

Country Reports 2020

Direct Thermochemical Liquefaction

(Canada, New Zealand, United States of America)



IEA Bioenergy

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Canada

POLICY ENVIRONMENT

Climate change policies have evolved across Canada over the past several years. Some provinces within Canada have implemented emissions trading systems (e.g. cap and trade) or taxes on CO₂ emissions. At a federal level, Canada implemented in 2018 a federal “backstop” policy that sets a minimum standard for provinces to meet with regards to carbon emissions. This policy requires that each province either institute a qualifying carbon emissions program or use the federal carbon-pricing model. The carbon price under the federal model was \$30 per tonne CO₂ in 2020. In December 2020, it was announced that the federal price is planned to rise to \$170 CAD per tonne CO₂ by 2030.

RESEARCH ACTIVITIES

CanmetENERGY

Across CanmetENERGY’s three labs in Ottawa, Devon, Varennes and in a related lab in Hamilton (CanmetMATERIALS), research is taking place related to development and support of direct thermochemical liquefaction and the application of the derived liquids. CanmetENERGY-Ottawa continues to operate their 5 – 10 kg/h fast pyrolysis facilities to enable the use of low quality forestry residues and exploit opportunities for the production of multiple liquid streams for targeted applications. Furthermore, CanmetENERGY-Ottawa is working with a variety of universities and research organizations in order to supply liquids produced from real Canadian forestry residues. CanmetENERGY-Ottawa also operates

- 50 kWth waste oil furnace modified for bio-oil and biocrude combustion furnace for developing technical data on the combustion performance of bio-oils and biocrudes,
- various systems for developing data on the handling of bio-oils and biocrudes (e.g. filtration and materials exposure),
- and operates a variety of catalytic upgrading equipment to assist technology development of viable routes to fungible hydrocarbon fuels.

In support of this work, CanmetENERGY-Ottawa and CanmetENERGY-Devon continue to develop methods and expertise for the advanced characterization and standardization of these liquids. CanmetENERGY-Devon works extensively with the oil & gas industry in Canada to establish technology, standards and guidelines for the co-processing of bio-oils and biocrudes. CanmetMATERIALS develops technical data and provides expertise on materials for biomass thermochemical processes and applications for the products derived from these processes.

Memorial University

The focus of Memorial University’s research is on the conversion and use of biofuels/products in regions where remoteness, infrastructure, distance to market, low volumes and highly diverse feedstock require innovative and integrated approaches. There are two areas of research are the use of pyrolysis in fish processing plant waste and forestry residue applications.

National Research Council

The National Research Council (NRC) has projects underway related to the direct thermochemical liquefaction of biomass. Namely, they are the hydrothermal liquefaction of wet bio-feedstocks and wastes and developing customized solutions for gas turbine and diesel engine application of biomass liquefaction oils. NRC has established an HTL pilot unit designed and custom fabricated for testing and demonstrating this technology.

Université du Québec à Trois-rivières

The mission of the *Institut d'innovations en écomatériaux, écoproduits, écoénergies* is the analysis, optimization and application to a specific local context of the key technologies necessary for the development of a regional bioeconomy with a view to accelerating its establishment and contributing significantly to the development of a regional bioeconomy. The production and modification of pyrolytic oils for specific applications is one of the technologies being evaluated.

University of New Brunswick

Researchers in the Civil Engineering Department are working with pyrolysis and asphalt companies to examine the opportunities for using bio-oil and byproducts from fast pyrolysis, such as biochar in asphalt applications.

University of Toronto

The Combustion Research Laboratory continues its work analyzing the combustion characteristics of biofuels, including pyrolysis oil. Recent work included the co-firing of pyrolysis oil with natural gas to improve the combustion of the bio-oil and running a diesel engine on bio-oil.

