Creating a Carbon Smart Future
Dr. Jennifer Holmgren
Impact on Coffee Growing Areas of Colombia

Source: Jarvis, CIAT (2012)
January 2018:
Arctic 45 degrees above
Normal
Limiting Global Warming to 1.5°C compared to 2°C

“rapid and far-reaching” transitions in land, energy, industry, buildings, transport, and cities. Global net human-caused emissions of carbon dioxide (CO₂) would need to fall by about 45% from 2010 levels by 2030, reaching ‘net zero’ around 2050. This means that any remaining emissions would need to be balanced by removing CO₂ from the air.
Global fossil CO₂ emissions have risen steadily over the last decades. The peak in global emissions is not yet in sight.

Source: CDIAC; Le Quéré et al 2018; Global Carbon Budget 2018
All 1.5°C Scenarios depend on Negative Emissions Technologies (NETs)

All exceed 1.5°C in early 2030s

65 years of overshoot

400 IPCC Scenarios with >50% meeting 2°C

344 Assume Large-scale NET Deployment
All Carbon is Precious
Energy can be Carbon Free

Chemicals for Everyday Products need Carbon

Aviation Fuel needs Carbon
Recycling Carbon

Industrial Off Gas Biomass, MSW Syngas

Gas Feed Stream

Compression Fermentation Recovery Product Tank

Proprietary Microbe

Carbon Smart™
>5 Million Gallons Ethanol Produced Since Start Up
It Takes…

**Data**

Multiple Demo plants at various scales

80,000 operating hours

**Time**

LanzaTech

CELEBRATING
14 YEARS

Lab

Pilot

Demo

Commercial

**Money**

>$250M

khosla ventures

CICC

NEW ZEALAND SUPERANNUATION FUND

BAOSTEEL

PETRONAS

SBCVC
Compelling Project Economics at 1st Commercial Plant

- Production Levels that Enable Profitability
- CapEx per Gallon of $3.25
- Gas BTU Value
- Payback Period ~3 Years
“...relevant scale”

“...relevant cost”

“...relevant adoption”
A Bacteria Which Does Water Gas Shift...

\[ \text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2 \]

1. **Low H\textsubscript{2}:** If H\textsubscript{2} is not available in the feed gas, the microbe can make H\textsubscript{2} from CO and H\textsubscript{2}O as required.

2. **High H\textsubscript{2}:** Excess H\textsubscript{2} can be used to fix the carbon in CO\textsubscript{2}.

3. Higher carbon retention in presence of H\textsubscript{2}

Enables the use of any CO:H\textsubscript{2} Ratio.
## Stoichiometric Conversion of C, H -> Ethanol

<table>
<thead>
<tr>
<th>H₂:CO ratio</th>
<th>Reaction Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:1</td>
<td>6 CO + 3 H₂O → EtOH + 4 CO₂</td>
<td>High CO off-gas (e.g. steel)</td>
</tr>
<tr>
<td>1:1</td>
<td>3 H₂ + 3 CO → EtOH + CO₂</td>
<td>Syngas (e.g. MSW)</td>
</tr>
<tr>
<td>2:1</td>
<td>4 H₂ + 2 CO → EtOH + H₂O</td>
<td></td>
</tr>
<tr>
<td>5:1</td>
<td>5 H₂ + 1 CO + 1 CO₂ → EtOH + 2 H₂O</td>
<td>High H₂ off-gas (e.g. refinery)</td>
</tr>
</tbody>
</table>

Any combination or interpolation of these can be used for ethanol production with only a change in operating conditions.
Ethanol Build Out

Global Deployment using Multiple Feedstocks

- Gasified Biomass
- Steel Off Gas
- Ferroalloy Off Gas
- Refinery Off Gas
- Gasified MSW
<table>
<thead>
<tr>
<th>Totals/year</th>
<th>Relative to Today</th>
</tr>
</thead>
<tbody>
<tr>
<td>480B Gallons</td>
<td>~35% of transport fuel</td>
</tr>
<tr>
<td>705M Cars off the road</td>
<td>~75% of passenger cars</td>
</tr>
<tr>
<td>2.6M mt CO₂</td>
<td>~7% of Global CO₂</td>
</tr>
</tbody>
</table>

