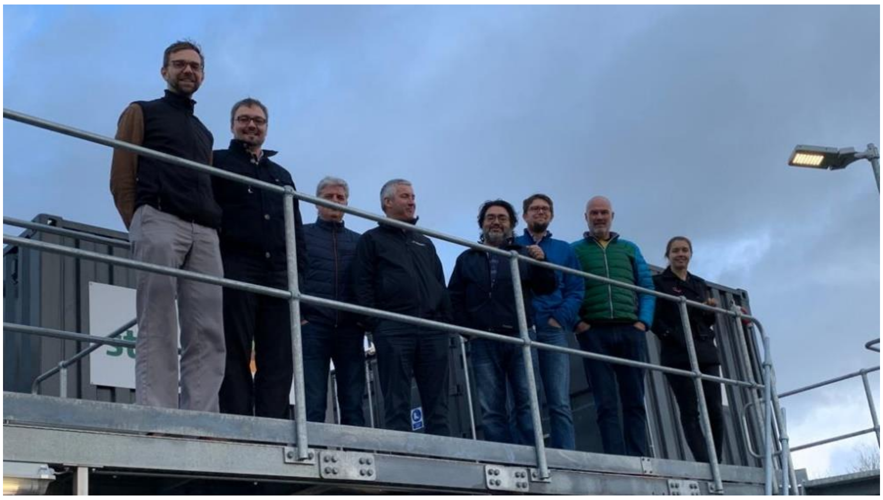
IEA Bioenergy
Technology Collaboration Programme
Task 34

Newsletter
Direct Thermochemical Liquefaction



PyNe 49

December 2021

A successful triennium is coming to an end and despite adverse circumstances we can conclude to have achieved a lot. We started this triennium with almost completely new members, but we finished it as a team.

The main focus of this newsletter will be to inform you what happened in the last 3 years in the countries that participated in Task 34 during these difficult times. Reports and tasks, newsletter and dissemination, restructuring of the website and intertask work, to name but a few, kept us very busy. The NTL's from the participating countries did a very good job and a lot of relevant activities took place these three years.

(Continued on page 2)

Inside this Issue:

Preface

In Denmark, a lot of progress was made in the last triennium. The Advanced Biofuels Group at Aalborg University was responsible for the upgrading activities aimed at converting HTL bio-breeds into drop-in fuels such as gasoline, diesel, and jet fuel. If you want to learn more about producing sustainable jet fuel components and what's key in hydrotreating: you'll find the article on page 3.

A number of activities around DTL took place in Finland during this triennium, many of them were related to R&D activities. The most important; however, was the Green Fuel Nordic industrial project, a Finnish biorefinery company producing bio-oil from sawdust.
Find out more in the article on page7.

In Germany, pyrolysis is considered a key technology for the future anthropogenic carbon cycle. The bioliq® demonstration plant at Karlsruhe Institute of Technology demonstrates a process chain from agricultural residues to gasoline-like 2nd generation biofuels. Fraunhofer UMSICHT has developed the thermocatalytic reforming (TCR®) process for biomass conversion to produce bio-oil, and HAW Hamburg's research in DTL focuses on solvolytic approaches.

Our newest member India is working on the utilization of biomass waste into transportation fuels. The HP Green R&D Centre (HPGRDC) in Bangalore is involved in developing various technologies to convert biomass into biofuels such as biogas, bioethanol, bio jetfuel, and drop-in fuels for gasoline and diesel. More details are available in the related article.

The Netherlands' activities in the field of DTL mainly concern fast pyrolysis. A new biomass collection and pretreatment system has been added to the industrial-scale demonstration plant, called Empyro, to allow the use of other regional biomass feedstocks in addition to pellets. Eindhoven University (TU/e) is evaluating in detail the combustion behavior of FPBO in engines, while BTG and ABATO engines have modified an engine to run on pure FPBO. Also, read how electrochemical processing of FPBO opens up new and unique possibilities.

In New Zealand, the government is increasingly interested in sustainable biofuels
Scion has a Bioenergy Research Program Liquid biofuels research under this program supports: the adoption and adaptation of best international technologies for the production of aviation biofuels; and the development of technologies for the production of marine biofuels from woody biomass.
For more information, see the article on page 19.

In the last triennium, there have been numerous biomass liquefaction initiatives in Sweden, mainly with forestry feedstocks. A major event in Sweden in recent years has been the construction and commissioning of a commercial pyrolysis plant at a sawmill. Another important event is that Cortus Energy's first commercial plant (6 MW) was completed in late 2019. The technology is based on pyrolysis of biomass and subsequent gasification of char. Envigas is a company involved in pyrolysis of forest residues. For details and what else is new in Sweden, read the article on page 21

Successes worth seeing were also achieved in the United States. Pacific Northwest National Laboratory (PNNL) hosted a virtual workshop with more than 250 national and international experts on HTL and sustainable aviation fuel (SAF) to accelerate the commercialization of hydrothermal liquefaction (HTL) technology to produce SAF by identifying and discussing the current state of this process and identifying short- and long-term research opportunities. The workshop helped to identify four critical areas that are being addressed, which are further explained in the related article.

Task 34 has published a series of reports in this triennium, including updated country reports, results from the latest Round Robin, an explanation of DTL technologies in general, commercialization activities in the field of DTL, a case study for the supply of industrial heat by FPBO, and REACH relevant analyses of specific FPBO components. You find these and more updates from Task 34 on our website.

Finally, it remains to us to thank you for your interest in our work and your loyalty and support. We wish you a Merry Christmas and an excellent start into 2022!

Yours sincerely,

Alexandra Böhm
Task Assistant

Sustainable aviation fuel from hydrothermal liquefaction biocrude

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Fighting against climate change has become an important necessity of our society and the field of transportation is definitely one of the most relevant in terms of emission of greenhouse gases. This is even more true when long-haul transportations are involved and especially for the aviation field. Indeed, whereas in other sectors different solutions, such as electrification, are viable, in the aviation field this is a relatively less feasible route.

Biofuels could be the solution to this issue. Being able to produce jet fuel from a renewable source such as biomass, but yet chemically identical to its fossil counterpart, could represent a ready-to-go solution to the aviation field.

Recently, a consortium of 10 European partners has successfully completed the project "Hyflexfuel", funded by the European Commission under the Horizon 2020 program. Scope of the project was that of exploring the potential of hydrothermal liquefaction as a flexible technology for the production of drop-in biofuels from different types of biomass feedstock, including algae, sewage sludge and lignocellulosics (Fig. 2).

The group of Advanced Biofuels at Aalborg University – AAU Energy was in charge of the upgrading activities, aiming at converting HTL biocrude into finished drop-in fuels, such as gasoline, diesel and jet-fuel. Results were highly successful and all the three investigated biocrudes could be converted into useful fuels, which were characterized against the current specifications. A great potential was observed towards sustainable aviation fuels (SAFs).

Hydrotreating: from biocrude to biofuels

HTL biocrude "as it is" is not suitable to be employed as a fuel for combustion engines. Its relatively high content of oxygen and nitrogen, and consequently its unfavorable physicochemical properties, require that it undergoes an upgrading process.

This can be carried out through hydrotreating, i.e. by reacting biocrude with high pressure H_2 in the presence of a suitable catalyst. Hydrogen is able to remove oxygen, nitrogen and other unwanted species (e.g. sulfur and other inorganics), therefore converting biocrude into a mixture of hydrocarbons.

Fig. 1: Continuous hydrotreater at Aalborg University.

