The Road to Awesome!



Tokyo

November, 2014

Carbon is Pervasive

Heavy Industry

Steelmaking, ferroalloy production, and other industrial processes use carbon as a reagent

Transportation Fuels

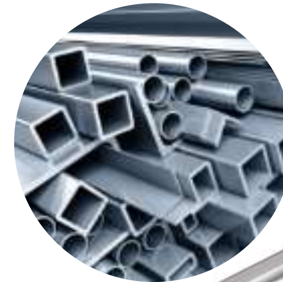
High energy density fuels allow for cars, boats, and planes

Chemical Products

Carbon forms the backbone of all organic chemical and material products

Nutrition

Our biochemistry is entirely dependent on carbon, as is all of the food that we eat

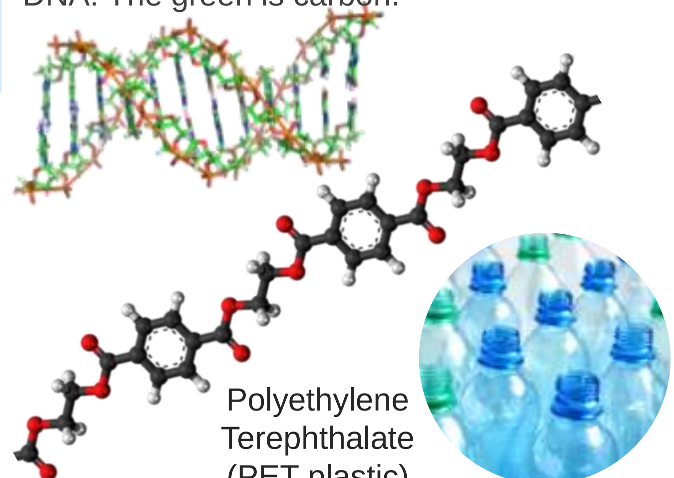


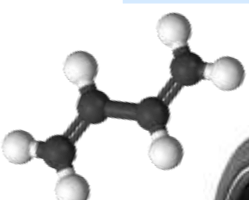
Steel

Liquid Fuels

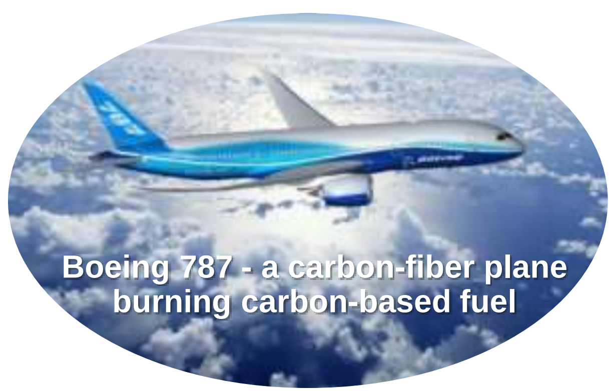
All food contains carbon

DNA: The green is carbon.





1,3-butadiene (precursor for rubber)



Boeing 787 - a carbon-fiber plane burning carbon-based fuel

Polyethylene Terephthalate (PET plastic)

LanzaTech
capturing carbon. fueling growth.

But Problematic When Combusted

GHG Emissions (CO_2, CH_4)

Climate Change

Particulate Emissions

Increased Respiratory Illness

NOx, SOx, and Hg Emissions

Acid Rain

The Carbon Imperative

<u>Energy</u> can be Carbon free

Wind: 

Solar: 

Hydro: 

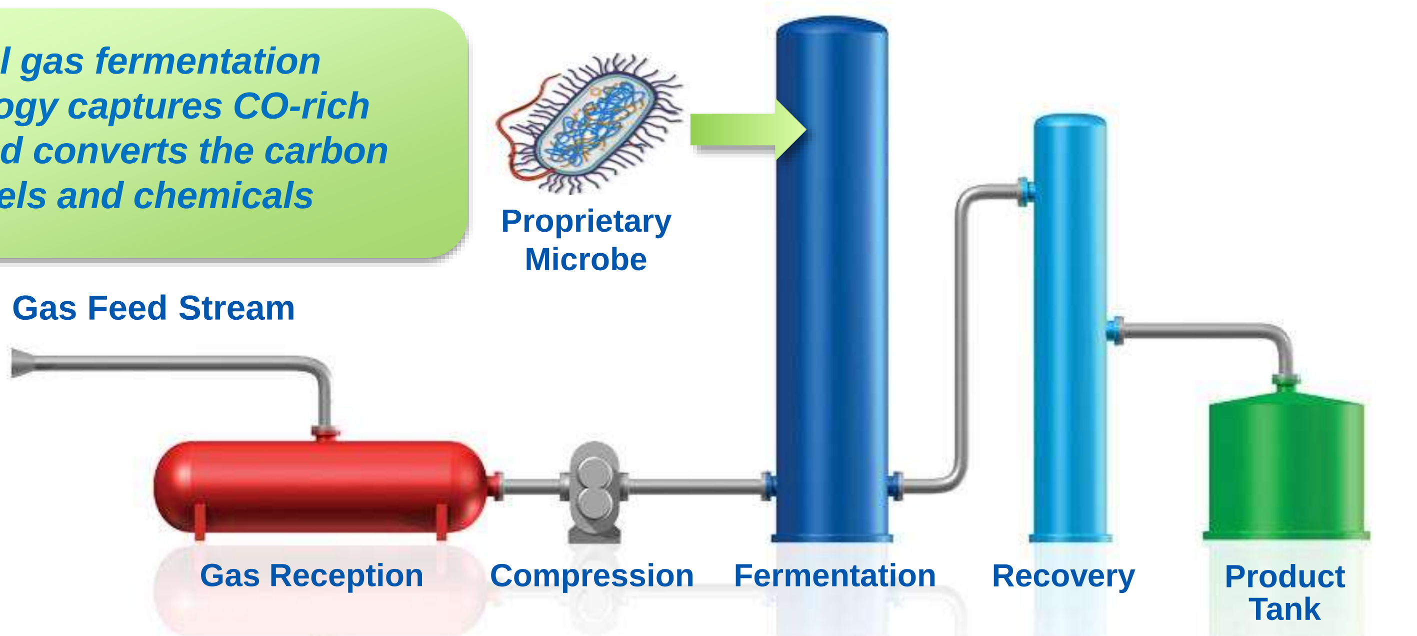
<u>Liquid Fuels & Petrochemicals</u> must contain

<u>Efficiency</u> Recycle C

Use only as much carbon as we must!

The LanzaTech Process

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



- **Process *recycles* waste carbon into fuels and chemicals**
- **Process brings underutilized carbon into the fuel pool**
- **Potential to make material impact on the future energy pool (>100s of billions of gallons per year)**

