The feed rate is controlled by means of a throttle valve.
- **Mechanical lubrication:** The driver does not have to worry about lubrication while running. Lubrication is carried out in the shed at intervals.
- **Vigilance systems:** Vigilance pedals are provided for safety protection.

The task of driving the new steam locomotive is nevertheless more challenging (and interesting) than driving a diesel locomotive. Eleven years of experience show, however, that the one-man operation is safe and works very well.

5.2 Oil firing

Oil fired steam locomotives are not new, but most of them burned heavy fuel oil. For the new rack locomotives this was ruled out. Heavy fuel oil has to be preheated for filling-up and firing, necessitating heating coils. This means more weight and extra energy consumption. The high sulphur content (>1%) is detrimental to the environment and to boiler life (corrosion). Since heavy fuel oil is used by major industries it is difficult to obtain in tourist resorts, whereas light oil, also used in domestic heating, is easy to get.

The decision to go for light oil meant that a new firing system had to be developed, as there were no suitable models on the market. The main problem was to achieve complete combustion in the small firebox. The advantages of designing anew were exploited by enlarging the firebox volume significantly. On account of the overall dimensions and the weight limit, however, there was no room for a combustion chamber. Therefore the quantity of fuel delivered had to be divided to shorten the length of the flame. In view of the almost square firebox shape, four main burners were provided to achieve a uniform firebox loading. To ignite the main burners there is a pilot burner located in the middle. The pilot burner is also used for stand-by and shunting. All burners fire vertically upwards. The flames do not touch the firebox. This is essential for optimal emission values.

In view of the new concept it was decided to test the oil firing while the locomotives were being built. The first boiler was given a specially designed superheated steam collector from which steam was discharged to atmosphere after passing through a stable throttle valve. The amount of exhaust steam could thus be adjusted, maintaining conditions with the regulator wide open. Draught was produced with a blower, enabling the lowest amount of excess air to be established.

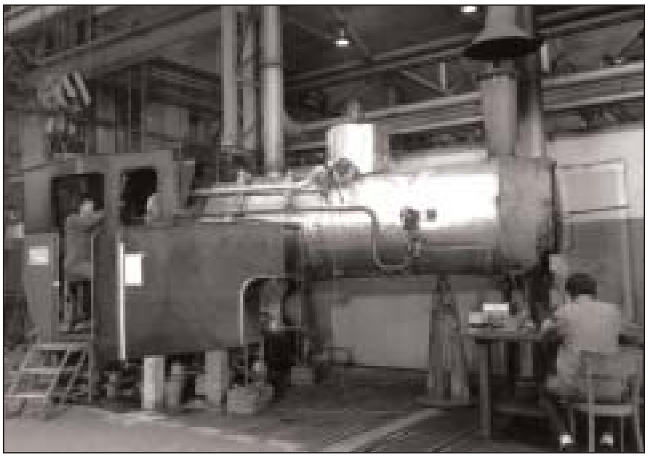


Fig. 2: Test stand for the new light oil firing. The boiler is provisionally insulated. The cab is a mock-up.

Development work in its truest sense was necessary to tune up the oil firing system to the required standard. With the first attempt (figure 3), the combustion was awful, producing a lot of smoke. The air flow around the burners had to be changed radically (figure 4). With these and other modifications, very clean combustion was then achieved.

Fig. 3: Oil firing system as delivered.

Fig. 4: Oil firing system after the tests.

5.3 Boiler and Superheater

Oil firing and the weight limitations dictated an all-welded boiler with a steel firebox (figure 5). The inner and outer fireboxes are joined by the U-shaped foundation ring and thread-less hollow stay bolts. The boiler is bolted to the cylinder block at the smoke box and rests on two swing plates at the foundation ring to allow for thermal expansion.

Special care was necessary to secure an adequate water level over the firebox crown at all inclinations over which the locomotives are worked, from level up to gradients of 250 ‰ (1 in 4). As a safeguard, an electronic low water alarm system shutting off the oil flow by means of an electromagnetic valve is provided. It replaces the fusible plug usual with coal firing.

For feeding the boiler, the century-old system of the mechanical feed pumps was "re-invented" in a modern form. The feed pump is belt driven from a toothed wheel on the crankshaft. The feed pump delivers the feedwater taken from the side tanks via an exhaust steam feedwater heater to the check valve. The water supply is controlled by means of a bypass valve easily operated by the driver. When not in motion, the non-lifting injector is used. The boiler has no steam manifold. Auxiliary steam is extracted directly at the dome. The regulator fitted in the dome is a commercial valve which allows finely graduated operation thanks to its special geometry. After the regulator the wet steam passes through the regulator pipe, before being delivered to the superheater.

Initial thermodynamic boiler calculations showed that superheating with elements in six series stages is necessary to achieve the desired steam temperature of 420°C. This called for the special arrangement of the superheater elements (figure 6). The superheated steam is led directly to the cylinders.

Fig. 5: Construction of the boilers.

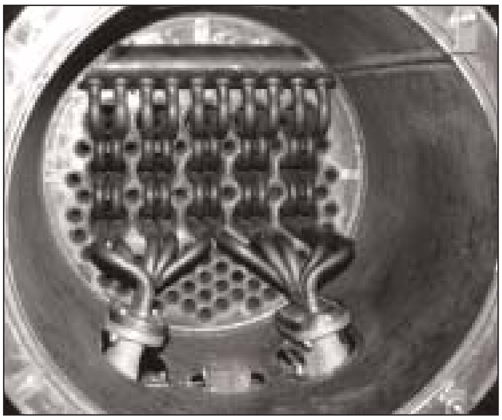


Fig. 6: All-welded light weight superheater.

