Technology Collaboration Programme
by IEA

Country Reports 2019

Direct Thermochemical Liquefaction

(Finland, Germany, The Netherlands, Sweden)

IEA Bioenergy

IEA Bioenergy:
Task 34: Direct Thermochemical Liquefaction

Country Reports 2019

Direct Thermochemical Liquefaction

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Finland

Major stakeholders in Finland around DTL technologies are summarized in Table 3. All of these stakeholders have been actively researching and/ or promoting DTL technologies in 2019.

Table 1: DTL Stakeholders in Finland

Institution	Main Contact / CEO	Key activities
VTT	Christian Lindfors, Anja Oasmaa	Fast pyrolysis, liquefaction, HDO, catalytic processes for biomass residues and wastes, i.e. plastics
Neste		Development project targeting to use liquefied waste plastic as a raw material for its fossil refinery Biomass DTL routes to produce refinery co-feed
Green Fuel Nordic		Bio-oil production plant in Lieksa
Pohjanmaan Hyötyjätekuljetus		Diesel fuel and other products by modified rotary kiln technology

RESEARCH ACTIVITIES

EU Residue2Heat

The aim of the Residue2Heat project (2016-2019) is to develop competitive, residential boilers (20-200 kWth) fuelled with 'standardized' FPBO produced from locally available biomass resources. In this concept, various 2nd generation agricultural, and forestry residue streams are converted into a liquid energy carrier near the biomass origin at an economic viable scale of 15-30 MWth using the fast pyrolysis process. Existing residential heating systems are tailored and optimized to allow the use of this standardized biofuel.

Significant market potential exists in Europe for condensing, oil fuelled boilers achieving high efficiency and cost effectiveness. The introduction of these systems will reduce greenhouse gases, and importantly provide a boost to local economy by generating jobs on all levels and in different branches.

https://www.residue2heat.eu/

EU 4REFINERY

The project 4refinery (2017 – 2021) focusses on the transformation of bio-liquids from fast pyrolysis and hydrothermal liquefaction into advanced biofuels, through intermediate process steps combined with downstream co-processing technologies.

The goal will be to bring these technologies from TRL3-4 to TRL4-5. The project will establish relations between product's properties, the quality of renewable feedstocks and all relevant process parameters along the value chain. The study of these combinations will allow a full understanding of the influence of feedstock and treatment processes on product characteristics. The results from the project will be used as a draft for the standardization of the quality of biocrude for refinery fuels.

https://www.sintef.no/projectweb/4refinery/objectives/

EU Waste 2 Road

WASTE2ROAD project (2018-2022) aims to develop a new generation of cost-effective biofuels from a carefully selected range of low cost and abundant biogenic residues and waste fractions (contaminated wood, black liquor from pulp and paper industry, and municipal solid organic waste incl. food residues)

The target is to achieve high overall carbon yields > 45% while reducing greenhouse gases emissions (GHG) > 80%. The WASTE2ROAD focuses on co-refining, leading to a mixture of bio-based and fossil fuels.

https://www.sintef.no/projectweb/waste2road/

EU Becool

BECOOL – Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels runs from 2017 to 2022. The two projects adopts a synergistic work programme that is based upon three common pillars:

- Biomass production and feedstock diversification;
- Biomass logistics;
- Conversion processes.

https://www.becoolproject.eu/

EU NONTOX

NONTOX (2019-2022) aims to develop a cost-effective recycling solution able to increase the recycled volumes of plastic fraction contaminated by additives and even substances of concern from key waste streams as WEEE, C&D and ELV, achieving the production of recycled plastic material characterized by high quality and safety standards. Additionally NONTOX solution will be able to effectively manage hazardous substances, purifying and reintroducing them in the productive cycle.

EU ICEBERG

2020-2023

Innovative Circular Economy Broad solutions demonstrating the efficient upcycling of valuable material Resources from the Generation of representative End-of-Life building waste. Pyrolysis of wood waste and resin production.

EU BL2F

BL2F runs from 2020 to 2024 and covers liquefaction of biomass in black liquor by HTL and subsequent upgrading by hydrotreament technologies to produce aviation and marine fuels. Integration of HTL processes to the chemical circulation of a pulp mill.

Tekes - LF4Materials

2017 – 2022
Aim is to produce chemicals, materials, and bio-oils from lignin via HTL and fast pyrolysis. The project considers lignin as the primary biomass component for valorization rather than a side-stream (i.e. lignin first philosophy) in these two thermal biomass processes. Strategy is to use chemical additives (and catalysts) to avoid condensation reactions of lignin and preserve its reactivity for selected applications, such as e.g. composites, resins, and fuels (by hydrodeoxygenation). Project duration is from 2020 to 2024)

BF - BioFlex

The overall goal of the BioFlex project (2020-2023) is to identify and develop a least-cost solution for the production of sustainable and storable liquid fuels that meet the specifications for both flexible power generation and marine transport with large diesel engines.

