IEA Bioenergy
Technology Collaboration Programme

Country Reports 2022

Direct Thermochemical Liquefaction

(New Zealand, The Netherlands)

IEA Bioenergy: Task 34

December 2022

Country Reports 2022

Direct Thermochemical Liquefaction

(New Zealand, The Netherlands)

Francois Collard, Bert van de Beld

Edited by Alexandra Böhm

IEA Bioenergy: Task 34

December 2022

Published by IEA Bioenergy

New Zealand

Major stakeholders in New Zealand around DTL technologies are summarized in Table 1. All of these stakeholders have been actively researching and/or promoting DTL technologies in 2022.

Table 1: DTL stakeholders in New Zealand

Institution	Main contact	Key Activities
Blended Fuel Solutions NZ	Simon Arnold	Biofuels blending
Cetogenix	Daniel Gapes	Hydrothermal oxidation
Nufuels	Leigh Ramsey	Pyrolysis of plastic/biomass waste
Scion	François-Xavier Collard	Catalytic Fast Pyrolysis of wood
University of Canterbury	Shusheng Pang	Catalytic pyrolysis Steam reforming of bio-oil

DTL WITHIN THE NATIONAL POLICY FRAMEWORK

Marsden Point refinery, the only oil refinery in New Zealand closed in March 2022 and is being dismantled. Several decisions were made by the Government to express its commitment to creating a more sustainable energy system:

- It is not allowed to install new coal boiler anymore. Most of the running coal boilers will be replaced by wood or electric boilers by 2037, which will impact biomass availability,
- Climate Emergency Response Fund (CERF)
  NZ$91 million will be provided to stimulate greater production of woody biomass and provide more options for business to switch away from the use of fossil fuels,
  NZ$20 million funding to support innovations in the decarbonisation of freight
- Air New Zealand has started flying with Sustainable Aviation Fuels (SAF). The company has imported 1.2 million litres of jet fuel, which represents 1% of total fuel purchased by the company this year. The objective is to fuel the fleet with 10% SAF by 2030 and reach the goal of net-zero emissions by 2050. A joint RFP between Air New Zealand and the Ministry of Business, Innovation and Employment is assessing the feasibility of SAF domestic production,
- Sustainable Biofuels Obligation aiming at reducing greenhouse gas emissions in the transport sector. Fuel wholesalers will be required to deploy biofuels as a part of their fuel supply. From 2024, the target percentage of biofuels will increase on a yearly basis and could reach up to 9% by 2035.
- A NZ$2 million feasibility study to explore the development of hydrogen and bio-fuels at Tokoroa's Kinleith pulp and paper mill, to be completed in 2023

RESEARCH ACTIVITIES

Scion

Scion's bioenergy research programme focusses on wood-based transport biofuels and industrial energy. In the liquid biofuel area, Scion is working on the difficult to decarbonise sectors, including marine and aviation fuels. Scion plays a role in technology development as well as adopting/adapting the best international technologies for implementation in New Zealand. Scion’s liquid biofuels R&D programme is currently focussed on catalytic fast pyrolysis of wood.

University of Canterbury

The Faculty of Engineering of the University of Canterbury has several projects around liquefaction, including pyrolysis of biomass and waste plastic for liquid fuels production, catalytic pyrolysis for high value products and catalytic steam reforming of bio-oil.

Nufuels Ltd

Nufuels (100% owned subsidiary of BFSNZ) has a programme addressing disposal of difficult wastes that consist of multi-layered products, which include biomass as one component. It is close to market with a pyrolysis system for one such feedstock. It is also experimenting co-pyrolysis of some plastic products with biomass to improve fuel products.

Blended Fuel Solutions NZ Ltd

Blended Fuel Solutions NZ has a development programme under way targeting the blending of less refined biofuels with fossil fuels to give fit-for-purpose drop-in fuels for use in selected internal combustion engines.

Cetogenix

Cetogenix is developing a processing technology based on a combination of hydrothermal oxidation and fermentation. Hydrothermal oxidation breaks down complex waste streams (agriculture, food processing, sewage treatment and industrial) into simple components, making them a great feedstock for biological conversion to clean energy and bio products.

DEMONSTRATION ACTIVITIES

Currently, there is no demonstration or commercial application of DTL technologies in New Zealand.

The Netherlands

Major stakeholders in the Netherlands around DTL technologies are summarized in Table 1. All of these stakeholders have been actively researching and/or promoting DTL technologies in recent years. Commercial activities are mainly covered by BTG Bioliquids, Technip, Empyro (Twence) and FrieslandCampina.