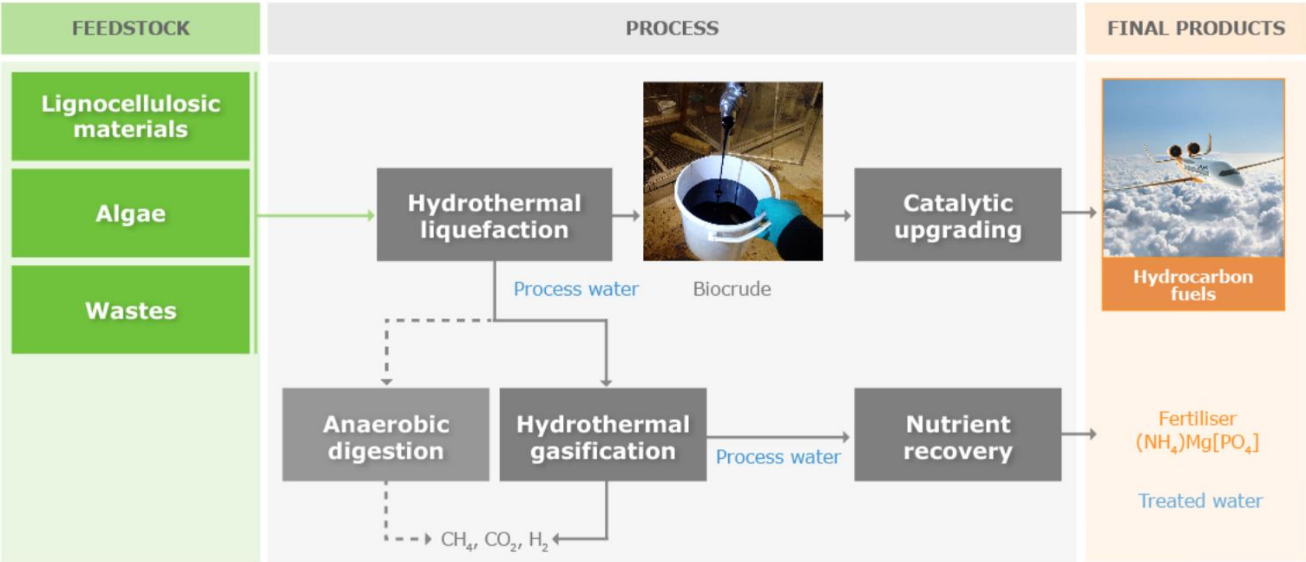

Fig: 2: Concept of the Hyflexfuel project.

In the Hyflexfuel project, HTL biocrude was produced at Aarhus University (Denmark), in a continuous pilot plant [1]. The process proved to be quite reliable, being able to process diverse feedstocks, such as algae, sewage sludge, *Miscanthus* and wheat straw. The biocrude produced at Aarhus University was then processed at Aalborg University in a continuous hydrotreater with a throughput of around 50 mL/h (Fig. 1) [2]. This experimental unit features two trickle-bed reactors, each of them placed in a three-zone furnace and a high-precision syringe pump, able to deliver a very precise flowrate of H_2. Hydrotreating tests were carried out with sulfided $NiMo/Al_2O_3$ and Mo/Al_2O_3 catalysts, supplied by Haldor Topsøe A/S (Denmark). In total, three continuous upgrading campaigns were established, carried out on *Spirulina*, sewage sludge and wheat straw biocrudes.

Results showed that hydrotreating can be successfully carried out for long time. Each campaign was run for several hundred hours, with overall ca. 920 total hours of operations. In most cases, hydrotreating operations were suspended only due to the feed being exhausted, hence without observing any pressure drop or incipient plugging. This is a noticeable indication of the potential high reliability of the process.

A key for the success of the upgrading operations was found in the proper selection of process conditions, including the number of stages, their operating temperatures and

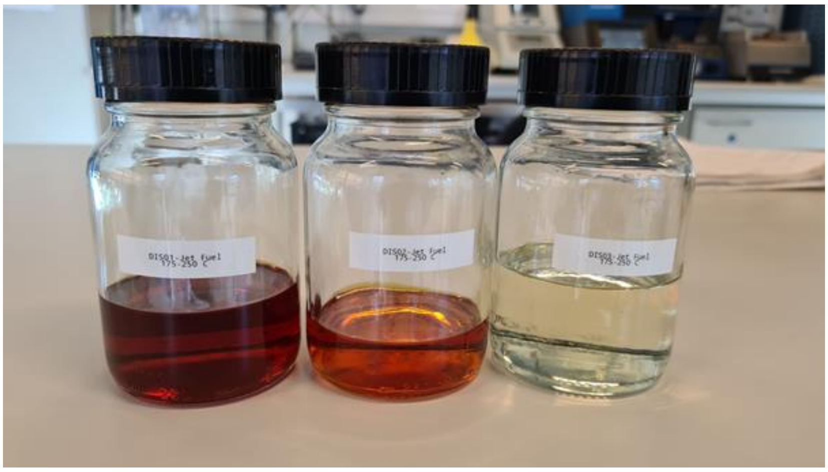

Fig. 3: Samples of HTL-derived jet fuel.

Fig. 4: – Aviation engine used for testing.

space velocity and the proper grading of the catalyst bed. Each investigated biocrude came from a different origin and therefore displayed different types of chemical species within its composition [3].

Moreover, HTL biocrudes come along with a non-negligible content of inorganics, whose correct removal is crucial for the success of long-time hydrotreating operations [4]. Therefore, a deep understanding of the physicochemical properties of each feedstock is necessary in order to select an appropriate upgrading procedure. More details can be found in the public report from the Hyflexfuel project [5].

Producing sustainable aviation fuel components

Upon upgrading, biocrudes experienced a dramatic change in their physicochemical properties. Normally, complete removal of oxygen was achieved, while nitrogen could be removed to a large extent. This resulted in low-viscosity, highly non-polar liquids, sometimes with a visual color change from deep black to almost color-less. Analyses showed a prevalence of alkanes.
The upgraded products were then distilled in a standard distillation column and fractions were collected at different boiling ranges, producing gasoline (<175 °C), jet fuel (175-250 °C) and diesel (250-350 °C) products. In Fig. 3 some produced samples of jet-fuel can be observed. HTL-derived jet fuels from *Spirulina* and sewage sludge were found compliant with the specifications in ASTM D4054 Tier 1, sometimes showing even better properties than traditional fossil-derived jet fuel. Moreover, all the investigated samples were on-specification upon blending up to 50% with standard Jet A-1 kerosene. More details can be found in the project report on fuel production, publicly available at [6].

Testing in a small aviation engine

As a final activity of the Hyflexfuel project, the obtained SAF components were blended with commercial Jet A-1 (supplied by ENI, Italy) and were tested in a small lab-scale turbine (Fig. 5), in order to observe the difference in the combustion behavior between pure Jet A-1 and the obtained SAF. The test, first of its kind in the open literature, was conducted at Aalborg Airport and was highly successful.
No appreciable differences could be observed when switching from traditional Jet A-1 to SAF and vice versa, with combustion temperature, pressure and exhaust emissions remaining basically unchanged. Although this was a small-scale test, yet it is quite indicative of the high potential of HTL for the production of sustainable aviation fuel. Next step should involve the establishment of a certification procedure for HTL-derived SAF which could allow its commercial utilization. Aalborg University will address this issue in the project "LowCarbFuels.dk", funded by the Innovation Fund Denmark, involving 17 industrial and research partners.

Acknowledgments
The authors would like to thank Saqib S. Toor and Anna Lyhne Jensen (Aalborg University) for assistance with the turbine test, as well as the other partners in the Hyflexfuel consortium for collaboration. This research has received funding from the European Union's Horizon 2020 Research and Innovation Program under grant agreement no. 764734.

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Green Fuel Nordic a Finnish biorefining company

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As explained in the detailed country report from Finland, quite some activities around DTL took place during this triennium – many of which were related to R&D activities. For occasion of this PyNe 49 and the review of activities during 2019-2021, it was decided to focus on one industrial project that was realized in this period to produce fast pyrolysis bio-oil from sawdust.Green Fuel Nordic Oy is a Finnish biorefining company producing bio-oil from sawdust. The company was founded in 2011, but it took almost 8 years to design and collect the funding for the plant. The Dutch pyrolysis technology based on rotating cone was selected for the project. This pyrolysis technology has been developed by BTG-BTL for more than 30 years and demonstrated successfully in the Empyro plant (in the Netherlands), which has been in operation since 2015. The capacity of the GFN plant is similar to the plant in Netherlands and it converts around 90 000 m3 of raw material into 20 million liters (24 000 t) of bio-oil annually. The investment of the plant was around 30 M€.

The construction of the plant was started in late 2019 in the town of Lieksa, in Lieksan Teollisuuskylä Oy’s Kevätniemi industrial area. Technip was responsible for the implementation of the plant and Zeton for the manufacturing of the core production facility. Like with Empyro plant in Netherlands, the components of the prefab facilities were first built in the Netherlands, shipped and then reassembled on location in Finland. Commissioning of the unit was started during summer 2020 and continued to late autumn. Already on 2nd December same year, bio-oil production was started. The bio-oil is sold to Savon Voima, who is burning the oil for district heating during winter seasons.

