Pathways from Bio-Crude to Sustainable Aviation Fuel: Where are we at?

By

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Pathways to SAF

Ten SAF production pathways have been approved by ASTM to date (eight under ASTM D7566 and two co-processing pathways under D1655). Includes:

- Lipid-based HEFA – dominant source of SAF (TRL 9)
- Alcohol-to-Jet – Lanzajet's Freedom Pines plant in Georgia opened in Q1/2024 (TRL 8)
- Gasification/Fisher-Tropsch – Fulcrum first with Nevada plant, but closed in May 2024 (TRL 7-8)
- Power-to-Jet – (TRL 6-7 for Reverse Water Gas Shift Reaction)
- Catalytic Hydrothermolysis (CH) – (TRL 6?)
- Co-Processing
  - Lipids are commercial (TRL 9)
  - F-T liquids from cellulosic feedstock. (TRL 7?)

Biocrude made from solid cellulosic biomass can be used as the feedstock for the G/F-T, A-to-J, CH and Co-Processing pathways.

Co-Processing Bio-crude

- Co-processing lipids for producing RD & SAF is already commercial – especially in Europe.
  - Sustainable supply of lipids at a reasonable price is the concern
  - Future growth is limited

- Co-processing of Cellulosic-based biocrudes
  - Advantages in both Capex and Opex vs freestanding bio-refineries.
  - In commercial production with Pyrocell (Preem/Setra JV)
  - The key barrier to commercializing co-processing of cellulosic-based biocrude in N.America is regulatory (related to C-14 tracking of “green” molecules), not technical.

Why Biocrude for SAF?

Economies of scale and site location are critical wrt being cost competitive.

The required scale can likely be eventually achieved through the HEFA, Alcohol-to-Jet and Power-to-Jet pathways, but is more challenging when dealing with solid cellulosic biomass….the cheapest and most widely available feedstock for SAF.

Without densification of the biomass, it is difficult to sustain large scale biorefineries – the energy density of solid cellulosic biomass is too low, and the feedstock logistics are difficult.

Biocrude made for solid cellulosic biomass helps solve these problems, and the leading producers of biocrude are Ensyn (Fast Pyrolysis) and Licella/Arbios (HTL). What are they doing?

ENSYN'S RTP® – Scale-up & Commercial Deployment

ENSYN - **40+** years in business

Rapid Thermal Processing (RTP®)

- Ensyn's core technology – a platform for multiple products
- Converts solid biomass to high yields of liquid biomass
- Fast thermal conversion - no pressure, H_2, or catalyst
- Scalable now to at least **20**M gpy (~80M l/y) – economy of scale

RTP Production

- Continuous commercial production since **1989**
- **10** commercial RTP facilities commissioned
- **8** currently operating, **2** decommissioned after 20 yr & replaced
- Oldest of current RTP units operating since **1996**
- Additional **6** RTP demonstration and pilot units for testing

Renfrew, Ontario, 3M gpy commissioned 2006

Cote Nord, Quebec, 10M gpy commissioned 2018

ENSYN'S Initial Energy/Heating Fuel Projects

US Project – Millinocket, Maine

- Castlerock Biofuels JV first US project
- 20M gpy RFO heating fuel
- US$ 9 million development capital financing agreement with Nexus Development Capital
- Engineering underway, FID Q2/2025

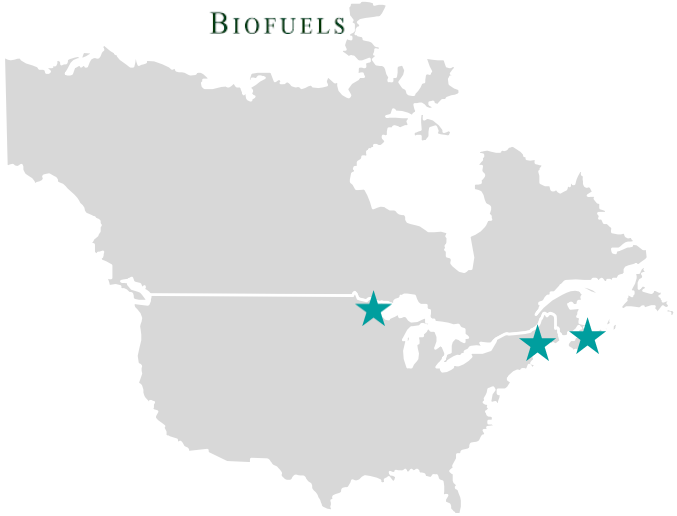
Canadian Project – Enfield, Nova Scotia

- 10M gpy heating fuel (~38 M litres)
- Co-located with Ledwidge Lumber mill
- Offtake based on Michelin combustion demo

