Innovation in Sustainable Fuels Webinar Series

Session 4 – Sustainable Aviation Fuel

Document prepared by Zemo Partnership

Thursday 1st April 2021

Gloria Esposito, Head of Sustainability
Zemo Partnership

Gaynor Hartnell, CEO, RTFA

Zemo Partnership
Accelerating Transport to Zero Emissions

Renewable Transport Fuel Association

Today's Agenda

10:30am	Welcome and housekeeping	Gaynor Hartnell, CEO, RTFA
	Session Chair	Leigh Hudson, Sustainable Aviation Fuels and Carbon Manager, International Airlines Group
10:35 am	Building the UK SAF supply chain	Michelle Carter, Head of Transport, KTN
10.50 am	The Altalto project	Neville Hargreaves, VP, Velocys
11:05 am	Alcohol to jet pathways and projects	Freya Burton, Chief Sustainability and People Officer, Lanzatech
11:20 am	The Fulcrum Northpoint project	Jeff Ovens, Managing Director, Fulcrum BioEnergy
11:35 am	Panel Discussion	
12:00 pm	Session wrap up and next session	Gloria Esposito, Head of Sustainability Zemo Partnership

All attendees on mute, camera off, please enter your questions in the chat function

Building the UK SAF Supply Chain

Michelle Carter
Head of Transport
KTN

1 April 2021

Zemo Partnership

KTN exists to connect **innovators** with new **partners** and new **opportunities** beyond their existing thinking – accelerating ambitious ideas into real-world **solutions**.

ktn

Our Network

46,229

Unique Organisations

72%

Small

15%

Medium

13%

Large

234,478

Individuals

All UK universities

Building the UK SAF Supply Chain

Zemo Partnership

Across the supply chain

120

Companies supported

450

Individuals in the SAF network

85

B2B or B2R Introductions

10

Collaborations brokered

4

NDA's with UK airline

Data: 2017-2019

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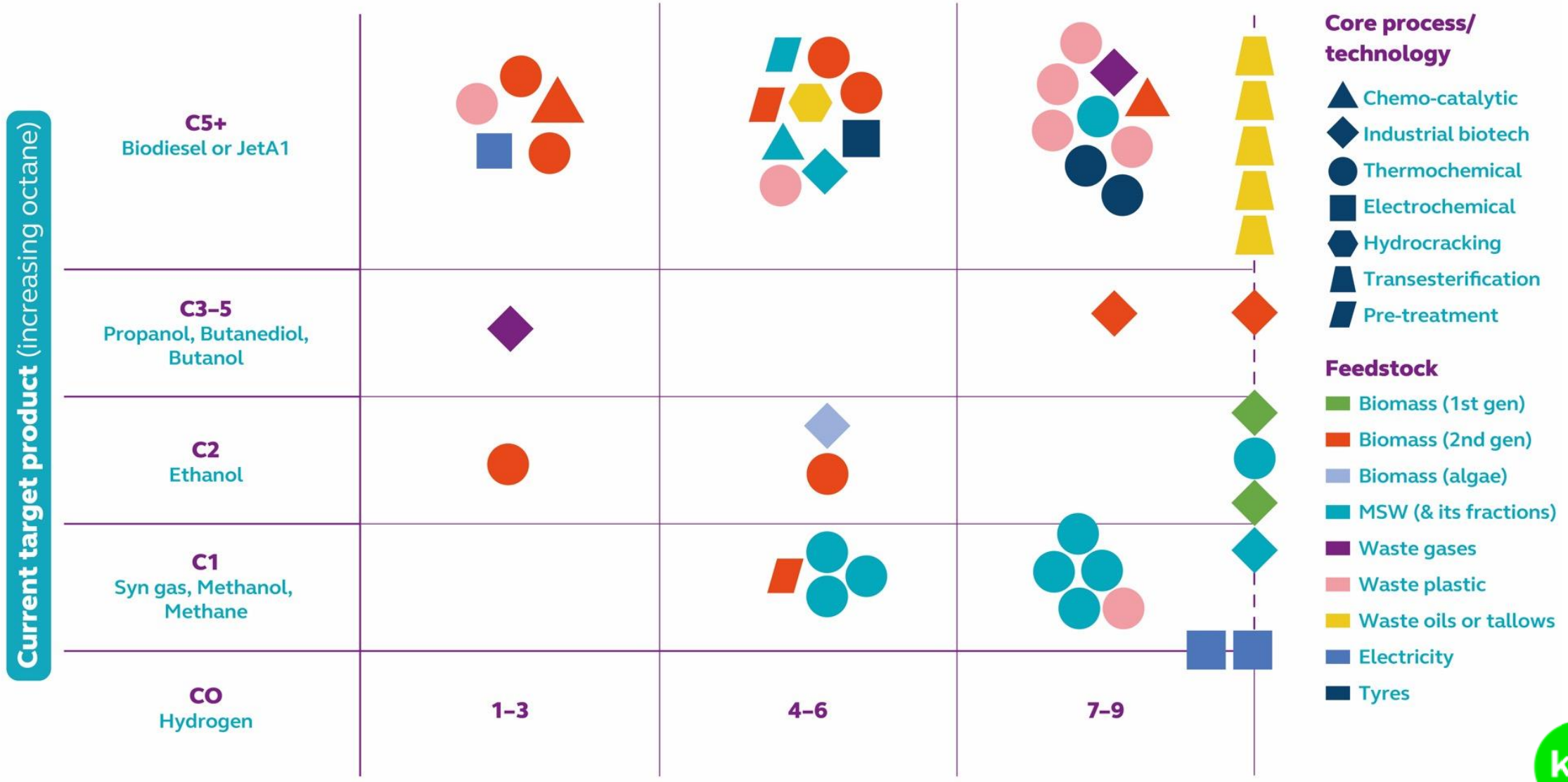


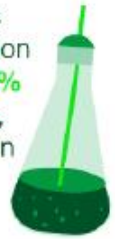
Feedstock

25%

of companies analysed convert municipal solid waste and its fractions

14% companies utilise plastic waste to make fuels

24% of companies utilise 2nd generation biomass, whilst **35%** utilise waste gases, tyres, 1st generation biomass or algae



Technology

46%

of companies use a thermochemical processing route

18% of companies use industrial biotechnology based routes. The remaining **36%** use transesterification, chemocatalytic, electrochemical or hydrocracking processes

Product

55%

of companies produce high-octane fuels like diesel or Jet A1

45%

of companies are developing simpler, less-energy dense fuel products (e.g. syngas, hydrogen, methanol, ethanol) for non-aviation fuel markets

