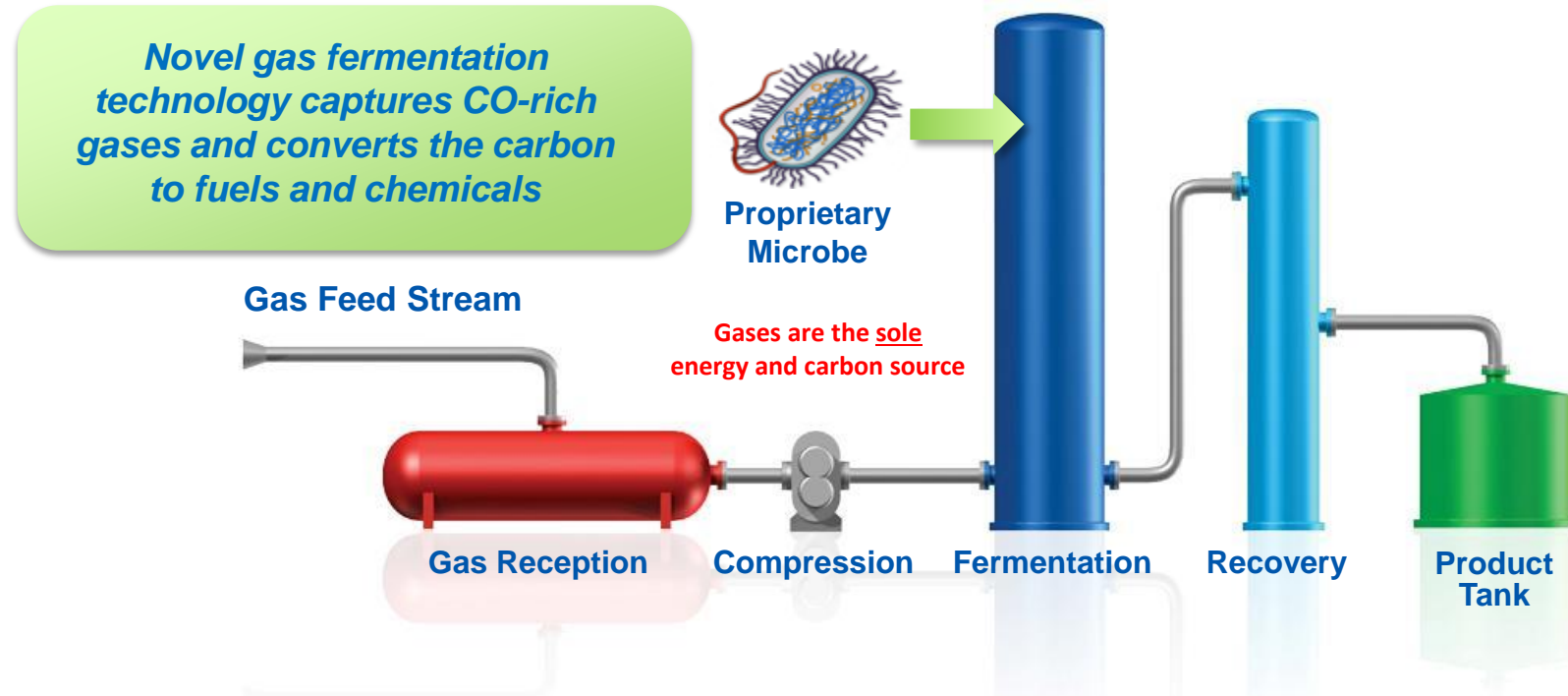




# The LanzaTech process for sustainable fuel and chemical production



- 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)

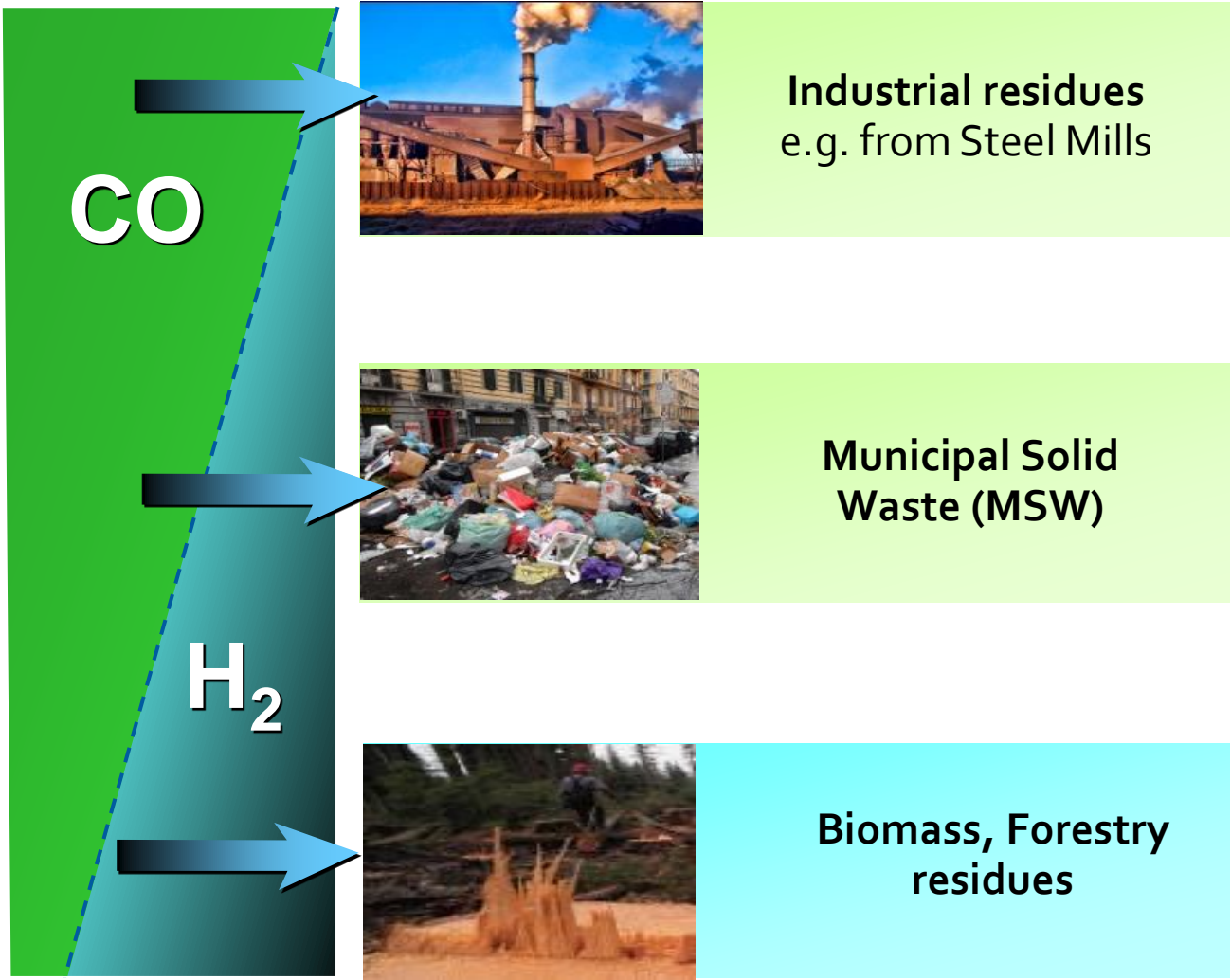


# Resources for biofuels “Done Right”

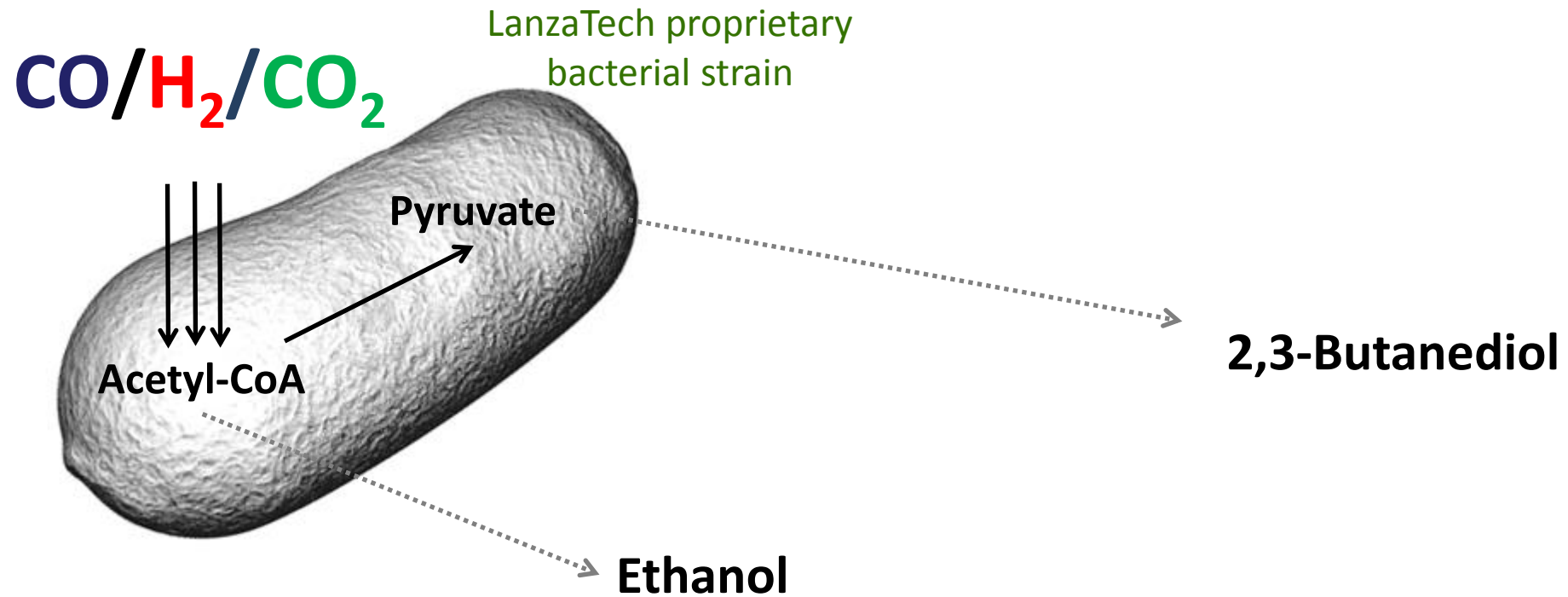
- *Available*
- *Abundant / high volume*
- *Point Sourced*
- *Low Value*