Table 1: 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 (energy. Advanced biofuels, chemicals & materials)
BTG Bioliquids	Gerhard Muggen	Fast pyrolysis, implementation/commercialization of technology
BTG-neXt	Hugo Borger	Upgrading fast pyrolysis oil, implementation & commercialization
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	Felipe Ferrari	Upgrading pyrolysis oil to drop-in marine fuel
OPRA Turbines	-	Use of fast pyrolysis oil in a modified turbine
SkyNRG	Eva van Mastbergen	Jetfuel/SAF from pyrolysis oil
Technical University Delft	Wiebren de Jong	Gasification/reforming of fast pyrolysis oil
	Arvind Gangoli Rao	Jetfuel/SAF from pyrolysis oil
Technical University Eindhoven	Bart Somers	Engine testing, combustion properties of crude & upgraded pyrolysis oil
TechnipEnergies	Jacco Kroeze	Implementation of fast pyrolysis technology / FCC application
TNO	Berend Vreugdehil	Fast pyrolysis, catalytic pyrolysis, fractional condensation
University of Groningen	Erik Heeres	Catalytic pyrolysis, hydrogenation, pyrolysis in molten salts, chemicals from pyrolytic lignin & pyrolytic sugars, co-fcc
University Twente	Gerrit Brem	Catalytic pyrolysis, turbine application
	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. The application of biomass derived intermediates can also be supported

provided all sustainability criteria are fulfilled. Pyrolysis oil derived fuels for transportation have been introduced in 2022 in SDE+. Demonstrtaion activities are supported within the DEI+ programme, but use of biomass (or pyrolysis oil) in real demo-plants are excluded.

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.

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.

In the SmartCHP project FPBO is used in modified diesel engines. In 2021, a milestone was achieved of running the engine on FPBO (with 10 wt% ethanol added) for 500h without replacing fule pump and injector. Also the operation on pure FPBO was demonstrated. Meanwhile,over 1,000h of operation has been accumulated with a single fuel injection system. A 50 kW_e prototype is under construction and will be completed early 2023. SmartCHP is a European project and besides BTG also the Dutch partners Abato Motoren and the University of Eindhoven are participating.

For the upgrading of FPBO BTG has developed –in cooperation with Groningen University and Boreskov Institute of Catalysis- a new catalyst (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 four hydrotreaters (~1 kg/h feed) are available to develop the process as well as a pilot unit (20-50 kg feed/day). 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. More recently, a project called PureJet involving SkyNRG and Delft University was initiated. It concerns the production of jetfuel (SAF) from pyrolysis oil.

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 to produce chemicals and/or fuels. The syngas contains around 50 v% of hydrogen and relatively independent of the original biomass feedstock.

Fractionation of FPBO into its main fractions is of interest to produce 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. In the European Horizon Europe project NewWave different products are validated like ethylene/propylene glycol, polyols, resins, phenols and formulations for wood modification.

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. The activity started with a national project together with the University of Twente, and further extended in the European project called EBIO (Biofuels through Electrochemical transformation of intermediate BIO-liquids).

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 supports and initiates 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. Additionally, the MUSIC project aims to facilitate the further introduction of intermediate bioenergy carriers by developing feedstock mobilisation strategies, improved logistics and trade centres for these intermediates.

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", which was completed in 2022. 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.

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. RUG is one of the partners in the European NewWave project. Specific activities include the catalytic treatment of pyrolytic lignin and sugars as well as detailed analysis of the different streams.

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). The pilot unit designed and built by RUG is installed at BTG, and commissioning is expected early 2023.

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.

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. In 2022, Harsha Mysore Prabhakara completed his thesis named, " Sorption enhanced catalytic fast pyrolysis for the production of high-quality bio-oil from biomass" The existing equipment of the group are, bench scale 1 kg/hr biomass feed fluidized bed, gasifier/pyrolysis unit. Drop tube reactor for biomass pyrolysis reaction kinetics measurements and a cyclonic TGA for kinetic measurements under fast pyrolysis conditions.

The group of Guido Mul is working in the field of electrochemical reactions and processes. In 2019 a collaboration was started with BTG (national project EC2Fuel) on the electrochemical conversion of pyrolysis oil and/or its components into fuels and chemicals. The work and collaboration is continued in the European project EBIO.

Technical University Eindhoven

TU/e is performing research on the combustion properties of fast pyrolysis oil as well as upgraded pyrolysis oil. For this activity a dedicated CRU (Combustion Research Unit) is available at TU/e as well as research engines. 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 (HPO) is evaluated as potential drop-in fuel for application in the shipping sector. Blends of marine diesel and HPO were successfully tested in an engine up to 50% HPO.

TNO

TNO has developed several tools over the years to support pyrolysis activities. In this area they have the possibility to perform slow pyrolysis and fast pyrolysis in installations up to 5 kg/h. The experience over the years has been used to develop their tools also for plastics pyrolysis with a strong focus on the fractionated recovery of liquid products. As part of the Biorizon shared research centre a fast pyrolysis unit was build connected to a staged condensation unit to allow the valorization of various liquid products.

As technology development, TNO is investigating various pathways starting with pyrolysis for the production of fuels. Part of this research falls within the scope of Biorizon where the production of aromatics is put central. These components can be used as blend components in f.i. aviation fuels to reach specifications.

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. For commercialization and implementation of the process the company BTG-neXt was established.

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 constructed a new biomass storage and supply unit. 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. Operation is challenged by the current energy prices and high costs of biomass feedstock.

BTG Bioliquids (BTL)

The aim of BTG Bioliquids is to sell pyrolysis plants based on their technology. For the implementation of plants BTLcooperates with TechnipEnergies. The core of the technology is built by Zeton (Enschede, 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) owns and operate the plant, and the oil is mainly meant for heating. In

Sweden, Pyrocell (a joint venture of Setra and Preem) produces pyrolysis oil which is 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 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.