5.4 Efficient Boiler Insulation

Even in heavy traffic conditions the locomotives operate only 8 to 10 hours per day, the rest of the time they stand in the shed. To save energy and staff costs, the boiler has very efficient insulation and stays in steam overnight, the oil firing being shut off. With a boiler pressure of 6 to 9 bar on the following morning, the pilot burner is lit and the locomotive is ready for service immediately. The electric preheating device is needed only after a boiler wash-out or a long period out of service.

In the past energy losses by radiation were grossly underestimated by most railway engineers. Admittedly 3 to 5 % of the maximum evaporation does not seem a lot, but in terms of energy, 20 kW for small, 50 kW for medium size and more than 100 kW for large European locomotives used to be constantly radiated from traditional boilers and fittings all the time the engine is in steam. If a main line locomotive is in steam for say 300 days a year, the energy losses by radiation amount to 300 x 24 h x 100 kW = 720,000 kWh per year, not really negligible. Considerable amounts of energy can thus be saved by proper insulation. The state of the art can be derived from standards applied to industrial boilers, where the importance of optimum insulation was recognised much earlier. Whilst on coal fired locomotives, some of the energy saved by proper insulation will be lost by increased blowing off at the safety valves for lack of fine modulation of the coal fire on the grate, the insulation of oil fired boilers cannot be too good.

5.5 Steam Engine and Valve Gear

The steam engine is a classical two-cylinder simple expansion engine with Walschaerts valve gear. Numerous improvements have been realised compared with earlier designs:

- enlarged steam chest volume
- straight steam ports
- minimal clearance volumes
- reducing power absorbed in exhaust back pressure
- optimised blast pipe
- generous valve travel

The welded double cylinder unit has cast-iron liners. The piston valves are guided on both sides, with the front guide inside. They have 7 narrow rings per valve head, ensuring good steam tightness. The piston with piston rod is of all-welded lightweight design. To connect the piston rod with the crosshead, a design based on American practice was chosen.

The rods and valve gear have been kept as bright as possible and matt chromed to inhibit corrosion. Reversing is done by hand wheel from the cab.

To enable the steam engine to operate within its economical speed range, the locomotive has an intermediate gear in the final drive with a reduction ratio of about 2.3 : 1.

5.6 Frame, Springs and Drive

The all-welded frame had been designed following the principles of lightweight construction, necessitating FE-calculations. Leaf springs are used for the locomotive suspension.

The crank pins on the large gear wheels drive the two road axles through the front and rear coupling rods. The driving axles to the rack are supported in their bearings and in the supporting road wheels. The tractive force is transmitted solely via the driving pinions which engage in the rack. These are sprung in the direction of rotation to compensate for pitch errors in the rack. On account of weight the driving axles have hollow shafts.

The hind truck is of the classical bissel or pony type. The support is via leaf spring through a carrying roller, which turns on a slightly V-shaped plate. This arrangement allows perfect centering while travelling on the straight and good curve negotiation thanks to the moderate centering effect. To minimise rolling the hind truck is equipped with a stabiliser.

5.7 Adaptability to Gauge and Rack Systems

Rack railways employ a variety of gauges, rack types and electric power systems, so that standardised motive power to get an economy of scale in production is difficult to achieve. The steam locomotive has inherent advantages, which have been exploited. Gauges from 800 mm (Brienz-Rothorn, Montreux – Glion – Rochers-de-Naye) to metre gauge (Schafberg, Schneeberg) are accommodated by merely altering the disks of the wheels (figure 7). The height of the rack above the rail is accommodated by the varying diameter of the road wheels.

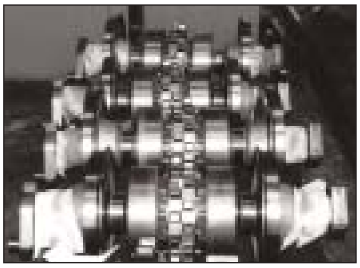


Fig. 7: Driving axles for 800 mm and metre gauge. Note the wheels, the centres of which are simply turned to accommodate the difference in the gauges. All the other parts are identical.

5.8 Brakes

The locomotives are equipped with three independent brakes:

- A Riggenbach counter-pressure brake serves as a wear-free service brake. The steam engine then acts as a compressor, the valve gear being set against the direction of travel. In the braking process heat is generated, which is converted into steam by injecting cooling water. The braking action can be controlled by means of a throttle valve. To reduce the hissing noise a silencer, integrated in the rear buffer, is provided.
- Mechanical brake system I is a spring-operated brake actuated by compressed air. Locomotive and coaches each brake their own masses proportionally. Brake system I is normally operated by the driver. All emergency brake applications act on brake system I via electro-pneumatic valves.
- Mechanical brake system II is concentrated on the locomotive and is able to stop the entire train without the assistance of the coach brakes.

5.9 Exhaust System

Initially three exhaust systems, all of proven efficiency, have been evaluated: Kylchap, Giesl and Lempor. For reasons of simplicity, weight, availability of the calculation method and optical appearance, a single Lempor draught apparatus was chosen. The original design with four nozzles was simplified to one nozzle only. All parts are made of stainless steel thereby eliminating corrosion.

