IEA Bioenergy
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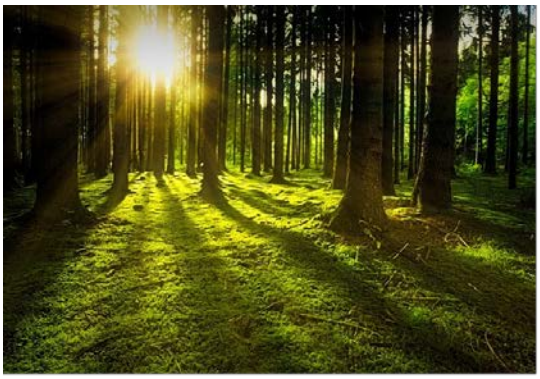
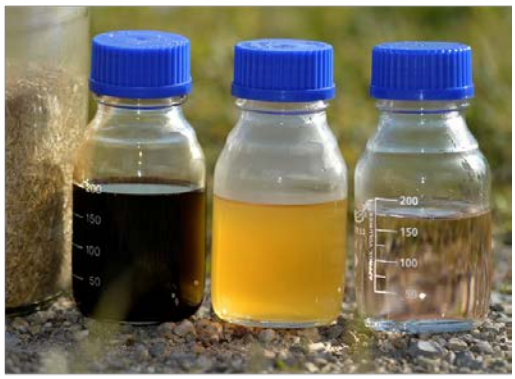
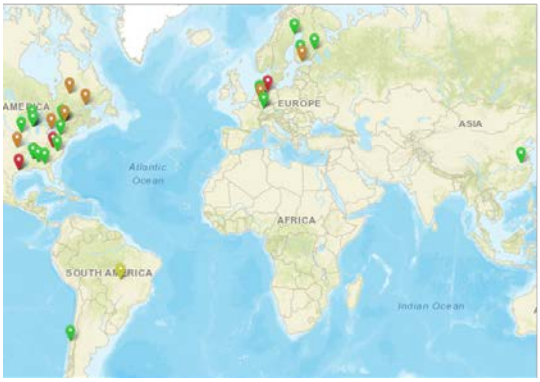
Commercial status of direct thermochemical liquefaction technologies

IEA Bioenergy: Task 34

August 2020

Commercial status of direct thermochemical liquefaction technologies

Suren Wijeyekoon, Kirk Torr, Hilary Corkran and Paul Bennett

IEA Bioenergy: Task 34

August 2020

Cover pictures (to the right) by Thomas Zevaco

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Executive summary

Direct thermochemical liquefaction (DTL) of biomass is an important pathway to bioenergy and biochemical production in the circular economy.

The aim of this report is to highlight how DTL technologies currently have a role to play in mobilising biomass into the energy sectors (heat, power and transport), and to highlight the key features of commercially successful DTL operations.

The IEA Bioenergy's Task 34 commissioned Scion to compile this report in consultation with its National Leaders.

The report covers current commercial activity, near-to market activities (e.g. demonstration plants) and some recently decommissioned near-to market plants. A database of DTL activities that includes pilot-scale operations is also attached to the report to capture some research activities that may move into commercial-scale production in the future.

Brief details of 10 commercial and 10 demonstration scale DTL plants that are either operational or late stage development, spread across 11 countries, are provided. The commercial-scale plants are mostly (9) pyrolysis technologies while the demo operations are a mixture of fast pyrolysis (6) and hydrothermal liquefaction (4). Wood and forest residues are the feedstock of choice for all the commercial plants. The bio oils produced are sold as fuel for heating or for co-processing in petroleum refineries. In most cases, co-products such as electricity, syngas and chemicals are also produced that improve the plant economics. For example, the Red Arrow facilities in USA produce speciality chemicals from fast pyrolysis of wood residues. The largest plants produce around 80 million litres of bio oil per annum. Commonly, the feedstock producers such as pulp mills and end-product producing petroleum refineries partner with technology developers in joint ventures. Commercial-scale DTL plants require significant investments of the order of USD 80 million for an 80 million litre plant and are financed through mechanisms such as equity, debt financing, shareholding and government grants.

