NRC·CNRC

Low Carbon Fuel Research @NRC

Shouvik Dev

Outline

Introduction

Characterization and Utilization of LCFs

Hydrothermal Liquefaction

Hydrothermal Gasification

LCA and TEA

Gas Fermentation

Bioelectrochemical Systems

Conclusions

Introduction

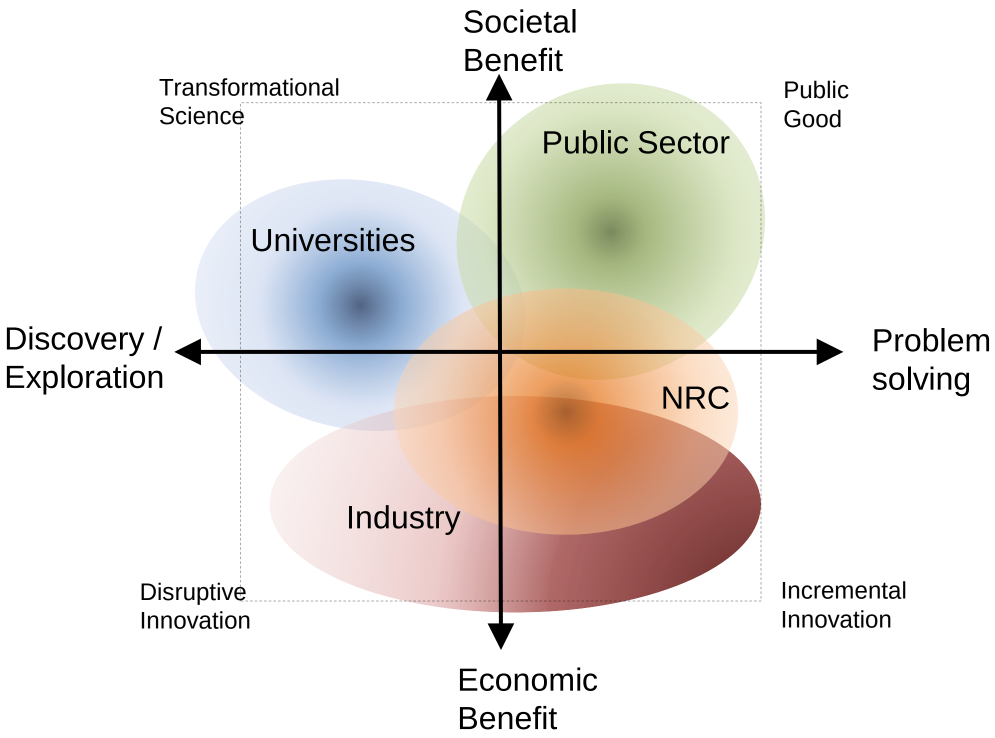
The NRC - What We Do

WE ADVANCE SCIENTIFIC AND TECHNICAL KNOWLEDGE

WE SUPPORT GOVERNMENT POLICY OBJECTIVES

WE SUPPORT BUSINESS INNOVATION

Positioning the NRC in Canada’s Innovation Landscape



Clean Energy Innovation Research Centre

~~**Energy, Mining and Environment**~~

Clean Energy Innovation (as of April 01, 2024)

Vision: *To accelerate Canada's transition to a thriving net-zero economy, built on clean energy and decarbonized industries*

Mission: *To catalyze Canadian innovation for a sustainable future by leveraging our diverse scientific capabilities, cutting-edge technologies and strategic partnerships to pioneer solutions for net-zero energy, critical minerals, advanced materials, and industrial decarbonization*

Advanced Clean Energy (ACE) Program

- Over 65 projects with partners from industry, academia and government
- Focus on mid to high TRL clean energy technologies that can be moved into multiple sectors
- Designed to support priorities of the Government of Canada to meet 2050 targets and fill R&D gaps for industry

1 - Battery Energy Storage

New Battery Critical Materials Initiative

Supporting the emerging battery supply chain

2 - Low Carbon Fuels

Fuel switching using clean fuels produced from waste

3 - Hydrogen

Supporting the production and distribution of fossil-free hydrogen

4 – Grid Integration

Validation and integration of renewables for grid resiliency

ACE Program Pillar 2 – Low Carbon Fuels

Enabling fuel switching by using **negative value waste streams and feedstocks** for the production of low carbon fuels, and their efficient utilization to reduce net greenhouse gas emissions

	Materials	Components	Devices	System Integration
Conversion • **Biochemical** • **Thermochemical**	• Waste feedstock analysis • Reactor materials compatibility • Catalysts	• Kinetics analysis • Phase conversion optimization	• Bioreactor design • Thermo-chemical reactor design	• Combined bio and thermo processes • Decision making tools (LCA/TEA)
Utilization • **Reciprocating engines** • **Turbine engines**	• Fuel properties • Material compatibility • After treatment materials	• Nozzles and fuel injectors • After-treatment design	• Combustion strategies • Emission reduction strategies	• Technology evaluations • Fleet conversion • Performance evaluation

Advanced Clean Energy Program (green)

End Use collaborations (grey)

Characterization and Utilization of LCFs

Characterizing and Utilizing LCFs

PIs: Engines – Shouvik Dev & Hongsheng Guo / Turbines – Sean Yun

Reciprocating engines (CEI) and Turbines (Aerospace RC)

Advanced strategies for combustion of renewable fuels/blends

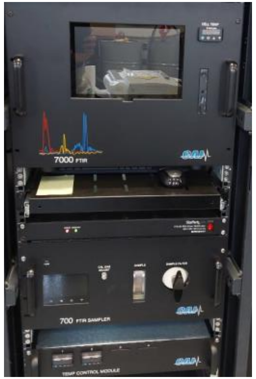
- Efficiency optimization
- Emission reduction

