July 2021

WASTE TO VALUE – Cat-HTR™ ADVANCED CARBON RECYCLING

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Licella™ LICELLA HOLDINGS LIMITED

Cat-HTR™

Alan joined Licella with 35 years in the petrochemical industry with Shell. Building upon experience with production of fossil-crude-derived petrochemicals during his earlier years at Shell, Alan shifted his focus toward development of more sustainable solutions. He led activities to identify, validate, scale up and deliver sustainable commercial solutions including production of low carbon-intensity petrochemicals and base oils, renewable petrochemicals, hydrocarbon fuels and hydrogen. Prior to retiring from Shell Alan had successfully led technical and commercial activities supporting circular economies in post-consumer waste plastics and production of renewable 'drop in' hydrocarbon fuels from biomass. He has implemented novel partner-based risk-mitigation strategies for the first deployment of new technologies.

His responsibilities at Licella include development of commercial opportunities in North America, certification of renewable fuels produced by Licella's Cat-HTR™ process and supporting the expansion of the technology platform through diversification of applications.

Alan holds a Bachelor of Science degree in Chemistry from Purdue University and a Ph.D. in Inorganic Chemistry from University of California, Berkeley which he attended as a National Science Foundation pre-doctoral fellow. Alan has attended Executive Development courses at the University of Houston and University of Pennsylvania, Wharton School of Business.

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LICELLA AT A GLANCE

As global leaders in the next generation of advanced recycling, our vision is to pioneer versatile, affordable and effective circular economic solutions for a lower carbon future by deploying our hydrothermal liquefaction decarbonization platform to enable our customers to meet their net-zero carbon commitments.

When conventional mechanical recycling has reached its limits, hydrothermal liquefaction is a solution to be considered