Bioruukki and Otaniemi

Research and pilot equipment for scaling up of processes:

- VTT 0.5 tpd Fast Pyrolysis Pilot
- Bench scale BFB pyrolysis unit
- Small (2-3 kg/h) BFB/CFB reactor under construction
- MAT unit
- High pressure liquefaction units from micro scale to 10 liters batch reactors in Otaniemi

https://www.vttresearch.com/en/ourservices/process-piloting-and-scale

COMMERCIAL APPLICATIONS

Neste

In recent years, Neste has focused primarily on waste and residues as renewable raw materials. Approximately 80 % of the production of renewable products is based on waste and residual fats and oils. Neste is continuously searching for new renewable raw materials, such as even lower quality waste and residues, for the production of premium-quality products. With the NEXBTL technology, renewable products can be refined flexibly from a wide range of low-quality raw materials while the end product retains their high quality.

Neste has started a development project targeting to use liquefied waste plastic as a raw material for its fossil refinery. The aim is to proceed to an industrial scale trial during 2019. By 2030, Neste targets to process more than one million tons of plastic waste annually.

Green Fuel Nordic

Green Fuel Nordic Oy is a Finnish biorefining company who has decided to build a bio-oil production plant in Lieksa.

The project is being implemented by Technip and Zeton is responsible for manufacturing the core unit of the production facility. Like with Empyro the components of the prefab facilities will first be built in the Netherlands, shipped and then reassembled in Finland on location.

Green Fuel Nordic Lieksa Oy will produce 20 million litres of oil per year that will be used for various production facilities in Finland and the Netherlands. The pyrolysis plant will be located next to a sawmill in Lieksa, in the east of Finland. The sawdust from the sawmill serves as raw material for the oil production, and the steam released as a result is used sustainably for the internal plant processes. The pyrolysis plant is expected to open end 2020.

The first phase of the investment is worth approximately 25 million euros, and is expected to bring approximately a hundred new jobs, including indirect employment, to the Lieksa area.

Pohjanmaan Hyötyjätekuljetus

A Finnish waste managing company having also a 12-14 TPD pyrolysis (cracking unit) based on rotary kiln technology for plastic pyrolysis. Batch reactors in series, one batch 10 tonnes at about 400 ºC for 15 hours. The process includes product upgrading by distillation.

The present production capacity is 3 million litres diesel fuel per year, which qualifies e.g. to slow-speed diesel engines (cetane number of upgraded product over 50). A continuous system is under construction.

ST 1

St1 has built a demonstration scale lignocellulosic biorefinery plant in Finland using softwood sawdust as feedstock. The sawdust is available from the local saw milling industry and nameplate capacity of the plant is 10 ML bioethanol per year. The developed process called St1 Cellunolix™ is based on hydrothermal treatment, enzyme hydrolysis, yeast fermentation, distillation and biogas production. The side streams include solid hydrolysis lignin, concentrated fermentation residue, furfural, turpentine, biogas and CO2. The produced bioethanol is blended into different gasoline products according to the stipulated blending mandates and distributed through St1 retail station network in Scandinavia. The value chain upgrading work is continuously ongoing at St1 to find out the most cost-effective commercialization pathways for other side products, particularly to hydrolysis lignin.

St1 has worked together with VTT to evaluate the technological maturity level of producing bio crude from hydrolysis lignin using circulating fluidized bed (CFB) technology. The results indicate that hydrolysis lignin can be pyrolyzed into bio crude with certain technical challenges and the post stability of the bio crude still requires some further development work.

St1 is constantly looking for more clever ways to produce liquid biofuels from solid biomass more sustainable way. The direct thermochemical liquefaction technologies are considered as important approach in the future lignocellulosic biorefineries than biochemical routes, which is currently applied at St1 Cellunolix demonstration plant. The hydrothermal liquefaction (HTL) methods are particularly interesting due to feedstock flexibility and more advanced fractionation properties.

Germany

Major stakeholders in Germany around DTL technologies are compiled in Table 3. All of these stakeholders have been actively researching and/or promoting DTL technologies in 2019. Commercial DTL activities are re-appearing with the start-up of Susteen Technologies and their Thermo-Catalytic-Reforming (TCR®) concept.

Table 2: DTL Stakeholders in Germany

Institution	Main Contact	Key activities
German Biomass Research Center (DBFZ)	Mario Klemm	Hydrothermal liquefaction
Fraunhofer Institute UMSICHT	Andreas Hornung	Intermediate pyrolysis, TCR® process
Hamburg University of Applied Sciene (HAW)	Thomas Willner	Solvolytic reactive distillation, READi process
Karlsruhe Institute of Technology-IKFT	Nicolaus Dahmen	Fast pyrolysis, hydrothermal and solvothermal liquefaction, bioliq® process
Karlsruhe Institute of Technology-ITC	Hans Leibold	Intermediate pyrolysis with hot gas filtration
Susteen Technologies	Thorsten Hornung	TCR® process
Thermophil	Dietrich Meier	Consultant FPBO analytics and fast pyrolysis
Thünen Institute of Wood Research	Jörn Appelt	FPBO analytics, FPBO upgrading
Technical University of Berlin	Frank Behrendt	Hydrogenolysis

