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Task 34: Direct Thermochemical Liquefaction

For more info: PyNeEditor@gmail.com or task34.ieabioenergy.com/

Welcome to the New Triennium of Task 34

Alan, Axel, Bert, Magnus, Ferran, Fernando, Justin, Doug at the MHTLS Hydrothermal Liquefaction Demo Plant at PNNL in Richland, WA, USA

Welcome to 2019 and welcome to the new triennium of Task 34! In reading this, you are part of our experts' network for advancing liquid biofuels using technologies such as pyrolysis, hydrothermal liquefaction, and solvent liquefaction. The completion of 2018 brings us to the close of the 2016-2018 Triennium, and time to summarize the old Triennium.

These last three years have been healthy growing and expanding of our community, and it is time to look back and celebrate those accomplishments. We welcomed new colleagues, bid farewell to some. New members included New Zealand and Canada joining participation with Finland, Germany, the Netherlands, Sweden, and the USA. We missed the unique contributions of the UK and Norway, and look forward to the day they rejoin.

We welcomed a mix of new national team leads and a new Task leader. We missed the impact of some of the giants in our community as they moved on to new adventures, including Doug Elliott, Tony Bridgwater, Anja Oasmaa, Dietrich Meier, and others.

We gave the Task a new name and broadened our focus. Direct thermochemical liquefaction was no longer about pyrolysis alone, but international research advances have demonstrated hydrothermal liquefaction and solvent liquefaction as viable routes to liquid biofuels.

For the first time in 20 years, the Task found a new electronic home at http://task34.ieabioenergy.org as Aston University in the UK handed off their multi-decade leadership. This transition served as an opportunity to restructure the pyrolysis focused resources at the Task webpage and include considerations for HTL and SvTL.

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Inside this Issue:

The new Round Robin for this triennium on Analytical Methods also served as an opportunity to apply the community experience to the mixed challenge of applying analytical techniques to both bio-oil (from pyrolysis) and bio-crude (from HTL.) The findings will be published in 2019, but it was observed that there are specific needs for method development for both bio-crudes and bio-oils.

Meetings were held alongside workshops, conferences, and technical tours to showcase the advancing research in liquefaction. These included Sweden, New Zealand, Canada, the Netherlands, Germany, and the USA. From these interactions, the task disseminated research data and provided leadership towards advancing biomass derived Marine and Aviation fuels, analysis, upgrading, and others.

This triennium saw multiple successful pilots and commercial enterprises for both bio-oil and bio-crude applications. The big announcements and success stories include Ensyn, BtG, Fortum, Lycella, Genifuel, Steeper, and others. Many are reported in this triennium's PyNe publications, which also publicized efforts in research and bio-oil standardization in addition to the reports on successful pilots and commercialization of bio-oils and bio-crudes. While advancement in science is rewarding, seeing commercial applications with international impact on bio-fuels is even more rewarding. Application is one of the highest compliments that can be given to research.
As the Task embarks upon the new Triennium, you will find a new and renewed cadre of voices seeking to encourage research collaborations and advancement in bioenergy from liquefied biomass. This includes a new leader of the Task, new national team leads, and new member countries. As this was my final year in the Task, I will pass on the leadership of the Task to Dr. Axel Funke of Karlsruhe Institute of Technology, and pass on the US national team lead to Justin Billing. At the time of publication, the NTLs member countries had not yet been finalized, so check back frequently at http://task34.ieabioenergy.com/country-members/ for the latest list.

Thank you for allowing me to steward the Task through this triennium, it has been an honor and a privilege to count many of you as both colleagues and friends as we have done research together. As I leave the Task in search of new adventures, I would like to wish you each a happy new 2019, a good new triennium for Task 34, and may all of your research be interesting and impactful.

Sincerely,
Alan Zacher
Task 34 Lead and USA NTL, 2016-2018

Members of IEA Bioenergy Task 34: 2016-2018

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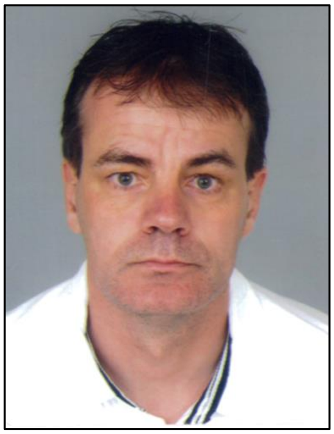
EC2Fuels: Electrocatalytic upgrading of pyrolysis liquid



R.H. Venderbosch
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Introduction: Pyrolysis liquids require substantial upgrading to allow use as transportation fuels. Overall yields of around 30 to 35 wt% from the liquids are shown, corresponding to around 40 to 45 wt% for the biomass-to-final product carbon yield. An essential step in the transformation of pyrolysis liquid is a prior liquid stabilisation step. The reasoning behind this is that pyrolysis liquids merely are syrups, in which the higher molecular weight, fairly apolar lignitic fragments are emulsified. The acids stabilise the emulsion and are essential in keeping it a single phase. Improving the quality of pyrolysis liquids by hydrogenation has been part of extensive research for the last 15 years at BTG. Extensive laboratory tests have been carried out to produce hydrocarbons through ‘conventional’ stabilized intermediates (‘SPO’ or stabilized pyrolysis oil). The developed ‘stabilisation step’ requires rather severe conditions (pressures up to 200 bar; temperatures up to 300°C), and catalysts. Alternative solutions are investigated, with the objectives to deploy modest operating conditions, to consume less and greener hydrogen and to improve the stabilization with respect to an improved selectivity. Challenges are (i) the removal of the smaller molecular weight acids, preferably yielding larger molecules, and (ii) hydrogenating the most unstable components in the pyrolysis liquids causing the charring (viz. mainly ketones and aldehydes). These two reactions can occur simultaneously in electrochemistry, while at the same time reduced carbon losses, higher biomass-to-products yields, and greener processing seem possible. Interestingly, excess electricity is produced in a pyrolysis unit that can be used for such intermediates for advanced biofuels (Figures 1 and 2).

Electrochemistry: Electrochemistry is the chemistry area that studies the relationship between electricity and chemical changes. Advantages of electrochemistry are clear: the reaction conditions can be very mild, and usually reactions can occur at ambient temperature and pressures, the operating principles rather simple and robust, and the process is environmentally friendly. The selectivity and rate of the reactions are enhanced by catalysts, but also by the applied potential. The principle of electrochemistry is straightforward: electrons are transferred between molecules and/or atoms by separated reduction-oxidation reactions. The reduction and oxidation reactions are connected by an external electric circuit, while membranes and electrolytes can be applied.

<u>Reduction:</u> Reduction refers to ‘the gain of electrons’. Phenolics and diaryl ethers are hydrogenated and carbonyl functionalities are reduced by electrocatalytic reactions, and some are partially hydro-deoxygenated. Typical examples as phenol, guaiacol and syringol are converted into cyclohexanol, acetophenone, and benzophenone, respectively. The latter can be transformed into phenylethanol and diphenylmethanol, which can be further reacted to ethylbenzene and diphenylmethane, respectively. Aldehydes and ketones like acetone and butanone are reduced to isopropyl alcohol / propane and butanol / butane

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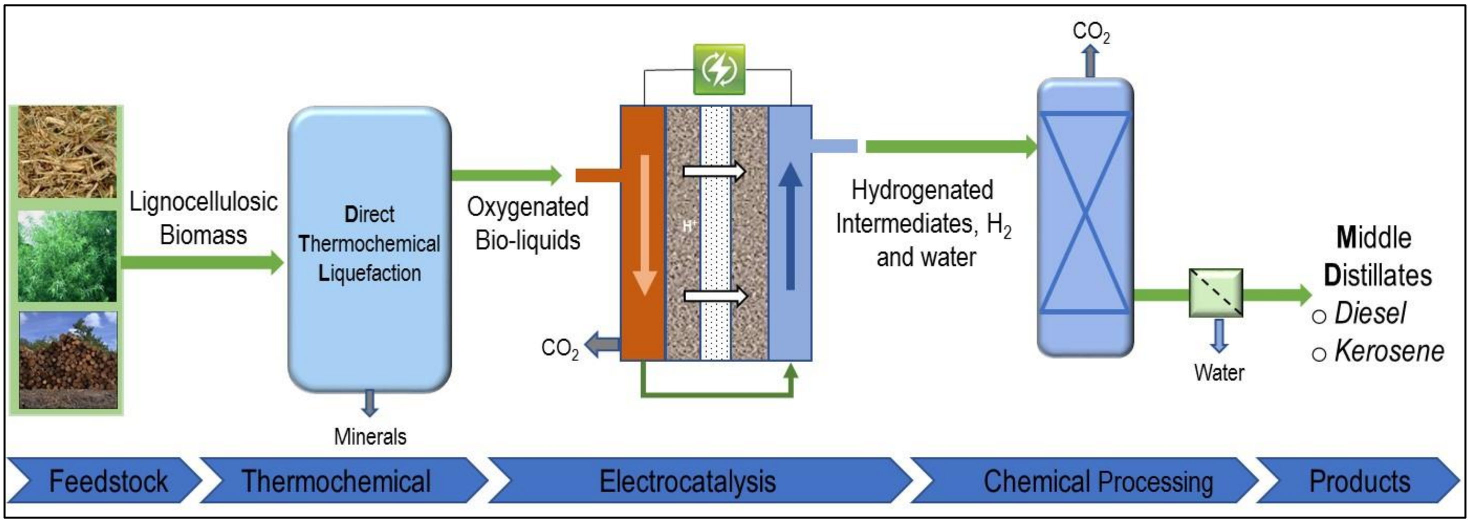