The demonstration-scale activities show growing interest in hydrothermal liquefaction technologies. More diversified feedstocks such as agricultural and urban waste and sewage sludge are targeted with recent interest in non-bio feedstocks such as waste plastics and used tyres.

Some operations have been discontinued during the past years for various reasons. Notable among them are the Kapolei plant in Hawaii, United States that never became operational and the Muradel plant in Australia that has gone into voluntary administration.

The information presented shows that DTL technologies have matured to become a key vehicle for bioenergy commercialisation. Increasing number of pilots have succeeded bridging the technology valley of death by advancing the technology readiness level beyond 6 at reasonable costs to demonstrate scalability and financial viability. Favourable policy initiatives will further increase the number of commercial DTL plants contributing to increasing bioenergy production.

It is recommended that the data base is frequently updated by keeping a watching brief on the developing commercial space.

Introduction

The Direct Thermochemical Liquefaction (DTL) technologies for biomass conversion have been investigated since the 1970s and are receiving renewed interest due to global decarbonisation efforts, supported by favourable policies and financial incentives. DTL refers to the thermal depolymerisation of biomass under a range of controlled temperatures, pressures and catalysts to derive useful energy and chemical products. DTL technologies include the different modes of pyrolysis, hydrothermal and solvo-thermal liquefaction processes.

Pyrolysis is a technique for thermochemical decomposition of biomass through rapid heating (450-600 °C) in the absence of oxygen. Three products, solid char, bio-oil and gas are always produced. By-products of pyrolysis can be heat (steam), power (electricity) and chemicals. Different modes of pyrolysis are carried out depending on the preferred end-product. By fast pyrolysis, different types of biomass can be converted into a homogeneous energy carrier called bio-oil.

Fast pyrolysis is proven at commercial scale with worldwide capacity expanding. Fast pyrolysis bio-oils are used as renewable heating oil replacing petroleum oils and gas. The bio-oils can also be upgraded to produce drop-in fuels. Co-processing crude bio-oil in fluidised catalytic cracking (FCC) units in petroleum refineries is a "low-capex" upgrading option. Other applications of pyrolysis oil are under development such as recovery of sugar-derived components as platform chemicals and use of pyrolytic lignin as a phenol replacement in resin, adhesives.

Hydrothermal liquefaction (HTL) utilises elevated temperature and pressure to break the carbon bonds in feedstocks and reform them into long chain molecules that take the form of a bio-crude oil. This can be upgraded into transport fuels such as diesel. Feedstocks such as pulp mill residues and sewage sludge have been transformed to bio-crudes by HTL (Licella and Muradel plants).

A large number of laboratory and pilot DTL investigations have been reported trialling different feedstocks, reactor configurations and catalysts to improve product quality and yields. Some DTL technologies have now matured and moved into commercial production. The number of successful commercial ventures provide the confidence and pathway for others to follow. This report collates the current commercial and demonstration DTL plants planned, and in operation, from publicly available information sources in an endeavour to further publicise successful DTL technologies.

The information is presented in summary form in alphabetical order of countries they are located in. Further information can be accessed from the website links provided. A separate spreadsheet database with DTL plants including pilot facilities is provided with this report.

Materials and methods

Commercial and near-to market (demonstration plants) DTL biomass plants were investigated from publicly available sources. This compilation updated the IEA Bioenergy Task 34 pyrolysis-demoplant-database (http://task34.ieabioenergy.com/publications/pyrolysis-demoplant-database/). Country reports from the Task 34 national leaders was also used in conjunction with information from the existing T34 database.

A full literature search was conducted to assess activities outside the T34 member countries.

The information as gathered was exchanged with T34 members and their feedback was incorporated in the final analysis.

