Hybrid Routes to Fuels and Chemicals

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LanzaTech Inc.
Biomass 2011
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Agenda

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- Introduction
- LanzaTech Ethanol Process
- LanzaTech Platform
- Hybrid Routes to Hydrocarbon Fuels

Company Profile

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- **Founded in January 2005**
- **Funding**
  - New Zealand Government – $US 10M
  - Series A: Khosla Ventures - $US 12M in 2007
  - Series B: Qiming Ventures - $US 18M in 2010
- **Team**

  CEO: Dr. Jennifer Holmgren
  CSO/Founder: Dr. Sean Simpson

  - 70 staff
    - Synthetic Biology
    - Analytical
    - Engineering
  - Chicago (USA)
    Auckland (New Zealand)
    Shanghai (China)
- **IP Portfolio**
  - >60 patents filed
  - 2 proprietary microbe families

Carbon Capture, Beneficial Re-Use & the Need for Renewable Fuel

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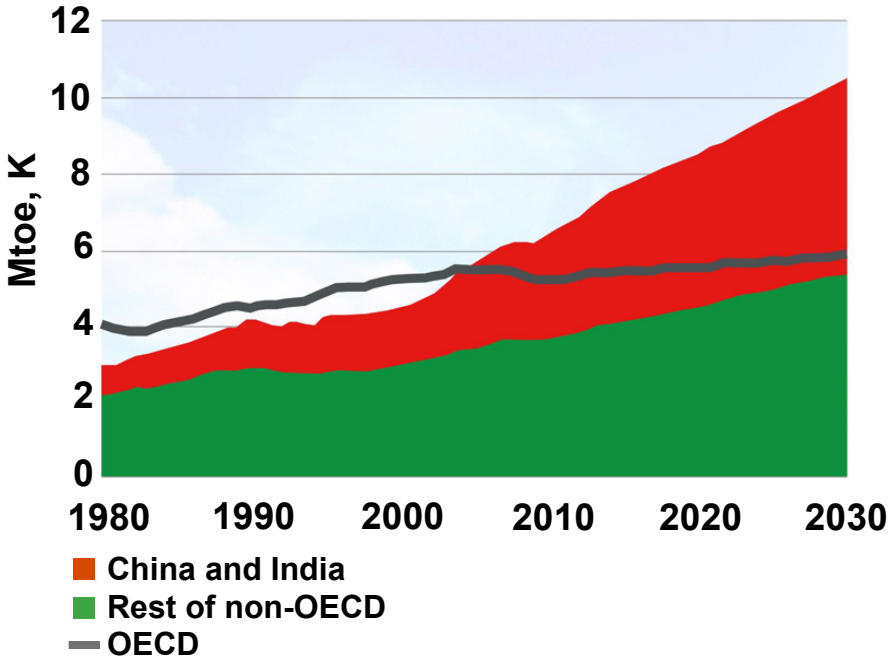

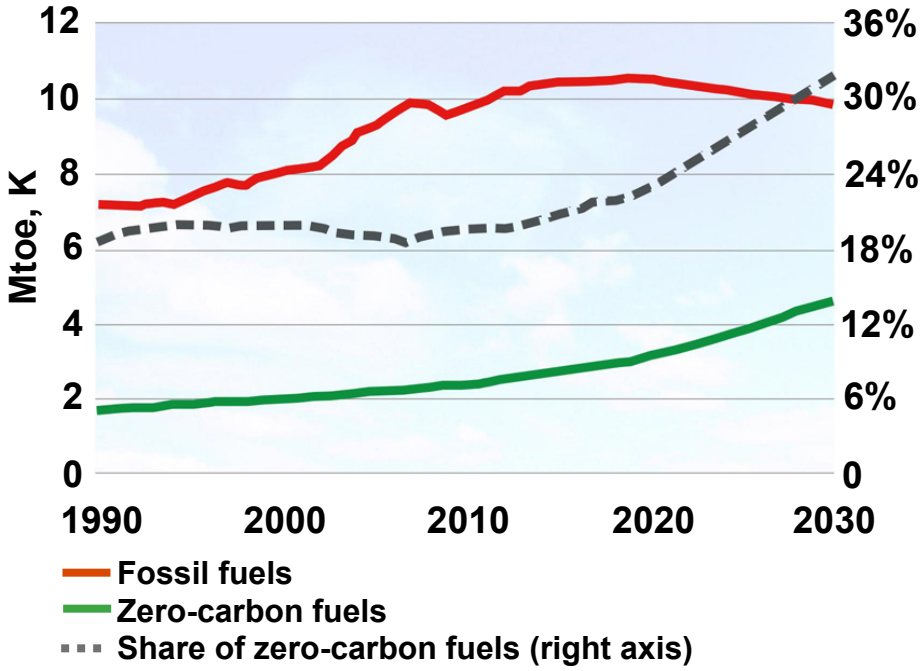

Source: IEA World Energy Outlook 2009

- **Carbon reduction and energy security are global issues**
- **Global energy demand will double over the next 40 years.**
- **Containing CO_2 growth to safe atmospheric levels requires that zero carbon renewable fuels make up more than 30% of the fuel pool.**
- **Industrial growth must be offset by increased energy efficiency, minimized waste and a reduced GHG footprint to protect climate.**

Why Biofuels…?

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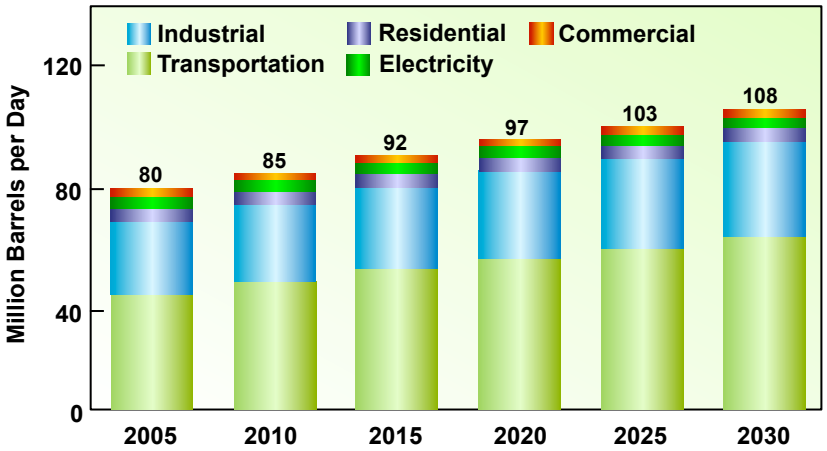
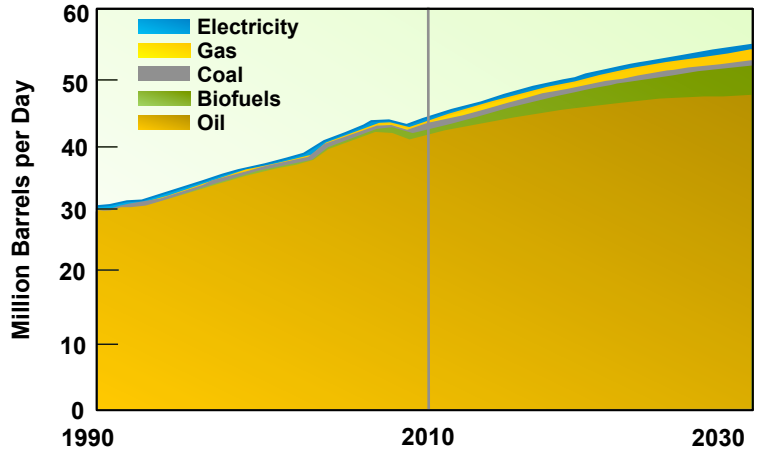
Global Hydrocarbon Liquids Consumption