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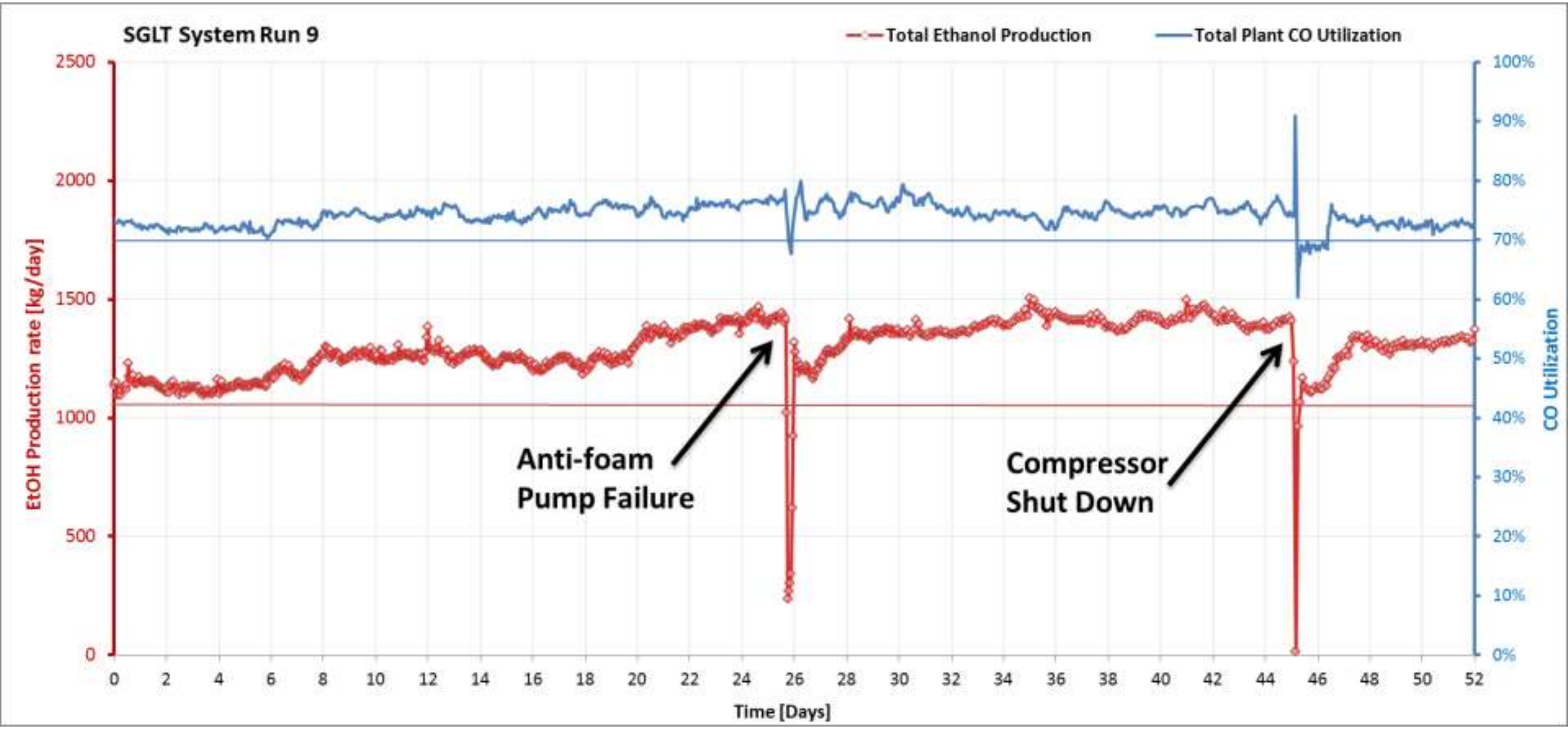
Shougang Demo Plant
December 2012

Shougang Demo: Extended Runtime, Robustness

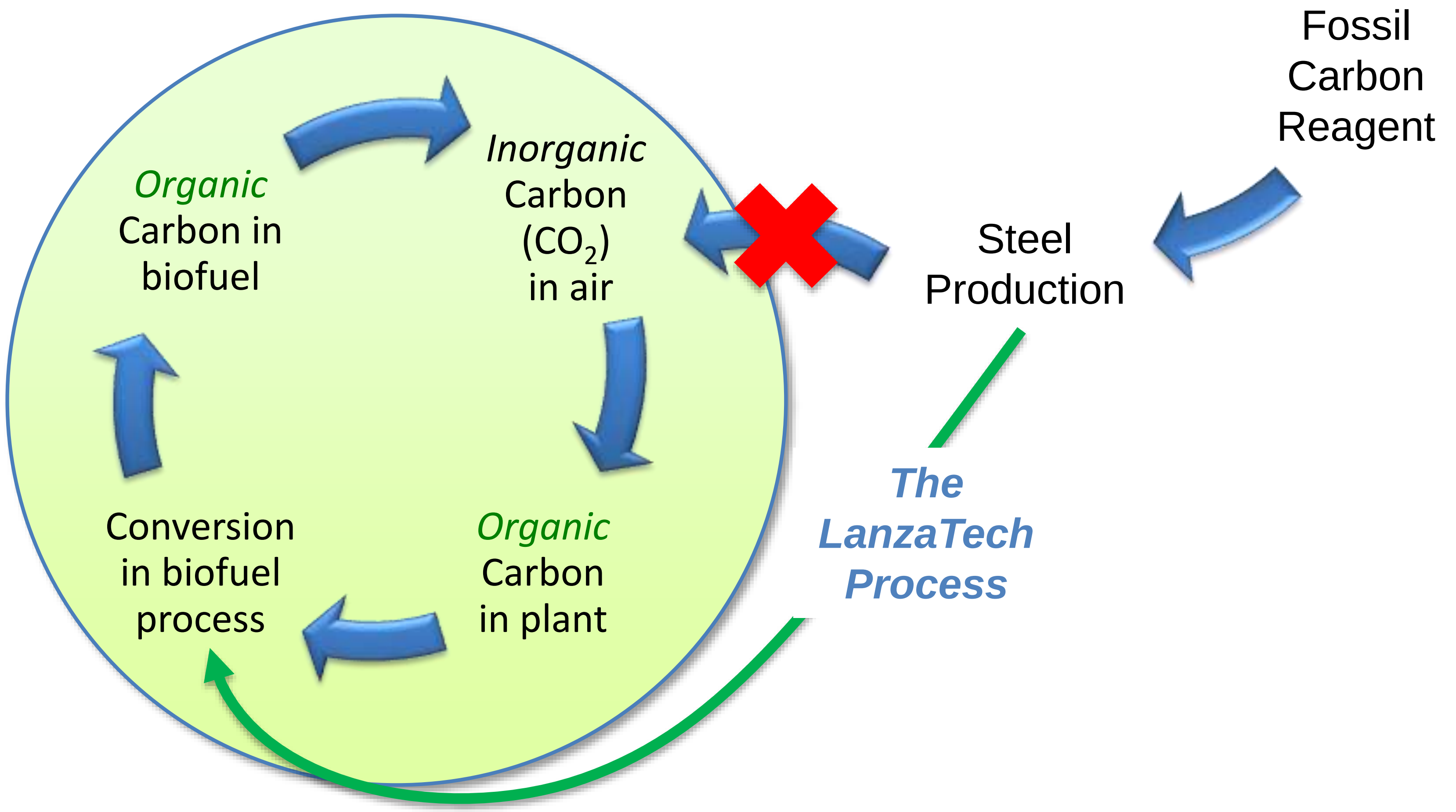
Performance milestones achieved and exceeded for >1000 hours



System Run	Runtime (days)	Average CO Utilization (%)	Average Ethanol Production + Stripping (kg/day)	Average Ethanol Production (kg/day)
9	52+	74.4	1344	1286

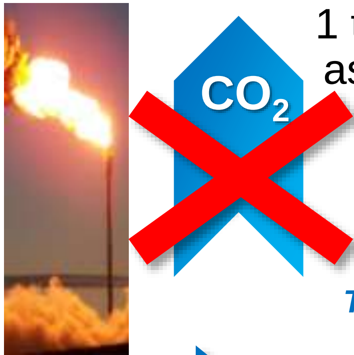
LanzaTech capturing carbon. fueling growth.

Direct Conversion of Carbon Increases the Efficiency of the Carbon Cycle



Shortening the carbon cycle!

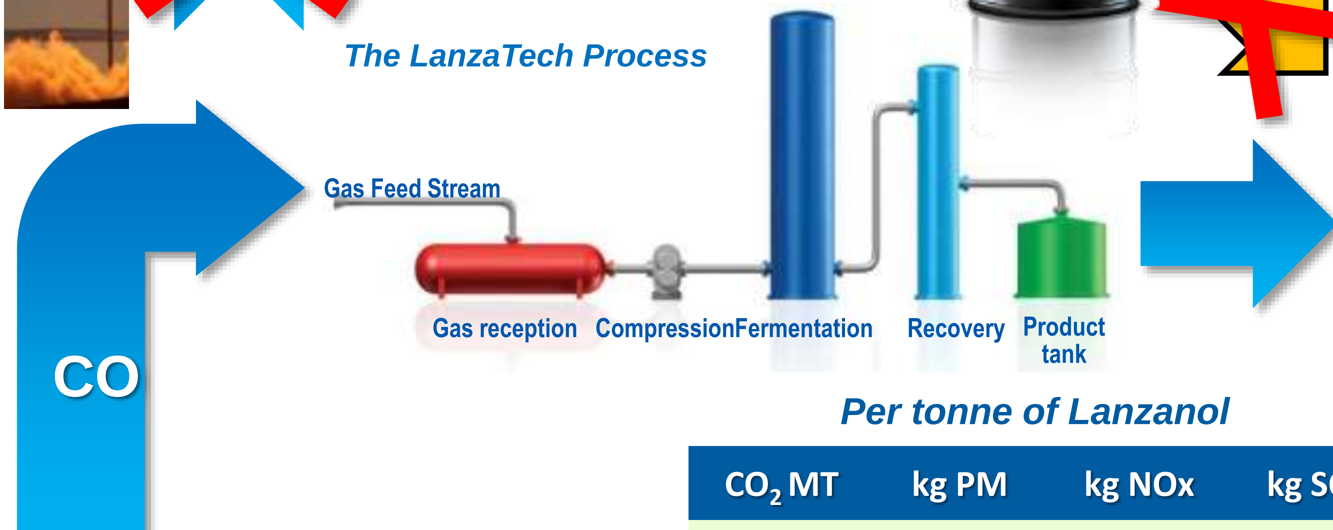
Carbon Efficiency Means Cleaner Air: Emissions Savings (WtT)