Fig. 1: Green Fuel Nordic a Finnish biorefining company

Fig. 2: Green Fuel Nordic a Finnish biorefining company

The pyrolysis plant is operated by GFN Lieksa Oy, which is a Green Fuel Nordic subsidiary. The Lieksa-based company will produce the bio-oil, with parent company Green Fuel Nordic Oy responsible for sales, marketing and product development. From GFN Lieksa's point of view, the Kevätniemi area offers an ideal location for a bio-oil refinery. The same area can also be utilized for continued investments, both in bio-oil production and further refinement. Green Fuel Nordic plans to build multiple Finnish bio-oil refineries close to the resource in the near future. At the same time, the company strives to achieve the goals set for Finnish renewable energy production while helping boost energy self-sufficiency.

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DTL related activities in Germany 2019-2021

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Policies

Germany implemented the European Renewable Energy Directive by several national laws. There are clear financial incentives in place for renewable power generation; however, this is not the case for heating and transportation sectors which are more relevant for products from DTL. Instead, a general CO_2 price has been introduced in 2021 starting with 25 €/t CO_2 which will increase to 55 €/t CO_2 until 2025. The generated income will primarily be used to compensate the increase in prices for electricity that arise from the financial incentives for renewable power generation.

Also implemented in this triennium was a central element for reducing GHG emissions from heating in private homes. Starting from 2026, boilers based on fossil heating oil will only be allowed for installation if they are used to support a heating system that includes renewable energy. Heating systems based on biomass have been implemented widely across Germany already; these are predominantly based on wood as fuel. It is open how this will develop with the new restrictions for fossil heating oil since the associated policy tool does not directly support one renewable technology over the other.

Regarding transportation sector, Germany implemented a blending quota for biofuels in 2015 already which is calculated based on savings in GHG emissions. This triennium the GHG emission reduction target in the fuel mix for the entire fuel sector increased to 6% in 2020 (starting from 3.5% in 2015). Biofuels used for blending in Germany are predominantly based on FAME biodiesel and bioethanol. There are no specific policy tools in place to support 2nd generation biofuels and their share in biofuels is negligible in consequence.

It is foreseeable that BECCU/S technology will play an increased role in future transition of the fossil-based economy, also in Germany. A recently published pilot study of the German Energy Agency dena on climate neutrality in Germany by 2045 underlines the importance of negative emissions created via the use of biomass for energy and materials [1]. It includes a potential of a little over 100 Mt CO_2 to be introduced from biomass into the future German carbon cycle that require sequestration to contribute to overall negative CO_2 emissions.

Projects/ Research

Even though there are different funding opportunities in Germany for R&D around DTL technologies, it has been observed that most Third Party funds attracted in this field can be attributed to the European H2020 funding scheme. Apart from that, pyrolysis is considered a key enabling technology of the future anthropogenic carbon cycle within the Energy research field of the German Helmholtz Association [2]. It is considered a scalable technology to convert carbon rich waste streams (e.g. biogenic residues and waste plastic) into (intermediate) products that can be further upgraded to maintain circulation of carbon. In case of pyrolysis of agricultural residues it is also key to make up for inevitable carbon losses of the anthropogenic carbon cycle. Even though it is not explicitly limited to liquid products, liquefaction is obviously a focus in this context.

Demonstration

Several important test campaigns were conducted with the bioliq® demonstration facility at Karlsruhe Institute of Technology in the last years. This unit demonstrates a process chain from agricultural residues to 2nd generation drop in gasoline type biofuels at 2-5 MW scale via fast pyrolysis, gasification, and DME synthesis (www.bioliq.de). Fast pyrolysis of wheat straw, as the initial, decentralized

Fig. 1: bioliq® BtL demonstration unit (left) and EnergyLab2.0 PtX plants (right) at KIT (Markus Breig, KIT)

step of this concept, was finalized as part of this long term project [3] and focus shifted to miscanthus as feedstock instead to test flexibility of the installation. A total of 30 metric tons miscanthus were converted to fast pyrolysis bio-oil in two experimental campaigns. The observations are still being evaluated and reported to the scientific community in adequate manner soon. The fast pyrolysis bio-oil from wheat straw and miscanthus, including char content of around 5%, was gasified in the bioliq® entrained flow gasifier with special focus on how to achieve stable operation with the formed ash slag. Combined operation of this gasifier and the attached methanol synthesis unit was intensified to produce different gasoline fractions in a total of 500h on stream during this triennium. Roughly 3 m³ of products were used to generate different gasoline blends for emission tests [4], including real drive test emissions.

Fraunhofer UMSICHT has developed the thermo-catalytic reforming (TCR®) process for biomass conversion to produce bio-oil [5] and a 500 kg/h feed capacity demonstration unit was planned during this triennium for conversion of sewage sludge. The unique selling points of TCR® are the thermal stability of its oils and the high hydrogen content of the TCR® gases. By integrating hydrodeoxygenation and conventional refining processes, the bio-oil can be upgraded to green fuels complying with European standards for gasoline and diesel EN228 and EN590. Commissioning of the demonstration unit was expected in 2021.

The research of the Hamburg University of Applied Sciences (HAW Hamburg) in the field of DTL focuses on solvolytic approaches, such as solvolytic reactive distillation and solvolytic reactive stripping. The basic approach of both variants is using a self-regenerating heavy-oil sump phase as a solvolytically acting reaction medium. Previous research results have confirmed that the sump phase can develop towards a stable state over time as intended, with the exception of the formation of small proportions of solid residues (char). The READi pilot plant at TRL 6-7 for treatment of waste fat is planned for commission in March 2022 and an extension to TRL 7-8 foreseen in a follow-up project.

Commercial

Currently, Susteen Technologies GmbH for implementation of the TCR® intermediate pyrolysis process is one of two commercial endeavours in Germany for DTL of biomass. They already sold installations in several parts of the world and are also involved in constructing the demonstration scale unit mentioned above. The other is construction and consultancy services for the Biogas Energy Inc fast pyrolysis unit in California. It becomes obvious that it is difficult to develop business models in Germany around DTL given current market policies. This looks very different for DTL of plastic waste, which has seen steep uptake by industry lately.

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Valorization of Waste Biomass to Transportation Fuels

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The ever-increasing global energy demand, accompanied with the rise in greenhouse gas emissions from the use of fossil fuels, have forced the world to look for alternate energy sources. Countries are trying to reduce their carbon footprint, while still meeting their energy needs, by investing into renewable energy like solar, wind, geothermal, tidal and biomass. Many countries have set a target to achieve net zero emissions target by 2050. However, the penetration of renewable energy in the global energy mix remains meagre as around 80% of the global energy supply still comes from fossil fuels like coal, oil and natural gas[1]. As per data published by International Energy Agency in its recent report 'Key World Energy Statistics 2021', the share of world's total energy supply by source is shown in Figure 1. Although the share of biomass-based energy is 9.4%, a major portion of it comes from traditional burning for heating and cooking applications in developing countries. Biomass is a renewable source of carbon and has gained renewed interest as an alternative to fossil fuels in the last few decades. Biomass can be converted into a variety of fuels like bioethanol, bio diesel, green diesel, bioATF as well as drop-in gasoline and diesel fuels to replace the conventional petroleum derived gasoline, diesel and jet fuel. The technologies to produce these fuels are currently at different stages of development with some being available at commercial scale, while others still at lab to demo scale. India has huge potential for bioenergy as it produces around 500 million MT/year of surplus biomass, which includes agricultural and forestry residue [2]. India is the second largest rice producer after China and produces around 120 – 140 million MT/year of rice straw [3]. Due to the lack of profitable options to the farmers apart from its use as cattle fodder, a major portion of the rice straw in burnt in open fields causing significant air pollution in the some parts of the country. Therefore, it is imperative to find commercially viable ways to valorize rice straw and other crop residue into valuable products. India's National Policy on Biofuels 2018 emphasizes on utilization of agricultural waste, among other biomass sources, for production of bioethanol and biodiesel for blending as well as of drop-in fuels to substitute conventional diesel and gasoline.