Commercial Direct Thermochemical Liquefaction Plants

BRAZIL: ARACRUZ PROJECT

Owner: Ensyn, Suzano S.A.
Technology Provider: Envergent
Location: Aracruz, Espirito Santo, Brazil
Scale: Commercial
Technology Readiness Level (TRL) 8
Status: Under development

The Aracruz Project is to be an 83 ML/year pyrolysis oil production facility that is currently in late stage development. The plant is located in Aracruz, Espirito Santo, Brazil. This project was developed by Ensyn and Suzano (formerly Fibria Celulose S.A.), where both firms share equity. The technology was supplied by Envergent (Ensyn /Honeywell UOP joint venture). The project was financed by partner equity and USD 77M debt financing from local sources. The plant will use Ensyn's Rapid Thermal Processing (RTP®) technology to convert approximately 17 000 kg eucalyptus forest residues into 11 000 kg of pyrolysis bio-oil per hour to be shipped from a neighbouring port and sold to refinery and heating markets in the USA. The Ensyn RTP® technology is a fast pyrolysis technology that uses a circulating fluidised bed reactor to produce a liquid pyrolysis oil, with char and non-condensable gas by-products used for process heat.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – circulating fluidised bed reactor	Eucalyptus forest residues	Pyrolysis oil	83 ML/y	USD 77M	Unknown

Website and image source: **http://www.ensyn.com/brazil.html**

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CANADA: CANFOR-LICELLA JOINT VENTURE

Owner: Canfor (CPPI) Pulp Mills and Licella Pty Ltd
Technology Provider: Licella Pty Ltd
Location: Prince George, British Columbia, Canada
Scale: Demonstration to Commercial, TRL7-8
Status: Under development

The development of a demonstration to commercial scale hydrothermal liquefaction plant at the Canfor Pulp and Paper mill site, in Prince George, Canada, is currently in progress. The project is a joint venture between Canfor and Licella. The proposed plant will use Licella's Cat-HTR™ technology to convert residues from the pulp and paper factory into Hydrothermal Liquefaction (HTL) bio-crude at a rate of 500 000 barrels per year. A CAD 13M grant from Sustainable Development Technology Canada was awarded in March 2017, towards the CAD 39M project.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Hydrothermal liquefaction	Wood and pulp residues from Kraft pulping	Bio-crude	500 000 barrels/y (*ca.* 80 ML/y)	CAD 39M	Unknown

Website: **https://www.licella.com.au/pulp-paper/**

Image source: Robert Puhr Photography, IEA Bioenergy Task 34, Canada Country report, June 2019 meeting

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CANADA: CÔTE NORD

Owner: Ensyn, Arbec Forest Products, Groupe Remabec
Technology Provider: Envergent
Location: Port Cartier, Canada
Scale: Commercial, TRL8-9
Status: Active

Côte-Nord is a 38 ML/year pyrolysis oil production facility located in Port-Cartier, Quebec. This project was developed by Ensyn, Arbec Forest Products and Groupe Rémabec, and the technology was supplied by Envergent. The project was financed by partner equity, funding from the Government of Canada (Sustainable Development Technology Canada and the Department of Natural Resources Canada) and Investissement Quebec, the leading Quebec provincial financing corporation. Ensyn owns a minority interest in the equity of the project. Côte-Nord was completed and commissioned in 2018. Côte-Nord used Ensyn's RTP® fast pyrolysis technology to convert approximately 65,000 dry metric tons/year of cellulosic woody biomass to pyrolysis oil. The pyrolysis oil is sold to customers in the Northeast US and in Eastern Canada for heating purposes and as a renewable feedstock for refinery co-processing.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – circulating fluidised bed reactor	Wood residues from Arbec saw-mill	Pyrolysis oil	38 ML/y	USD 78M	2018

Website and image source: **http://www.ensyn.com/quebec.html**

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CANADA: ONTARIO FACILITY

Owner: Kerry Group (Ensyn)
Technology Provider: Ensyn
Location: Renfrew, Ontario, Canada
Scale: Commercial, TRL9
Status: Active