1 tonne ethanol produced as CO averted from flare

5.2 barrels of gasoline are displaced by every tonne of ethanol produced

The LanzaTech Process



Per tonne of Lanzanol

	CO_2 MT	kg PM	kg NOx	kg SOx
Averted from flare	2.1	0.6	4.1	0.9
Displaced gasoline	+0.5	+2.5	+7.4	+4.0
Energy required for LanzaTech Process	-0.8	-0.2	-0.8	-1.6
Avoided per tonne of ethanol	**1.8**	**2.9**	**10.7**	**3.3**

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LanzaTech RSB Certification

- **LanzaTech received RSB certification for Shougang demonstration plant in October 2013**
- **Certification included evaluation of:**
  - Environmental, economic and social management practices
  - Greenhouse gas emissions of process
  - On-site audit of production process
  - Safety procedures
- **Shougang on site demo plant audit occurred September 2013**

RSB
ROUNDTABLE ON SUSTAINABLE BIOMATERIALS

News Release

Beijing Shougang LanzaTech New Energy Science & Technology Company Earns Roundtable on Sustainable Biomaterials (RSB) Certification

LanzaTech's joint venture with Shougang Jingtang Iron and Steel United Company and the Tang Ming Group earns first-ever RSB certification for waste-gas to biofuel process

WASHINGTON, D.C., USA and Beijing, China (November 5, 2013) Beijing Shougang LanzaTech New Energy Science & Technology Co., Ltd. and the Roundtable on Sustainable Biomaterials Services Foundation, the implementing entity of the RSB, announced today that Beijing Shougang LanzaTech New Energy Science & Technology Co., Ltd. has earned RSB's sustainability certification for the joint venture's facility that converts waste steel mill gases to sustainable biofuels. The RSB is a global sustainability standard and certification system for biofuels and biomaterials production. The facility, which utilizes LanzaTech technology, is the first RSB-certified biofuel plant in China, and the first of its kind anywhere to receive this key certification for industrial carbon capture and utilization.

"The joint venture uses a process that creates a sustainable biofuel and does so by efficiently reusing greenhouse gases that would have otherwise been released into the atmosphere," said Peter Ryus, RSB Services' CEO. "This solution, which does not impact the food chain or land use, meets the RSB principles and practices and serves as an example of how continued innovation in the industry will lead to sustainable biofuels in the future. We are honored to be working with LanzaTech and their joint venture partners on greenhouse gas reduction and global sustainability improvements."

RSB certification shows the joint venture's commitment to environmental improvements through a novel biological approach that converts waste carbon emissions from steelmaking into biofuels and chemicals. Using the RSB methodology and assumptions based on commercial production, it is estimated that ethanol from the process may reduce life cycle greenhouse gas emissions by 60 percent compared to petroleum fuels.

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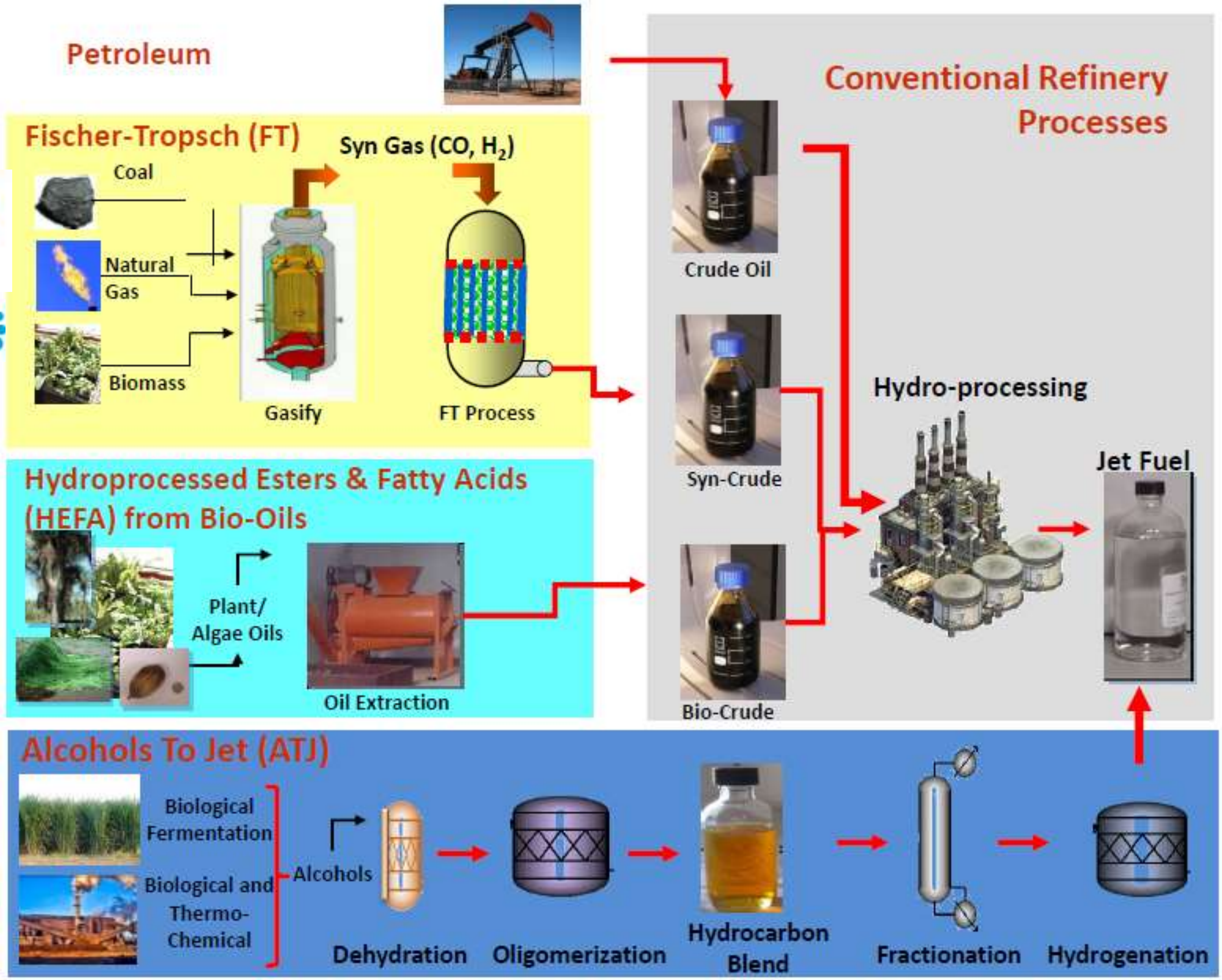
Routes to Alterative Jet



The Road to Awesome!