US Project – Hoyt Lakes, Minnesota

- MN Department of Economic Development
- 20M gpy heating fuel (plus 5M gpy chemicals)
- Hoyt Lakes / Iron Range Resources (IRRRB) / MN Power

CASTLEROCK BIOFUELS



ENSYN

ENSYN'S Additional Growth:
Fast Pyrolysis Bio Oil Capacity Expansion Pathways

- Project expansion planned for U.S. in MN, WA and WI
- Anchored on de-risked heating fuel projects
- Additional production expansion to leverage production of Fast Pyrolysis Bio Oil for *growth products*

- **FCC Coprocessing**
  - Renewable gasoline & diesel
  - 10+ years of successful commercial trials
  - Regulatory framework evolving in a positive direction

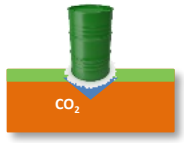
Honeywell UOP

- **Gasification**
  - Working with Linde
  - Green methanol and ethanol
  - Green hydrogen
  - Marine fuels
  - SAF (through either AtJ or FT)

Linde

- **Carbon sequestration**
  - RTP liquids downhole injection in commercial use
  - Generating CDR credits

★ ***Growth Targets***



Gasification of Biocrude

Much easier to gasify liquid than solid biomass.

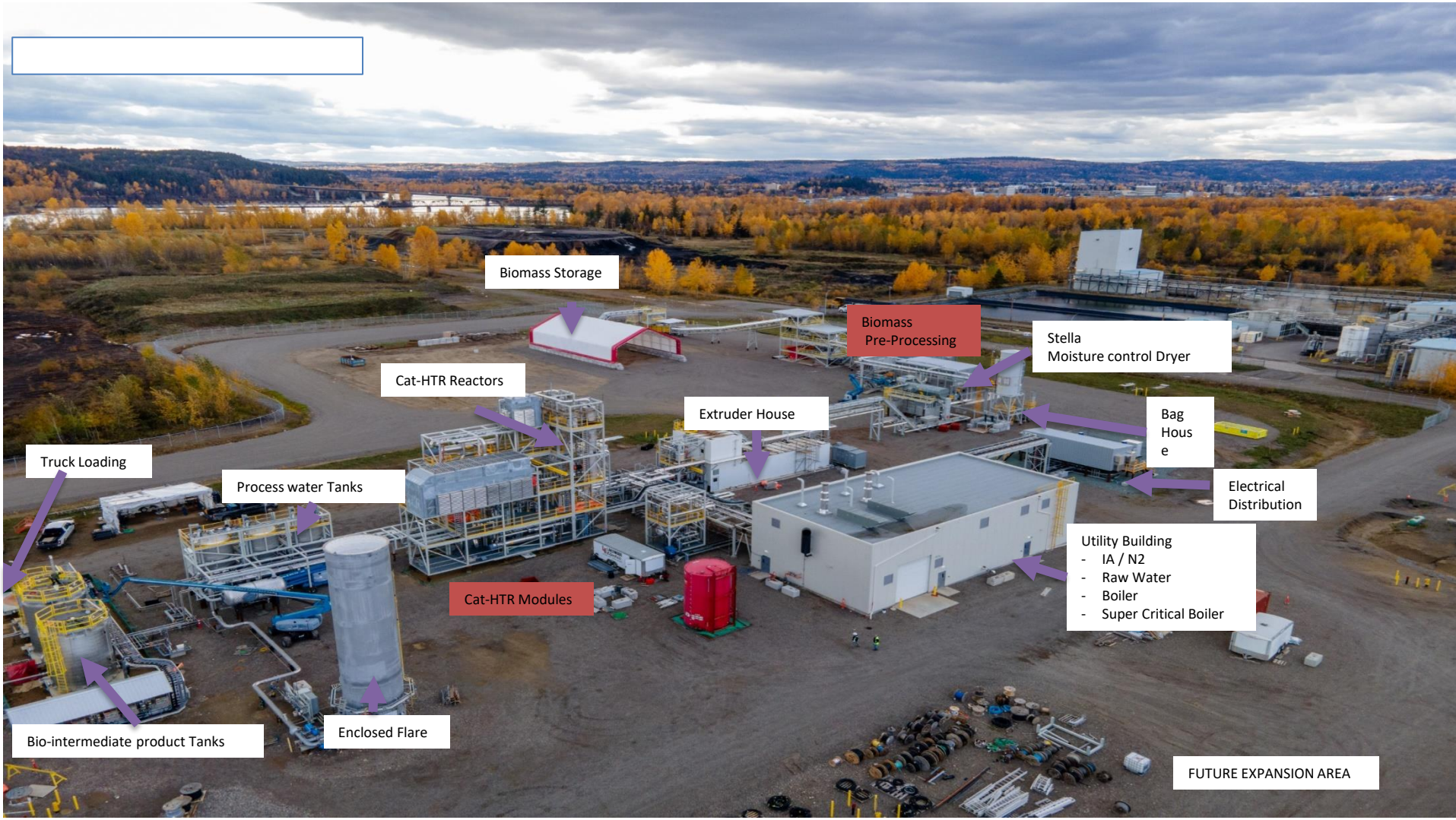
Linde's widely deployed Hot Oxygen Burner (HOB) technology opens different pathways to produce SAF from biocrude:

- Alcohol to Jet (eg., with Lanzatech)
- F-T (eg., with Topsoe)

Allows:

- Integration of proven technologies to produce SAF at scale.
- Geographic flexibility:
  - Decouple feedstock source from syngnas production
  - Easier to transport bio-ethanol to SAF location
- Optimal siting of plants wrt:
  - Best economic & regulatory environment
  - Reduced power cost
  - Proximity to oxygen/hydrogen networks and off-takers

Arbios Biotech's Chunhoh Ghuna Facility in Prince George, B.C.



Commissioning in Q4/2024

Chunhoh Ghuna – World's Largest HTL Plant

Strategic importance	○ World's first Cat-HTR™ biomass-to-biocrude plant ○ Supports SAF / upgrading opportunities
Location	○ Prince George, British Columbia (BC), Canada
Feedstock	○ Biomass ○ Woody - sawmill residues, primarily bark
Capacity (Stage 1)	○ 25,000 ODMT to produce ~50,000 Bll (~8 M litres). ○ First of multiple trains to be considered
Expansion opportunity	○ Significant scale-up opportunity, which is needed to make the site commercial - material government funding available
Project funding	○ Fully funded; Significant support from BC & Canadian Governments
Community engagement	○ Strong partnership formed with Lheidli T'enneh, regional First Nation
Commissioning	○ On-track Q4 2024 target[1]
Ownership	○ Arbios JV (between Licella & Canfor)
Licella's interest	○ Retains 50% ownership without directly funding Prince George project; Canfor holds remaining 50% ownership

[1] Target dates are indicative and may be subject to change

Licella's Upgrading Platform with Shell

Cat-HTR™ Biocrude

Shell Upgrader Technology

Renewable Fuels and Chemicals

Ex-Reactor Whole Crude

Oxygen	17 wt%
Nitrogen	<0.2 wt%
Aromatics	<50 vol%
TAN	~ 50-100 mg KOH/g
Cl	<1.5 ppmw
Cu Corrosion	1A
Viscosity	medium to high
Ash	<50 ppmw
HHV (daf)	32-33 MJ/kg

Light Naphtha
30 vol% expected
Gasoline blend component
Steam Cracker feed for green olefins
BTX/Chemical intermediate

SAF
65 vol% expected
Tunable aromatics 0-10 vol%
ASTM D-4054 certification planned
ASTM D-7566 annexation under A6

Heavy Diesel
5 vol% expected
Low S, Low aromatic diesel
ISO marine distillate

- Upgrading through the Catalytic Hydrothermolysis pathway

- Uses a fixed bed reactor in the HDO process to remove oxygen, which is easier, cheaper and quicker to scale-up.

Bottom-line?

Of all the uneconomical SAF technologies available for solid cellulosic biomass (and they are ALL currently uneconomical), those using biocrude are arguably the most ”commercial ready” and the least uneconomical ☺.

If governments establish policies that monetize climate change mitigation and provide a truly economical framework for SAF, the biocrude pathways should prove to be among the most cost-effective options.