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WORKSHOP ON FUNDAMENTAL SCIENCE NEEDS TO ADDRESS WASTE TO CHEMICAL CONVERSION

Thank You

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- Phil Britt
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- Cynthia Jenks
- Tom Russell
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Focused effort on a complex problem

WHERE THERE IS WASTE, THERE IS ENERGY

Energy Everywhere Concept

Locally transform

the nation's stranded, underutilized, and distributed waste into fuels and chemicals

Wet or energy-light resources best processed at source

Need a Paradigm Shift in Manufacturing

Is bigger actually better?

Chemical Plants are not Cheap

- DuPont cellulosic ethanol plant Cost: $225 million
- BASF propylene plant. Cost: $1.4 billion
- LyondellBasell Industries propylene oxide/ t-butanol plant Cost: $4 billion
- Oil refinery Cost: $5-15 billion

x 1000

We envision local process size of 125 BOE/D

scaling by mass production

x 1000

We envision local process size of 125 BOE/D

ENERGY EVERYWHERE

Clean Energy through Modular Chemical Conversions

Impact

Enough fuel to fuel 200 million homes or 240 million cars.

IMPACT

Clean – Reduce wet and dry waste disposal by 10x

- Create value from and better manage waste, reduce landfills, protect water supplies

Adaptive – Improve energy security while reducing greenhouse gas by 30%

- Create a regional network of modular processing systems that provide 1/3 of our carbon needs currently met by crude


JUST BECAUSE
YOU'RE TRASH
DOESN'T MEAN
YOU CAN'T DO
GREAT THINGS.
IT IS CALLED
GARBAGE CAN,
NOT GARBAGE
CANNOT.