Biomass Research at HP Green R&D Centre

HP Green R&D Centre (HPGRDC), Bangalore, the research & development division of Hindustan Petroleum Corporation Limited (HPCL), India, is involved in development of various technologies for conversion of biomass to biofuels such as biogas, bioethanol, bioJet fuel and drop-in gasoline and diesel fuels. The authors of this article are involved in developing thermochemical routes like pyrolysis, hydrotreating of pyrolysis oil and hydrothermal liquefaction of biomass to produce drop-in fuels. HPGRDC has established experimental facilities to carry out various research activities pertaining to process and catalyst development. Major equipment at HPGRDC include a biomass

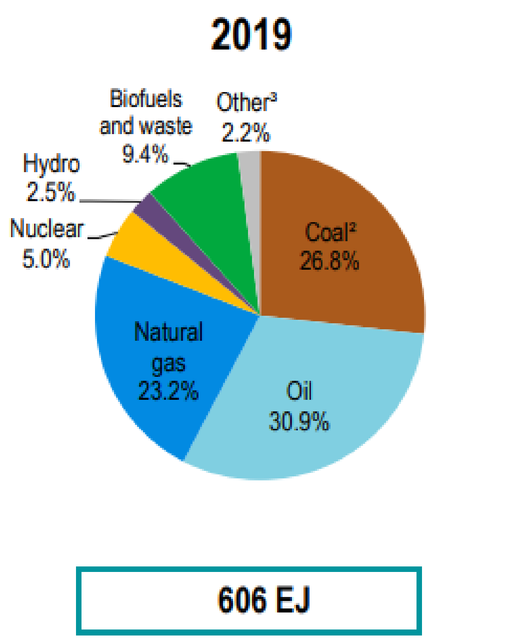
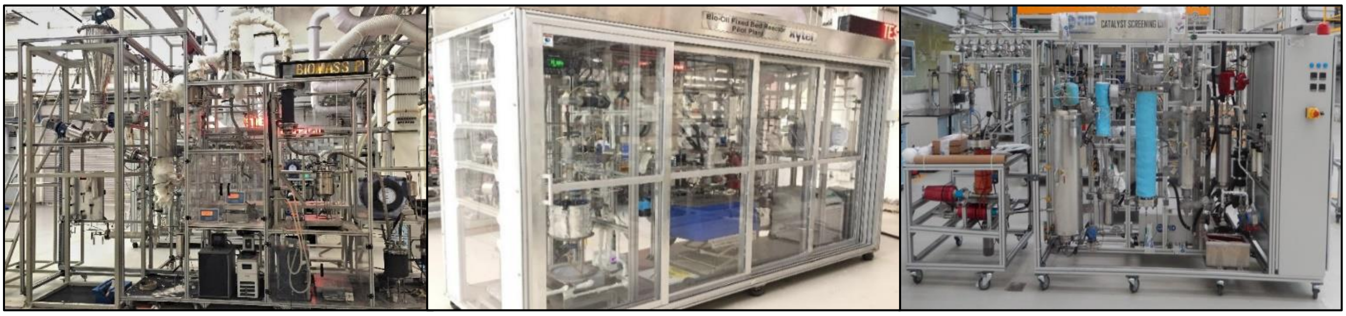


Fig. 1: World total energy supply by source



Biomass Pyrolyses Pilot Plant Bio-oil Hydrotreating unit Biomass Hydropyrolysis unit

Fig. 2: Experimental Facilities at HPGRDC

pyrolysis pilot plant of 1 kg/hr biomass processing capacity employing a bubbling fluidized bed reactor, a bio-oil hydrotreating unit employing a fixed bed reactor capable of operating up to 100 bar pressure, a biomass hydropyrolysis unit of 50 g/hr biomass feeding capacity employing a fluidized bed reactor for biomass hydropyrolysis and a fixed bed reactor for vapor phase hydrotreatment. HPGRDC has also setup analytical equipment like CHNS Analyzer, GC-MS, GCXGC, PyGC-MS etc. for detailed characterization of biomass feedstock and products.

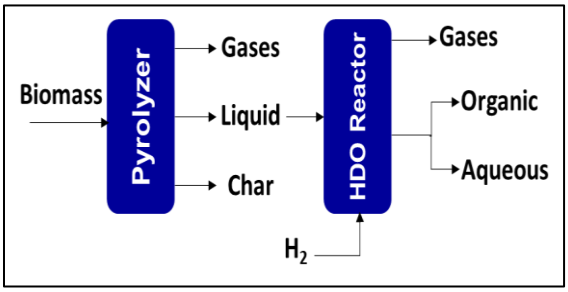
Apart from these, catalyst synthesis equipment like spray drier, extruder and kneader and characterization equipment like TPR, TPD, BET surface area and particle size analyser have been established.

Different Approaches for Biomass to Drop-in Fuels

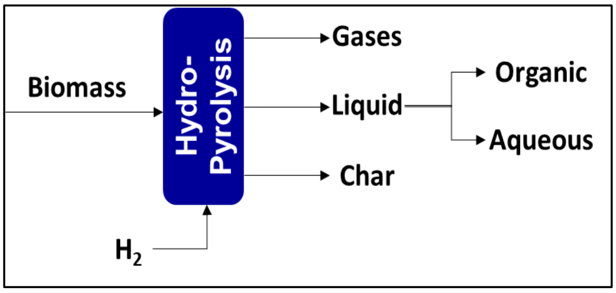
HPGRDC has adopted a dual approach for converting biomass into drop-in fuels. First approach is a two-stage process comprising of biomass pyrolysis at atmospheric pressure to produce raw or partially upgraded bio-oil, followed by hydrotreating of bio-oil in presence of hydrogen and a suitable catalyst at elevated pressures to produce fuel grade hydrocarbons. The second approach is single stage conversion of biomass to drop-in fuels via catalytic hydropyrolysis wherein, simultaneous pyrolysis of biomass and hydrodeoxygenation of pyrolysis vapors into fuel grade hydrocarbons in a single fluidized bed reactor is being attempted. Figure 3 shows the schematics of different approaches being followed for biomass conversion at HPGRDC.

Experimental Studies carried out at HPGRDC

Under the two-stage approach, thermal pyrolysis of different biomass like rice straw and wood saw dust was carried out in the pyrolysis pilot plant. Rice straw was sourced from local rice fields in Bangalore, India and wood saw dust was procured from a local carpentry shop. The biomass feedstock was sun-dried and pulverized in a cutting mill to micron size for ease of feeding as well as rapid heat transfer with the sand in pyrolysis reactor. Pyrolysis was carried out at atmospheric pressure and in a temperature range of 500 -550 °C. The operating conditions and product yields are summarized in Table 1.



Two-stage pyrolysis and hydrotreating



Single Stage Hydropyrolysis to Drop-in fuels

Fig. 3: Different approached for biomass conversion at HPGRDC

Table 1: Pyrolysis conditions and product yields

Feedstock	Sawdust, Rice straw
Feedstock size	300-700 micron
Feeding rate	0.75 kg/hr
Reactor type	Bubbling fluidized bed
Heating medium	Sand (300-700 micron)
Fluidizing Gas	Nitrogen
Pyrolysis Temp.	500-550 °C
Pyrolysis Pressure	Atmospheric
Product yields	
Bio-oil	30 - 35 wt%
Biochar	18 - 22 wt%
Gases	48 - 52 wt%
Oxygen content of bio-oil	31- 35 wt%

The bio-oil product was vacuum filtered to remove the char particles before the hydro-treating stage. Hydrotreating of the filtered bio-oil was performed in a lab scale fixed bed reactor using in-house developed catalysts. Different catalysts were synthesized and their hydrodeoxygenation activity was evaluated under different hydrogen pressures ranging from 10 to 60 bar.
Different degrees of deoxygenation were achieved with different types of catalysts. The best performing catalyst reduced the oxygen content in the upgraded bio-oil to < 1wt%. The operating conditions and product yields of hydrotreating step are summarized in Table 2.

