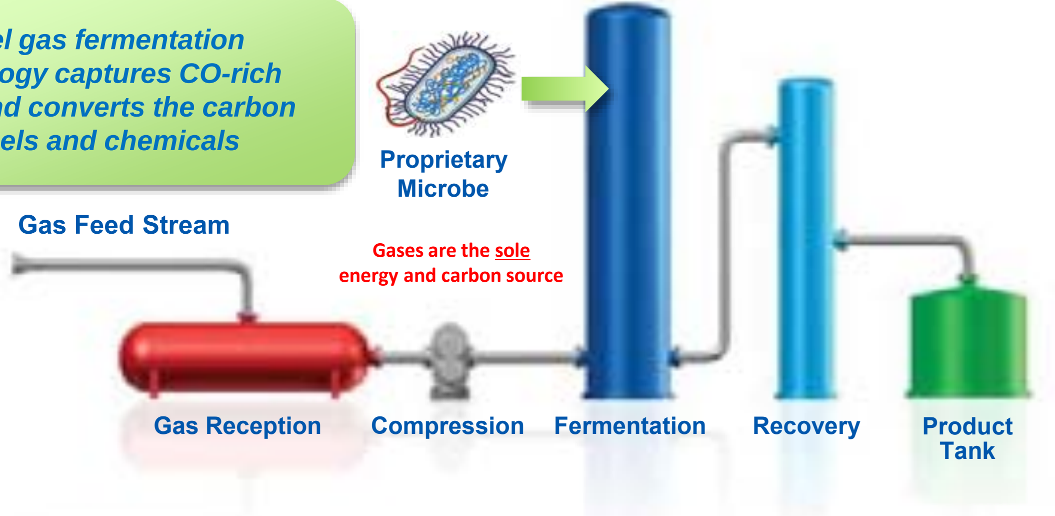
LanzaTech
capturing carbon. fueling growth.

The LanzaTech process is driving innovation

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 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

CO_2

Reforming

Gasificatio
n

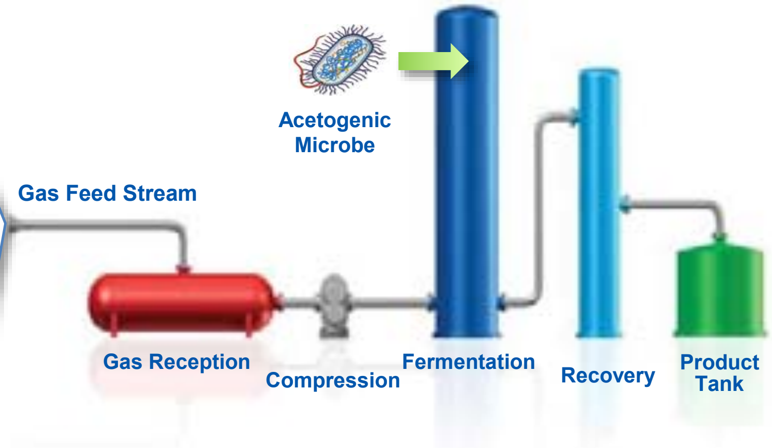
CO

$CO + H_2$

$CO + H_2 + CO_2$

$H_2 + CO_2$

$e^- + H_2O + CO_2$



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

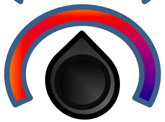
- ✓ Gases are the sole energy and carbon source
- ✓ Pure continuous process

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

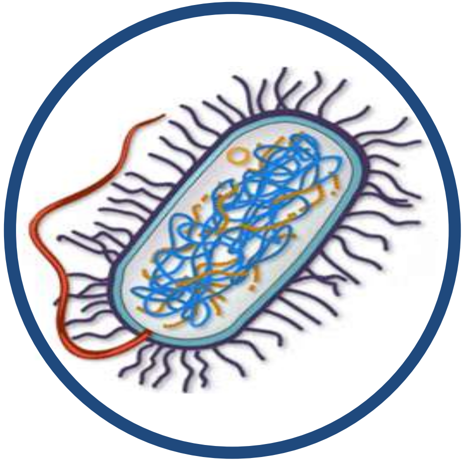
Liew et al., 2016, Gas Fermentation – A Flexible Platform for Commercial Scale Production of Low Carbon Fuels and Chemicals from Waste and Renewable Feedstocks. *Frontiers Microbiol* 7: 694.

Gas flexibility = feedstock flexibility

$$CO + H_2O \leftrightarrow CO_2 + H_2$$



$[H_2]$



1. **Low H_2:** If H_2 is not available in the feed gas, the microbe can make H_2 from CO and H_2O as required

2. **High H_2**: Excess H_2 can be used to fix the carbon in CO_2

3. Higher carbon retention in presence of H_2

Any CO:H_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

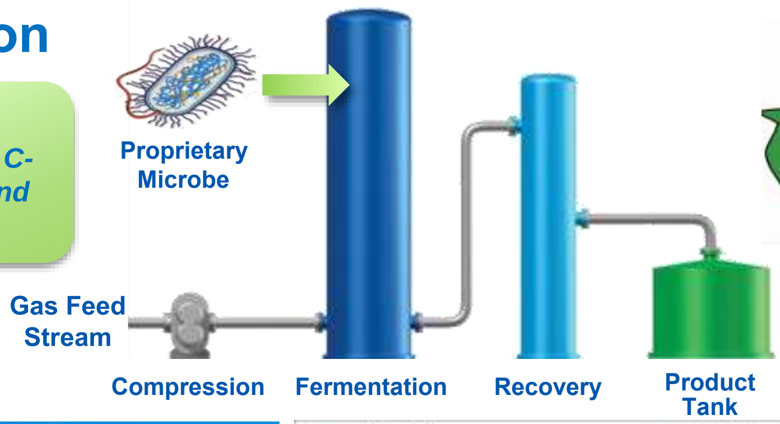
Global Technology "Lab"…..Data, Data, Data

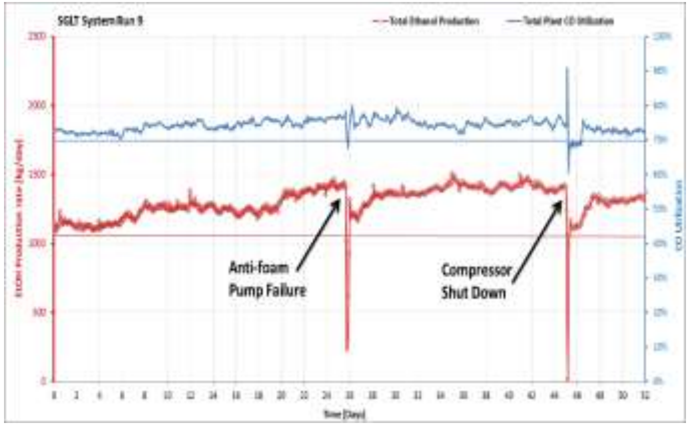
55,000 combined hours on stream
Multiple runs exceeding 2000 hours