DTL WITHIN THE NATIONAL POLICY FRAMEWORK

Germany is realizing a blend in mandate of biofuels according to EU legislation. There are currently no efforts to extend blending quota and/or support the use of 2nd generation biofuels over that of 1st generation (which are currently predominating the blend in mandate). Recent decisions on introducing a CO_2 price of 10 €/ton starting from 2021 are unlikely to motivate enough incentives for an increase in biofuel use in a short term. The previously extremely successful German Renewable Energy Sources Act grants subsidies for combined heat and power generation only (with special rules for combined heat & power generation) and DTL technologies could not compete against other bioenergies (such as anaerobic digestion and wood combustion) in this sector, yet.

RESEARCH ACTIVITIES

DBFZ

The DBFZ is running a 'Biorefinery Laboratory' consisting of several technologies and a wide

variety of equipment around hydrothermal processing of biomass. DBFZ has established an annual symposium on hydrothermal processing, which is German based but bilingual (www.htp-inno.de) and usually takes place around early autumn in Leipzig/ Germany.

Active research involves an on-going project named HTKkChem. Within this project, carbohydrate-rich residues (starch, cereal husks, corn cobs) are used as starting material for the production of platform chemicals. The aim is the development of a two-stage hydrothermal process to provide the platform chemicals levulinic acid and γ-valerolactone (GVL). While in the first stage, the carbohydrates are hydrothermally converted to levulinic acid using homogeneous acid catalysts, in the second stage those levulinic acid process liquor will be converted to GVL by in-situ hydrogenation with the aid of heterogeneous catalysts. Besides DBFZ, the project consortium is consisting of the "Leibniz Institute for Catalysis (LIKAT)" as well as the "ifn Research and Technology Centre GmbH (ifnFTZ)". Process development and hydrothermal conversion processes are examined by DBFZ, while LIKAT is responsible for the development of the heterogeneous hydrogenation catalysts of the second stage. ifnFTZ is entrusted with the downstream processing of the corresponding platform chemicals.

Fraunhofer UMSICHT

Fraunhofer UMSICHT has developed the thermo-catalytic reforming (TCR®) process for biomass conversion. Based on intensive experience in intermediate pyrolysis, TCR® is the latest technological step forward in innovative thermo-chemical conversion of biomass, particularly biogenic residues. The unique selling points of TCR® are the thermal stability of its oils and the high hydrogen content of the TCR® gases. Due to these unique product qualities, the EU H2020 project To-Syn-Fuel will operate and demonstrate the production of synthetic fuels and green hydrogen from waste biomass, mainly dried sewage sludge (see www.tosynfuel.eu). Horizon 2020's new research and innovation programme is assisting in the long-term goal of bringing innovative biofuels from sustainable raw materials to the market. The To-Syn-Fuel process is built around Thermo-catalytic reforming (TCR®) technology developed by Fraunhofer UMSICHT. TCR® produces renewable liquid fuels from poor quality waste organic feedstocks such as sewage sludge, paper industry residues, the organic fraction of municipal solid waste, anaerobic digestate, etc.

The Fraunhofer UMSICHT (location Sulzbach-Rosenthal) operates TCR® units with 2, 30, and 300 kg h^{-1} feedstock capacity. Main focus is on conversion of agricultural residues, such as e.g. digestate, and sewage sludge. EN 590/ EN 228 compatible Diesel/ Gasoline is achieved via hydrodeoxygenation of bio-oil. Fraunhofer UMSICHT (location Oberhausen) is also investigating fast pyrolysis, specifically scale up of the ablative fast pyrolysis process originally planned for conversion of wheat straw decentralized on the field.

HAW Hamburg

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 (SRD) and solvolytic reactive stripping (SRS). The basic approach of both variants is using a self-regenerating heavy-oil sump phase as a solvolytically acting reaction medium. The main challenge is the stabilization of the sump phase in continuous long-term operation. 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). These solids must be separated continuously to prevent them from accumulating in the reactor.

SRD: The SRD variant is called READi™ process indicating "Reactive Distillation" in the name. It is working at low pressures in the range of usually 1 to 5 bar. The reaction temperature is also the boiling point of the reaction medium. Thus, the cracked product molecules are continuously

removed by distillation from the sump phase. Cracking reactions are accompanied by deoxygenation reactions. Contents of other heteroatoms such as sulphur or nitrogen, if present, are also reduced significantly. The separated and condensed product is free of heavy-oil molecules. All these effects are expected to be cost reducing by minimizing further refining and hydrotreating efforts. Furthermore, the process is a non-catalytic approach. Thus, it is resistant to impurities in the feedstock as no catalyst can be contaminated or deactivated. The SRD approach has been successfully applied on the one hand to liquid feedstock such as oils and fats, used cooking oil, different heavy-oil residues and others, and on the other hand to solid waste material such as plastic waste mixtures.