Table 2: Bio-oil hydrotreating conditions and product yields

Feedstock	Raw bio-oil
Feeding rate	3 g/hr
Reactor type	Fixed bed
Catalyst amount	3 g
Reaction Temp.	300 °C
H2 pressure	10-60 bar
Product yields	
Organic liquid	20-25
Aqueous liquid	25-30
Gases	45-50
Oxygen content in organic phase	<1 wt%

Currently, the time-on-stream studies of the in-house developed catalysts are in progress to understand the long-term stability and activity towards hydrodeoxygenation.
Under the single-stage approach, catalytic hydropyrolysis of wood sawdust is being carried out at different hydrogen pressures in presence of ZSM-5 catalyst. The main purpose of these experiments is to standardize the operation of biomass hydropyrolysis unit at HPGRDC before proceeding for evaluation of advanced catalysts. The major operating conditions and product yields obtained in the single stage hydropyrolysis reactions are summarized in Table 3.

Table 3: Hydropyrolysis conditions and product yields

Feedstock	Sawdust	
Feedstock size	300-700 micron	
Feeding rate	40 g/hr	
Reactor type	Bubbling fluidized bed	
Catalyst	ZSM-5(100-200 micron)	
Fluidizing Gas	N2 + H2 (1:3 vol/vol)	
Pyrolysis Temp.	550 °C	
Pyrolysis Pressure	10	20
Product yields		
Total Liquid	31 wt%	26 wt%
Organic/Aqueous	13/18 wt%	11/15 wt%
Biochar	22 wt%	19 wt%
Gases	45 wt%	52 wt%
Oxygen content of bio-oil	25 wt%	22 wt%

Currently, experiments are being conducted to optimize the operating conditions for increasing the liquid yield by minimizing the slippage of condensable vapors in the gaseous product.

Way Forward
HPGRDC is striving to develop efficient catalytic systems and to optimize the process conditions for conversion of biomass to drop-in fuels to make the whole process economically viable.
Once the process is successfully demonstrated at lab scale, a continuous pilot plant of 5 kg/hr biomass processing capacity is planned to be setup for generating data for the design and development of tonnage level demonstration units.

Conclusion

HPGRDC has setup a state of the art facility for carrying out research in the field of biomass valorization to fuels. Various routes are being explored for technology development and scale-up to commercial scale for reducing country's dependence on fossil fuels and to find an economically feasible solution to the problem of air pollution caused by open field burning of agricultural residue. The research at HPGRDC is currently at lab scale where different catalytic systems are being developed in-house and evaluated under different operating conditions to find the most suitable and efficient catalyst systems. After shortlisting of most promising catalysts and operating conditions, the process will be scaled up to kg level pilot and further to tonnage level demo units.

HPCL is delighted to join the Task 34 of IEA's Bioenergy program as a representative of India and looking forward to working together with other member countries for development of direct thermochemical routes for valorization of biomass.

Acknowledgement

The authors acknowledge the support provided by Hindustan Petroleum Corporation Limited for carrying out the research work described in this article.

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The Netherlands: Development of the Bioliquids Refinery

Bert van de Beld
BTG Biomass Technology Group bv The Netherlands

The activities of the Netherlands in the field of DTL mainly concerns fast pyrolysis. All developments can be illustrated along the development of the so-called bioliquids refinery, see Figure 1. Such refinery is based on (the regional) conversion of a variety of biomass & residues into fast pyrolysis oil (FPBO) and subsequent use of the liquid as product or raw material in different sectors of the bioeconomy.
In this article a brief overview of the NL-activities in the current triennium (2019-2021) on different parts of this biorefinery will be given.

Fast pyrolysis process
The industrial-scale demonstration plant named Empyro was implemented by BTG Bioliquids in 2014/15 and at the beginning of this triennium sold to Twence, a regional company active in the field of waste collection & conversion, renewable energy and sustainable raw materials. In 2020, a new biomass collection & pretreatment system was added to the plant to enable the use of other regional biomass feedstocks next to the pellet crumbles.

Fast pyrolysis plants based on the same technology and design have been implemented and successfully commissioned in Finland (GFN, 2020) and Sweden (Pyrocell, 2021). To date, more than 30,000 operating hours have been achieved and the FPBO production exceeds 70 million liters.

Heat & Power
Nearly all the FPBO produced at Empyro is used to replace natural gas as a fuel in the industrial process steam boiler of FrieslandCampina. A case study concerning the design, performance and experience of this application, is presented in the Intertask project on industrial heat [1]. The use of FPBO in small scale boilers was investigated in the European project Residue2Heat. OPRA Turbines -in cooperation with the University of Twente- further developed the use of FPBO as a fuel in their OP16 gas turbine. The modification of a standard ignition-compression engine is the core of SmartCHP™. The University of Eindhoven (TU/e) evaluates in detail the combustion behavior of FPBO in engines, whereas BTG and ABATO-Motoren have modified an engine to run on FPBO.

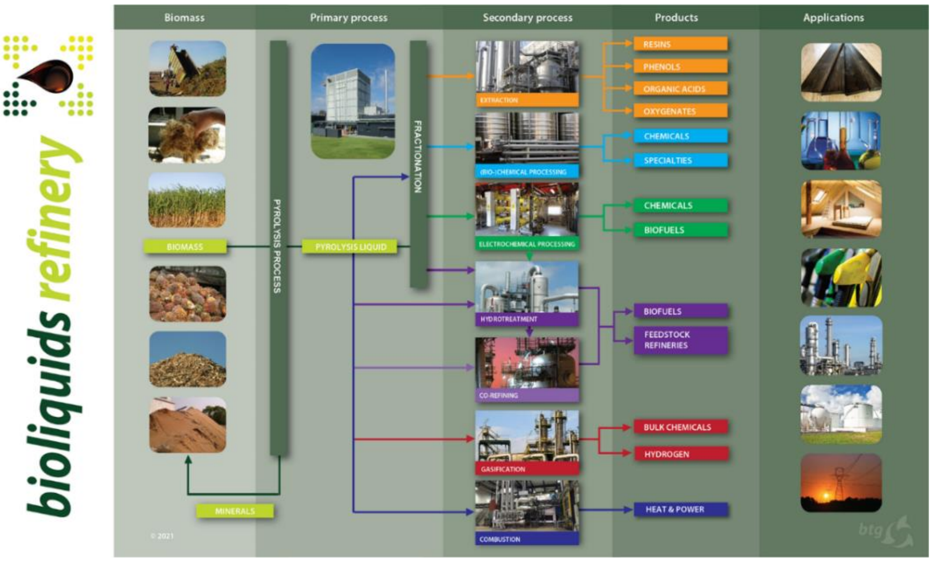

Fig. 1: The FPBO-based Bioliquids Refinery

Recently, an important milestone was reached by demonstrating smooth running of the modified engine for over 500h on FPBO.

Gasification

FPBO is easy to pressurize and low in minerals and therefore considered to be an interesting feedstock for (catalytic) gasification to produce syngas and/or hydrogen. In the H2020 Becool project, TNO successfully used FPBO in an indirect fluidized bed gasifier, whereas BTG applied an oxygen blown, catalytic gasifier. The Technical University of Delft evaluates different process concepts to produce fuels/chemicals via FPBO gasification. An interesting hybrid approach is to combine an oxygen-blown gasifier with an electrolyzer. Roughly for each H2 molecule generated by the electrolyzer another 2 will be produced by the gasifier system.

Biofuels

A short-term approach to produce biofuels is by co-feeding FPBO to existing FCC units. The proper allocation of biogenic carbon is challenging and NEN (Dutch standardization institute) is leading a European standardization activity on this aspect. Groningen University and Utrecht University are collaborating in this field, and a.o. it resulted in the design and construction of a research facility to investigate the co-fcc approach in detail. The focus of BTG is on a multi-step hydrotreating process starting with the so-called Picula™ catalyst for the initial stabilization step. The product SPO (stabilized pyrolysis oil) can be co-fed to an existing FCC unit at a higher replacement ratio than pure FPBO. Alternatively, stand-alone hydrotreatment of SPO to a drop-in biofuel is an option. The Dutch project Renewell is a cooperation between TU/e, Goodfuels and BTG aiming at the production of drop-in marine biofuels. BTG is producing the fuels, TU/e is investigating the combustion properties of the biofuel and Goodfuels provides the fuel specification and market insights. Meanwhile, BTG has established sister company BTG-neXt for the implementation and commercialization of the FPBO upgrading process based on Picula™.