Figure 1: EC2Fuel: the concept from biomass to fuels

EC2Fuels: Electrocatalytic upgrading...continued

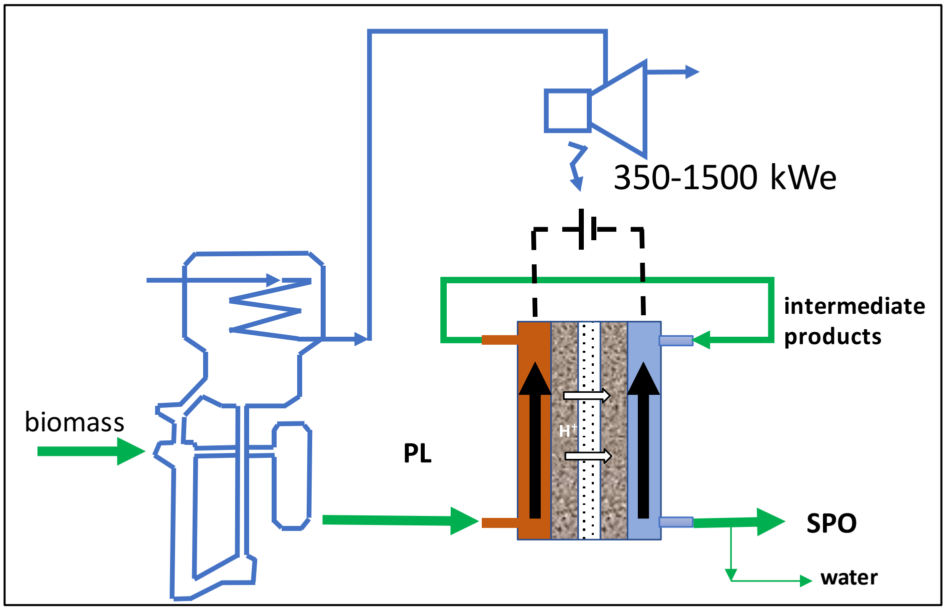

Figure 2: Excess electricity produced in a pyrolysis unit for intermediates for advanced biofuels. PL=pyrolysis liquids, SPO= stabilised pyrolysis oils. In blue the pyrolysis plant (here Empyro is taken as an example).

respectively. Furfural (as a typical sugar derivative) yields furfuryl alcohols and methylfuran. Interestingly, glucose can be converted to sorbitol or 2-deoxysorbitol. Finally, acids are reduced as well. For example, formic acid to carbon monoxide and water with methanol and methyl-formate as by-products, lactic acid to lactaldehyde and propylene glycol, and levulinic acid yields γ-valerolactone or valeric acid.

Oxidation delivers the electrons. For acids, reactions are initiated by decarboxylation of the acid, for acetic acid resulting in CO_2 and methyl-radicals. Depending on the conditions the radicals combine to ethane via Kölbe or are further oxidized to methyl-cations which react with hydroxyl-ions to methanol in the so-called Hofer-Moest reaction. The Kölbe reaction may be one of the oldest electrochemical reaction and relatively well understood for acetic acid. Oxidation of levulinic acid yields octanedione, hydroxybutanone or butenone. For alcohols, components as sorbitol can be deoxygenated to 2-deoxysorbitol. Oxidation of methanol, ethanol and iso-propanol yields formaldehyde and formate, acetaldehyde and acetate, and acetone respectively. Not much information is yet known on aldehydes. An interesting working example for this is the oxidation of hydroxymethylfurfural to furandicarboxylic acid. The information available on genuine biomass processing, either reduction or oxidation, is limited, but promising. Some data can already be found in the literature regarding reactions, reaction products, selectivity, and alike. Reference can be made to the work done in the group of Chris Saffron, Michigan State University (US), and Marc Koper, Leiden University (NL), see for examples [1,2].

Electrochemical synthesis on an industrial scale is limited to a narrow spectrum of chemical production processes, such as in the chlor-alkali industry, aluminium production and synthesis of specific chemicals (for example adiponitrile as an intermediate in nylon 6 synthesis on a scale of 300 kt/y). Several small and medium sized processes are applied in industry, especially for fine chemicals such as aromatic aldehydes or perfluorinated organic. Amongst others, due to the excess of decentralised renewable electricity generation expected in the next decade(s), new opportunities for electro-catalytic processes arise, for example for fuels. Electrochemistry obviously offers a high potential in upgrading pyrolysis liquids, and the concept of interest to BTG is referred to as EC2Fuel ('easy to fuel', see also Figure 1). The main mechanisms aimed at are oxidation of acids by the Kölbe reaction at the anode and hydrogenation of aldehydes at the cathode. Most of these reaction systems are carried out in divided or undivided cells, while using electrolyte solutions (acid/base).

Electrochemical transformation of pyrolysis liquids at BTG: Model compounds of pyrolysis liquids are being validated in our lab, and the results show a selective reduction or further oxidation. The approach proposed in EC2Fuel (Figure 3) is to apply a proton exchange membrane cell (PEM), taking advantage of both, reduction of the acid content on the anode side to generate protons and hydrogenate the aldehydes at the cathode. The work is carried out in cooperation with the University of Twente (Photocatalytic synthesis 'PCS headed by Guido Mul). This provides a synergy between electrochemistry and pyrolysis liquids, moreover as water separation may occur in the absence of the acids. The excess hydrogen generated through water splitting can be used in a further catalytic upgrading concept. In the concept presented here the feed enters at the anode side, where decarboxylation takes place (Kölbe), and the decarboxylated product is fed in the cathode compartment where reduction takes place. A typical example is the transformation of levulinic acid into n-octane.

All this information points at a successful electro-reduction /oxidation of biomass-derived feedstocks to

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EC2Fuels: Electrocatalytic upgrading...continued

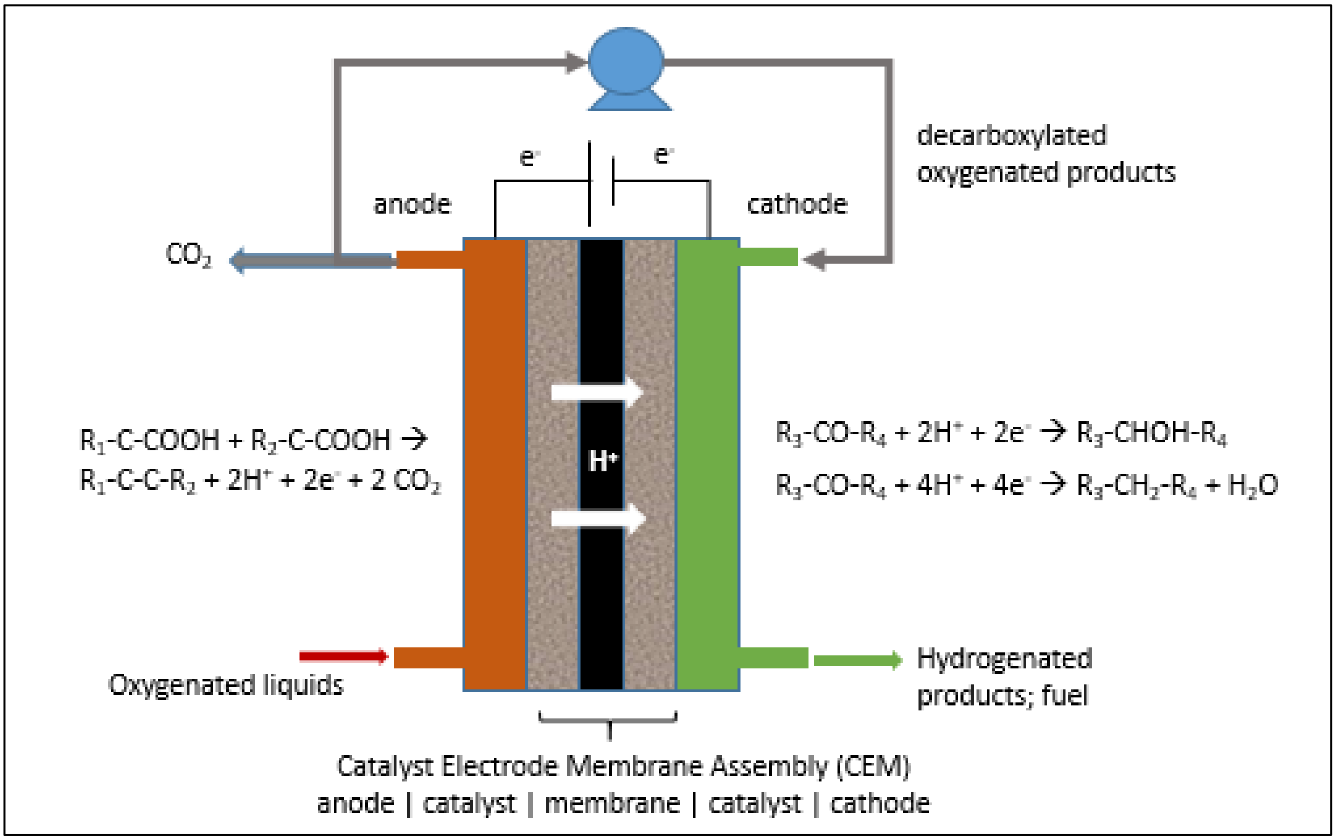

Figure 2: EC2Fuel: The electrocatalytic reactor for conversion of oxygenated oil to fuel. Feed enters at the anode side, where decarboxylation takes place (Kolbe). The decarboxylated product is fed in the cathode compartment where reduction takes place. Protons flow through the membrane from the anode layer to the cathode layer, to react with oxygenates).

‘electro-fuels’. It is evident that substantial improvement can be accomplished in the years to come. Specific electrochemical cells are required: currently, the project can take advantage of the large number of cells that are currently commercially available. A careful selection must be made for the specific conversion system aimed at in EC2Fuel. Advances are to be made in reactor design considering engineering aspect on pH, fouling (especially in combination with presence of contaminants in the bio-liquids), potential integration of product separation, design of relevant reactor parts (including the use of divided / undivided cells), integrated reduction /oxidation, alternating currents, the Catalyst, Electrodes and Membranes assembly (CEM), and scale up.

References

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Progress toward Commercialization of Hydrothermal Processing

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Figure 1: Engineering-Scale Hydrothermal Processing System at PNNL

Hydrothermal Processing (HTP), including both direct Hydrothermal Liquefaction (HTL) and wet gasification (sometimes called Catalytic Hydrothermal Gasification or CHG), have had a long history. Numerous review papers, published research, patent applications, and research programs testify to the interest in this field for many years. Yet widespread commercial application has been elusive.

A primary advantage of the process is that wet organic materials can be converted into oil, gas, or both without drying, and eventually used for finished fuels. With substantial (and still growing) interest in reducing the use of fossil fuels and associated atmospheric emissions, the concept of biogenic fuels is obviously attractive.

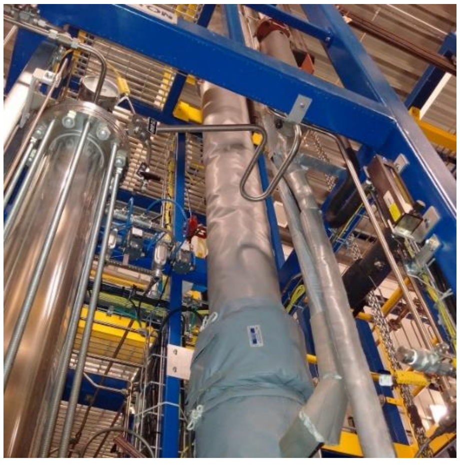

Figure 2: Upgrading System at PNNL

Yet, despite the history and interest, the process is still not in widespread commercial use. Why? The obvious answer is lack of economic viability, but this is a rather broad characterization. The critical issues involve process conditions, materials of construction, feedstock characteristics, separations, and final fuel production, among others.