Ensyn's Ontario facility produces 11 ML/year of pyrolysis oil for use as renewable fuel oil. This facility, one of the first for Ensyn, was commissioned in 2006 and was originally focussed on the production of specialty chemicals and heating fuels. In 2014, the plant was refitted as a dedicated fuels plant to produce pyrolysis oil, with up to CAD 4 million reportedly invested. The facility used Ensyn's RTP® fast pyrolysis technology to produce heating oils for clients in USA under long term contracts. Production capacity is also reserved to support the commercialisation of refinery co-processing, with upgrades for this capability in progress. Kerry Group are reported to have purchased the Ensyn Ontario facility in December 2019 to produce food ingredients.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – circulating fluidised bed reactor	Mill and forest woody residues	Pyrolysis oil	11 ML/y	Unknown	2006

Website and image source: **http://www.ensyn.com/ontario.html**

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FINLAND: FORTUM

Owner: Fortum, Valmet
Technology Provider: Valmet
Location: Joensuu, Finland
Scale: Commercial, TRL8
Status: Active

The Fortum Plant in Joensuu, Finland is an integrated pyrolysis oil commercial demonstration plant that is connected to the Joensuu power plant. The project co-owned by Valmet and Fortum, with support from VTT, a research, development and innovation partner. The plant was commissioned in 2013 and uses Valmet's fast pyrolysis technology to produce 50 000 tonnes/year pyrolysis oil, as well as heat and electricity. The feedstock is forest residues and other wood-based biomass. Fortum invested EUR 30M in the project, of which the Finnish State subsidized EUR 8M. Valmet and Fortum are collaborating with Preem to develop and commercialize pyrolysis technology, based on the Joensuu plant, for producing upgraded pyrolysis oil suitable as a refinery co-feed.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis - VTT fluid bed riser reactor	Forest residues, sawdust	Pyrolysis oil	50 kt/y (*ca.* 43 ML/y)	EUR 38M	2013

Website: **http://pyrowiki.pyroknown.eu/index.php/Commercial_plants**

Image source: **https://www.goodnewsfinland.com/finnish-industrial-companies-active-worldwide/fortum-joensuu-energy-plant-2/**

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FINLAND: GREEN FUEL NORDIC OY

Owner: Green Fuel Nordic Oy
Technology Provider: BTG BioLiquids (BTG-BTL)
Location: Lieksa, Finland
Scale: Commercial, TRL8
Status: Active

Green Fuel Nordic Oy is a planned fast pyrolysis commercial scale facility that is currently under construction next to a sawmill in Lieksa, Finland. The plant will use the BTG-BTL fast pyrolysis technology that will be implemented by Technip, with the core unit being manufactured by Zeton. The BTG-BTL technology uses a rotating cone fast pyrolysis reactor. The plant is expected to be operational by the end of 2020. The project is funded by venture capital, the North Karelia ELY Centre and Green Fuel Nordic Oy shareholders with the first phase of the investment worth EUR 25M. The plant will produce 20 ML/y pyrolysis oil, utilising primarily sawdust and wood residues from the sawmill. The pyrolysis oil will be sold to production facilities in Finland and the Netherlands.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – rotating cone reactor	Sawdust and wood residue	Pyrolysis oil	20 ML/y	EUR 25M	Q4 2020

Website and image source: **https://www.greenfuelnordic.fi/**

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THE NETHERLANDS: EMPYRO

Owner: Twence
Technology Provider: BTG BioLiquids (BTG-BTL)
Location: Hengelo, The Netherlands
Scale: Commercial, TRL8
Status: Active

Empyro is a 20 million litres/year pyrolysis oil production facility at the AkzoNobel site in Hengelo, The Netherlands. The Empyro plant was commisioned in 2015 and reached its rated capacity in October 2017. The project was financially supported by the 7th Framework Programme of the European Commission, by the Dutch government via the Topsector Energy: TKI-BBE and by the province of Overijssel via the Energy Fund Overijssel. The plant uses the BTG-BTL fast pyrolysis technology to convert clean woody biomass (e.g. sawdust) into pyrolysis oil, steam and electricity. The process steam is used directly on site by AkzoNobel. The pyrolysis oil is largely used by dairy company FrieslandCampina to replace natural gas for the production of process steam. The Empyro plant was sold to Twence at the beginning of 2019.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – rotating cone reactor	Clean woody biomass	Pyrolysis oil	20 ML/y	EUR 19M	2015