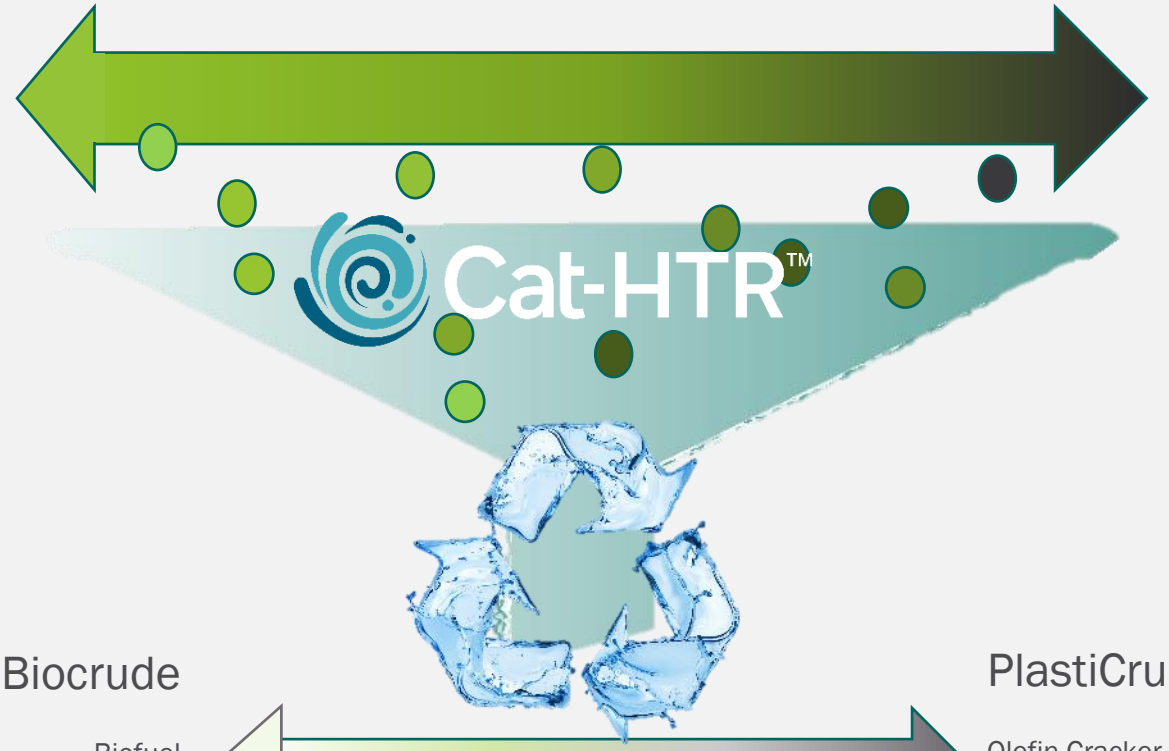
A HYDROTHERMAL PLATFORM FOR **RECYCLING CARBON**

Biomass

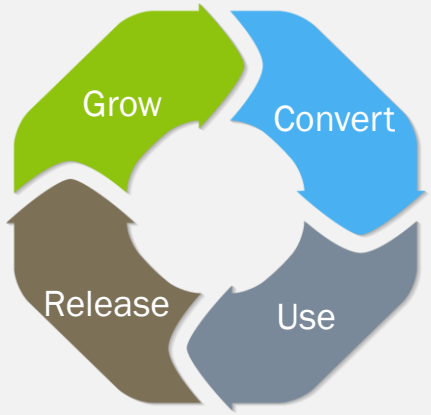
Forestry residues
Agricultural residues
Mixed municipal residues