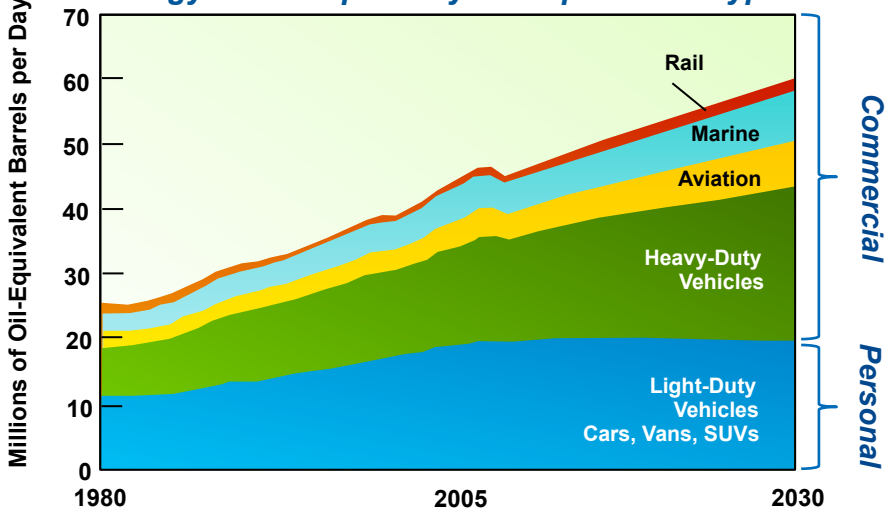
Source: EIA, World Energy Projections Plus (2008).

Energy Sources Utilized in Transportation



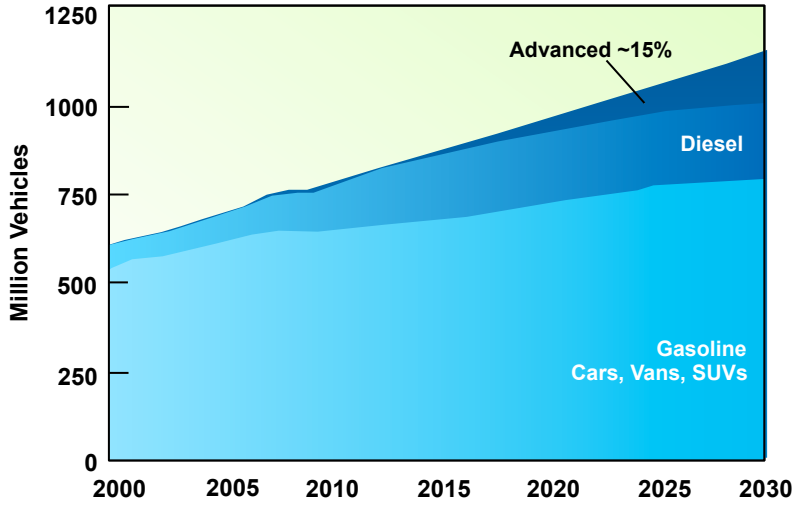
Source: Energy Outlook 2030 - BP (2011)

Energy Consumption by Transportation Type



Source: Outlook for Energy: A View to 2030 – Exxon Mobile (2009)

Personal Vehicles by Fuel Type



Biofuels remain the primary source of sustainable, alternative transport fuels for the foreseeable future

Continued Demand for Fuel Ethanol

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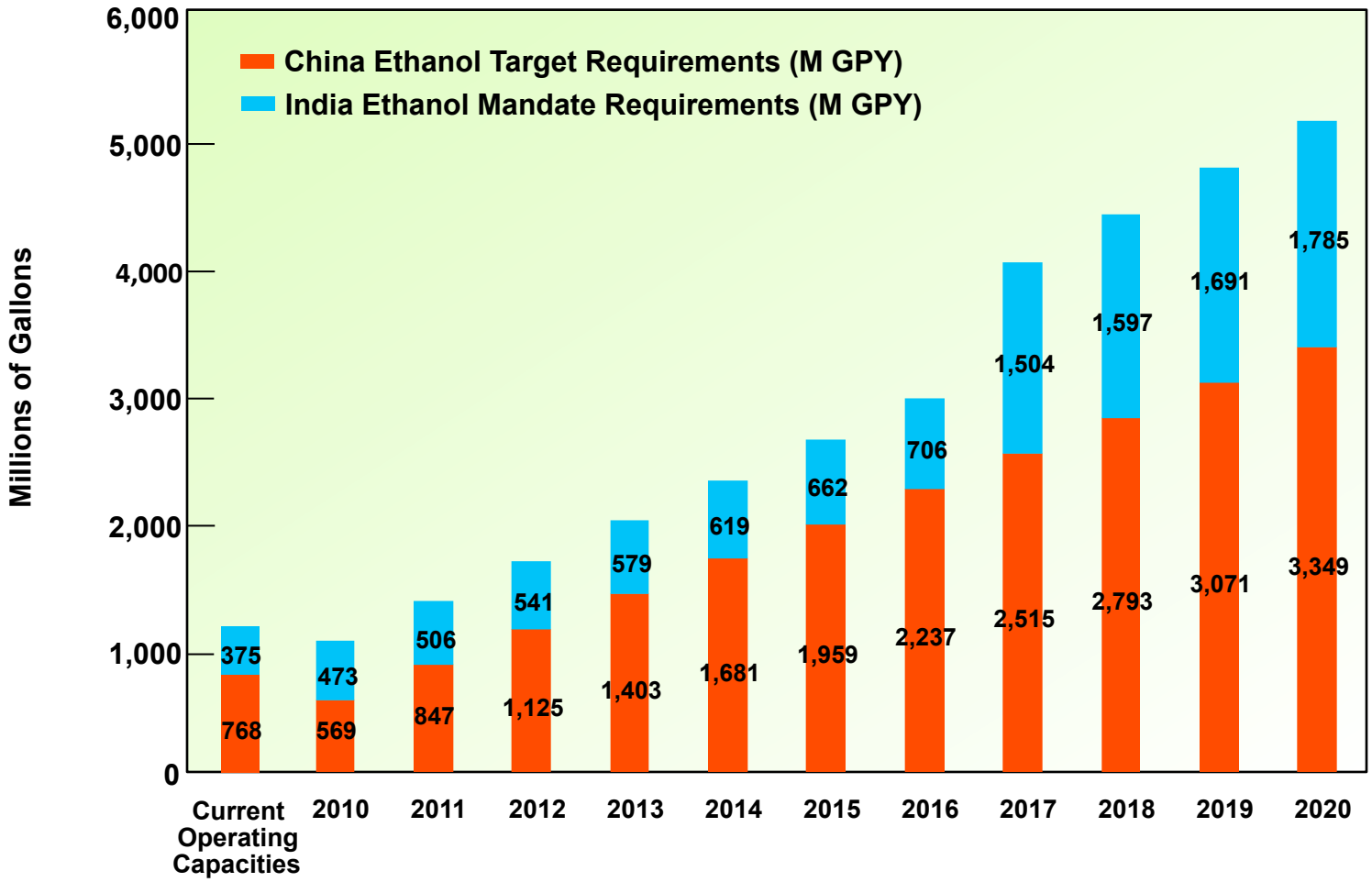