Website: **https://www.btg-btl.com/en/company/projects/empyro**

Image source: **https://www.twence.nl/energie/hoe-maken-wij-energie.html**

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SWEDEN: PYROCELL

Owner: Pyrocell AB
Technology Provider: TechnipFMC and BTG BioLiquids (BTG-BTL)
Location: Kastet, Gävle, Sweden
Scale: Commercial, TRL8
Status: Under construction

Pyrocell is a pyrolysis plant under development for the conversion of sawdust into pyrolysis oil with an expected capacity of 25 000 tonnes of bio-oil per year. Pyrocell AB is a joint venture between the Swedish wood processing company Setra and oil refinery Preem AB. The fast pyrolysis technology will be provided by Dutch companies TechnipFMC and BTG BioLiquids. The Swedish government's "Climate Step" programme provided Setra with SEK 117M (EUR 12M) in funding to build the pyrolysis oil plant and establish a value chain between sawmills and the oil refinery industry. Ground-breaking at Setra's Kastet sawmill took place in March 2020. The pyrolysis oil produced at Pyrocell will be further refined by Preem for use as a fossil-free fuel. The Pyrocell plant is expected to be operational by the end of 2021.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – rotating cone reactor	Sawdust	Pyrolysis oil, oil refinery co-feed	25 000 t/y (*ca.* 21 ML/y)	EUR 12M	2021

Website: **https://www.setragroup.com/en/pyrocell/about-pyrocell/**

Image source: **https://www.btg-btl.com/en/company/projects/pyrocell1**

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USA: GEORGIA PROJECT

Owner: Ensyn and Renova Capital
Technology Provider: Envergent
Location: Roseburg Vienna, Dooley County, Georgia, USA
Scale: Commercial, TRL8
Status: Late stage development

Currently in late stage development, the Georgia Project is to be a 76 ML/year pyrolysis oil production facility, located in Roseburg Vienna, Georgia, USA. This project is owned by development partners Ensyn and Renova Capital. The project was financed by partner equity and a conditional USD 70M Loan Guarantee from the USDA with Citibank as the Lender of Record. The plant will use Ensyn's RTP® fast pyrolysis technology supplied by Envergent. The plant will convert wood residues from Roseburg Forest Products' Vienna mill, and forest residues from local sources, to pyrolysis oil. The pyrolysis oil will be directed to refineries for co-processing and/or clients for use in heating and cooling applications.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – circulating fluidised bed reactor	Mill wood residues, forest residues	Pyrolysis oil	76 ML/y	USD 70M	Unknown

Website: **http://www.ensyn.com/georgia.html**

Image source: Roseburg Vienna Mill
https://www.energy.gov/sites/prod/files/2017/10/f38/jacobs_bioeconomy_2017.pdf

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USA: RED ARROW FACILITIES

Owner: Kerry Group
Technology Provider: Ensyn
Location: Rhinelander, Wisconsin, USA
Scale: Commercial, TRL9
Status: 5 Licenced Facilities Active

Red Arrow was a specialty chemical company that was purchased by the Kerry Group in 2015. The Red Arrow Facilities are a series of 5 commercial RTP plants in Rhinelander, Wisconsin. The 3 largest processing plants, commissioned in 1995, 2002, and 2014, have a capacity of 30 – 40 tons/day of pyrolysis oils. These plants are used by Kerry Group to produce specialty chemicals for the food industry. The facilities utilise Ensyn's RTP® technology and receive ongoing operations supervision, maintenance and technical support from Ensyn. Ensyn's Ontario Facility in Renfrew was sold to the Kerry Group in 2019.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – circulating fluidised bed reactor	Wood residues	Specialty chemicals	30-40 tons/d (*ca.* 9 ML/y)	Unknown	1995

Website: **http://www.ensyn.com/licensed-production.html**

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Demonstration Direct Thermochemical Liquefaction Plants

