Population growth and climate change put pressure on land, food, water, and ecosystems...

Share of Global Energy Demand

IEA World Energy Outlook 2012
While Carbon Emissions Keep Rising

Containing CO$_2$ growth to safe atmospheric levels (below 450 ppm) requires that zero carbon fuels make up > 30% of the fuel pool. Current Rate: ~8 billion tonnes of CO$_2$ per year

Source: IEA World Energy Outlook 2011

Data from NOAA* taken at Mauna Loa, Hawaii for May 10, 2013 shows CO$_2$ levels have exceeded 400 ppm

* National Oceanic and Atmospheric Administration
Despite Large Energy Access Gap

1.3B people still lack access to basic energy
The LanzaTech Process

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

- Gases are sole source of carbon and energy
- Production of fuels and chemicals
- Potential to make material impact on the future energy pool (>100s of billions of gallons per year)
- Biofuel/chem, carbon capture and energy efficiency solution

No impact on water, food, land or biodiversity
Fast Path to Commercialization

- Two Demonstration facilities in China 100,000 gallon/year ethanol capacity
  - Exceeded all production and performance milestones
  - Commercial facility approved for construction 2014
- Demonstration facility in Taiwan 12,000 gallon/year ethanol capacity
- China commercial facility in design; financing completed

- MSW Mobile Lab in Japan demonstrated operation with a syngas stream
- MSW Demonstration facility in Japan 6,000 gallon/year ethanol capacity Q4 2014
- Integrated syngas to Butadiene Demonstration facility Q1 2015 in Korea
Scaling Up LanzaTech’s Technology

Commercial Scale-up Factor Less Than What Has Been Proven at Demo Scale
Waste Carbon as a Resource for Product Synthesis

- **Industrial Waste Gas**: Steel, PVC, Ferroalloys
- **Natural Gas, CH₄**: Associated Gas, Biogas
- **Solid Waste**: Industrial, MSW, DSW
- **Biomass**: Renewable H₂, Renewable Electricity
- **Inorganic CO₂**: Carbon as a Resource for Product Synthesis

**Gas Fermentation**

- CO
- CO + H₂
- CO + H₂ + CO₂
- CO₂ + H₂
- CO₂ + H₂O + e⁻

**Products**
- **Fuels**
- **Food**
- **Chemicals**
Butadiene: Key Chemical Intermediate

- Syngas
  - Industrial Waste
  - Biomass
  - NG
  - Coal
  - MSW/DSW
- 2,3-BDO
- Ethanol
- Advanced Biofuel
- Butadiene
  - Styrene Butadiene Rubber (SBR)
    - Global Market Size: ~4.9 million tons, ~$13 billion
  - Polybutadiene Rubber (BR)
    - Global Market Size: ~3 million tons, ~$8 billion
  - Acrylonitrile Butadiene Styrene (ABS) Resins
    - Global Market Size: ~8 million tons, ~$16 billion
  - Nylon 6,6 (from Adiponitrile/HDMA)
    - Global Market Size: ~1.8 million tons, ~$6.9 billion

Global Market Size:
- Polybutadiene Rubber (BR): ~3 million tons, ~$8 billion
- Acrylonitrile Butadiene Styrene (ABS) Resins: ~8 million tons, ~$16 billion
- 2,3-BDO: ~11 million tons, ~$22 billion
- Ethanol: ~1.8 million tons, ~$6.9 billion
- Syngas: Global Market Size: ~8 million tons, ~$16 billion
1 organism, 20 products...so far!

- CO/H₂
- Pyruvate
- Acetyl-CoA
- Fatty Acids, Terpenoids
- 3-HB
- 1,3-BDO
- Butyrate
- n-Butanol
- Acetone
- i-Propanol
- n-Propanol
- Propanal
- Acetoin
- 1,2-PDO
- sec-Butanol
- MEK
- Succinate
- Lactate
- D-(−)-2,3-Butanediol
- meso-2,3-Butanediol
- Farnesene
- Isoprene
- 3-HP
- FAEE/FABE

All targets Exemplified
Output: Diverse Products in Large Markets

- Ethanol
  - Hydrocarbon Fuels
    - ~1.7M bpd
    - ~5.5M bpd
    - ~51M bpd
  - Butanol, Butanediol, Propanol
    - ~4 M MTA
    - ~50 M MTA
- Other Products
  - Acetic Acid
  - Succinic Acid
  - Isoprene
  - ...