Additional Demand Expected from Industrial Ethanol Use

Source: Hart Energy, Purvin & Gertz

Biomass Conversion to Fuels

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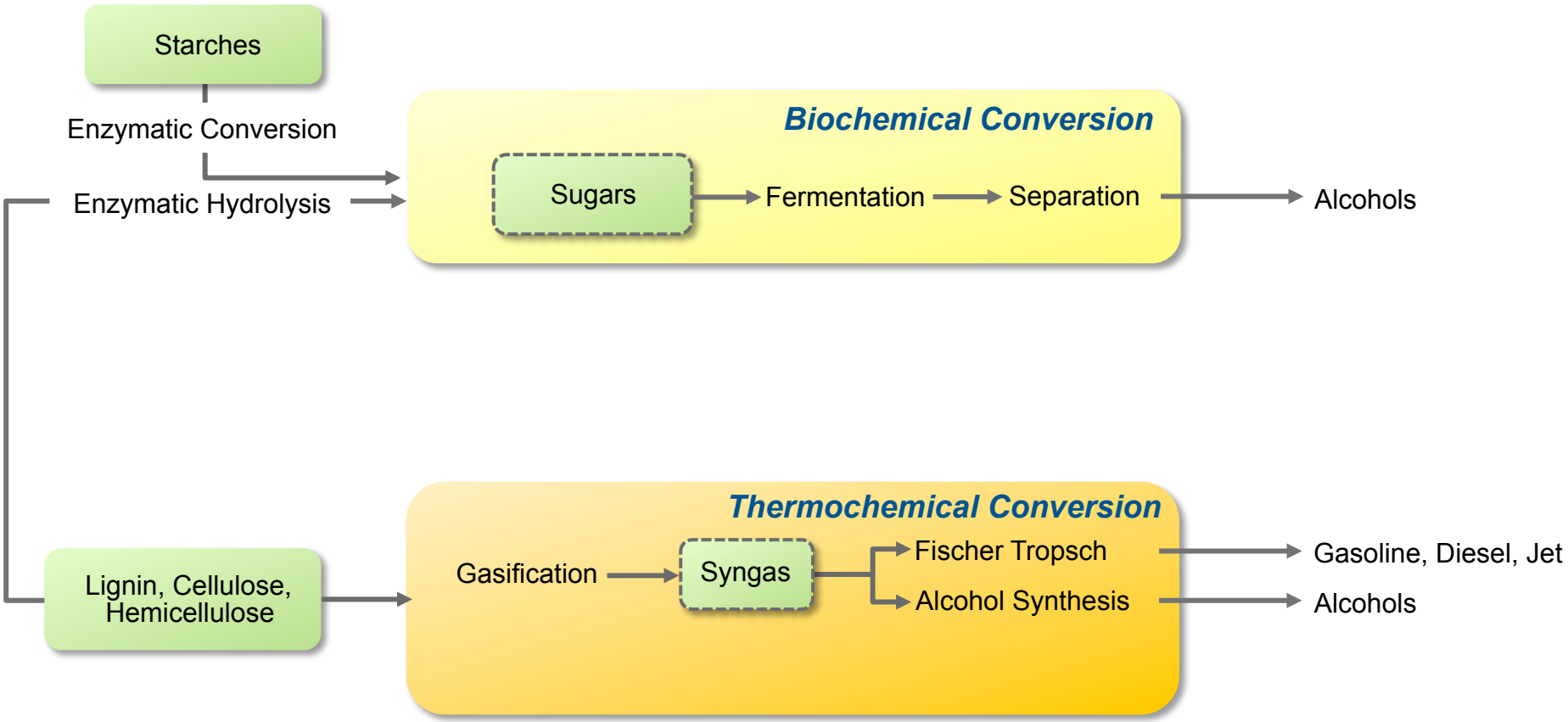

"Traditional" Conversion Pathways

Diverse Approaches Create New Pathways to Fuels and Chemicals

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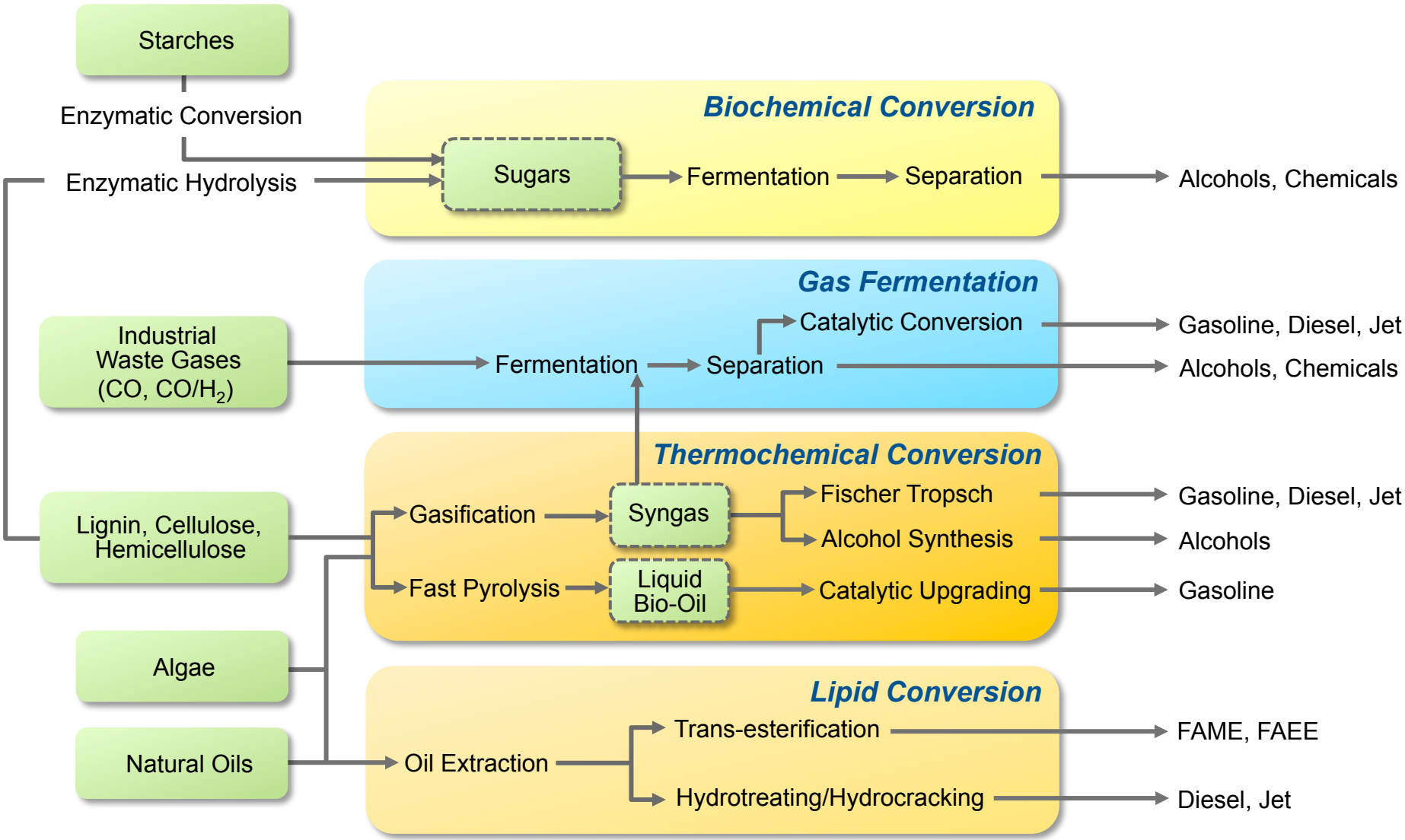