When some of the Austrian drivers complained about the noise in the cab at full power, an analysis showed that sound absorbtion in the cab would not be sufficient and a silencer on top of the chimney would spoil the looks and foul the loading gauge. By slightly increasing the angle of the diffuser part of the Lempor exhaust, the height of the chimney could be reduced without reducing the draught, a silencer in the shape of a “Kobel” spark arrester could be fitted. Such spark arresters were quite common in Austria on coal and wood fired steam locomotives. The “stack talk” is thus reduced by 6 dB(A) and not all passengers like the whispering sound, but the drivers are happy.

5.10 Electrical Equipment

The locomotive is equipped with a modern electronic safety and emergency brake control system. Batteries are provided for the locomotive’s current supply. These are charged via a mechanically driven alternator while running and in the shed through an external battery charger as necessary. Apart from the alternator and batteries, all electrical equipment is in the rear of the cab, separating the electrics from steam equipment.

5.11 Safety provisions

One-man operation of the locomotive and the strict regulations for rack railways dictate comprehensive safety provisions:

- Vigilance systems pedals with quick and slow action
- over-speed trip
- roll-back protection

All monitoring functions, speed and distance displays and recording are provided by the electronic TELOC 2000 S unit.

5.12 Electric Feedwater Preheating Device

To improve the operational readiness of the new steam locomotives and to save man-hours for preparation, an electric preheating device was developed. A ‘cold’ locomotive can thus be put in steam or a ‘warm’ locomotive can be kept in steam without supervision.

The principle of operation is quite simple (figures 8 and 9): Water from the boiler flows by gravity to the circulation pump, which forces the water through the electrical heater back into the boiler. The forced circulation causes extremely uniform heating, because the entire boiler is heated from the water side and therefore has the same temperature everywhere - unlike conventional warming-up, which heats the firebox and the tubes first while the outer firebox and boiler barrel are still cold. The electric preheating device warms up the water slowly to the temperature set on the control thermostat.

Fig. 8: The electric preheating device can also be used for coal-fired steam locomotives, considerably reducing the amount of smoke produced during lighting up. Neighbours are delighted.

Fig. 9: Two flexible hoses connect the boiler to the preheating device. Note that the hoses can only be disconnected if both ball valves are shut. This ensures that the preheating device cannot be disconnected under pressure.

The preheating device for the new rack steam locomotives, which have fully insulated boilers, is rated at 25 kW only. When starting with cold boiler water, it takes 12-16 hours to reach a pressure of 10 bar. The intention is to preheat a cold locomotive overnight, so that the locomotive is in steam the next morning. Before moving the locomotive, the preheating device must be detached. Switching it off and disconnecting the two flexible hoses takes five to ten minutes.

If the preheating device is used to keep a locomotive in steam or just warm, the desired temperature can be selected with the control thermostat, which maintains the set temperature within +/- 5°C by switching the heating on and off. A safety valve and a second thermostat prevent the maximum pressure or temperature being exceeded in case the control thermostat should fail.

6. WORK LOAD TRIALS

The fact that the "last" steam locomotives had been built by SLM in 1952, and the abundance of technical innovations made works trials advisable. The concept of employing a second steam locomotive as brake locomotive made it possible to build an attractive, low-cost test stand. The two locomotives were set up on inclined ramps and coupled by means of a Cardan shaft (figure 10). Whilst one locomotive was driving, the other one was retarded by means of the counter-pressure brake.

First the locomotive No. 12 of the Brienz-Rothorn-Railway was put on the test stand and instrumented with the measuring equipment. Five days later, the first revolutions under steam took place. Everything went right from the start. When the second locomotive, No. 999.201 of the Austrian Federal Railways was ready, the tests began. Even under load there were few problems. The main tasks were to tune the draughting to the oil firing for optimum combustion and to take electronic indicator diagrams to check the valve events and determine the power. The measured results were better than calculated.

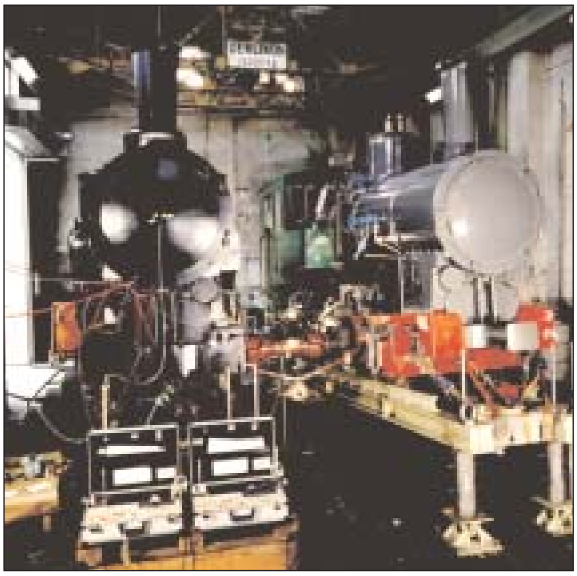


Fig. 10: Work load trials at SLM with locomotive No.12 of the Brienz -Rothorn Railway on the left side and 999.201 of the Austrian Federal Railway. The two bright cases in the foreground contain the emission analysers.