Scale

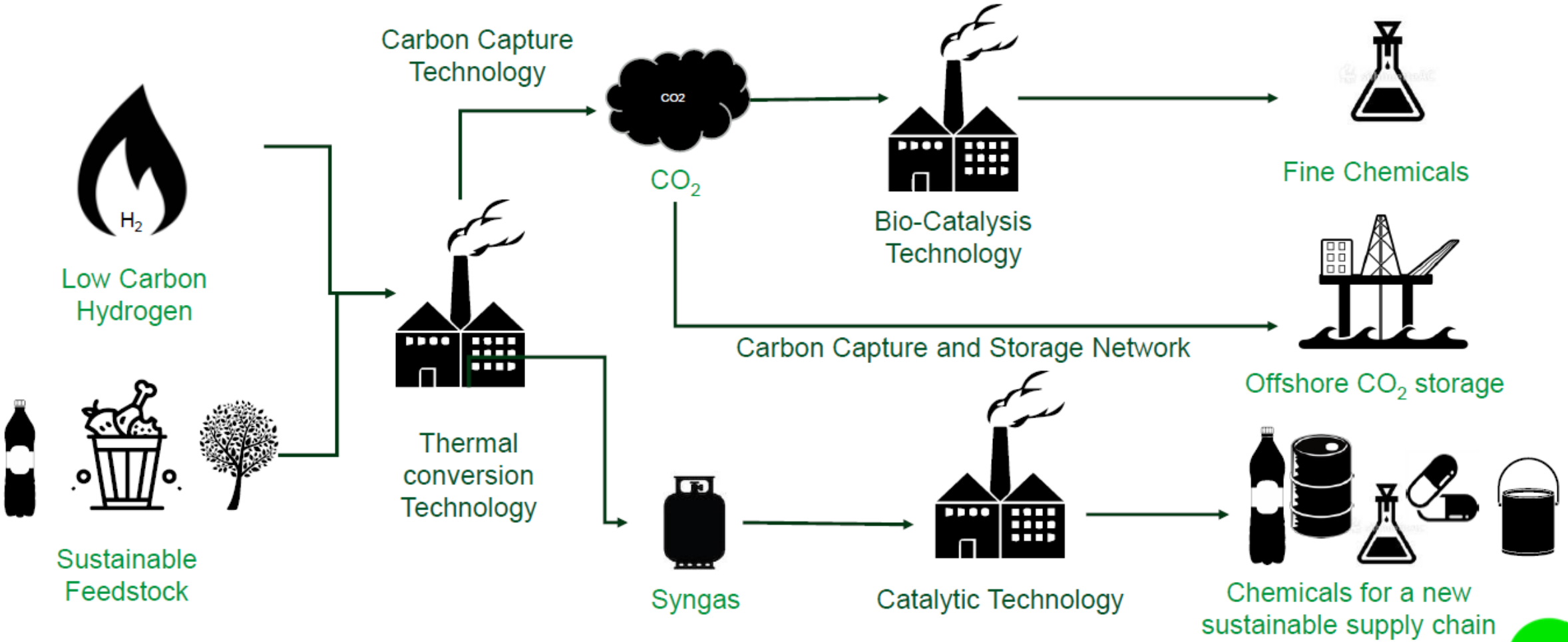
31%

of companies operate at **TRL 7-8**, **31%** at **TRL 4-6** and **14%** at **TRL 1-3**

24%

of companies are operating at commercial scale

Example of a future sustainable chemical supply chain



Unlocking the UK sustainable chemical industry

Low-cost/low C energy & H_2

Critical to commercialise sustainable chemicals

New end-to-end supply chains

- New partnerships across the value chain
- Demonstrate the techno-economic viability of producing chemicals from alternative feedstocks

Policy

Creating the market opportunities to incentivise the production of sustainable chemicals

Systems of systems approach to innovation

Local opportunities & need, feedstock, energy supply, product & market requirements as part of a wider system

Feedstocks

Robust processes to mitigate fluctuations in feedstock quality, availability, variability, volume & contaminants

Connecting for
Positive Change.

Zemo Partnership

ktn-uk.org | ktn

March 2021

Sustainable aviation fuel from waste
Altalto Immingham project

VELOCYS

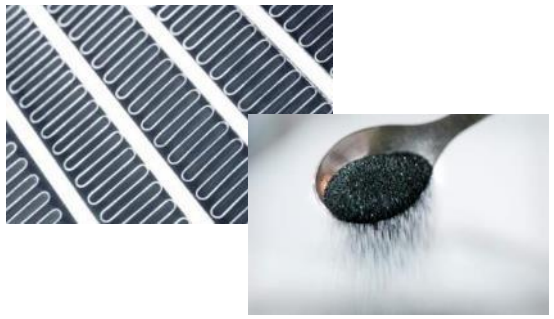
Introduction to Velocys

Velocys is a sustainable fuels technology provider traded on the AIM index (LSE)

19 years of innovation in the development of catalytic technology and advanced renewable fuels projects

- Valuable IP created including more than 180 granted patent claims in over 40 patent families
- Supply proprietary Fischer-Tropsch (FT) technology and co-develop FT-based biorefineries
- The Red Rock Biofuels project is using our FT reactors, validating our technology and strategy
- Commercial biorefinery projects advancing in the US and UK

Velocys plc evolution



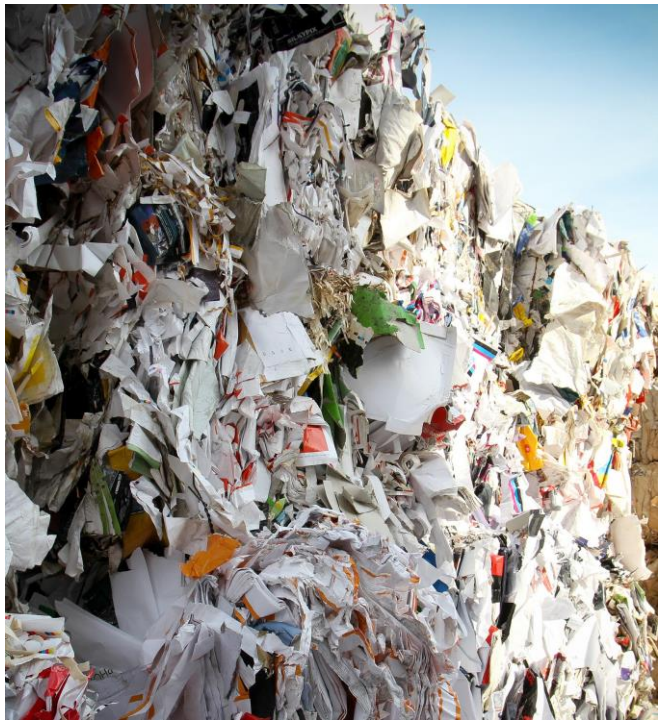
Catalyst and microchannel reactor technology

Multiple demonstrations, globally

Commercial scale reactors fabricated and operated

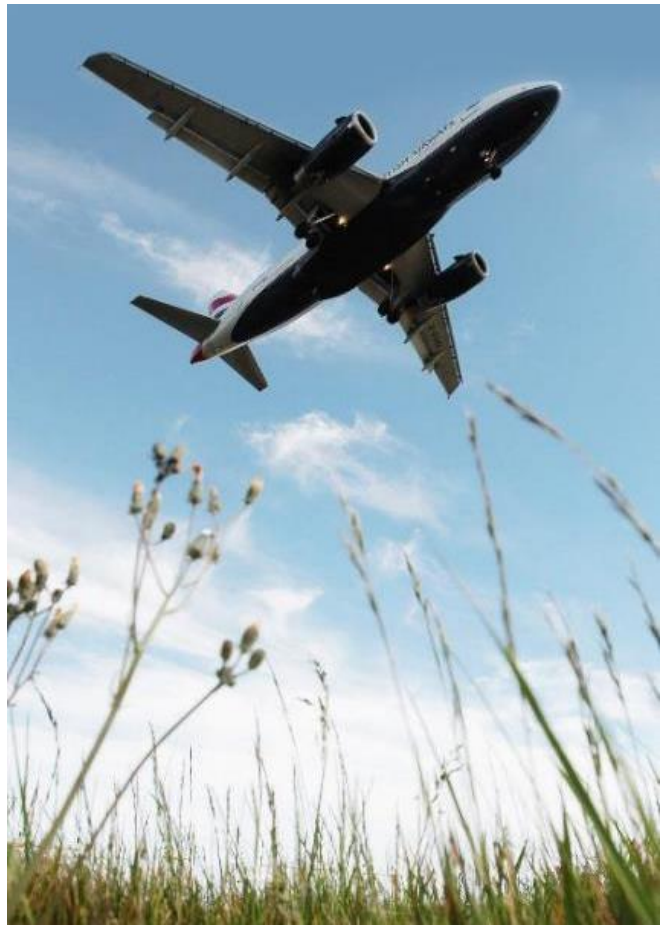
Technology demonstrated at full scale in Oklahoma City, 2017-18