Multiple plants at various scales all demonstrating <u>different</u> 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

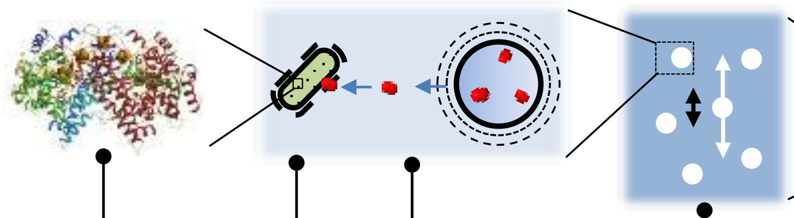

Pilot plant at gasification site

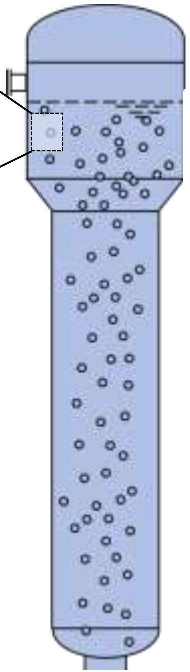
Project overview

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





Multiphase flow hydrodynamics

- Flow regimes and void fractions
- Mass transfer area

Gas-Liquid mass transfer

- Interaction with reaction kinetics
- Interaction with hydrodynamics

Metabolism

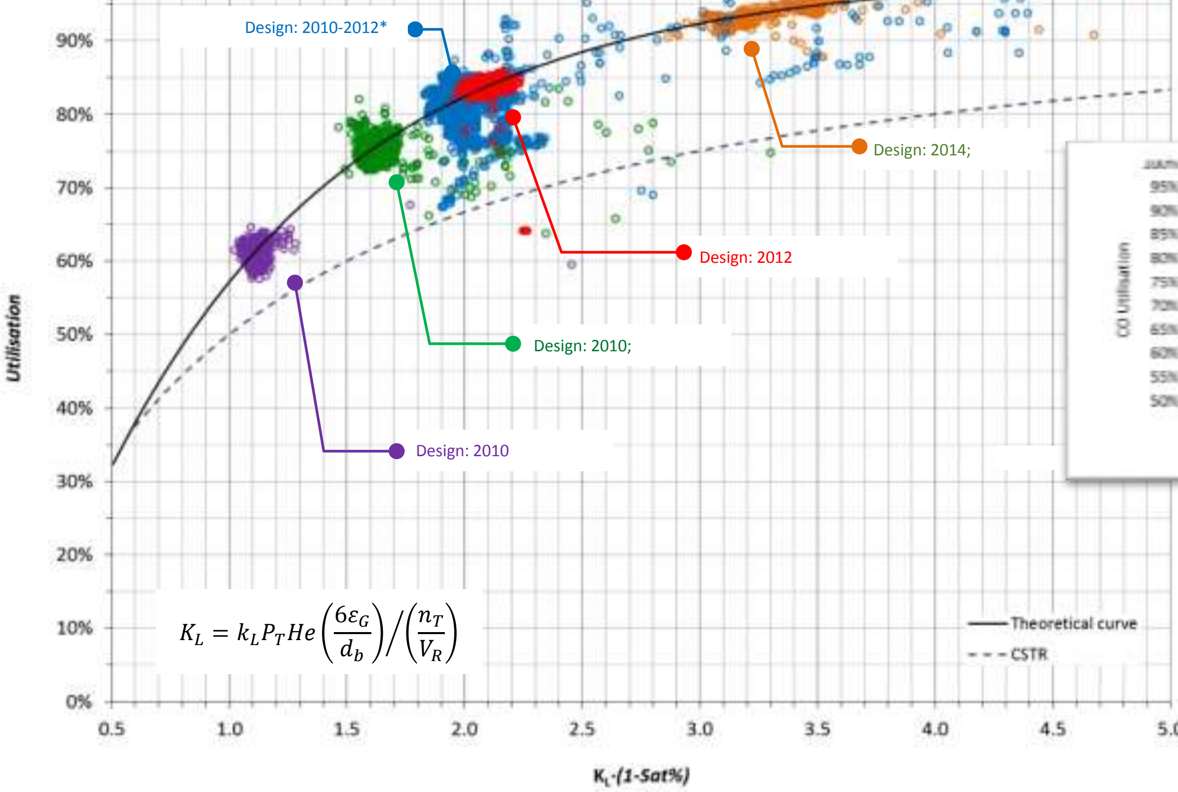
- Substrate uptake and cell growth
- Product formation and selectivity
- Different culturing conditions

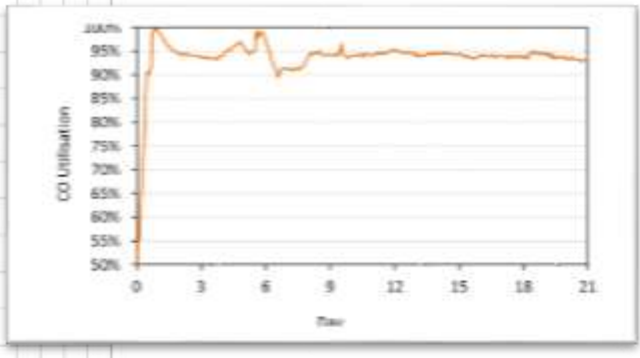
Enzyme Kinetics

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

Validation of Reactor Technology

CO utilisation of existing LanzaTech reactors compared with theoretical curve.