7. EMISSIONS

Traditional steam locomotives cannot claim to be particularly environment-friendly. Our intention was to change this with the new light oil firing system and to achieve clean combustion, but no more than that. We measured the emissions mainly to determine the quantity of excess air. Only when we realised how good the values actually were did we get more ambitious and attempted to find the optimum. We then thought it worthwhile to compare the measured emissions with the ones of the latest diesel of the Brienz-Rothorn Railway. Because diesel locomotive No. 11 was five years older than steam locomotive No. 12, the manufacturer of the diesel engine was asked to provide the cleanest actual emission data. For the sake of a truly fair comparison, No. 11 was thus "equipped" with data from the latest diesel engine. The measured emission values were then calculated in relation to the power at the rack driving pinions. A mountain railway cycle, consisting of 10 % stand-by, 45 % uphill and 45 % downhill working was used for comparison of the total emissions per round trip. The diesel locomotive benefits from its higher thermal efficiency, which is partly offset by the ability of the new steam locomotive to go downhill with the oil firing shut off. The result of the comparison can be seen in figure 11.

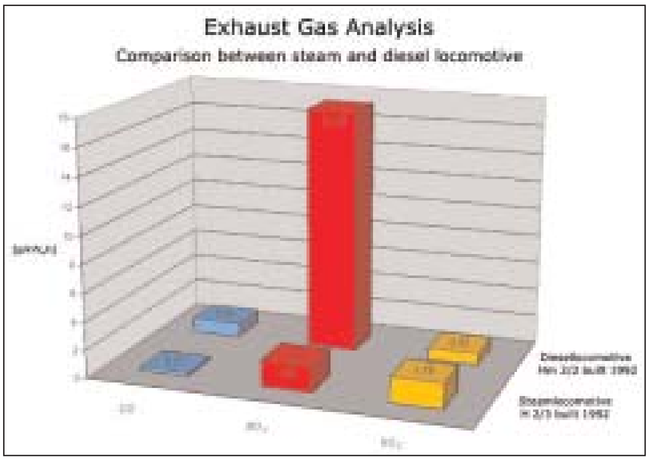


Fig. 11: CO-, NOx- and SO2-Emissions for diesel and steam locomotives on a mountain railway cycle.

If steam locomotives had always been treated with the same fairness in former comparisons as we have treated the diesel locomotives here, steam traction might have lasted longer.

8. OPERATING EXPERIENCES

Thanks to the good basic concept, an abundance of calculations, the preliminary testing of new components on other locomotives, the development of the oil firing on the test stand and the extensive testing and instrumentation in the works, the new steam locomotives worked straight away and went in to revenue service soon after delivery. Of course there were teething troubles too, but these did not interfere with the daily operation. Modifications were made when the engines were out of service due to boiler wash-outs or in the winter, when the railways do not normally operate.

Fig. 12: Locomotive No. 12 of the Brienz Rothorn with 120 passengers just outside Brienz. White exhaust steam can be seen thanks to the cold outside temperature.

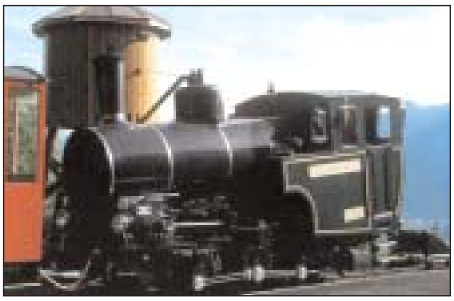


Fig. 13: Locomotive No. 1 of the Montreux – Glion – Rochers-de-Naye at Caux on its separate, non-electrified track. The rest of the line is electrified. Note the American style water tower with integrated fuel station.

Fig. 14: Locomotive No. 999.201 of the Schafberg Railway with a full load of passengers on 1 in 4 grade. Note the clean combustion at full load.

The good technical and economic results led to an order for a further lot of five modern rack steam locomotives. In 1996, two locomotives were delivered to the Brienz- Rothorn Railway and three to the Schafberg Railway. These locomotives are almost identical to the prototypes, the main modification being a lighter crosshead. With hindsight this modification was not really necessary.

Fig. 15: Environment-friendly transport of environment-friendly products. Two brand new rack steam locomotives built in 1996 for the Schafberg Railway, ready to be sent by rail transport

9. STEAM – DIESEL – STEAM

Diesel traction had been introduced to the previously all steam operated railways on the Brienzer-Rothorn and the Schafberg to increase traffic capacity and to reduce operating costs. The old steam locomotives remained in service, but less and less passengers were transported by steam trains. Figures 16 and 18 illustrate that the introduction of modern, economic steam locomotives led to a reversal of this trend:

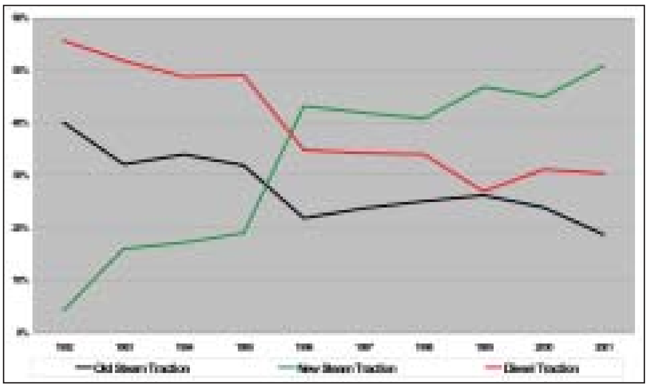


Fig. 16: Brienz-Rothorn Railway: Modal split between old steam traction, diesel traction and modern steam traction from 1992 to 2001. The percentages relate to actual mileage multiplied by seat capacity.

On the Brienz-Rothorn Railway the percentage of passengers hauled by diesel traction has been reduced from 70 % before the new steam locomotives were introduced to now only 30 %.