SRS: The SRS approach is also a sump phase concept, but in contrast to the SRD variant applying pressurized hydrogen. The elevated pressures result in an increase of the boiling temperature of the liquid sump phases (solvent) far above reaction temperatures. Therefore, volatile reaction products are stripped out by a hydrogen flow (SRD → SRS). The use of catalyst is again avoided because catalyst deactivation in long-term operation is promoted by the conditions in the sump phase and the use of waste feedstocks. To enable the reactivity of hydrogen without catalyst, temperatures around 400 °C and above are required. The research aims to develop a process with hydrogen serving as a radical scavenger shifting the product distribution from heavy bio-crude to light bio-oils easier to handle and upgrade. However, heavy oil should still be produced sufficiently to regenerate the sump phase contributing to the light oil yield at the severe operation conditions. One typical field of application is solid lignocellulosic biomass the HAW Hamburg research is focussing at.

KIT

There is both research on fast pyrolysis as well as HTL at KIT. Fast pyrolysis research is closely connected to the bioliq® concept (see demonstration activities below) but also investigates other solutions for DTL of ash-rich biogenic residues. KIT operates a lab-scale (100 g/h feed capacity) bubbling fluidized bed reactor and a pilot scale (10 kg/h and 500 kg/h feed capacity, respectively) twin-screw mixing reactor. Research focuses around auger reactor design (design, simulation, and scale up), condensation of pyrolysis vapours (fractionated condensation, phase equilibria, condensation design), and process design (simulations and concepts). Alternative uses of the condensates are investigated with a focus on mild hydrodeoxygenation, water removal, microbial conversion of aqueous condensate and use of CO_2 to enhance downstream processing of FPBO. Research on HTL has recently focused around lignin degradation pathways/ kinetics to bifunctional monomers and oligomers within a lignocellulose biorefinery, integration with microalgae utilization by extraction of lipids and/or proteins or amino acids, and the fate of nitrogen containing species.

Research activities around intermediate pyrolysis is currently focussing on plastic recycling (i.e. focus has shifted away from biomass conversion).

Current participation in large research projects includes H2020 projects Brisk 2 (https://brisk2.eu) and the recently finished Ambition (https://ambition-research.eu) as well as the federal funded reFuels project with participation of several German automotive companies and the largest German crude oil refinery (see below).

reFuels Project

Advance fuels from regenerative sources (reFuels) can be produced from carbon-containing residues from agriculture and forestry, from industrial and municipal waste, as well as from CO2 in combination with renewable hydrogen obtained by electrolysis of water. These fuels together form the reFuels group.

The two-year project aims to demonstrate the feasibility of regenerative fuels for the existing car,

truck, and rail fleet, taking into account sustainability from raw materials to synthesis and use. The project consortium, based on a technology partnership established in 2017, is composed of strong industrial partners from the fields of energy supply, fuel production, engine and vehicle production, suppliers and system developers in the field of mobility, as well as a cluster of supporting research institutes at KIT (www.refuels.de).

Through the refuels project, the competences of the involved partners will be integrated to reach the following targets:

(1) Production, definition and supply of renewable fuels in tons-scale, determination of efficiency potentials as well as holistic evaluation of production chain

(2) Demonstration in the application and evaluation of relevant properties in current existing vehicles (drop-in)

(3) Involvement of civil society actors and communication in society.

The bioliq® unit operated at KIT for synthetic biofuels production is part of this consortium, including fast pyrolysis as DTL technology for pretreatment of agricultural residues such as e.g. wheat straw.

Thünen Institute

Thünen Institute of Wood Research is still actively in research on thermochemical conversion of wood and other lignifying biomass including residual and secondary materials. Thereby the work focuses on the production of basic and valuable substances. For this purpose processes like slow and fast pyrolysis, hydrothermal liquefaction and as well, extractions with liquids and supercritical substances are examined with regard to their suitability for biomass conversion. Thünen Institute operates some lab-scale batch reactors with various volumes (50 to 1000 mL) for the screening of different biomass by pyrolysis, hydropyrolysis and hydrothermal processes. Furthermore the condensates of such processes can be upgraded by hydrodeoxygenation at a continuous lab-scale hydrogenation plant. Wet biomass can be converted directly by hydrothermal processes at a continuous lab-scale liquid phase reactor. For investigations to holistic usage of biomass a continuous extraction plant for supercritical CO_2 is also available to extend the product range.

Liquid condensates and intermediate products are usually examined by different chromatographic methods. Low molecular products can be identified and quantified by a typical coupling of GC with mass spectrometry and flame ionization detection. Therefore various GC systems are available at the Thünen Institute. Additionally high volatile compounds at the liquid condensates are examined by techniques like headspace measurements and solid phase micro extractions (SPME). For all of these techniques a database with mass spectra and calibrations of biomass- and lignin-derived compounds is available at the institute. Thereby up to 90% of biomass-derived compounds at a typical condensate can be usually identified and quantified. Liquid chromatographic methods like size exclusion chromatography is used for the distribution of compounds with a higher molecular mass.