JAL
JAPAN AIRLINES

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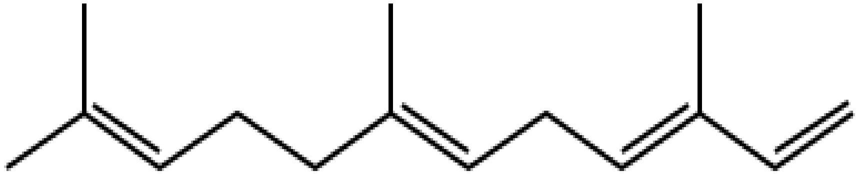
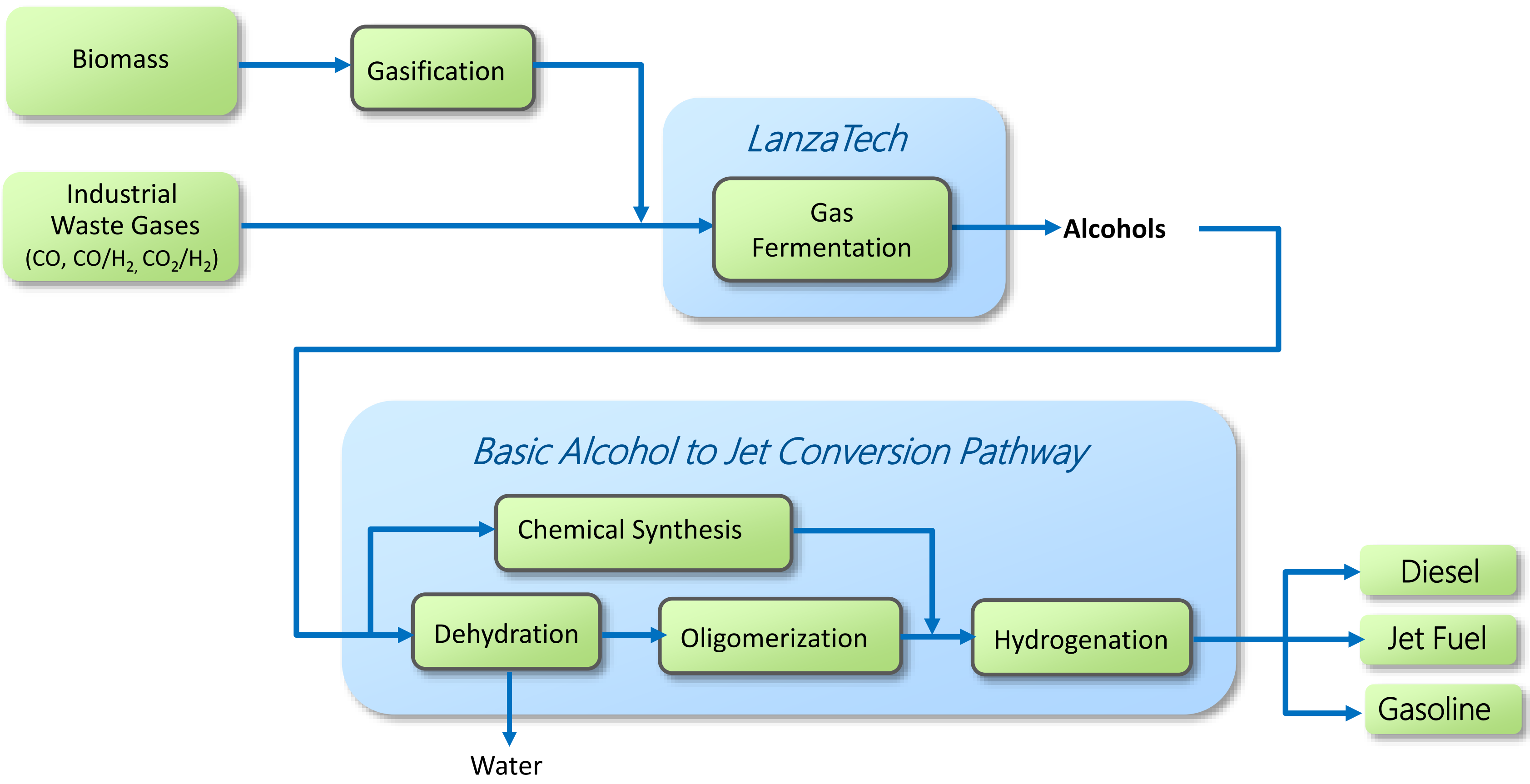
Farnesene

- **Sugar Fermentation for Farnesene production**
- **Commercial plant the Paraíso Bioenergia mill (Brazil)**
- **First Flight this year: GOL 737 from Orlando to Sao Paulo**



Alcohol to Jet (ATJ) Pathway



A novel route to synthetic jet fuel

LT-PNNL SPK Sample Properties

Property	*ASTM Test Method*	*ASTM D7566*	*Lanzanol Jet*
Hydrogen Content, mass%	D7171	n/a	15.1
Freeze point, °C	D5972	≤ -40	< -70
Flash point, °C	D93	≥ 38	56
Density at 15°C, kg/L	D4052	0.775 – 0.840 (Jet A) 0.751 - 0.770 (SPK)	0.782
Viscosity at -20°C, cSt		<8	7.4
Heat of combustion, MJ/kg	D4809	≥ 42.8	43.8
Thermal Stability (325°C)	D3241	2/25	1/0 (pass)
Hydrocarbon Type Analysis			
Aromatics, volume %	D6379	≤ 0.5	0.21(GC)
Paraffins, mass%	D2425	report	99.73 (GC)
Distillation	D86		
10%		205 max	181
Final Boiling Point		300 max	284
T90-T10, °C		>22	85

LT–SB SPK Sample Properties

Property	ASTM Test Method	ASTM D7566	LT-SB ATJ-SPK
Total Aromatics, volume %	D1319	≤ 25	0.4
Freeze point, °C	D5972	≤ -40	< -60
Flash point, °C	D93	≥ 38	46
Density at 15°C, kg/L	D4052	0.775 – 0.840 (0.751 - 0.770)	0.756
Heat of combustion, MJ/kg	D4809	≥ 42.8	43.8
Hydrocarbon Type Analysis			
Aromatics, volume %	D6379	≤ 0.5	< 0.2
Paraffins, mass%	D2425	report	83
API Gravity at 60°F	D1298	52 - 57	53.1
Olefins, % volume	D1319	report	0.8

Key Properties Confirmed

LT–SB Fully Synthetic Sample Properties

Property	ASTM Test Method	ASTM D7566	DARPA LT-SB ATJ-SKA	FAA LT-SB ATJ-SKA
Total Aromatics, volume %	D1319	≤ 25	14.0	16.9
Freeze point, °C	D5972	≤ -40	<-60	<-80
Flash point, °C	D93	≥ 38	44	49
Density at 15°C, kg/L	D4052	0.775 – 0.840	0.781	0.788
Heat of combustion, MJ/kg	D4809	≥ 42.8	43.4	43.4
Hydrocarbon Type Analysis				
Aromatics, volume %	D6379	≤ 0.5	12.9	14.5
Paraffins, mass%	D2425	report	75	64
API Gravity at 60°F	D1298	52 - 57	49.6	NA
Olefins, % volume	D1319	report	2.0	1.2

100% Fully Synthetic Jet Fuel

Swedish BioFuels

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LanzaTech Ethanol Life Cycle Assessment
Third Party Study – EU Basis

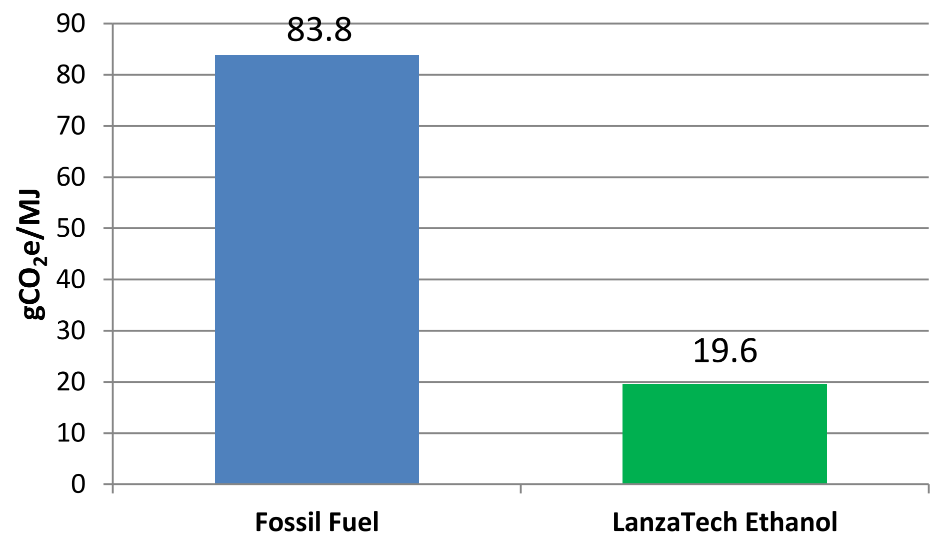
E4tech

LanzaTech ethanol achieves a *76.6% reduction* in greenhouse gas emissions over baseline fossil fuel