In 1996 the prototype diesel locomotive No. 8 was sold. Diesel locomotive No. 9 is relegated to works trains whereas No. 10 is on stand-by and helps out in peak traffic. Only the latest diesel locomotive No. 11 is still used regularly. The rolling stock now consists of:

Rolling Stock of the Brienz Rothorn Railway as from 1996						
Engine No.	Type	Built	Coaches	Seats	Train Crew	Productivity
1...5	Steam	1891/92	1	48	3	100 %
6, 7	Steam	1933/36	2	80	3	167 %
9, 10	Diesel	1975	2	112	2	350 %
11	Diesel	1987	2	112	2	350 %
12	Steam	1992	2	112	2	350 %
14, 15	Steam	1996	2	112	2	350 %

Table 3: Rolling Stock of the Brienz-Rothorn Railway as from 1996. Productivity relates to the number of passengers per train crew member in relation to the oldest steam train. The locomotives No. 11, 12, 14 and 15 are also capable to haul two heavier coaches seating 120 passengers. There is no No. 13!

Thanks to the new steam locomotives, the total number of passengers has increased considerably. In the ten years before the introduction of the new steam locomotives, the Brienz-Rothorn Railway carried 1,585,645, in the ten years with the new steam locomotives, 1,869,290 passengers, an increase of 18 %. This required only 3% more train journeys, a result of the higher capacity of the modern steam trains.

Railways are usually reluctant to release figures of their operating costs. Several attempts to get these from electric rack railways remained unsuccessful. We are therefore very grateful to the Brienz-Rothorn Railway to have released their figures, which allow one to compare the respective operating costs of old steam, diesel and modern steam traction on the same line and the same staff.

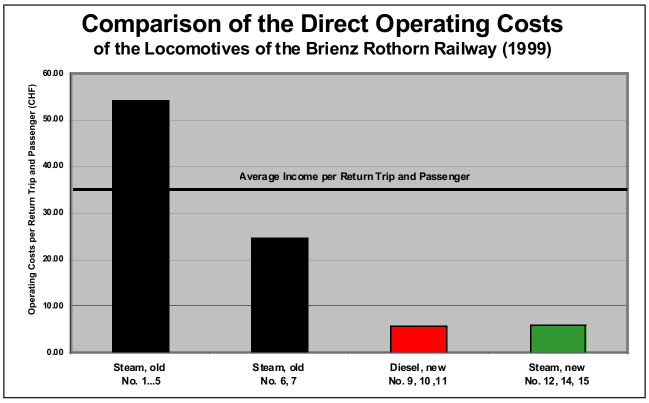


Fig. 17: Comparison of operating costs per passenger of old steam locomotives, diesel locomotives and modern steam locomotives in relation to the average income per passenger. The operating costs include all costs for staff, maintenance, fuel, water and lubricants.

Figure 17 shows clearly why the Brienz-Rothorn Railway preferred to use diesel locomotives before new steam locomotives were introduced. In Switzerland there is not only competition amongst the many rack railways, but also an overabundance of cable railways and aerial ropeways. This limits the ticket prices. With the price level more or less fixed and considering the fact that tourist railways are not subsidised, the operating costs have to be competitive, or else the railway will close. If the oldest steam locomotives are used, the income doesn't even cover the operating costs, so that the railway loses money on each passenger. By using either new steam or diesel locomotives, most of the income remains to cover capital costs, track maintenance, overheads and all other costs. Figure 18 proves what had been claimed when the new steam locomotives were introduced: the shortcomings of the traditional steam locomotives are a matter of old age and design concept and can be overcome by employing modern technology.

On the Schafberg Railway traffic is now almost entirely in the hands of the modern steam locomotives:

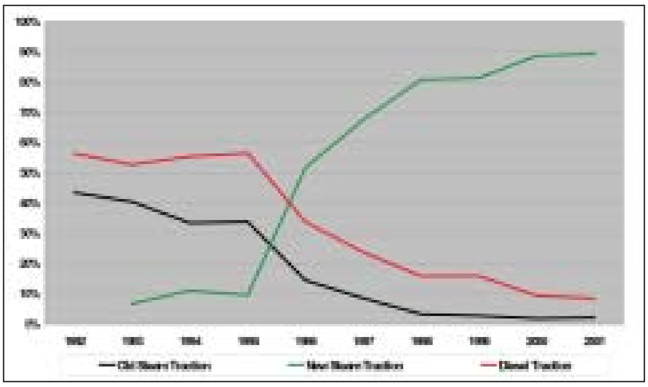


Fig. 18: Schafberg Railway: Modal split between old steam traction, diesel traction and modern steam traction from 1992 to 2001. The percentages relate to actual mileages times the seat capacity.

The diesel railcars are still there, but are being used less and less. Before the new steam locomotives arrived, the diesel railcars carried some 55 % of the passengers, but this was down to about 8 % in 2001. The old coal-fired steam locomotives transported some 3 % only. This may be explained by the much longer journey time and the "nostalgia"- supplementary fare. According to observations of the railway staff, the average passengers, whilst exactly discriminating between diesel and steam traction, do not differentiate between old and new steam trains.

The rolling stock of the Schafberg Railway now consists of:

Rolling Stock of the Schafberg Railway as from 1996							
Engine No.	Type	Built	Coaches	Seats	Train Crew	Productivity	Speed
999.102...106	Steam	1893	1	60	3	100 %	7 km/h
5099.001, 002	Diesel	1965	Railcar	77	2	192.5 %	12 km/h
999.201	Steam	1992	2	110	2	275 %	12 km/h
999 202 - 204	Steam	1996	2	105	2	262.5 %	12 km/h

Table 4: Rolling Stock of the Schafberg Railway as from 1996. Productivity relates to the number of passengers per train crew member in relation to the oldest steam train. The seating capacity of the diesel railcars has been reduced to 70 passengers as from 2001 for reason of fire safety.