Western University

The Institute for Chemicals and Fuels from Alternative Resources (ICFAR), led by Franco Berruti is one of the major research groups in Canada working on pyrolysis. Their work includes the conversion of biomass, residues and wastes into value-added products from pyrolysis; the production of bio-oils, bio-char and gas from biomass; bio-oil and bio-char upgrading and applications, including the use of bio-oils as pesticides, antioxidants and adhesives; bio-char as a soil amendment, in carbon sequestration, adsorbent and other uses and the separation and purification of valuable chemicals from bio-oils. This group developed the mechanically fluidized reactor (MFR) pyrolysis process that BioTechFar is commercializing.

DEMONSTRATION ACTIVITIES

ABRI-Tech

ABRI-Tech Inc. is a partnership between the Leggett family and Peter Fransham (Ph. D.), who has been developing biomass pyrolysis and drying technologies. ABRI-Tech's objective is to add value and convert these byproducts into bio-oil, which can serve as an alternative to fossil fuels. ABRI-Tech Inc has been actively developing biomass dryers and auger pyrolysis systems since 1988. The company's line of products includes an auger pyrolysis system using steel shot as a heat carrier. The entire system of dryer, reactor, char management and condensation consists of seven modules that can be relocated easily and quickly. The largest modular plant is 50 dry tonnes per day. Plants have been installed in Canada and Russia. A 1 tpd plant at their facility in Namur, Quebec, Canada offices is available for feedstock testing. ABRI-Tech is a subsidiary of the Leggett Group, a forest products company with logging and sawmill operations.

BioTechFar

BioTechFar (BTF) is a biorefinery technology provider for the conversion of biomass into energy and non-energy products through an innovative mechanically fluidized reactor (MFR) pyrolysis process. BTF has an initial focus on processing 2nd Generation biomass feedstock, i.e. derived from non-food biomass such as lignocellulosic materials and waste / byproducts from forestry, agriculture, industry and households. Unlike other thermochemical conversion processes with a "single product output", The MFR pyrolysis system enables the production of all three products (oil, char and gas) with both energy and non-energy value potential for improved ROI potential. The founders of the company are also associated with the Institute for Chemicals and Fuels from Alternative Resources (ICFAR), University of Western Ontario.

Canfor – Licella

In 2016, Canadian Forest Products Ltd (Canfor) signed an agreement with Licella Fibre Fuels of Australia to form a joint venture to determine whether they could use a process developed by Licella, called the Cat-HTR process to economically convert wood biomass and pulp mill streams from their Prince George pulp mills into a stable biocrude. Using water at near or supercritical temperatures, the Cat-HTR™ converts a wide variety of low-cost, waste feedstocks and residues into high-value products.

In 2020, Licella Holdings announced that they entered into a new joint venture called Arbios Biotech <https://arbiosbiotech.com/>, with Canfor. With a vision to provide low-carbon circular economy solutions around the world using Licella's Cat-HTR™ technology, Arbios aims to create high-value, sustainable carbon-based products, including advanced biofuels, from post-consumer biomass and residues. Arbios sees significant potential upside from stand-alone plant applications. As such, Arbios is currently prioritizing efforts to commercialize the Cat-HTR™ technology in this setting. The first stage towards commercialization of a stand-alone Cat-HTR™ plant - Commercial Stage 1 ('CS-1'), is well underway at Licella's facility in Somersby on the NSW Central Coast, Australia. Licella has completed a number of successful trial runs on their Cat-HTR™ small pilot plant for Arbios, and also commenced commissioning of the CS-1 plant. Full commissioning and feedstock testing for Arbios' CS-1 plant is on track for the end of Q1 2021. Once completed, this CS-1 facility will process up to 5,000 tonnes of feedstock (producing approximately 10,000 barrels) annually and is anticipated to be one of the largest Hydrothermal Liquefaction ('HTL') facilities in the world. Feedstock and products offtake discussions are on-going.

Pyrobiom Énergies

Pyrobiom's mission is to create several production plants across Quebec's forest regions, through the industrial-scale production of pyrolytic oil thus promoting the valorization of residual woody material. The first Pyrobiom Énergies demonstration project, a 50 ton/day auger pyrolysis technology, took place at a softwood sawmill, located in Parent, Québec belonging to the Rémabec Group.