AUSTRALIA: LICELLA – NEW SOUTH WALES

Owner: Licella Pty Ltd
Technology Provider: Licella Pty Ltd
Location: Somerby, New South Wales, Australia
Scale: Demonstration to Commercial, TRL6-7
Status: Active

Licella is an Australian company based in New South Wales with hydrothermal liquefaction technology trademarked as catalytic hydrothermal reactor (Cat-HTR™). The company developed the technology to the large pilot or demonstration scale (10,000 t/y) at Somerby in New South Wales. Subsequently Licella partnered with Canfor (Canada) to transform pulp and paper residues into bio-crude oils that can be used to produce biofuels and chemicals (see below). Additionally, Licella partnered with Armstrong Chemicals (UK) to build the first commercial plant for chemical recycling of end-of-life plastics using the Cat-HTR™ technology.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Hydrothermal liquefaction	Wood, agricultural residue, pulp and paper	HTL bio-crude	Demo: 10,000 t/y (*ca.* 9 ML/y)	AUD 75M	2012
	End-of-life plastics	Recycled oil	125,000 t/y (*ca.* 114 ML/y)	Unknown	Under planning

Website and image source: **https://www.licella.com.au/**

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AUSTRALIA: MURADEL

Owner: Muradel Pty Ltd (University of Adelaide, Aban Australia Pty Ltd, SQC Pty Ltd)
Technology Provider: Muradel Pty Ltd
Location: Whyalla, South Australia, Australia
Scale: Demonstration, TRL7
Status: Inactive – Entered voluntary administration in 2019

Muradel was a pre-commercial plant that produced bio-crude oil from microalgae via hydrothermal liquefaction using a subcritical water in a process trade-named Green2Black™. Commissioned in 2014, the plant was situated in Whyalla, South Australia. Aban Australia, Southern Oil and SQC were industry partners and the University of Adelaide was a research and development partner. The Muradel project was partly supported by AUD 5M in grants from the federal government's Australian Renewable Energy Agency. Muradel went into voluntary administration in 2019.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Hydrothermal liquefaction	Sewage sludge, microalgae, recycled tyres	HTL bio-crude	Unknown	AUD 11.8M	2014

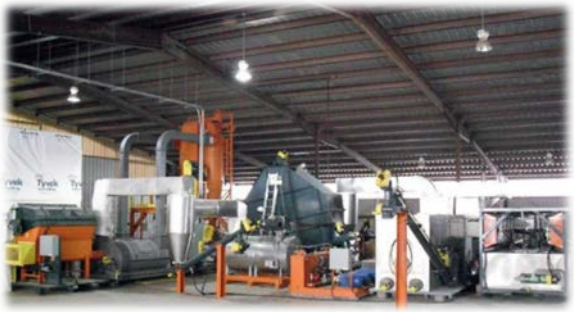
Website: **https://arena.gov.au/projects/advancing-marine-microalgae-biofuel-to-commercialisation/**

Image source: **https://www.whyallanewsonline.com.au/story/6030891/muradel-enters-administration/**

Past contact:
Andreas Isdepsky
Chief Operations Officer
Muradel Pty Ltd

CANADA: ABRI-TECH PARENT

Owner: Pyrobiom Energies Inc.
Technology Provider: ABRI-Tech Inc
Location: Parent, Quebec, Canada
Scale: Demonstration, TRL6
Status: Active



ABRI-Tech provides modular biomass thermochemical transformation systems that include a biomass dryer and an auger-based fast pyrolysis reactor. A 50 tonne/day demonstration unit is available as well as a smaller mobile pyrolysis unit with 1 tonne/day capacity.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – auger reactor	Woody residues	Pyrolysis oil	50 t of biomass/d (up to 6 ML bio-oil/y)	CAD 7M	Unknown

Website: **https://abritechinc.com/en/home/**

Image source: Direct thermochemical liquefaction for energy applications, Lasse Rosendahl (Ed.), Woodhead Publishing, 2018, p 22.