Emission analysis

- CO_2, CO, HC, CH_4, NH_3, NO_x – stationary and mobile
- Particulate matter and particulate number measurement
- Online multi-gas analyzer for regulated and unregulated emissions

Fuel Characterization

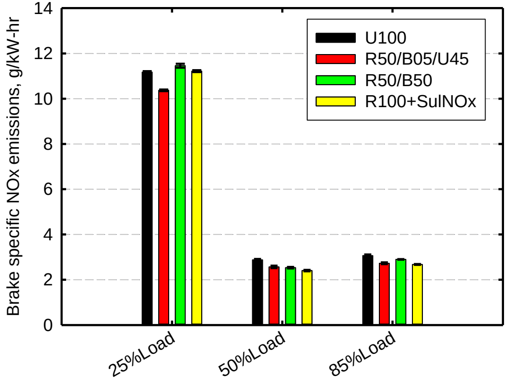
- Viscosity, density, lubricity, turbidity, cetane number, elemental analysis

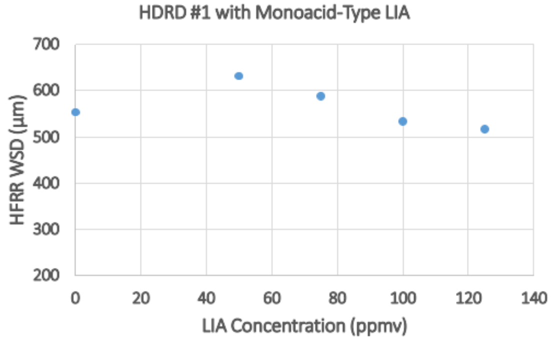


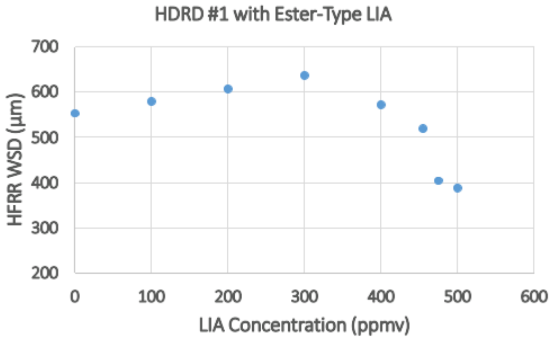
Characterizing and Utilizing LCFs @NRC

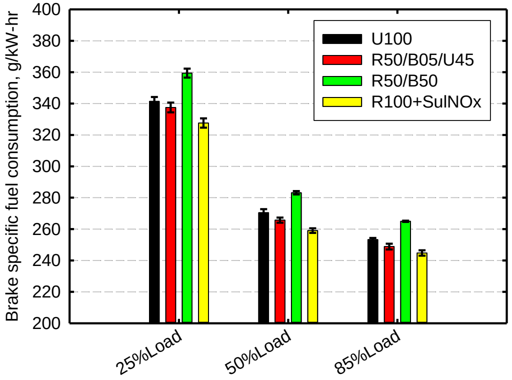
PIs: Engines – Shouvik Dev & Hongsheng Guo / Turbines – Sean Yun

Fuel	T (°C) Temp. Set Point	Eta (MPa-s) Dyn. Viscosity	Nu (mm^2/s) Kin. Viscosity	Rho (g/cm^3) Density
RD	+10	5.5667	6.9606	0.7998
RD	0	7.7721	9.6358	0.8066
RD	-8	10.601	13.050	0.8123
RD	-10	11.500	14.137	0.8135
Arctic Diesel	+40	1.3544	1.6801	0.8062
Arctic Diesel	0	3.1690	3.7948	0.8351
Arctic Diesel	-30	9.0394	10.552	0.8566