Pyrovac Inc

Pyrovac is developing, designing and constructing industrial pyrolysis plants for various applications including forestry and agricultural biomass, waste plastics, used tires and bituminous waste materials. The Pyrovac focus is on the conversion of various wastes into valuable products such as wood vinegar, bio-oils, biochar, pyrolytic carbon black and different kinds of valuable chemicals. In 2019, SDTC provided \$3 million to Pyrovac for a project to develop a plastic-to-fuel pyrolysis technology that avoids the production of conventional diesel and reduces plastic waste in landfills.

Steeper Energy

Hydrofaction® is Steeper Energy's proprietary implementation of hydrothermal liquefaction which applies supercritical water as a reaction medium for the conversion of biomass directly into a high-energy density renewable crude oil, referred to as Hydrofaction® Oil. The City of Calgary and Steeper Energy Canada announced a cooperation agreement on future transformation of Calgary's sewage sludge and other urban generated bio-organic wastes for the production of sustainable biofuels such as renewable diesel or jet fuel. Calgary and Steeper Energy are planning the development of a demonstration plant at the Pine Creek Wastewater Treatment Plant in South-East Calgary. The City would host Steeper Energy at its state-of-the-art wastewater treatment plant, as well as to supply a portion of Calgary's primary and secondary sewage sludge to produce advanced biofuels via Steeper's Hydrofaction® technology.

Vancouver Metro

The City of Vancouver has a hydrothermal processing pilot project underway, using the Genifuel process, that was developed by the USDOE Pacific Northwest National Laboratory. A pilot facility has been planned at the city's Annacis Island Wastewater Treatment Plant to will convert wastewater biomass solids from treatment plants into biocrude oil that can be refined to a low carbon transportation fuel. The Parkland Fuel is hoping to co-process the bio-crude from the HTP unit at its Burnaby, B.C. refinery. The project is expected to be operational in 2024.

COMMERCIAL APPLICATIONS

Ensyn

Ensyn has provided their RTP technology (fast pyrolysis) for commercial operations in Rhinelander, Wisconsin (3 x 30 - 40 dry tons per day) and Renfrew, Ontario (70 dry tons per day) operated by the Kerry Group and Côte-Nord, Québec (200 dry tons per day) under a partnership with forestry companies. Their major products from their include food flavourings, Renewable Fuel Oil, and refinery feedstocks. The company continues to provide support for commercial operations and develop new commercial projects.

New Zealand

There are few stakeholders currently active in DTL technologies in New Zealand (Table 1). All activities in 2021 can be defined as research and development. No demonstration/commercial-scale operations currently exist.

Table 1. DTL R&D in New Zealand

Institute	Main Contact	Activity
Scion (NZ Forest Research Institute Ltd)	Kirk Torr Paul Bennett	Fast pyrolysis, Catalytic fast pyrolysis Hydrothermal processing of organic waste
University of Canterbury	Shusheng Pang	Fast pyrolysis of woody biomass and waste plastics Bio-oils for thermal gasification
Solvent Rescue	Chris Bathurst	Hydrothermal liquefaction of algal biomass and organic wastes
Nufuels Ltd	Leigh Ramsey Simon Arnold	Slow pyrolysis of tyres

RESEARCH ACTIVITIES

Scion

Scion's bioenergy research programme focusses on wood-based replacements for transport biofuels and industrial energy, both of which currently use large amounts of non-renewable resources in New Zealand. In the liquid biofuel area, Scion is focused on the difficult to decarbonise fuels including marine, heavy transport 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 fast pyrolysis and catalytic fast pyrolysis. <https://www.scionresearch.com/science/bioenergy>

Scion has an active research programme in hydrothermal processing for recovering value from organic waste streams. <https://www.scionresearch.com/science/environmental-technologies/recovering-value-from-waste>

University of Canterbury

Prof. Shusheng Pang (Director, Wood Technology Research Centre), College of Engineering, University of Canterbury leads research in fast pyrolysis and gasification technologies for production of liquid and gaseous biofuels. <https://www.canterbury.ac.nz/engineering/contact-us/people/shusheng-pang.html>

