

Newsletter

Direct Thermochemical Liquefaction

PyNe 54

December 2023



The third Task 34 meeting of this triennium took place National Renewable Energy Laboratory (NREL) Campus Golden, Colorado in November with a beautiful view to the Rocky Mountain. We are very grateful for the local organisation by Robert Baldwin from IEA Bioenergy Task 33 that made meeting in this interesting and great place possible. The first day was a Task 34 meeting and day 2

a workshop with US stakeholder. The meeting convened the majority of the national team leads (NTL) on Task 34 from various countries, focusing on the advancement of Direct Thermochemical Liquefaction (DTL) of biomass and bio-based waste. A central part of the discussion revolved around the objectives and scope of Task 34 for the next triennium. (Continued on page 2)

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It was agreed that while the core principles set three years ago remain relevant, certain aspects need re-emphasis or addition. Notably, the role of DTL bio-oils for the production of transportation fuels and in supporting circular carbon economy were highlighted.

The key work packages for the next triennium were identified, focusing on (ASTM) SAF approval pathways, fuel specs comparison, byproduct utilization, non-woody material use in Fast Pyrolysis (FP), and advancements in catalytic pyrolysis, among others.

Of course, successful continuation of our work also includes publication of this PyNe 54. It includes an article about staged condensation of pyrolysis vapours, which CanmetENERGY/Canada recently started to explore to summarize developments of this application which opens up the pathway for fuel and chemical synthesis.. You can find it on page 3.

In the second article Fraunhofer Umsicht will inform you about the current developments in the field of TCR technology. Read more on page 7.

VTT presents their experience to assess bio-oils suitable for power plants and ships. It is necessary to find bio- and waste-based alternatives to fossil fuels. These were identified and evaluated in a national BioFlex project. You will find the article on page 11. You will find interesting information about the EU project „Cocpit“ which is supporting

sustainable transport fuels uptake through a new tool able to identify the best solution forend-users needs. Find out more in the article on page 16.

And last but not least, you can find an article about the workshop of IEA Bioenergy Task 34 with the US stakeholders on page 19.

As our work progresses we continue to supply you with latest information from the field of DTL. We recently published a report on „Gasification of Liquids derived from Direct Thermochemical Liquefaction“

[\(https://task34.ieabioenergy.com/dtl-oil-gasification-2/\)](https://task34.ieabioenergy.com/dtl-oil-gasification-2/).

Personally, I am very excited about a workshop about „Materials and Chemicals from DTL processes“ that is planned for the beginning of 2024 for experts to discuss material and chemicals production from DTL oils. This workshop is organized in conjunction with an associated report by Task 34 that will be published in January 2024..

There are plenty of projects to follow up on over the next year and we are going to make sure to keep you updated!

Finally, it remains to us to thank you for your interest in our work and your loyalty and support. All the members of IEA Bioenergy Task 34 wish you a Merry Christmas and an excellent start in 2024!

Yours sincerely,
Alexandra Böhm, Task Project Manager



Fig. 1: Labtour at NREL

Heat recovery and product stabilization using staged condensation of pyrolysis vapours

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Fast pyrolysis is an attractive process to convert solid biomass into solid char, pyrolysis liquids and off gases. Although, highly polar in nature, pyrolysis liquids are also widely referred as “bio-oil”. Rapid biomass heating and rapid vapour quenching have been the essence of fast pyrolysis to maximize the yield of bio-oil but at the cost of poor quality of bio-oil containing more than 300 compounds.

Nearly all the existing commercial pyrolysis technologies employ single step rapid condensation of pyrolysis vapours from 500 to 50 oC using sprays of cold bio-oil or liquid hydrocarbon as a quench fluid.

While single step rapid quench helps maximize the quantity of the liquid product obtained, this liquid product becomes a non-homogenous mixture of hundreds of oxygenated polar compounds and contains large fraction of water and acids. In addition to chemical instability of bio-oil, the one-step quench also leads to loss of high quality heat (energy) to the surroundings (primarily cold water utility or ambient air) with no possibility to recover or recycle this energy back to upstream heat requirements.

Recently, some researchers have initiated exploring the possibility of staged condensation [2-4]. However, their focus has

been to remove water and other low boiling condensates by reducing condenser temperatures in the range of 150 – 4 oC. These low condenser temperatures not only limit any useful heat recovery but also incur more energy loss because of cooling utility requirements at temperatures lower than ambient.

Multi-stage vapour condensation and heat recovery approach

CanmetENERGY at Natural Resources Canada has initiated efforts to address gaps on heat recovery and product stabilization using multistage condensation. The intent is to produce targeted stable products for value-added applications and to enhance the overall efficiency of pyrolysis processes.

The first phase of this research work involves modelling and simulation of staged condensation of pyrolysis vapours using Pro/2 process software. A pyrolysis model with 13 representative compounds was developed. To simulate condensation process, representative compounds were chosen from Pro/2 library to have molecular structures as close as possible, as well as the phase behaviour (melting and boiling points) of the key functional groups in bio-oil [4].

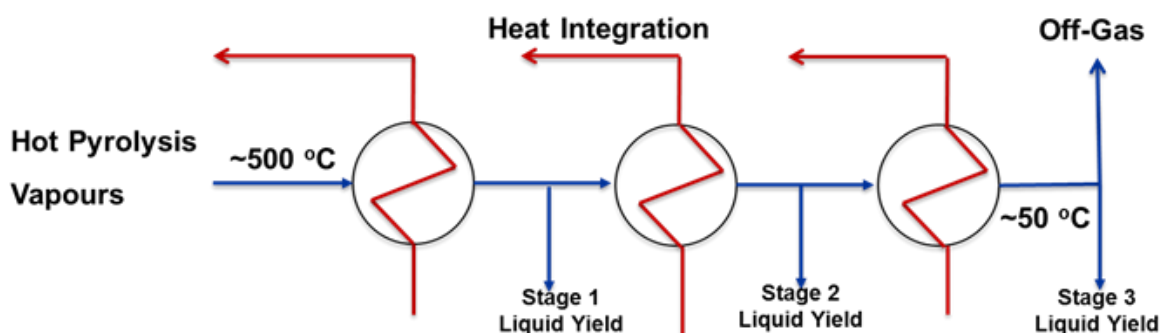


Fig. 1: 3-stage fractional condensation concept for heat recovery and product stabilization.