Further research activities in the field of DTL and holistic usage of biomass include the examinations of conversion processes for some annex concepts for pulp mills. How can the by-products be used to develop a biorefinery based on a pulp mill?

Technische Universität Berlin

Research activities around DTL have been focussing around fundamental pyrolysis kinetics research and hydrogenolysis. This includes coal/ lignite liquefaction with the Bergius-Pier process, which could also be of potential interest to biomass feedstocks.

DEMONSTRATION ACTIVITIES

X-Energy Project

Hamburg University of applied sciences is scaling up their solvolytical reactive distillation process in cooperation with Nexxoil. In this process, waste fat and vegetable oil is deoxygenated in a stable, liquid phase without the addition of catalysts. This way hydrogen consumption of subsequent hydrotreatment can be reduced. The technology has been proven at TRL 5-6 (10 t/a) and the project aims at increasing the TRL to 6-7 (100 t/a) with the READi pilot plant (commission scheduled end of 2019). If proven successful, the TRL is planned to be further increased to 7-8 (1000-10000 t/a) in 2nd project phase from 2021 to 2025.

Thermophil

Dietrich Meier is supporting the construction of a fast pyrolysis demonstration unit in California with his expertise by acting as consultant. A more detailed description of the project is available in the country section of the U.S.

Susteen

Susteen Technologies is currently constructing the first TCR® industrial demonstration facility together with Zweckverband Müllverwertung Schwandorf (a German municipal waste disposal company). Operation based on dried sewage sludge is scheduled for 2020 with a rated feedstock capacity of 7 tons per day. The produced bio-oil will be applied for power generation together with the pyrolysis gas. The process includes recovery of phosphate.

bioliq®

KIT operates a pilot unit to demonstrate the technical feasibility of the bioliq® concept (www.bioliq.de/english). The whole concept is more close to an indirect thermochemical liquefaction via gasification and subsequent (DME) synthesis. However, the first step of this concept is decentralized fast pyrolysis of agricultural residues to produce an FPBO/char slurry (biosyncrude) suitable for transport and feeding into an entrained flow gasifier. This fast pyrolysis step is DTL technology, just with a very specific product use.

The fast pyrolysis unit demonstrated at KIT has a feed capacity of 2 MW. The fast pyrolysis reactor is based on auger technology, which was developed and realized in various commercial applications by Lurgi (now Air Liquide). Unique about this unit at this scale is also the separate recovery of char and a two stage fractionated condensation system. The three different product fractions (char, organic-rich condensate and aqueous condensate) are mixed on site to produce slurry for subsequent gasification and there are storage facilities to validate long-term handling feasibility. This demonstration unit is operated once to twice a year for varying campaigns and has been primarily operated with wheat straw. The latest experimental campaign in 2019 was conducted with miscanthus.

COMMERCIAL APPLICATIONS

Currently, there are no commercial applications of DTL technologies and/ or processes in Germany.

The Netherlands

Major stakeholders in the Netherlands around DTL technologies are summarized in Table 3. All of these stakeholders have been actively researching and/or promoting DTL technologies in 2019. Commercial activities are mainly covered by BTG Bioliquids, Technip, Empyro (Twence) and FrieslandCampina.

Table 3: DTL Stakeholders in the Netherlands

Institution	Main Contact / CEO	Key activities
ABATO motoren	Daan Preijde	Development modified diesel engine for fast pyrolysis oil
BTG	Bert van de Beld	Fast pyrolysis, further development of technology, development of oil applications
BTG Bioliquids	Gerhard Muggen	Fast pyrolysis, implementation/commercialization of technology
ECN>TNO	Paul de Wild	Fast pyrolysis, catalytic pyrolysis, fractional condensation
Empyro/Twence	Wim de Jong	Owner/operator of the Empyro fast pyrolysis plant
Foreco	Klaas Jan Swager	Wood modification using (fractions of) pyrolysis oil
FrieslandCampina	-	Owner/operator pyrolysis oil steam boiler
Goodfuels Marine	Bart Hellings	Upgrading pyrolysis oil to drop-in marine fuel
OPRA Turbines	-	Use of fast pyrolysis oil in a modified turbine
Technical	Wiebren de Jong	Gasification/reforming of fast

Institution	Main Contact / CEO	Key activities
University Delft		pyrolysis oil
Technical University Eindhoven	Bart Somers	Engine testing, combustion properties of (upgraded) pyrolysis oil
TechnipMFC	Jacco Kroeze	Implementation of fast pyrolysis technology / FCC application
University of Groningen	Erik Heeres	Catalytic pyrolysis, hydrogenation, pyrolysis in molten salts
University Twente	Gerrit Brem	Catalytic pyrolysis, turbine application
	Sascha Kersten	Current ?
	Guido Mul	Electrochemical conversion of pyrolysis oil
Utrecht University	Bert Weckhuysen	Catalyst development FCC
	Martin Juninger	LCA/LCC of pyrolysis oil chains

DTL WITHIN THE NATIONAL POLICY FRAMEWORK

The major support scheme in the Netherlands is called SDE+, which provides operational support for all kinds of renewable energy including biomass (https://www.rvo.nl/subsidie-en-financieringswijzer/stimulering-duurzame-energieproductie-sde). The application of biomass derived intermediates can also be supported provided all sustainability criteria are fulfilled. Fuels for transportation are not supported in SDE+.