*2010 global consumption data - Harts, IEA
Hybrid Route to Aviation Fuel

BETO is supporting LanzaTech and PNNL on a new route to jet fuel from biomass and other CO point sources.

System Integration, Optimization and Analysis

Integration

Gasification & Syngas Conditioning
Gas Fermentation & Alcohol Recovery
Catalysis
Catalysis

Integration

Wood
Stover
Switchgrass

EtOH
2,3BD

Jet Fuel
Diesel / gasoline
Butadiene

Alcohol to Jet (ATJ) is in process of ASTM Certification
Commercialization of Aviation Fuel

- Production of jet fuel from LanzaTech ethanol demonstrated in 2012
- Off-take agreement executed with Virgin Atlantic
- ASTM certification: Approval targeted for 2014

Team Work is Key to Success
Waste Carbon as a Resource for Product Synthesis

Industrial Waste Gas
Steel, PVC, Ferroalloys

Natural Gas, CH₄
Associated Gas, Biogas

Solid Waste
Industrial, MSW, DSW

Biomass

Inorganic CO₂

CO

CO + H₂

CO + H₂ + CO₂

CO₂ + H₂

CO₂ + H₂O + e⁻

Fuels

Chemicals

Gas Fermentation

Renewable H₂

Renewable Electricity

Reforming

Gasification

Food
Conversion of Acetate to Lipids

CO₂ Carbon Source

H₂ Energy Source

Acetate

2nd fermentation

Yeast

• Yeast accumulate lipids to >70% of their cell mass

Algae

• Algae accumulate lipids to >50% of their cell mass
• 40% of algal lipids content are Omega-3 fatty acids (Specifically DHA)

Lipids Product Markets

Hydrocarbon Transport Fuels
>US $ 3 trillion/year

Oleochemicals
US $15 billion/yr

Animal Feeds
US $370 billion/yr

Food, Nutritional Supplements
US $25 billion/yr
Defining Commercial

**It’s not just about size... the plant needs to make money**

- Is it enough money to satisfy all project investors?
- Is this a model that can be replicated?
- Will this activity guide a company toward financial sustainability?

**But first commercials are difficult, as the technology has never performed at this scale, economically**

- They take time
- They take money
- And more time, and more money
- Need supportive investors/partners and project stakeholders that will stick with you – willing to take a risk
Bridging the Valley of Death
Getting a New Process to Scale

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

Ease of funding vs. Evolution
So What’s Really Needed to be Commercial?

- Viable technology - mitigated risk through rigorous scale up
- Capital
- Market
- Regulatory environment
- Strong/invested partners
- Luck

Long, Difficult Path
Funding Options Enable Scale-up

**Seed Funding**
- Government (i.e., FAA, DARPA-E, Office of Science, NSF)
- Angel Investors

**Development/Deployment Capital**
- DOE, USDA (i.e. IBR’s, Loan Guarantee Programs)
- DPA
- Competitive grants

**VC’s (Venture Rounds)**
- Khosla Ventures
- MLSCF
- K1W1
- Qiming Ventures

**Strategies**
- Petronas
- Bao

**Liquidity Event**
- IPO
- Merger/Acquisition

10+ Years to Cash Flow Positive
### IT/Software

<table>
<thead>
<tr>
<th>Company</th>
<th>Development Years (prior to buyout)</th>
<th>Liquidity Event Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whatsapp: Bought by Facebook 2014</td>
<td>5</td>
<td>$19B</td>
</tr>
<tr>
<td>NEST Labs: Bought by Google 2014</td>
<td>~4</td>
<td>$3.2B</td>
</tr>
<tr>
<td>Instagram: Bought by Facebook 2012</td>
<td>2</td>
<td>$1B</td>
</tr>
<tr>
<td>LinkedIn: IPO 2011</td>
<td>8</td>
<td>$4.5B</td>
</tr>
</tbody>
</table>