Innovation Enables a Portfolio of Options

The LanzaTech Process

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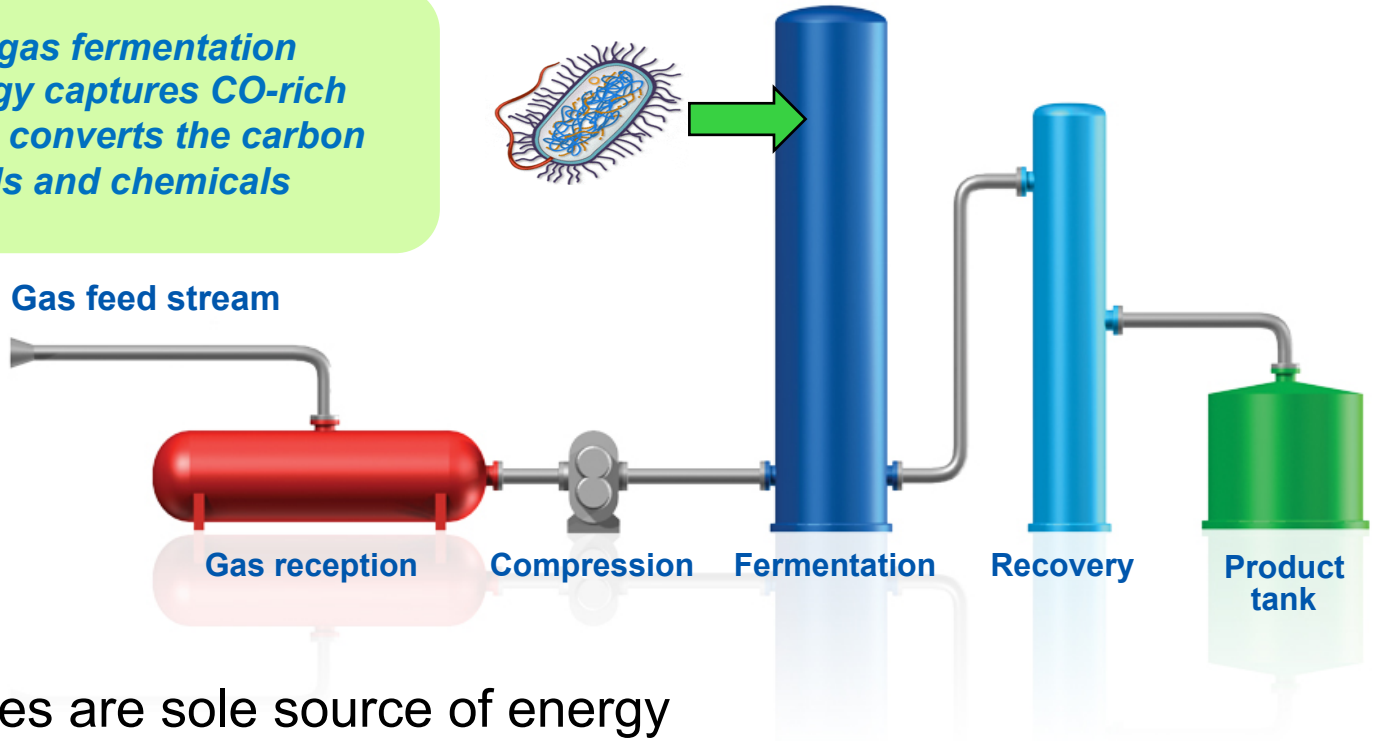
Novel gas fermentation technology captures CO-rich gases and converts the carbon to fuels and chemicals



- Gases are sole source of energy
- Production of fuels and chemicals
- Potential to make <u>material</u> impact on the future energy pool (>100s of billions of gallons per year)
- Completely outside of the food value chain
- Biofuel, carbon capture and energy efficiency technology solution

A Fast Path to Commercialization

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Pilot

2008

- 15,000 gallons ethanol per year
- BlueScope steel mill, NZ
- Operating since 2008

Demonstration

4Q2011

- 100,000 gallons ethanol per year
- Baosteel
- March 27: Ground breaking

Commercial

2013

- > 30 million gallons per year
- Baosteel

Commercial Production by 2013

Flexible CO:H2 Ratio

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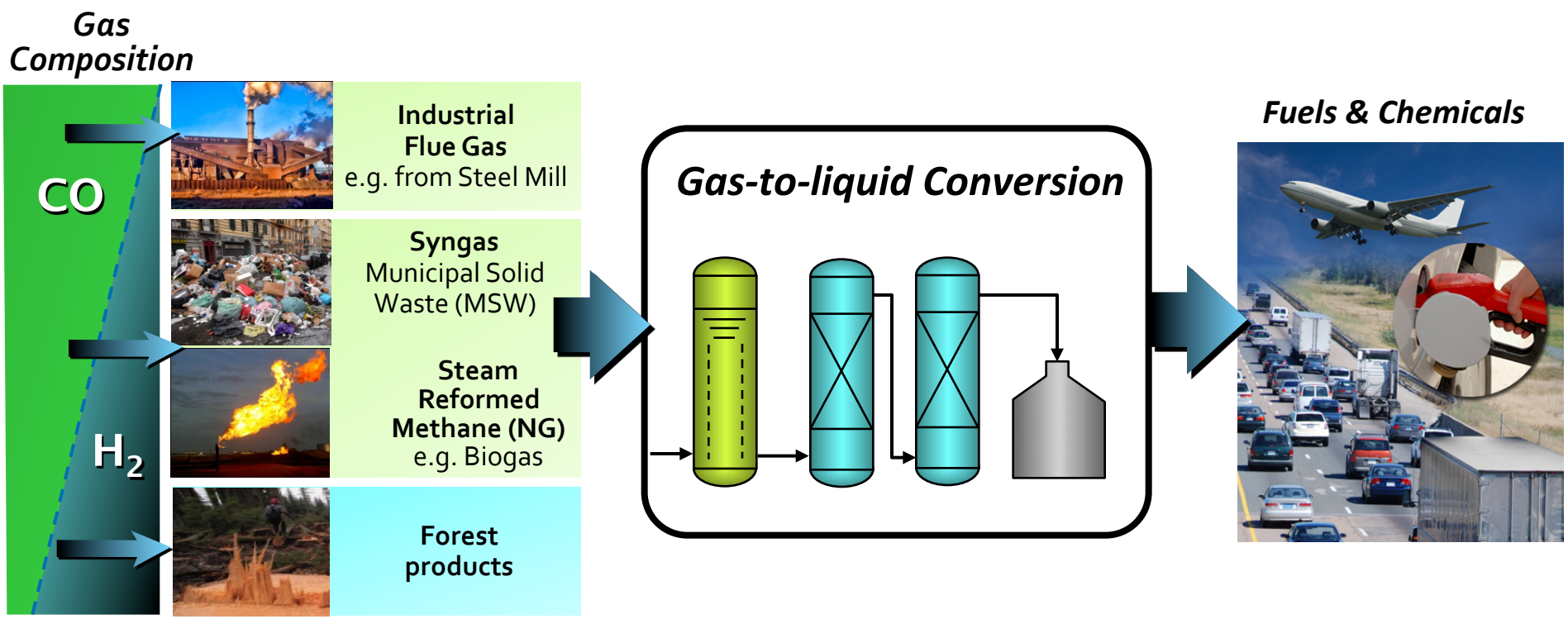