This article is not intended to treat each of these issues in depth, but only to say that they have been difficult and typically require much practical experience in addition to scientific and engineering advances. Even now the ability to fully predict equipment design and relevant chemical processes is far from complete, so that extensive testing is still important. Despite these hurdles, HTP is moving toward commercialization, with a number of pilot systems progressing throughout the world and helping to move the technology from the laboratory to the field. Several of these projects are described below to illustrate some of the progress being achieved.

Genifuel's Pathway to Commercialization

The projects described are based primarily on work performed by the US Department of Energy (DOE), at the Pacific Northwest National Laboratory, one of the DOE's 17 National Labs. PNNL's work in this field dates back almost 40 years, but took an important step forward in 2008 when an alliance for commercialization was formed with Genifuel Corporation, a company formed in 2006 to produce biofuels from wet organic materials. Since that time the two partners have worked closely together on research and testing, including patents and various programs with total funding approaching $100 million. The partners have won several awards including an R&D 100 Award in 2015, and a Federal Laboratory Consortium Award for progress in commercialization.

Throughout this period PNNL was adding equipment to support both HTP and upgrading of the biocrude oil into finished fuels. A new bench-scale system was built, as well as a much larger engineering-scale system with a capacity of 400 L/d of oil output. Hydrotreating capability was developed to upgrade the biocrude,

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Commercialization of Hydrothermal Processing…continued

Table 1: Raw biocrude and upgraded oil qualities from wastewater sludge

	Unit	Upgraded Product	Biocrude
H:C Ratio	Mol ratio	2.03	1.6
O	Wt%	1.0%	6.2%
N	Wt%	<0.05%	4.7%
S	ppm	9	11,000
TAN	mgKOH/g	<0.01	59
Density	g/cm³	0.79	0.98
Viscosity	cSt @ 40°C	2.7	400

and distillation columns were added to fractionate the upgraded biocrude into finished fuels. Since the biocrude oil is dominated by diesel-range hydrocarbons, the first fuels produced were diesel blendstocks, which were characterized and tested in engines. These fuels passed all fuel standards and engine emission tests.

Pilot System Installed in Field

The next opportunity for significant advancement toward commercialization came from a DOE program called the National Alliance for Advanced Biofuels and Bioproducts (NAABB), with work beginning in 2010. This program eventually grew to a total budget of more than $60 million, and involved 39 research institutions—laboratories, universities, and private companies. The goal was to produce biofuels from algae and define a baseline of processes, equipment, and costs. One of the most important findings of the program was that hydrothermal liquefaction and catalytic hydrothermal gasification contributed more than any other factors to reduce the cost of the biofuel products.

Three of the parties in this program were PNNL, Genifuel, and Reliance Industries Ltd. (RIL). Reliance is a large private company in India, and operates both natural gas production facilities and their Jamnagar Refinery, which processes 1.2 million barrels of petroleum per day. RIL was interested in the possibility of producing a biogenic substitute for both oil and gas to address growing concerns about fossil fuel emissions.

Accordingly, the parties agreed to work toward a pilot-scale HTP system which would produce both oil and gas from algae, with an initial target of at least one barrel of oil per day. PNNL and Genifuel cooperated on the system design. Detailed engineering was provided by Merrick & Company, who also supervised fabrication near Denver in Colorado, USA. The system was commissioned and became operational in India in 2017. Initial experience showed some system plugging in the front-end heat exchangers, which were redesigned in 2018. The system is currently running in continuous operation processing algae grown by RIL.

Commercial Focus on Wastewater Treatment

In 2014 the Water Research Foundation (WRF), a non-profit organization which sponsors research in the water and wastewater industry, learned about hydrothermal processing and wondered if it could be used for resource recovery by processing wastewater solids. The management and disposal of wastewater solids is a major challenge for wastewater utilities, and can make up more than 50% of operating cost. In addition, regulations on the disposal of wastewater solids are steadily increasing. Beginning in 2015 WRF organized a study with the US Environmental Protection Agency (EPA), the DOE, PNNL, and Genifuel to study the potential application of HTP to wastewater solids. The study was quite successful, and an independent third-party report recommended that the next step

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Figure 3: Hydrothermal Processing System installed at RIL in India to process algae

Commercialization of Hydrothermal Processing...continued

Figure 4: Metro Vancouver's Annacis Island Treatment Plant

should be a pilot installation at a working utility.

One of the parties involved with the WRF-Genifuel study was Metro Vancouver, the entity which manages water and wastewater for the Canadian city of Vancouver, BC. Metro Vancouver supplied the sludge samples used throughout the WRF testing, and based on their observations agreed to become the host city for the pilot test. Engineering work is planned in early 2019. The system is to process the wastewater sludge from an equivalent of 30,000 persons, a small percentage of the 2.4 million population served by Metro. The system will be installed at Metro's Annacis Island facility, and will produce approximately 5 barrels of oil per day. A gasification section is a potential add-on after the HTL section is operational.

Another Wastewater Project Begins

As interest in wastewater sludge continued to grow, the DOE saw an opportunity for this feedstock to contribute strongly to its goal of expanding the production of biofuels. In early 2017 the DOE announced an award to WRF for a $2.4 million project to design a pilot system for wastewater solids in California, at a utility east of San Francisco called Central Contra Costa Sanitary District (Central San). This project, called HYPOWERS, will process wastewater solids from an equivalent population of 45,000 people (like Vancouver, a fraction of their total), and produce approximately 7 barrels of oil per day. The system will include a gasification section. The design of this system is now being completed. Pending successful evaluation of the design and business plan, DOE may provide additional funding to fabricate, install, and support the system, which will then be operated by the project team for three years to produce cost and operational data.

The Question Answered

A number of wastewater utilities around the world are following these developments because of the promise they hold for addressing the issue of solids management. The combination of HTP and wastewater processing is a fortunate match, because in addition to producing oil and gas with associated revenue, HTP eliminates the wastewater sludge completely, so that the cost otherwise incurred for treatment and disposal can be applied to the HTP system.

This combination of product revenue and avoided sludge management cost provides at least one answer for commercial application of HTP. Other feedstocks and pathways are likely to emerge in the future as HTP becomes fully commercial.

References

1. Photos in Figures 1 and 2 from Pacific Northwest National Laboratory, 902 Battelle Boulevard, Richland, WA 99352, USA

2. Photo in Figure 3 from Ramesh Bhujade, Reliance Industries Ltd., Reliance Corporate Park, Thane Belapur Road, Ghansoli, Navi Mumbai 400701, Maharashtra, India

3. Photo in Figure 4 from Paul Kadota, Metro Vancouver, 4730 Kingsway, Burnaby BC, V5H 0C6, Canada

4. Data in Table 1 from Dan Anderson and Andy Schmidt, Pacific Northwest National Laboratory, 902 Battelle Boulevard, Richland, WA 99352, USA

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Forestry and fishery residues – sustainable feedstocks for pyrolysis in rural and remote regions

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Figure 1 - Forestry residues and raw crab bodies

Introduction

The bioeconomy is a sustainable method of developing and growing a region while maintaining the health of the environment. Bioproducts such as fuels, chemicals and material from biomass is an area of rapid growth in the bioeonomy. However, rural and remote locations are often left out of this emerging economy even though most of the biomass feedstock is located in these regions. One of the largest source of biomass in Northern regions of Canada are "residues" from the forestry and fishery industries. Nevertheless, most processes and bioproducts are developed for larger demographics which may not be appropriate to the regional infrastructure/markets of small and medium sized regions or take into account the varied nature of the type and state of the biomass. In our work we focus on developing green processes to extract value added product from these residues to enhance the sustainability of the local/regional market so these regions can join the bioeconomy. We work in several areas from extraction of platform chemicals and development of biomaterials from shellfish and finfish by-product to thermal conversion of fishery and forestry residues. In this paper we will review some of our work in the fast pyrolysis of forestry and fishery.

Over 250 kt/y of residues (bark, sawdust, sludge) are generated by sawmill and forestry operations in NL (Jayasighne et al., 2011). Atlantic Canada accounts for approximately 76% of harvested commercial fish and 50% of aquaculture in Canada (DFO, 2017). Residues from fish processing plants are between 40-70% of weight of harvested fish depending on the product and processing techniques (AMEC, 2003). This represents a significant underutilized resource. Thermochemical conversion, via fast pyrolysis, offers flexibility in feedstock type and quality. In our work we study the products from pyrolysis of forestry and fishery and potential applications. Some initial results of comparing pyrolysis products of sawdust and waste crab bodies and future work are presented here.

Feedstock Properties

Crab bodies produced in the processing operations are particularly suited to pyrolysis as any residual meat left within the body is less likely to impact the quality of liquid or solid product produced. This reduces costs in cleaning the crab bodies which is required if the raw material is used as an adsorbent, biomaterial, or other applications. To determine the best possible fast pyrolysis conditions, the feedstock should be characterized with respect to proximate and elemental analyses. After the meat has been removed, the remaining crab body contains chitin (15-40wt%), proteins (5-40%), and calcite (20-40wt%) (Lage-Yusty et al., 2011; Dai et al., 2017). The range reflects the variation in species, cleaning, and processing methods. Lipids can vary from less that 1 wt% up to 15 wt% depending on meat processing and final product. TGA of the shells indicates chitin and protein decomposition between ~220-480 °C followed by decomposition of the $CaCO_3$ to CaO and CO_2 to 750 °C+. The TGA estimated compositions, chitin+protein at ~25wt% and calcium carbonate at ~27-40wt% correspond well to the measured values outlined above. Elemental analyses are limited for crab shells, Dai et al. (2017), analyzed crab shell from market for selected elements and found 27wt% Carbon, 3.6 wt% Hydrogen, 5.15 wt% Nitrogen, 15.15 wt% Calcium and trace magnesium (0.66 wt%). Figure 1 shows the feedstock crab material and forestry (sawdust and chips) residues.