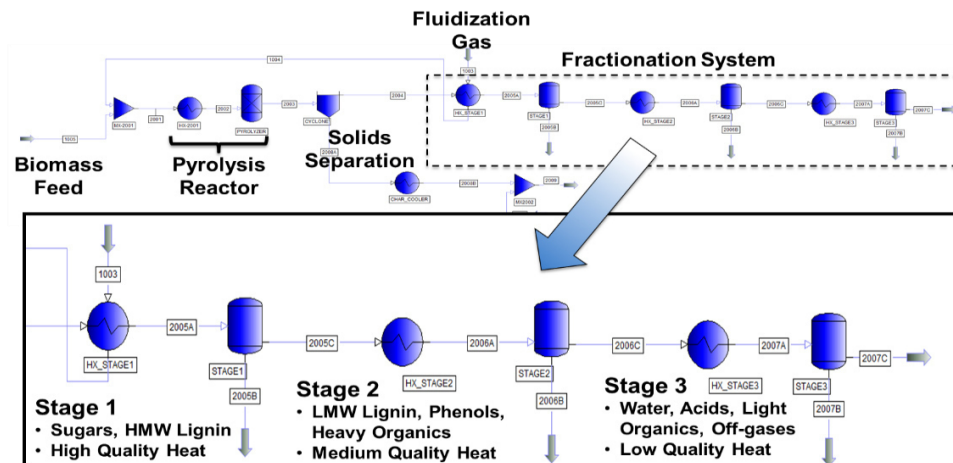


Fig. 2: A generic pyrolysis process model with three-stage condensation in Pro/2

The three-stage condensation concept (as shown in Figure 1) targeted to bring down pyrolysis temperatures from 500 to 50 °C, offering three different qualities of heat available for recovery. Figure 2 shows a sample Pro/2 process model used for three staged condensations.

Comparative analysis of staged condensation in ablative and fluid bed pyrolysis

Multiple cases involving staged condensations in ablative and fluid bed pyrolysis systems were investigated. These two systems represented low and high carrier gas to

biomass ratios respectively. In each case, the intent was to reach a trade-off between high quality heat recovery and early separation of lignin and sugars with that of acids in order to enhance product stability and quality. Figure 3 shows striking differences between ablative and fluid bed systems. For example, high amount of fluidization gas causes dew point depression in the product vapours. As a result, pyrolysis vapours containing HMW lignin, LMW lignin and extractives that typically exit the system as liquid in stage 1 of an ablative process, remain vapours in fluid bed process. At around 250 °C, most (95%) of

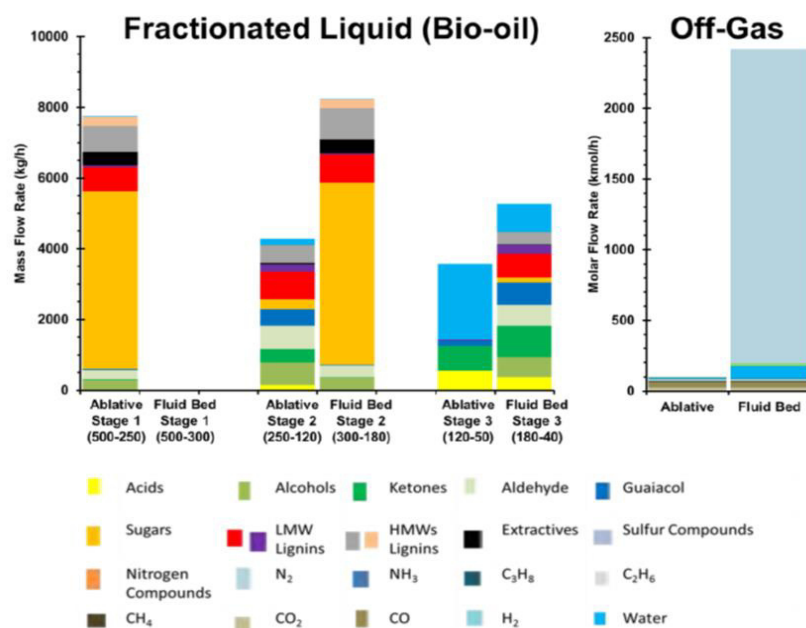


Fig. 3: A comparative analysis of 3-staged condensation in ablative and fluid bed systems

high melting sugar and HMW lignin as well as extractives are condensed early in the first stage while most of the acids and water are discarded in the third stage. As lignin and sugar are very distinctive in chemical properties and in term of energy density (33 MJ/kg and 17 MJ/kg respectively – see Figure 4a), their early recovery and isolation from acid catalyzing reactions offers additional opportunities for immediate end uses or for further selective upgrading [4].

In the first stage of fluid bed system, no condensation occurs when the exchanger temperature is around 300 °C. This is disappointing from fractionation perspective. However, this also negates any change of fluid state in first stage, thus offering more flexibility for fouling free heat recovery. The effect of dew point depression can be further noticed in stage 3 and in off gas.

Compared to ablative pyrolysis, large fractions of water and acid vapours slip through in the

off gases, which also contain significant amount of inert fluidization gases. Although high relative volume of fluid bed gases could be a matter of concern as any gas recycle strategy will require larger equipment and larger plant footprints, need for heat recovery in fluid bed is much more intense than in ablative systems (See Figure 4b).

Conclusions

Staged condensation and heat recovery offer better product selectivity and better process efficacy. Judicious selection of condenser temperature configurations offers opportunity for early isolation of sugars and lignins with acids, thus reducing instability of product stream. Quality of product fraction and heat recovery is dependent on type of reactor. Given the high ratios of fluidization gas to biomass in fluid bed pyrolysis, heat recovery and recycle is very crucial for these systems. These simulation models need to be tuned further using additional and more detailed experimental results.