A broad range of CO:H_2 ratios can be used by the LanzaTech process

- **Fuel production has been demonstrated with a wide range of <u>available</u> waste gas resources**

Hybrid Processing: Biomass Syngas

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- Process used with biomass syngas
- Syngas from two biomass gasification technologies successfully tested
- Real biomass syngas used in all process demonstrations

✓ Tolerates <u>all</u> gas contaminants
✓ Commercial production rates achieved

Potential for Significant Impact

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Ethanol Potential From LanzaTech Process

1.4 billion tons steel/yr Globally → ***30 billion gal/yr***

1.3 billion tons/yr potential in US → ***190 billion gal/yr***

- Access to opportunity and on purpose derived gas streams
- Potential to make significant impact on the fuel pool
- No impact on food production
- Significant development potential utilizing US biomass

LanzaTech Gas to Liquid Platform

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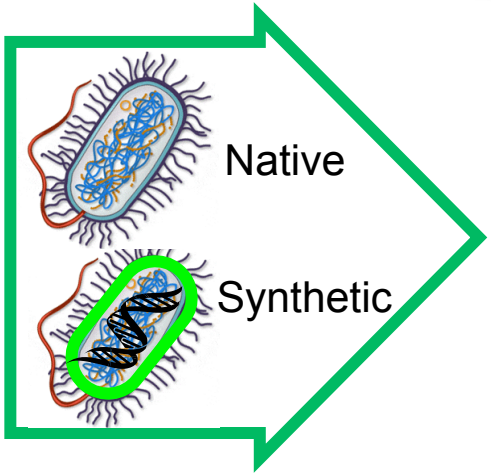
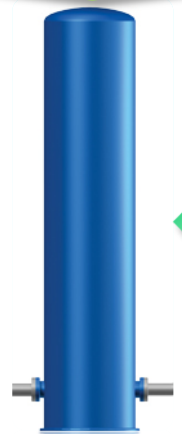
Resources

- CO — Industrial
- CO, H_2 — Syngas: Biomass, Coal, Methane
- H_2, CO_2 — COG, Chemical
- CO_2 — Power

Customized Catalysts





Engineering
Control
Chemistry

Product Suite

C_2	C_3	C_4	C_5	*Other*
• Ethanol • Acetic acid	• *i*-propanol • acetone	• BDO • *n*-Butanol • *i*-Butanol • Succinic acid	• Isoprene	• PHB • …….

Thermochemical Approaches

Product Suite

- Hydrocarbon Fuels (diesel, jet, gasoline)
- Chemical Intermediates
- Olefins
- Chemicals

2,3 BDO: a 4-carbon First

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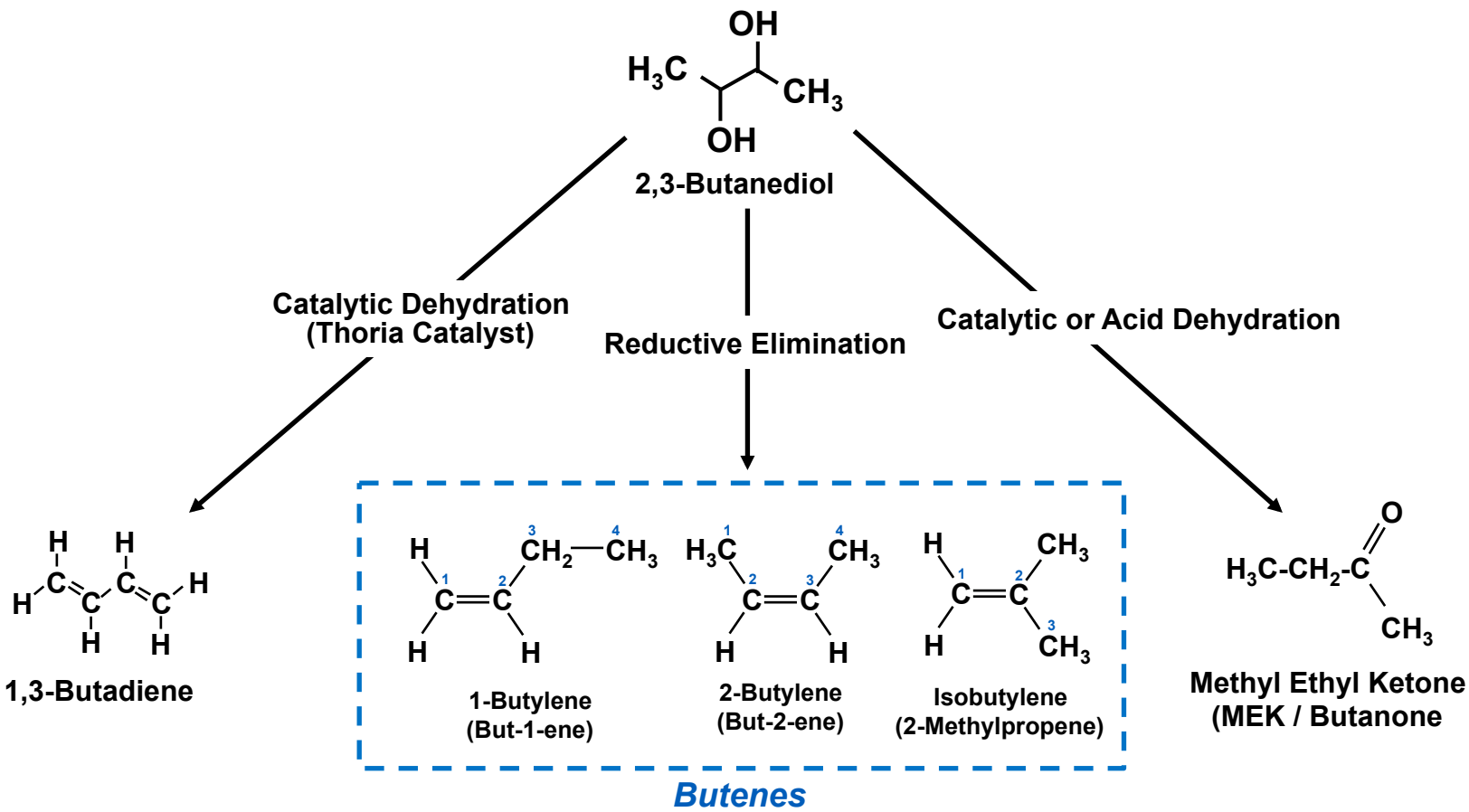