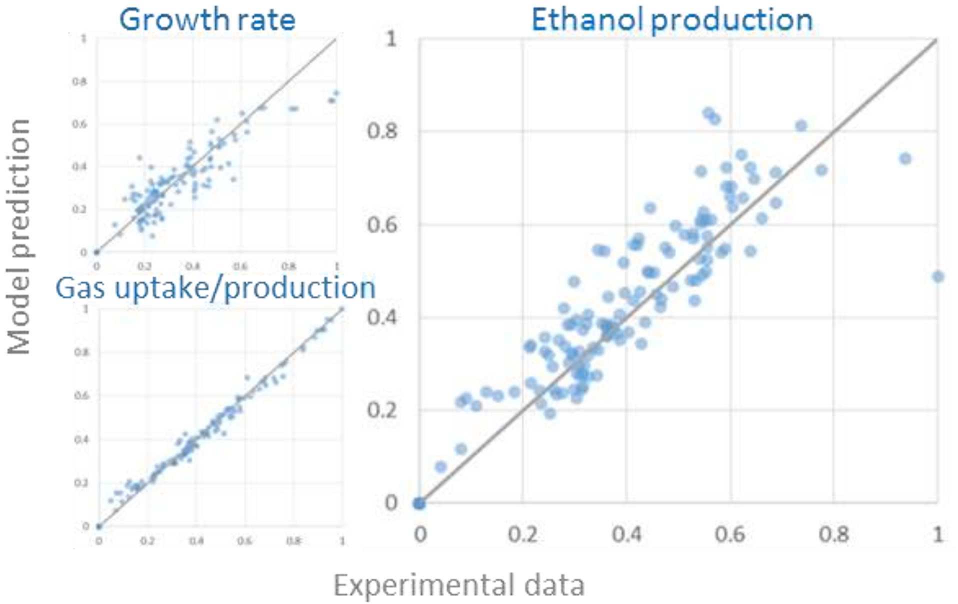




NOTE: kL*(1-Sat%) is a dimensionless parameter that combines everything that affects mass transfer, including pressure, gas holdup, bubble size, gas flow per liquid volume, dissolved gas concentration, etc.

Sat% is percentage saturation of the gas in question.

LanzaTech genome-scale model – summary



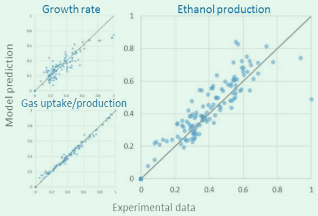
Synthetic Biology Capabilities – Advanced genetic toolbox in place

- **Unique genetic toolbox for gas fermenting organisms developed**

Robust DNA transfer
- Scalable electroporation and conjugation methods

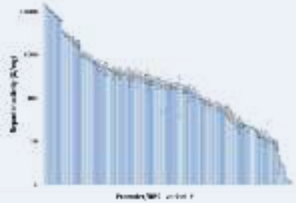
Ensures efficient strain construction

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



Reduces time and cost

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



Ensures efficient strain construction

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

Reduces time and cost

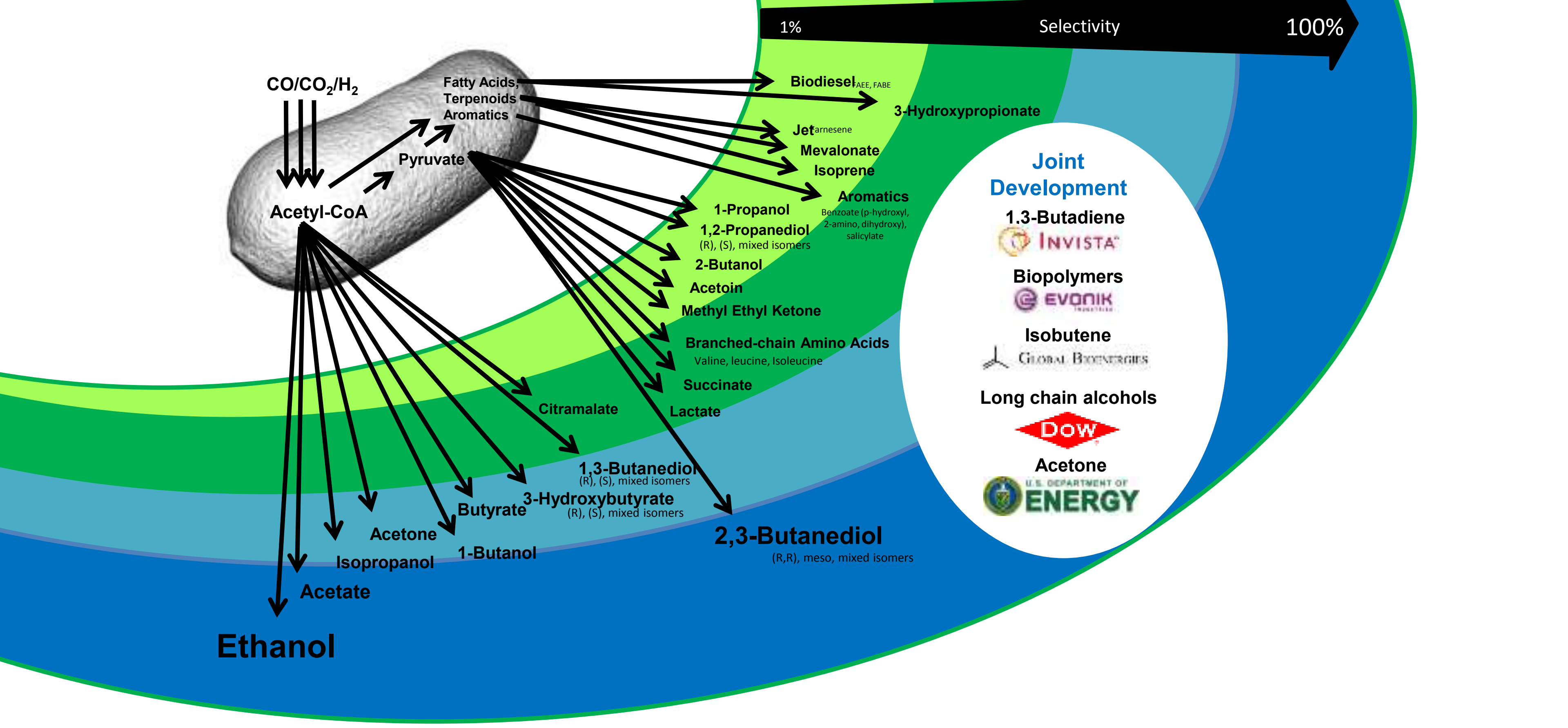
Efficient genome editing
- Robust transformation method
- Scarless gene knock-out and/or Integration (Proprietary tools & CRISPR)