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Forestry and Fishery Residues...continued

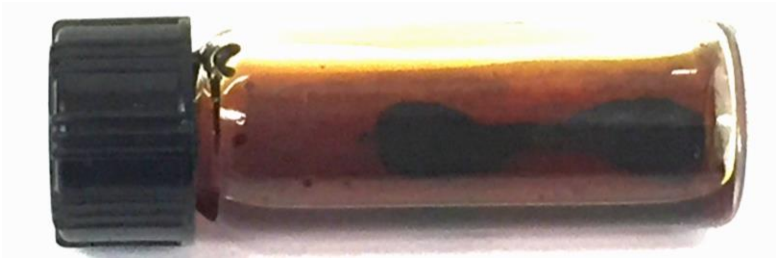

Figure 2 – Crab pyrolysis oil (at 500°C no temperature ramp). The second phase is seen in the centre of the bottle.

Pyrolysis Experiments

We initially did screening lab scale pyrolysis on snow crab bodies, co-pyrolysis of crab and sawdust and compared to sawdust pyrolysis (Balsam residues from a local sawmill). Of crab species, the harvested snow crab and invasive green crab are most common in Atlantic Canada. Our lab scale system is a semi batch tube reactor (Thermolyne 21100 tube furnace, USA), where a glass sample boat (3 cm ID and 70 cm length) is connected to a nitrogen supply to sweep produced gases (Figure 2). A full description of the system is outlined in Papari and Hawboldt (2015).

The nitrogen flow rate was varied from 50-300 mL/min (STP). The solids residence time was varied from “fast” conditions (vapour and solid residence times from seconds to a minute) to “slow” (10 min solid residence time) through temperature ramp. The vapour residence time was set by the nitrogen flowrate (several seconds). After some screening of temperatures, we investigated two temperatures initially (450 and 500 °C) with no temperature ramp (fast pyrolysis), 10 °C/min ramp (slow pyrolysis), and 50 °C/min (fast pyrolysis with ramp) for crab and softwood samples. For co-pyrolysis only results for 500 °C, 150 mL/min nitrogen flow, 5-minute solid residence time, and 10-30wt% crab bodies are presented here.

Pyrolysis oil results

The oil yields varied from 40 wt% for slow pyrolysis of crab bodies (450 °C and 10 °C/min ramp) to ~45 wt% fast pyrolysis at 450 °C and 50wt% at 500 °C . There was a corresponding increase in the water content of the oil from 50wt% at 450 °C to 55wt% at 500 °C for fast pyrolysis. The oil produced from crab bodies was two phase, whereas the sawdust pyrolysis oil is a single phase.

We plan to analyze both phases independent of each other. A preliminary GC-MS analysis a vigorously mixed crab oil, showed phenol and methylated phenols, organic nitrogen compounds such as indole and benzenepropanenitrile, and propanoic acid. Unlike pyrolysis oil from forestry residues the number of peaks was low reflecting the high water content. This oil analyses continues as there is potential for value added chemicals to be present in extractable amounts (economically attractive). When crab and forestry were co-pyrolyzed the oil yield was a function of the ratio of crab to sawdust, varying from 57wt% yield for 10wt% crab bodies (90 wt% sawdust) and 34wt% water in oil to 50wt% oil yield (39.5 wt% water content) for 30wt% crab body. As a reference we pyrolyzed pure sawdust and pure crab at 500 °C , 150 mL/min and 5 minute hold. At these conditions the oil yield was 60wt% with a water content of 30 wt% for sawdust and 39wt% oil with 44.5 wt% water.

The total acid number(TAN) is an indirect measurement of oxygenated organics and acids. Pure crab pyrolysis showed no measurable TAN due to basic nature of the shells. The pH of the oil was on average 9. In the co-pyrolysis experiments, the TAN increased due to the sawdust. Sawdust pyrolysis oil has a very high TAN depending on conditions. As the crab bodies were added the TAN decreased linearly from 83.7 mgKOH/g to 68 mgKOH/g (10wt% crab) to 38 mgKOH/g (30wt% crab body). Figure 3 summarizes the results of oil analyses.

Biochar results

The char yield was consistent regardless of temperature and ramp conditions at 55 wt% for the crab. Most crab pyrolysis studies have focused on char production with long residence times (hours) (e.g. Dai et al., 2017). In the Dai et al. (2017) study, the yield of char varied from 64% at 300°C to 38% at 900 °C and at 500 °C char yield was approximately 50wt% with an ash

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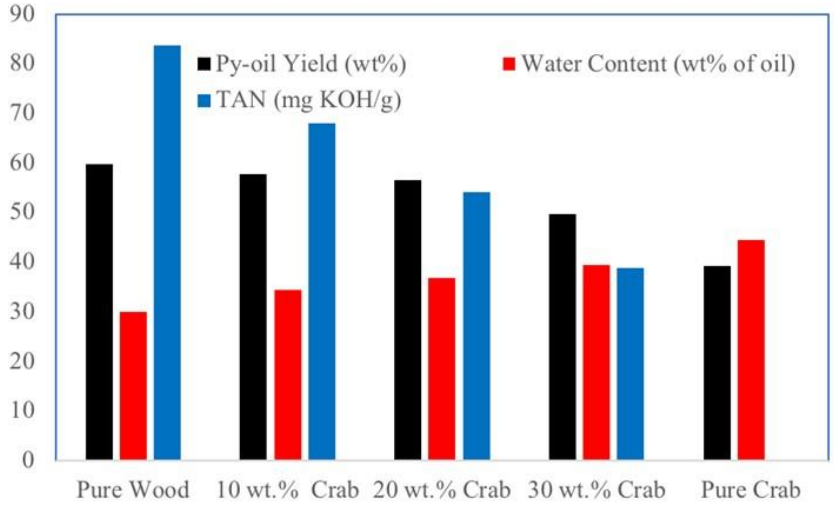

Figure 3 - Comparison of oil product from pyrolysis of different crab:forestry ratios.

Forestry and Fishery Residues...continued

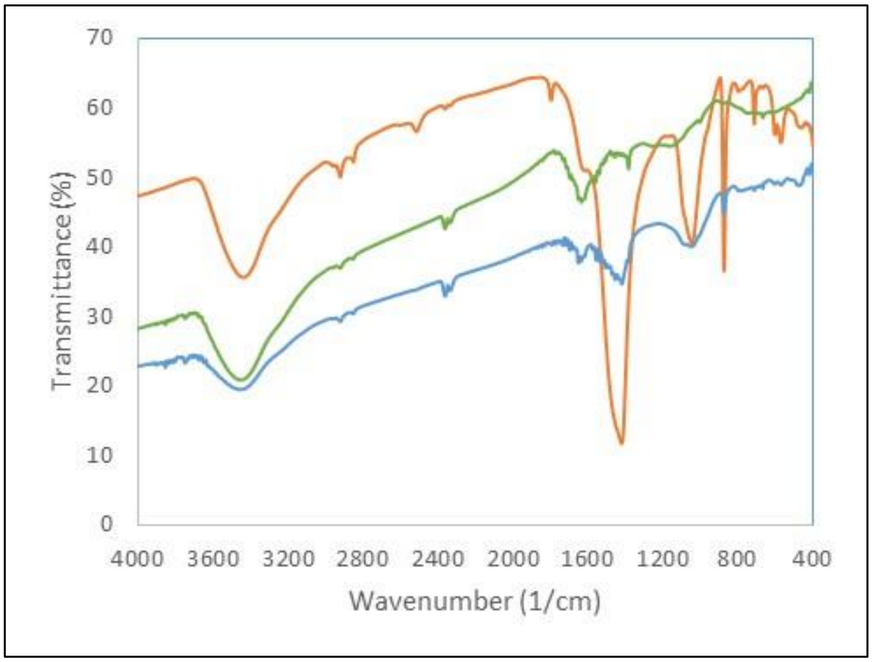

Figure 2 FTIR spectra for crab(orange), forestry and crab (30wt%) (blue), and forestry (green).

content of 55wt% and a pH of ~12. Our crab char was much lower in ash at 30wt%. In co-pyrolysis experiments the char yield varied from 16wt% (pure sawdust), 21.6 wt% for 10wt% crab, 29.9 wt% for 30wt% crab and 52.5 wt% for pure crab. Surface areas for chars were similar regardless of temperature and ramp at ~20 m^2/g. This was on the same order of magnitude as Dai et al. (2017) study which showed 15m^2/g at 500^{o}C, however the residence time for these samples was 2 hours, much longer than our maximum solids residence time of 10 minutes. Although this appears to be a low surface area, in our work with sawdust biochar we have seen that low surface areas can be outweighed by high surface functionality when it comes to using the biochar as an adsorbent (Bamdad et al, 2018). Figure 4 outlines surface functional groups detected using Fourier Transform Infrared (FTIR) analyses for crab, sawdust and carb(30 wt%)+sawdust biochar, all produced at 500^{o}C.

The most prominent peaks in the crab char spectra (red) are at 1420 cm^{-1}, 875 cm^{-1}, and 715 cm^{-1}. These bands are characteristic of $CaCO_3$. There is a small peak at 1580 cm^{-1} that is characteristic for calcium oxide. The sharp bands at 875cm^{-1} and 715 cm^{-1} are characteristic of the rocking and bending vibrations for CO_2^{2-} as well as CaO. These peaks are also present in the spectra for the crab and forestry char (blue) but at much lower intensity as concentrations of $CaCO_3$ and CaO are significantly less. C-O stretching is also evident in both crab char and forestry char at 1040 cm^{-1}. We plan to perform molecular modelling of the surfaces to determine adsorbent applications. We have used this approach in forestry biochar to screen the chars against target adsorbents and use as a soil amendment.

Summary

Feedstock of variable quality, such as fishery and forestry residue, are ideal feedstocks for pyrolysis. Initial oil and char yield and quality results of carb and the co-pyrolysis are promising although further characterization of the oil in terms of composition and other key and the char with respect to surface functionality is required. The basic pH and addition of CaO in the co-pyrolyzed char makes it a promising adsorbent for mining and other wastewater applications and as a possible addition to cement/asphalt. The crab pyrolysis "oil" is unexplored in the literature and we work to further elucidate its use as a source of valuable chemicals and/or bioenergy. As outlined above, crab and forestry residues are abundant across Atlantic and Northern Canada and currently represent an environmental, safety, and economic burden. Thermochemical conversion of these residues in the form of co-pyrolysis offers the potential to develop a bioproduct that benefits the region as a whole.