Fig. 19: No rule without exception. Modern steam train of the Schafberg Railway in winter operation

While the modern steam locomotives carry the major part of the traffic on both the Brienz-Rothorn and the Schafberg Railway, locomotive No. 1 of the Montreux–Glion – Rochers-de-Naye has the task of increasing the attractions of this otherwise electric railway. Ancient wooden "Belle Époque" coaches are being used, which look very good, but are not of lightweight construction. As this steam train is in contrast to the electric railcars, a "steam"- supplementary fare is charged. Due to the different operating concept and the restriction marked in the timetable ("in fine weather only"), the locomotive No. 1 does only about half the mileage the other new steam locomotives do. The entire steam operation on this railway relies on the one locomotive, there is no spare locomotive and hardly any spare parts!

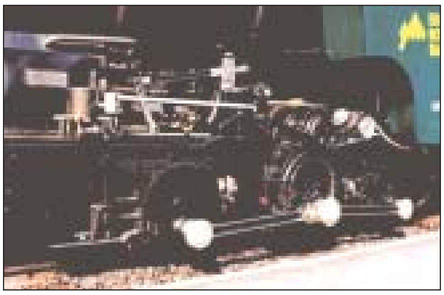


Fig. 20: The drive mechanism of the new steam locomotives is of modern technology, but none the less attractive to watch.

10. REBUILDS AND MODERNISATIONS

The following locomotives have been rebuilt using *modern steam* technology:

- 0-4-0 900 mm gauge tank locomotive, Borkumer Kleinbahn
- 2-10-0 Standard gauge locomotive 52 8055, Eisenbahnfreunde Zollernbahn e.V.
- HG 2/3 Rack and adhesion metre gauge locomotive, Brig-Visp-Zermatt Railway

All have been converted to light oil firing. The most comprehensive modernisation was done to 52 8055, which proved that *modern steam* technology is not limited to rack locomotives. A new light oil firing system, ten times more powerful, had to be developed and this created quite a few headaches, especially in view of undesired noise and vibrations. In the end we succeeded, but with hindsight, an entirely new design of the locomotive would have made life much easier.

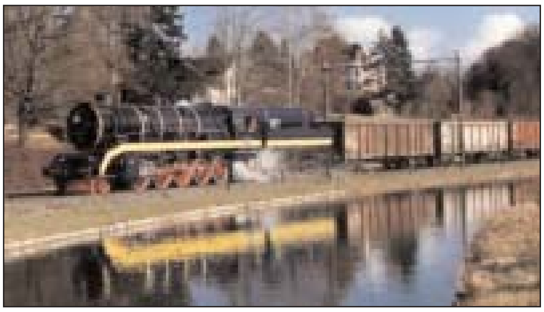


Fig. 21: Modernised 52 8055 with a test train. With the new lightweight drive, equipped with roller bearings throughout, 41 % of the reciprocating masses were balanced compared to 15 % on the original design. The result was a very smooth ride even at maximum speed, whilst the original 52 class locomotives were notorious for their rough riding behaviour.

Fig. 22: Modernised oil-fired 52 8055 leads un-rebuilt coal-fired 52 7596 on the Orient Express. Each time a coal fired locomotive was used, the entire train had to be cleaned from soot and coal particles. Using 52 8055 saved a lot of man-hours of train cleaning alone.

It must be stressed that modernisation does not generally give the same excellent results that can be achieved with entirely new designs. The old components usually severely limit the scope for engineering re-design. As a consequence, the economic and technical results are usually much closer to those of the old design than to those that could be achieved with an all new locomotive.

11. NEW STEAM ENGINES FOR PADDLE SHIPS

Between 1933 and 1977 the Swiss Compagnie Générale de Navigation sur le Lac Léman (CGN), which operates passenger ships on Lake Geneva, converted six paddle steamers to diesel-electric drive in order to save on operating costs. Four were still in service in 1996. By that time, because diesel and electric units have a generally shorter life expectancy than steam engines, the time to replace the propulsion units was clearly close at hand. It seemed quite clear at first that new diesel-electric drives would be installed, but a new concept of the author to control a steam engine from the bridge by means of a remote control in combination with automatic boiler controls would enable steamships to run with the same number of staff as diesel ships of equivalent size. In this way the previously biggest economic disadvantage of the traditional steamer could be eliminated.

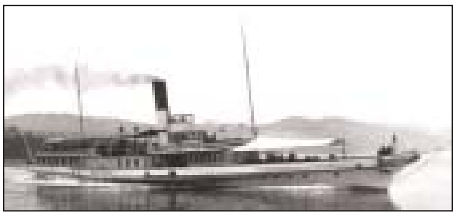


Fig.23: The "Montreux" was built in 1907 as a coal fired paddle steamer by the well-known Swiss company Sulzer Ltd.

Fig. 24: The "Montreux" after conversion to diesel-electric drive, which improved the economics but certainly not the aesthetics.

Fig. 25: Equipped with a new economic steam engine remote-controlled from the bridge, the entirely refurbished "Montreux" delights passengers, onlookers and accountants.

The paddle steamer re-entered commercial service on 19th May 2000, when it was leading the parade of the four other traditional paddle steamers.

The new steam engine for the "Montreux" had been ordered at the end of 1997, following a feasibility study. It was the first ship steam engine to be built in Switzerland since 1928! As with to the modern rack steam locomotives, the ship steam engine was tested and instrumented extensively before delivery (figure 26).