Plan to create the first waste-to-jet-fuel plant in Europe



Over 500,000 tonnes of black bag waste saved from landfill or incineration...

...making enough clean Sustainable Aviation Fuel...



...to power over 1,000 transatlantic flights a year

Sustainable Aviation Fuel is critical for decarbonising the industry

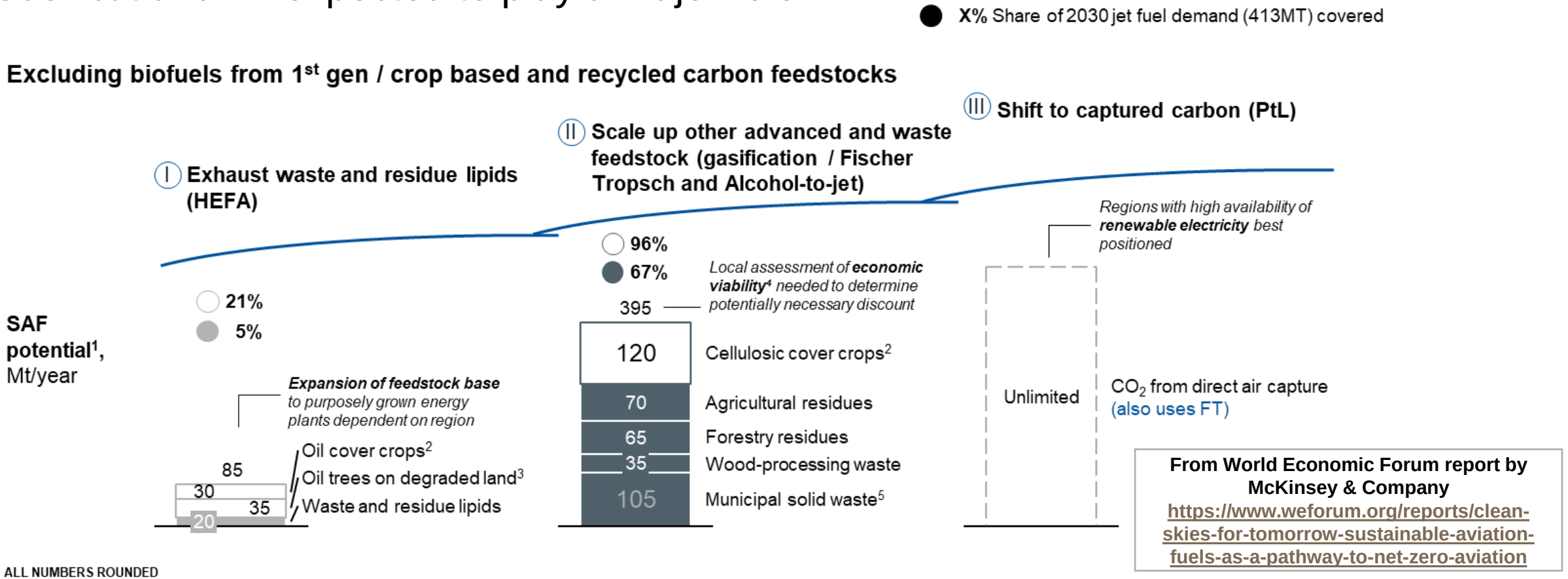
	2020	2025	2030	2035	2040	2045	2050
Commuter » 9-50 seats » < 60 minute flights » <1% of industry CO_2	SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF
Regional » 50-100 seats » 30-90 minute flights » ~3% of industry CO_2	SAF	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Short haul » 100-150 seats » 45-120 minute flights » ~24% of industry CO_2	SAF	SAF	SAF	SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF
Medium haul » 100-250 seats » 60-150 minute flights » ~43% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF potentially some Hydrogen
Long haul » 250+ seats » 150 minute + flights » ~30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

Source: Waypoint 2050, *ATAG*, p48

VELOCYS

A mix of feedstock and technology pathways will be needed to meet SAF demand

Gasification / FT expected to play a major role



From World Economic Forum report by McKinsey & Company
https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation

ALL NUMBERS ROUNDED

1. Assuming exhaustion of practically available feedstock in plants optimized for jet fuel output (HEFA at 46%, AtJ at 77%, gas./FT at 55%); 2. From land under non-permanent crops, assuming 5% available for oil cover crops, and 20% available for cellulosic cover crops; 3. Assuming 1% of degraded land used for oil trees; 4. Including accessibility and collection rates; 5. Organic waste, may contain up to 20% non-reusable plastic

Source: FAOstat, USDA, ACRE McKinsey solution (based on e.g., GLADA; Bai et al. 2008; Gibbs et al., FAO, Mapspam, FAO 2015 FRA, ESA CCI Land Cover), World Bank, .S. Environmental Protection Agency, IRENA, E4TECH (2020), BEIS (2017), ICCT (2016), Wan Nur Aifa Wan Azahar et al., OECD, EC 142/2011, Greenea, USDA, Ecofys, Fischer Solve, Statistik der Verarbeitung Tierischer Nebenprodukte 2016, research articles, press search