Support for research, development and implementation can be obtained via the TKI-programme. TKI means **T**opconsortia for **K**nowledge & **I**nnovation and different sectors are covered. For biomass related topics the most relevant ones are TKI Agri&Food, TKI Chemistry and TKI Energy (https://www.topsectoren.nl/innovatie).

RESEARCH ACTIVITIES

BTG

BTG is further developing the fast pyrolysis process based on rotating cone technology as well as applications of the fast pyrolysis oil. With respect to the production process the focus is on using other feedstocks than clean wood. Examples are waste wood, verge grass, straw and lignin from 2G ethanol production. Part of the work is focusing on the after-treatment/conditioning of the oil with the aim to obtain pyrolysis oils with similar properties as obtained from clean wood or even better. Initial activities started to recover CO2 from the pyrolysis process.

BTG developed the *Bioliquids refinery* concept using FPBO as starting point for a range of applications. Roughly, it can be divided in bioenergy, biofuels and biomaterials & chemicals.

Within the European project Residue2heat a residential boiler was developed by German partners OWI and MEKU. A prototype boiler (40-60 kW_{th}) has been installed at BTG and integrated with the existing gas-fired heating system for the laboratory. The Residue2heat project was finished by the end of 2019, but testing and monitoring will be continued.

In one of the projects FPBO is used in modified diesel engines. So far these engines have been operated for over 800 hrs on FPBO or FPBO-ethanol blends. The objective is to have a 50 kW_e prototype running in a 2-3 years timeframe. In the project BTG is cooperating with Abato Motoren and the University of Eindhoven.

For the upgrading of FPBO BTG has developed –in cooperation with Groningen University and Boreskov Institute of Catalysis- a new catalysts (so-called Picula™). This catalyst is used specifically for the first low temperature stabilisation step required for the FPBO. After such a stabilisation step the oil can be further upgraded with traditional catalysts like e.g. NiMo or CoMo. In the laboratory several hydrotreaters are available to develop the process. European H2020 projects in this field are 4-refinery and Waste2Road. Renewell is a national TKI-project focusing on the production of drop-in marine fuel from pyrolysis oil; the project is a cooperation between BTG, Goodfuels and Eindhoven University.

In 2020 a cooperation started with Delft University (de Jong) on the reforming/gasification of FPBO. BTG has designed and built an autothermal catalytic reformer (ACR) to produce syngas and/or hydrogen from FPBO. Syngas could be used as feedstock for the production of chemicals and/or fuels.

Fractionation of FPBO into its main fractions is of interest for the production of fuels and biobased chemicals/materials. This process is based on liquid-liquid extraction and work is done on laboratory and pilot scale (see demonstration activities). Fractions can be used directly or as a feedstock for further chemical/physical processing.

A relatively new activity on the use of FPBO concerns the application of electrocatalysis. It may (partially) replace the stabilisation of pyrolysis oil, a way to store electricity or a concept to produce specific chemicals. One PhD project recently started at University of Twente, while the topic is also part of a second PhD project at the same university.

In January 2020 a new project started with RUG and University Utrecht on the co-refining of pyrolysis oils (see section University of Groningen)

The BTG consultancy group is leading the European BIOFIT project which will support and initiate bioenergy retrofitting opportunities in five industry sectors, namely first-generation biofuels, pulp and paper, fossil refineries, fossil firing power and Combined Heat and Power (CHP) plants.). The

use of FPBO in these sectors is one of the options.

The European project ArtFuels is dealing with "Support for alternative and renewable liquid and gaseous fuels forum (policy and market issues)". BTG is involved in issues related to fast pyrolysis oil.

ECN>TNO

The main theme of ECN is the conversion of lignin rich material by fast pyrolysis. They have abubbling fluidized bed (1 kg/h) and a PYRENA pyrolysis unit (3 kg/h) available. The PYRENA concept is comparable to the MILENA gasifier developed by ECN. Typically, staged condensation is applied and multiple products are obtained.

Furthermore, ECN is performing research using analytical pyrolysis to study the catalytic pyrolysis of seaweed.

ECN is also an active member of the BIORIZON shared research centre (joint centre of TNO and Belgium research institute VITO). The aim is to produce biobased aromatics, and pyrolysis is considered as one of the possible routes.