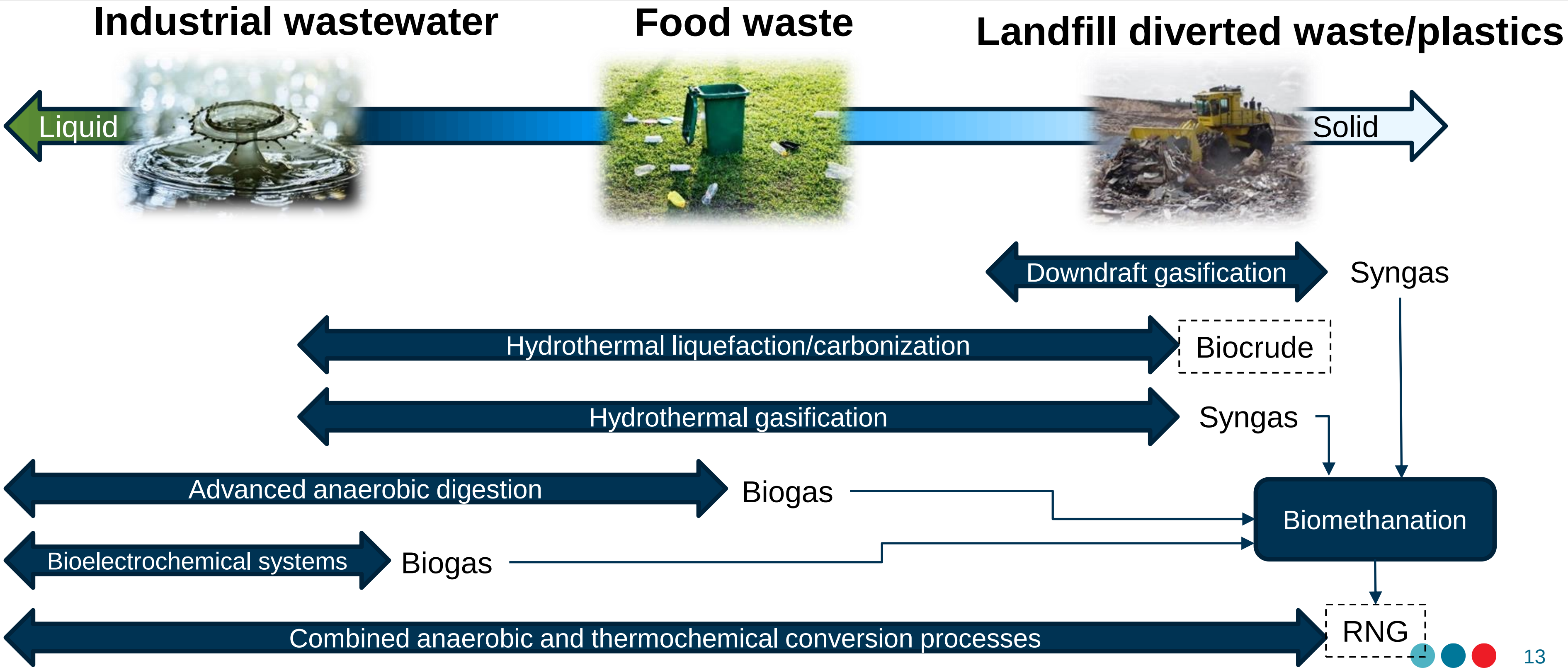




LIA: Lubricity improver additive | RD: Renewable Diesel

Conversion Processes for LCF Production

Creating Low Carbon Fuels from Waste



Thermochemical Processes

Hydrothermal Liquefaction

Hydrothermal Liquefaction

PI: Devinder Singh

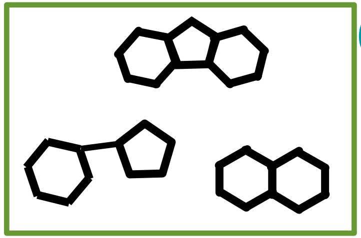
Waste Feedstock
(Sludge, Food Waste)

Hydrothermal
Liquefaction

Bio-Crude
Intermediate

Upgrading

Fungible Transportation Fuels
(SAF/RD)



Heating Fuel

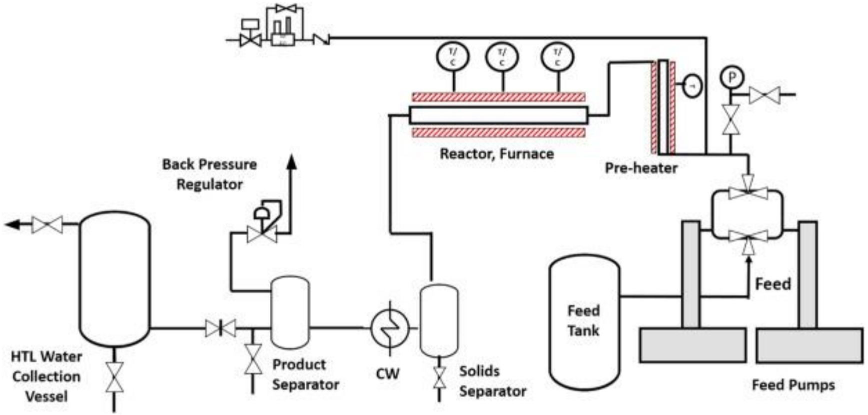
Characterization of produced Bio-crude

Gas chromatography/mass spectrometry, CHNS analysis, Nuclear magnetic resonance, thermal gravimetric analysis

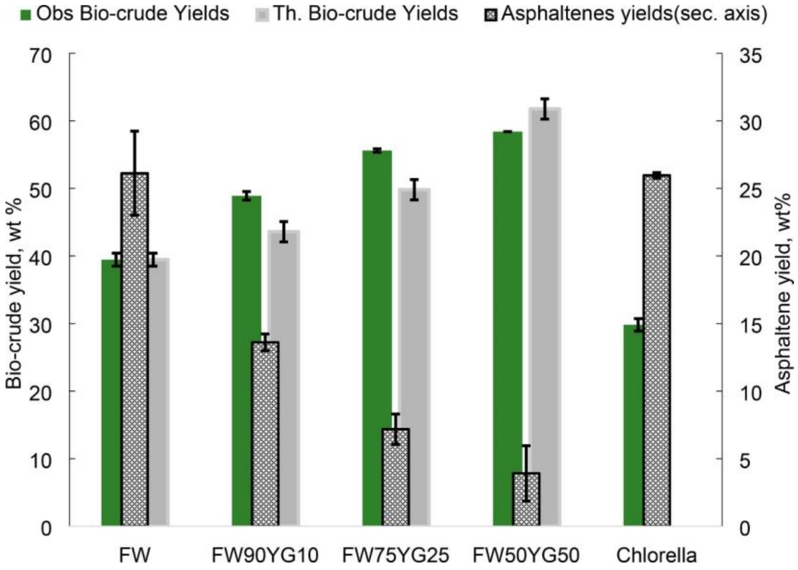
Hydrothermal Liquefaction

PI: Devinder Singh

HTL Pilot Facility
(5 kg/hr Continuous)