VELOCYS

It's not only about CO_2: cleaner burning drop-in fuel improves air quality

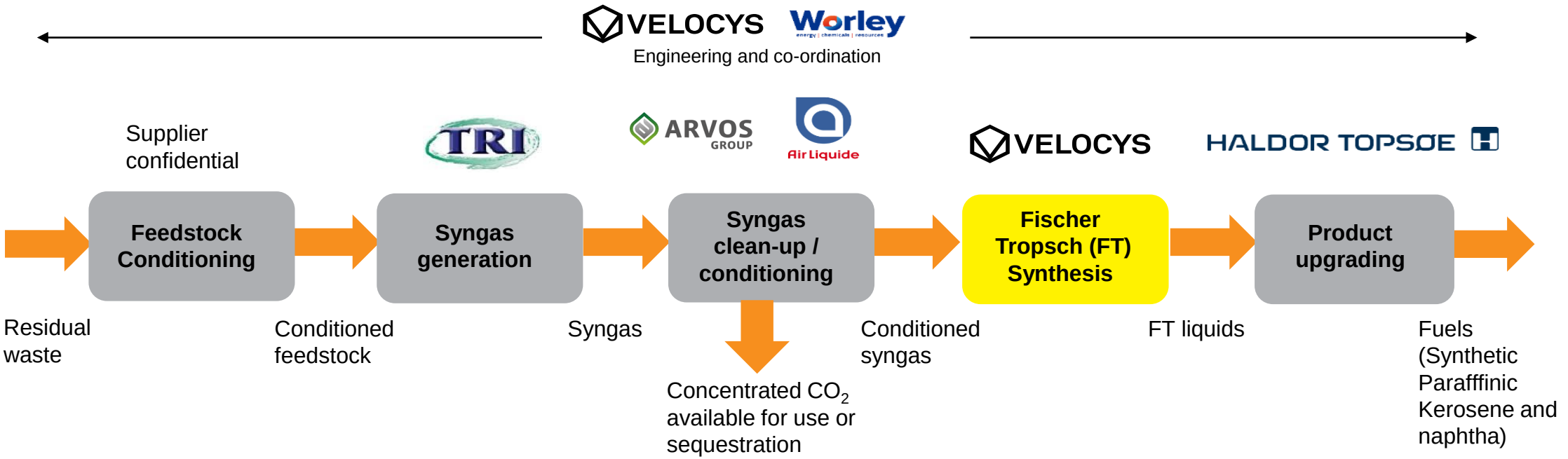
- Product is Synthesized Paraffinic Kerosene (SPK) meeting ASTM D7566 Annex A1
- Blended with conventional fuel, can be **used in existing engines without any modifications**
  - Approved at up to 50% in blend for commercial aviation worldwide
- Synthetic aviation fuel made by this route **burns more cleanly than conventional fuel**
  - **Particulate matter** emissions reduced by up to 90%
  - **Sulphur** close to zero
- Target 70% Greenhouse Gas reduction[1]; could be >100% with Carbon Capture & Storage

Diesel made using **Velocys** process

Diesel from filling station

[1] On biogenic fraction; methodology for non-biogenic fraction to be specified by Government

Process overview and technology licensors



VELOCYS

Altalto Immingham site

- Situated in the Humber “Energy Estuary” with excellent transport and infrastructure
- Skilled local workforce
- Target for inward investment
- Planning consent granted June 2020
- Close to Carbon Capture and Storage cluster

Sustainable Aviation Fuel – next steps

- Second- and third-generation SAF projects essential in order to deliver volume

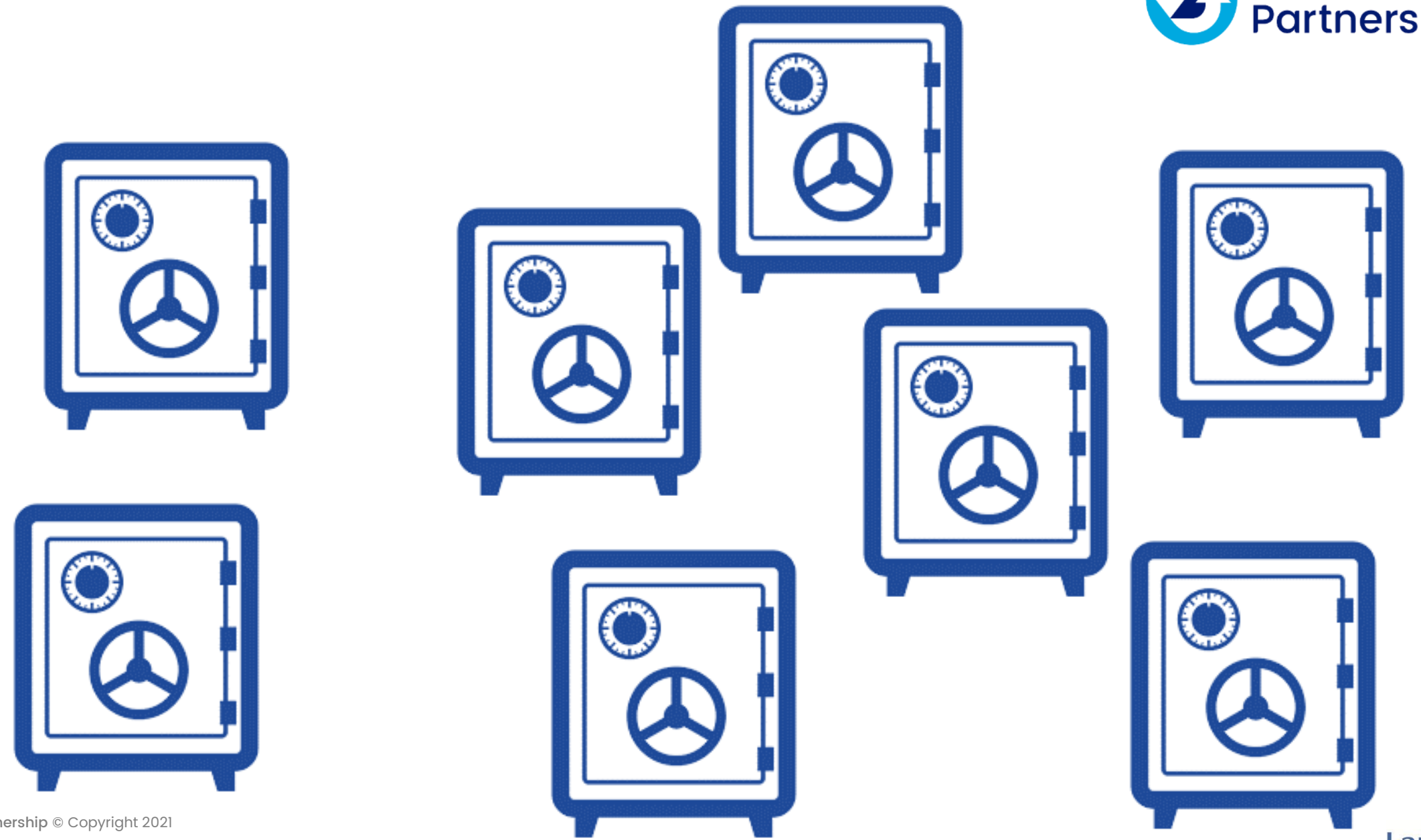
- Development of projects such as Altalto depends upon the regulatory framework
  - Renewable Transport Fuel Obligation in UK provides mechanism for support of SAF
  - Industry seeking mechanism to give price stability – key to financing

