ICAO ENVIRONMENT

ICAO SEMINAR ON ALTERNATIVE FUELS 2017

ICAO Headquarters, Montréal, 8-9 February 2017

Recycling Carbon for Sustainable Aviation Fuel

Laurel Harmon
LanzaTech

The Carbon Imperative

Energy can be Carbon free

Wind

Solar

Hydro

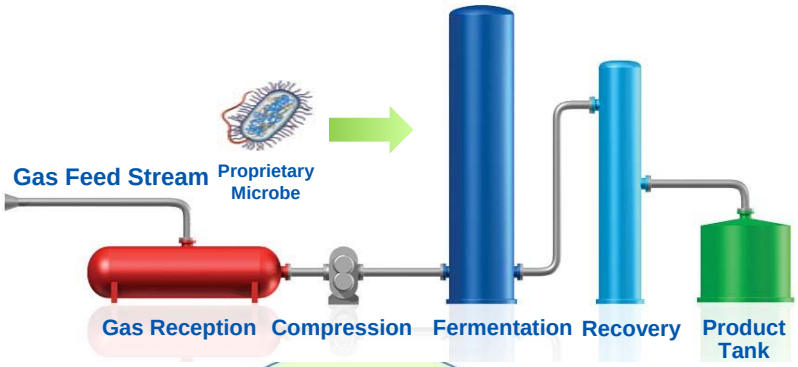
Liquid Fuels & Chemicals must contain

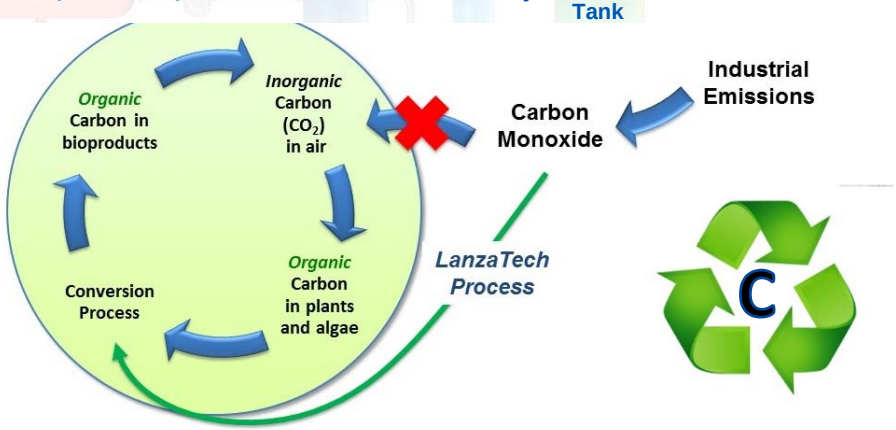
Efficiency
Recycle C

Be Carbon Smart!

Recycling Carbon

Gas fermentation technology converts C-rich gases to fuels and chemicals





Shortening the carbon cycle!

Demonstration to Commercial

50,000+ combined hours on stream
Multiple runs exceeding 2000 hours

BAOSTEEL CHINASTEEL 首钢集团 SHOUGANG GROUP WBT

Commercial Scale
Q2 2018

Ton (gallons) Lanzanol per year

ArcelorMittal	64k (21M)
CHINASTEEL	20k (6.7M)
首钢集团 SHOUGANG GROUP	46k (15M)

LanzaTech
CELEBRATING 10 YEARS

From Waste to Wing

Lanzanol produced in an RSB-certified facility (100,000 gpy Shougang-LanzaTech demo plant)

Lanzanol

Jet and diesel produced from Lanzanol in US facilities for proving flight and testing

Lanzanol → Dehydration → Oligomerization → Hydrogenation → Fractionation → **Jet Diesel**