Key Assumptions:

- *Cradle-to-pump lifecycle of ethanol*
- *EU's Renewal Energy Directive methodology*
- *BOF gas considered as waste gas by steel industry and as residue by RSB.*
- *GHG emissions for LanzaTech ethanol from steel mill waste gas (BOF)*

Lifecycle GHG emissions following RED methodology



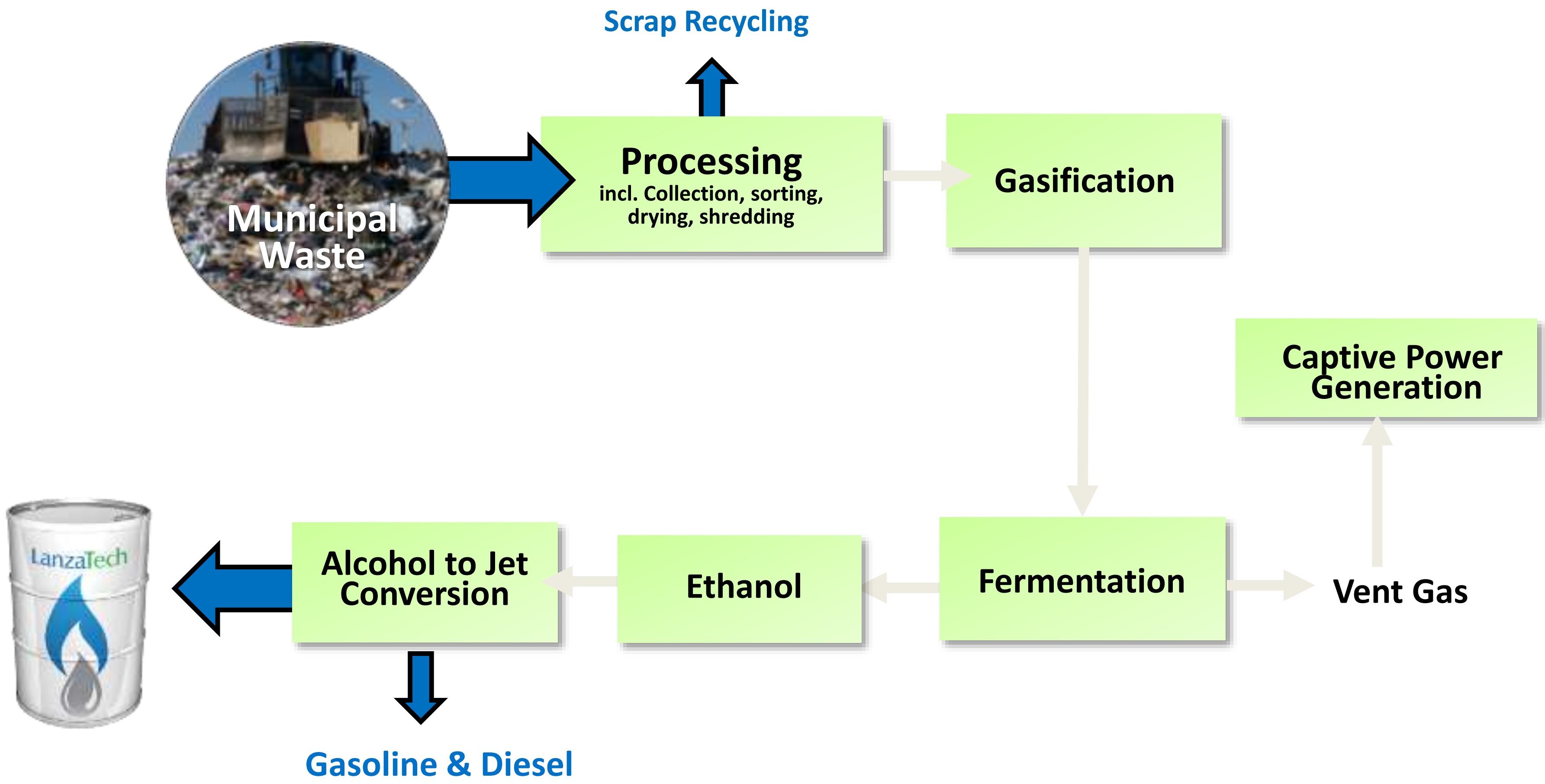
Fossil fuel comparator emissions (83.8 gCO2eq/MJ) from EU's FQD

Jet Life Cycle Assessment (China Basis)

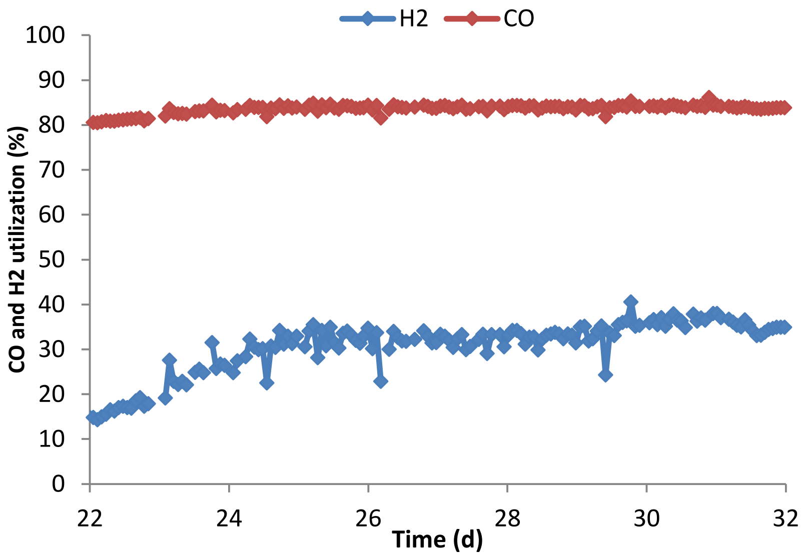
	GHG Emissions (g CO2e/MJ fuel)
LT ethanol, cradle-to-gate	-40.33
Hydrogen, SMR	2.51
Electricity, China grid	0.38
Fuel combustion	72.71
TOTAL	***35.26***
Reduction from fossil fuel	***60.8%***

