The LanzaTech process is driving innovation

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

- **Proprietary Microbe**
- **Gases are the sole energy and carbon source**

- **Gas Feed Stream**
- **Gas Reception**
- **Compression**
- **Fermentation**
- **Recovery**
- **Product Tank**

- **Process recycles** waste carbon into fuels and chemicals
- **Process brings** underutilized carbon into the fuel pool via *industrial symbiosis*
- **Potential to make material impact** on the future energy pool (>100s of billions of gallons per year)
Waste Carbon Streams as a Resource for Gas Fermentation

Industrial Waste Gas
Steel, Ferroalloys

Biogas

Solid Waste
Industrial, MSW

Biomass

CO₂

CO + H₂

CO + H₂ + CO₂

H₂ + CO₂

e⁻ + H₂O + CO₂

Gas Feed Stream

Gas Reception
Compression
Fermentation
Recovery
Product Tank

Acetogenic Microbe

Available
High Volume/ Low Intrinsic Value
Non-Food
Most point-sourced

Gases are the sole energy and carbon source
Pure continuous process

Data: IEA, UNEP, Index Mundi, US DOE Billion Ton Update, 2010 global production; 2012 proven gas reserves data

Gas flexibility = feedstock flexibility

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

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}

**Any CO:H\textsubscript{2} ratio can be used**
Ready Now: Scale-up of the LanzaTech Technology

State-of-the-art gas fermentation facilities with over 40 dedicated reactors

- Complete gas composition flexibility
- Online analytics and control (gas, biomass, metabolites)
- Multiple reactor configurations

Commercial Reactor Scale-up Factor Less Than What Has Been Proven at Demo Scale

- Strain Development
  - Lab: 2005 - 50 X
  - Pilot: 2008 - 32 X
  - Demo: 2012 - 25 X
  - Commercial: 2016
Industrial waste gases: Are there Enough to make an Impact?

Steel: 30B gallons/year

Refinery Waste Gas: 5B gallons/year

Significant Value Enhancement
Integrates into industrial infrastructure
China: Scorpions, Drinking, and Deals
Global Technology “Lab”…..Data, Data, Data

55,000 combined hours on stream
Multiple runs exceeding 2000 hours

Multiple plants at various scales all demonstrating different key aspects of process
Recycling Carbon

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

Performance milestones achieved and exceeded for >1000 hours at 100K GPY (~400 KL/yr)
MSW to fuel

Project overview
LanzaTech has a two year partnership with a major Asian chemical company to convert live-feeds of syngas produced from municipal solid waste (MSW) into ethanol.

*LanzaTech has designed, installed, and operates a pilot plant producing ethanol at a MSW processing facility.*
LanzaTech’s Modelling Capacity

Enzyme Kinetics
- Context-dependent reaction rates
- Substrate inhibition
- Multiple reactants

Metabolism
- Substrate uptake and cell growth
- Product formation and selectivity
- Different culturing conditions

Gas-Liquid mass transfer
- Interaction with reaction kinetics
- Interaction with hydrodynamics

Multiphase flow hydrodynamics
- Flow regimes and void fractions
- Mass transfer area

Flow regimes and void fractions
- Mass transfer area

Interaction with reaction kinetics
- Interaction with hydrodynamics
Validation of Reactor Technology

\[ K_L = k_L P_T H_e \left( \frac{6 \varepsilon}{d_b} \right) \left( \frac{n_T}{V_R} \right) \]

**NOTE:** $k_L^*(1-\text{Sat}%)$ is a dimensionless parameter that combines everything that affects mass transfer, including pressure, gas holdup, bubble size, gas flow per liquid volume, dissolved gas concentration, etc.

Sat% is percentage saturation of the gas in question.
LanzaTech genome-scale model – summary

- Growth rate
- Ethanol production
- Gas uptake/production

Experimental data
Synthetic Biology Capabilities – Advanced genetic toolbox in place

• Unique genetic toolbox for gas fermenting organisms developed

Robust DNA transfer
- Scalable electroporation and conjugation methods

Ensures efficient strain construction

Model-guided design
- Computer aided design tools (BioCAD)
- Predictive Metabolic model
- Validated DNA design algorithms (Codon Usage & RBS)
- Metabolic knowledgebase for identification of new pathways

Ensures efficient strain construction

Comprehensive genetic parts library
- Modular vector system
- Validated genetic control parts (promoters, library)
- Antibiotic free markers

Automated construction
- Automated DNA construction using robotics
- Advanced sequencing capabilities to QC and troubleshoot strains

Reduces time and cost

Efficient genome editing
- Robust transformation method
- Scarless gene knock-out and/or Integration (Proprietary tools & CRISPR)

Ensures efficient strain construction

From Mill to Wing-An ATJ Pathway

RSB-certified facility
China

Ethanol “Lanzanol”
Chemical Conversion

Diesel & Jet Fuel

4,000 gallons of on-spec jet and 600 gallons of diesel produced
Excellent analytical and Fit for Purpose results
Phase 1 Research Report Submitted
$4M DOE Award
Integrated Multi-Scale Platform