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Identifying correlations between catalysts' activity and deactivation characteristics for bio-oil upgrading

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KTH Royal Institute of Technology

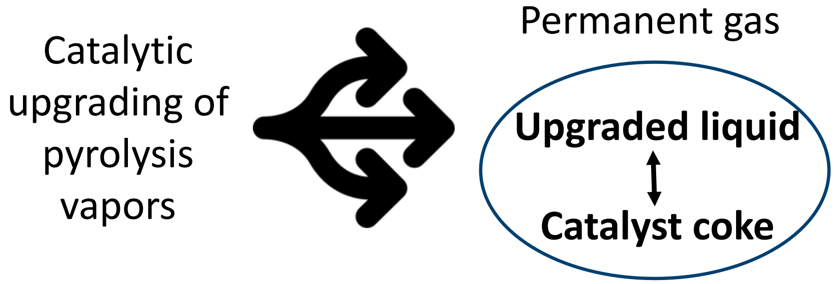

Figure 1: Illustration of catalytic upgrading of pyrolysis vapors, its products and the focus of study.

Pyrolysis research in Sweden is facing a rapidly increasing interest from the industry for producing a green substitute to fossil crude oil. Sweden's paper and pulp industry foresees an economic opportunity in converting forestry residues into renewable feedstocks for the petrochemical industry. At the same time, Swedish petrochemical industry is rapidly investing in pioneering pathways to cut their consumption of fossil resources, for example by using available polymeric and organic renewable or recyclable feedstocks in existing refineries. One main reason for the movements from the two different industrial sectors is the national goals of transportation and carbon emissions stated by the Swedish government – to reach a 100 % fossil-free transport sector until year 2045.

Catalytic upgrading of bio-oil over zeolites is a promising approach to increase the feasibility to utilize pyrolysis oil as a drop-in fuel in existing oil refineries. Also, doping zeolites with metals can further promote the production of certain compounds. Catalytic upgrading of biomass-derived pyrolysis vapors enhances the bio-oil's similarities to fossil resources, for example by making it miscible with fossil crudes, reducing its oxygen content and acidity, as well as increasing its concentration of aromatic hydrocarbons which are vital in the petrochemical industry. Zeolites are well-established in industrial refining applications to catalyze cracking and deoxygenating reactions of fossil-based crude oils. Therefore, the physical and chemical properties of the catalytic materials for upgrading such feedstocks are well-known, for example their activity and deactivation characteristics. One example of deactivation is coke deposition formed on the catalyst surface that arises when catalytically upgrading crudes. Coke is a carbonaceous material that is formed during the heterogeneous reactions and covers the active surface area by for example pore blockage. However, based on a catalyst's characteristics such as selectivity, pore size and chemical properties its efficiency to for example deoxygenate a certain feed is dependent of the feed composition. Compared to fossil resources, raw bio-oil has a high oxygen content which is distributed in a wide range of oxygenated hydrocarbons and water, which contributes to aging and its acidic nature. Therefore, the difference in composition between bio-oil and fossil crudes results in other deactivation characteristics when treated in catalytic processes over similar materials. An important step in optimizing catalytic pyrolysis of biomass is to understand the correlation between a catalyst's activity as well as its deactivation characteristics. However, little is known about the deactivation of zeolites when upgrading bio-oil. Therefore, recent works at KTH Royal Institute of Technology in Stockholm, Sweden have investigated this for several zeolite-based catalysts. The materials were prepared and screened for upgrading biomass vapors followed by studying the correlation between bio-oil and coke composition, illustrated in Figure 1.

In recent studies we investigated the characteristics of upgrading pyrolysis vapors from softwood biomass over HZSM-5 with and without metal-doping. The main results and trends

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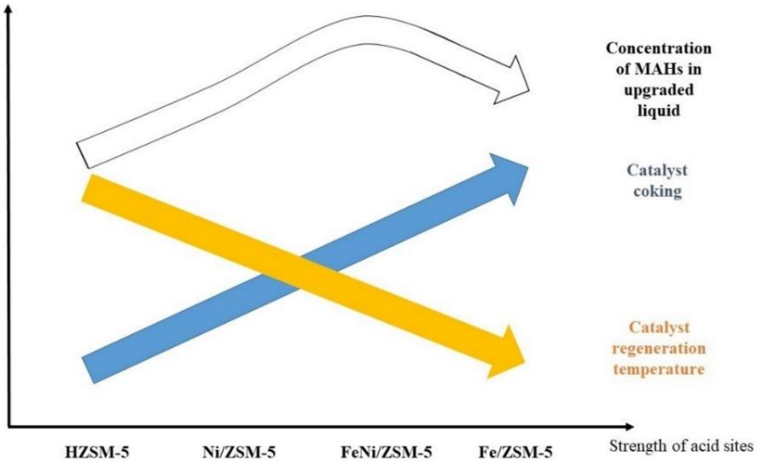

Figure. 2: Trends observed when comparing catalyst activities, characteristics and deactivation properties in bio-oil upgrading. [1]

Correlation for catalyst activity and deactivation...continued

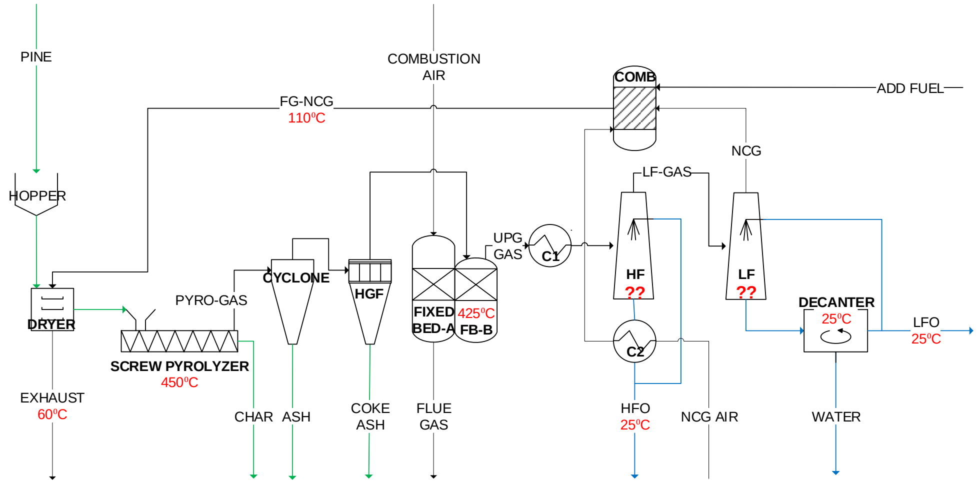

Figure. 3: Illustration of the process model for co-production of biochar and bio-oil.

observed are presented in Figure 2. In the case of using metal-doped catalysts it was seen that the rate of coke formation was increased compared to the non-doped parent zeolite material. Also, metal-doping was seen to promote the formation of monocyclic aromatic hydrocarbons, seen by an increased concentration of such compounds in upgraded bio-oil. Metal-doping was also seen to catalyze the oxidation of coke during catalyst regeneration, which may suppress irreversible deactivation of the catalyst such as sintering and dealumination, i.e. loss of active catalyst surface area and acid sites respectively. When comparing the composition of upgraded bio-oil and the coke deposited on the surface of the corresponding catalyst, it was seen that similar compounds were found in the catalyst coke as the main compounds found in the catalytically upgraded bio-oil. The coke mainly consisted of aromatic hydrocarbons, both monoaromatic compounds such as benzenes but also polycyclic compounds such as naphthalenes, fluorenes. [1]

The research presented above was recently presented at Pyro2018 in Kyoto, Japan in June 2018 by PhD Candidate Henry Persson. During the conference Gala Dinner, the work received Frontier Lab's *Young Scientist Award*.

Other recent works on catalytic pyrolysis of biomass

The research group of Dr Weihong Yang at KTH has its history in thermochemical conversion of biomass, where pyrolysis has been the main focus for the last decade. In the last years, experimental as well as conceptual modelling studies on catalytic pyrolysis has been the main focus. At the moment, four PhD students are studying biomass-related pyrolysis for producing renewable feedstocks for enhanced energy and material recycling. Some examples of other research works from the group that has been published in 2018 are presented below:

- Two-stage catalytic upgrading of biomass pyrolysis vapors to produce gasoline-range chemicals. In this study, different mass ratios of the microporous HZSM-5 and mesoporous Al-MCM-41 was experimentally investigated for upgrading bio-oil, together with varying the temperature of pyrolysis and catalytic upgrading. Optimum conditions were found at 500 °C using a HZSM-5:Al-MCM-41 ratio of 3:1 in terms of production of gasoline-range chemicals. [2]
- Catalytic upgrading of bio-oil in a hydrogen atmosphere. In this work, hydrogen gas was investigated as the carrier gas for pyrolysis and catalytic upgrading of the pyrolysis vapors at atmospheric pressure. Compared to inert N_2, H_2 was seen to enhance the activity of the catalyst in terms of a higher yield of aromatic hydrocarbons as well as to reduce the char yield. [3]
- Modelling of a biomass pyrolysis process based on ex-situ catalytic upgrading and two-stage condensation. The process model consisted of an auger reactor for co-production of char and vapors to be upgraded over a fixed catalytic bed. The influence of temperature of the two condenser units was studied respectively. The process design is illustrated in Figure 3. [4]
- Stepwise pyrolysis of lignocellulosic biomass. In this work, biomass was thermally treated in two separated steps, investigating the bio-oil composition's dependency on the choice of pyrolysis temperature. [5]

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Biomass to Drop-In Diesel with Hydrofaction™

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Steeper Energy Aps (“Steeper”) developed its proprietary hydrothermal liquefaction (“HTL”) process, Hydrofaction™, to revolutionize the thermochemical conversion of non-food biomass to advanced long-haul transport (bio)fuels. By emulating the pressure and temperature conditions that lead to the conversion of marine biota into petroleum, Steeper is able to efficiently convert forestry residues, agri-wastes and urban wastes into high value drop-in fuels.

HTL is increasingly recognized as the most cost, resource and energy-effective technology for the conversion of biomass to liquid fuels while delivering compelling GHG emission reduction potential, especially for fuel switching-adverse industries associated with heavy and long-distance transport.

Although HTL was initially described in a 1930s patent, the main body of work on the chemistry started in the 1980s. There are a number of advancements that have occurred in the 2000s which have enabled the cost-effectiveness of HTL, including: enhanced metallurgy, particularly related to the adoption of super-critical coal fired power plants; and, the introduction of high-pressure pumps for viscous materials in the form of fracking and cement pumps.