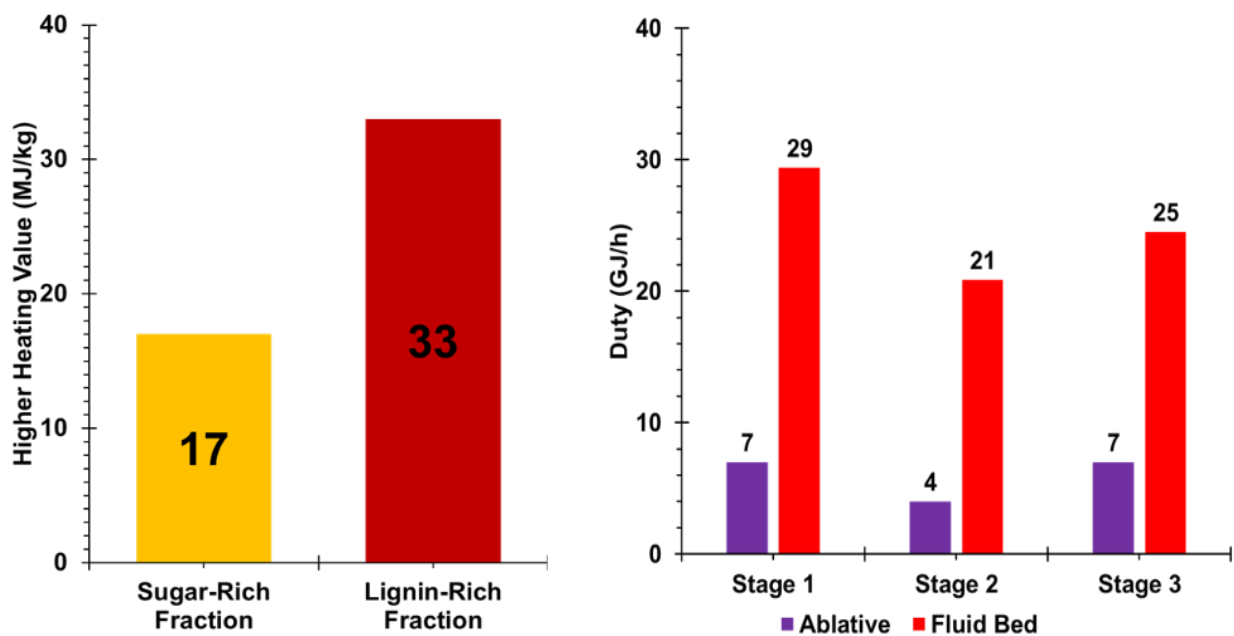


Fig. 4a: Relative higher heating values of sugar rich and lignin rich fractions in stage 1 of ablative pyrolysis unit
Fig. 4b: Relative recoverable heat available for 3 staged vapour condensation in ablative and fluid bed systems

Acknowledgement

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Conversion of biogenic waste into high quality hydrocarbons: recent progress in development of TCR-technology

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The Fraunhofer TCR process could be a game changer in the field of carbon conversion technologies: it enables biogenic, pyrolysis-based oils to be used as co-feed in conventional refinery processes.

The latest projects have demonstrated the feasibility of large-scale industrialisation. A commercial application now appears possible. The TCR® process (Thermo-Catalytic Reforming) developed by Fraunhofer is in TRL 7 demonstration scale. The TCR Technology works with a broad spectrum of biomasses and residues with a dry content of 70 percent or more. The process is based on intermediate pyrolysis and is combined with a unique downstream catalytic reforming unit.

The pyrolysis takes place at temperatures of 400 to 500 °C at a moderate heating rate. In the reforming step, the carbonate produced in the pyrolysis reactor is reacted with the pyrolysis vapours at temperatures of 500 to 700 °C. The main goal of the reforming step is to crack the vapours to improve the quality of the pyrolysis products. (1)

Demonstration Project TO-SYN-FUEL

Since its invention about a decade ago, various research has been conducted on the TCR technology. Recently the largest project on TCR was completed: TO-SYN-FUEL. (2)

The objective of the EU funded project was to demonstrate the feasibility of a new integrated process combining Thermo-Catalytic Reforming (TCR), with hydrogen separation through pressure swing adsorption (PSA), and hydrotreatment (HDO), to produce an equivalent gasoline and diesel substitute and green hydrogen for use in transport at a decentralised location.

The demonstration plant in Hohenburg / Germany was tested with sewage sludge from a local drying company, which received the sewage sludge from regional municipalities. The dryer uses a state-of-the-art belt drying technology to dry the sludge to moisture content below 10 wt%. The drying temperature is obtained from off heat produced by an onsite wood gasification unit, using wood pellets. No further pre-treatment was carried out before TCR conversion and



Fig. 2: Complete process chain of TO-SYN-FUEL-demonstrator. Credit: Fraunhofer UMSICHT

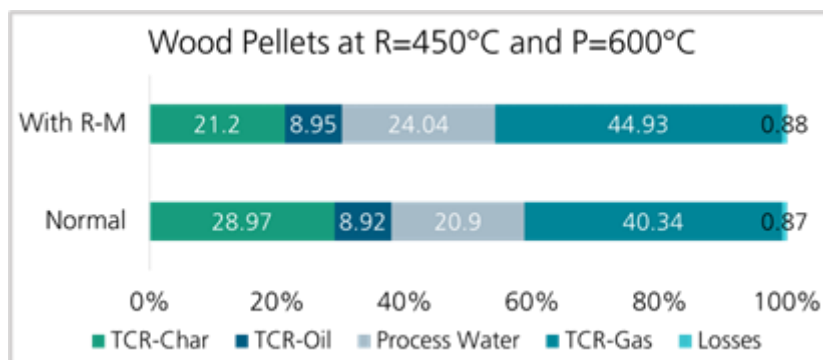


Fig. 2: Mass balance of TCR products

analytical characterisation as to give an accurate representation of the feedstock. The feedstock analysis shows that Carbon and Hydrogen yields in the sewage sludge were on average 29.9 and 4.5 wt% respectively, the presence of N and S elements were also detected. The average oxygen content of the feedstock was 21.5 wt%. The proximate analysis results indicate that the drying pre-treatment was effective in bringing the moisture content of the sludge down to below 5 wt% on average. The sewage sludge contains a relatively high amount of ash (38.6 wt% avg) and low fixed carbon (5.8 wt% avg) which corresponds to a calculated gross calorific value HHV of approximately 9.8-12.8 MJ/kg. The metal ICP analysis of the feedstock detected calcium, iron, phosphorus, aluminium, magnesium, potassium, and silicon. All of these metals with the exception of silicon are believed to play an important

role in the catalytic function within the reforming step.

Figure A shows the overall demonstrator system. On the right-hand side the feedstock is inserted via a screw conveyor into the TCR auger reactor. The feedstock is processed in the TCR reactor and the subsequent post reformer. The produced vapour is entering the product gas train (middle part of Figure a). After leaving the product gas train, the cold TCR-gas is fed into the PSA-unit. The produced TCR-crude oil is upgraded in the hydrotreatment unit. For this upgrade the hydrogen from the PSA unit is used.

Results

During more than 1,000 hours of operation in several test campaigns more than 0.5 million kg of sewage sludge were converted into approximately 50.000 litres of bio crude oil.