- LanzaTech is **the first** company to demonstrate 2,3-butanediol (2,3-BDO) production **by gas fermentation**
- **Process Control:** Ethanol:BDO ratios of 30:1–5:1 demonstrated

Unique Synthetic Biology Capability In Place

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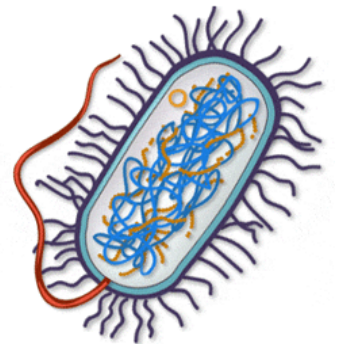
Strain Name: LZ-1561

Parent: *Clostridium autoethanogenum*

Proprietary microbe



Robust Genetic modification capability operational

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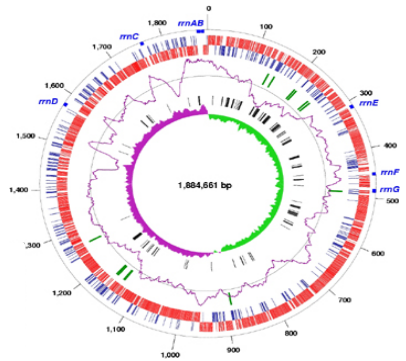
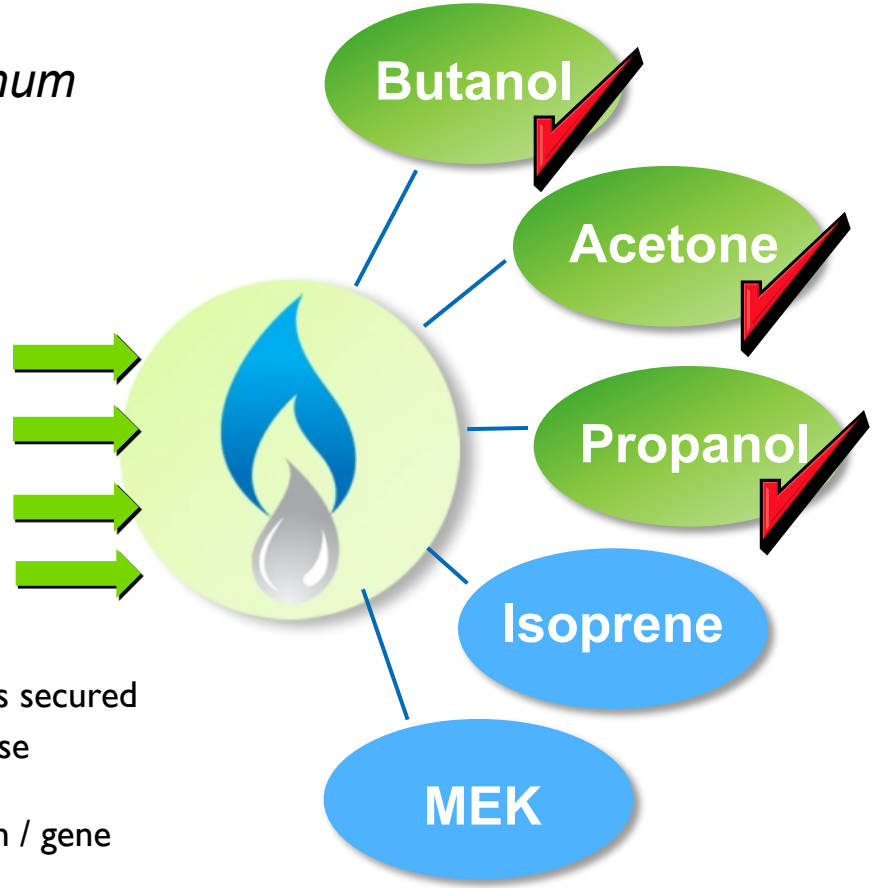
Genetic tool kit



- Multiple proprietary genomes secured
- Detailed gene control database constructed
- Plug-and play gene expression / gene regulation system developed



LanzaTech bacteria have been successfully modified to allow Butanol, Acetone and Propanol to each be separately produced from gases.

CO_2: A Carbon Source for Chemical Synthesis

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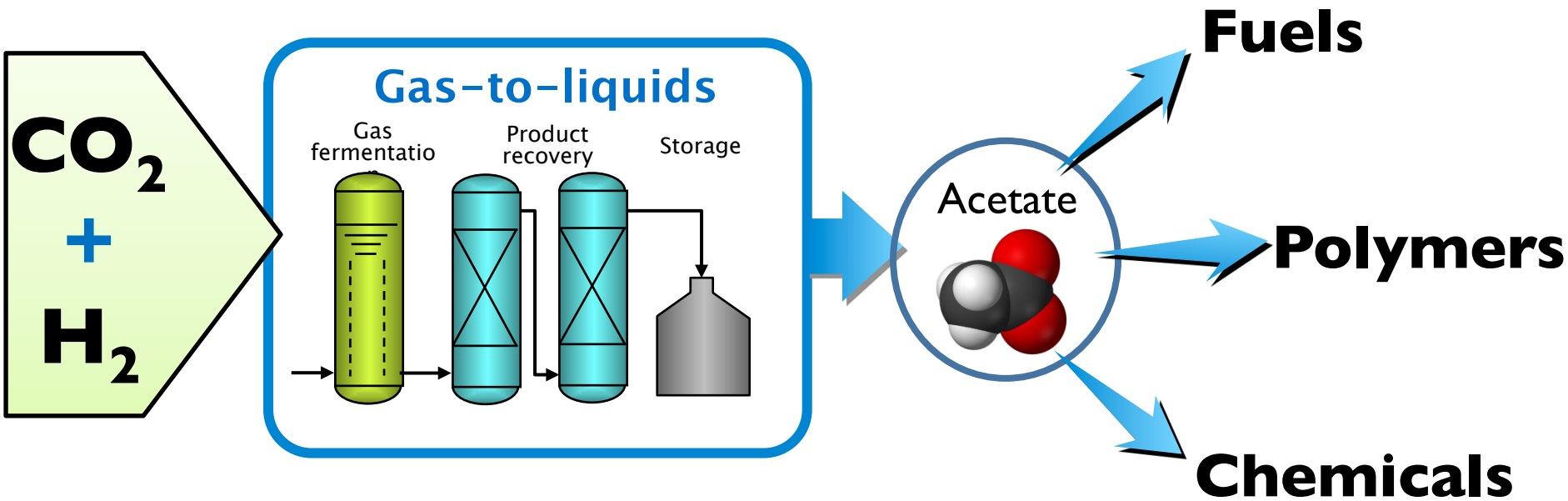