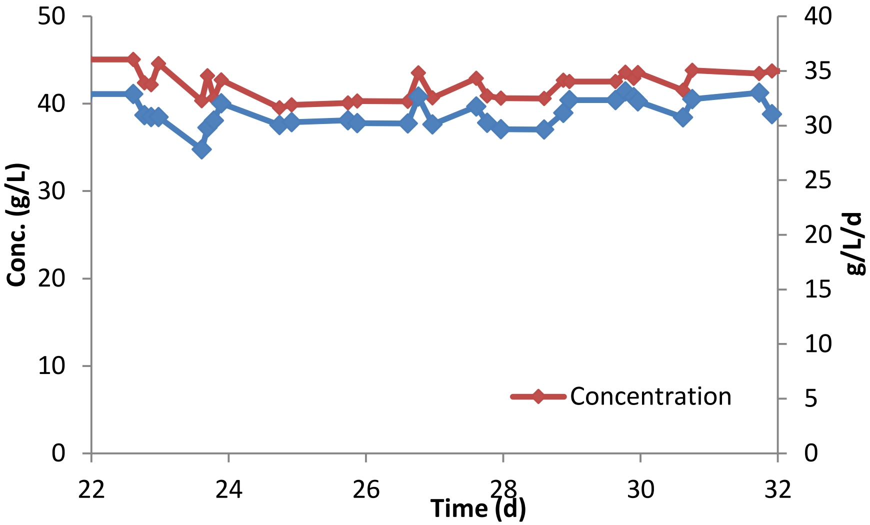
Meets all carbon reduction legislation

MSW to Jet Fuel Case



Gas Utilization in CSTR





Composition	CO (%)	H_2(%)	CO_2(%)	N_2(%)	CH_4(%)
Syngas	33.43	33.8	22.52	10.32	0

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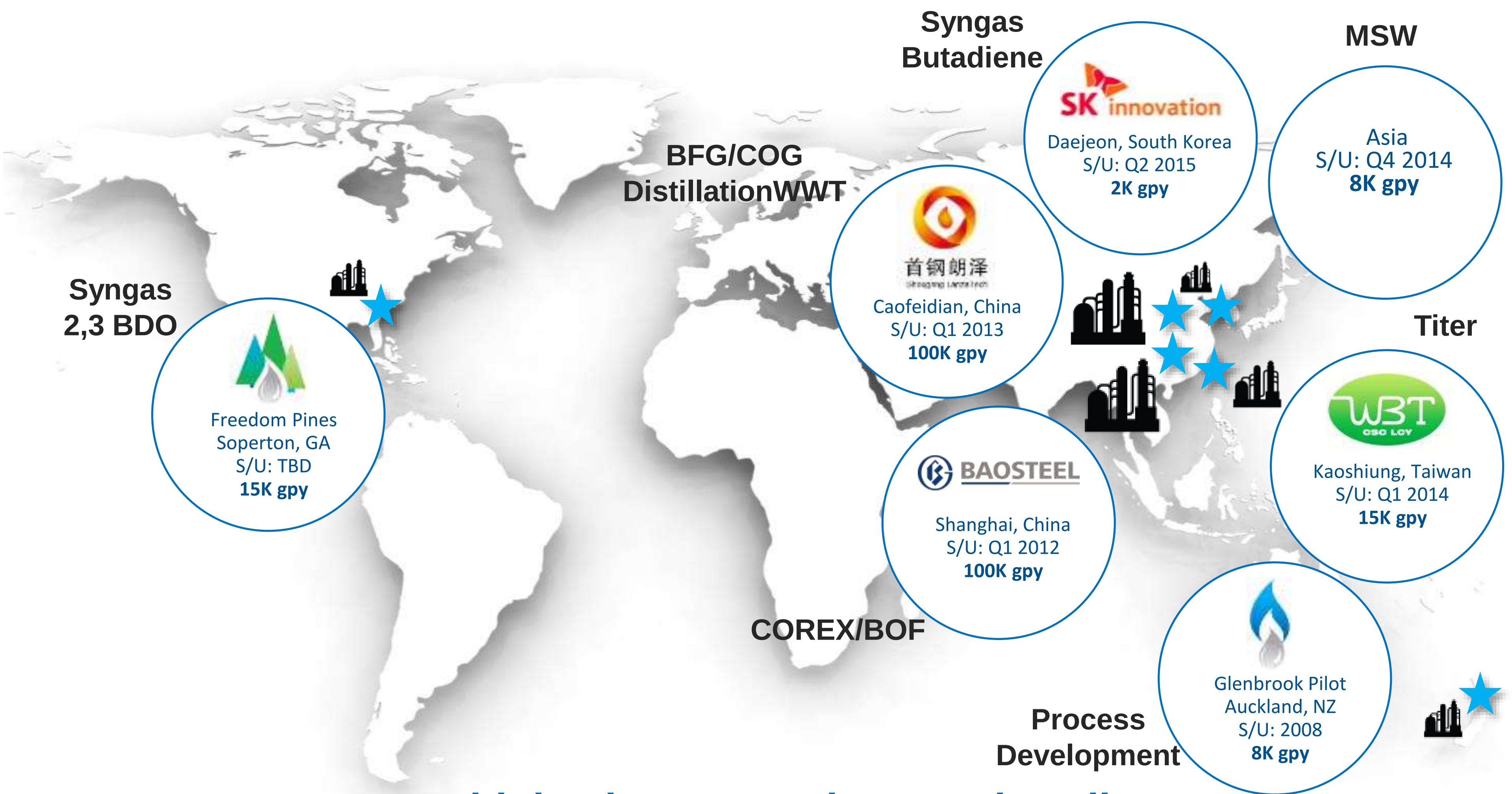
Global Technology "Lab"



Multiple plants at various scales all demonstrating <u>different</u> key aspects of process

Jet Life Cycle Assessment

	GHG Emissions (g CO_2e/MJ fuel)
LT ethanol from MSW	-73.3
Hydrogen, SMR	2.3
Electricity, China grid	0.1
Fuel combustion	74.4
TOTAL	3.4
Reduction from fossil fuel	96%

- Energy efficiency, MSW to hydrocarbon fuel: **55%**

PNNL, Imperium and LanzaTech Collaboration

- **Development**
  - Proprietary catalyst preparation method
  - Testing of process conditions to support scale-up
  - Integration of process steps for continuous production

- **Validation**
  - Production of specification samples from Lanzanol for certification of ASTM pathway

- **Scale-Up**
  - Scale-up of proprietary catalyst preparation to commercial vendor
  - Commercial catalyst selection for non-proprietary portions of process
  - Process modeling and Flow Diagram development

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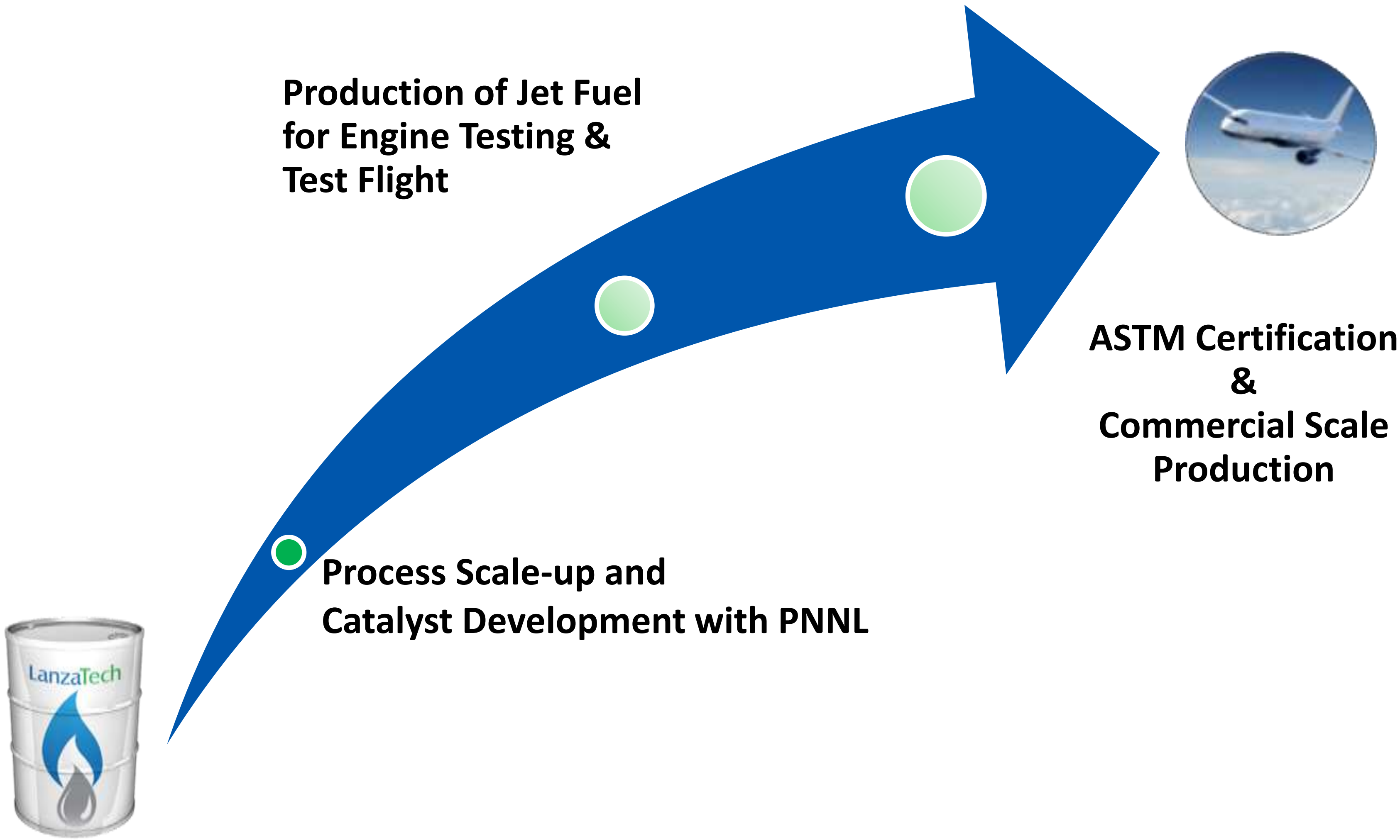
Lanzanol to Jet Fuel: Road to ASTM Pathway Certification & Commercialization