Ensures efficient strain construction

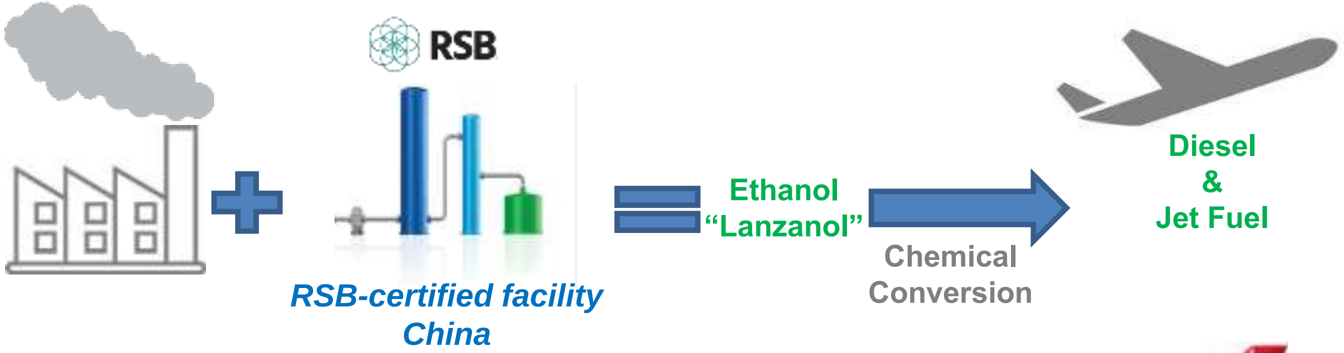
Liew et al., 2016, Gas Fermentation – A Flexible Platform for Commercial Scale Production of Low Carbon Fuels and Chemicals from Waste and Renewable Feedstocks. *Frontiers Microbiol* 7: 694.

Nagaraju et al., 2016, Genome editing of *Clostridium autoethanogenum* using CRISPR/Cas9. *Biotechnol Biofuels* 9: 219.

l Platform, >30 Products…



From Mill to Wing-An ATJ Pathway

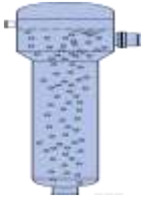


4,000 gallons of on-spec jet and 600 gallons of diesel produced
Excellent analytical and Fit for Purpose results
Phase 1 Research Report Submitted
$4M DOE Award

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

AEMETIS

- **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	
Location	Modesto, CA
Feed Gas	Biomass syngas
EtOH Production Capacity	8M gpy

Become leading Cellulosic EtOH producer in US

Commercial Scale Facilities

首钢朗泽

Shougang LanzaTech

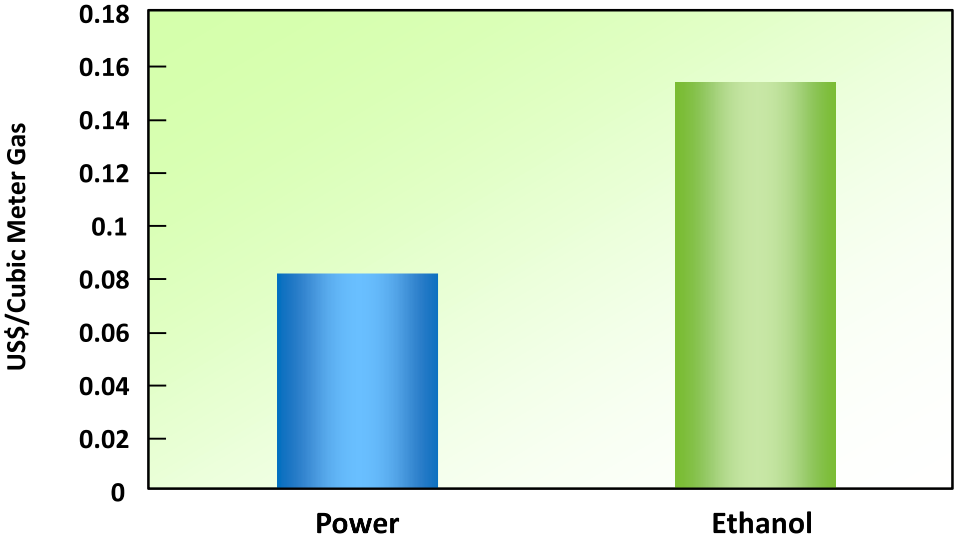
Caofeidian, China
16M gallons/year
2017

ArcelorMittal

Steelanol

Gent, Belgium
21M gallons/year
2018

Steel Mill Value Proposition

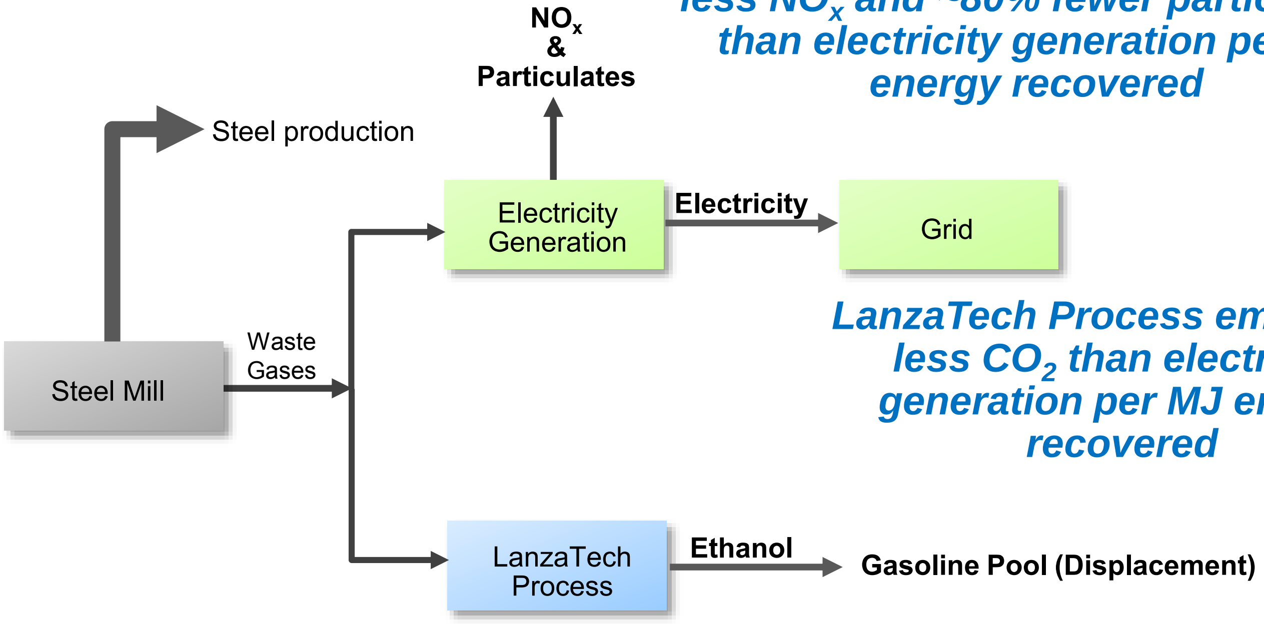


LanzaTech business case:

- Providing 2x More returns from ethanol than from electricity

Broader Environmental Impact

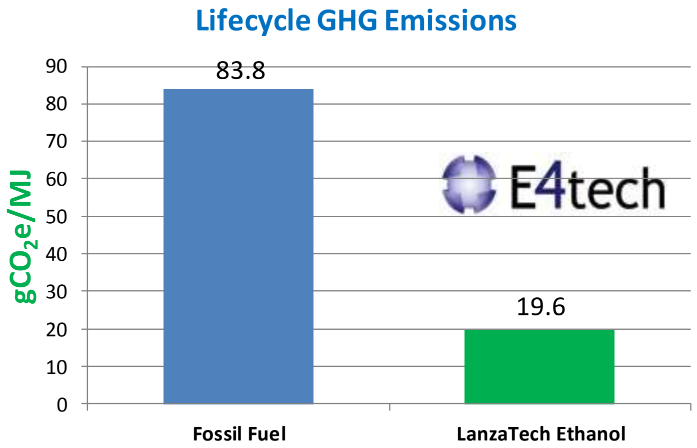
LanzaTech Process emits ~40% less NO_x and ~80% fewer particulates than electricity generation per MJ energy recovered



LanzaTech Process emits 33% less CO_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

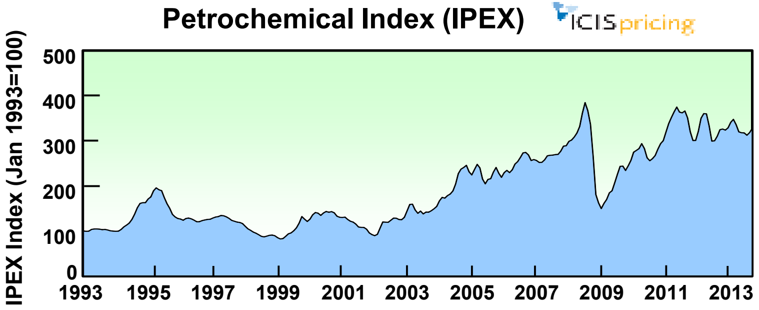
Provides economic development that creates "green jobs"

What Do you want to make Today?

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

Avoid the cycles

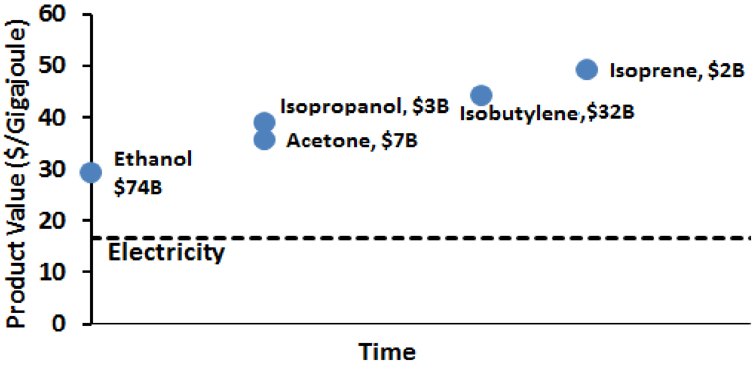
– Challenge: Peterochemical price volatility



Source: ICIS

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

"software"

Microbe 1.0

- ✓Ethanol

Microbe 1.1

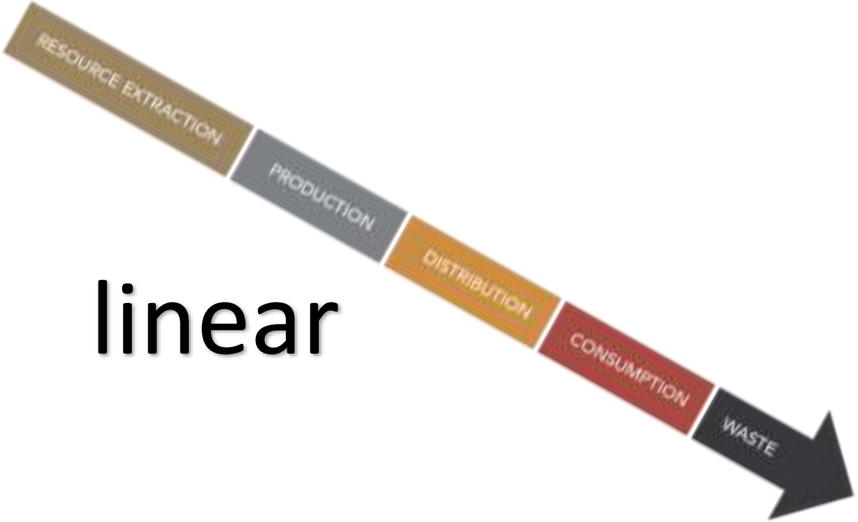
- ✓improved efficiency, tolerance, selectivity