Improving Biocrude Yield with Yellow Grease



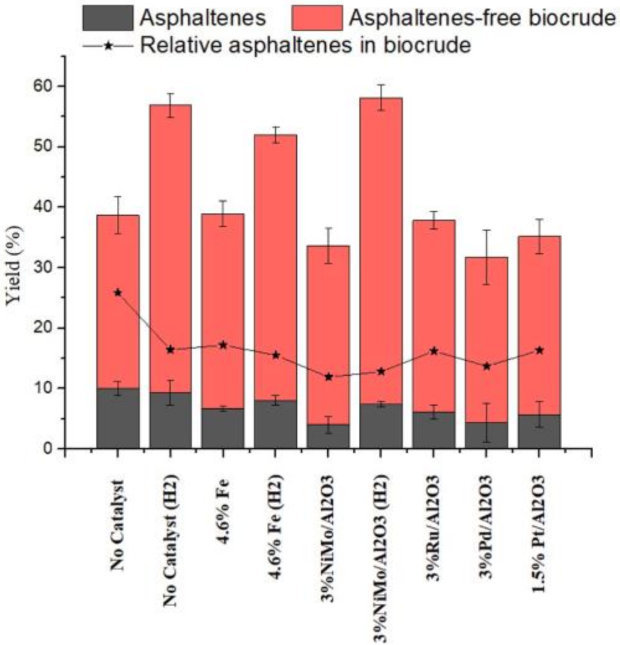
FW: Food Waste
YG: Yellow Grease

Devinder Singh et al, Fuel 344, 2023

Hydrothermal Liquefaction

PI: Devinder Singh

Catalyst Development for Improving Yield



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Catalytic hydrothermal liquefaction of food waste: Influence of catalysts on bio-crude yield, asphaltenes, and pentane soluble fractions

Sayed Ahmed Ebrahim [a], Gilles Robertson [b], Xin Jiang [b], Elena A. Baranova [a], Devinder Singh [b,*]

[a] *Department of Chemical and Biological Engineering, Centre for Catalysis Research and Innovation (CCRI), University of Ottawa, 161 Louis-Pasteur, Ottawa ON K1N 6N5, Canada*

[b] *Energy, Mining, and Environment Research Centre, National Research Council of Canada, Ottawa ON K1A 0R6, Canada*

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Full Length Article

Improving yields, compatibility and tailoring the properties of hydrothermal liquefaction bio-crude using yellow grease

Devinder Singh [*], Xin Jiang, Mladen Jankovic, Floyd Toll

Energy, Mining, and Environment Research Centre, National Research Council of Canada, Ottawa ON K1A 0R6, Canada

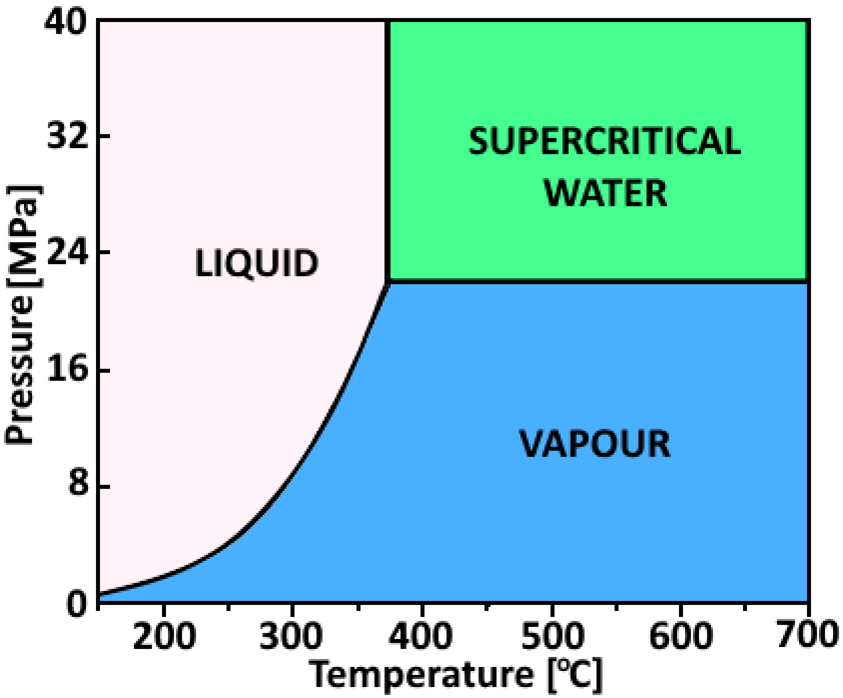
Thermochemical Processes

Hydrothermal Gasification

Hydrothermal Gasification

PIs: James Butler, Samira Lotfi

- Above the critical point, water is a very power solvent/oxidant
  - Organic molecules are broken down into base components to recombine as gases
- Suitable for high moisture and difficult to breakdown feedstock
- Does not require drying of high moisture feeds like conventional gasification
- Much smaller footprint and shorter residence time compared to anaerobic digestion
- Large feedstock flexibility: biomass, plastics, sewage sludge, food waste, etc.



Hydrothermal Gasification

PIs: James Butler, Samira Lotfi

Highly Heterogeneous Plastics Waste

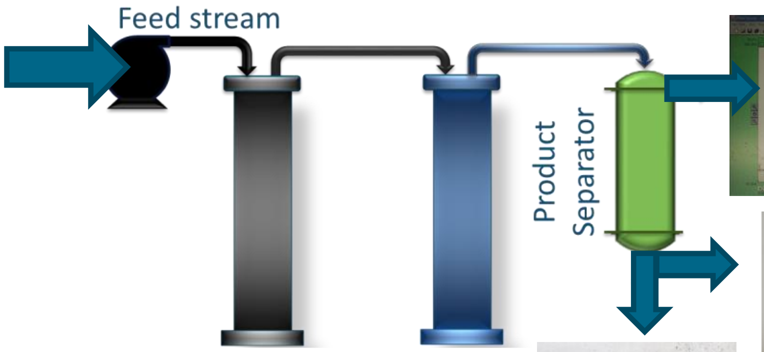
Automotive fluff (AF)