Commercialization of Aviation Fuel

HSBC

virgin atlantic

BOEING

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Pacific Northwest NATIONAL LABORATORY

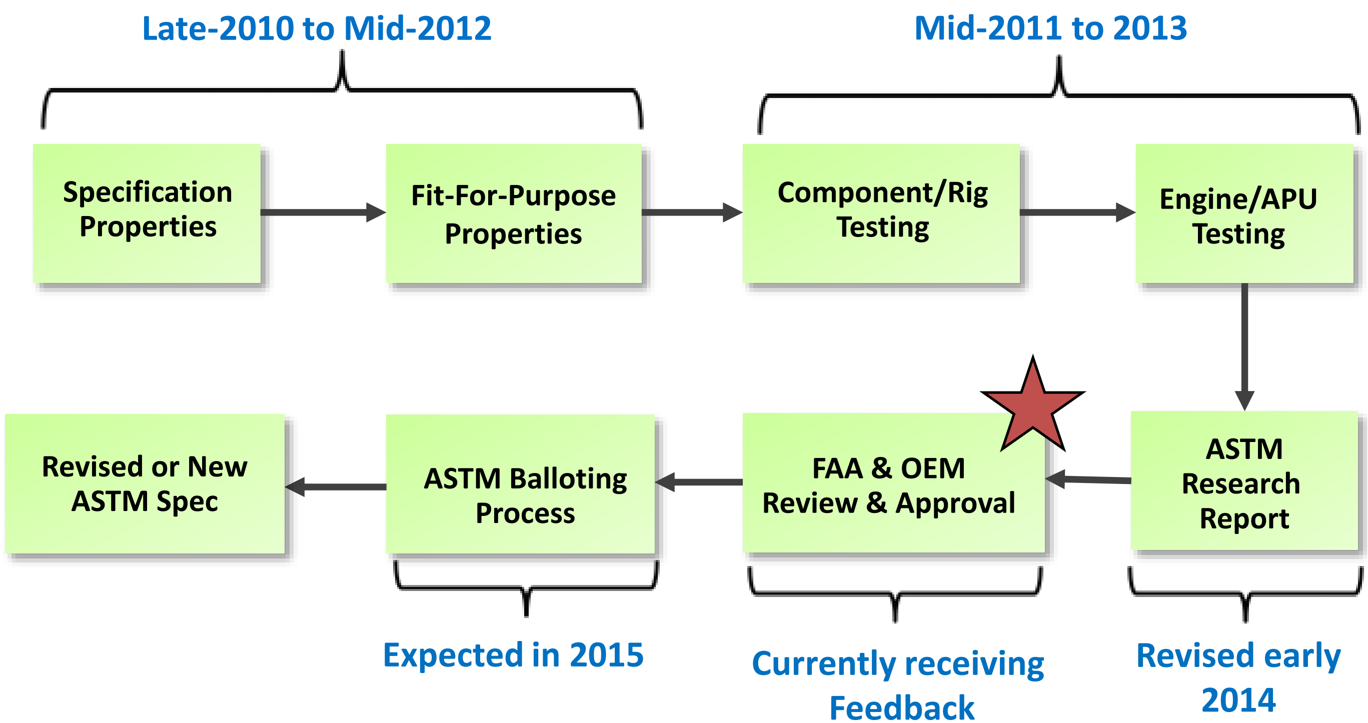
imperium renewables

- **World First Proving Flight using sustainable ATJ from steel mill off gases**
- **Flight will provide fuel performance data to help accelerate ASTM certification of ATJ production pathway**

ASTM Certification Progress

Alcohol to Jet (ATJ) Pathway

- Alcohol to Jet Fuel Taskforce created in 2010
- Taskforce Members: ATJ Technology Providers, Airlines, Engine OEMs, and Air Frame Manufactures
- ATJ Technology Providers at different scales and process readiness levels cooperating on ASTM pathway certification



ATJ-SPK ASTM Research Report Under review by FAA and OEMs

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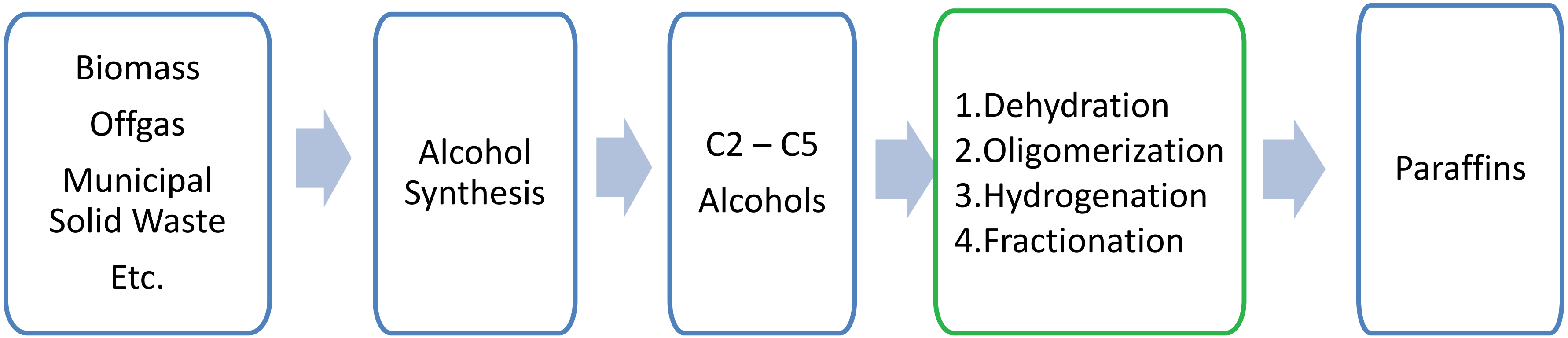
ASTM Alcohol to Jet Pathway



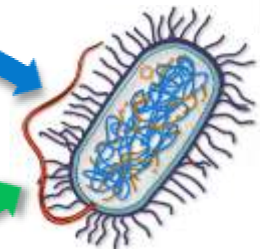
- C2 to C5 alcohols represent the feedstock for the ATJ-SPK pathway
- ATJ-SPK pathway
  - Dehydration of alcohol to an olefin
  - Oligomerization of olefin to a longer molecule
  - Hydrogenation
  - Fractional distillation to select the jet fuel
- Pathway steps have all been demonstrated at commercial scale individually (known thermochem technology)