# Accessing diverse resources



# Fuel and Chemicals from gas



*The natural LanzaTech gas fermenting microbe can make **both** ethanol and 2,3-butanediol*

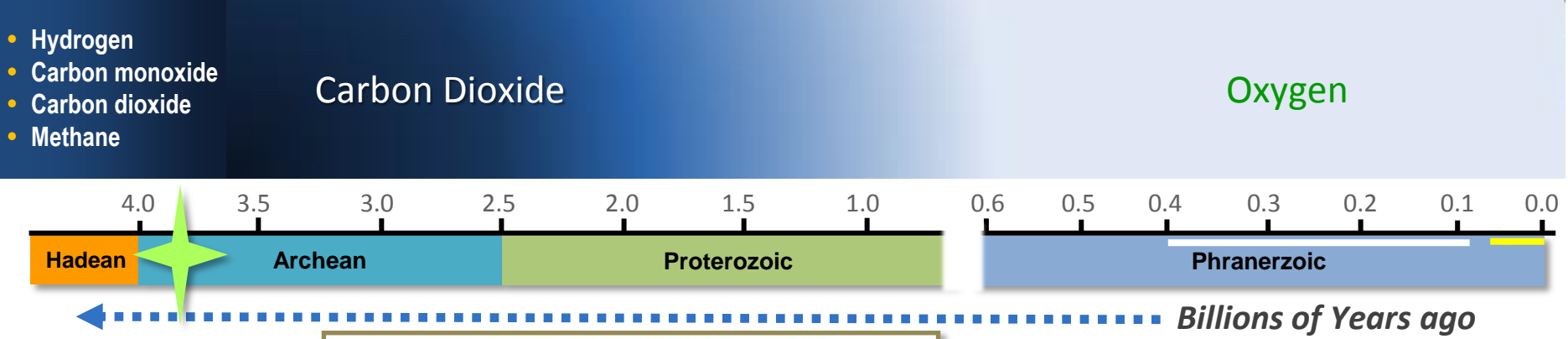


# Ancient biology for a modern need

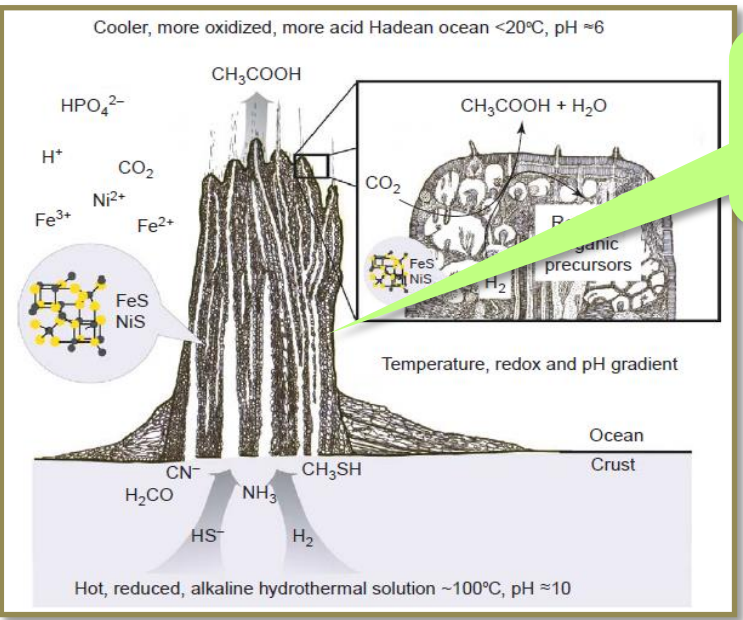
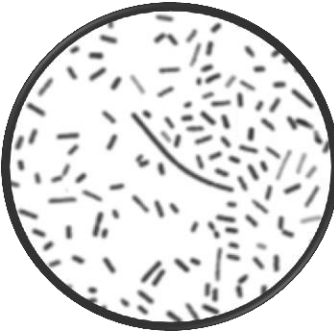
1. Reduced atmosphere

2. CO<sub>2</sub>-rich atmosphere

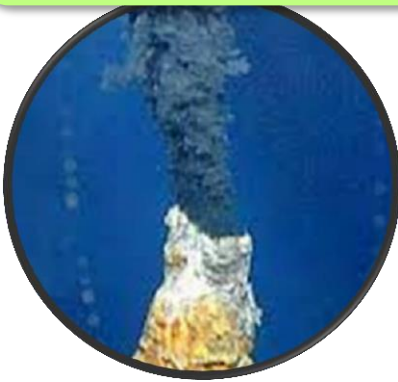
3. O<sub>2</sub>-rich atmosphere



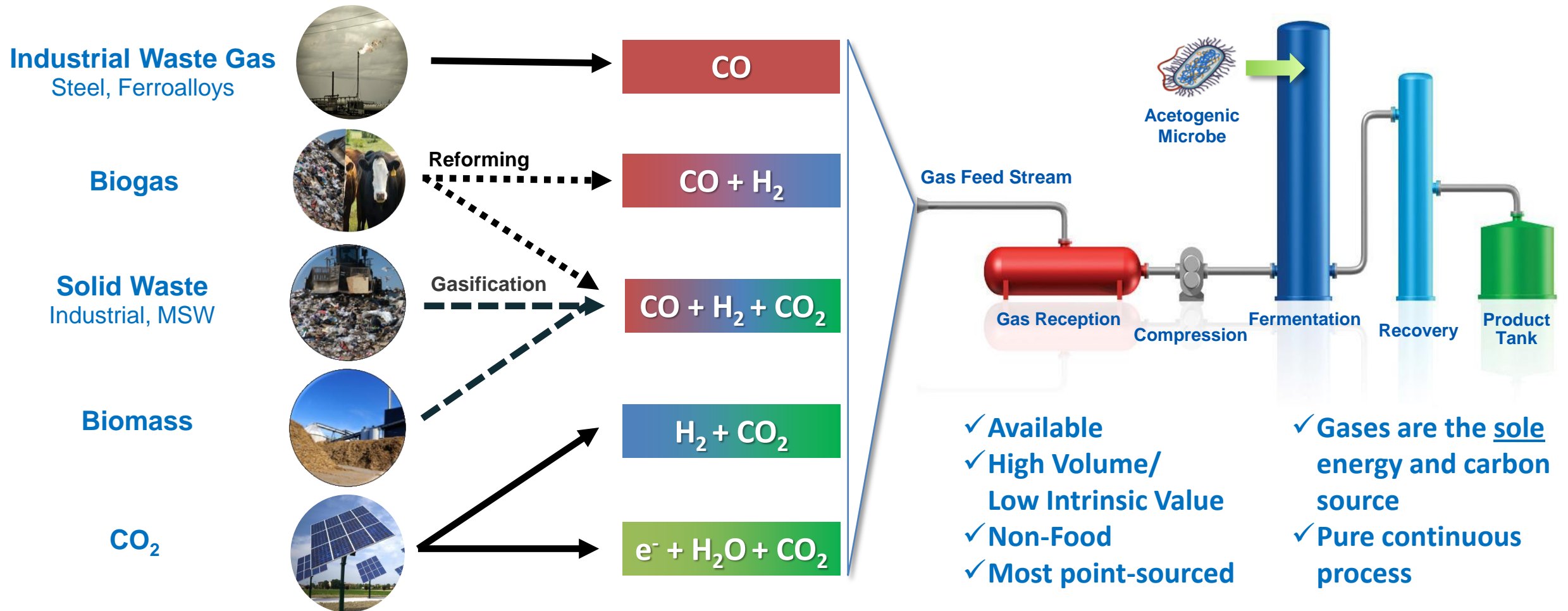
Life begins on earth!  
Gas fermentation



Gases were the only carbon and energy source used by the first life forms.



# Waste Carbon Streams as a Resource for Gas Fermentation



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.





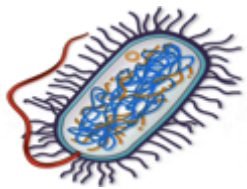
# Ready Now: Scale-up of the LanzaTech Technology