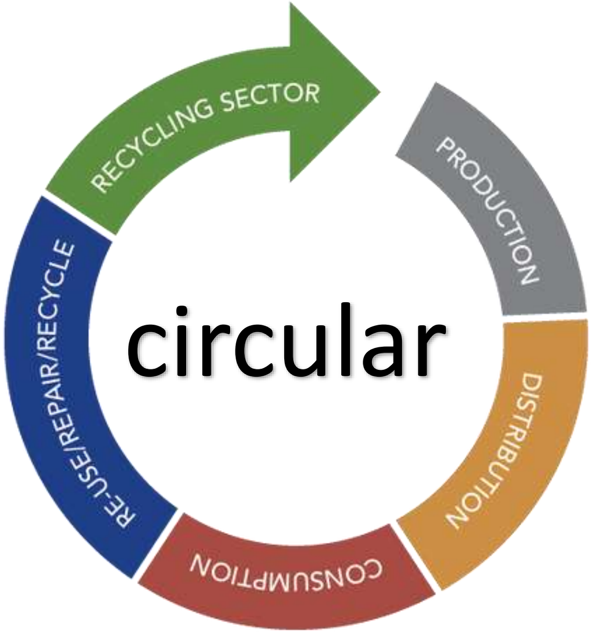
Microbe 2.0

- ✓new product molecule

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

Transitioning to a Circular Economy is Key





A Carbon Smart World

Energy can be Carbon free

Wind

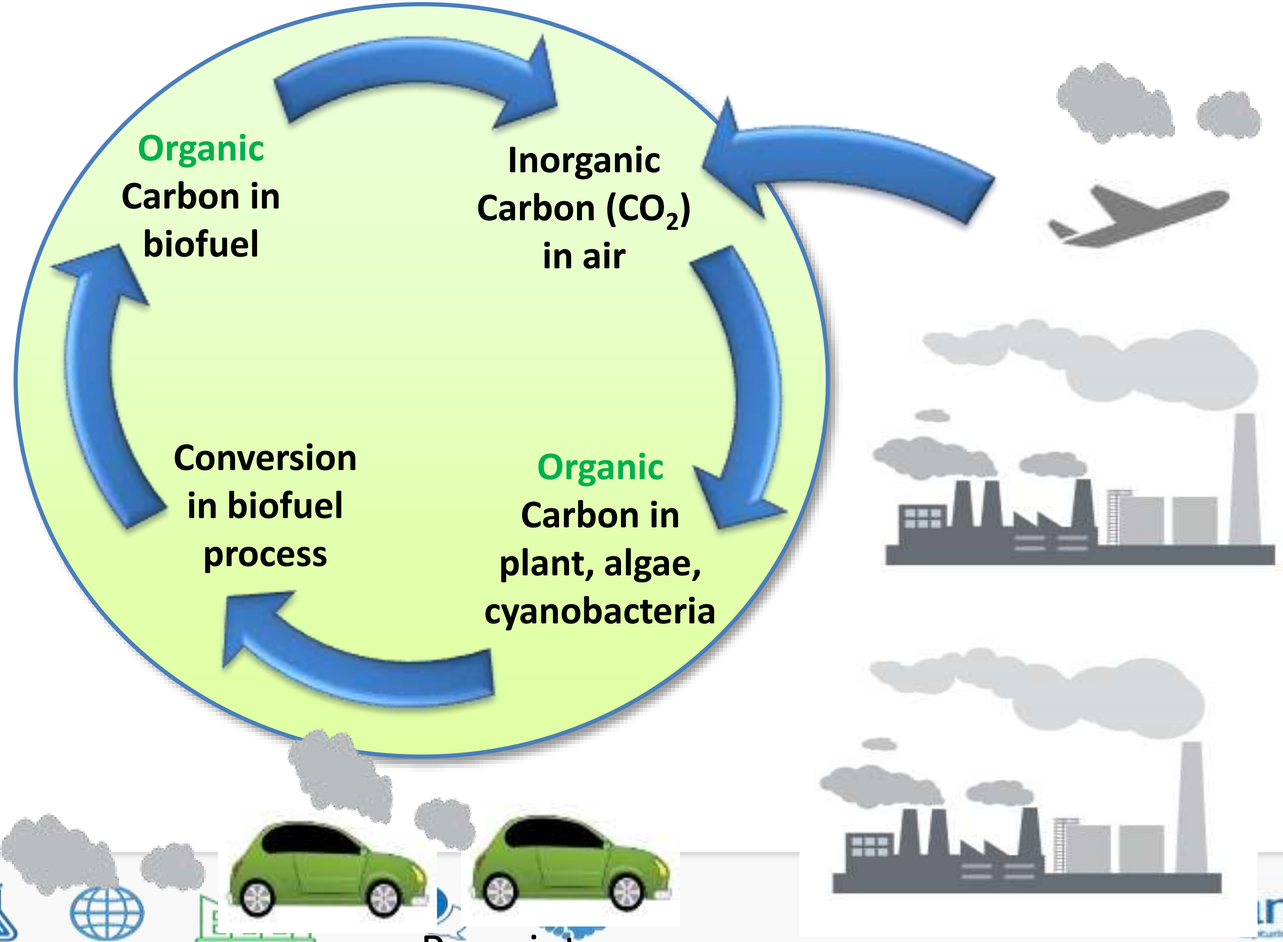
Solar

Hydro

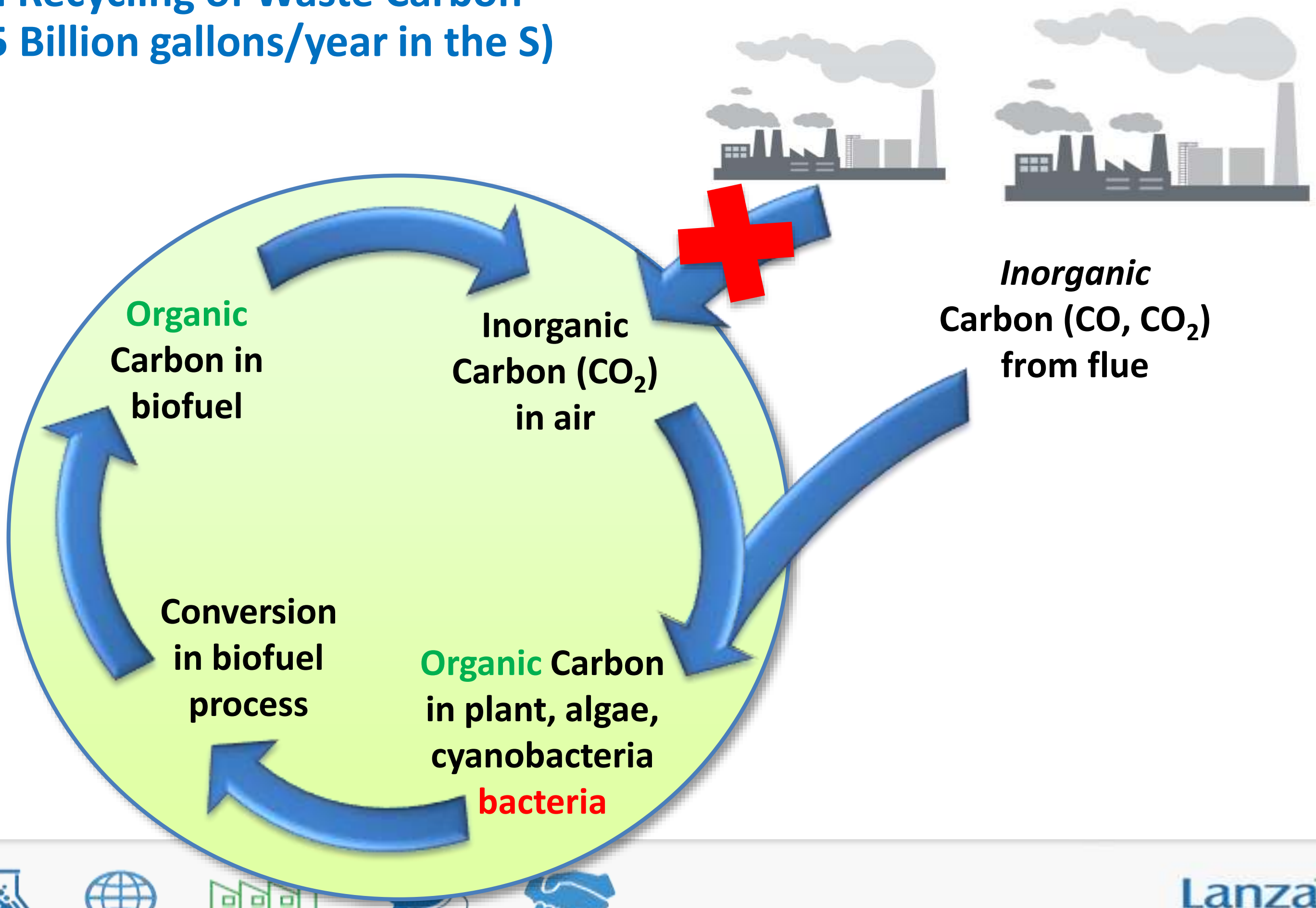
Liquid Fuels & Chemicals must contain

Efficiency Recycle C

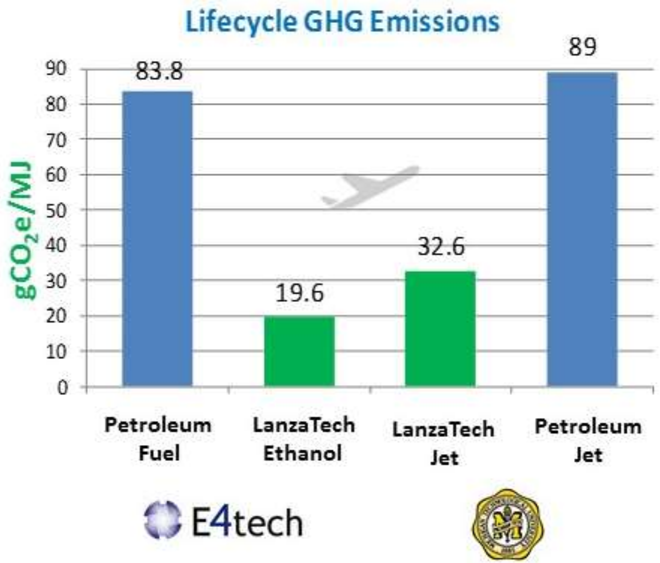