Table 1: Gas compositions from TCR trials showing the influence of red mud

Gas Compositions

(Wood at P = 600°C, others at P = 750°C; *calculated by difference)

| Experiment | H ₂ (vol. %) | CO (vol. %) | CO ₂ (vol. %) | Others* (vol. %) |
|----------------------|----------------------------|----------------|-----------------------------|---------------------|
| Wood (Normal) | 25.91 | 16.28 | 15.57 | 42.23 |
| Wood (with R-M) | 34.20 | 8.61 | 24.57 | 32.62 |
| Digestate (Normal) | 39.90 | 18.50 | 23.30 | 18.30 |
| Digestate (with R-M) | 40.76 | 16.85 | 23.91 | 18.48 |
| Straw (Normal) | 33.60 | 23.10 | 21.10 | 22.20 |
| Straw (with R-M) | 40.03 | 17.96 | 23.91 | 18.10 |

The liquid bio-oil being produced by TCR is thermally stable, has low viscosity and polarity, low water and oxygen content and a heating value LHV: ≈ 35 MJ/kg. It therefore represents an excellent precursor for hydrotreatment. The synthesis gas from the TCR process is an engine-ready gas with a heating value of ≈ 12 - 18 MJ/m³ (HHV). Its hydrogen content is 38 ± 3 v/v% (CO 8 ± 2 v/v%, CO₂ 30 ± 3 v/v%, CH₄ 14 ± 2 v/v%, C_xH_y 3 ± 1 v/v%). In the demo plant the hydrogen is separated via Pressure Swing Adsorption and then directly used in the HDO unit.

The hydrotreatment process is carried out at a temperature of around 260 - 400 °C and up to 200 bar pressure. The resulting products are H₂S, H₂O, NH₃ and hydrotreated TCR bio-oil (HBO).

The hydrotreated TCR bio-oil (HBO oil) presents some differences in comparison with the crude TCR bio-oil. It has an LHV of 42.25 MJ/kg, a viscosity of 0.97 mm²/s, a density of 815 kg/m³, as well as a flash point < - 20 °C. This liquid results as a mixture of EN conforming diesel and gasoline.

The carbonisate from dried sewage sludge has a very low H and O content as well as an HHV of about ≈ 10.5 MJ/kg (LHV ≈ 9.5 MJ/kg).

The TO-SYN-FUEL plant in Germany will continue to be operated by Fraunhofer after the project and is available for additional test campaigns. The focus here will be on the further optimisation of the process chain and the testing of additional input materials in order to find the right boundary conditions for the first commercial application in industrial petrochemical value chains.

Use of red mud as catalyst

Another strand of TCR research is concerned with improving product quality by using innovative catalyst systems. Recently, red mud (R-M), a solid waste from the processing of bauxite has been tested by Onyishi et al (3). The utilization of red mud holds significant economic importance due to the challenges associated with its disposal. It is incorporated

into the system by blending it with the feedstock in a ratio of 1:3.

Although the addition of red mud as a support catalyst does not impact the yield of TCR oil, it does enhance the yield of TCR gas (as shown in Figure B) and increase the hydrogen content of the gas (as shown in Table 1). This effect remains consistent regardless of the feedstock material used.

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<https://doi.org/10.5071/31stEUBCE2023-5BV.6.8>



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VTT to assess bio-oils suitable for power plants and ships

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The increase in wind and solar power requires load-following capacity to flexibly compensate for gaps in electricity production on windless and cloudy days. Power plants that use fuels will continue to be part of energy systems, but there are differences in their flexibility. Conventional coal- or biomass-fired steam boilers are not capable of load changes that are as fast as those of natural gas-fired gas turbine power plants or the most flexible power plants of them all: internal-combustion (IC) engine power plants. IC engine power plants use natural gas or heavy fuel oil in diesel engines. In order that large diesel engines would be environmentally sustainable both on land and at sea, it is necessary to find bio- and waste-based alternatives to fossil fuels. These were identified and evaluated in a three-year national BioFlex project (1921-23) coordinated by VTT [1]. The BioFlex project was co-financed by, along with Business Finland and VTT, the participating companies: Auramarine, Meriaura, Fortum, Neste, Pohjanmaan Hyötyjätekuljetus, Polartek, St1, Valmet and Wärtsilä.

Bio-oils

Three bio-oils were evaluated in the Bioflex project: fast pyrolysis bio-oil (FPBO), biomass catalytic fast pyrolysis bio-oil (CFP) (Table 1), and hydrotreated FPBO. The first ones were manufactured at VTT for upgrading tests. Two batches of hydrotreated FPBO (SDPO,

stabilised and deoxygenated FPBO) with oxygen content of 5-7 % were purchased from BTG (NL) for quality assessment and diesel-engine tests.

Upgrading of bio-oils

Besides stabilized and hydrotreated FPBO purchased from BTG, upgrading of FPBO and CFP on a smaller scale was studied at VTT. Based on the continuous stabilization and HDO (hydrodeoxygenation) experiments, there are a lot of challenges in the upgrading of FPBOs by fixed bed hydrotreatment technologies related to catalyst deactivation and even reactor blockage. The deactivation and catalyst blockage observed were mainly originating from the instability of studied bio-oils and they caused thermal coke and oligomer formation.

Deactivation by impurities in the feed such as sulphur also contributed to the deactivation. Despite these challenges, continuous stabilization of FPBO was operated successfully in a fixed bed hydroprocessing reactor ~ 70 hrs with a commercial Ru/C catalyst. Stabilized oil with reduced carbonyl number and oxygen content was obtained. However, the stabilization stage seems to be the most challenging one and therefore it was concluded that other solutions than fixed bed hydroprocessing are needed to enable the commercialization of bio-oil stabilization by hydroprocessing.

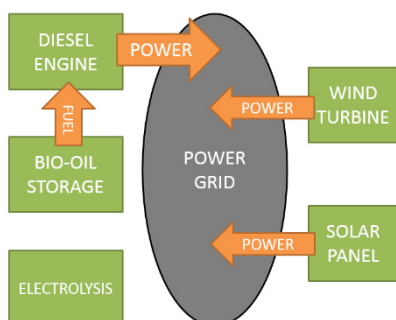


Table 1: Properties and composition of FPBO and CFP oil

| | Bio-oil | CFP oil |
|-------------------------------|---------|---------|
| Water, wt % | 22.7 | 8.3 |
| Solids, wt % | 0.03 | 0.76 |
| Ash (from MCR), wt % | 0.02 | 0.6 |
| Carbonyl content, mmol/g | 4.8 | 2.8 |
| CAN, mg KOH/g, VTT | 80.0 | 29.8 |
| MCR, wt % | 19.1 | 29.3 |
| Carbon dry, wt% | 53.6 | 71.5 |
| Hydrogen dry, wt% | 6.2 | 6.4 |
| Nitrogen dry, wt % | 0.1 | 0.0 |
| Sulfur dry, wt % | 0.01 | 0.03 |
| Oxygen dry by difference, wt% | 40.1 | 22.0 |

In parallel Business Finland project CaSH [2], slurry hydroprocessing has been investigated as an alternative for bio-oil stabilization/first-stage HDO. In slurry hydroprocessing, fine catalyst particles form a slurry phase together with a liquid phase in the reactor. Opposite to fixed bed reactors, fresh catalyst can be continuously added to the reactor and spent catalyst removed. Furthermore, reactor blocking is less probable compared to fixed beds. In CaSH, very promising results were obtained with unsupported Mo-based slurry catalysts developed at VTT. These catalysts were successfully tested at RISE in Sweden in their slurry hydroprocessing bench plant.