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



Strain Development



Lab

2005



Pilot

2008

50-100 kg/day



Demo

2012

~1500 kg/day



Commercial

2016

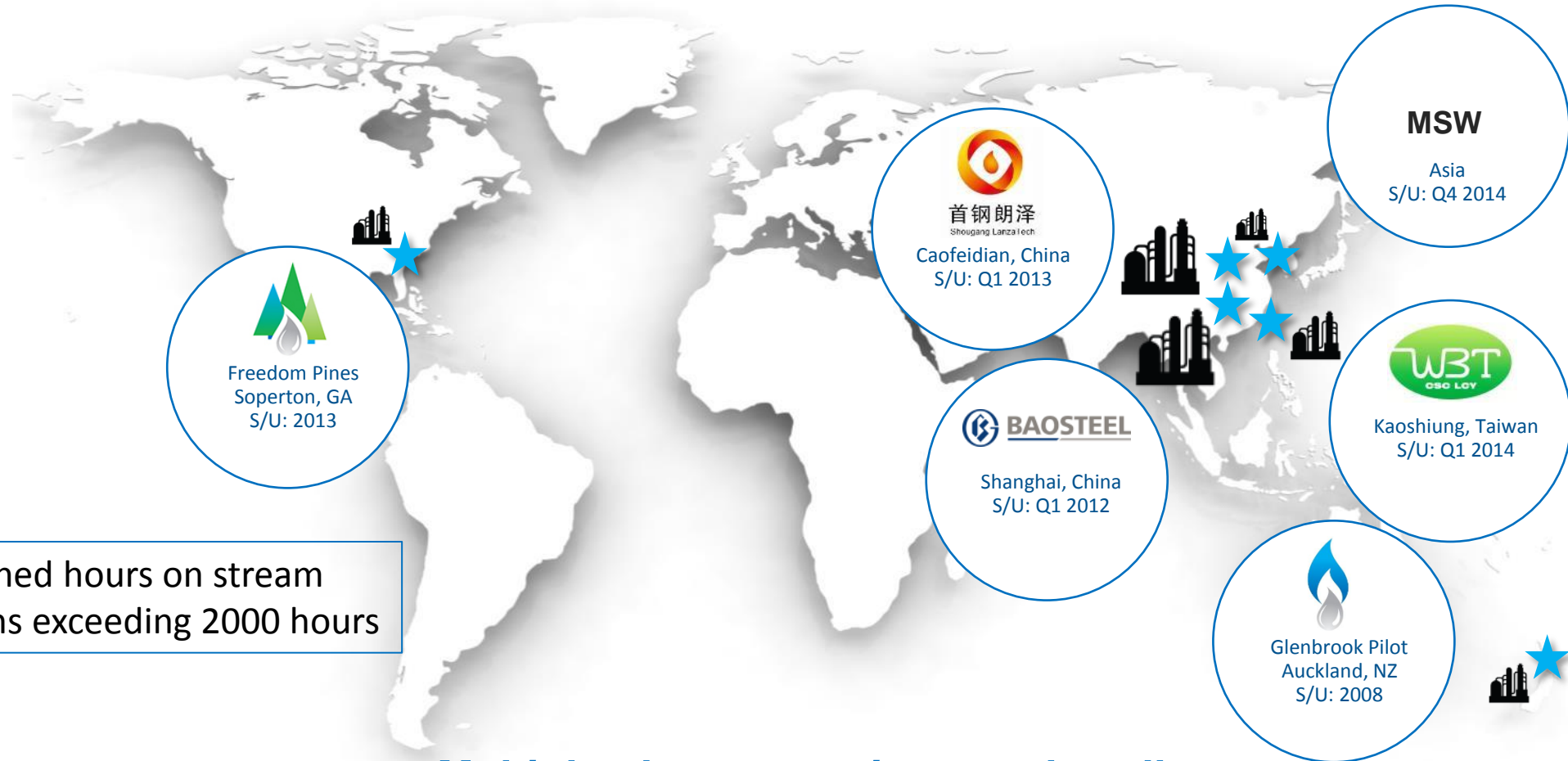
~300,000 kg/day





# Global Technology “Lab”

## Data, Data, Data

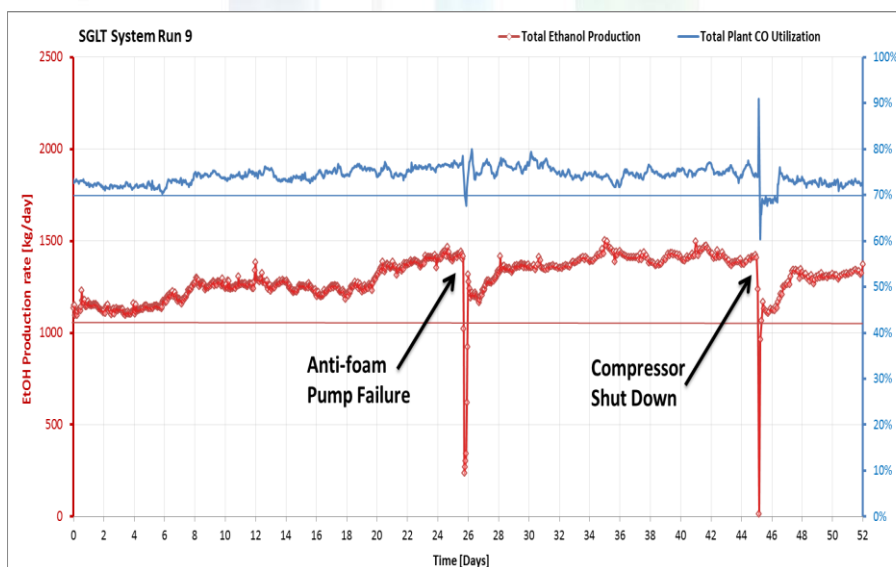
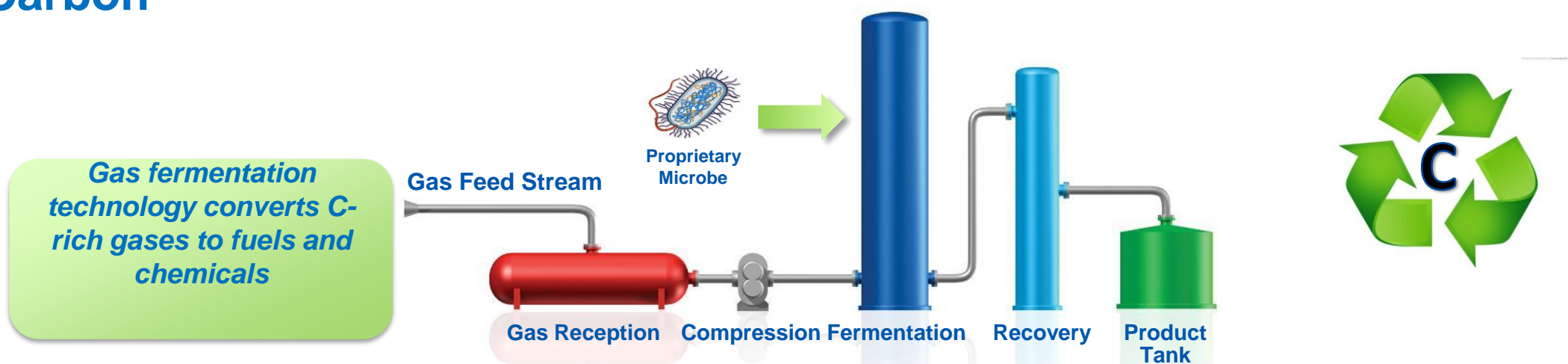


40,000 combined hours on stream  
Numerous runs exceeding 2000 hours

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



# Recycling Carbon

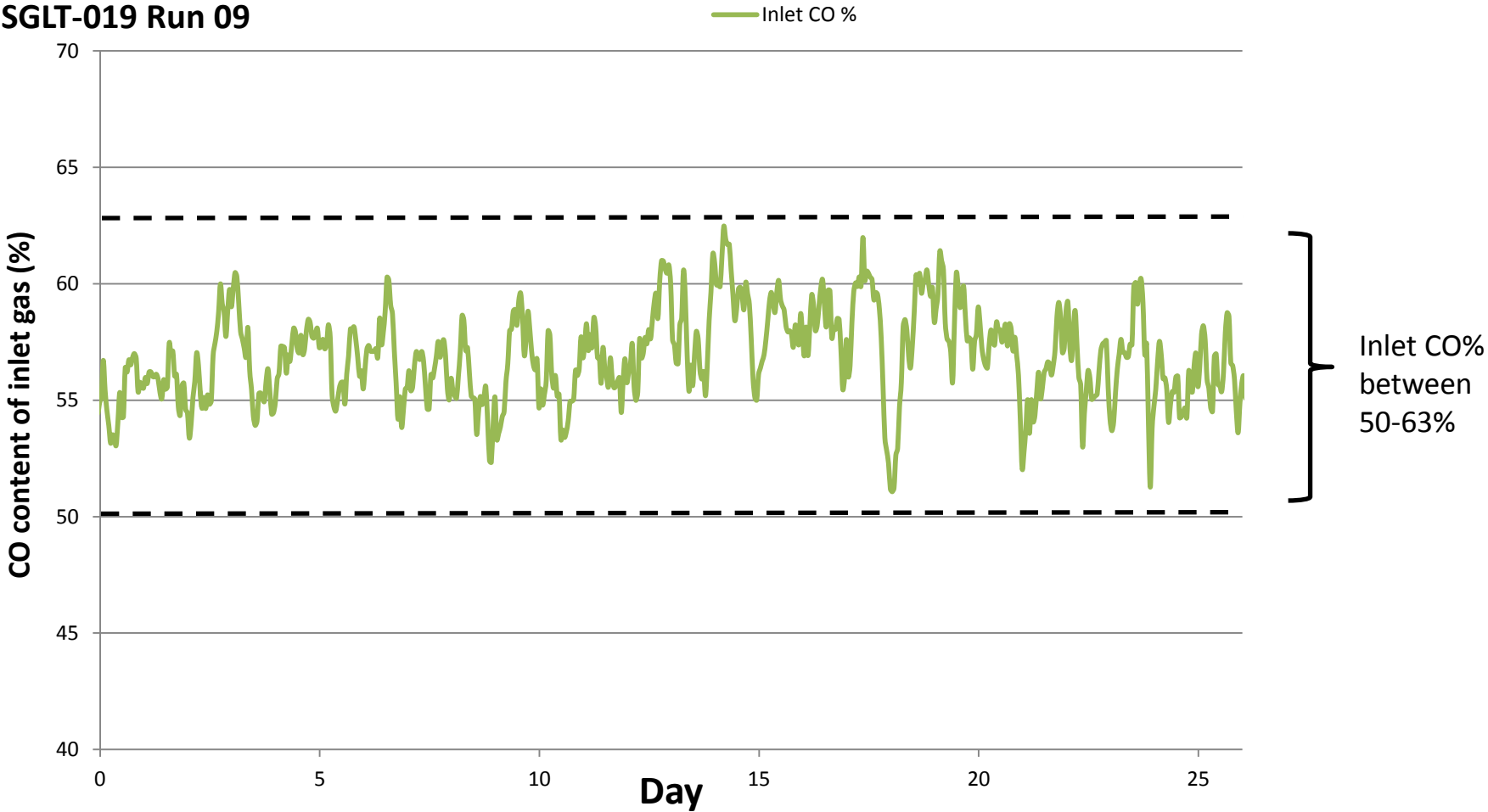


Performance milestones achieved and exceeded for >1000 hours  
100K GPY (~400 KL/yr)