***CO_2 uptake and capture** demonstrated in a **continuous** fermentation*

- CO_2 is the carbon source, H_2 is the energy source for product synthesis

Hybrid Hydrocarbon Fuels Process

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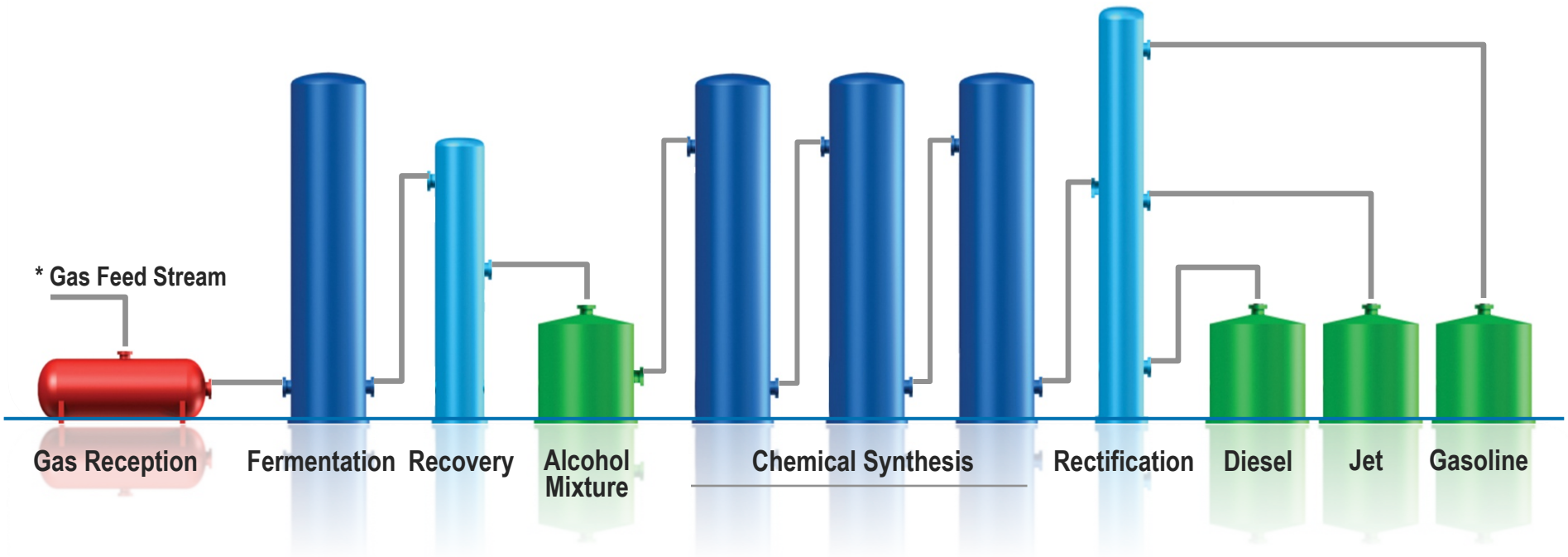

Gas Feed Stream

- CO from Industrial Waste Gases
- Syngas from Biomass, MSW, Reformed Natural Gas or Other Sources

Novel Route to Drop in Hydrocarbon Fuels

Drivers for Aviation Biofuels

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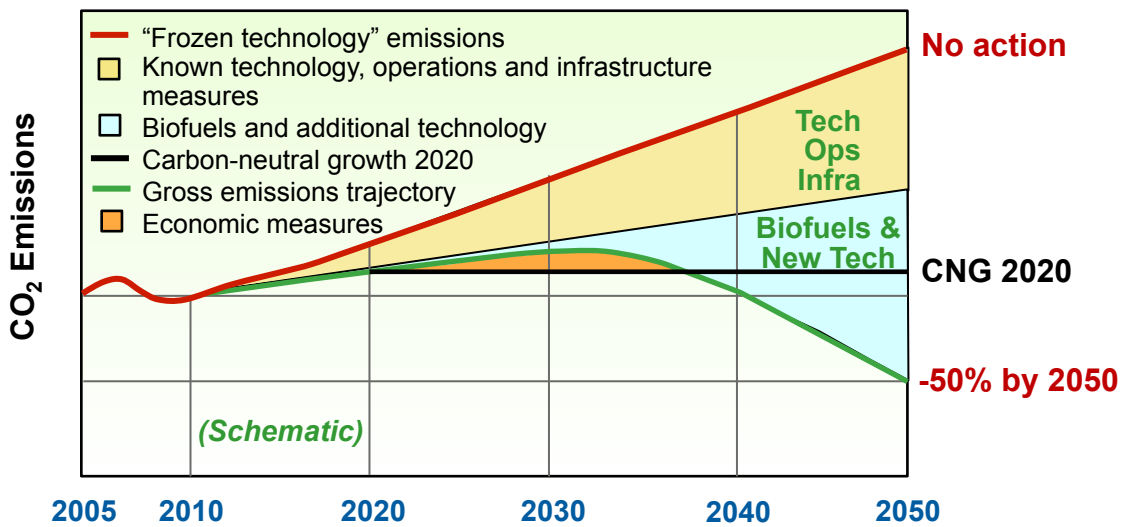
- **Commercial aviation commitments to carbon neutral growth**
  - **Visibility of aviation industry dictates sustainability is a key factor**
  - **European ETS dictates C reductions starting in 2012**
- **US Defense Sector commitments**
  - **Air Force: 50% of all domestic aircraft running on 50/50 blend by 2016**
  - **Navy: 50% of all systems running on alternatives by 2020**
- **Global jet fuel consumption (2008)**
  - **5 M bpd or 80 B gpy**
  - **US Military: 0.3 M bpd or 4.5 B gpy**

Emissions Reduction Roadmap



Presented to ICAO GIACC/3 February 2009 by Paul Steele on behalf of ACI, CANSO, IATA and ICCAIA