Biofuels From Recycling of Atmospheric Carbon



Biofuels from Recycling of Waste Carbon (Potential: 2.5 Billion gallons/year in the S)



Example:
Recycling Waste Gases with Bacteria: Ready Today (>40,000 hours on stream @ demo scale)



Water Recycle

No Land Biodiversity

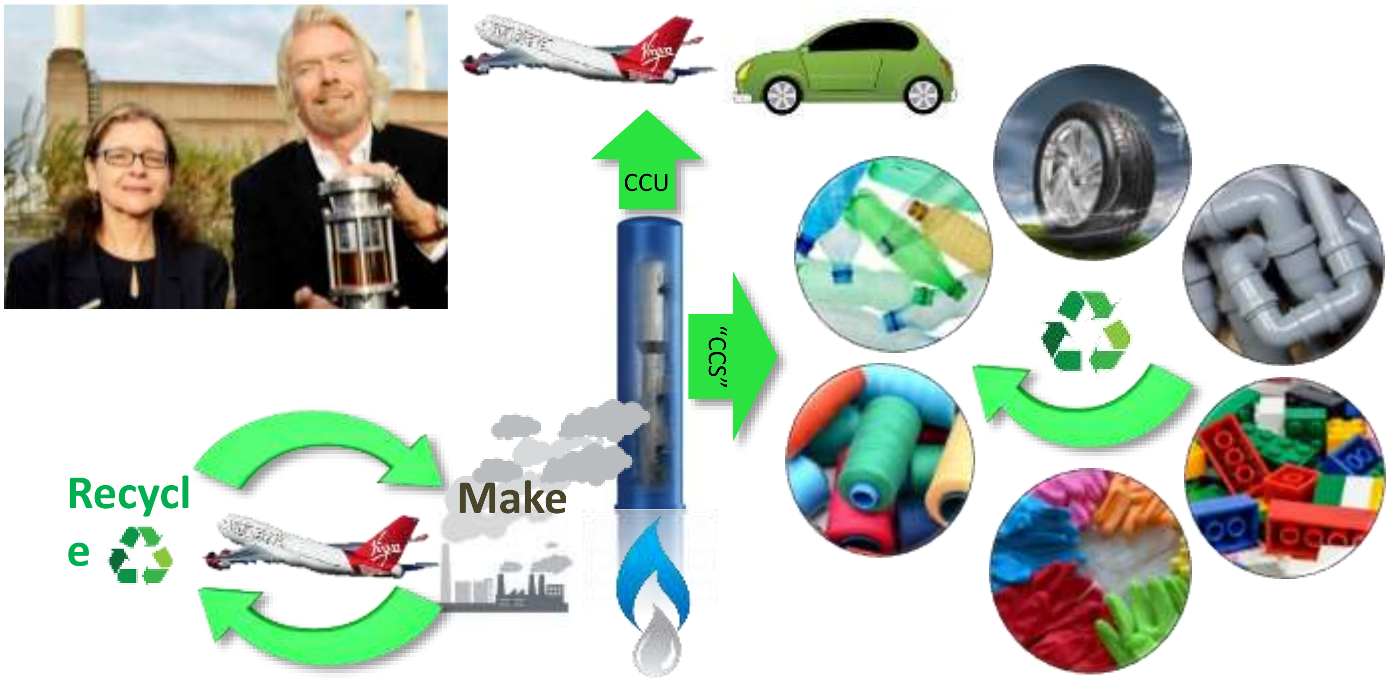
Provides energy security from sustainable, regional resources

Provides economic development that creates "green jobs"