# Dealing with change: Inlet CO% and Gas Flow Trends

SGLT-019 Run 09



- Inlet CO% +/-10% throughout run between 50-60% CO
- Inlet gas flow is adjusted to accommodate changes in inlet CO%





# MSW to fuel



Pilot plant at gasification site

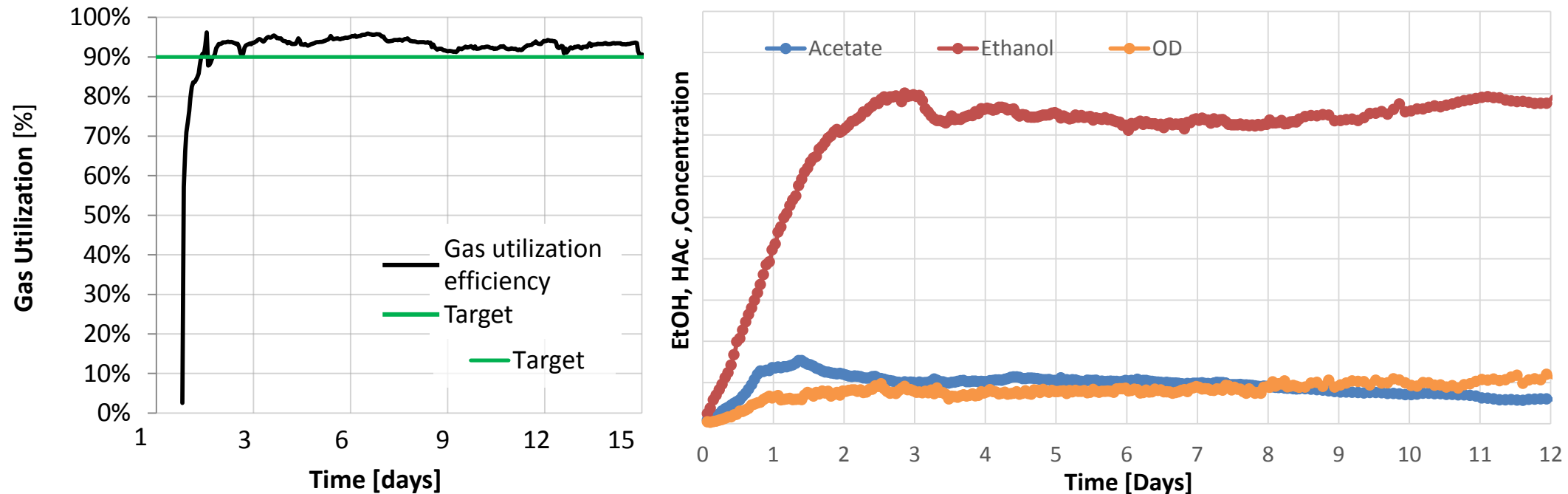
## Project overview

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.*



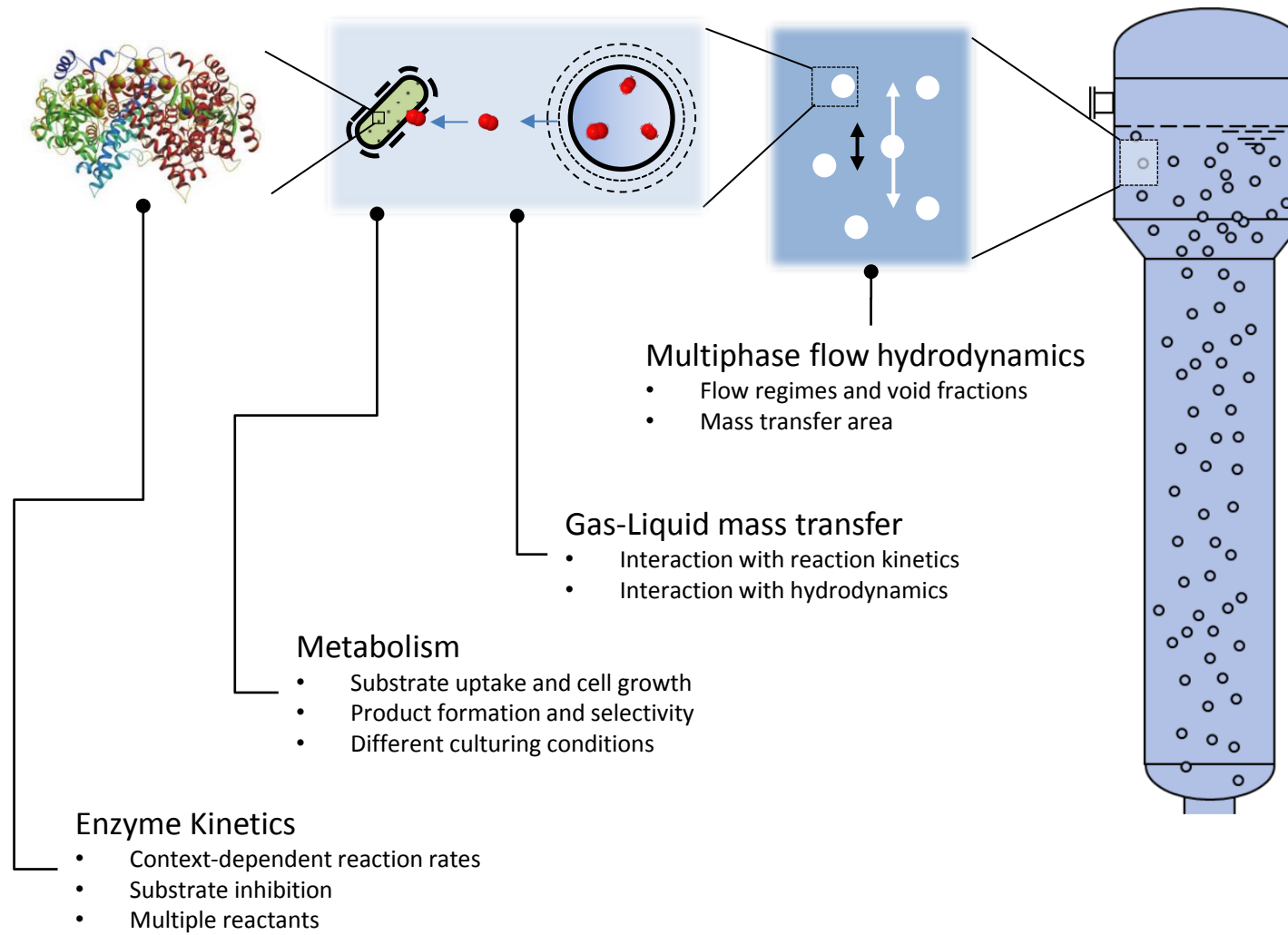
# Continuous stable ethanol production from MSW



- Continuous with live feeds of MSW Syngas proven
- Operation at commercial ethanol production rates and yields
- Gas utilization efficiency exceeds 90%
- All gas contaminant and variability issues understood and overcome.

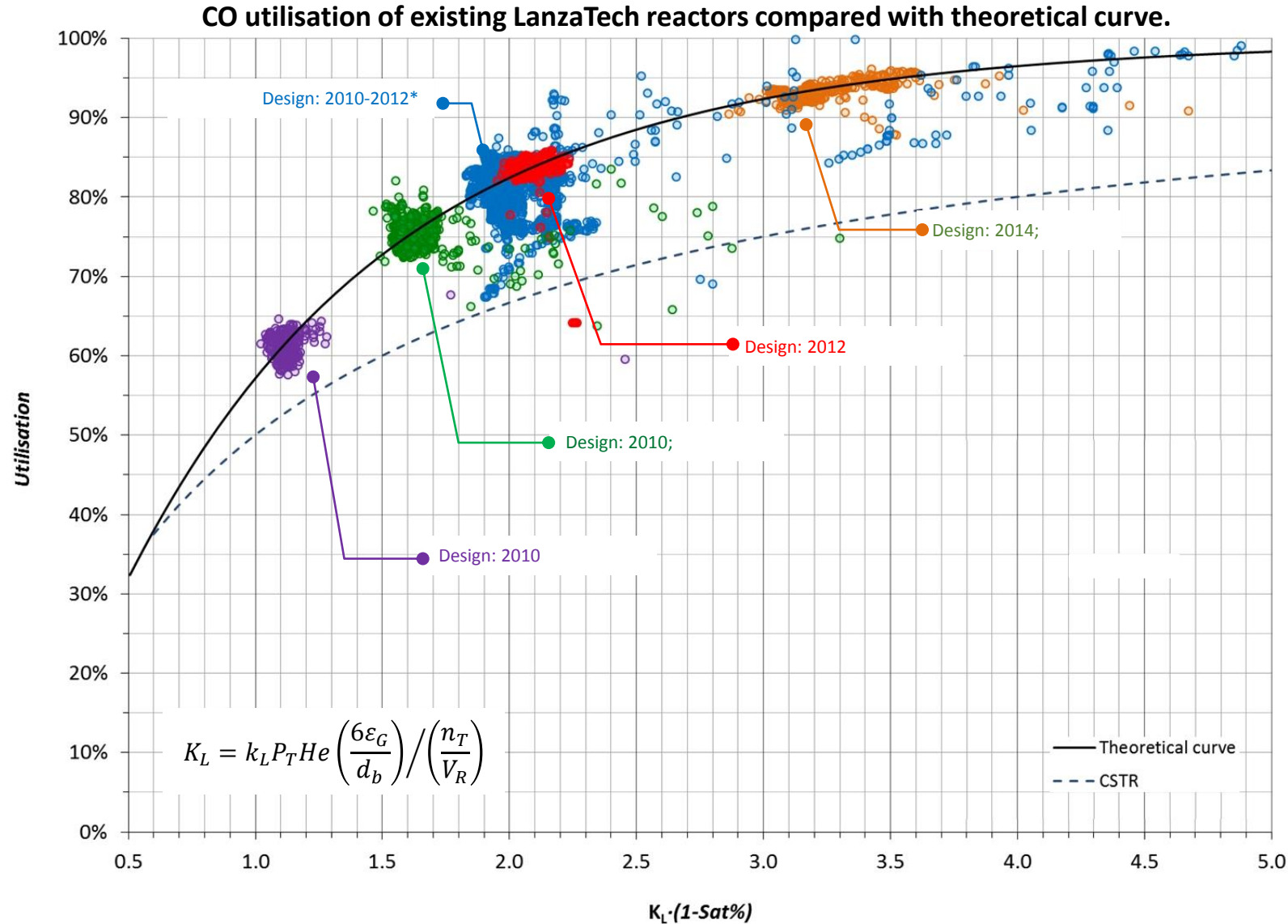


# LanzaTech's Modelling Capacity





# Validation of Reactor Technology



NOTE:  $k_L \cdot (1-Sat\%)$  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.