Solvent Rescue

Solvent Rescue is a small independently-owned company with an interest in liquid biofuel production from algae and organic wastes using hydrothermal liquefaction technology. <http://www.solventrescue.co.nz/>

Nufuels Ltd

Nufuels Ltd is a subsidiary of Blended Fuel Solutions NZ Ltd which is developing decentralised waste-to-fuel processes in New Zealand based on pyrolysis of tyres. <https://www.bfsnz.biz/nufuels>

RELATED POLICY

Recent New Zealand Government communications and strategic reports include:

- Introducing a new biofuel mandate - "Our Government has agreed in principle to mandate a lower emitting biofuel blend across the transport sector" NZ Transport Minister, Michael Wood, 28 January 2021

- Climate Change Commission Draft Advice for Consultation 2021 – “Use of low carbon fuels, such as biofuels and hydrogen, needs to increase, particularly in heavy trucks, trains, planes, and ships”. <https://www.climatecommission.govt.nz/get-involved/our-advice-and-evidence/>
- New Zealand Productivity Commission Low-emissions Economy Report – “Biofuels can potentially deliver considerable emissions reductions”. <https://www.productivity.govt.nz/inquiries/lowemissions/>
- The Primary Sector Science Roadmap Te Ao Tūroa - “Developing biofuels as a major part of the bioeconomy”. <https://www.mpi.govt.nz/science/primary-sector-science-roadmap-te-ao-turoa/>
- Wood Fibre Futures Report – Identified a role for biocrude oil and liquid biofuels in substituting fossil fuels. <https://www.mpi.govt.nz/dmsdocument/41824/direct>

RELATED INDUSTRY NEWS

- New Zealand's sole refinery, the Marsden Point refinery owned by Refining NZ, plans to reduce operating capacity from 135,000 to 90,000 b/d in 2021. The decision to reduce capacity follows a strategic review of operations. The future of the refinery will impact on co-processing opportunities for bio-crudes in New Zealand.
- Oji Fibre Solutions (NZ) signed a memorandum of understanding in 2019 with iQ Renew and Licella (Australia) to investigating IQ Review/Licella’s Cat-HTR™ liquefaction technology for waste plastic chemical recycling in New Zealand.

United States

Major stakeholders in the United States around DTL technologies are summarized in Table 1. All of these stakeholders have been actively researching and/ or promoting DTL technologies in 2020. There are scores of universities and small businesses who are active in the field at smaller scale, and they are also stakeholders even if they are not included individually.

Table 1: DTL Stakeholders in the United States

Company or Institution	Main Contact/ CEO	Key activities
RTI International	Dave Dayton	Pilot plant for catalytic fast pyrolysis, development of reactive catalytic fast pyrolysis
NREL	David Robichaud	Thermal and Catalytic Process Development Unit for catalytic and fast pyrolysis
PNNL	Andrew Schmidt	Hydrothermal Process Development Unit for HTL, catalytic upgrading, and hydrothermal gasification
Iowa State University	Robert Brown	
Biogas Energy Ltd.	Brian Gannon	Ablative fast pyrolysis reactor from thermophil international
HYPOWERS	Jeff Moeller	Pilot scale system for hydrothermal processing of wastewater solids
Anellotech	David Sudolsky	BioTCat™ catalytic pyrolysis for production of aromatics and fuels
Ensyn	Robert Pirraglia	Commercial-scale Rapid Thermal Processing (RTP) plant proposed in Dooley County, Georgia

DTL WITHIN THE NATIONAL POLICY FRAMEWORK

The United States has continued to support the development of sustainable liquid transportation fuels through a continuation of the Renewable Fuels Standard (RFS) and the market for Renewable Identification Numbers (RINs). Second generation biofuels from non-food sources generate higher-value RINs and incentivize cellulosic ethanol, DTL, and gas-to-liquids approaches, among others. In addition to Federal programs, certain states have their own programs, such as the Low Carbon Fuel Standard (LCFS) in California. Abundant incentives and public and private commitment to carbon emissions reductions is creating opportunities for new bioenergy technologies to reach the market.