Plastic

Mixed End-of-Life plastics
Multilayer packaging
Tires



The C Cycle for Biofuels



Biocrude

Biofuel
Renewable Chemicals
Biomaterials

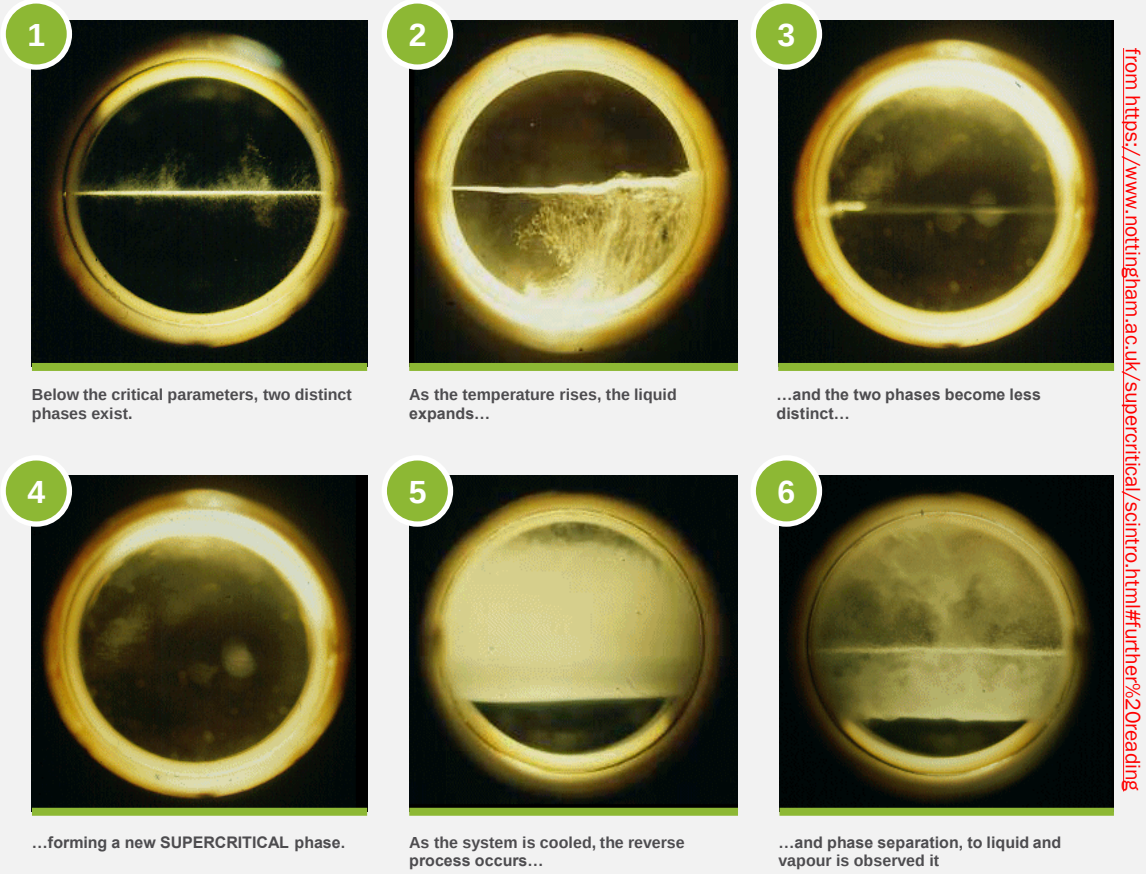
PlastiCrude

Olefin Cracker Feed
Recycled Plastics
Recycled Chemicals

The C Cycle for Plastics

WATER IS THE AGENT OF CHANGE

- Water at high temperature and pressure is used in HTL process (‘critical’ conditions of 374°C and 218 bar).
- Supercritical water is a ‘fourth’ state of matter – not solid, liquid or gas but somewhat like a vapor.
- Under these conditions water is:
  - a solvent – rapidly diffusing through the feedstock to selectively break polymer bonds, which then re-arrange to form stable oils.
  - a reagent – promoting the removal of oxygen atoms from biomass as CO_2 and donating hydrogen atoms to replace them. Oxygen content is reduced from ~45wt% in the biomass to 12-14wt% in the biocrude.
  - a control rod – ensuring controlled, homogenous heating from within, eliminating local hotspots. Hotspots lead to runaway reactions which reduce yield, produce char and create light products.



Below the critical parameters, two distinct phases exist.

As the temperature rises, the liquid expands…

…and the two phases become less distinct…

…forming a new SUPERCRITICAL phase.

As the system is cooled, the reverse process occurs…

…and phase separation, to liquid and vapour is observed it

from https://www.nottingham.ac.uk/supercritical/scintro.html#further%20reading

LICELLA'S MULTI-YEAR PATH TO BRING HTL TECHNOLOGY TO **COMMERCIAL READINESS**

Licella Founded

Cat-HTR™ described by Accenture report as **"Potentially Revolutionary".**

3rd Gen Cat-HTR™ Large Pilot Plant upgraded and commissioned.

AUSTRALIAN MUSEUM EUREKA PRIZES WINNER

ARBIOS BIOTECH

2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021

1st Gen Cat-HTR™ Small Pilot Plant commissioned.

2nd Gen Cat-HTR™ Large Pilot Plant commissioned.

End to End Small Pilot Plant for End-of-Life Plastic commissioned

MURA

ARMSTRONG

ReNew ELP

CS1 Small Commercial Plant Commissioned

DOW

lyondellbasell

Nestlé

amcor

KBR

MITSUBISHI CHEMICAL

LG Chem

Chevron Phillips CHEMICAL

OUR BUSINESS STRUCTURE ALLOWS US TO
COMMERCIALISE ALONGSIDE OUR STRATEGIC PARTNERSHIPS

Licella™ HOLDINGS

Licella™ TECHNOLOGY DEVELOPMENT

- **Global Centre of Excellence**
- Runs CS1 & Commercial Demonstration Facilities
- Leads global R&D innovation
- Technical support to partner network

PATENTED TECHNOLOGY PLATFORM

Cat-HTR™

Global (ex ANZ) Post-Consumer **Plastic** & Tyres

MURA · DOW · KBR · ARMSTRONG

Americas/Europe Post-Consumer **Biomass**

ARBIOS BIOTECH · Shell · CANFOR · Licella™ HOLDINGS

ANZ Post-Consumer **Plastic** & Tyres

ARA™ Advanced Recycling Australia · Licella™ HOLDINGS

New Market Opportunities

(Sugarcane Tops & Trash, Rice Straw, Bamboo…)

Licella™ HOLDINGS

UNIQUE PREMIUM QUALITY BIOCRUDE

- HTL process produces high yields of low CI biocrude.
- Low CI is a net result of embracing feed moisture, lower reaction temperatures, energy dense biocrude produced in high yield.
- HTL biocrude successfully:
  - derived from high ASH, high SILICA feedstocks
  - upgraded via hydrotreating – not limited to FCC
- Collaboration with Shell Catalysts & Technologies (SC&T) led to a strategic alliance announced in May 2021 where SC&T provides technology to Arbios targeting conversion of biocrude to low CI 'drop in' transportation fuels with an emphasis on SAF. Shell can also offtake products.