# From Demonstration to Commercial



40,000 combined hours on stream  
Multiple runs exceeding 2000 hours



Commercial Scale  
Q2 2018



Ton (gallons) per year



ArcelorMittal

64k (21M)



CHINA STEEL

20k (6.7M)



首钢集团  
SHOUANG GROUP

46k (15M)



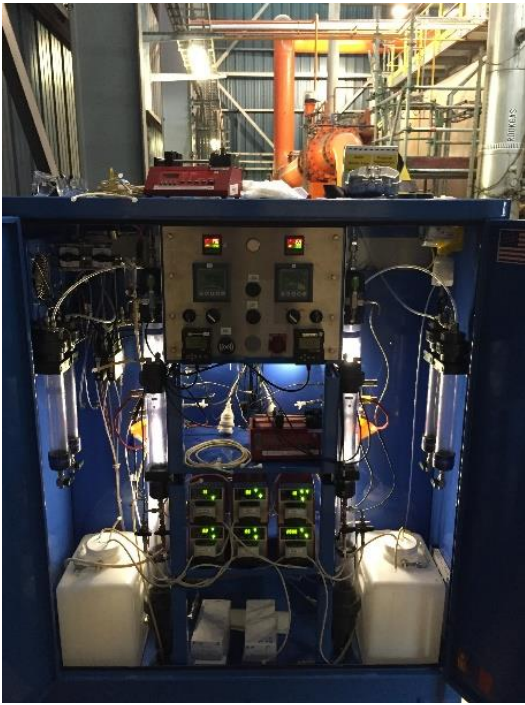


# ArcelorMittal, Gent

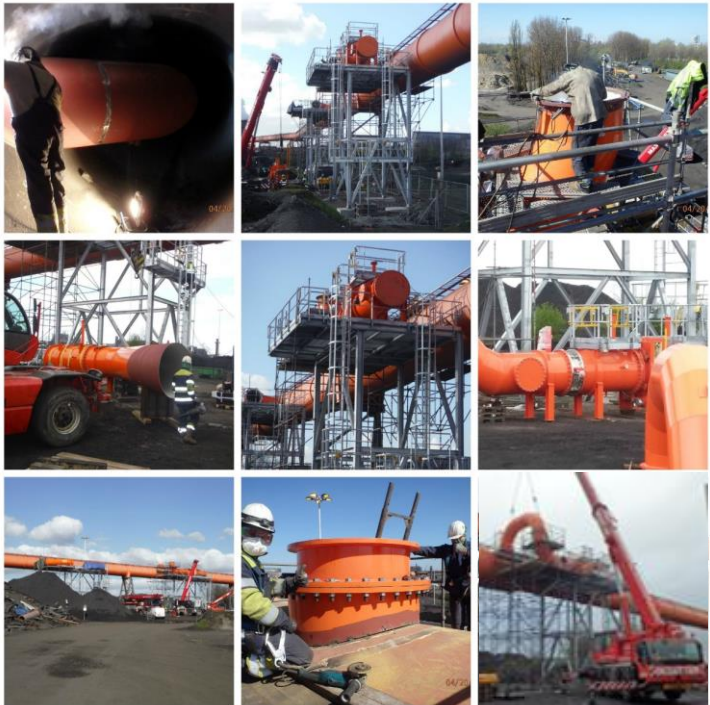
October 2015  
Ground Works Started



January 2016  
Gas Testing Station  
Produces Ethanol

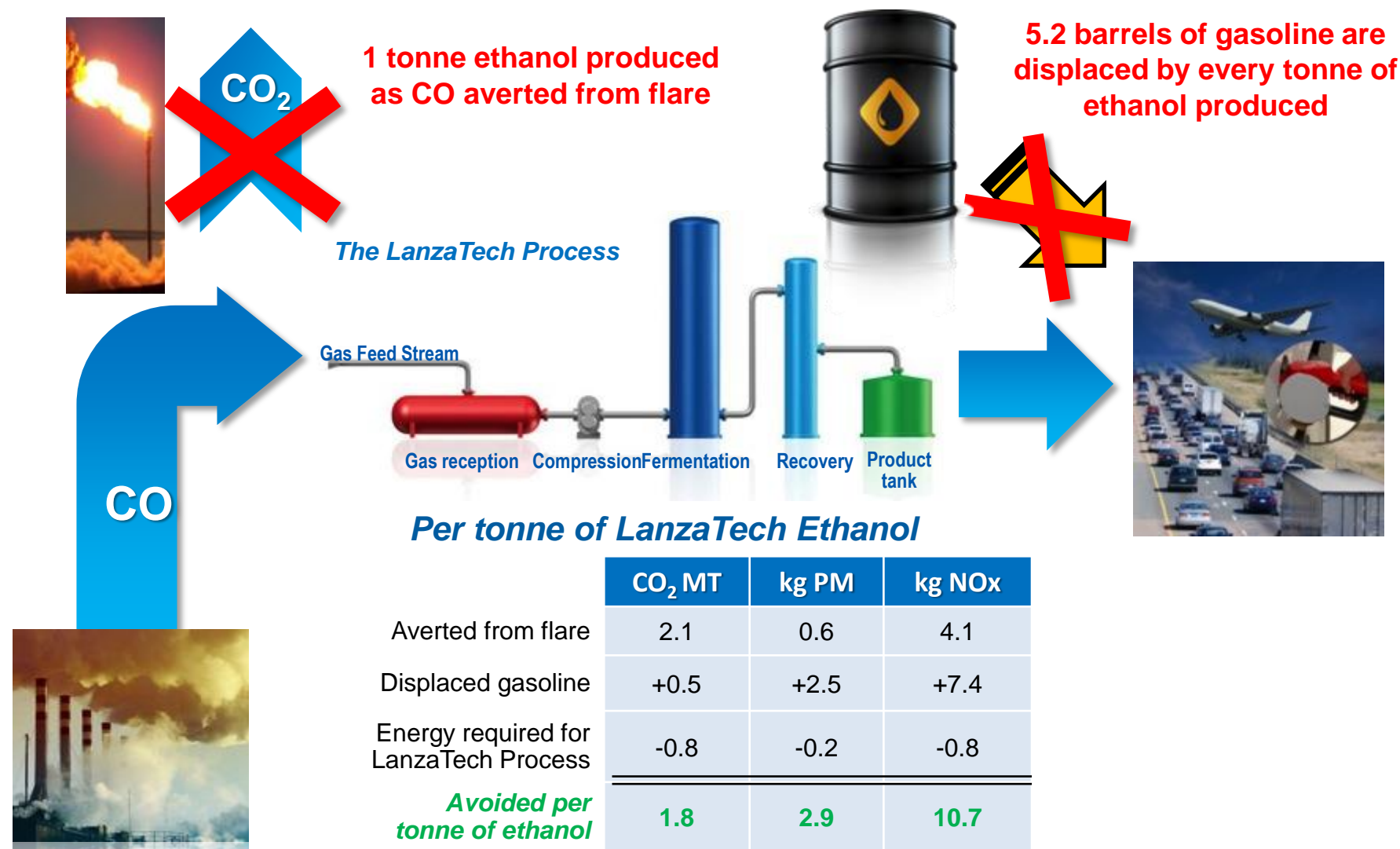


March 2016  
Connection to  
Steel Mill Gas Lines

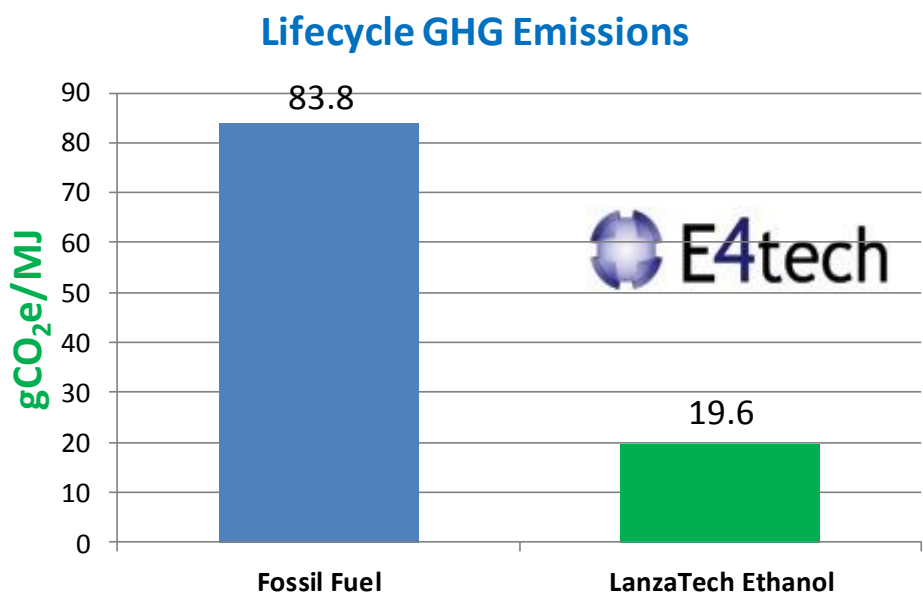




# Carbon Efficiency means Cleaner Air: Emissions Savings



# Recycling Gases: Environmental, Economic, Social Benefit



**Additional 3<sup>rd</sup> Party Life Cycle Analyses (LCA)**

- Michigan Tech University
- Roundtable on Sustainable Biomaterials (RSB)
- Ecofys
- Tsinghua University