Image 1: Hydrofaction™ Oil

Unlike other advanced biofuel thermochemical processes, HTL uses water as the reaction medium. The wet biomass is mixed into a slurry and pumped into a high-temperature, high-pressure reactor. This allows for exceptionally high energy efficiency due to a) low parasitic losses and no requirement for latent heat addition as there is no feedstock drying or water phase change and, b) efficient heat exchange between outgoing hot product and the incoming cold slurry.

Compared to other HTL processes Hydrofaction™ delivers higher quality biocrude oil at higher biomass-to-oil yields (**about 45% on mass basis and over 80% on energy basis**). This is achieved by a unique combination of the following process characteristics: a) relatively high operating pressure (300-350 bar) at 380-420 °C ensures higher density supercritical water compared to processes that operate near the critical point of water. This increases the ionic product which minimizes radical reactions and coke formation. High density water also has enhanced heat capacity and heat transfer properties which lower the energy requirements of the overall process. b) recirculation of produced organic compounds, in the form of water-soluble organics, act as radical scavengers (minimizing coke formation) while also improving the rheological properties and heat capacity of the feed slurry, c) alkaline Na and K catalysts along with carbonates, promote hydrogen-generating reactions such as water-gas-shift and reforming. Details on the unique operating conditions of Hydrofaction™ and the associated reaction chemistry can be found in a peer reviewed paper in Biomass Conversion and Refinery.

Steeper’s current experience with processing woody-residues builds upon the engineering team’s past experience of using HTL to convert over 40 different bio-organic feedstocks or combinations into advanced bio-fuels.

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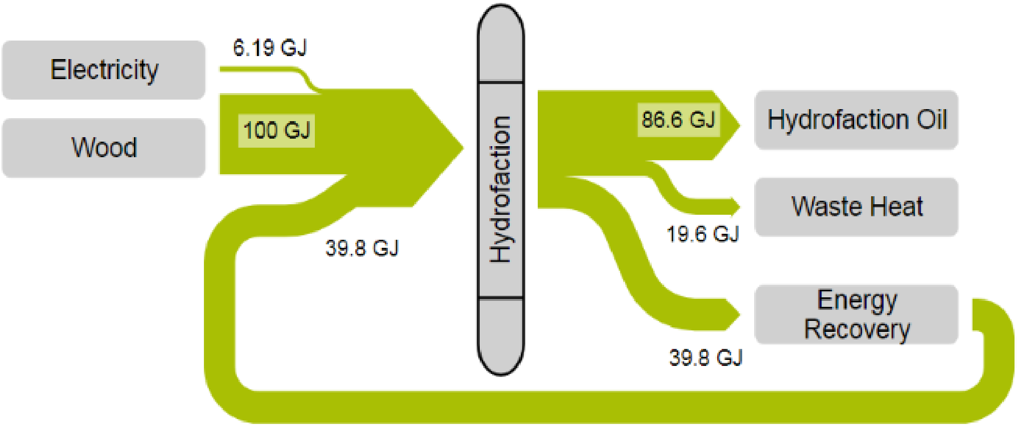


Image 2: Hydrofaction™ Energy Balance (*simplified*)

Biomass to Drop-In Diesel...continued

Image 3: Hydrofaction™ pilot plant after retooling (Aalborg, Denmark)

Significant GHG reductions are achieved when replacing fossil fuels with Hydrofaction™ derived transport fuels. For example in a published book chapter in "Direct Thermochemical Liquefaction for Energy Applications" emissions savings of 77% to 108% relative to fossil-derived fuels are reported.

Hydrofaction™ is protected by a strong intellectual property (IP) position consisting of over 100 pending and granted patents across 21 different patent families. The portfolio goes beyond the hot section of the process covering upstream slurry preparation and pressurization as well as downstream depressurization, CO_2 recovery, separation sections and biocrude upgrading.

Company

Steeper was founded in 2011 by Dr. Steen B. Iversen and Mr. Perry E. Toms with the main purpose of describing, developing and commercializing its in-house developed HTL technology platform – Hydrofaction™. Steeper's technical team brings a history of successful innovative and disruptive technology development from concept to commercial demonstration and market uptake.

Scale-up

After more than 5,000 operating hours at the Hydrofaction™ pilot-plant, the team has accumulated strong operational and innovation skills required in support of ongoing technical and business activities. The operations have generated strong intellectual property in the form of patents, know-how and trade-secrets as well as establishing operating protocols and validating the efficiencies of Hydrofaction™ in the form of mass and energy balances.

First Hydrofaction™ Licensee

In December 2017, Silva Green Fuel (SGF) licensed Hydrofaction™ to transform forest residuals into renewable fuels. Silva is proceeding with phase 1 of its first commercial project: a 50 million € demonstration & de-risking facility. SGF, itself a joint venture between Statkraft A/S (State Utility Company of Norway) and Södra Skogsägarna (Sweden), evaluated Hydrofaction™ against 40+ other biofuel technologies and adopted in their quest to produce advanced biofuels for the Scandinavian market.

Biocrude to transport fuels

The Hydrofaction™ biocrude produced from woody biomass has low oxygen and high calorific value compared to other bio-oils, and in many ways resembles its fossil couterparts. However, the upgrading/refining processes need to be adjusted in order to address the biocrude's distinct properties such as higher viscosity, Total Acid Number and oxygen content. To address these properties, an extensive program for characterizing and upgrading the biocrude to "Drop in" transportation fuels or blend stocks has been undertaken. Different upgrading strategies, catalysts, reactor configurations, and process conditions have been tested both in screening experiments and longer-term stability tests (>700 hours). Those tests have proven that the oil is upgradable utilizing industry standard equipment and methods with processes modified to accommodate the distinct biocrude properties. For example, a modified catalyst bed configuration and the ability to remove water product after deoxygenation reactions are required. Key results are shown in Table 1, further described in detail in these sources: [1], [2], [3], [4].

(Continued on page 16)

Image 4: Location of upcoming Hydrofaction™ facility in Tofte, Norway

Biomass to Drop-In Diesel...continued

Sucessful biocrude upgrading results were achieved by a combination of hydroprocessing stages using commercial sulphided catalysts. A significant reduction of boiling point and residue are obtained after partially upgrading the biocrude, i.e. the fraction from the initial boiling point to 350°C is more than doubled by the upgrading process, and the residue (BP > 550°C) is reduced from 28% to 7.9%. Also, the TAN and oxygen content is reduced to below detection level for the fully upgraded oil, and the H/C ratio has been increased from 1.25 to 1.73. Image 6 shows the different fractions obtained after distillation of upgraded Hydrofaction™ oil according to ASTM D2892 [23].

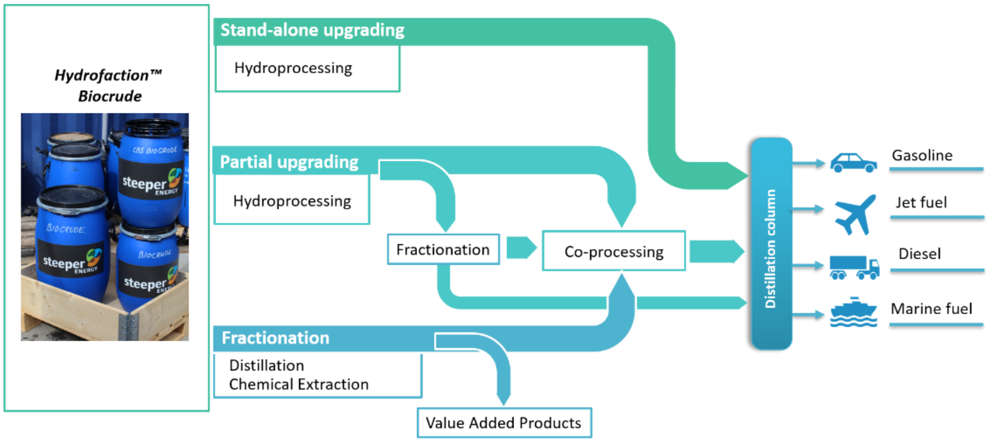
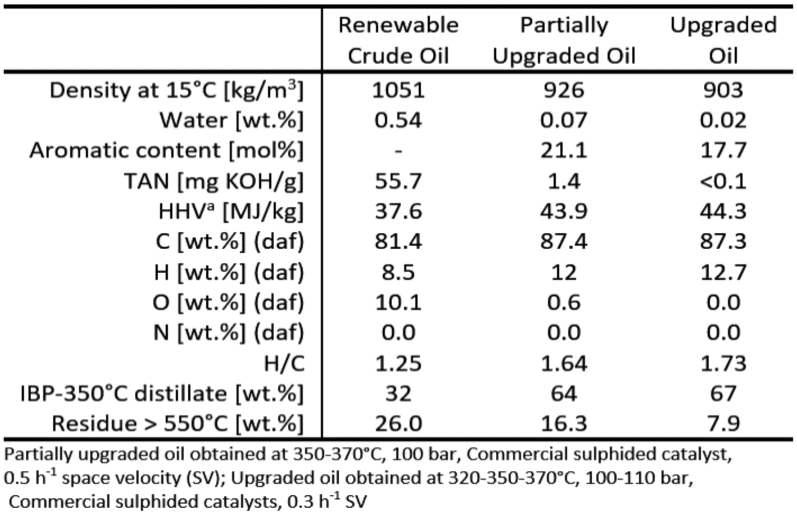


Image 5: Hydrofaction™ biocrude upgrading strategy

Table 1. Key properties for biocrude, and upgraded oils



	Renewable Crude Oil	Partially Upgraded Oil	Upgraded Oil
Density at 15°C [kg/m^3]	1051	926	903
Water [wt.%]	0.54	0.07	0.02
Aromatic content [mol%]	-	21.1	17.7
TAN [mg KOH/g]	55.7	1.4	<0.1
HHV^{a} [MJ/kg]	37.6	43.9	44.3
C [wt.%] (daf)	81.4	87.4	87.3
H [wt.%] (daf)	8.5	12	12.7
O [wt.%] (daf)	10.1	0.6	0.0
N [wt.%] (daf)	0.0	0.0	0.0
H/C	1.25	1.64	1.73
IBP-350°C distillate [wt.%]	32	64	67
Residue > 550°C [wt.%]	26.0	16.3	7.9

Partially upgraded oil obtained at 350-370°C, 100 bar, Commercial sulphided catalyst, 0.5 h^{-1} space velocity (SV); Upgraded oil obtained at 320-350-370°C, 100-110 bar, Commercial sulphided catalysts, 0.3 h^{-1} SV

Successful blending of diesel fraction (up to 30% vol.%) with fossil diesel and the fraction with boiling point > 350 °C (up to 62 vol.%) with Marine fuel oils (RMG 180) were obtained. These blends comply with the specification of Diesel EN590 (2013) for ultra-low sulfur diesel and ISO 8217 (2012) for Marine fuel.