### Biofuels/Bioproducts

<table>
<thead>
<tr>
<th>Company</th>
<th>Development Years (Lab to Commercial)</th>
<th>Liquidity Event Value</th>
<th>Current Market Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gevo: IPO 2011</td>
<td>~7: Commercial production initiated at Luverne facility in 2012 but faced delays/shutdowns. Planned butanol ramp up in future.</td>
<td>$373M</td>
<td>$66.1M</td>
</tr>
<tr>
<td>Kior: IPO 2011</td>
<td>~7: Columbus, MS facility started limited commercial production Nov 2012 and early shipments began in 2013. Currently facing production problems. Developing plans for flagship commercial facility in Natchez, MS.</td>
<td>$1.5B</td>
<td>$153.8M</td>
</tr>
<tr>
<td>Amyris: IPO 2010</td>
<td>~8 : Past contract manufacturing. Ramp up commercial facility in São Paulo, Brazil this year.</td>
<td>$688</td>
<td>$336.2M</td>
</tr>
<tr>
<td>Solazyme: IPO 2011</td>
<td>~8: Commercial production online in February 2014 at Clinton, IA facility.</td>
<td>$853M</td>
<td>$918.2M</td>
</tr>
<tr>
<td>LS9: Bought by REG 2013</td>
<td>~9 (no commercial production)</td>
<td>$61.5M</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Significantly More Time and Development Funds Needed to Commercialize Industrial Biotech**
With The Help of Our Friends
Jump to the Next Curve
Creating a Low Carbon Future

**Built for small scale**
- Extremely high selectivity
- Direct, one-step conversion
- Single set of process conditions

**Adapted for changing environments**
- Feedstock flexible for same product
- Tolerant of contaminants
- Evolved for high efficiency

**Complexity is free**
- Regenerative catalysts
- Process upgrades with no down time
- Tailor products for each application
Woman on Catwalk in a Fashion Show, Shanghai
As Shown in Taiwan Paper 12/7/13

View out of Sheraton Pudong 12/8/13 and 1/14/14
### A Few Predictions

<table>
<thead>
<tr>
<th>Year</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>1876</td>
<td>“This ‘telephone’ has too many shortcomings to be seriously considered as a means of communication” <em>Western Union Memo</em></td>
</tr>
<tr>
<td>1895</td>
<td>“Heavier-than-air flying machines are impossible” <em>Lord Kelvin, President Royal Society</em></td>
</tr>
<tr>
<td>1920</td>
<td>“The wireless music box (radio) has no imaginable commercial value” <em>David Sarnoffs Associates in response to his urgings for investments in the radio</em></td>
</tr>
<tr>
<td>1943</td>
<td>“I think there’s a world market for maybe five computers” <em>Thomas Watson, Chairman IBM</em></td>
</tr>
<tr>
<td>1949</td>
<td>“Computer in the future may weigh no more than 1.5 tons” <em>Popular Mechanics forecasting the relentless march of science</em></td>
</tr>
<tr>
<td>1977</td>
<td>“There is no reason anyone would want a computer in their home” <em>Ken Olson, President, Chairman and Founder of Digital Equipment</em></td>
</tr>
<tr>
<td>1981</td>
<td>“640K ought to be enough computer memory for anyone” <em>Bill Gates</em></td>
</tr>
</tbody>
</table>
Predictions are simply extrapolations of the past…

...innovation expands the ‘art of the possible’

...today’s ‘unimaginable’ is tomorrow’s ‘conventional wisdom.’
“It is very difficult to predict the future, it is much easier to invent it.”

Alan Key
A
INNOVATION
the Game Changer...