Commercial activity in fast pyrolysis or hydrothermal liquefaction is currently small. There are several pilot and demonstration projects and several proposed commercial plants. There is a flurry of investment for renewable diesel by lipid hydroprocessing. This requires preferably used cooking oil or tallow as a feedstock. Both small and large energy companies have retrofitted existing refinery assets to produce renewable diesel, known also as hydrotreated vegetable oil (HVO). As the demand for used oils has grown beyond the supply, it has put pressure on oilseed prices and renewed the food versus fuel debate. Since DTL technologies rely on abundant, non-food biomass there may be an opportunity to market liquid intermediates like bio-oil or biocrude to meet the current refinery capacity expansion for renewable fuels.

RESEARCH ACTIVITIES

RTI International

Researchers at RTI International have been developing technology and capabilities for fast pyrolysis for many years. They currently operate a fast pyrolysis pilot plant with a capacity of 1 tonne of biomass per day. In-situ catalytic fast pyrolysis (CFP) is supported by this plant, broadening the range of process conditions and configurations. RTI has also been developing reactive catalytic fast pyrolysis (RCFP), a process that entails the introduction of hydrogen into the riser but not under pressure. The added hydrogen reduces the oxygen content of the pyrolysis vapors and leads to a more thermally stable bio-oil intermediate.

RTI International has partnered with Haldor Topsoe for catalyst development for RCFP and bio-oil upgrading. David Dayton of RTI has been featured on recent episodes of Haldor Topsoe's "Fuel for Thought" podcasts (Episodes 5 and 6) discussing the fundamentals of fast pyrolysis and the current status of RTI's projects.

US Department of Energy National Laboratories

Two US Department of Energy (DOE) national laboratories house DTL capabilities at the pilot or engineering scale. Known as Process Development Units (PDUs), these integrated systems provide data to bring the gap between applied research and commercialization.

The National Renewable Energy Laboratory (NREL) manages the Thermal and Catalytic Process Development Unit (TCPDU). This facility has a high-throughput fast pyrolysis reactor (18 kg/h) and also a Davison Circulating Riser (DCR) for vapor phase upgrading that is coupled to a fast pyrolysis reactor with a capacity of 2 kg/h. NREL maintains supporting capabilities in feedstock preparation, gas cleanup, catalyst development, material characterization, and process analytics.

Pacific Northwest National Laboratory (PNNL) manages the Hydrothermal Process Development Unit (PDU). The main reactor is the Modular HTL System (MHTLS), an engineering-scale system that includes process heat integration, continuous product separation, and feed slurry preparation. With a nominal throughput of 12 L/h of wet biomass slurry, the scale is optimized for obtaining

useful data for scale up without staging and storing enormous quantities of wet and sometimes perishable biomass.

Included with the Hydrothermal PDU is a continuous hydrotreater with a bed volume of 400 mL and a trailer-mounted system for catalytic hydrothermal gasification (CHG). Together, these reactors transform wet biomass slurries into fuel blendstocks, methane, and clean water.

Iowa State University

During the tenure of Dr. Robert Brown, Iowa State University has developed significant test beds for fast pyrolysis and solvent liquefaction. Two major facilities contain the reactors: the Biorenewables Research Laboratory (BRL) and the BioCentury Research Farm (BCRF). Several pyrolyzers are in operation at the 1-2 kg/h scale, including an autothermal pyrolysis reactor, a free-fall reactor, and an auger reactor. The BCRF contains the fast pyrolysis process development unit, with a throughput of 8 kg/h. These capabilities enable leading-edge research into fast pyrolysis fundamentals and process integration.