- Industrial proven host strain
- Efficient genetic toolbox
- Scalable reactor designs
- Process optimization and scale up

Integrated models and algorithms

Intellectual Property
>200 granted patents on all aspects of process
Aemetis Background

- Advanced renewable fuels and biochemicals company
- Operating facilities:
  - 60M gpy 1G EtOH facility in CA
  - 50M gpy Biodiesel facility in India
- Vision to convert 1G to advanced
- 2015 revenues: $147M
- Headquartered in Cupertino, CA
- Project funding in progress

Aemetis Project

<table>
<thead>
<tr>
<th>Location</th>
<th>Modesto, CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Gas</td>
<td>Biomass syngas</td>
</tr>
<tr>
<td>EtOH Production</td>
<td>8M gpy</td>
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</tbody>
</table>

Become leading Cellulosic EtOH producer in US
Commercial Scale Facilities

Caofeidian, China
16M gallons/year
2017

Gent, Belgium
21M gallons/year
2018
Steel Mill Value Proposition

LanzaTech business case:
- Providing 2x More returns from ethanol than from electricity
**Broader Environmental Impact**

LanzaTech Process emits ~40% less NO\textsubscript{x} and ~80% fewer particulates than electricity generation per MJ energy recovered.

LanzaTech Process emits 33% less CO\textsubscript{2} than electricity generation per MJ energy recovered.

**Carbon is Only Part of the Story**
Recycling Gases: Environmental, Economic, Social Benefit

Additional 3rd Party Life Cycle Analyses (LCA)
- Michigan Tech University
- Roundtable on Sustainable Biomaterials (RSB)
- Ecofys
- Tsinghua University

50-80% GHG Reduction over Petroleum Gasoline

Water Recycle
No Land Biodiversity

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”

Lifecycle GHG Emissions

<table>
<thead>
<tr>
<th></th>
<th>gCO₂e/MJ</th>
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<tbody>
<tr>
<td>Fossil Fuel</td>
<td>83.8</td>
</tr>
<tr>
<td>LanzaTech Ethanol</td>
<td>19.6</td>
</tr>
</tbody>
</table>

83.8
19.6
0
10
20
30
40
50
60
70
80
90

Fossil Fuel
LanzaTech Ethanol
What Do you want to make Today?

Paradigm Shift: chemical production plants that rapidly react to market conditions

Avoid the cycles
- Challenge: Petrochemical price volatility

Steel in the ground is “hardware”
- Same reactor vessel
- Same feedstock
- Minor changes in separation

On-demand “software” upgrades using the same hardware
- Minor: Improved efficiency
- Major: New product molecule
Disrupting Market Cycles

- Same reactor
- Same operating conditions
- Same feedstock

DISRUPTION = 1) Rapid Reaction to Fluctuating Chemicals Market 2) Feedstock ≠ Commodity

“hardware”

Microbe 1.0
- ✓ Ethanol

Microbe 1.1
- ✓ improved efficiency, tolerance, selectivity

Microbe 2.0
- ✓ new product molecule

“software”
Transitioning to a Circular Economy is Key
A Carbon Smart World

Energy can be Carbon free
- Wind
- Solar
- Hydro

Liquid Fuels & Chemicals must contain Carbon

Efficiency Recycle C
Biofuels From Recycling of Atmospheric Carbon

Organic Carbon in biofuel

Inorganic Carbon (CO₂) in air

Conversion in biofuel process

Organic Carbon in plant, algae, cyanobacteria
Biofuels from Recycling of Waste Carbon
(Potential: 2.5 Billion gallons/year in the S)

Conversion in biofuel process

Organic Carbon in biofuel

Inorganic Carbon (CO₂) in air

Organic Carbon (CO, CO₂)
from flue

Inorganic Carbon (CO, CO₂)
in air

Organic Carbon in plant, algae, cyanobacteria, bacteria
Example:
Recycling Waste Gases with Bacteria: Ready Today (>40,000 hours on stream @ demo scale)

Lifecycle GHG Emissions

- Petroleum Fuel: 83.8 gCO₂e/MJ
- LanzaTech Ethanol: 19.6 gCO₂e/MJ
- LanzaTech Jet: 32.6 gCO₂e/MJ
- Petroleum Jet: 89 gCO₂e/MJ

Water Recycle
No Land Biodiversity
Provides energy security from sustainable, regional resources
Provides economic development that creates “green jobs”

E4tech

An inclusive approach furthers the purpose of The Energy Independence and Security Act (EISA)

✓ Energy ✓ Environmental ✓ Economic
Enabling the Circular Economy
Fuel from CO$_2$: A path to carbon neutrality?

CO$_2$ is fixed into fuels and materials using “unlimited” lowest cost sustainable electricity: Domestic production, No crops, No land
Crossing the Valley of Death

- Discovery
- Applied R&D
- Engineering Development
- Pilot and Demonstration
- First Commercial
- Diffusion
- Continuous improvement at scale
- Adapt and adopt from others
- Sustainable enterprise

Ease of funding

Evolution
Questions?