University of Groningen (RUG)

The University of Groningen (Group Erik Heeres) is coordinating the European H2020 project called "ABC Salt - Advanced Biomass Catalytic conversion to middle distillates in molten SALTs". The idea is to improve the performance of pyrolysis by dissolving biomass and/or lignins in molten salts, and subsequently to upgrade the resulting liquid and/or vapour into middle distillates. BTG is participating in this project.

RUG has been active for a long time in catalytic upgrading of lignin, pyrolysis oil or fractions thereof by hydrogenation and/or oxygenation to fuels and chemicals. Recently, a PhD thesis was published on the conversion of lignin (Figueirêdo M.B., 2020, Valorization Strategies for Pyrolytic Lignin, University of Groningen, The Netherlands). In addition, Doug Elliott received his PhD degree at RUG for his work on hydrotreatment boil-liquids (Elliott D.C., 2019, Catalytic Hydroprocessing of Bio-oils of Different Types, University of Groningen, The Netherlands)

In a collaboration with Ghent University, a PhD project was carried out on the pyrolysis of lignin-rich residues and microalgae.

As stated earlier, in 2020 a project funded by the Dutch TKI started on the co-refining of pyrolysis oil. This project is a collaboration with Utrecht University with emphasis on co-processing in a lab scale pilot plant (Groningen), feed stabilisation (BTG) and catalysts (UU)

Twente University

Various groups at the University of Twente are active in the field of fast pyrolysis.

The group of Gerrit Brem developed their own fast pyrolysis process (Pyros) and investigates the use of sorbent materials and catalysts for in-situ deoxygenation (ENCAT) with the aim to improve the quality of pyrolysis oil. Project member OPRA turbines (Hengelo, the Netherlands) will test the pyrolysis oil on their gas turbine.

Pushkar Satish Marathe –PhD in the group of Sascha Kersten- completed a thesis entitled "The interplay between chemistry and transport phenomena during the fast pyrolysis of cellulose, lignin and biomass". The thesis is on-line available.

The group of Guido Mul is working in the field of electrochemical reactions and processes. In 2019 a collaboration was started with BTG on the electrochemical conversion of pyrolysis oil and/or its components into fuels and chemicals.

Technical University Eindhoven

TU/e is performing research on the combustion properties of fast pyrolysis oil as well as upgraded pyrolysis oil. The fuel properties of crude FPBO are evaluated in relation to its application in a modified diesel engine for CHP application (SmartCHP). In cooperation with Goodfuels Marine and BTG hydrogenated pyrolysis oil is evaluated as potential drop-in fuel for application in the shipping sector. For this activity a dedicated CRU (Combustion Research Unit) is available.

Utrecht University

The group of Weckhuysen is partner in the CORE-project led by Groningen University. The aim/role is to understand and optimise the catalysts in co-refining the oils (pure and stabilised) together with fossil based feeds.

The group of Martin Juninger has been involved in a number of activities related to the environmental assessment of pyrolysis value chain. Recently, they performed a LCC assessment in cooperation with BTG for biobased products derived from fast pyrolysis oil.

DEMONSTRATION ACTIVITIES

BTG

BTG has a number of pilot demonstration facilities available:

Fast Pyrolysis Pilot Plant (up to 2-5 t/day biomass input) based on rotating cone technology. The process is very similar to the Empyro plant. It is used to generate engineering data for new feedstocks, and test new ideas/concepts on pilot scale prior to implementing on full scale. Reversely, experiences & improvements from the Empyro operation are implemented in the pilot plant.

FPBO fractionation plant (up to 3 t/d of FPBO). This pilot unit applies multiple liquid-liquid extraction steps to fractionate FPBO in e.g. extractives, pyrolytic lignin, and pyrolytic sugars. The fractions are evaluated for use in products like resins, insulation foam and wood modification. The latter one is developed and tested by Foreco, a Dutch company with their business in the wood industry.

FPBO hydrotreating plant (up to 50 kg/d of FPBO). This unit consists of multiple reactors to stabilize/hydrogenate FPBO. The unit can work at pressures up to 200 bar and temperatures up to 450 °C.

COMMERCIAL APPLICATIONS

Empyro

The Empyro plant has been acquired by Twence (January 1, 2019), and operation has been continued. Since its commissioning/start-up in 2015 the plant has produced around 50 million litre of FPBO. The feedstock is clean wood, but Twence is also experimenting with other feedstocks, and started the construction of a new biomass storage and supply unit. Likely, it will be commissioned in the first half of 2020. Besides FPBO, the Empyro plant also produces electricity and process steam.

Almost the complete production (> 99%) has been used as fuel to replace natural gas by

FrieslandCampina. The oil is transported by tank truck to their site (~ 30 km distance), and fed to their process steam boiler.

