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Navigating the Bumpy Road from Lab to Industrial Scale

Mike Schultz, LanzaTech

Technology Challenges and Opportunities Workshop in Commercializing Industrial Biotechnology,

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Scaling Up the Blast Furnace

1870 Lake Superior Bay Furnace
45 feet tall
15 tons iron/day

Modern Blast Furnace
100 feet tall
15,000 tons iron/day

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LanzaTech Company Profile

- **Corporate Headquarters and R&D in Chicago, IL**
  Offices and Operations in UK, China and India
- **Funding**
  - Series A: Khosla Ventures - $US 12M in 2007
  - Series B: Qiming Ventures - $US 18M in 2010
  - Series C: MLSCF - $US 60M in 2012 equity, $US 15M debt WTI
  - Series D: Mitsui - $US 112M in 2014
- **Team**

  CEO: ***Dr. Jennifer Holmgren***

  CSO/Founder: ***Dr. Sean Simpson***
  - Over 130 staff
    - Synthetic Biology
    - Analytical
    - Engineering
- **IP Portfolio**
  - 170 Patents granted, >300 applications pending
  - 2 proprietary microbe families
  - 15 recombinant microbe families

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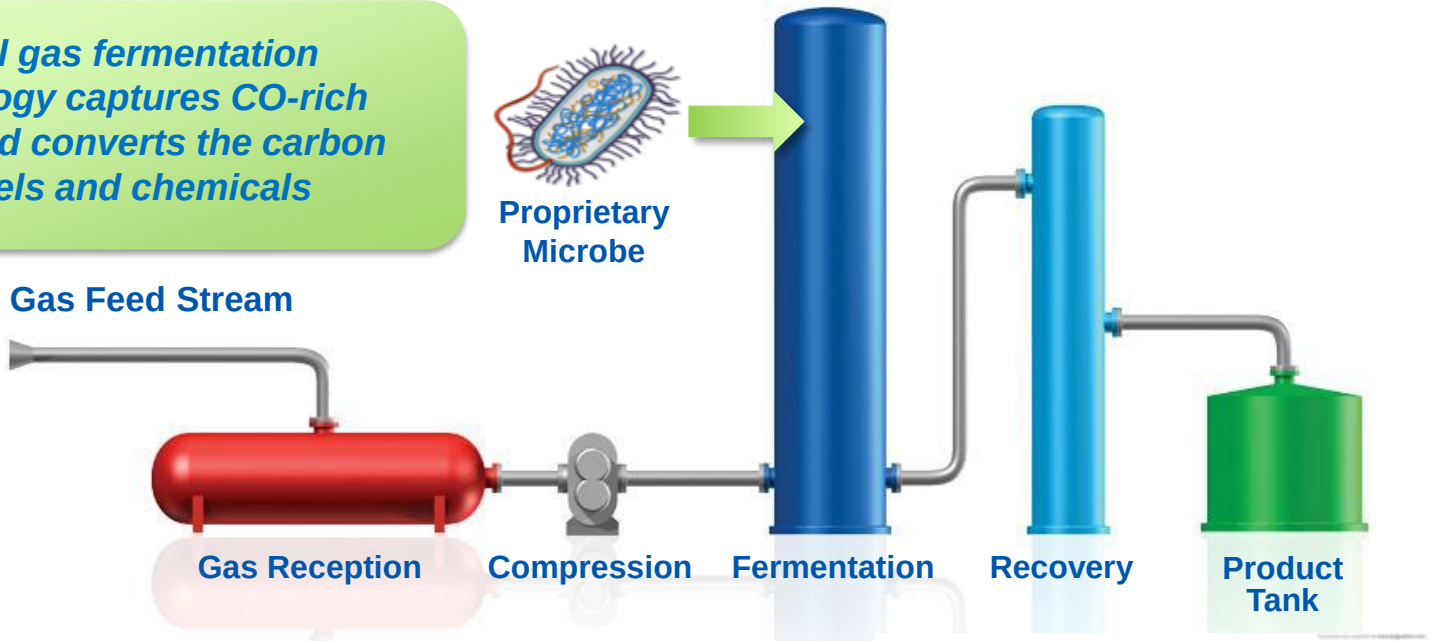
The LanzaTech Process

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)