An alternative DTL-concept called ABC-Salt is proposed by Groningen University. It concerns a concept to produce middle distillates via catalytic conversion of biomass (or lignin) in molten salts (“ABC-salt”). *Electrochemistry*

Electrochemical processing of FPBO can offer new and unique pathways to sustainable fuels and chemicals. Electrochemical processing of FPBO is also considered as an approach to store (excess) renewable electricity as chemical energy in a liquid. Fundamental aspects are being investigated by the University of Twente and BTG, and both are also participating in the European project EBIO on producing biofuels via electrocatalytic conversion of FPBO or fractions thereof. A dedicated IEA-task-34 report on the potential of electrochemistry is being prepared by the task members and will be available soon.

Fig. 2: Stabilized and hydrotreated FPBO's

Fig. 3: Biobased paint containing pyrolytic lignin

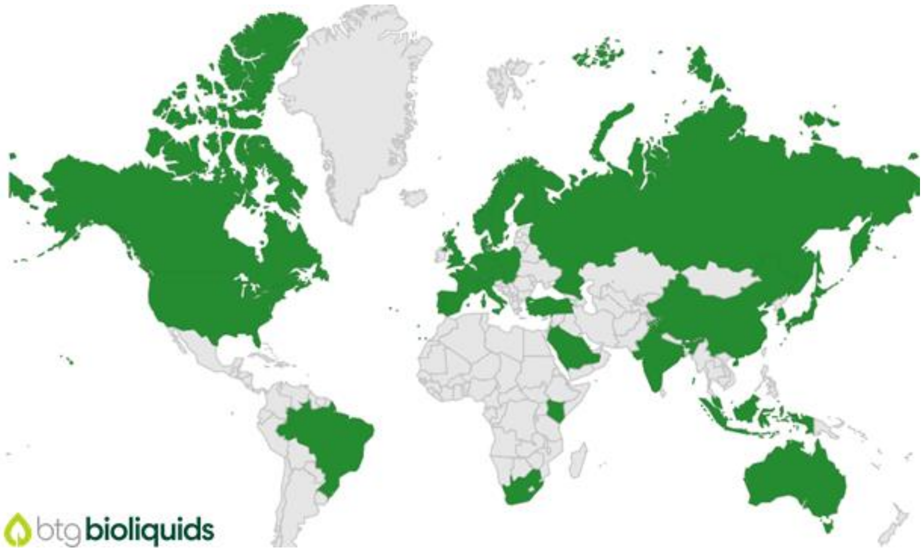

Fig. 3: Worldwide growing interest in FPBO. Sales of FPBO via webshop for Research, Development, and Demonstration activities.

Fractionation & biobased products
FPBO contains many different molecules with different chemical functionalities (aldehydes, ketones, carbohydrates, lignin fragments etc). BTG developed a fractionation process based on liquid-liquid extraction yielding separate FPBO fractions of lignin, sugars, and extractives, and each of the fractions can be used as raw material in biobased products. An example is the use of pyrolytic lignin in biobased paints, see Figure 3. Within the H2020 project Bio4Products BTG has implemented a 3 t/d fractionation pilot plant. REACH registrations of the pyrolytic lignin and pyrolytic sugars have been filed allowing large scale demonstration on the use of these fractions by industrial end-users. For example, Dutch wood company Foreco demonstrated the use of the FPBO derived sugar fraction in wood modification. Here, a very nice example of circularity is obtained by using end-of-life treated wood as feedstock again for fast pyrolysis.

FPBO for RTD
BTG Bioliquids -in close cooperation with TechnipEnergies- is a technology supplier for fast pyrolysis, and therefore they also have a clear interest in different end applications of FPBO. To avoid that each researcher/developer must produce its own FPBO prior to starting the actual research it was decided to set-up a webshop enabling them just to order good quality FPBO and focus on the core of their research. So far, almost 100 unique clients from 36 different countries covering all continents ordered FPBO via the webshop in quantities ranging from a few kg up to tens of tons.
For many of the activities mentioned above short videos or webinars are available via PyroMovie [2].

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An Emerging Pathway to Producing Biofuels in New Zealand

Kirk M. Torr and Paul J. Bennett
Scion, New Zealand

Overview

New Zealand consumes around 8.6 billion litres of liquid fuels per year (including fuels for international aviation and marine), almost all imported fossil fuels. Combustion of liquid fossil fuels is responsible for approximately 20% of New Zealand's domestic greenhouse gas (GHG) emissions and 43% of total domestic CO_2 emissions. Replacing fossil fuels with biofuels would have a big impact on New Zealand's GHG emissions. To date there has been little progress on using biofuels in New Zealand, with biofuels making up less than 0.1% of the liquid fuels. However, this situation may be set to change with the New Zealand government becoming increasingly interested in biofuels.

New Zealand production of biofuels would bring additional benefits including increasing energy security, enhancing regional development, and protecting access to international markets for goods and services.

New Zealand Government Policy Signals

The Climate Change Response Amendment Act 2019 set out new domestic GHG emissions reduction targets for New Zealand including reaching net zero GHG emissions (except biogenic methane) by 2050 and reducing biogenic methane emissions by 24-47% below 2017 levels by 2050. A new, independent Climate Change Commission will be established to help keep successive governments on track to meet these target goals. In 2021, the New Zealand government published three consultation documents:

- Phasing out fossil fuels for process heat.
- Transport emissions: Pathways to Net Zero by 2050.
- Increasing the use of biofuels in transport: consultation paper on the Sustainable Biofuels Mandate.

The transport emissions document sets out potential pathways and policies to phase out transportation emissions with the goal of net zero GHG emissions by 2050. The document proposes a whole-of-system approach towards transport system decarbonisation. The Sustainable Biofuels Mandate consultation paper proposes a mandate on fuel suppliers to reduce the emissions of liquid fossils fuels they supply to New Zealand by a set percentage each year.

Fig. 1: Scion's lab-scale fluidised bed fast pyrolysis plant used for producing bio-oils from woody biomass.

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New Zealand Production of Biofuels

New Zealand currently has no significant production of biofuels. Z Energy built a $35 million biodiesel production plant in Auckland that started production in 2018. However, Z Energy hibernated this plant in 2020 because the price of diesel dropped by 20% and the price of the tallow feedstock increased by 40%. Z Energy may restart production at this plant if the economic and regulatory environment for New Zealand production of biofuels improves.

The New Zealand government is investigating the potential for producing biocrude and advanced liquid biofuels in New Zealand from woody biomass, as part of the Forestry and Wood Processing Transformation Plan. Scion, a New Zealand Crown Research Institute, completed a Biofuels Roadmap for New Zealand in 2018 with the following key findings:

- Large-scale biofuel production and use within New Zealand is achievable.
- Biofuels can be a large, longer-term answer to reducing New Zealand's GHG emissions, particularly for difficult-to-decarbonise sectors such as aviation, shipping and long-haul road freight.
- Drop-in biofuels from non-food feedstocks, particularly forestry grown on non-arable land, is the most attractive longer-term opportunity.
- Fast pyrolysis followed by upgrading appears to be particularly attractive for producing drop-in petrol, diesel, and marine fuels; but multiple options targeting all fuel types are being developed.
- Government policy support will be needed to kick-start large-scale biofuel production because market forces alone will not be sufficient.

Technical and summary reports are available at Scion's website: www.scionresearch.com/nzbiofuelsroadmap

Biofuels Research at Scion
Scion has a bioenergy research programme primarily funded by the New Zealand Strategic Science Investment Fund. Liquid biofuels research within this programme supports: i) adopting and adapting the best international technologies for producing aviation biofuels and ii) technology development for producing marine biofuels from woody biomass.

Aviation Biofuels: Air New Zealand, Z Energy, Lanzatech and Scion are all part of the New Zealand Sustainable Aviation Fuel (SAF) Consortium. The consortium's current goals are to accelerate the implementation of commercial SAF in New Zealand through:

- supporting feasibility studies with technology providers for New Zealand production, and
- instigating a public-private partnership to ensure the development of policies, infrastructure, production etc. for low emission aviation in New Zealand.