Ground

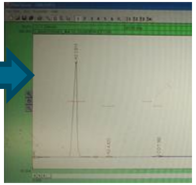
Washing / Water Addition

NRC's Lab Scale Dual Hydrothermal Conversion (DHC) System

- 1 mL/min feed
- Two reactors in series
  - First – Solid decomposition pre-treatment
  - Second – Gasification of the liquid product



Gaseous H_2 (>50% v/v)



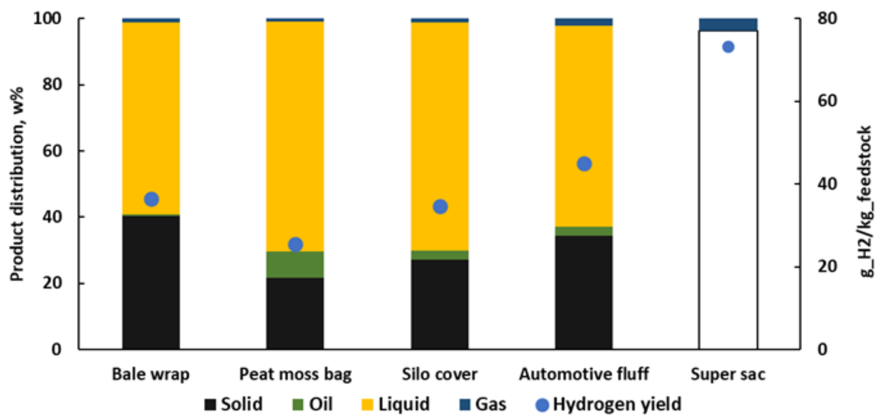
Liquid

Solid carbon

Hydrothermal Gasification

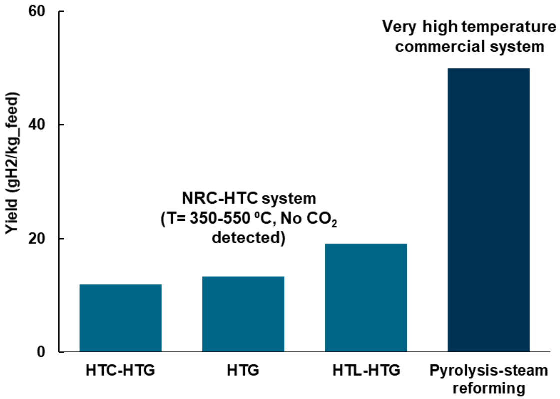
PIs: James Butler, Samira Lotfi

Product Distribution



Bench scale results
Scale-up to DHC System

Yield



Less extreme conditions
CO_2 captured in-situ

HTC: Hydrothermal carbonization
HTL: Hydrothermal liquefaction
HTG: Hydrothermal gasification

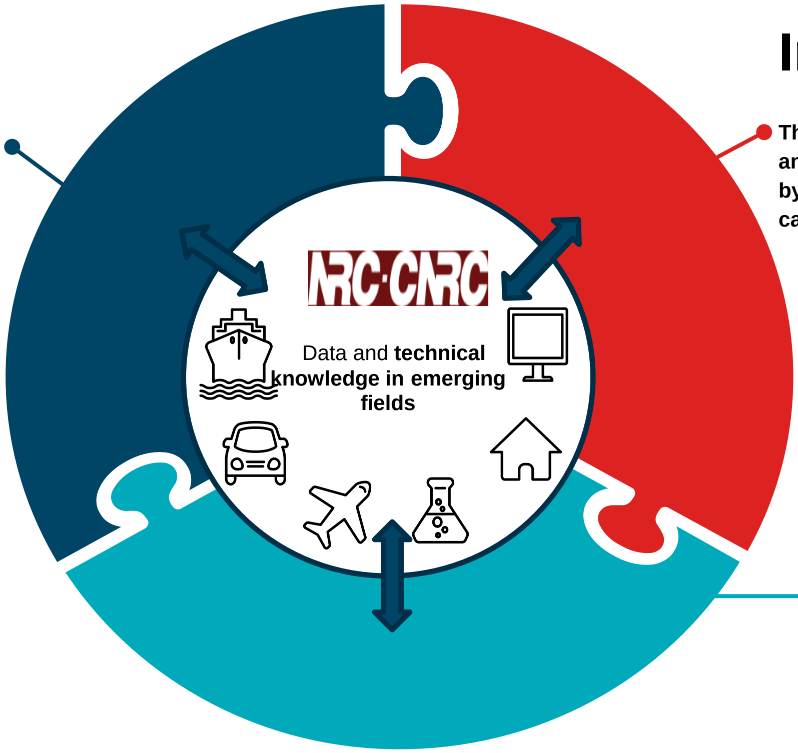
Thermochemical Processes

LCA and TEA

Lifecycle Assessment and Techno-Economic Analysis Integrated Platform

Policy

The NRC can provide platforms and data to make the most effective policy decisions and can work as a conduit for organized information from industry and academia