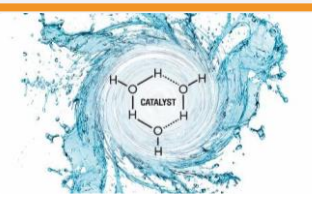
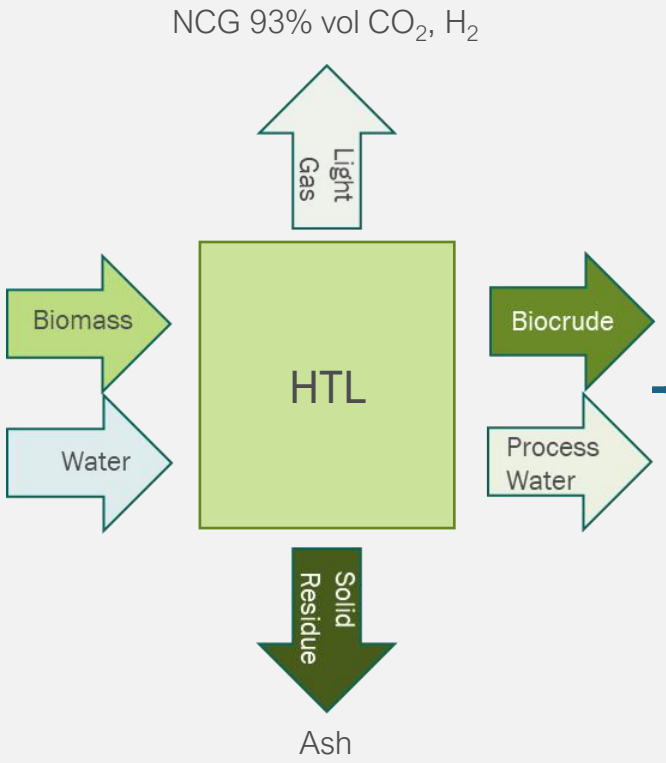
	HTL	PYROLYSIS
Drying Time	Unnecessary	Necessary
Temperature	200-400 deg C	370-525 deg C
Carbon	78%	58%
Hydrogen	8%	6%
Oxygen	14%	36%
High Heat Value (HHV)	35-36 MJ/Kg	<23MJ/Kg
Moisture Content	<5%	20-25%
		

Table data: Gollakota et al. (2018). A review on hydrothermal liquefaction of biomass

UNIQUE VALUE PROPOSITION – FLEXIBILITY
LOCATION, SCALE, FEEDSTOCK(S), PRODUCT (DISTILLATE VS WHOLE BIOCRUDE), TARGET MARKET

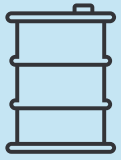


HTL BioCrude

Oxygen 14 wt%
Nitrogen <0.2 wt%
Aromatics <50 vol%
TAN <50 mg KOH/g
Cl <1.5 ppmw
Cu Corrosion 1A
Viscosity (Medium)
Ash <50 ppmw
HHV (daf) ≥35 MJ/kg

Distillate
- Light Fuel Oils
- Renewable Chemicals (BTX/olefins)
- Refinery Feed, Hydrotreating
- Refinery Feed, FCC Feed

Residue
- Biogenic Coker Feed
- BioCoke e.g. Cement Kiln
- BioCoke (Low Ash) for Steel
- Materials for Separations media
- Materials for Sorbent media
- BioMaterials