End Users Pulling the Industry

Collaboration Overview

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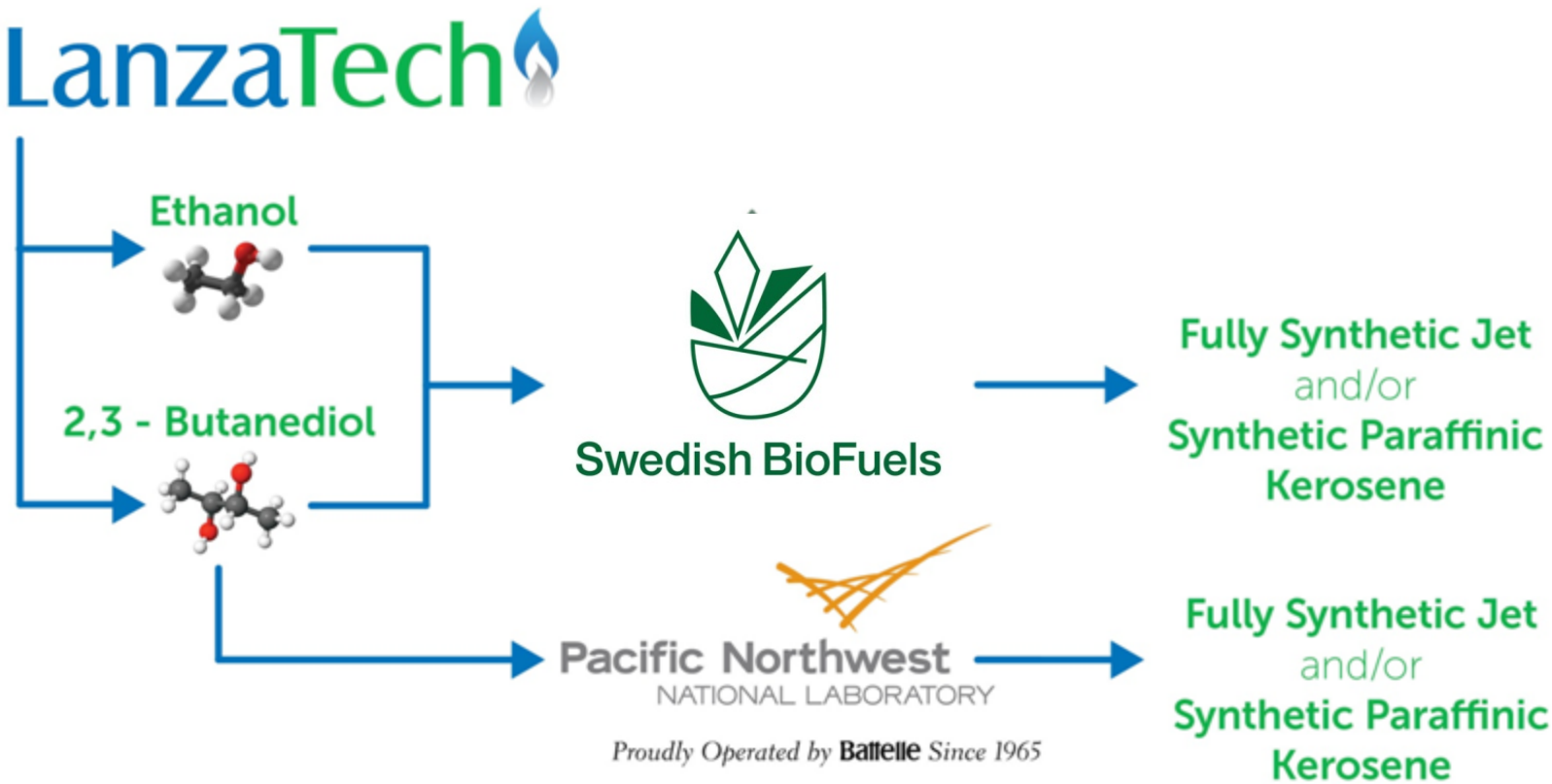

LanzaTech Awarded DARPA Grant to Develop ATJ Pathway

Swedish BioFuels

LT–SB SPK Sample Properties

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Property	*ASTM Test Method*	*ASTM D7566*	*LT-SB Sample*
Total Aromatics, volume %	D1319	≤ 25	0.6
Freeze point, °C	D5972	≤ -40	< -77
Flash point, °C	D93	≥ 38	54
Density at 15°C, kg/L	D4052	0.751 - 0.770	0.762
Heat of combustion, MJ/kg	D4809	≥ 42.8	43.5
Hydrocarbon Type Analysis			
Aromatics, volume %	D6379	≤ 0.5	< 0.2
Aromatics, mass %	D2425	≤ 0.5	< 0.3
Cycloparaffins, mass %	D2425	≤ 15	8
Paraffins	D2425	report	91
API Gravity at 60°F	D1298	52 - 57	54.2
Olefins, % volume	D1319	report	1.0

Key Properties Confirmed

Collaboration with PNNL

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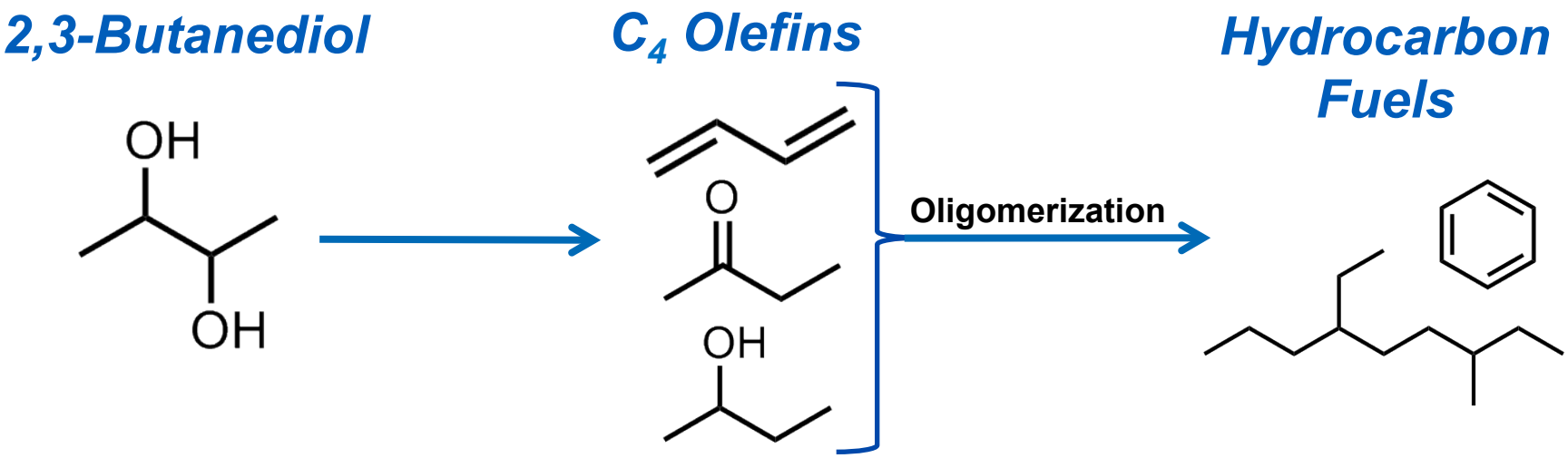

- Conversion of 2,3-BDO to C_4 olefins then to hydrocarbons
- Oligomerization of higher alcohols to hydrocarbons is known
- Control of process conditions will enable the selective production of isoparaffinic and synthetic jet fuel in high yields
- Concurrently conduct a preliminary Techno-economic analysis (TEA) and Life cycle assessment (LCA) of process(s)

Demonstrate Novel Route to C4 Olefins and to Jet Fuel

Summary

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- To meet growing energy demand & stabilize atmospheric CO_2 levels, need to diversify fuel pool and introduce >30% drop-in zero carbon fuels
- Innovation is creating viable options which will enable a clean energy future, energy security and energy equality
- Hybrid routes offer new opportunities to replace the "whole barrel" and create attractive economics
- The LanzaTech process captures a variety of feedstocks, including biomass, to produce low cost alcohols and other products
- Alcohols produced via the LanzaTech process are an excellent substrate for conversion to drop-in hydrocarbon fuels and chemicals
- Collaborating with leading conversion partners, industry agencies, and certification bodies to develop sustainable, low cost, integrated hydrocarbon fuels and chemicals processes from non-food sources

THANK YOU