Industry

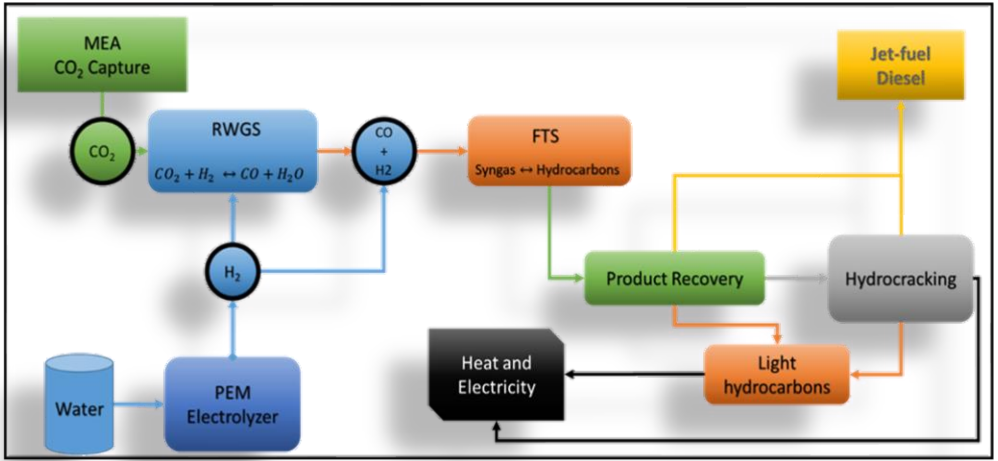
The NRC is an interface between government and industry. The NRC can support industry by enabling decision-making tools to reduce carbon footprint

Government Labs and Universities

The NRC collaborates extensively with academia and OGDs, including data sharing and LCA platform development

CO_2 to Jet Fuel Technology Platform

PI: Jalil Shadbahr



- Evaluates the impact of Fischer-Tropsch (FT) catalyst improvement on FT products
- Calculates the cost reduction per avoided CO_2 applying the Levelized Carbon Cost Abatement (LCCA) tool and the technology learning curves (TLC) approach on the overall performance of the CO_2 to jet-fuel (CtJ) platform
- Integrated TLC-LCCA tool provides a perspective toward implementing CCU technologies such as CtJ platform and their potential to decarbonize the transportation sector.

Integrated LCA/TEA Platform for Carbon Waste to Energy Conversion with CCS (WECCS)

PI: Jianjun Yang

Objectives

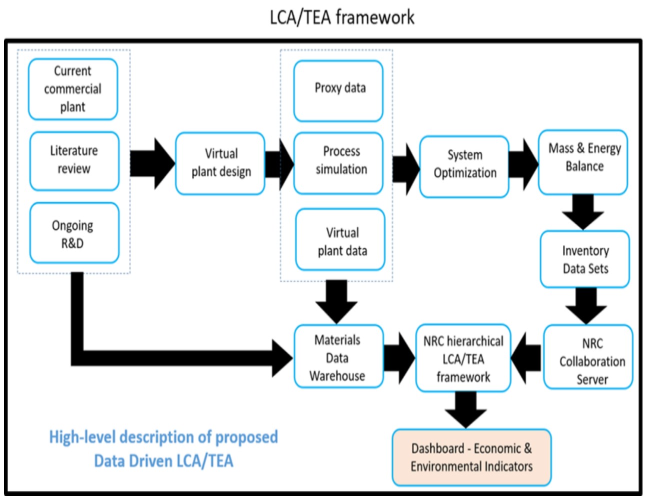
- Develop an integrated LCA/TEA platform including a data hub for assessing the cost and net emissions reduction clean fuel technologies, using a transparent science based methodology supported by harmonized datasets;
- Build a data hub integrating “qualified” datasets from different sources to enable timely decision making
- Assess the economic/environmental viability of carbon waste to energy conversion, and identify optimal operating conditions of CCS regarding the cost and net emissions reduction of the WECCS processes.

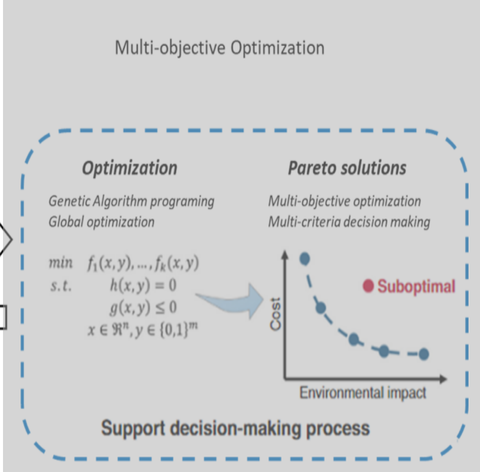
Achievements

- Application of the framework for case study: waste-to-H_2 with hydrothermal treatment process
- Designed scaled-up process PFD
- Developed specific TEA tool for LCOH
- Built a data hub by integrating the best available experimental data, supplemented with process simulation to obtain mass and energy balance data
- Sensitivity analysis to understand the impacts of key parameters on LCOH and GHG emissions

Impact

- This LCA/TEA framework will help R&D groups to identify hotspots and technology gaps to meet demands of low-carbon and sustainable solutions.