*50-70% 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”**



# Industrial waste gases: Are there Enough to make an Impact?



**Steel:**  
**30B gallons/year**



**Refinery Waste Gas:**  
**5B gallons/year**

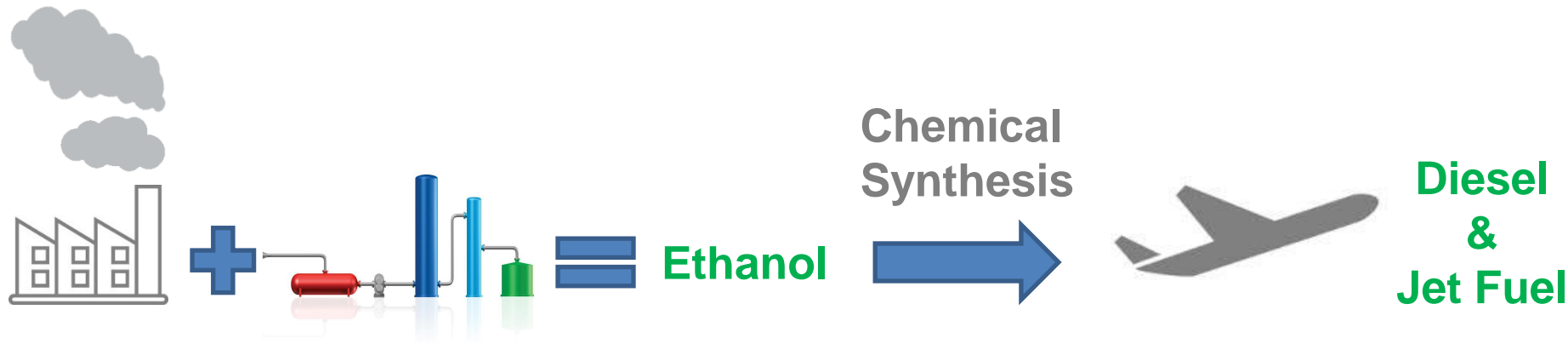


**Significant Value Enhancement**  
**Integrates into industrial infrastructure**

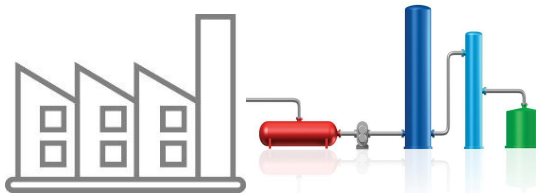




# From Mill to Wing



# Fixing Carbon into products. A Carbon Smart Future



|                         | Energy<br>(toe/t) | GHG<br>(kg CO <sub>2</sub> e/kg) |                         | Energy<br>(toe/t) | GHG<br>(kg CO <sub>2</sub> e/kg) |
|-------------------------|-------------------|----------------------------------|-------------------------|-------------------|----------------------------------|
| Fossil Gasoline         | 1.3               | 3.8                              | Fuel Ethanol            | 0.3               | 0.5                              |
| Plastic wrapping (LDPE) | 1.9               | 1.9                              | Plastic wrapping (LDPE) | 0.8               | -1.8                             |
| Plastic containers (PP) | 1.7               | 1.6                              | Plastic containers (PP) | 0.3               | -1.8                             |
| Plastic bottles (PET)   | 1.6               | 2.2                              | Plastic bottles (PET)   | 1.4               | 1.6                              |

**Carbon Recycling**  
**= less energy and less CO<sub>2</sub> than conventional pathways**



# LanzaTech's Integrated Gas Fermentation Platform

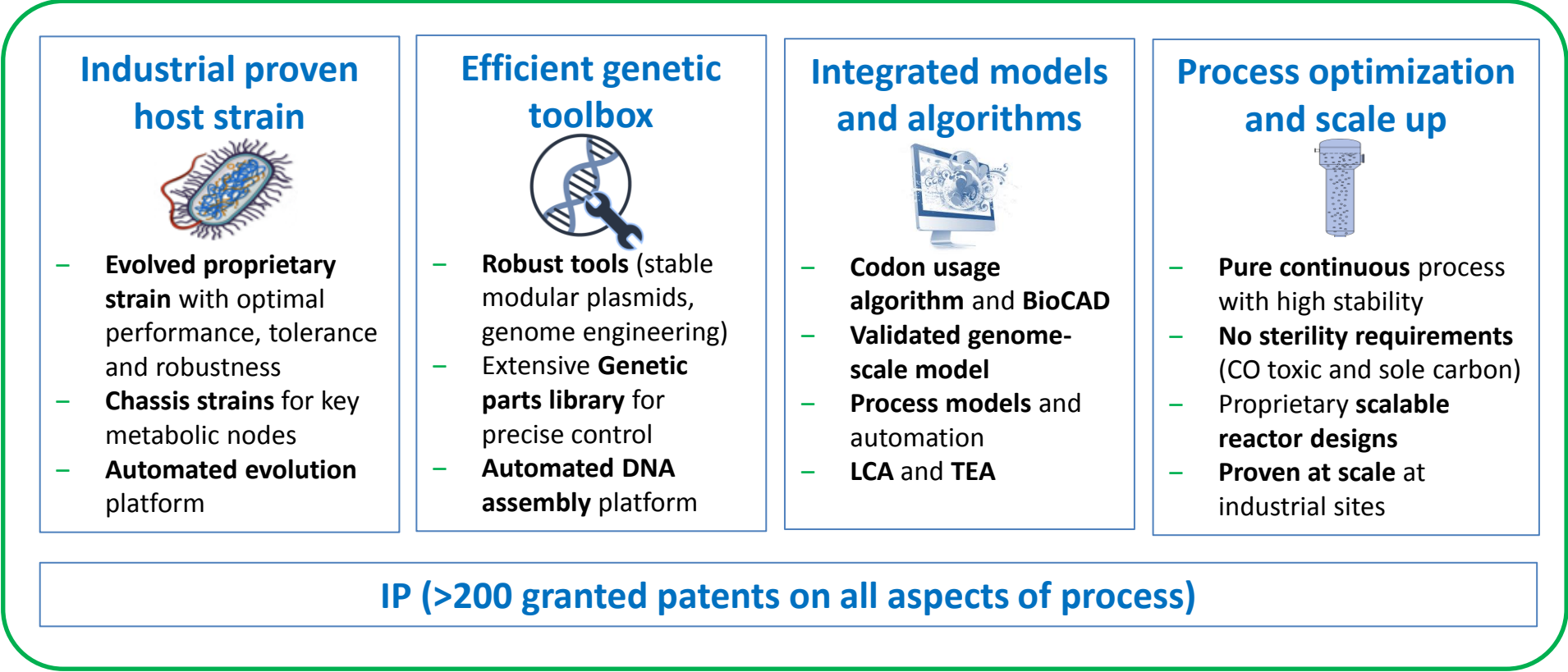
Plug-in of existing pathways (*in silico*, *in vitro*; *E. coli*/yeast, retrosynthesis)



Feedstock flexibility

Low Cost

Carbon Capture Utilization (CCU)