BTG Bioliquids (BTL)

The aim of BTG Bioliquids is to sell pyrolysis plants based on their technology. For the implementation of plants BTLcooperates with TechnipMFC. The core of the technology is built by Zeton 9Enschede, the Netherlands). Empyro was and is a reference case, and similar plants as Empyro have been sold to Finland and Sweden. In Finland, GFN (Green Fuel Nordic) will own and operate the plan, and the oil is mainly meant for heating. In Sweden, Pyrocell (a joint venture of Setra and Preem) will produce pyrolysis oil which will be used as co-feed in the FCC unit of Preem (o.a. transportation fuels). In both cases sawdust is used as feedstock.

BTL pyrolysis oil can also be purchased via their webshop (www.btg-btl.com) starting with a few litres up to several tonnes. It appeared to be very helpful for researchers around the world to use this oil as starting point for their development.

Sweden

Major stakeholders in Sweden around DTL technologies are summarized in Table 1. All these stakeholders have been actively researching and/ or promoting DTL technologies in 2019. Efforts to produce lignin oils from black liquor are also included.

Table 1: DTL Stakeholders in Sweden

Institution	Main Contact / CEO	Key activities
PYROCELL (Preem + Setra)	Pontus Friberg	Fast pyrolysis plant (25 000 ton PO/year) from saw dust under construction.
Preem	Niclas Brantingson (press officer)	Working to introduce various biooils to the refinery, e.g. the pyrolysis oil from Pyrocell.
SCA Biorefinery	Roger Östlin (technical manager)	Investigating the prospects of building a biorefinery which will produce fuels and chemicals from forest and forest industry by-products.
Renfuel	Sven Löchen	Lignin bio-oil
SunCarbon	Peter Blomqvist	Lignin bio-oil
Envigas	Kurt Sjöblom	Pyrolysis followed by staged condenser
RISE	Linda Sandström	Fast pyrolysis, hydrothermal liquefaction
KTH Royal Institute of Technology	Weihong Yang	Fast pyrolysis

DTL WITHIN THE NATIONAL POLICY FRAMEWORK

The Swedish government has a target of 70% reduction of domestic transport greenhouse gases 2030 compared to 2010 (excluding domestic flights). The Swedish Energy Agency published a check point in 2019 for the suggested development of the reduction quota 2021 – 2030 to reach this target. Current (2020) reduction levels of 4% in petrol and 21% in diesel are suggested to increase linearly to 28% in petrol and 65.7% in diesel by 2030. These ambitious targets put high demands on increased production of biofuels.

RESEARCH ACTIVITIES

RISE

The fast pyrolysis pilot plant at RISE is based on an ablative concept with a cyclone reactor at the core. The capacity is about 30 kg of biomass per hour. Currently the plant is being used in the Biomates project (EU Horizon 2020). Other fast pyrolysis activities at RISE involve the start-up of a hydropyrolysis research project.

RISE Processum possess two pilots for hydrothermal liquefaction; a smaller plant which can simulate a continuous process and a larger, continuous pilot plant. The continuous pilot can operate at temperatures up to 400˚C and pressures up to 300 bar and is used for instance in the AGROinLOG project (EU Horizon 2020).

KTH Royal Institute of Technology

KTH performs research in the fast pyrolysis area using several bench-scale setups from batch type reactors to continuous fluidized bed system and screw reactor. Both catalytic and thermal pyrolysis are studied. Activities include catalyst development and catalytic process development. Studied feedstock includes soft wood, hard wood, lignin and leached biomass using woody-derived acid. Co-pyrolysis of waste plastic and biomass are also checked. Example of project CCFP funded by the Swedish Energy Agency.

DEMONSTRATION ACTIVITIES

Lignocity

Open testbed for lignin to chemicals and fuels, originally established to demonstrate the LignoBoost technology.

COMMERCIAL APPLICATIONS

Pyrocell

Pyrocell (owned by Preem and Setra) are constructing a fast pyrolysis plant based on BTG BTL's pyrolysis concept. The feedstock will be saw dust and the facility will provide around 25 000 tonnes of pyrolysis oil per year that, via Preem's refinery in Lysekil, Sweden, will be refined into biofuel. The aim is to have the plant up and running in 2021.

SCA Biorefinery

SCA is investigating the prospects of building a biorefinery which will produce fuels and chemicals from forest and forest industry by-products. The annual production will be about 300 000 tonnes of hydrocarbons at two full production lines. One of the lines will be based on by-products from the forest industry such as saw dust and bark, the other will be based on black liquor. SCA is now in the phase of investigating permissions etc., and the final investment decision is not taken.

RenFuel

RenFuel and Preem are together with Rottneros investigating to construct a lignin-based transportation fuel plant of 25 000 – 30 000 ton lignin/year.

SunCarbon

Sveaskog and Preem have during 2019 entered as part owners of SunCarbon. The aim is a lignin-based plant processing 45 000 ton lignin annually, to be commissioned in 2022.

Envigas

Pyrolysis of forest residuals for bio-carbon for metallurgic applications and biooil. Production in demonstration scale from early 2019 with a 30 000 ton biomass /year plant to be commissioned in middle of 2020.

IEA Bioenergy

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

Contact us:
www.ieabioenergy.com/contact-us/