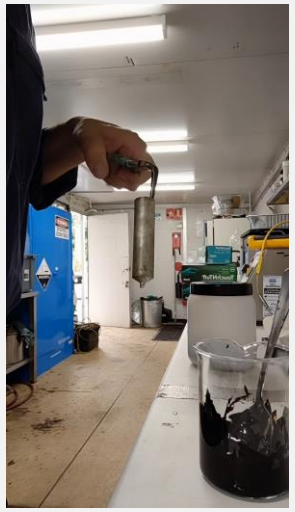
Whole BioCrude
- Refinery Feed, Hydrotreating
- Refinery Feed, FCC Feed
- Boiler Fuels
- Residual Fuel Oils
- Renewable Chemicals

UNIQUE VALUE PROPOSITION – ENHANCED FLEXIBILITY
UPGRADED PRODUCTS FOR RENEWABLE FUEL AND/OR CHEMICAL MARKETS

HTL technology

Ex-Reactor Whole Crude

Biocrude at 70°C



100K DAF tonnes wood waste

35K moisture free tonnes biocrude
Biocrude (density 1.1)
(200K barrels)

Shell Upgrader Technology

Renewable SAF and Chemicals

Light Naphtha
30-35 vol% targeted commercially
Gasoline blend component
Steam Cracker feed for green olefins
BTX/Chemical intermediate

SAF
60-65 vol% targeted commercially
Tunable aromatics 0-10 vol%

Heavy Diesel
~5 vol% targeted commercially
Low S, Low aromatic diesel
ISO marine distillate

32K moisture free tonnes
Biofuel (density 0.8)
(253K barrels)

UNIQUE VALUE PROPOSITION – ENHANCED FLEXIBILITY
UPGRADED PRODUCTS FOR RENEWABLE FUEL AND/OR CHEMICAL MARKETS

HTL technology

Ex-Reactor Whole Crude

100K DAF tonnes wood waste

35K moisture free tonnes biocrude
Biocrude (density 1.1)
(200K barrels)

Shell Upgrader Technology

Renewable Road Transport Fuels

Gasoline
35-45 vol% targeted commercially

Diesel
55-63 vol% targeted commercially

Heavy Diesel
≤2 vol% targeted commercially

32K moisture free tonnes
Biofuel (density 0.8)
(253K barrels)

COMMERCIAL SCALE -UP
ARBIOS BIOTECH PRINCE GEORGE

ARBIOS BIOTECH

On 5th October 2021, Arbios announced its decision to move forward with its first commercial scale biomass to biofuel plant in Prince George, BC.

FIRST PLANT

Will convert 25,000 dry tonnes of wood residue/waste to 50,000 barrels of renewable biocrude per year

EXPANSION

Potential to build 3 more processing lines

LOCAL AND REGIONAL SUPPORT

Project is working closely with the Lheidli T'enneh First Nation and has received significant support and funding from BC and Canadian Governments