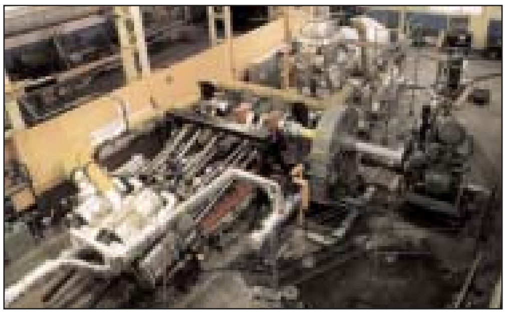


Fig. 26: Test stand with boiler, main steam pipe and steam engine exactly positioned as on the ship. The gear is from the obsolete diesel-electric drive and used here to increase the speed of the water brake.

The two-cylinder steam engine produces a continuous indicated power of 710 kW at 50 revs/min. With a bore of 560mm and a stroke of 1200 mm, the engine is rather impressive. Joy-valve gear has been chosen so that a 1000 kW three-cylinder version can be built without the need of a complete new design.

Fig. 27: Smooth and silent running even at full speed and power are synonymous with steam engines on paddle ships. This allows an open engine room, increasing the attractiveness to the passengers. An open engine room would be quite impossible on diesel ships where the best in acoustic insulation is needed to make it acceptable for the passengers.

With a reliability of 100 % since then, the steam engine installation has done very well indeed.

12. PROJECTS

12.1 Steam Locomotives for Tourist Trains

This paper is the first to publish the convincing economic results of the modern rack steam locomotives. The fact that the operating costs of *modern steam* power are not higher than the operating costs of diesel traction is largely unknown. It is therefore not surprising that most railway managers are still convinced that steam traction can only be considered for tourist trains. As long as this view prevails, justified or not, it makes sense to primarily search the market for projects linked with tourism.

The following details are from a selection of locomotive projects, most of them based on initial requests by a railway.

<u>Narrow Gauge Steam Locomotives for India</u>

The well-known 2 foot (610 mm) gauge Darjeeling is a spectacular line incorporating several loops and switch-back sections. As one of only two railways, the Darjeeling Railway has been declared a World Heritage Site by the UNESCO. The railway used to be operated exclusively by "B"-class locomotives, the design of which dates back to the 1880's. A crew of five is used on these small locomotives, quite a lot even by Indian standards! Diesel locomotives have been introduced recently, following the clean sweep policy of Indian Railways to eliminate steam. Nowadays there is more steam operation in tiny Switzerland than in giant India! The few operable Darjeeling steam locomotives have mainly been relegated to a new short-distance tourist train. Train operation on the Darjeeling railway is only a shadow of its former self and one can only wonder why UNESCO tolerates this.

However, in an attempt to keep some steam traction on this famous line, global tenders had been issued for three new oil fired steam locomotives. DLM presented an offer for an all-new design incorporating the latest *modern steam* technology with the external appearance closely resembling the old "B"-class locomotives. These locomotives would outperform the diesel locomotives by hauling five instead of four coaches at a higher uphill speed.

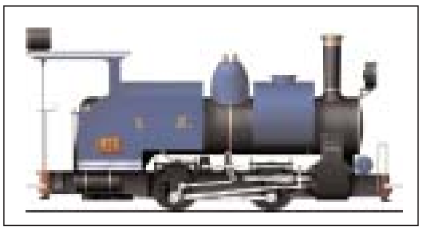


Fig. 28: New oil fired steam locomotive as proposed to the Indian Railways for the Darjeeling line. The distinct external appearance, which is characteristic for the Darjeeling Railway was intentionally retained in view of the UNESCO World Heritage status.

<u>Tank Locomotive for European Narrow Gauge Lines</u>

Back in 1990, the then DR (Deutsche Reichsbahn) heard of SLM's intention to build new rack steam locomotives and showed interest to buy no less than 30 new steam locomotives

(10 for metre gauge, 20 for 750mm gauge). Following this request, a modern 2-10-2 tank locomotive was initially proposed, incorporating all the features of the *modern steam* technology, but later SLM pulled out: the rack tank locomotives were not yet built and the order books were full.

Both SLM and DR exist no more, but the steam operated narrow gauge lines have survived. Most lines are now privatised, but two lines near Dresden remain with DB. The infrequent service and a maximum speed of 30 km/h on 750 mm gauge and 40 km/h on the metre gauge make these lines unsuitable for commuters. This was different in the days of communism when there was simply no alternative. Today commuters go by car or bus, and many lines in the former East Germany have been closed for lack of passengers. Not so the steam operated railways, where the tourists are more than happy to fill the trains. Even though the trains are mostly used by tourists nowadays, these lines are not typical tourist railways, offering a daily time-tabled service.

Whilst most of these lines have recognised the value of steam traction, DB is still unconcerned. As DB is now running trains as a subcontractor to the Verkehrsverbund Oberelbe, being paid by kilometres run, they have little interest in ticket revenue. DB's interest is to lower operating costs, for which the standard answer nowadays is diesel railcars. But who will use them on these lines? Modern steam locomotives provide a much better solution in terms of attractiveness, transport capacity and operating costs per seat. Since the track has been upgraded on all lines, DLM is offering a 2-8-2 with an axle load of 12.5 tons instead of the 2-10-2 with an axle load of 10 tons. Whilst the same tractive effort is retained, the maximum speed can be raised to 70 km/h, equal to the speed the railcars would achieve.