Fuel properties and quality of bio-oils

The fast pyrolysis bio-oil is addressed with challenging fuel properties [4,5,6], however, upgraded FPBO (SDPO) had fuel properties close to the requirements for marine fuels. Two batches of the SDPO from BTG were studied, the first one was reserved for storage stability and the second one for engine testing. For the first SDPO batch, fuel properties analysed according to the ISO 8217:2017 standard for marine fuels are shown in Table 2. It was obvious that further adjustments are needed, for example, regarding the distillation range, flash point, cetane number, density, viscosity, acid number, carbon residue and water-soluble phenolic compounds to meet marine fuel requirements defined in ISO 8217. Furthermore, the quality varied between the two batches studied, which is an important observation for defining criteria for quality control.

Stability and compatibility of the SDPO

The long-term and accelerated ageing studies showed promising results for the first SDPO batch, while the second batch of the SDPO for the engine tests was not studied by ageing tests. While blending the second batch of SDPO with DMB to make a 10% blend, some wax-like sediment was separated on the bottom of the container used. No sediment or phases were found in the pure SDPO canisters that had been stored for a few months, nor in the blends of the first SDPO batch and DMB. When SDPO would be used as a blend in DMB or other fuels, attention should be addressed to the quality control and compatibility of the product. SDPO products had rather rich odour that could cause challenges in certain environments. Low initial boiling temperature and high vapour pressure make the use of SDPO challenging and special arrangements would be needed for commercial use.

Engine-tests

VTT's medium-speed engine, Wärtsilä Vasa 4R32, was used in the tests with a blend of 10 wt% SDPO and 90 wt% of Marine Diesel Oil (DMB grade) and 100 wt% DMB. The Auramarine feeder-booster fuel supply unit was developed for the VTT engine research laboratory to test new drop-in replacement biofuels (Figure 1). The compact skid-mounted unit was designed with a focus on reliable and versatile use in a research environment. The fuel supply unit has variable speed-driven fuel pumps that enable testing fuel supply at varying flow rates and pressures. The unit's fuel heater, cooler and automatic filter were chosen with biofuels and laboratory use in

Table 2: Properties of hydrotreated FPBO (SDPO) compared to marine fuels.

| PROPERTY | | Upgraded FPBO's | Marine distillate ISO 8217:2017 | Marine residual ISO 8217:2017 |
|--------------------------|-------------------|---------------------|---------------------------------|-------------------------------|
| Density at 15 °C | kg/m ³ | 912; 949 | max. 900 | 991 |
| Viscosity at 40 °C | cSt | 17.5; 6.37 | 2.00 – 11.0 (40 °C) | 330 (50 °C) |
| Cetane number/index/CCAI | | 22.2/-/860 | -/Min. 35/- | -/-/Max. 870 |
| Sulphur | mg/kg | 5.2; 38.0 | Max. 5000 | Max. 5000 |
| Flash point | °C | < 40 in both | Min. 60 | Min. 60 |
| Pour point | °C | - 20; -36 | Max 0/6 (winter/summer) | Max. 30 |
| Cloud point/CFPP | °C | -/18 | - / - | |
| HFRR lubricity 60 °C | µm | 140 | Max. 520 | |
| Boiling point range | °C | 50-550; 30-550 | 150-420 ^a | 180-570 ^a |
| Acid number | mg KOH/g | 0.08; 3.13 | Max. 0.5 | Max. 2.5 |
| Strong acid number | mg KOH/g | (SAN < 0.1 in both) | | |
| Water | wt% | 0.59; 0.76 | Max. 0.30 (Vol-%) | Max. 0.50 (Vol-%) |
| Water soluble phenolics | wt% | 1.8; 3.9 | | |
| Total sediment | wt% | <0.01 in both | Max. 0.1 (hot filt.) | Max. 0.1 (aged) |
| Carbon residue | wt% | 0.70; 0.95 | Max. 0.3 | Max. 18 |
| Oxidation stability | g/m ³ | too viscous | Max. 25 | |
| Oxidation stability | min | 50.5; 53.3 | No spec | No spec |
| Ash (775 °C) | wt% | 0.006; <0.001 | Max. 0.01 | Max. 0.1 |
| V/Na | mg/kg | <0.5/<0.5; 0.8 | - | Max. 350/100 |
| Al+Si | mg/kg | <0.5+<0.5 | - | Max. 60 |
| Ca/Zn/P | mg/kg | <0.5/<0.5/<0.5 | | Ca>30, Zn or P >15 |

^a Distillation ranges obtained from the SDS of the marine distillate and marine residual.

mind. The instrumentation on the unit is extensive – temperature and pressure are measured at all relevant points in the piping, also viscosity and flow rate of the fuel oil are measured in various locations. The most important pressure sensors are separated with glycerin from the oil to ensure trouble-free measurement during testing of the most difficult oils. The unit is controlled by a logic controller that relays the measured values to the data logging system of the laboratory. The unit has several additional piping connections that can be used to by-pass components and to add external units for further handling or analysis of the oil making the fuel supply unit highly versatile for research purposes. [3]

With 10% SDPO, scattering in fuel mass flow results was observed probably due to light fraction of the 10% SDPO blend causing cavitation in the fuel feeder pump and

decreased pressure in the fuel system. As regards combustion characteristics, injection pressure curve and cylinder peak pressures were comparable with 10% SDPO and DMB. Only a small difference between fuels was observed in rate of heat release curves.

10% SDPO blend yielded nearly the same NO_x emissions as DMB. Specific NO_x emission was only 5% higher with 10% SDPO blend than with DMB at engine loads of 75% and 50%. Total hydrocarbon and carbon monoxide emissions were practically the same with 10% SDPO blend as with DMB.