Image 6: Distillation fractions obtained from upgraded Hydrofaction™ oil

Co-processing studies have been successfully conducted at CanmetENERGY in Devon, a federal petroleum research lab under the Department of Natural Resources Canada. Tests were conducted using blends containing up to 10% of the distillates fraction of Hydrofaction™ biocrude with petroleum-based feedstocks in a continuous bench scale hydroprocessing unit for about 1400 hours under industrially relevant conditions. The results suggested that co-hydroprocessing of the biocrude with heavy fossil distillates is a suitable point for Hydrofaction™ renewable crude oil refinery integration.

Seeking Strategic Partners

Steeper Energy is progressing the commercialization of Hydrofaction™ through scaling up projects while demonstrating and optimizing various pathways for integration of the biocrude oil in existing petroleum infrastructure. In this process Steeper is actively seeking additional strategic partners or licensees: Upstream (feedstock, biomass); Project Developers; and, Downstream (renewable crude, finished fuels).

Upstream, Steeper is engaging with foresters and large-scale agriculture in the development of commercial facilities capable of producing 2000+ barrels of transportation fuels per day. In parallel, Hydrofaction™ can be used for organic waste destruction projects, producing circa 100 bpd of fuels from municipal wastes such as sewage sludge and the organic fraction of MSW.

Downstream, Hydrofaction™ will provide low-carbon feedstocks or fuels to petroleum refining and fuel trading partners.

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Mission Innovation: Sustainable Biofuels Innovation Challenge

Fernando Preto
Canadian Lead for MI
Sustainable Biofuels
Innovation Challenge

Introduction

The use of fossil fuels in transportation and industrial production contributes up to 35% of global greenhouse gas (GHG) emissions. Advanced biofuels can be considered as sustainable biomass-derived fuels (liquid, solid or gaseous) with lower carbon emissions than fossil fuels over their entire life-cycle. Increased use of biofuels in transportation and industrial applications can contribute to mitigating climate change in key areas of the global economy. With global action, the International Energy Agency (IEA) projects that biofuels could provide around 30% of all transportation fuels by 2050, thereby avoiding around 2.1 giga-tonnes of CO_2 emission per year compared to continued use of petroleum-derived fuels. In addition to environmental benefits, biofuels can contribute to energy security by diversifying the energy mix and by providing a renewable energy resource. In the long-term bioenergy has an essential role to play in a low-carbon energy system. For instance, as documented in *IEA's Technology Roadmap: Delivering Sustainable Bioenergy*, modern bioenergy will be a key contributor in limiting global average temperatures from rising more than 2°C by 2100 to avoid some of the worst effects of climate change. This is particularly important in the transport sector, where advanced biofuels can help to decarbonise long-haul transport (aviation, marine and long-haul road freight).

Unfortunately, many of the most exciting biofuels remain at the pre-commercial stage of development and concerted international efforts are needed to accelerate their commercialization. One such effort is the Mission Innovation initiative. Mission Innovation was announced on November 30, 2015, as world leaders came together in Paris to undertake ambitious efforts to combat climate change. Mission Innovation (MI) is a global initiative of 23 countries and the European Union to dramatically accelerate global clean energy innovation. As part of the initiative, participating countries have committed to seek to double their governments' clean energy research and development (R&D) investments over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies. These additional resources will dramatically accelerate the availability of the advanced technologies that will define a future global energy mix that is clean, affordable, and reliable.

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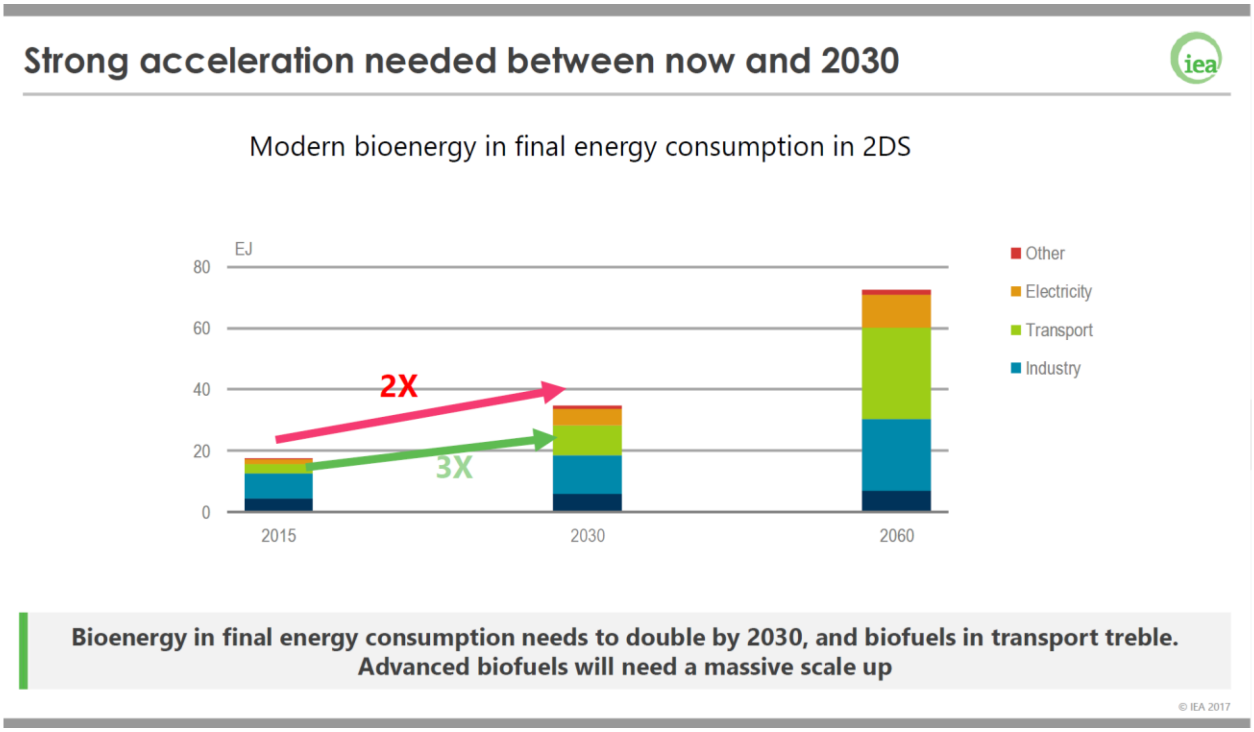


Strong acceleration needed between now and 2030

Modern bioenergy in final energy consumption in 2DS

Bioenergy in final energy consumption needs to double by 2030, and biofuels in transport treble. Advanced biofuels will need a massive scale up

Figure 1 From IEA Technology Roadmap: Delivering Sustainable Bioenergy (2017)- https://webstore.iea.org/technology-roadmap-delivering-sustainable-bioenergy

Mission Innovation...continued

MISSION INNOVATION
Accelerating the Clean Energy Revolution

Innovation Challenges: Midterm Results

Smart Grids #1
Objective
Enable future grids powered by affordable, reliable, decentralised renewable electricity systems.
Co-leads: CHINA, INDIA, ITALY

Off Grid Access to Electricity #2
Objective
Develop systems that enable off-grid households and communities to access affordable, reliable renewable electricity.
Co-leads: FRANCE, INDIA

Carbon Capture, Utilization, and Storage #3
Objective
Enable near zero CO_2 emissions from power plants and carbon-intensive industries.
Co-leads: SAUDI ARABIA, MEXICO, UNITED KINGDOM

Sustainable Biofuels #4
Objective
Develop ways to produce at-scale widely affordable, advanced biofuels for transportation and industrial applications.
Co-leads: BRAZIL, CANADA, CHINA, INDIA

Converting Sunlight #5
Objective
Discover affordable ways to convert sunlight into storable solar fuels.
Co-leads: EUROPEAN COMMISSION, GERMANY

Clean Energy Materials #6
Objective
Accelerate the exploration, discovery and use of new high-performance, low-cost clean energy materials.
Co-leads: CANADA, MEXICO

Affordable Heating and Cooling of Buildings #7
Objective
Make low-carbon heating and cooling affordable for everyone.
Co-leads: EUROPEAN COMMISSION, UNITED ARAB EMIRATES, UNITED KINGDOM

new Hydrogen #8
Objective
Accelerate the development of a global hydrogen market by identifying and overcoming key technology barriers to the production, distribution, storage, and use of hydrogen at gigawatt scale.
Co-leads: AUSTRALIA, GERMANY, EUROPEAN COMMISSION

Top Accomplishments in 2017

#1
- India & Australia launched **calls for proposals** in June to support effective collaboration among IC1 members.
- **Collaboration agreements** (India, US, UK, Italy) were announced on Nov. 16-18.
- 14 members contributed to the publication of the **2017 Country Report.**

#2
- India & France launched **calls for proposals** in June/July and each selected 9 winning projects. Winners of the French competition focused on access to energy in African countries while winners of the Indian competition partnered with at least one MI country.

#3
- A CCUS **experts workshop** was held in Houston with 257 academic and industry participants from 22 countries and across 13 panels to establish the current state of CCUS technology.
- The **workshop report** will serve as an important signpost for future R&D activities in carbon capture, utilization, and storage technologies.

#4
- Launched **survey** in partnership with Biofutures Platform and IEA to better understand the landscape of biofuels technology and identify research gaps, priorities, and collaboration activities.
- India launched a **funding call** worth USD $5 million, which can be replicated in other MI countries.

#5
- The EC launched an inducement **prize** called "Fuel from the Sun" to produce useful fuels using artificial photosynthesis.

#6
- Mexico hosted the **inaugural workshop** in September, which catalyzed subsequent workshops hosted by Canada and laid the foundations for a **collaborative research project** to accelerate the discovery of clean energy materials.

#7
- An Extreme Efficiency Cooling **Prize** is being developed in conjunction with the Rocky Mountain Institute.
- A **collaborative research project** with the IEA is underway to develop an integrated heating, cooling, and power system for buildings.

Current Status

#8
- Launched at the third Mission Innovation Ministerial in May 2018.
- A **deep-dive workshop** is planned for October 2018.