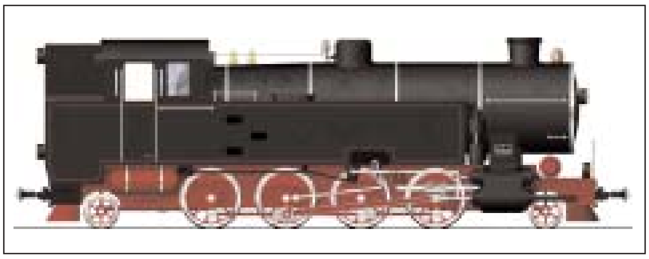


Fig. 30: DLM proposal for a narrow gauge 2-8-2 destined mainly for the steam operated lines in the eastern part of Germany.

The problem is that the diesel railcars would be subsidised by 90 %, whereas the modern steam locomotives are not, which is unfair competition. The "logic" behind this argument is that suburban traffic is losing money and therefore has to be subsidised, whereas steam locomotives are used in tourism, which is expected to make a profit! Some of the railways now try to convince the Government to equally subsidise the modern steam locomotives, realising it's the best solution for them.

<u>Tank Locomotive for European Standard Gauge Lines</u>

When a local committee took the initiative to re-activate the scenic standard gauge line from Merano to Malles in northern Italy, they proposed to use modern steam locomotives in combination with modern panoramic coaches, resembling the ones that had been built for Swiss narrow gauge railways. The artist's impression shows how well the new steam locomotive would match the coaches. Push-pull operation was also suggested whereby the locomotive would have been remote-controlled from the driving trailer car. But in 1997 the time was not ripe for such unconventional ideas. Later on diesel railcars were ordered, proving that it takes a long time to change a paradigm.

Fig. 31: Artist's impression of a modern standard gauge steam train. Drawing by H.R. Kaegi

More projects can be found on the DLM-Homepage: www.dlm.ag or www.dlm-ag.ch

12.2 Steam Locomotives for Industrial Use

Diesel locomotives nowadays have a virtual monopoly on shunting duties. Technically this is a bit difficult to understand, as the diesel engine has some shortcomings, which do not make it an ideal shunting locomotive. As the diesel engine alone cannot start under load, an electric or hydraulic transmission is necessary, making it a rather complicated and expensive locomotive. In service the diesel engine idles for most of the time, doing no useful work but polluting the environment with toxic and carcinogenic exhaust gases, noise and vibrations. Measurements show that diesel locomotives on shunting duties run at idling speed 75 % of the time. When the author checked the mileage and the operating hour meters of several shunting locomotives, the average speed turned out to be between 1.5 and 4.5 km/h! Because there is no energy storage, the diesel engine has to follow load in shunting duty frequent changes of the traction, thereby producing emissions of very bad quality.

Modern steam technology, employing old refurbished as well as new ideas, could provide a much more environmental-friendly shunting locomotive. For part of the trip, for instance in tunnels, completely emission-free operation could be guaranteed.

13. SUMMARY AND PROSPECTS

Eleven years of experience show that the new rack steam locomotives have acquitted themselves very well. The requirements laid down in the specification have been met or exceeded. Compared with other prototype motive power the commissioning time was extremely short, enabling the locomotives to assume commercial operation soon after delivery.

Most of the shortcomings of traditional steam traction have been eliminated on these modern locomotives. In operational readiness, availability and personnel costs they can match diesel and electric traction. Fuel costs now amount to a very low percentage of the operational costs. The comparison of operating costs on the Brienz-Rothorn Railway shows that they are five to ten times lower than those of old steam power, but more important, equal to those of diesel traction under the same conditions. Environmental nuisance is no longer a problem with the new oil fired steam locomotives. It has been demonstrated in practice that the CO- and NOx-emissions are even less than those from comparable diesel locomotives equipped with the latest engines.

The fact that the operating costs of new steam locomotives are not higher than those of good diesel locomotives opens up a new field of applications. Whereas the use of modern steam locomotives has been justified by the needs of tourism, *modern steam* locomotives can now be considered for other traction purposes as well. The author is well aware of the fact that this kind of lateral thinking will take more time until the majority of railways start to consider evaluating *modern steam* traction. But the economic results of *modern steam* in both rail traction and marine applications justify a fresh and wholly unbiased review of the merits of steam traction, not only for tourism. By the way, who said that only tourists like to ride clean steam trains? Decisions are not only based on rational arguments such as travel time, frequency of service and ticket price, otherwise less people would use cars. Emotions are a factor we engineers tend to overlook, but emotions are a fact of life and when it comes to the emotion factor, steam is top. The railways could take advantage of this again.

It has to be emphasised that the convincing results with the new rack steam locomotives were achieved with a very small fraction of the development money spent for the development of diesel and electric locomotives. This in turn means that the development of the steam locomotive is far from having reached its peak. Even if the classical reciprocating drive is retained, which is essential for tourist trains, there is still a lot of potential for improvements. For normal traction purposes not linked with tourism, other forms of steam power (i.e. steam-electric) could be considered, but it must be borne in mind that the more one deviates from the principles of the classical steam locomotive, the more development work is needed and the higher the technical and financial risks may be.

This author is not going to predict the future. However the future of railways might just be a little brighter if all traction options were considered. Nowadays economic calculations can be done easily. One has to considered that comparative conditions are not only different in each country but also for each line. To find the economic optimum for each line, all three forms of motive power will have to be considered again: diesel, electric and ***modern steam***.

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