Black carbon (BC) emission measured with the filter smoke number (FSN) method was 16-25% lower with 10% SDPO than with the DMB. However, total particulate matter (PM) emission was at the same level with 10% SDPO as with DMB fuels. PM emission may contain organic compounds, sulphates, ash and other constituents besides BC.



Fig. 1: The Auramarine feeder-booster fuel supply unit developed for test new drop-in replacement biofuels for testing.

Techno-economic evaluation

The production costs of upgraded bio-oil were estimated at 1200–1300 €/t for an n^{th} -of-a-kind plant processing 30 MW FPBO. The hydrogen required for HDO was assumed to be produced by electrolysis and the oxygen content of the product was set at 5 wt-%. For the corresponding first-of-a-kind plant, including additional costs related to new technology, the estimated production costs are 1600–1800 €/t. The system study indicates that the relatively low capital investment of the IC engine and the storability of the bio-oil make the solution specifically suitable for flexible operation between 1000 and 4000 hours per year. The concept is promising, but the economic feasibility depends on the prices and especially the volatility of the future electricity market.

Conclusions

Fast pyrolysis bio-oil upgraded by hydroprocessing is a promising product for large diesel engines. However, there are challenges using fixed-bed hydroprocessing

and new technologies such as slurry hydroprocessing are needed to secure commercialization. BioFlex project generated new information on the properties for upgraded FPBO (SDPO) reflecting its usability as a marine fuel and needs for further improvements. Further adjustments are needed, for example, regarding the distillation range, flash point, cetane number, density, viscosity, acid number, carbon residue and water-soluble phenolic compounds to meet marine fuel requirements defined in ISO 8217. Besides promising results, also sensitiveness between different batches of the refined FPBO production was observed. Further studies are needed to define the criteria analyses to ensure sufficient bio-oil quality as marine fuel, to be considered in standardisation. Notably, the product is still under development. The upgraded bio-oil is a potential low-carbon fuel to be used in IC engines to provide flexible power in an energy system dominated by variable renewable energy.

Based on the results the focus on upgrading at VTT will be slurry hydroprocessing.

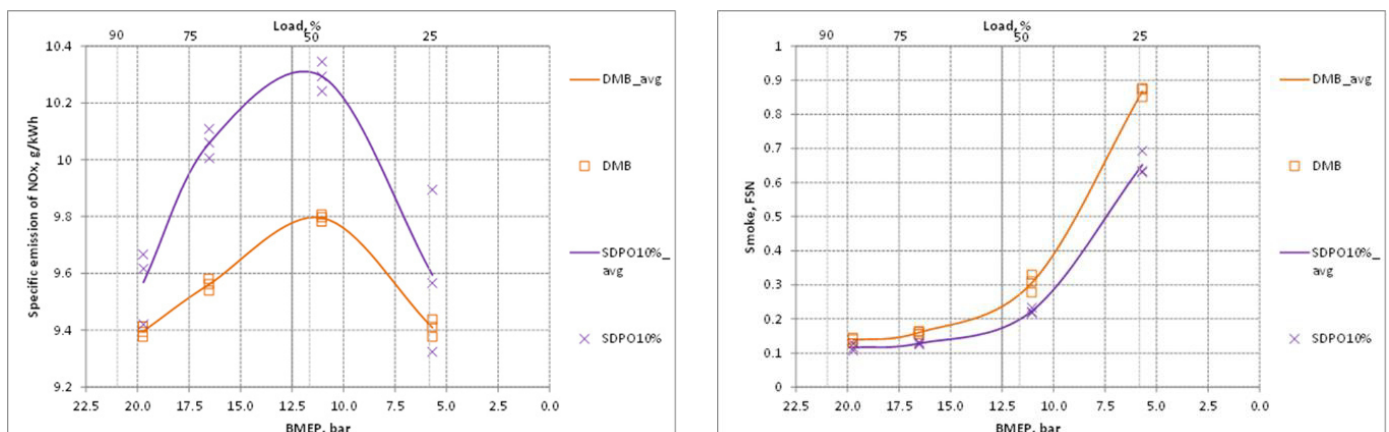


Fig. 2: NO_x and black carbon emissions with the 10% SDPO and DMB fuels.

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Innovative and circular production of microalgae-based fuels for shipping and aviation

Julien Prudhomme. Sary Award, IMT Atlantique, France

Claudia Batini, ETA Florence, Italy

COCPIT is a new EU funded project supporting sustainable transport fuels uptake through a new tool able to identify the best solution for end-users needs.

Transportation plays a crucial role for European Union to reach the Green Deal's targets, as it represents the 25% of total EU greenhouse emissions. In particular, **maritime** and **aviation transport** are areas of high interest, as they currently rely almost on fossil fuels and account for about one-third of overall EU transport emissions. Furthermore, these two sectors are the most difficult ones to be electrified, due to the high energy densities required.

In order to reduce these sectors environmental footprint, the European Council adopted the **FuelEU maritime** and the **RefuelEU aviation initiative**. These initiatives,

to increase sustainable fuels uptake, set targets of GHG intensity reduction for shipping fuels of 2% in 2025 and up to 80% by 2050, as well as a minimum share of SAF (Sustainable Aviation Fuels) equal to 2% in 2025 and up to 70% in 2050.

The COCPIT project fits into this virtuous trajectory supporting to the large-scale production of microalgae-based sustainable aviation and maritime fuels delivering an innovative, circular and complete production chain through two pathways:

HEFA (Hydroprocessed Esters and Fatty Acids) and HTL (Hydrothermal liquefaction). COCPIT will also develop a decision tool - based on economic, social and environmental indicators - analysing different scenarios that will facilitate investors to the best solution for their specificities.