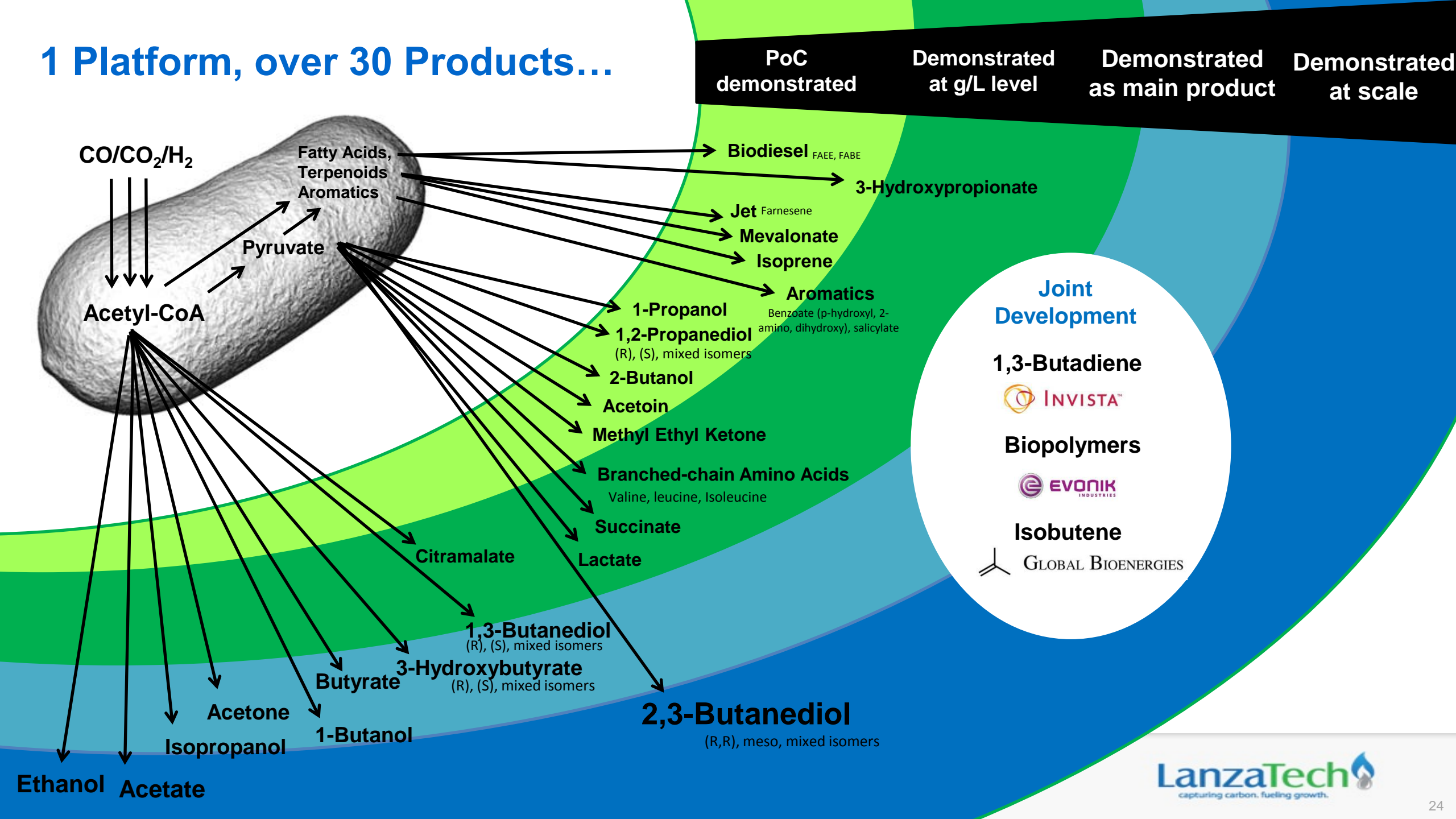
Products

Existing plants/  
partners





# 1 Platform, over 30 Products...

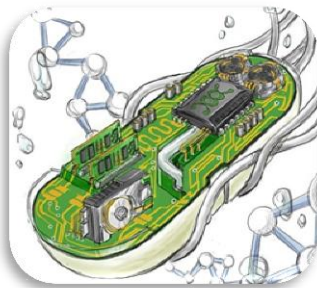


# Disrupting Market Cycles

- ✓ Same reactor
- ✓ Same operating conditions
- ✓ Same feedstock

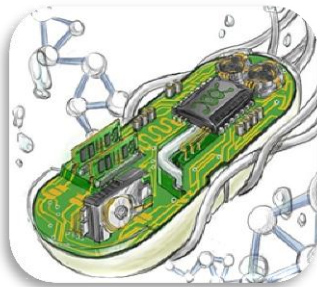


"software"



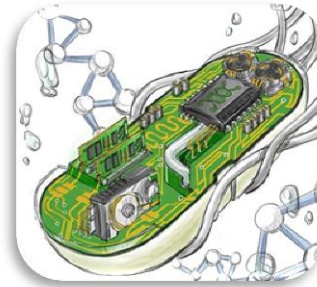
**Microbe 1.0**

- ✓ 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**



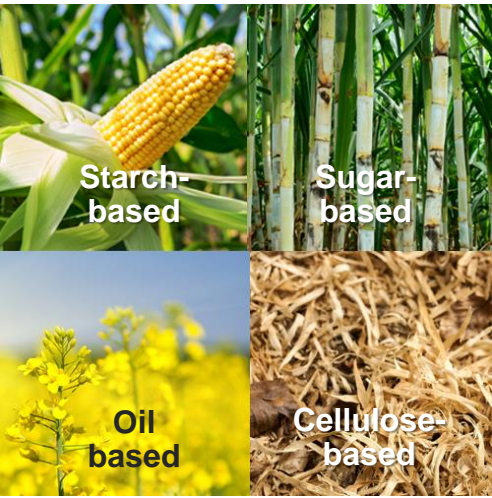
# A Carbon Smart World: Use All Strategies

*OR CARBON CAN  
BE RECYCLED*

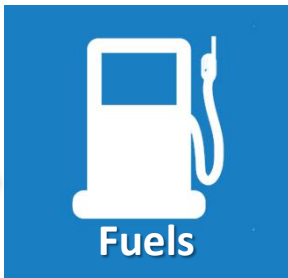


## Re-using

Atmospheric Carbon



(Today's approach)



**Reducing**  
Carbon footprint

## Recycling

Waste Carbon

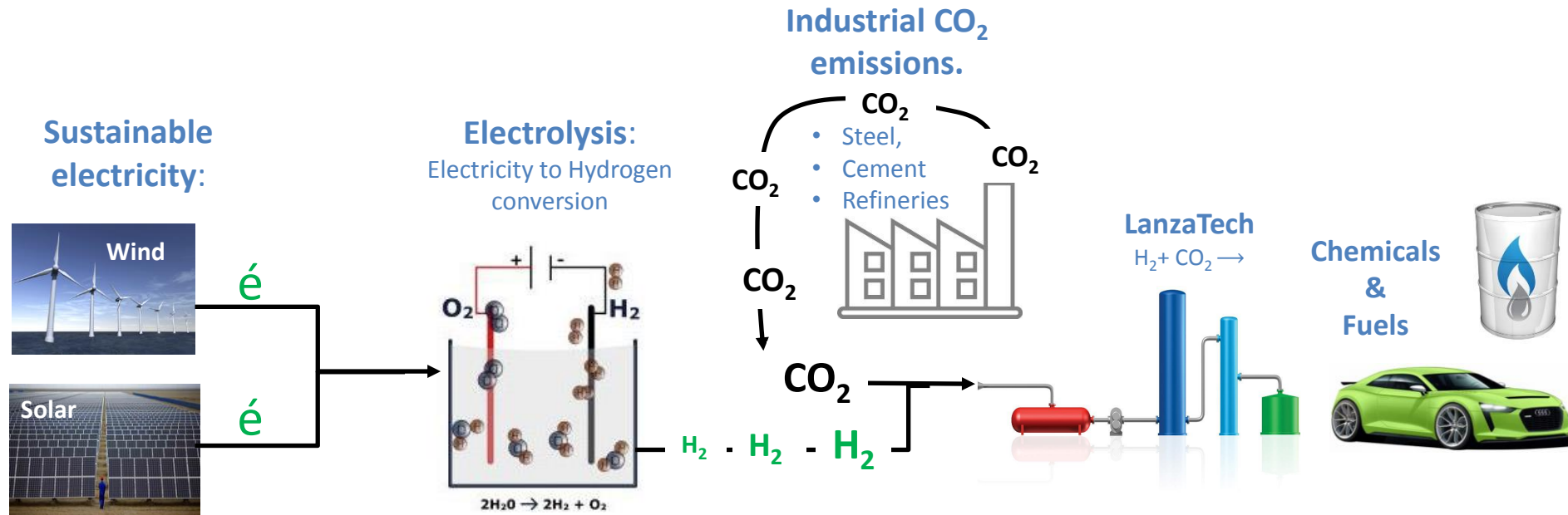


(Gas fermentation)





# Fuel from CO<sub>2</sub>



- Sustainable electrons and industrial CO<sub>2</sub> emissions
- Electrolysis (electricity to Hydrogen conversion) technology
- CO<sub>2</sub> and Hydrogen converted into Chemicals and Fuels technology.
- Incentivized market for low carbon Fuels

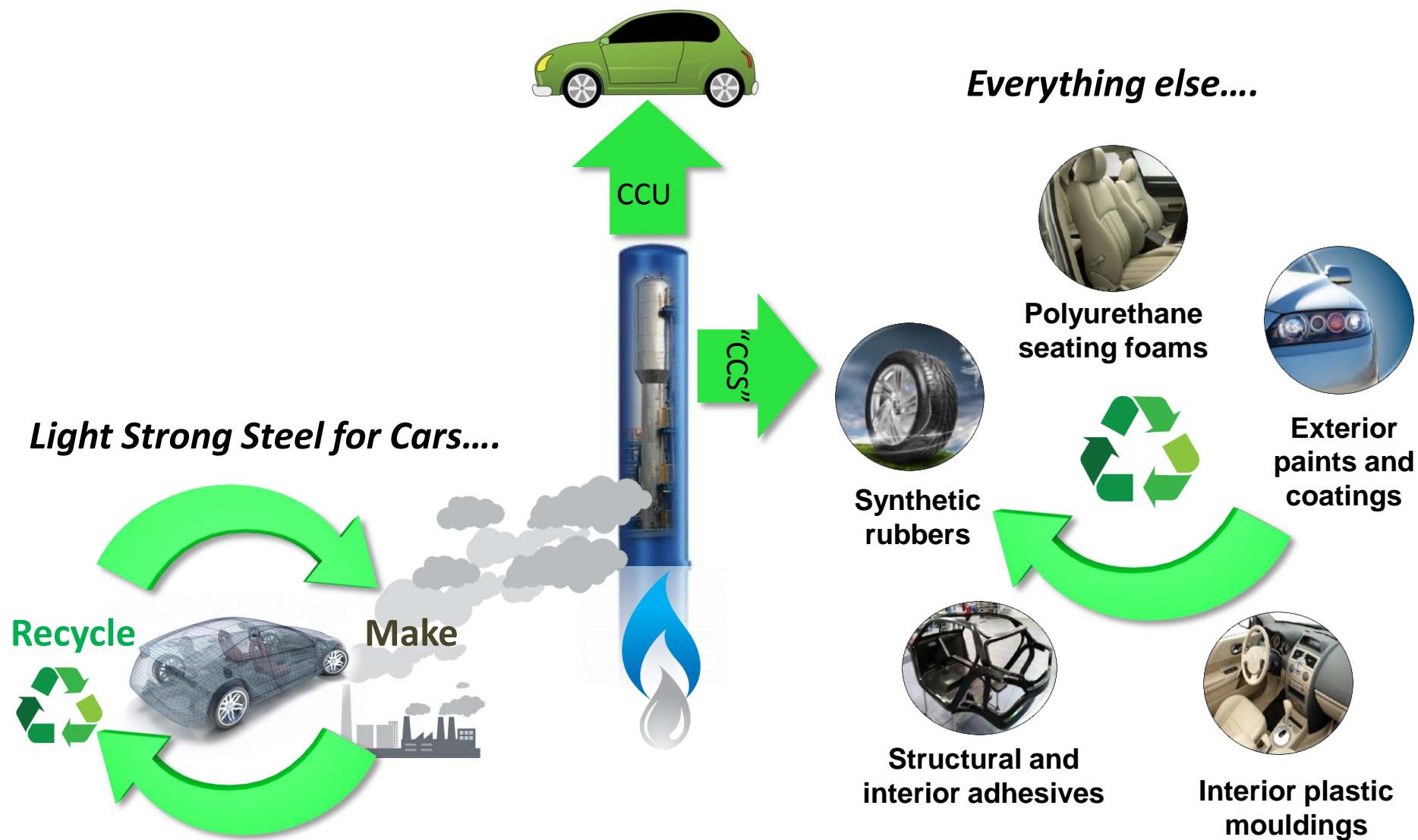
**Established policy incentivizes sustainable electricity production and low carbon fuel use**