OPERATIONS

Plant is expected to commence operations Summer 2023

UNIQUE VALUE PROPOSITION - FLEXIBILITY
ENABLING CIRCULARITY IN POST-RECYCLE END OF LIFE PLASTICS

PE (HDPE, LDPE)
PP
PB
PS

Tolerated Impurities
O
N
S
Cl

HTL technology

Plasticrude to Cracker

Naphtha
IBP – 175 deg C

Distilled Gas Oil
175 deg C – 360 deg C

Distilled Heavy Gas Oil
360 deg C – ~500 deg C

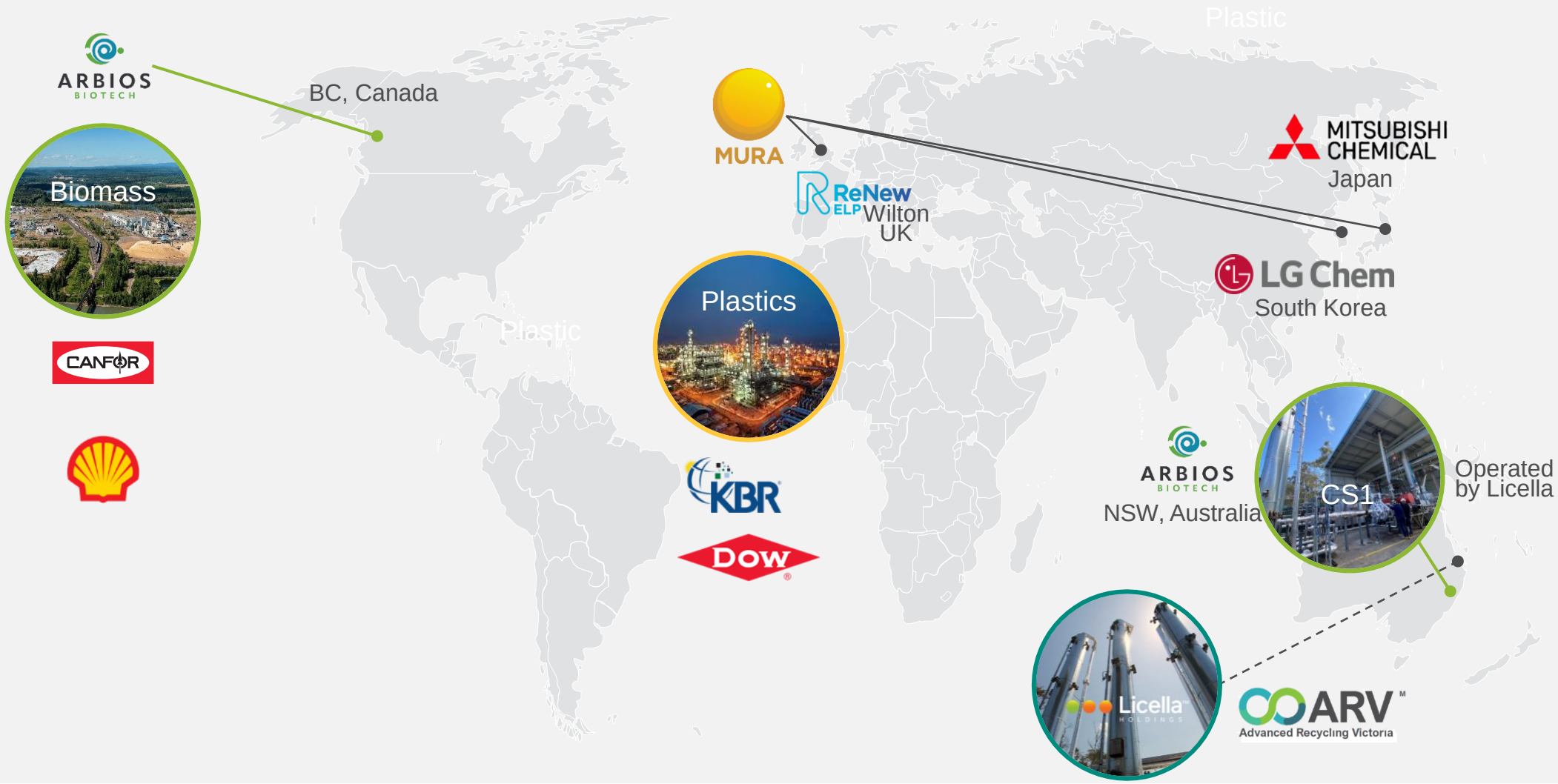
Heavy Wax Residue
≥500 deg C

100K tonnes post-consumer ELP waste

80-85K tonnes plasticrude

COMMERCIAL FACILITIES CONTAINING Cat-HTR™ TECHNOLOGY

Funded Biomass Conversion
Funded Plastic Conversion
Developing Plastic Conversion



Thank You

licella.com

https://vimeo.com/687820749

info@licella.com

PRODUCTION CONFIGURATIONS FOR US RIN ELIGIBILITY DRIVE SHORT TERM STRATEGY
RFS CURRENT AND AS PROPOSED/AMENDED

Production Site(s)		RIN Eligibility
Cat-HTR™ Upgrader[1] Renewable Fuels	Cat-HTR™ unit(s) constructed at refinery Cat-HTR™ unit(s) constructed with upgrader	YES under current RFS YES under proposed amendment to RFS
Cat-HTR™ Bio Intermediates / Upgrader[2] Renewable Fuels	Cat-HTR™ unit is constructed near feedstock Upgrading is performed at a second site	NO under current RFS YES under proposed amendment to RFS