- SAF mandates under consideration in UK and EU and through ICAO


LanzaTech
RECYCLES CARBON TODAY FOR A CLEANER TOMORROW

All Carbon is Precious

Zemo Partnership



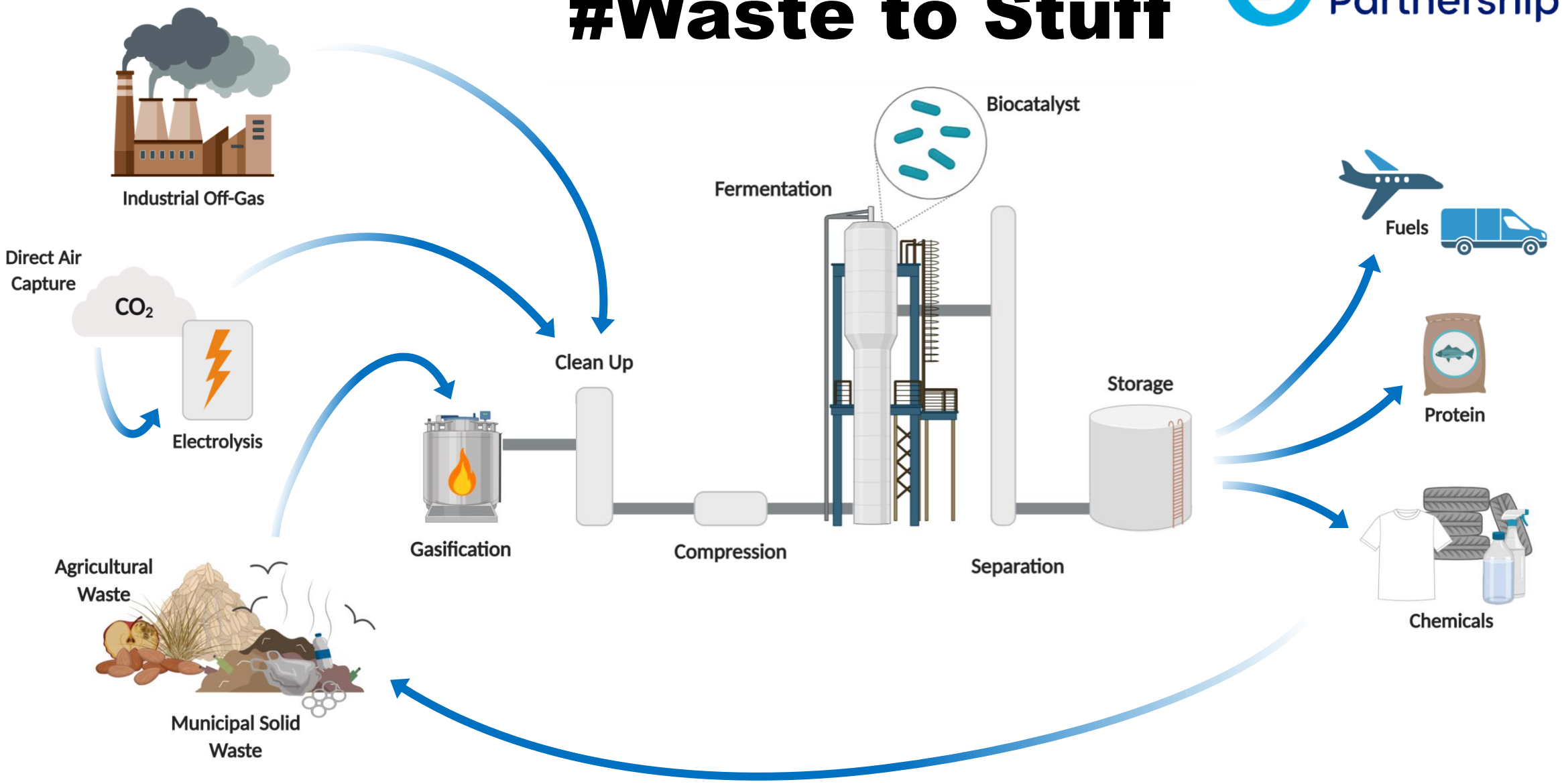
Power can be Carbon Free

Aviation Fuel needs Carbon

Utilizing all Waste Carbon

Zemo Partnership

#Waste to Stuff



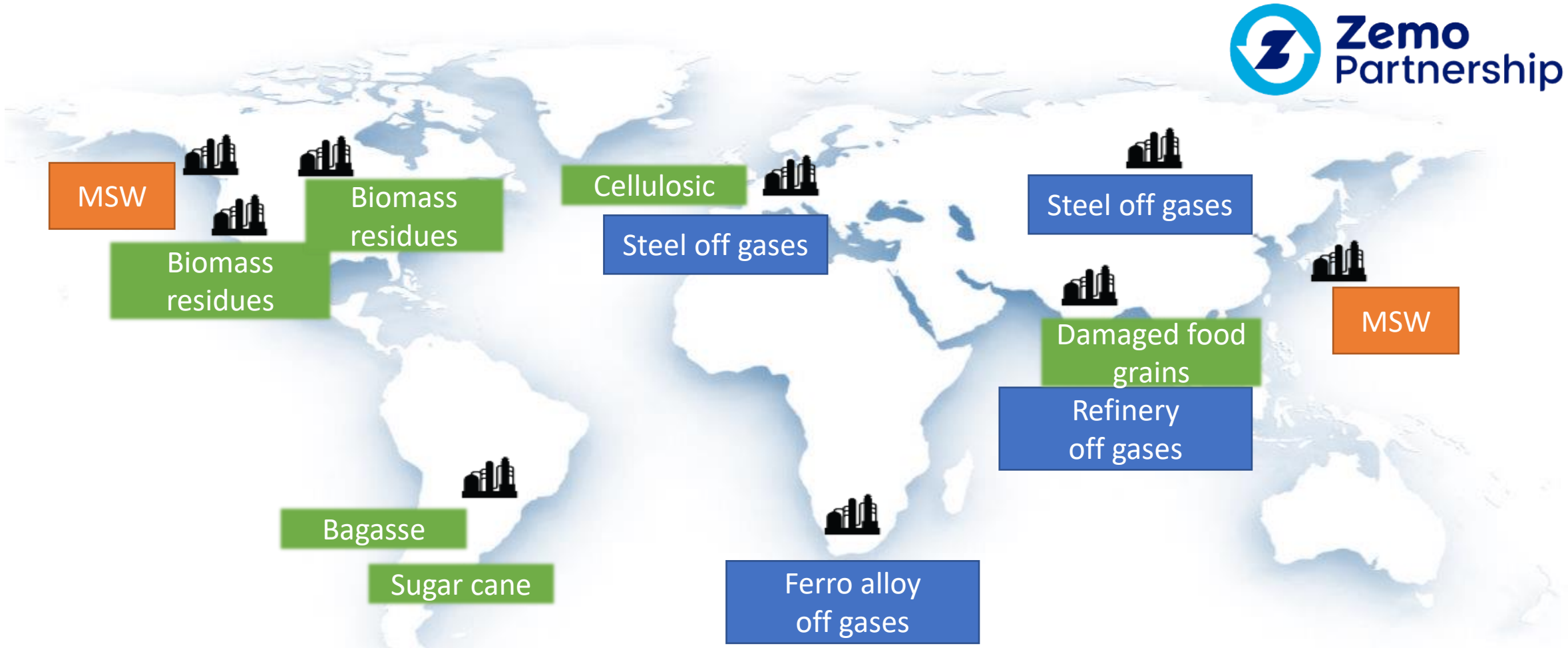
CarbonSmart™

LanzaTech

Operating Commercially

>20M Gallons Ethanol Produced
>100,000 metric tons CO_2 avoided

Global Platform Build Out



Ethanol Feedstock is a Regional Choice
AtJ can come from ANY Ethanol Source

Ethanol: A Starting Point for Multiple Pathways

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Ethanol

Paraffins
Isoparaffins

C_4-C_{24} Olefins

Ethylene

Polyethylene

MEG → PET

Etc.