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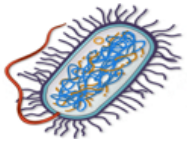
Ready For Commercialization



Strain Development

Lab

2005

~0.5-1 kg/day

50 X

Pilot

2008

50-100 kg/day

32 X

Demo

2012

~1500 kg/day

25 X

Commercial

2016

~300,000 kg/day

Two Commercial Projects in Basic/Detailed Engineering

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Global Technology "Lab"
Data, Data, Data

Over 40,000 combined hours on stream

Multiple Demo plants at various scales all demonstrating <u>different</u> key aspects of process

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Scale-up Considerations

- **Technical**
  - Getting to scale quickly is critical—find out what the challenges are as quickly as possible→ “Don’t let the perfect be the enemy of the good”
  - Identify the important scale up parameters
  - Identify limits in scale, and then seek to overcome these quickly
  - Scale with real feedstock, raw materials, etc—find out the problems early and learn how to deal with them
  - Make sure to capture the right data
- **Regulatory. Will my process meet local regulatory standards?**
- **Government. What government approvals are needed?**
- **LCA. Will my process meet local and global LCA standards?**

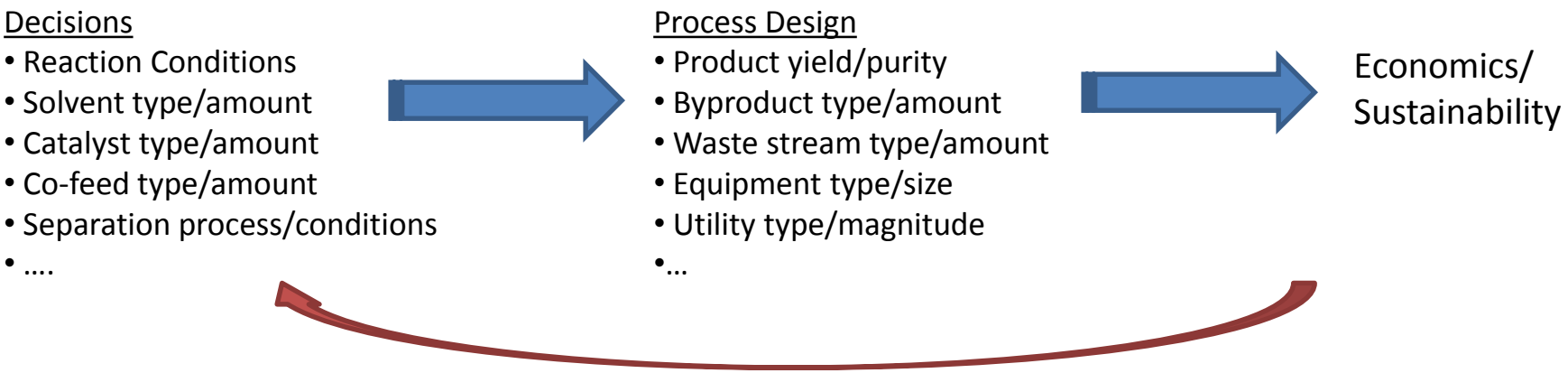
Models and Technoeconomic Analysis Are Critical

- **“All models are wrong but some are useful” (George Box)**
- **Tools to complement experiments and direct future opportunities**
- **Can be refined as more data is collected**
- **Multi-scale data is critical**

Make Sure your Models are Useful

Early Stage Process Development:
Accelerating Process Scale-up

Requires Science/Engineering Interaction



Should be More Collaborative, Less Iterative

- **Decisions drive the process design, with economics and sustainability assessment to inform the decision process**
- **Need fairly accurate estimates of process design, economics and impact on sustainability, but done with a minimal amount of time, effort, and money**

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Challenges in Scale-up at LanzaTech

- **Consistent operating procedures to enable stability**
  - Faster, repeatable startups
  - Extended time on stream
  - Reduce manpower
- **Reaching commercial targets**
  - Yield
  - Productivity
  - Titre
- **Reliable gas treatment performance**
- **Maximizing water recycle**

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LanzaTech Global Partnerships

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Summary and Conclusions

- **Scale up quickly to ensure success at the next scale**
- **Models and economics are critical throughout scaleup**
- **Capture knowledge and data**
- **Partnerships can help overcome challenges particularly outside of core expertise**