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

首钢朗泽 Shougang LanzaTech

Pacific Northwest NATIONAL LABORATORY

BOEING

virgin atlantic

HSBC

Neat Jet Fuel and 50% Blends Meet Specifications

Global ATJ Feedstock

Municipal Solid Waste

- Fermentation of Syngas or Cellulosic Sugars, FT
- Scales of operation - ~ 30 to 40 M L/year facilities
- Production model: Distributed

Cellulosic Residues

- Fermentation of Syngas or Cellulosic Sugars, FT
- Scales of operation - ~ 30 to 40 M L/year facilities
- Production model: Distributed

Ethanol

Refinery Offgas

- Gas fermentation
- Scales of operation: ~ 70 to 100M L/year facilities
- Feedstock: Point sourced

Steel Mill Offgas

- Gas fermentation
- Scales of operation - ~ 100M L/year facilities
- Feedstock: Point sourced

Ethanol: Available globally via sustainable supply chains linked to regional resources

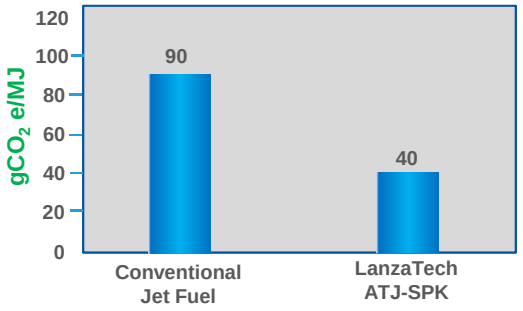
Benefits of Recycling Gases

- Provides new revenue stream from waste materials
- Provides energy security from sustainable, regional resources
- Provides affordable options to meet growing demand
- Provides economic development that creates "green jobs"

No Land Use Biodiversity

Water Recycle

Life Cycle GHG Emission



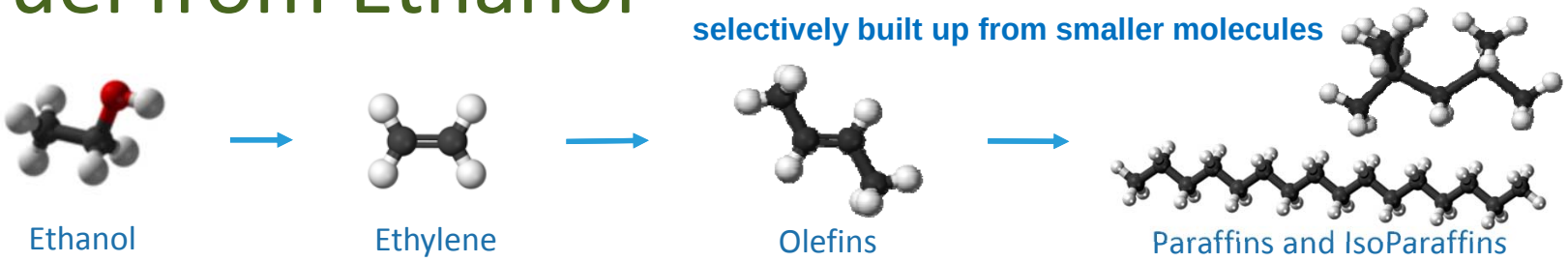
Life Cycle Analyses (LCA) for ethanol and jet performed in cooperation with:
Michigan Tech University,
Roundtable on Sustainable Biomaterials (RSB),
E4Tech, Ecofys and Tsinghua University

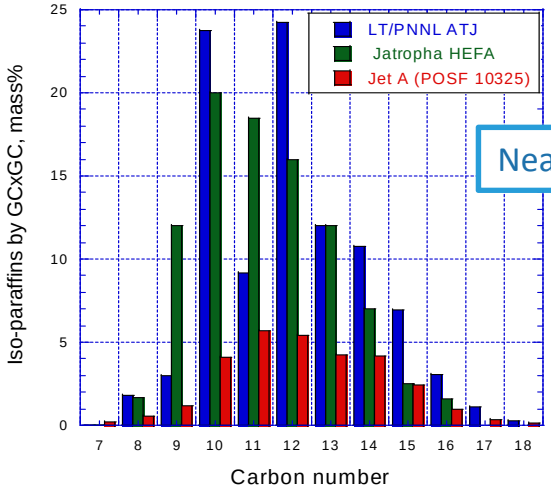
50-70% GHG Reduction over Petroleum Jet Fuel