Building Block of the Future

CarbonSmart™

LanzaTech

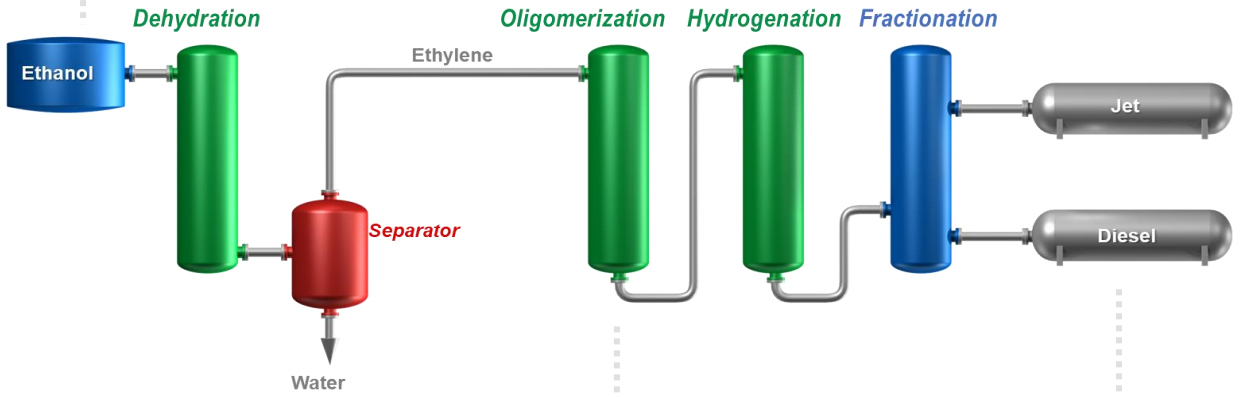
LanzaJet Platform

Pacific Northwest NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

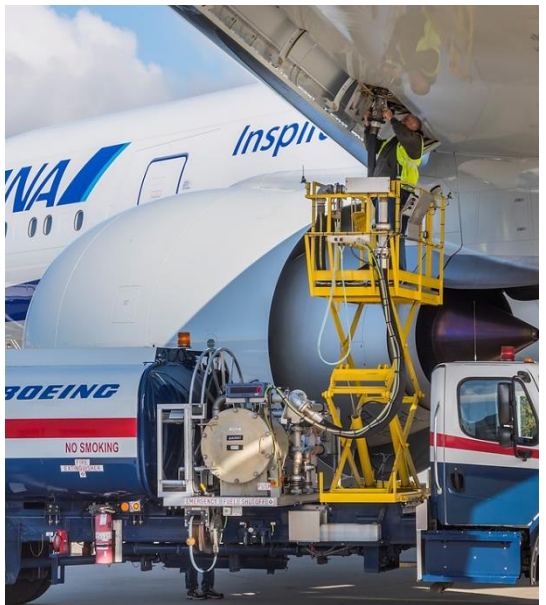
High yields

Feedstock agnostic



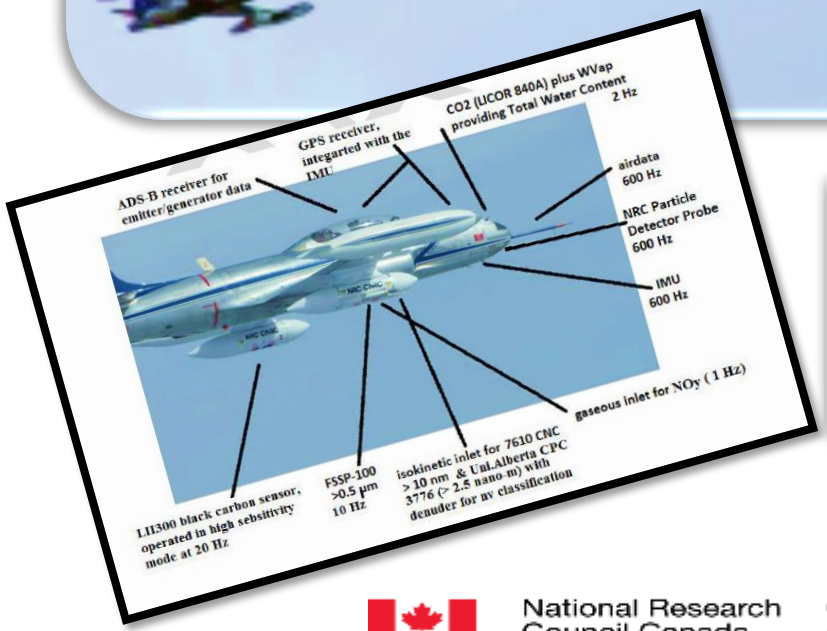
Proven catalyst

Valuable co-products

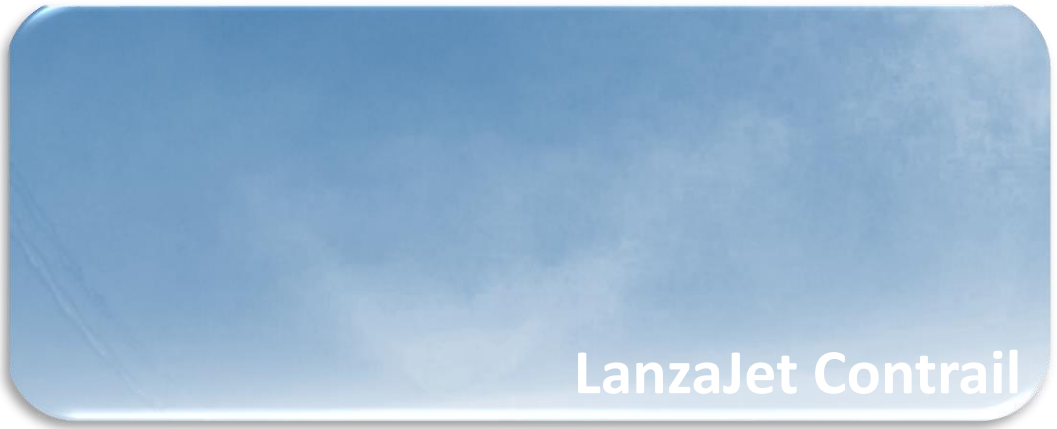


NRC Contrail Emission Flight Research using 92% LanzaJet

Zemo Partnership



LanzaJet 90% Lower Contrails and Soot Particles



National Research Council Canada | Conseil national de recherches Canada

Canada

LanzaJet: Capitalized through Commercial Scale

Efficient, economic sustainable aviation fuel (SAF)

Zemo Partnership

LanzaTech

Technology License

SUNCOR

MITSUI&CO.