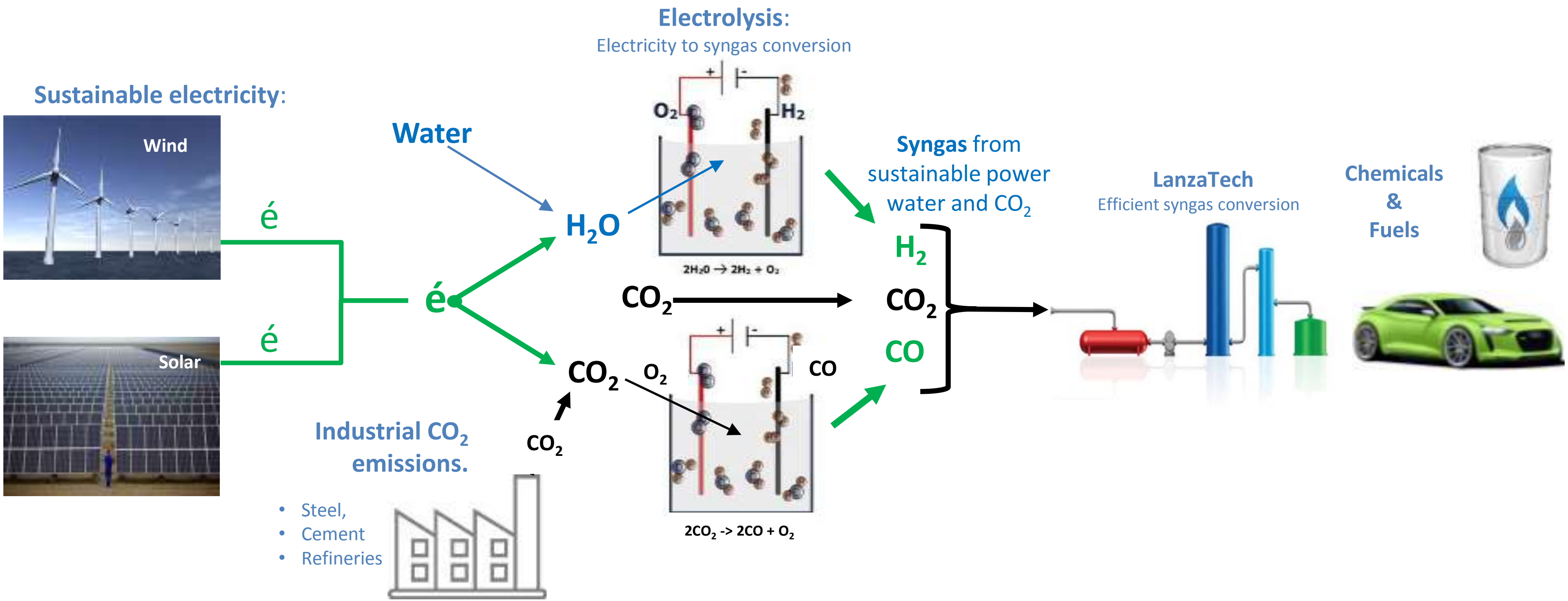
An inclusive approach furthers the purpose of The Energy Independence and Security Act (EISA)

✓ Energy ✓ Environmental ✓ Economic

Enabling the Circular Economy

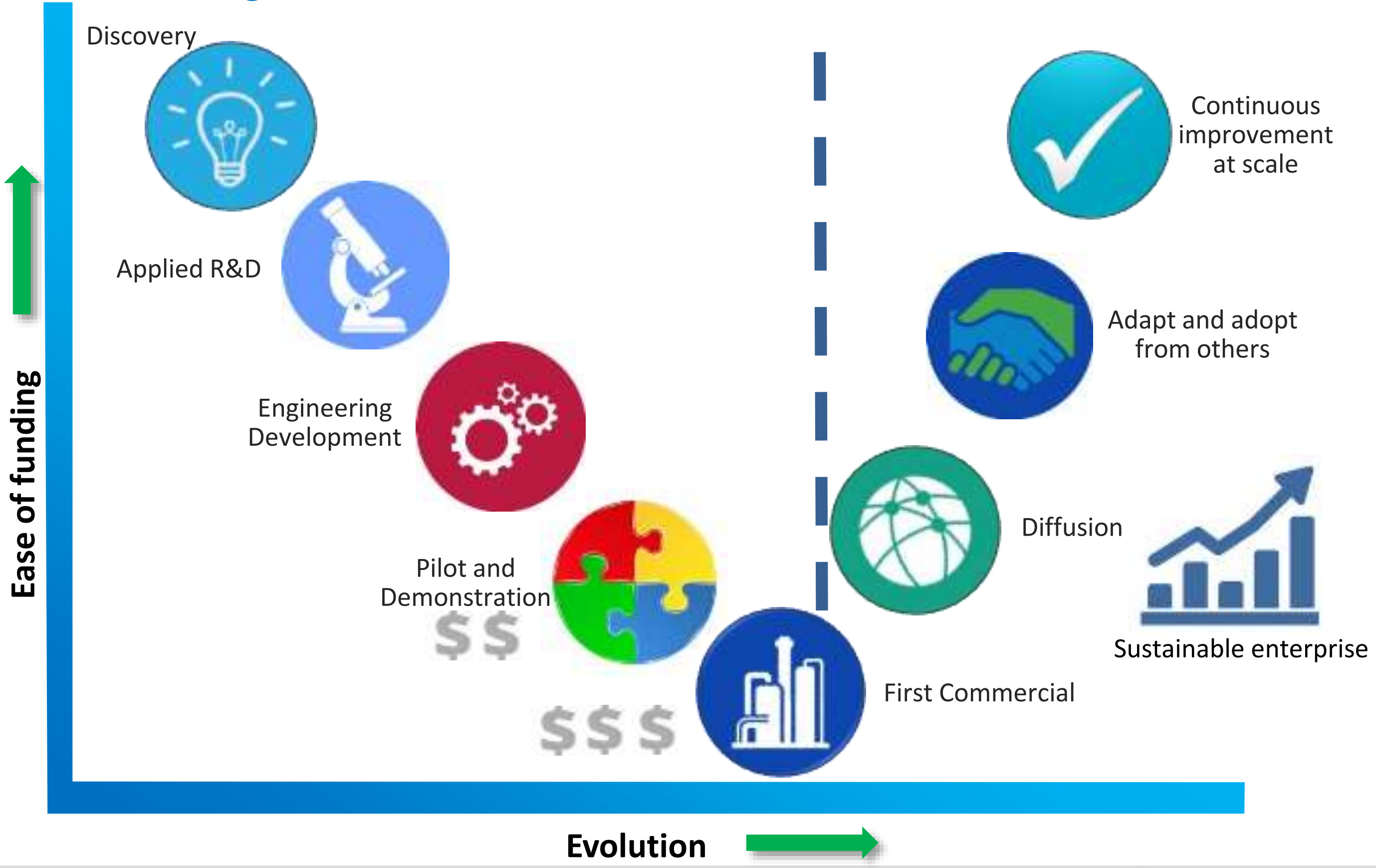


Fuel from CO_2: A path to carbon neutrality?



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



LanzaTech
capturing carbon. fueling growth.

Questions?


Harvest Oil From
Dinosaur Fossils
Clone Dinosaurs In
Laboratory
Kill and Bury
Dinosaurs