RSB Certification for Commercial Facilities is Key to Assure Broad Sustainability

Jet Fuel from Ethanol

Jet range hydrocarbons (C8-C16) selectively built up from smaller molecules





Neat Fuel Comparison

Carbon number range similar to conventional jet fuel and other SPK's

Neat fuel primarily isoparaffins with <0.2% aromatics

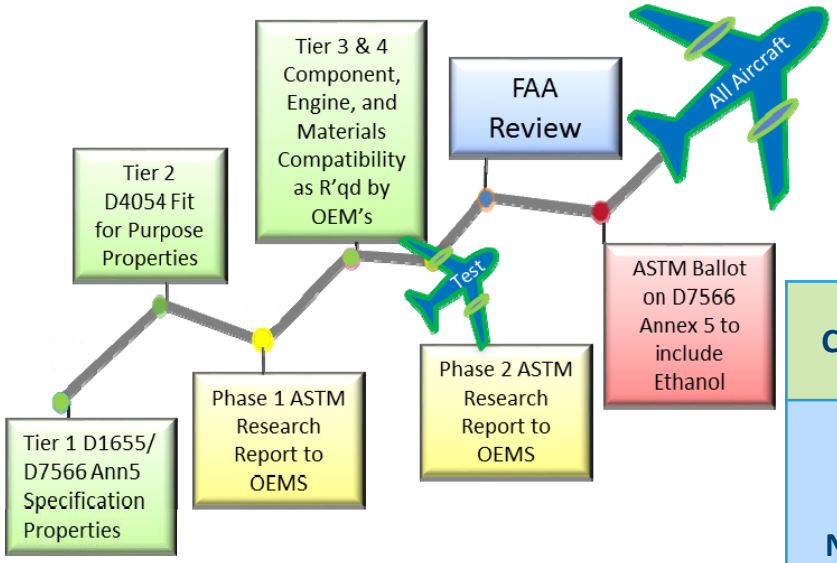
LanzaTech ATJ Status

✓ **4000 gallons Jet**
✓ **600 gallons Diesel**

- Demonstrated feedstock flexibility
  - 1,500 gal from Lanzanol
  - 2,500 gal from Grain Ethanol
- Technical feasibility established at demo scale
- Lanzanol produced in an RSB-certified facility
  - Shougang-LanzaTech 100,000 gal/yr demonstration plant in China
- Both Grain Ethanol and Lanzanol neat fuel meet ATJ-SPK specifications
- Both Grain Ethanol and Lanzanol blended with 50% Jet A meet D7566 specifications

Both Grain ethanol and Lanzanol Neat Fuel meet ATJ-SPK specifications

Aviation Fuels Demonstration Next Steps



Goal:

- **Approve C2 alcohol (ethanol) as ASTM Synthetic Jet Fuel Standard**
  - **Currently only C4 alcohol (isobutanol) allowed**

Completed	✓ **Phase 1 Report Submitted September 2016** ✓ **Report in queue for Engine and Aircraft OEMs**
Next Steps	• **OEM's Decide Extent of Tier 3 & 4 Data Needed** o **Engine, Material Compatibility, and Flight Demo** o **Ballot ASTM membership to incorporate as drop-in jet fuel**

Policy Recommendations

- Implement technology- and feedstock-neutral policies based on technical performance and sustainability
- Where incentives exist, ensure a level playing field for current, emerging and yet-to-be-invented technologies
- Provide support for demonstration and pioneer commercial plants to accelerate commercialization and reduce investor risk