*CO<sub>2</sub> is fixed into fuels and materials using “unlimited” sustainable electricity*

*No crops, no land, no oil*



# Embracing the Circular Economy: Change the Way you Think about Steel Mills...



## Climate change requires behavioral change:



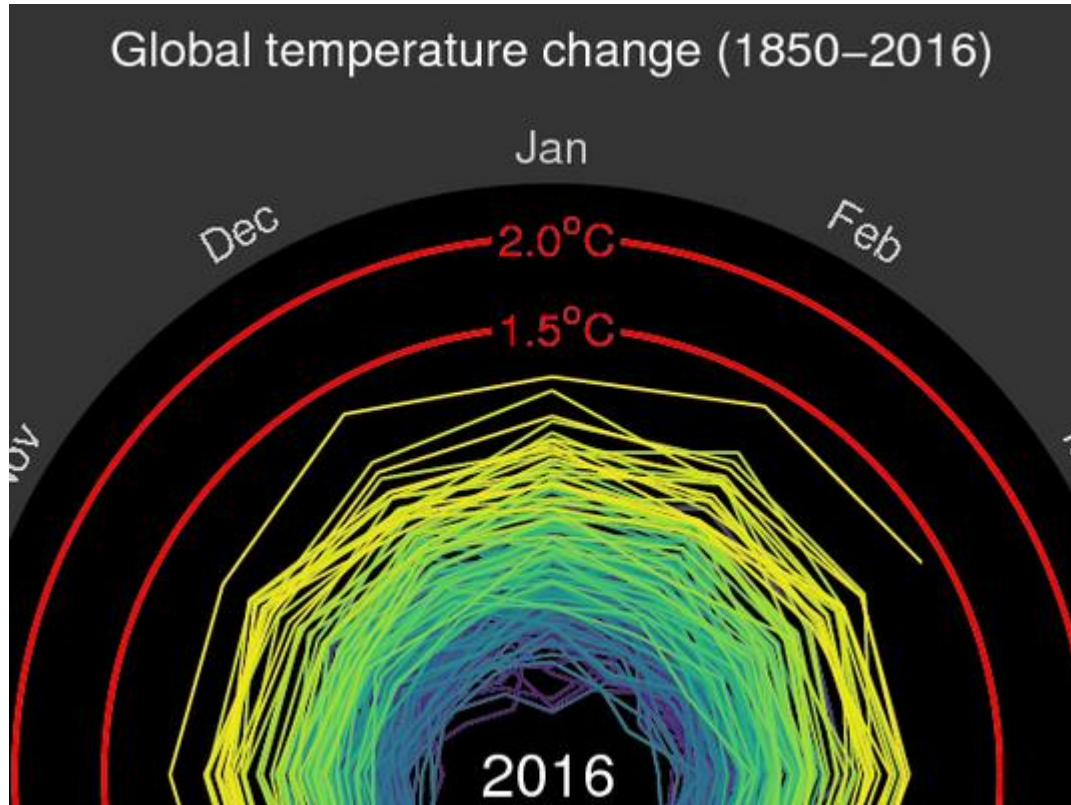
**“...you know that climate change is real when what ever year it is,...is the hottest year on record.”**

*Jimmy Kimmel 2016*

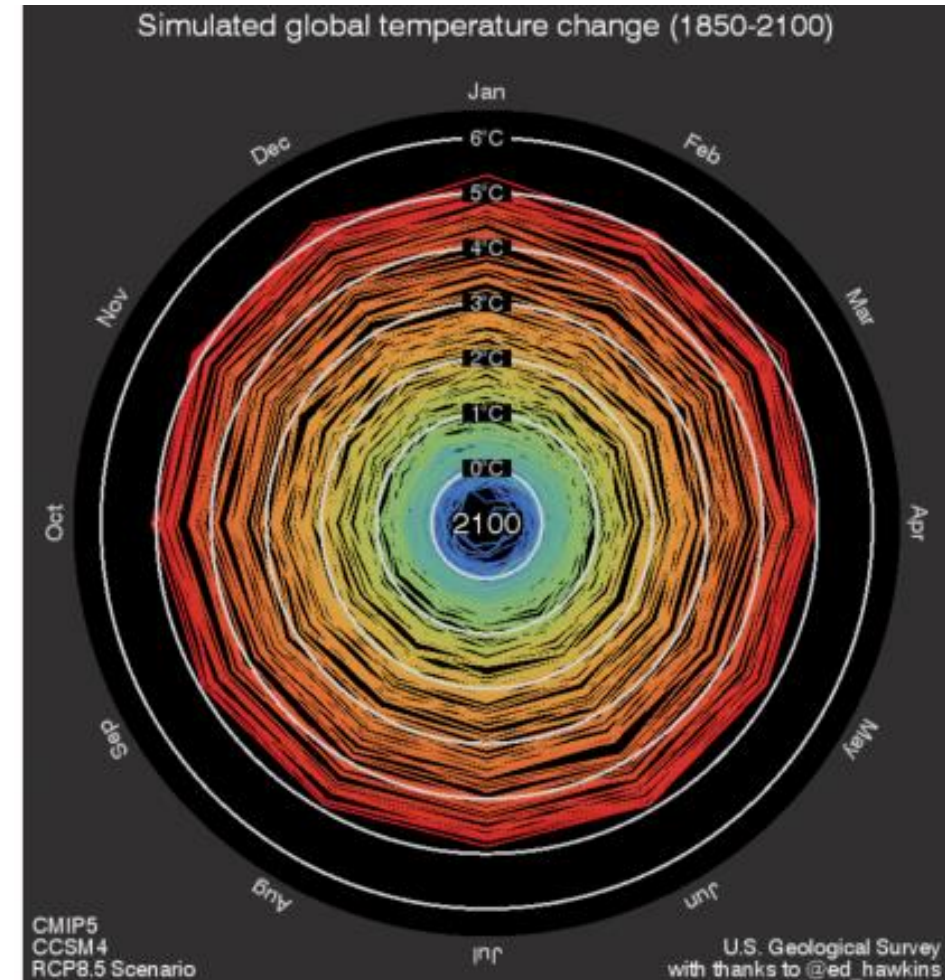




# Staying Within 2°C....???



**+1.5°C as early as 2017, average by 2024**



**+2.0°C By 2032, +4.0°C By 2080!**



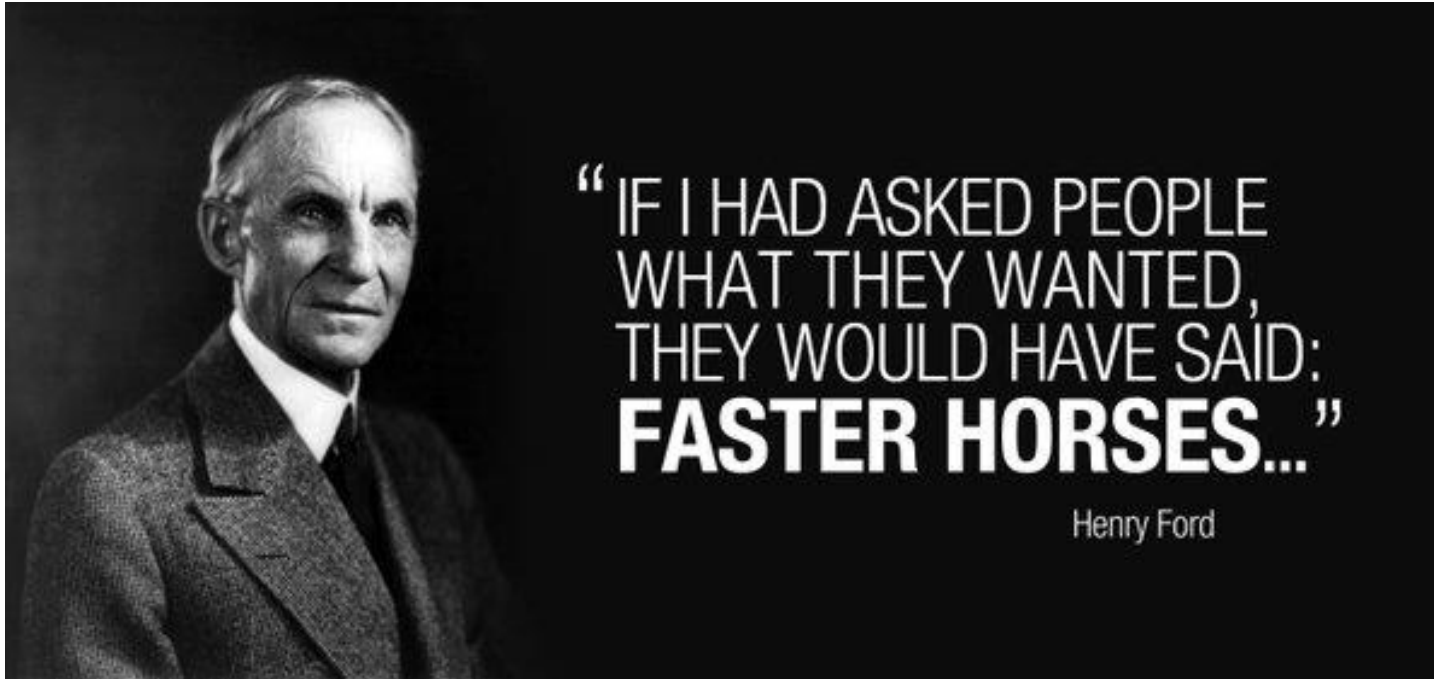
# Easter Parade New York City 1900





# Disruptive Innovation:

## *Solutions We Didn't Know We Needed*





# Easter Parade New York City 1913



Source: George Grantham Bain Collection.

**We *CAN* adopt the new FAST!**



# Questions?