Iowa State University has recently announced two commercial projects featuring a modular autothermal pyrolysis system. The design capacity is 50 tonne per day. The first project is funded by Stine Seed Company and will be located in Redfield, Iowa with commissioning planned for 2021. The targets products will be bio-asphalt and biochar, with net carbon removal. The second project is funded by the California Energy Commission (CEC) and will be sited in El Dorado Hills, California with commissioning planned for 2022. Wood waste is the proposed feedstock with liquid transportation fuels as the end product.

DEMONSTRATION ACTIVITIES

Biogas Energy Ltd.

Biogas Energy Ltd. has received a grant from the California Energy Commission (CEC) to operate an ablative fast pyrolysis pilot plant at an existing organics recycling facility in Placer County, California. Waste wood will be the proposed feedstock, and upon successful demonstration the commercialization plan is to develop modular systems that can be deployed close to biomass resources and to scale by numbering up in situations where greater capacity is required. Modular systems will be sized for a target of 12 dry tonne per day of biomass.

The ablative fast pyrolysis technology and system are being provided by thermophil international of Hamburg, Germany. The pilot plant modules arrived in California in May 2020 and installation started in November 2020 due to COVID-19 travel restrictions. The electrical installation is expected to start in early 2021 with plant commissioning in summer 2021.

HYPOWERS

The goal of the Hydrothermal Processing of Wastewater Solids (HYPOWERS) project is to demonstrate scale-up of a Hydrothermal Processing (HTP) System to convert wastewater solids into renewable biofuel and methane at an operating water resource recovery facility (WRRF). HTP includes both hydrothermal liquefaction (HTL) and catalytic hydrothermal gasification (CHG).

The pilot project will process 15 wet metric tons per day (3 dry metric tons) of wastewater solids and will be sited at the Central Contra Costa Sanitary District (Central San) in Martinez, CA. This pilot unit will handle about 1/10 of the daily wastewater solids produced at Central San. The project team includes the Water Research Foundation (WRF), Genifuel (commercial technology provider), Pacific Northwest National Laboratory, Merrick Engineering, Brown and Caldwell, Microbio Engineering, and SoCal Gas. Additionally, 16 utilities are participating in this project.

Phase 1 of the project has been completed, leading to a Critical Decision 3 (CD-3) design while addressing regulatory and environmental requirements and building a business plan for commercial success. Phase 2 activities are to build and operate the system. Phase 2 authorization is pending the required cost share from project partners.

Anellotech

Anellotech has developed and piloted the BioTCat™ process for producing a mixture of aromatics and a middle distillate stream from woody feedstocks. It is a catalytic pyrolysis process in a single fluidized bed. The TCat8© pilot facility in Silsbee, Texas has accumulated over 5000 hours time-on-stream. A commercial facility was announced in 2018 but no further information is available at this time.

COMMERCIAL APPLICATIONS

Ensyn Development Partners

Ensyn Development Partners (EDP) has announced the construction of a Rapid Thermal Processing (RTP) plant in Dooley County, Georgia with a capacity of 20 MM gal/yr of pyrolysis oil from wood residues. Proposed feedstocks are mill residues, forest residues and thinnings from local sources. The plant will be sited a decommissioned particle board mill owned by Roseberg Forest Products.

Envergent, a technology venture between Ensyn and Honeywell UOP, will design, construct and deliver the thermochemical conversion plant. EDP is joint venture between Ensyn and Renova Capital Partners. The project has secured a US\$70 MM conditional loan guarantee from the United States Department of Agriculture (USDA). No further status is available at this time.



Fast pyrolysis pilot plant at RTI International in Research Triangle, North Carolina. The plant has a capacity of 1 tonne of dry biomass per day.



The Thermal and Catalytic PDU at NREL in Golden, Colorado.



PNNL's Modular HTL System in Richland, Washington.



Biogas Energy Ltd.'s ablative fast pyrolysis pilot plant modules at an organics recycling facility in Placer County, California. The technology and reactors were provided by thermophil international.



Roseberg Forest Product's particle board mill in Dooley County, Georgia. This mill is the proposed site of a Rapid Thermal Processing (RTP) plant proposed by Ensyn Development Partners.

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Further Information

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