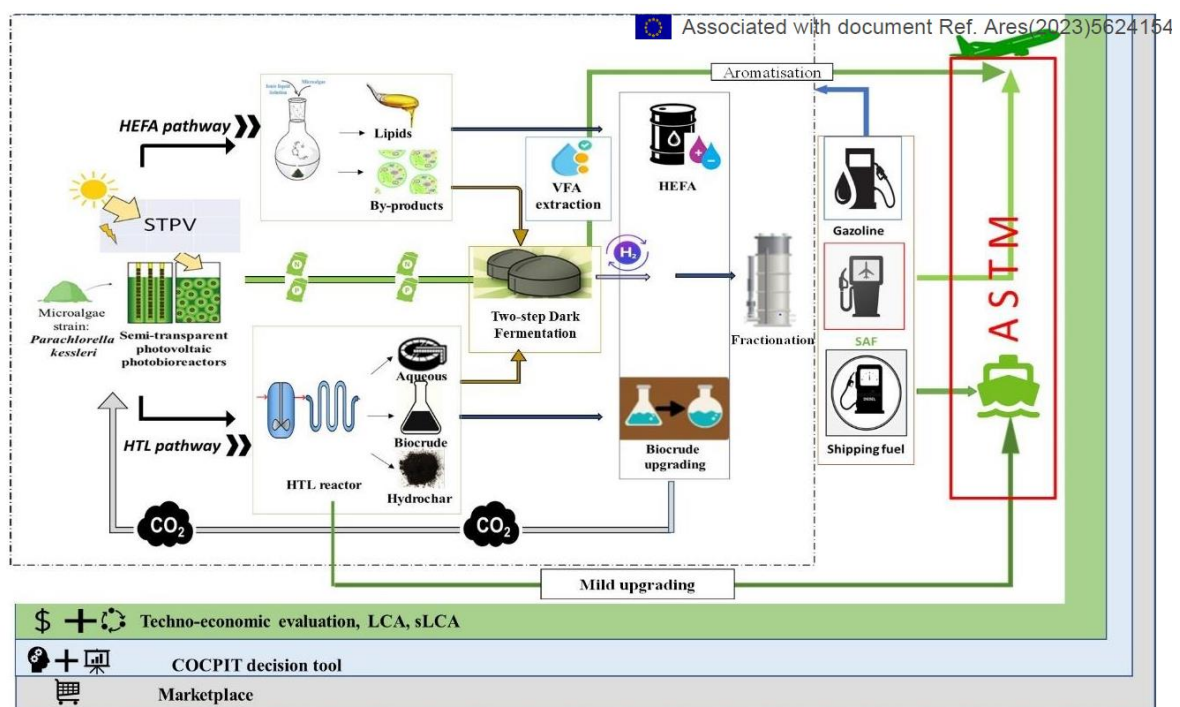


Figure 1: COCPIT concept

Innovations within the production chain

COCPIT will enable innovations at multiple phases of the production chain: in the **microalgae cultivation stage** the algae strain will be combined in a thin film reactor - to intensify photosynthesis - and covered with a semi-transparent photovoltaic (STPV) shell - to produce electrical power.

At the **transformation stage** of algal biomass into sustainable fuels, ionic liquids will be used to extract lipids and to catalyse the *HEFA pathway* at the same time, making the process more affordable, efficient and eco-friendly, while in the *HTL pathway*, the main obstacles to HTL upscaling (clogging and biocrude separation) will be overcome, and a more accurate design tools for reactor and heat exchangers will be implemented.

Moreover, different upgrading approaches of HTL biocrude will be established in order to ensure flexibility towards the desired fuel output distribution between shipping and SAF. Furthermore, the project will adopt different techniques in order to reduce the nitrogen

content on the final **SAF allowing its certification under ASTM norms**.

HTL constitutes a promising pathway due to its adaptability to a wide range of feedstock, its ability to shift from shipping fuel to SAF oriented applications and its possibility of transforming the whole biomass into biofuels.

Circular approach

COCPIT will enhance the circularity and the viability of the value chain by valorising and recirculating all coproducts and power streams. **Dark fermentation** is used to valorise different byproducts to produce hydrogen for fuel refining purposes, aromatics as fuel boosters and to recirculate nitrogen and phosphorus to the photobioreactor.

Moreover, using STPV panels feeds the system with power from the infrared spectrum of solar radiation all along with reducing PBRs cooling utility. COCPIT also opens to new adaptive options, by studying scenarios in which other waste streams are used for dark fermentation or microalgae cultivation and industrial symbiosis is established by mutualizing by-products and energy streams.



Figure 2: The COCPIT team at the kick-off-meeting at IMT Atlantique in Nantes, France, October 2023.

Comprehensive sustainable aviation and maritime fuels marketplace

Within the project, the **COCPIT** AI-based decision **tool** will be developed: it will be fast and flexible, allowing the examination of several prospective scenarios, the comparison of established and novel technologies (HEFA or HTL) and the identification of the most sustainable conversion pathways. Moreover, COCPIT will work towards the centralisation of sustainable transport fuels innovations, delivering a **comprehensive marketplace** where COCPIT decision tool and a range of technological solutions will be at investor's service, helping them to choose the best solution for their algal-based sustainable fuels project.

About COCPIT

COCPIT – Scalable solutions Optimisation and decision tool Creation for low impact SAF Production chain from lipid-rich microalgae strain is a 4-years Horizon Europe Research and Innovation Action project started the 1st October 2023.

This project has received funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement No. 101122101. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Partners

Coordinated by IMT Atlantique, France, COCPIT has a consortium of 10 partners from 6 different EU countries. The project is carried on by an international consortium composed by 5 academic partners and 5 non-academic partners, from 6 different EU countries, including the whole production of sustainable fuels from microalgae, the sustainable fuels pre-screening and the scenario development.



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Task 34 Workshop on DTL activity in North America at National Renewable Energy Laboratory (NREL) Campus, Golden, Colorado

Michael Thorson, PNNL

The workshop included insightful talks presenting on efforts to advance DTL commercialization.

The morning session commenced with Beau Hoffman from the Bioenergy Technology Office (BETO), who provided an overview of BETO's efforts enabling DTL efforts to convert biomass in sustainable transportation, discussing the SAF grand challenge, and detailing the qualities of SAF derived from HTL and pyrolysis. He also highlighted the significance of co-processing, resource consolidation, and the social impacts of organic waste processing, along with the BETO's funding efforts in these areas. Following Hoffman, Gary Lee from Parkland shared insights from a refinery's perspective, particularly their strategies to co-process tallow and HTL biocrude.

Lillian Zarembo from Metro Vancouver discussed their ongoing HTL project to convert organic wet waste into crude oil through a pilot plant.

Allan Del Paggio from Licella presented their global HTL projects aimed at converting wood, and various wastes (especially plastics) into biocrude and intermediates, including MURA and Arbios.

Juan Lopez from PNNL described his pioneering work in using electrochemistry to clean up the HTL aqueous phase.

Mike Thorson, also from PNNL, highlighted PNNL's innovative approaches in steam flashing, autothermal HTL, and solvent extraction, enhancing operability and safety in HTL facilities.

Brian Gannon from Biogas Energy shared his experiences with ablative pyrolysis in California. Derek Vardon from Alder Fuels delved into their pioneering work on converting pyrolysis oils into Sustainable Aviation Fuel (SAF) using a novel separations process. This presentation highlighted the innovative approach Alder Fuels is taking in addressing the challenges of converting pyrolysis-derived oils into high-quality aviation fuel, an essential component in the pursuit of sustainable transportation.