BRITISH AIRWAYS

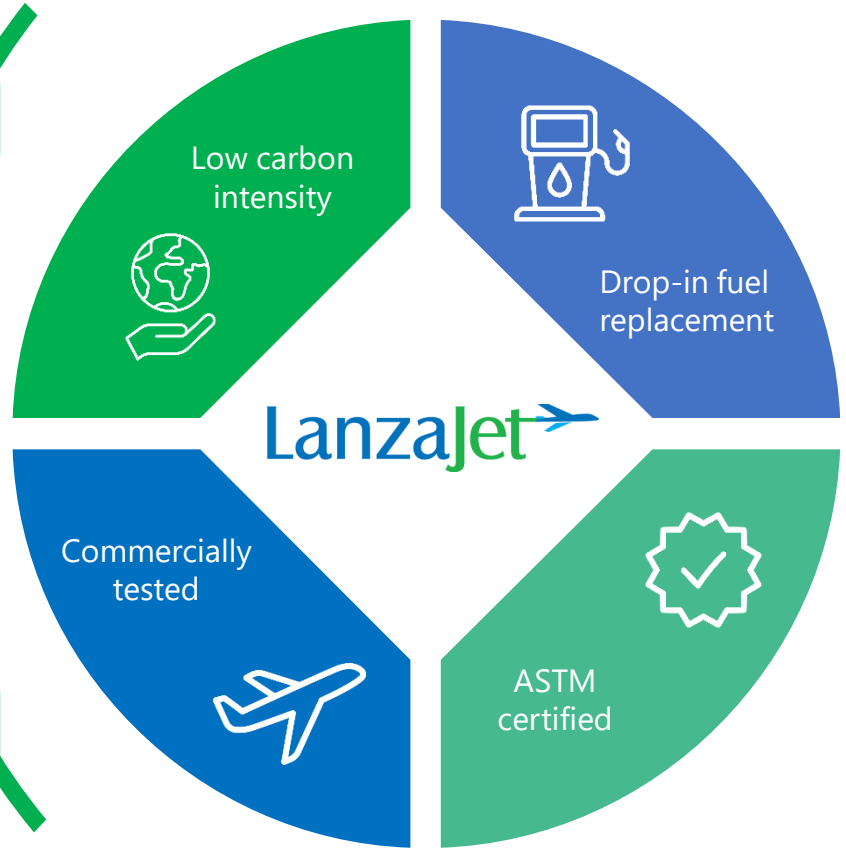
Capital

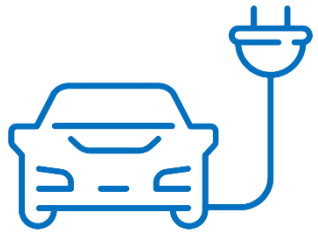
ANA

Pre-Paid Offtake

U.S. DEPARTMENT OF ENERGY

Grant Funding





SAF in the aviation market is analogous to **batteries** in the electric vehicle market

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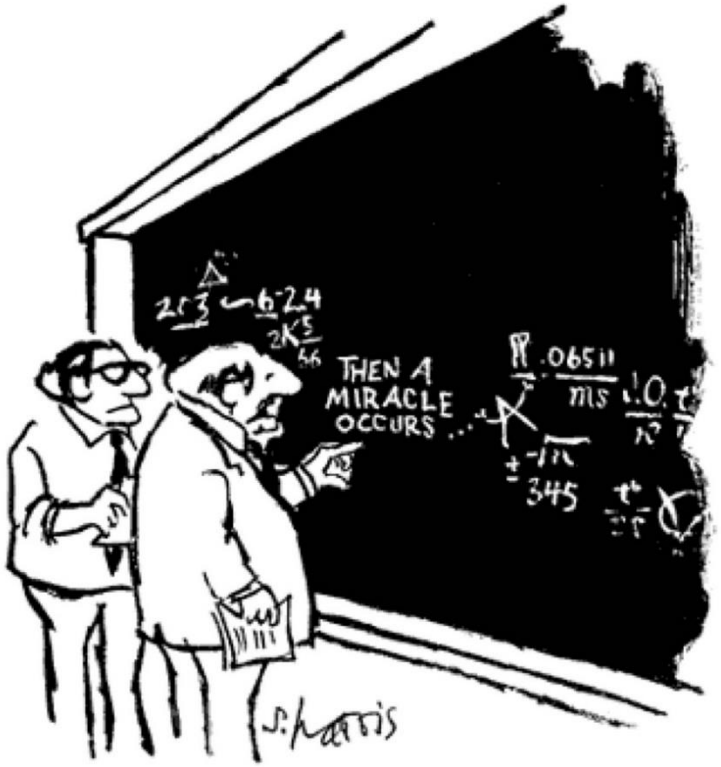
We must adopt technology neutral position and support all solutions.

We must collaborate to address environmental concerns and get recycled carbon, including Power-to-X, fuels and chemicals to market.

We must fail quickly and move on.



"I think you should be more explicit here in step two."

Policies, Definitions and Funding Drive or Block the Build Out of Disruptive Technologies

Aviation Fuels from Waste

Zemo Sustainable Aviation Fuels Webinar

Fulcrum BIOENERGY

Fulcrum Bioenergy
MSW to Renewable Fuels

- Renewable Fuels Company founded in 2007
- 14 years designing, developing, testing waste to fuel process
- Attracted investment from airlines, oil companies and conglomerates
- Worlds first commercial waste to aviation fuel facility nearing completion
  - **Uses process equipment designed in the UK**
- Expanding growth program beyond North America to UK market
  - **Will contribute to UK's 2050 Net Zero Commitment**

Fulcrum – MSW to Renewable Fuels

Zemo Partnership

Disposal of Municipal Solid Waste (MSW) at Landfills

Decarbonisation of Aviation

Fulcrum – Solving Two Global Challenges

Fulcrum BIOENERGY

The Fulcrum Process

The Fulcrum propriety process uses a combination of proven technologies. - waste processing to remove recyclables and inorganic materials, - conversion of the waste into a synthetic gas or 'syngas', syngas clean-up,
- fuel synthesis.

01 Feedstock Processing
Sorting and preparation of waste and removal of recyclable material

02 Gasification
Breaking down the sorted waste using heat to produce syngas

03 Syngas Cleanup
Remove impurities from the sngas stream

04 Fischer Tropsch (FT)
React the clean syngas in a catalyst to produce hydrocarbons

05 Hydrocracking
Refine the hydrocarbons into Sustainable Aviation Fuel or Diesel

MSW to Fuels process

Fulcrum BIOENERGY

- Renewable ‘Drop-in’ Fuel
- Passed Numerous Market Fuel Certifications
  - Ultra-Low Sulfur Diesel
  - Commercial/Military Jet Fuel
- Life-Cycle Carbon Emissions Can be Less Than Zero with CCS installed
- Qualifies for Numerous Renewable and Sustainability Standards
  - United States Renewable Fuels
  - California Low-Carbon Fuels
  - European Union Sustainable Fuels
  - UK Renewable Transport Fuel Obligation (RTFO)

Fulcrum’s Valuable Fuel Products

Zemo Partnership

Feedstock Supply → Waste to Syncrude → Fuel Refining → Fuel Logistics → Customers