Marine Biofuels
Drs. Torr and Bennett, and their team at Scion, are investigating the development of novel zeolite catalysts, biomass pretreatment and an ex-situ catalytic fast pyrolysis process (Figure 1) to produce upgraded bio-oils that could replace heavy fuel oils used in marine engines. Scion in collaboration with the University of Canterbury (New Zealand), Luleå University of Technology (Sweden) and RISE (Research Institutes of Sweden) are seeking funding from the New Zealand Endeavour Fund to develop the technology.

The programme entitled 'From Forest to Low GHG marine Biofuels' is supported by seven major companies from the energy, marine, export and infrastructure sectors. The programme is closely aligned with the New Zealand government's objectives to reduce the carbon footprint of New Zealand exports, to enhance regional development and to meet New Zealand's international climate change commitments.

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scion
FORESTS ▪ PRODUCTS ▪ INNOVATION

Country report Sweden 2019 – 2021

Linda Sandström
Rise Energy

Many initiatives related to biomass liquefaction have taken place in Sweden during the last triennium, mainly with forest-based feedstock. Some examples are given below.

Commercial and demonstration scale

A major event in Sweden in the recent years is that a commercial pyrolysis plant has been constructed and commissioned. The pyrolysis plant, situated at the Setra Kastet saw mill in Gävle, is operated by Pyrocell, which is a joint venture between the refinery company Preem and the wood industry company Setra. The plant was constructed with support from the Swedish Environmental Protection Agency. The facility is designed to produce about 25 000 ton of biobased pyrolysis oil per year and the target is that all this pyrolysis oil will be upgraded to renewable fuel at Preem's refinery in Lysekil, Sweden. Production started in September 2021

The pyrolysis oil from the Pyrocell plant is to be upgraded to transportation fuel at the fluidised catalytic cracker (FCC) at Preem and the first short-term test of feeding pyrolysis oil to the FCC has recently been performed. The test was performed in a demonstration project supported by the Swedish Energy Agency. In this test a few hundred tons of pyrolysis oil was treated as a mixture of 2 percent pyrolysis oil and 98 percent fossil feedstock. The next step in this venture is to perform a long-term test where 50 000 ton of pyrolysis oil will be processed during two years. This corresponds to two years of pyrolysis oil production from the Pyrocell pyrolysis plant and will result in approximately 25 000 ton of renewable products, mainly gasoline.

Another important event is that Cortus Energy's first commercial plant (6 MW) was completed in late 2019. The company's technology, Woodroll®, is based on pyrolysis of biomass followed by gasification of the char. The pyrolysis gases and vapours are combusted to provide heat for the gasification as well as for the drying of the biomass. Commissioning of the integrated process is ongoing, with hopes to reach the next

Fig. 1: Picture of the Pyrocell pyrolysis plant.

milestone of 7 days (168 h) uninterrupted, integrated run in the very near future.

Envigas is a company working with pyrolysis of forest residue. The company’s first development facility was commissioned in January 2019. During spring 2021, the company commissioned its large-scale production facility, which will initially produce approximately 5 000 tons of biochar and 2 000 tons of bio-oil annually. Production of biochar for the metallurgical industry is Envigas’ primary focus area, but other uses of the biochar are also investigated, as well as refining of the bio-oil into transportation fuel.

The forest industry company SCA was in 2020 granted an environmental permit to construct a biorefinery in Östrand. In 2021 a joint venture with refinery company St1 was announced. As part of the agreement, St1 also became 50% owners of the SCA Östrand Biorefinery. The biorefinery environmental permits are applicable for the production of 300 000 tonnes of liquid biofuels annually, based on black liquor (a by-product from kraft pulp production) and solid biomass such as sawdust or bark. The biorefinery in Östrand is a development project where a number of technological challenges remain to be solved before a project design can be finalized.

Other

Bioshare, founded in 2017, has a vision to transform large scale combustion plants to biorefineries, by converting fluidised bed boilers to perform co-pyrolysis or co-gasification in order to produce renewable products in addition to heat and power.
Sun Carbon and RenFuel are both active in the area of converting lignin from black liquor to valuable chemical, materials and fuels.

Research

Some of the larger research efforts in the liquefaction area is the pyrolysis research that is performed at KTH Royal Institute of Technology, as well as at RISE and the research on hydrothermal liquefaction that is performed at RISE.

Linda Sandström
Rise Energy

US workshop reports on the path to sustainable aviation fuel from HTL

Justin Billing, Circlia Nordic, Michael Thorson, Karthikeyan Ramasamy,
Pacific Northwest National Laboratory

Pacific Northwest National Laboratory (PNNL) hosted a virtual workshop with over 250 national and international experts in HTL and sustainable aviation fuel (SAF) to accelerate the commercialization of hydrothermal liquefaction (HTL) technology to produce SAF, by identifying and discussing the current state of this process and identify short and long-term research opportunities.

The workshop helped solidify four critical areas that must be addressed to deploy HTL quickly to produce SAF, including (a) Feedstock Availability and Formatting, (b) Hydrothermal Liquefaction Process Development, (c) Upgrading and Refining of HTL Biocrude, and (d) Extracting Value along the Supply Chains as shown in Figure 1.

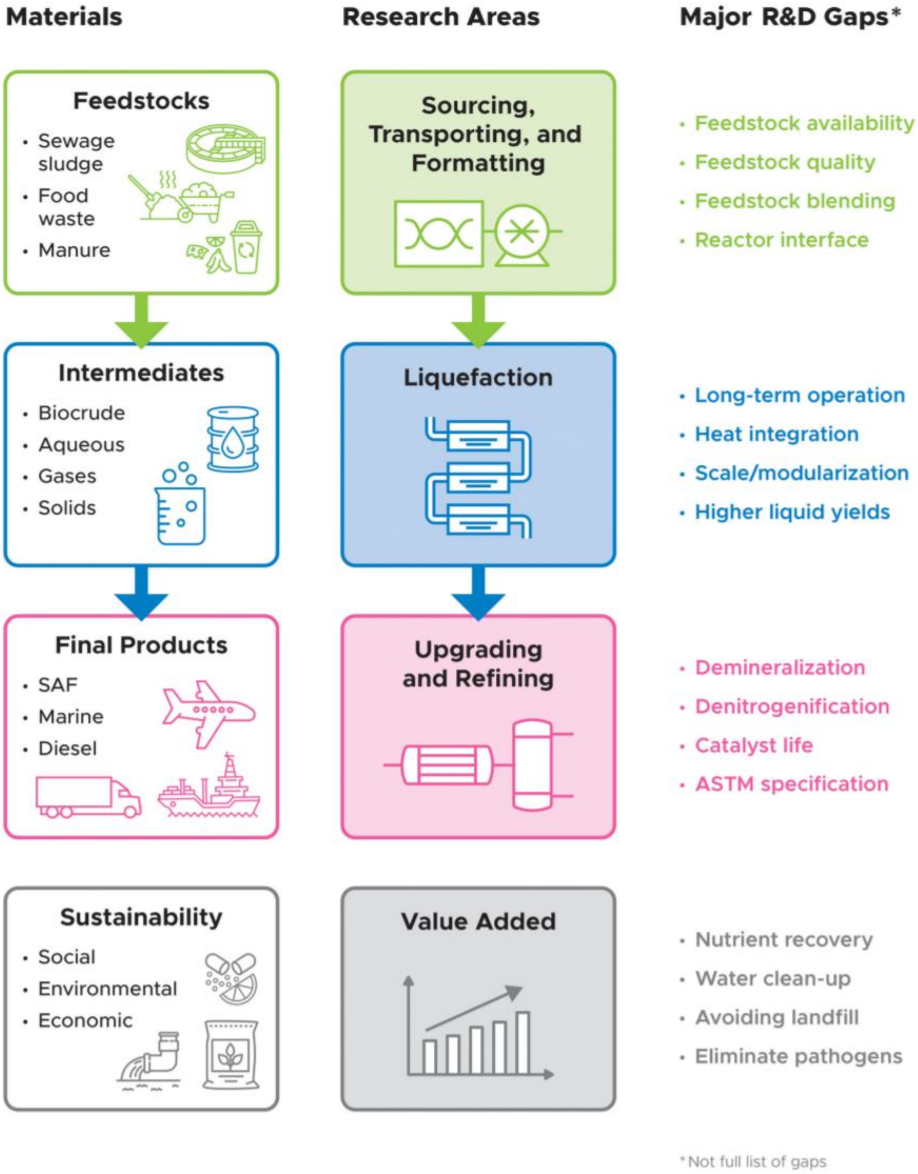

Fig. 1. Four critical areas of development needed to accelerate the commercial deployment of HTL for SAF.