[1]co-located at refinery or biocrude production includes on site upgrader
[2]off-site refinery or upgrader, including hub & spoke

EXAMPLES OF PUBLISHED LICELLA UPGRADING WORK

[3]Mathieu, Y., Sauvanaud, L., Humphreys, L., Rowlands, W., Maschmeyer, T., Corma, A. Faraday Discussions, 197 (Catalysis for Fuels), 389-401 (2017). https://pubmed.ncbi.nlm.nih.gov/28177341/

[3]Mathieu, Y., Sauvanaud, L., Humphreys, L., Rowlands, W., Maschmeyer, T., Corma, A., Production of High Quality Syncrude from Lignocellulosic Biomass. Cat. Chem., 9(9), 1574-1578 (2017). https://www.mendeley.com/catalogue/126951eb-fb9f-3ba9-a306-f0cead472bcb/

[3]Sauvanaud, LL.; Mathieu, Y.; Corma Canós, A.; Humphreys, L.; Rowlands, W.; Maschmeyer, T. (2018). Co-processing of lignocellulosic biocrude with petroleum gas oils. Applied Catalysis A General. 551:139-145. https://doi.org/10.1016/j.apcata.2017.09.029

EXAMPLES OF PUBLISHED 3RD PARTY HTL UPGRADING WORK

[1]Taghipoura, Alireza., Hornung, Ursel., Ramirez, Jerome A., Brown, Richard J., Raineya, Thomas J., *Fractional distillation of algae based hydrothermal liquefaction biocrude for co-processing: changes in the properties, storage stability, and miscibility with diesel.* Energy Conversion and Management, Volume 236, 15 May 2021, 114005
https://pubag.nal.usda.gov/catalog/7333468

[2]Haghighat, Parsa., Montanez, Anderson., Aguilera, Gonzalo Rocha., Guerrero, Julie Katerine Rodriguez., Karatzos, Sergios., Clarke, Matthew A., McCaffrey, William. *Hydrotreating of Hydrofaction™ biocrude in the presence of presulfided commercial catalysts.* Sustainable Energy Fuels, 2019,3, 744-759.
https://pubs.rsc.org/en/content/articlelanding/2019/se/c8se00439k.

[2]Subramaniam, Senthil, Santosa, Daniel M., Brady, Casper O., Swita, Marie S., Kallupalayam Ramasamy, Karthikeyan, and Thorson, Michael R.. *Extended catalyst lifetime testing for HTL biocrude hydrotreating to produce fuel blendstocks from wet wastes.* United States: N. p., 2021. Web. doi:10.1021/acssuschemeng.1c02743.
https://www.osti.gov/biblio/1829675-extended-catalyst-lifetime-testing-htl-biocrude-hydrotreating-produce-fuel-blendstocks-from-wet-wastes

[2]Thorson, Michael R., Santosa, Daniel M., Hallen, Richard T., Kutnyakov, Igor V., Olarte, Mariefel V., Flake, Matthew D., Neuenschwander, Gary G., Middleton-Smith, Lisa A., Zacher, Alan H., Hart, Todd R., Schmidt, Andrew J., Lemmon, Teresa L., and Swita, Marie S.. *SCALEABLE HYDROTREATING OF HTL BIOCRUDE TO PRODUCE FUEL BLENDSTOCKS*. United States: N. p., 2021. Web. doi:10.1021/acs.energyfuels.1c00956.
https://www.osti.gov/biblio/1819934-scaleable-hydrotreating-htl-biocrude-produce-fuel-blendstocks

[2]Salman Haider, Muhammad., Castello, Daniele., Rosendahl, Lasse Aistrup. *Two-stage catalytic hydrotreatment of highly nitrogenous biocrude from continuous hydrothermal liquefaction: A rational design of the stabilization stage.* Biomass and Bioenergy, Volume 139, August 2020, 105658
https://www.sciencedirect.com/science/article/abs/pii/S0961953420301926