Potential Impact: Gas Fermentation

- **Steel:** 50B gpy
- **Ferro-Alloy:** 1B gpy
- **Refining:** 3B gpy

**Global Impact**

- **Potential Impact, Gas Fermentation:**
  - 480B Gallons (~35% of transport fuel)
  - 705M Cars off the road (~75% of passenger cars)
  - 2.6M mt CO₂ (~7% of Global CO₂)
Recycling Carbon to Ethanol

Proprietary Microbe

Excellent Substrate
Building Block of the Future
Alcohol-to-Hydrocarbons

Ethanol → Dehydration → Oligomerization → Hydrogenation → Fractionation → Jet & Diesel

Ethanol $\rightarrow$ Ethylene $\rightarrow$ $C_4$–$C_{24}$ Olefins $\rightarrow$ Paraffins and IsoParaffins

Energy Efficiency & Renewable Energy

Pacific Northwest National Laboratory

U.S. Department of Energy

DARPA

FEDERAL AVIATION ADMINISTRATION

Boeing

Virgin Atlantic

HSBC

Carbon Smart™
Alcohol-to-Jet: Taking Off

✓ 4,000 gallons Jet
✓ 600 gallons Diesel
Waste Gas Ethanol from RSB Certified Facility
Grain Ethanol

<table>
<thead>
<tr>
<th>Fuel Property</th>
<th>Jet A Spec</th>
<th>LanzaTech ATJ-SPK</th>
<th>50/50% v with Jet A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeze Point, °C</td>
<td>-40 max</td>
<td>-61</td>
<td>-54</td>
</tr>
<tr>
<td>Energy Density, MJ/kg</td>
<td>42.8 min</td>
<td>44.4</td>
<td>43.8</td>
</tr>
<tr>
<td>Thermal Stability</td>
<td>Baseline</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Viscosity @ -40 °C mm²/sec</td>
<td>12 max</td>
<td>7.0</td>
<td>9.3</td>
</tr>
<tr>
<td>Hydrogen %</td>
<td>13.4 min</td>
<td>15.1</td>
<td>14.5</td>
</tr>
<tr>
<td>Aromatics %</td>
<td>8 min, 25 max</td>
<td>Nil</td>
<td>8.8</td>
</tr>
<tr>
<td>Sulfur, total mass %</td>
<td>0.30 max</td>
<td>&lt;0.001</td>
<td>0.02</td>
</tr>
</tbody>
</table>

April 1, 2018
D7566 ATJ SPK Annex A5
✓ Ethanol feedstock
✓ Final blend ratio to max 50 %

October 3rd 2018 First Commercial Flight
80% Lower Contrails and Soot Particles
4 Flights
Path to Economic Volumes

2015 Lab Scale

2016 Pilot Scale

2020 10MGY

2022 90MGY
I don’t want your hope. I don’t want you to be hopeful. I want you to panic.... and act as if the house was on fire.

Greta Thunberg
We must adopt technology neutral positions and support all solutions.

We must fail quickly and move on.

We must collaborate to address environmental concerns and get new fuels to market quickly.

We need funding for every scale of commercialization from proof of concept through to first commercial units.

Need to Ensure all Solutions can Contribute Quickly

By Ray Burgess
on October 07, 2011 at 6:00 AM

Solar panels do not work that well. Often far below expectations.
2017

70% net additions to global generating capacity
Moore’s Law: Computer processing power doubles every 18 months. If you want to fill Lake Michigan one drop at a time...
"The fight is won or lost far away from witnesses - behind the lines, in the gym and out there on the road, long before I dance under those lights."

Muhammad Ali