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CHINA: DALI COUNTY FACILITY

Owner: Shanxi Yingjiliang Biomass Company and Shanghai Jiao Tong University
Technology Provider: Shanxi Yingjiliang Biomass Company and Shanghai Jiao Tong University
Location: Dali County, Shanxi Province, China
Scale: Demonstration, TRL6-7
Status: Active

The demonstration plant at Dali County in China utilises downdraft circulating fluidised bed fast pyrolysis technology. The facility processes 1-3 tonnes/hour of rice husks producing pyrolysis oil as the major product, as well as char and non-condensable gas.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – downdraft circulating fluidised bed reactor	Rice husks	Pyrolysis oil	1-3 t of biomass/h (*ca.* 2-6 ML bio-oil/yr)	Unknown	2016

Reference: W. Cai, R. Liu, Performance of a commercial-scale biomass fast pyrolysis plant for bio-oil production, Fuel, Volume 182, 2016, Pages 677-686, doi.org/10.1016/j.fuel.2016.06.030

Image source: **http://uest.ntua.gr/naxos2018/proceedings/presentation/05.pdf**

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CHINA: HEFEI FACILITY

Owner: University of Science and Technology of China
Technology Provider: University of Science and Technology of China
Location: Hefei, China
Scale: Demonstration Plant, TRL6
Status: Unknown

The University of Science and Technology in Hefei, China has a demonstration fast pyrolysis plant capable of processing 15 tonnes of biomass/day. The plant uses fluidised bed fast pyrolysis technology to convert crop residues into pyrolysis oil (in 50-60% efficiency) with char and non-condensable gas by-products being burnt for process heat.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis, fluidised bed	Wood and agricultural waste	Pyrolysis oil	15 t of biomass/d (*ca.* 2 ML bio-oil/yr)	Unknown	2010

Reference: Mulligan, C., Strezov, L., Strezov, V. Pyrolysis of Biomass, in Biomass Processing Technologies, V, Strezov, T. Evans (Eds.), CRC Press, 2015, 123-154.

INDIA: IH^2 DEMONSTRATION FACILITY

Owner: Shell Catalysts & Technologies
Technology Provider: Gas Technology Institute (GTI), CRI Catalyst Company (CRI)
Location: Shell Technology Centre, Bangalore, India
Scale: Demonstration, TRL6-7
Status: Active

Shell Catalysts and Technologies operates an integrated hydropyrolysis and hydroconversion (IH^2) demonstration facility in Bangalore India. The plant can convert forestry, agricultural, and mixed urban waste into hydrocarbon transportation fuels at a rate of 5 tonnes dry feedstock/day. The plant uses the IH^2 technology, invented by GTI (Chicago) in 2009 and further developed with CRI Catalyst Company (CRI) from 2010. GTI licensed the IH^2 technology to CRI for exclusive worldwide deployment. The technology involves hydropyrolysis and hydroconversion reactors, hydrogen manufacturing units, and hydrogen compressors, integrated into a commercially viable process.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Integrated hydropyrolysis + hydroconversion	Forestry, agricultural, and urban waste	Gas, jet and diesel fuels	5 t biomass/d (up to 0.5 ML fuel/y)	Unknown	Commissioned 2018-2019

Website: **https://www.shell.com/business-customers/catalysts-technologies/licensed-technologies/benefits-of-biofuels/ih2-technology.html**

Image source: C. S. Laxminarasimhan, An Introduction to Shell New Energies, and IH$^{2®}$ Technology – Drop in Fuels from Waste Biomass, IEU Trade Delegation, March 6-8, New Dehli,

https://ec.europa.eu/energy/sites/ener/files/documents/29_laxmi_narasimhan-ih2_advocacy_lead.pdf

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INDIA: MASH ENERGY

Owner: MASH Energy
Technology Provider: MASH Energy (Denmark)
Location: Ahmedabad and Bakrol, Gujarat, India
Scale: Demonstration, TRL7
Status: Unknown