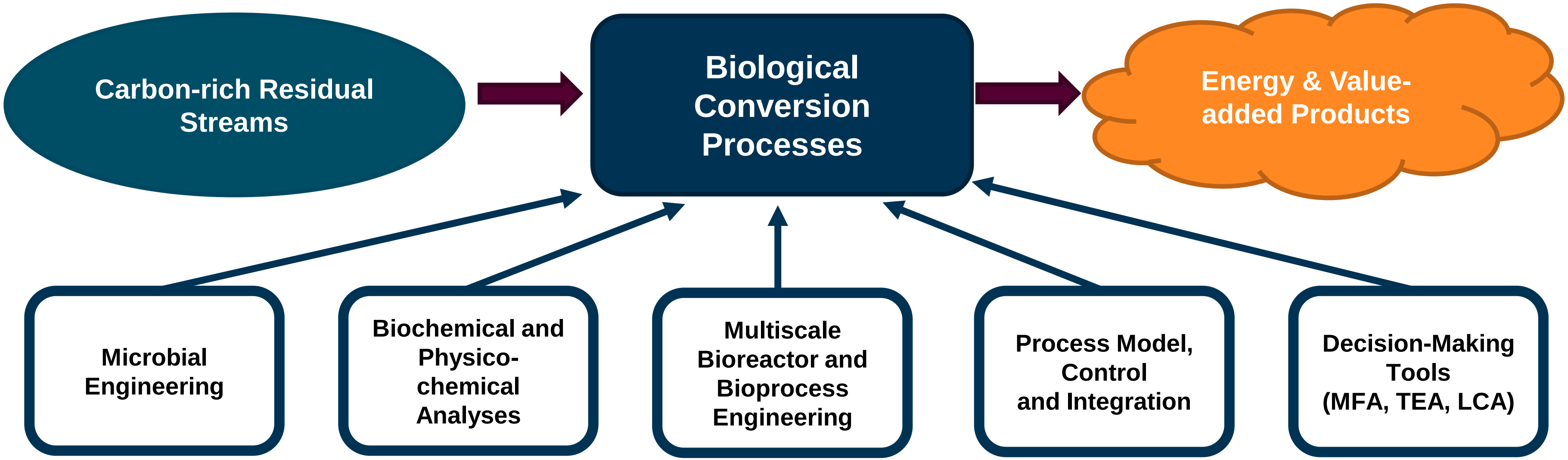


This part to be completed in the 2nd phase of the project

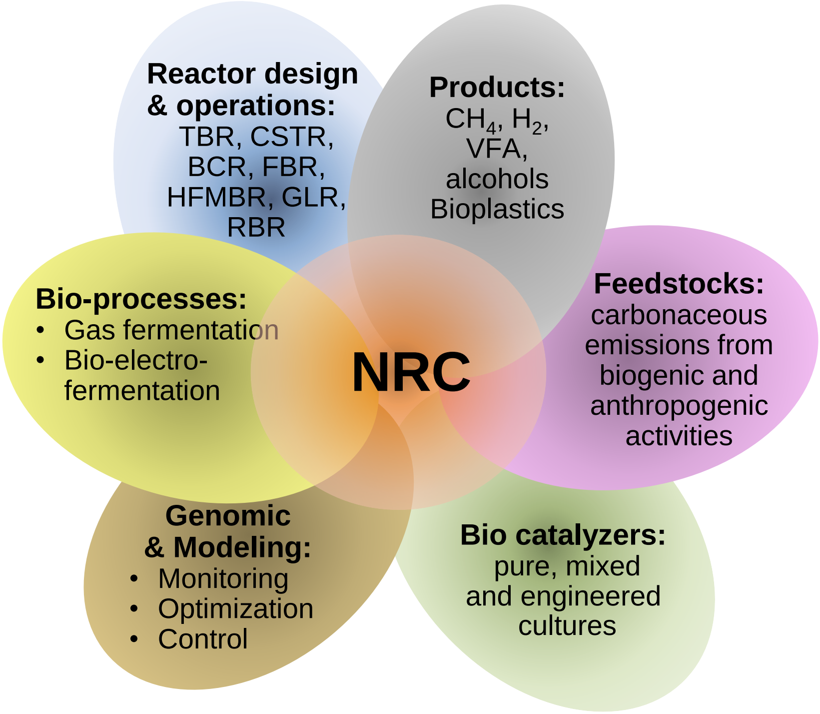
LCOH: levelized cost of hydrogen
GHG: greenhouse gases
PFD: process flow diagram
CCS: carbon capture and storage

Biochemical Processes

Next-generation Bioprocesses to support Canada's Clean Transition



Scope rationale
NRC unique position



TB: tubing bomb; CST: continuous stirred tank; BC: bubble column; FB: fluidized bed; HFMB: hollow fiber membrane bio; GL: glass-lined; RB: rotating bed

We envision great opportunities for the future of …

• **Integration of AD and thermochemical processing**
↔ pressure for zero waste plan adoption, with highest methane yield possible

• **Bio-electrochemical system**
↔ needs for energy-neutral or -positive wastewater treatment in remote locations and CCUS processes

• **C1-gas fermentation (syngas, iron and steel industrial fumes, CO_2, etc.)**
↔ RNG, SNG, H_2 & bio-based chemicals: directly from flue gas, or indirectly from biomass (low-cost syngas platform, compared to the expensive sugar-based platform, as a carbon source)

• **CO_2 biomethanation**
↔ power-to-gas conversion: effective way to store stranded electricity, with CO_2 capture

• **AD diagnostic platform**
↔ anticipated high demand for rapid diagnosis of problematic large-scale plants (microbial community composition & performance)