Waste Connections, Inc. — Connect with the Future

Marubeni

Cathay Pacific

WM — Waste Management

Marathon

Department of Defense

Abengoa

bp

United

World Fuel Services

citi Ventures

JAL — Japan Airlines

Fulcrum's Strategic Partner Model

Fulcrum BioEnergy

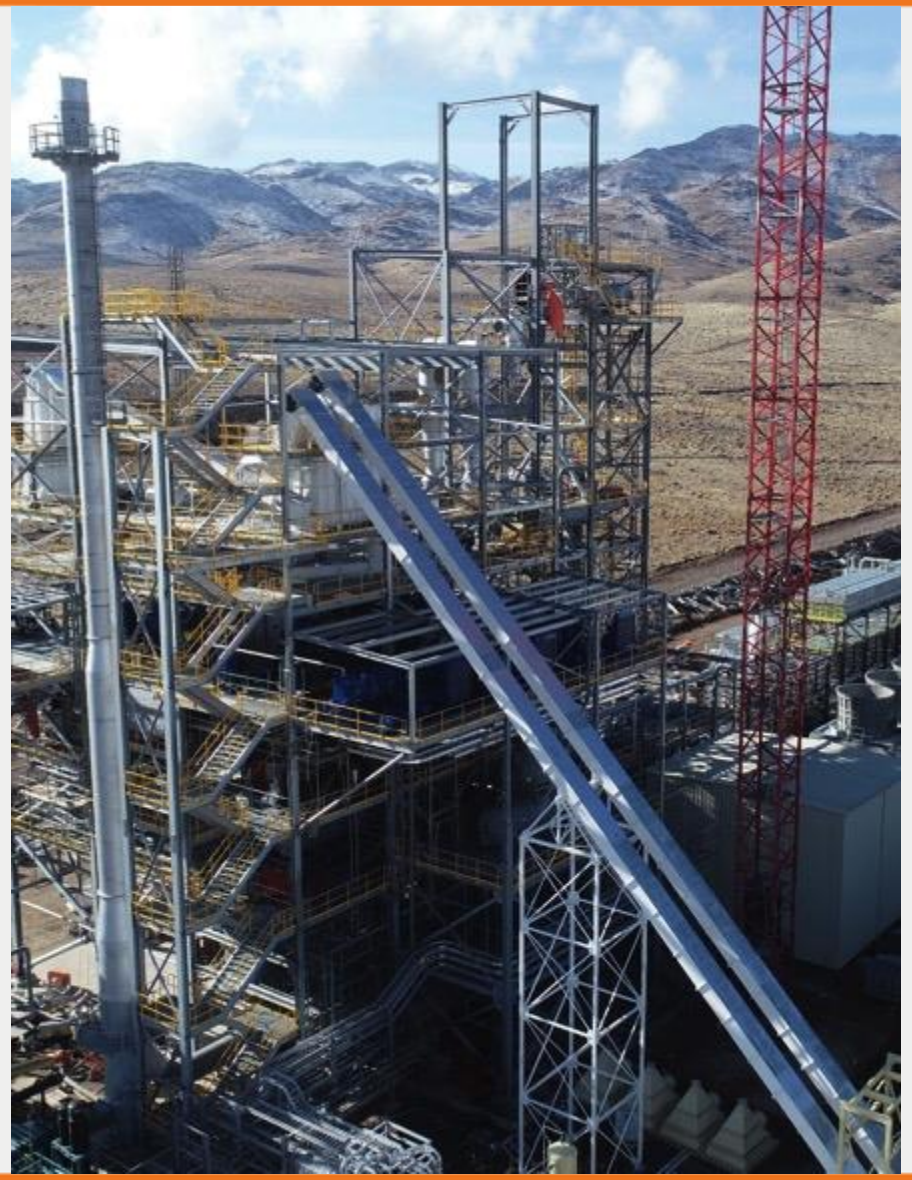
Sierra BioFuels Plant

Feedstock Processing Facility

- Feedstock Processing Facility Entered Operations in 2017
- Household Waste Delivered by Waste Service Partners
- State-of-the-art System Sizes, Sorts and Processes MSW Into Prepared Feedstock
- Per Year, 350,000 Tons of ‘black bag’ MSW Processed into 175,000 Tons of Prepared feedstock
- Currently producing ‘on spec’ engineered feedstock for Sierra.

Sierra BioFuels Plant – Nevada US

Sierra BioFuels Plant – Nevada US



Zemo Partnership

Sierra Biorefinery

- 98% Mechanically complete
- 10 Million Gallons of sustainable Fuel Produced Annually from 175Kt of processed MSW
- Plant is energized with systems operating
- Initial Commissioning has commenced
- Fuel production expected in 2022

Sierra BioFuels Plant

Fulcrum BIOENERGY

Sierra BioFuels Plant

Biorefinery Construction – July 2020

Sierra BioFuels Plant - US

Biorefinery Construction – July 2020

Fulcrum's International Growth Program

Fulcrum NorthPoint

UK

Fulcrum NorthPoint

- Advanced plans to develop a UK waste to jet fuel facility located at the Essar Manufacturing Complex, Stanlow
- Operational by 2026
- Lessons learned and technical improvements from Sierra plant to be incorporated into UK operations – **unique attribute for Fulcrum**
- 100+ highly paid refinery jobs
- 800+ jobs during construction period
- North West of England offers skilled workforce, especially technical/ fabrication/operations/petrochemical disciplines
- Readily available Infrastructure
- Large conurbations for waste collection
- Excellent Transport links
- Direct Pipeline connection to Manchester Airport

SAF in the UK – The Opportunity

- UK has opportunity to be world leading in the SAF market.

- Legally binding 2050 net zero targets provide market catalyst
- New supportive policy tools need to be tailored to the needs of a new fuels market - mandates will help, but nearer term support is welcomed.

- Inclusion of aviation fuel in the RTFO was a great first move, but additional changes need to happen at a rate that matches the development timelines for new SAF projects, in order to meet NetZero ambitions.

- Without additional support, full potential of a UK SAF market will not be realised to enable a meaningful contribution to NetZero – projects will happen, but the implementation time will be protracted.

- Recycled Carbon Fuels support consideration also welcomed – DfT clearly taking a global lead and is highly commendable.

Sierra BioFuels Plant

Zemo Partnership

Fulcrum™ BIOENERGY

www.fulcrum-bioenergy.com

Thank you

Zemo Partnership

Accelerating Transport to Zero Emissions

Any questions? Please get in touch

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Interested in joining the Partnership?

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T: 0207 304 6880

Zemo Partnership, 3 Birdcage Walk, London SW1H 9JJ
T: +44 (0)20 7304 6880 | E: hello@zemo.org.uk @Zemo_Org | www.zemo.org.uk

Interested in joining Zemo

Zemo Partnership

Our work covers six areas related to accelerating the transition to a zero transport future.

Buses & Coaches

Action programmes to speed the introduction of zero emission buses in the UK by working with passenger transport companies and local authorities

Cars

Working with manufacturers, fleet operators, environment and consumer groups to accelerate the adoption of zero emission cars.

Fuels

We explore measures to increase the adoption of sustainable low carbon fuels such as biofuels and renewable hydrogen.

Commercial Vehicles

For manufacturers, freight transport operators, technology suppliers, technical expert and others interested in accelerating the transition to cleaner, greener road freight.

Energy Infrastructure

Formed to make suggestions to Government and industry to ensure that the GB energy system is ready for and able to facilitate and exploit the mass take up of electric vehicles.

Collaborative Initiatives

Joint working group projects where content crosses over, overseen by the members' council.

Renewable Transport Fuel Association

Zemo Partnership

- Established end of August 2020, with 12 founder members
- Membership now exceeds 30 (and includes all UK bioethanol and biodiesel producers, all companies dispensing biomethane to transport, along with prospective SAF and development fuel producers)
- Formed to champion the contribution that renewable and low carbon fuels can make towards the decarbonisation of UK transport
- www.rtfa.org.uk
- Contact: Gaynor Hartnell, CEO

  gaynor@rtfa.org.uk