MASH Energy is a spin-off company from the Technical University of Denmark that is focussed on providing energy solutions for India. A demonstration scale plant has been established in the city of Ahmedabad for the processing of dried sewage sludge into pyrolysis oil using MASH Energy's pyrolysis technology. There is very little publicly-available information on this facility.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Pyrolysis	Waste materials, nuts, sewage sludge	Pyrolysis oil	Unknown	Unknown	Unknown

Website: **http://www.mash-energy.com/**

Contact:
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NORWAY: SILVA GREEN FUEL

Owner: Silva Green Fuel
Technology Provider: Steeper Energy
Location: Tofte, Buskerud, Norway
Scale: Demonstration, TRL7-8
Status: Active

Silva Green Fuel is a joint venture between Statkraft and Sødra for the development of advanced biofuels. The construction of a EUR 50.6M demonstration plant was completed in 2019 at the Statkraft Tofte site, a former pulp mill. The facility utilises Steeper Energy's hydrothermal liquefaction technology (Hydrofaction™) to convert forest residues into a bio-crude oil at a rate of 4000 L/day. The goal is to upgrade the bio-crude oil to produce renewable diesel, jet or marine fuel. After a 2-year validation period, the plant should officially open in 2021, potentially leading to a future commercial scale operation by 2025.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Hydrothermal liquefaction	Forest residues	HTL bio-crude	4000 L/d (*ca.* 1 ML/y)	EUR 50M	2019

Website and image source: **https://www.statkraft.com/about-statkraft/Projects/norway/value-creation-tofte/silva-green-fuel**

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TURKEY: ALTACA ENERGY

Owner: Altaca Energy
Technology Provider: Altaca Energy (SCF Technologies)
Location: Gönen, Turkey
Scale: Demonstration, TRL7
Status: Active

The Altaca Energy facility is a demonstration facility in Gönen, Turkey. Construction was completed in 2016. The demonstration plant uses the catalytic hydrothermal liquefaction technology, CatLiq®, invented by SCF Technologies (Denmark). Altaca Energy acquired the international intellectual property rights for the CatLiq® technology in 2011. The demonstration plant was built by Altaca Energy based on the SCF Technologies pilot plant, which was relocated to Gebze, Turkey. The plant converts various biomass sources, including biogas plant digestate, forest waste, sewage sludge, agricultural waste, food plant waste, organic household waste, into a HTL bio-crude, with 70% recovery of process heat.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Catalytic hydrothermal liquefaction	Various biomass sources	HTL bio-crude	15 t of biomass/h (up to 20 ML bio-crude/y)	Unknown	2016-2017

Website and image source: **http://www.altacaenerji.com/projeler/catliq-demo-tesisi**

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USA: BIOGAS ENERGY PROJECT

Owner: Biogas Energy
Technology Provider: Bioenergy Concept (Germany) and EnergoLesProm (ELP Group, Russia)
Location: Sacramento, California, USA
Scale: Pilot to Demonstration, TRL6-7
Status: Under development

Biogas Energy (CA, USA) and their partners are developing a fast pyrolysis demonstration facility in Sacramento, California. Project partners include Thermophil International (Hamburg), Bio Energy Concept (Lüneberg) Joint BioEnergy Institute and California State University, with financial support (USD 5.7M) from the California Energy Commission. The demonstration plant will process up to 500 kg of biomass/h with the goal of producing 190 000 L of pyrolysis oil over the 3.5-year lifetime of the project. The demonstration plant will be located on the waste management site of Western Placer Management Authorities. The plant will use fast pyrolysis technology using an ablative reactor to produce pyrolysis oil from forestry residues, beetle infested wood, and demolition wood. Commissioning of the plant is scheduled for the middle of 2020.

Key metrics:

Technology	Feedstocks	Primary product	Capacity	Capital investment	Operation date
Fast pyrolysis – Ablative reactor	Demolition wood, Bark beetle infested trees, forest & agriculture residues	Pyrolysis oil	500 kg biomass/h (up to 1.3 bio-oil ML/y)	Unknown	June 2020

Website: **https://dc.engconfintl.org/pyroliq_2019/32/**

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IEA Bioenergy

Technology Collaboration Programme