Biochemical Processes

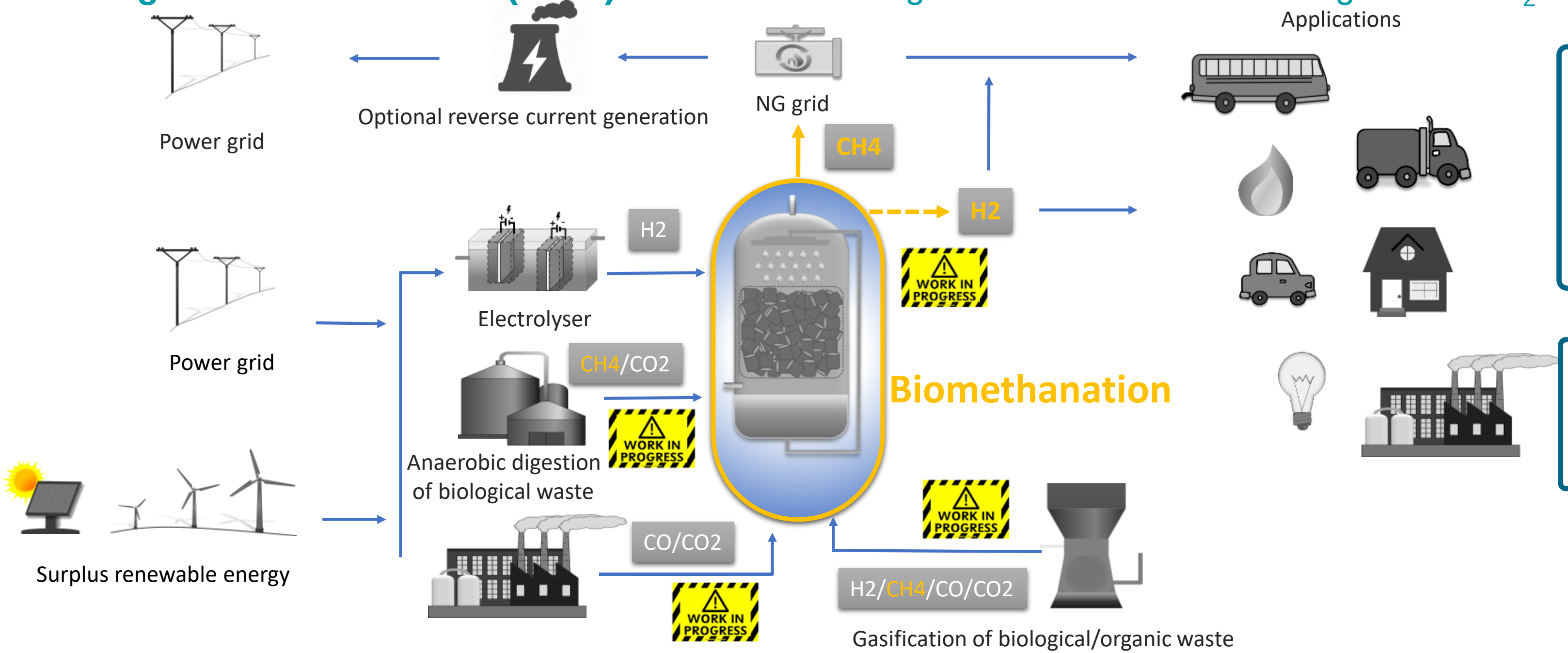
Gas Fermentation

Gas Fermentation – Overview

PIs: Ruxandra Cimpoia, Charles-David Dubé, Guillaume Bruant

Biological methanation & Power-2-Gas (P2G) → Conversion of gaseous streams containing CO/CO_2 into CH_4

Biological Water Gas Shift (WGS) → Conversion of gaseous streams containing CO into H_2



Upgrading biogas or syngas into RNG/H_2

Industrial fuel switching

Biochemical Processes

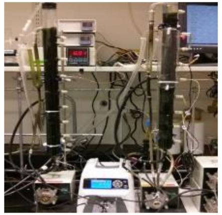
Bioelectrochemical Systems

Bioelectrochemical Systems – Overview

PIs: Boris Tartakovsky, Emmanuel Nwanebu, Guillaume Bruant

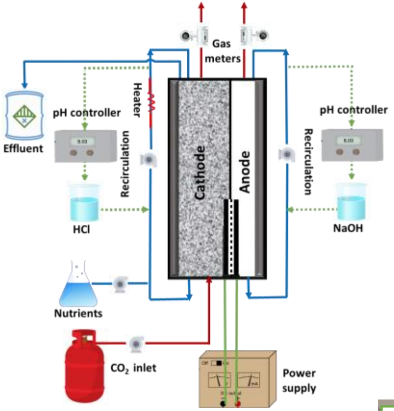
Microbial electrolysis cell (MEC) applications:

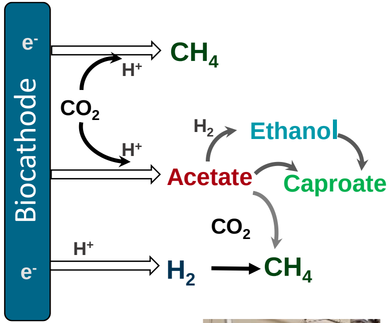
- **BEAST** (BioElectrochemical Anaerobic Sewage Treatment):
  → Energy recovery and sewage treatment with a patented heat-recovery system by micro-aeration.
- **BEAD** (Anaerobic digestion-MEC)
  → Enhanced biomethane production from food waste by adding electrodes in an anaerobic digester (e.g. Upflow anaerobic sludge blanket [UASB] digester).

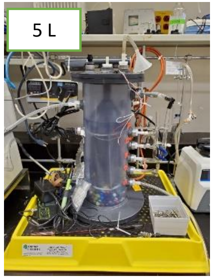


Microbial Electrosynthesis (MES)

Production of carboxylic acids and methane from carbon dioxide.







Conclusions

- Waste-to-energy technologies can convert negative value waste feedstock into useful fuels and intermediates which can be either used on their own or further upgraded to fungible fuels – biocrude, hydrogen, syngas, renewable natural gas
- Characterizing the waste is the first step in determining a suitable conversion process – many parameters such as composition, moisture content, homogeneity, and impurities have to be taken into consideration
- Next generation conversion processes can adapt to changes in feedstock to maximize the yield of the fuel
- A gas fermentation process such as biological methanation can capture CO_2 as well and convert to methane and hydrogen
- NRC also has engine and turbine research facilities and fuel characterization facilities for evaluating LCFs

Thank you

Shouvik Dev • Program Technical Lead • Clean Energy Innovation

Shouvik.Dev@nrc-cnrc.gc.ca