Using and Commercializing CO_2

Direct Conversion of CO_2

CO_2

H_2



PETRONAS

Acetate

Yeast

DALIAN INSTITUTE OF CHEMICAL PHYSICS,
CHINESE ACADEMY OF SCIENCES

Lipids >70% of cell mass

Algae

इंडियनऑयल
IndianOil

Lipids >50% of cell mass; 40% Omega-3s

Lipids Product Markets

Hydrocarbon Transport Fuels
>US $ 3 trillion/year

Oleochemicals
US $15 billion/yr

Animal Feeds
US $370 billion/yr

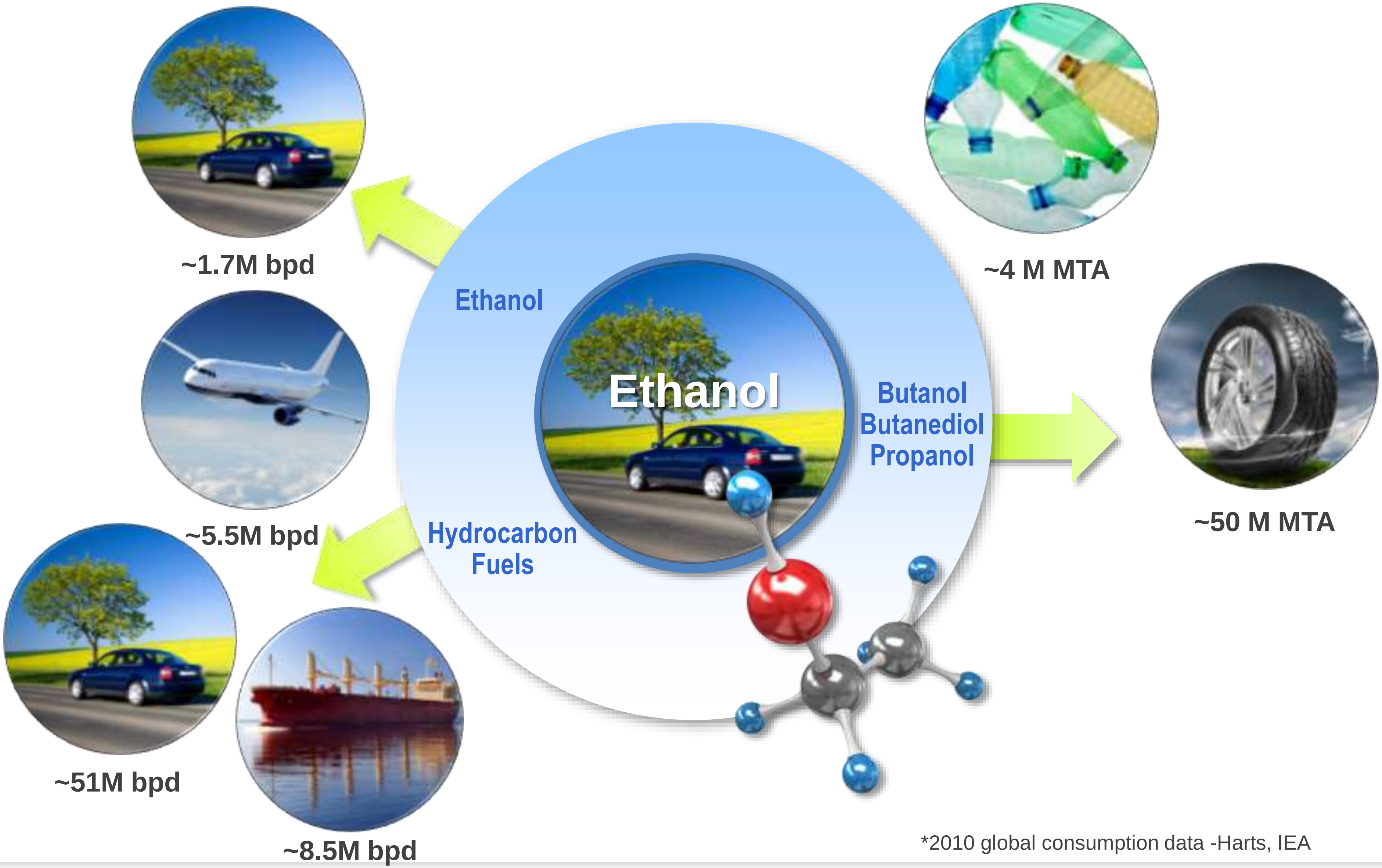
Food, Nutritional Supplements
US $25 billion/yr

Biofuels “Done Right”

No impact on water, food, land or biodiversity

- **Provide a sustainable solution to our climate and energy challenges**
- **Provide energy security from sustainable, regional resources**
- **Provide affordable options to meet growing demand in emerging economies**
- **Provide economic development that creates “green jobs”**

Diverse Products in Large Markets



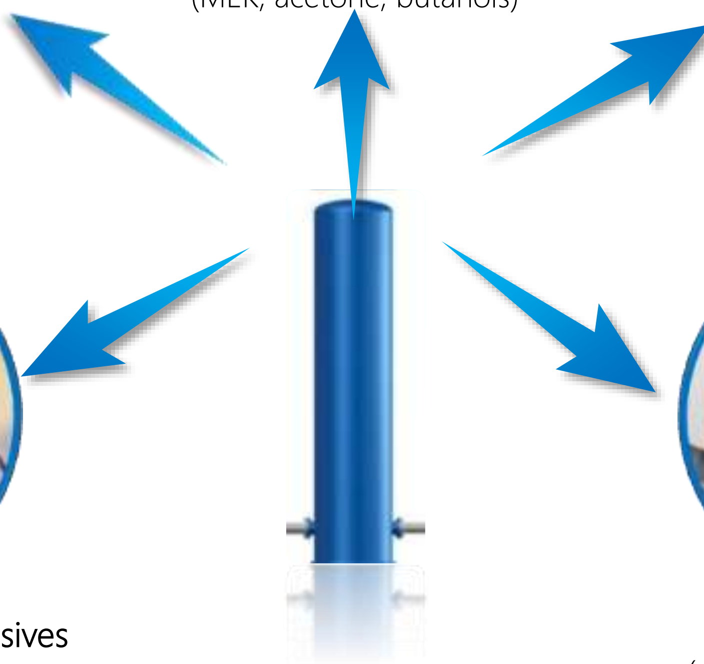
*2010 global consumption data -Harts, IEA

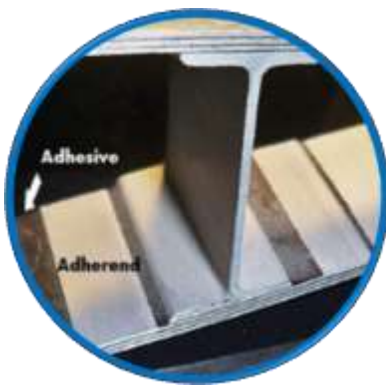
Potential Future Aviation Applications

Exterior paints and coatings
(MEK, acetone, butanols)

Polyurethane
seating foams
(2,3-BDO, other polyols)

Synthetic rubbers
(butadiene, butylenes, isoprene)





Structural and interior adhesives
(butadiene, butylenes)

Interior plastic mouldings
(acetic acid, ethanol, butadiene,
acrylates, 2,3-BDO, other polyols)

LanzaTech Global Partnerships

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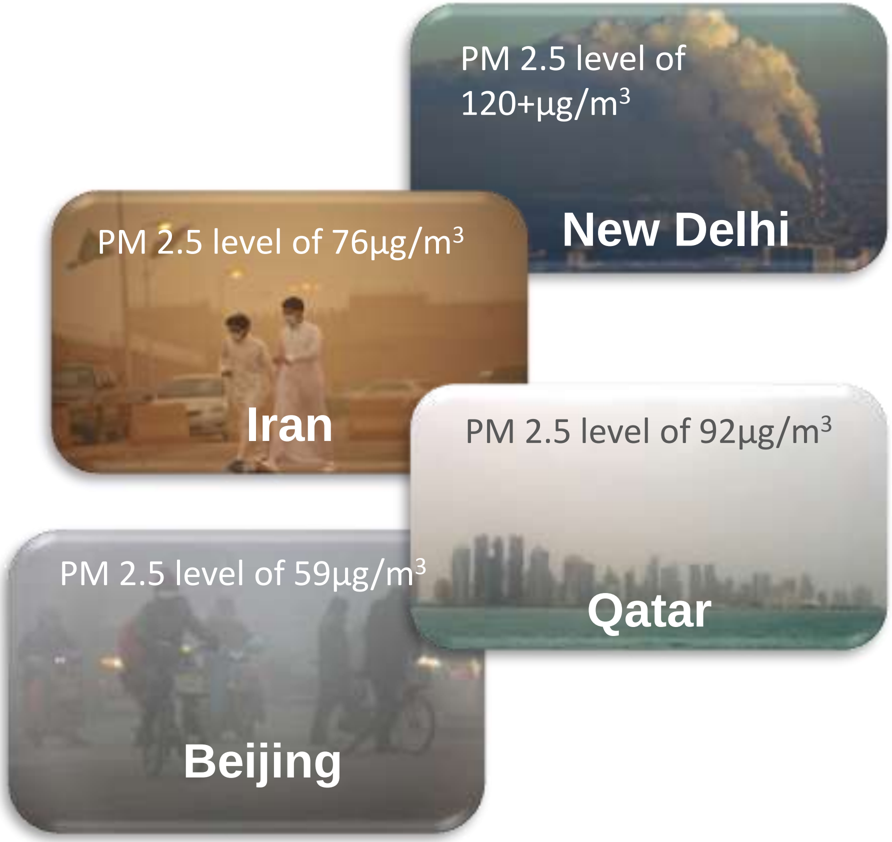
Innovation, Strong Will and Regulation!

Environmental regulations have improved conditions…but it is a work in progress

Unsafe and inefficient industrial products and processes continue to lead to dangerous levels of pollution in the air we breathe



May 2014, WHO global PM2.5 annual mean

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Carbon, the Final Frontier.

"I BELIEVE THAT IF ONE ALWAYS LOOKED AT THE SKIES, ONE WOULD END UP WITH WINGS."

GUSTAVE FLAUBERT

We all Need to be Superheros!