Reinhard Seiser and Fred Baddour from NREL concluded the morning presentations with their respective insights into fast pyrolysis work and the processing and co-processing of pyrolysis oils.

The workshop concluded with a tour of NREL's integrated biorefinery and thermochemical conversion labs.



Fig. 1: Participants of the Task 34 workshop

What happened 20 years ago?

It is interesting to see how the field of direct thermochemical liquefaction developed over the years. We are thus presenting one example highlight from the PyNe newsletter twenty years ago in this regular feature....:



Opportunities for Bio-oil in European Heat and Power Markets

By Maximilian Lauer,* John Brammer** and Tony Bridgewater,**
*Joanneum Research, Austria, **Aston University, UK

Competitiveness

The opportunities for use of bio-oil in heat and power applications across Europe have been evaluated by measuring its competitiveness to conventional alternatives. Economic competitiveness is a relative issue and the overall costs of a technology meeting a given duty should be at the same level or lower than the overall costs of a competing technology meeting the same duty.

In order to provide a measure of competitiveness, a non dimensional Index dF (competitiveness factor) is introduced, which is defined as the ratio of the total annual cost of meeting the required duty using conventional energy to that of meeting the same duty using a purpose-built bio-oil or biomass plant:

$$dF = \frac{\text{total annual cost of conventional energy}}{\text{total annual cost of bio-oil or biomass plant}}$$

A value of $CF < 1$ means that bio-oil is not competitive while values > 1 mean that bio-oil is more attractive than the conventional alternative.

Approach

Calculation of the Competitiveness Factor requires knowledge of the costs associated with the bio-oil production process and with the bio-oil or biomass utilisation process, the latter being split into technology-related elements and location-related elements. By standardising the conventional alternative across all applications, then it is possible to compare options that are different in scale, location and service provided.

• Technology related elements (investment cost, O&M cost, labour requirements, efficiencies etc. for a set of bio-oil applications and biomass applications (combustion and gasification);

• Location specific data acquisition by using a questionnaire asking all European PyNe country representatives to describe the national situation by answering the questions on feedstock available, cost situation for energy and labour in industry etc.; Data acquisition and data processing done by Joanneum Research with the help of PyNe country representatives.

• Bio-oil production cost calculation by using relations based on assumptions (single bio-oil production facility in an area of high biomass availability) and location specific parameters.

Table 1 lists the feedstocks specified by PyNe country representatives, and Table 2 outlines the range of technology options considered.

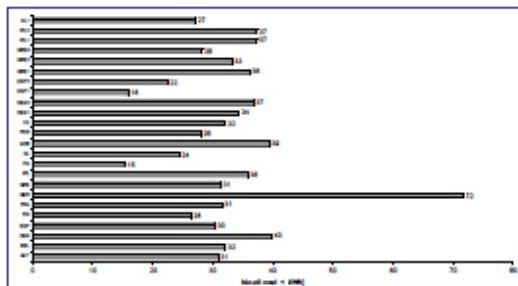


Figure 1: Bio-oil cost across Europe (see Table 1 and Table 2 for further specification of feedstock).

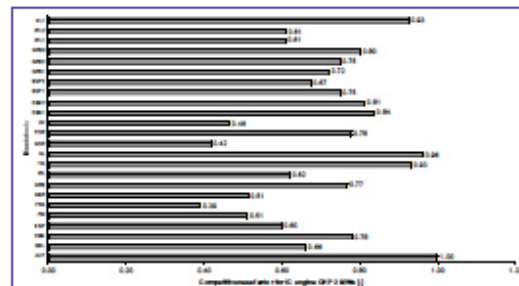


Figure 3: Competitiveness Factor of bio-oil IC-engines for CHP (2 MWe) across Europe; (see Table 1 and Table 2 for further specification of feedstock).

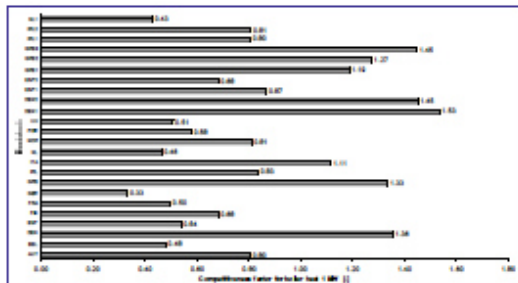


Figure 2: Competitiveness Factor for bio-oil boilers for heat production (1 MWh); (see Table 1 and Table 2 for further specification of feedstock).

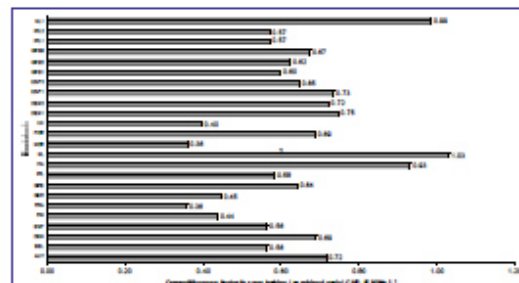


Figure 4: Competitiveness Factor of bio-oil GTCC for electricity (15 MWe) across Europe; (see Table 1 and Table 2 for further specification of feedstock).

You can access the full article by using the following link:

[Pyne 16](#)

Upcoming Events



22. - 23. January 2024

Fuels of the future, Berlin, Germany

<https://icb2023.scievent.com/>



LIGNOFUELS 2024

7th & 8th February / Helsinki, Finland



07. + 08. February 2024

13th Annual Lignofuels Conference, Helsinki, Finland

<https://www.wplgroup.com/aci/event/lignocellulosic-fuel-conference-europe/>

ABL C2024

13. - 15. May 2024

ABLC 2024, Washington DC, United States

<http://biofuelsdigest.com/ablc/>



ECRES 2024

12. European Conference on Renewable Energy Systems

16-17 May 2024 Mallorca/Spain

16. – 17. May 2024

Ecres 2024, Mallorca, Spain

<https://ecres.net/>



19. – 22. May 2024

IconBM 2024, Palermo, Italy

<https://www.aidic.it/iconbm2024/page.php?pipe=testohistory>



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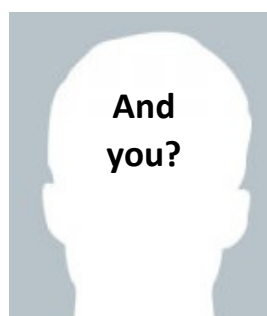
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How To Become a Member



Contact your national
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 Task 34.

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If you would like to contribute an article to the Task 34 newsletter or have questions, please contact:

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Task 34: Direct Thermochemical Liquefaction



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