Figure 2 Mission Innovation: Innovation Challenges - http://mission-innovation.net/

Through a collaborative process between Mission Innovation members, eight Innovation Challenges were developed. These challenges are global calls to action aimed at catalyzing global research efforts in areas that could provide significant benefits in reducing greenhouse gas emissions, increasing energy security, and creating new opportunities for clean economic growth. The Innovation Challenges cover the entire spectrum of RD&D; from early stage research needs assessments to technology demonstration projects. One of the challenges is focused on advanced biofuels: The Sustainable Biofuels Innovation Challenge is co-led by Brazil, Canada, China, and India. Other participating countries include: Denmark, European Commission, Finland, France, Germany, India, Indonesia, Italy, Mexico, Norway, Sweden, the Netherlands, the United Kingdom, and the United States.

Sustainable Biofuels Innovation Challenge (SBIC)

SBIC aims to accelerate biofuels-related research, development, and demonstration in order to achieve performance breakthroughs and cost reductions with the potential to substantially lower GHG emissions. It also aims to drive research and innovation not only in the refining and production stages, but also upstream and downstream at the feedstock and utilization stages including, for example, the development of high-efficiency energy crops and the leveraging of biofuels in new, more efficient, vehicle engines. Three parallel work streams have been proposed to allow each country in the SBIC to focus on areas where they have the greatest interest and expertise:

> The SBIC objective is to develop ways to produce, at scale, widely affordable, sustainable, advanced biofuels for transportation and industrial applications.

A. Improve the large-scale production and supply of biological feedstocks including cultivation, harvesting, collection, handling, transport and pre-treatment practices including investigating:
   i. Regional opportunities to grow high yield energy crops without adversely affecting food & feed supply;
   ii. A variety of geographies such as deserts/arid areas with coastlines where marine algae (both macro and micro) can be grown at scale;
   iii. Global biomass types, distribution and properties; and
   iv. Transportation options including consideration of different biomass types and intermediates using conventional and advanced transport approaches.

B. Overcome barriers to demonstrating technologies for at-scale production of biofuels meeting end-use specifications.
   i. Biofuels production to be considered for liquid, solid and gaseous products as well as production of intermediates suitable for secondary conversion.

C. Research and improve upon new technologies for the high-efficiency utilization of biofuels in transport and industry, including biogas applications, high-efficiency combustion engine applications, and applications combining electric, fuel cell and biofuels, as well as applications for heavy duty road freights, aviation and shipping.

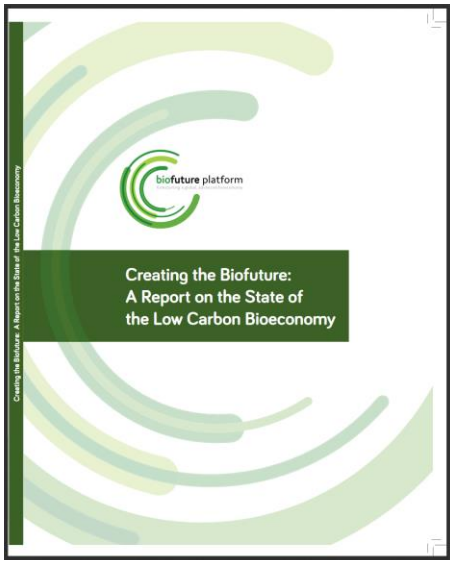
(Continued on page 19)

Mission Innovation...continued

If emission reduction targets are to be achieved, especially in the short and medium terms, advanced biofuels have an important contribution to make. One role is the use of biofuels when zero-emitting electrification cannot be implemented practically and at a reasonable cost. For some industrial applications which require high operating temperatures and for some forms of transportation, such as long distance shipping and aviation where the added weight of batteries makes electrification impractical, biofuels are the best near term low-carbon renewable alternative to petroleum fuels.

SBIC participating countries are working to develop and implement a work plan based on the work streams noted above. SBIC will build on the existing work of individual countries and international institutions, such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) to identify and prioritise innovation needs and collaboration opportunities where research and development can result in significant advances in biofuel technologies. SBIC will also define joint work and collaboration to pursue with the Biofuture Platform – a policy-focused government-led, multi-stakeholder initiative to support the development of the sustainable, low carbon bioeconomy.

SBIC has collaborated with the Biofuture Platform initiative to develop "maps" of the work being done in the participating countries, and is using use this information to develop roadmaps for future collaborative work. The mapping and roadmap exercises are crucial in identifying gaps and opportunities. Arising out of this multilateral collaboration is the "Creating the Biofuture" report commissioned by the Biofuture Platform based on insights and data by 19 countries and the European Commission, collaborating as members of the Biofuture Platform coalition or the Mission Innovation - Sustainable Biofuel Innovation Challenge.


biofuture platform

Creating the Biofuture:
A Report on the State of
the Low Carbon Bioeconomy

Creating the Biofuture: A Report on the State of the Low Carbon Bioeconomy

Figure 3 Creating the Biofuture (http://biofutureplatform.org/wp-content/uploads/2018/11/Biofuture-Platform-Report-2018.pdf)

The report, *Creating the Biofuture: A Report on the State of the Low Carbon Bioeconomy (2018)* looks at how biofuels and bioproducts must play an integral role to enable the achievement of global greenhouse gas mitigation targets, in tandem with a range of complementary mitigation efforts across all sectors and lays out the scale of the challenge ahead. Following the mapping exercise, the development of detailed work plans has commenced through a series of meetings:

- Side-event on "Scaling Up the Advanced Low Carbon Bioeconomy" at the CEM8-MI2 in partnership with Biofuture Platform in Beijing, June 2017
- Bioenergy for the Future (IEA Bioenergy Roadmap/Mission Innovation IC4 Scale-up Workshop) in Ottawa, November 2017
- International Workshop on Sustainable Biofuels, New Delhi – February 2018 in partnership with Biofuture Platform to prioritise innovation needs and collaboration opportunities
- Trilateral (US/Mexico/Canada) Biojet Fuel Collaboration, Richland – May 2018

and funding opportunities:

- Funding Opportunity Announcement for $5M by India for Sustainable Biofuels (IC#4) http://mission-innovation-india.net/sustainable-biofuel-ic4/
- "Sky's the Limit Challenge" to accelerate sustainable aviation fuels production in Canada with opportunity for participation of other countries and offering total prizes of up to $15M (https://impact.canada.ca/en/challenges/green-aviation)

The SBIC co-leads (Brazil, Canada, China, India) together with participating countries are continuing their discussions and work plan development culminating in a workshop to be held in conjunction with the 10th Clean Energy Ministerial and 4th Mission Innovation Ministerial (CEM10/MI-4) to be held in Vancouver on May 27-29th, 2019. This event will provide an opportunity to highlight global clean energy innovation and advance the global transition to a clean energy future.

The MI Sustainable Biofuels Innovation Challenge will continue to leverage the existing work of individual countries and international organizations, prioritise innovation needs and identify collaboration opportunities where research and development can result in significant advances in biofuel technologies.

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CEM10/MI-4
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Wishing you "Productive Collaborations!" from the Task 34 NTLs of 2016-2018

Introducing the new Leader of Task 34: Axel Funke

Dr.-Ing. Axel Funke
Karlsruhe Institute of Technology

While the important work of Task 34 was approved to continue in the upcoming triennium 2019-2021, the changes in Task 34 initiated over the past years are continuing. There will be exciting new members leading to an increase in the task team and almost all faces from last triennium will change. This opens up great opportunities for the intended work program and networking activities. At the same time, the current changes might represent a threat if the legacy of the Task's excellent work over the past decades was ignored. There have been many important contributions to the field of fast pyrolysis originating from this group and I strongly believe that, while looking ahead to the new challenges and opportunities, a sensible look into the past will be an important fundament for the future work of this new team.

I will be leading Task 34 in the upcoming triennium as well as representing Germany as national task leader. For sure I am not as recognized in the biomass liquefaction community as my predecessors have been, so please allow me to introduce myself to the PyNe and IEA Bioenergy audience at this point. I have been working in the field of biomass conversion for over ten years now based on my educational background of chemical engineering. After having received my Diploma from Technical University of Berlin/ Germany and an MSc in Sustainable Power Generation from Royal Institute of Technology Stockholm/ Sweden, I started off as project engineer at SGS Germany in the quality assurance of a variety of plants, including biodiesel and bioethanol production as well as waste incineration integrated in paper recycling plants. My desire to step ahead of state of the art technology has lead me to conduct my PhD in the field of hydrothermal carbonization of biomass back at Technical university of Berlin, followed by a PostDoc period at Leibniz-Institute of Agricultural Engineering and Bioeconomy in Potsdam/ Germany within the young researcher group 'APECS'.

In 2013 I joined KIT in my current position as principal investigator for fast pyrolysis technology development. KIT has a strong focus on bridging fundamental and applied research, which is also reflected in the fast pyrolysis research work. Relevant fundamental heat and mass transfer processes are being investigated to enable design of critical components such as the pyrolysis reactor and condensation of hot pyrolysis vapors. I very much emphasize to combine modelling work with experimental validation and experience in order to develop meaningful design criteria. While some of this work is restricted to the reactor design in use at KIT, i.e. an auger type twin-screw mixing reactor, many of the fundamental aspects are relevant to fast pyrolysis processes in general. At KIT we primarily investigate the production of fast pyrolysis bio-oil (FPBO) as feedstock for gasification within the bioliq® concept, but we do also have a look at promising value-added byproducts. In consequence, the research covers TRL 1 to 6 with the bioliq® pilot plant being our flagship to demonstrate the feasibility of converting agricultural residues such as e.g. wheat straw to 2nd generation drop-in fuel components via thermochemical conversion.

The next triennium is full of exciting work for the upcoming Task 34 team. I very much endorse the decision to keep a task with more technical focus and will do my best to continue the valuable work to support bio-oil becoming an increasing tradable commodity. Many of the lessons learned for FPBO can be used to better supported bio-oils derived from hydrothermal liquefaction. At the same time there are also remaining open issues to promote an increased use of FPBO. Finding a proper balance between these two requirements will be a challenging quest for the next three years. It was also concluded in the expiring triennium that public dissemination of direct thermochemical liquefaction technologies and successful industrial solutions needs special attention. Alan Zacher exhaustively worked on redesigning Task 34 website and its content, which was highly appreciated by the whole group. This work definitely continue to make sure these highly valuable efforts will not be in vain.

I am looking forward to collaborating with you to effectively address the challenges associated with implementing sustainable biomass solutions to foster the much needed decrease in fossil carbon use. Task 34 is a very efficient platform to support this aim and it is only as a team that we can achieve relevant contributions that can keep up with its legacy built up over the past decades.

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For More Information

NEW: Task 34 Upcoming Events
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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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