Product Quality: SAF has tight fuel specifications and requirements. Depending on the feedstock, HTL produces the four hydrocarbon families allowed in jet fuel (n-, iso-, and cycloalkanes, and aromatics). However, the fuel also contains small or trace quantities of nitrogen-containing heterocyclic compounds, which will require much increased heteroatom removal. Research is needed to address quality requirements including:

- Heteroatom removal: It is expected that the nitrogen level in the SAF from HTL will likely need to be less than 10 ppm.
- Prescreening for SAF in Tiers α and β testing: Early-stage prescreening of the fuel from HTL for SAF will reduce the time and resources required to develop HTL-derived biocrude upgrading strategies to meet the ASTM qualifications.

Feedstock Sources and Formatting: HTL is amenable for a variety of individual feedstocks. These include algae, organic wastes (municipal sludge, food waste, fats/oils/greases, manure), and forestry residues. HTL provide an opportunity to cost effectively dispose of wet wastes such as sewage sludge. A key value proposition for HTL is its ability to reduce waste volumes at levels far beyond anaerobic digestion (90% vs. ~50%). The following feedstock quality attributes have critical implications on downstream processing: (a) inorganic content, (b) nitrogen content, (c) biochemical speciation, (d) aromatic content, and (e) solids content. The following areas were identified as critical opportunities:

- Specifying the feedstock homogenization process requirements at-scale, including the specifications for the pumps feeding the sludge to the HTL reactor.
- Understanding the potential for food waste and manure aggregation and blending for HTL. Food waste (if aggregated economically) and manure (if cleaned cost-effectively) both make ideal feedstocks for HTL blending.
- HTL conversion costs are significantly affected by plant size. Increasing total available feedstocks by including additional wastes such as plastics, municipal solid waste, food waste, manure, and plant or wood wastes has the potential to enable significantly increased regional wet waste blending and plant sizes.

Hydrothermal Liquefaction Process: While the HTL technology is quite extensively studied at the bench-scale, the needs primarily focus on scale-up and cost-effective modularization.

- Pilot-scale demonstrations: Engineering scale to pilot scale HTL facilities have been operated, and/or planned by workshop participants. Additional facilities at even greater scale are in development. Both commissioning plants at sizes relevant to commercialization and achieving months of continuous operation are critical to decreasing commercial risks across the board.
- Plant scale and modularization: Wet waste feedstocks are geographically distributed and will require transportation to a large central HTL facility or modularization of the HTL reactor for deployment at individual feedstock sources.
- Heat integration: Moving to a larger scale will allow design and testing of improved product feed heat exchangers. Process modeling has shown that heat exchangers represent up to 40% of the installed capital cost; thus, cost reduction through better design will have an outsized impact.

Upgrading HTL biocrude: To produce SAF via hydroprocessing HTL biocrude, the following is needed:

- Increase the hydrotreater catalyst activity to achieve an industrially relevant weight hourly space velocity and to reduce the nitrogen content of the upgraded fuel, with catalyst development focused on catalysts specifically for high nitrogen feedstocks.
- Reducing the guard-bed costs by developing low-cost guard-bed catalysts and possibly non-fixed guard-bed configurations.

- Extending the demonstrated catalyst upgrading experiments to understand catalyst deactivation and establishing commercially relevant catalyst lifetimes.
- Maximizing the value of the heavy fraction through either cracking to increase the jet and diesel yield or producing lubricants.

Beyond the core HTL to liquify wet organics and upgrading the biocrude, the byproduct aqueous phase must be addressed commercially. Sending the HTL aqueous stream to a water resource recovery facility (WRRF) presents challenges by increasing the nitrogen load on the plant, adding toxic components to the feedstock, and potentially hindering the ultraviolet (UV) disinfection process of the treatment facility.
Any aqueous clean-up, upgrading, or purification strategy will need to (a) be low cost, (b) reduce the chemical oxygen demand and the nitrogen content of the aqueous stream, and (c) reduce the UV-Vis absorbance of the aqueous stream.

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What happened 10 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...:

New European standards for solid biofuels

A synopsis from Eija Alakangas of VTT (Technical Research Centre of Finland)

"This article describes the main principles of fuel specification and classes standards, and especially classification of pellets."

Introduction to standards, certification and fuel specification

In 2000, the European Commission gave a mandate to the European Committee for Standardization, CEN under committee TC335 to prepare standards for solid biofuels. In the first phase 27 pre-standards (technical specifications) were published during 2003–2006. These pre-standards have been updated to full European EN-standards during 2007–2011. In total 36 standards will be published.

The standards will be included in the following topics:

- terminology, EN 14588 fuel specification and classes, EN 14961 series
- quality assurance, EN 15234 series
- sampling and sample preparation, EN 14778 and EN 14780
- analysis physical, mechanical and chemical properties (21 different standards)

26 EN-standards have been published and the rest will be published during 2012. When EN-standards are published the conflicting national standards shall be withdrawn.

This article describes the main principles of fuel specification and classes standards (EN 14961-series), and especially classification of pellets. Because of CEN copyright reasons no tables of standards are provided.

The European Pellet Council, which is working under AEBIOM is launching the certification scheme (ENplus and EN) for wood pellets for non-industrial use (www.pelletcouncil.eu). Also German DINplus has updated their certification system to EN standards. Certification is third-party attestation (i.e. issue of a statement) that specified requirements related to wood pellets have been fulfilled. ENplus and DINplus certification systems are based on European standards EN 14961-2 and EN 15234-2 with some modifications.

EUBIONET III (www.eubionet.net) has carried out a survey of the product standard for industrial use. Results of this survey will be used for prISO standard: Graded pellets ISO 17225-2, which is under preparation.

Fuel specification and classes and quality assurance – multipart standard

The two most important standards being developed deal with classification and specification (EN 14961) and quality assurance for solid biofuels (EN 15234). Both these standards will be published as multipart standards.

Working Group 2 of CEN/TC 335 has developed the following pellet standards:

- EN 14961-1:2010 General requirements
- EN14961-2:2011 Wood pellets for non-industrial use
- EN 14961-3:2011 Wood briquettes for non-industrial use
- EN 14961-4:2011 Wood chips for non-industrial use
- EN 14961-5:2011 Firewood for non-industrial use
- FprEN14961-6 for non-woody pellets for non-

Continued on page 9

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You can access the full article by using the following link: https://task34.ieabioenergy.com/wp-content/uploads/sites/3/2016/10/PyNe-newsletter-Issue-30-December-2011-Final.pdf

Upcoming Events

24th January - 28th January 2022
Fuels of The Future 2022, online

https://www.fuels-of-the-future.com/en/programme/programme-overview

15th March - 16th March 2022
Biofuels International 2022, Brussels, Belgium

https://biofuels-news.com/conference/biofuels/biofuels_index_2022.php

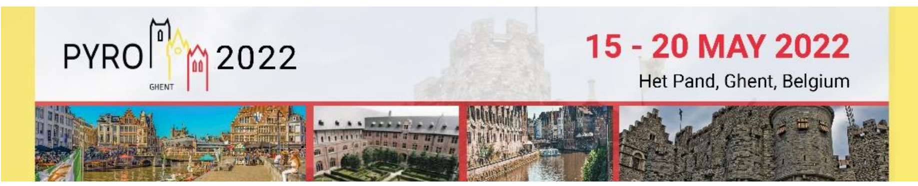
19th April – 21st April 2022
TC Biomass, Brown Palace Hotel and Spa, Denver, Colorado, United States

https://www.gti.energy/training-events/tcbiomass/

9th May - 12th May 2022
European Biomass Conference and Exhibition, EUBCE 2022, Online and Marseille, France

https://www.eubce.com/

15h May - 20th May 2022
Pyro 2022, Hed Pant, Ghent, Belgium



http://www.pyro2020.org/ehome/index.php?eventid=462106&

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IEA Bioenergy Task 34 Website

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Past Issues of the Task 34 Newsletters

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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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