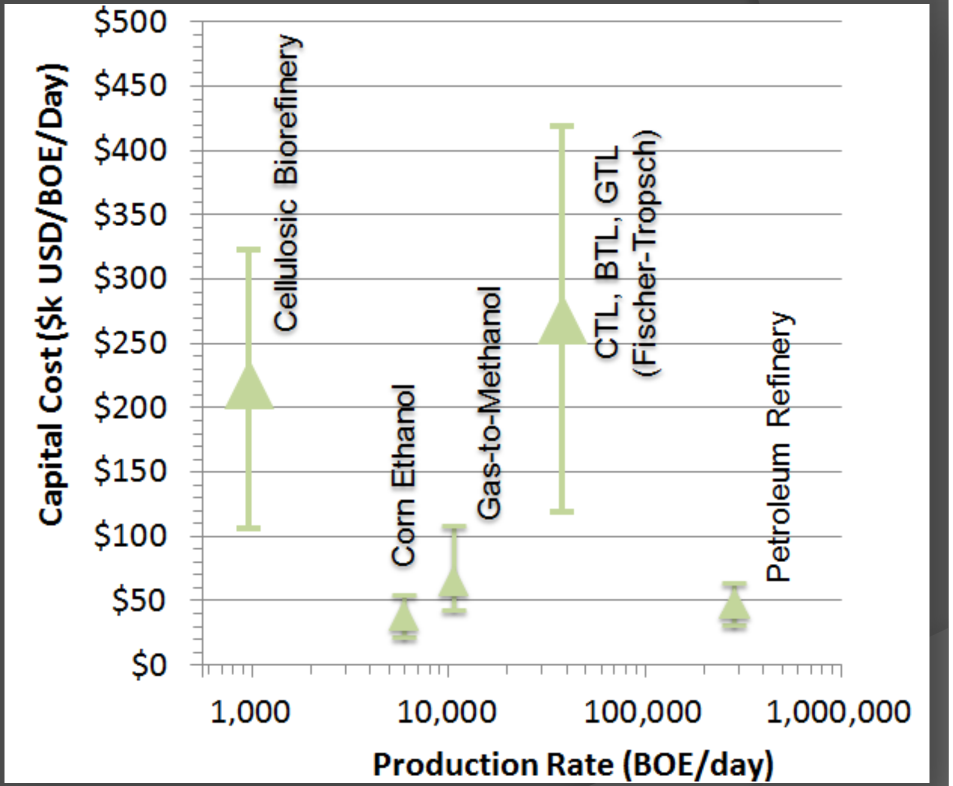
ECONOMICS OF SCALING SMALL

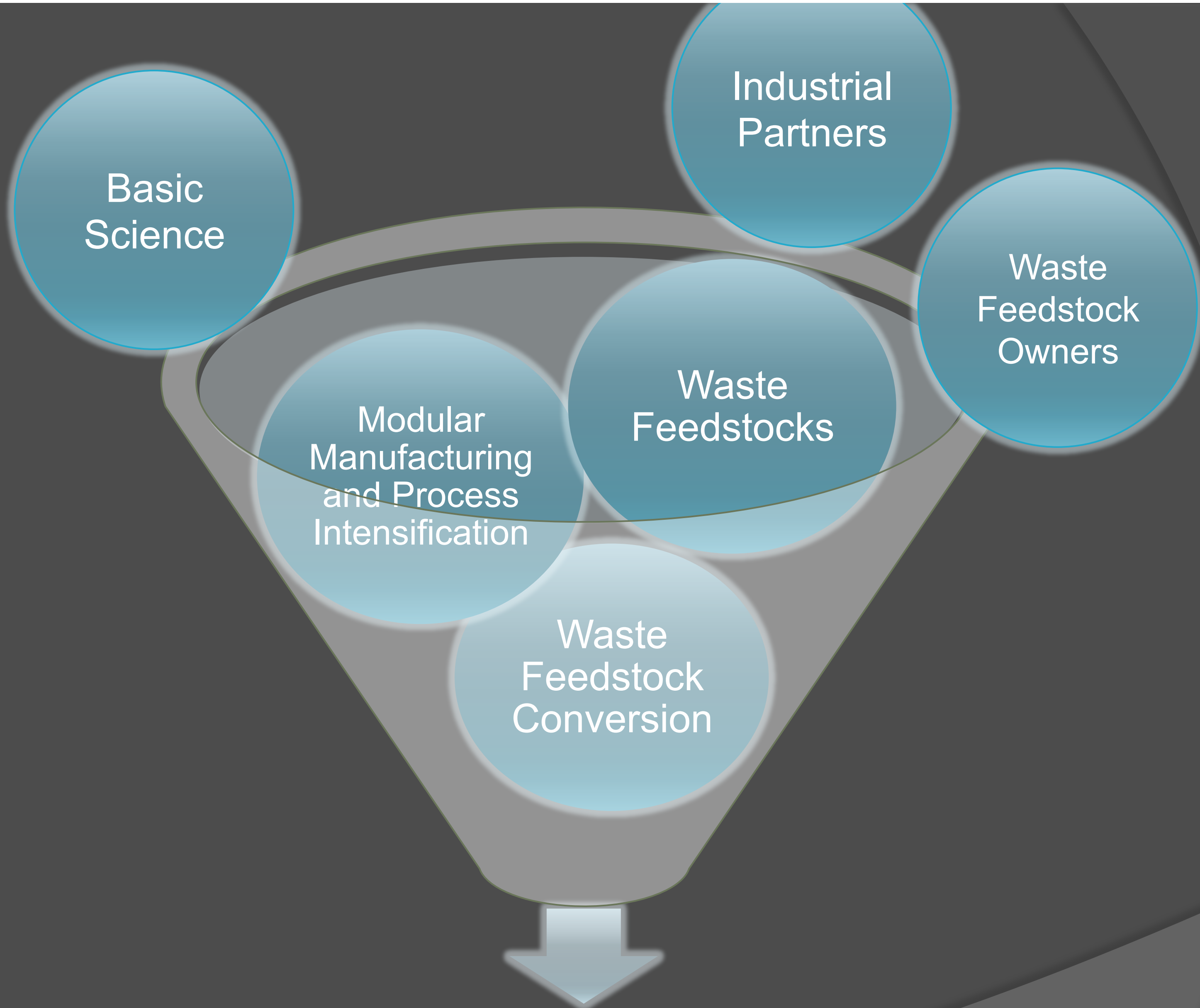
Goal

Goal is to achieve parity on capital cost on a per unit basis —$50k per BOE/day

How can it be economical?

- Savings through mass production
- Risk reduction at small scale
- Low cost feeds
- New science and technologies that scale linearly with cost



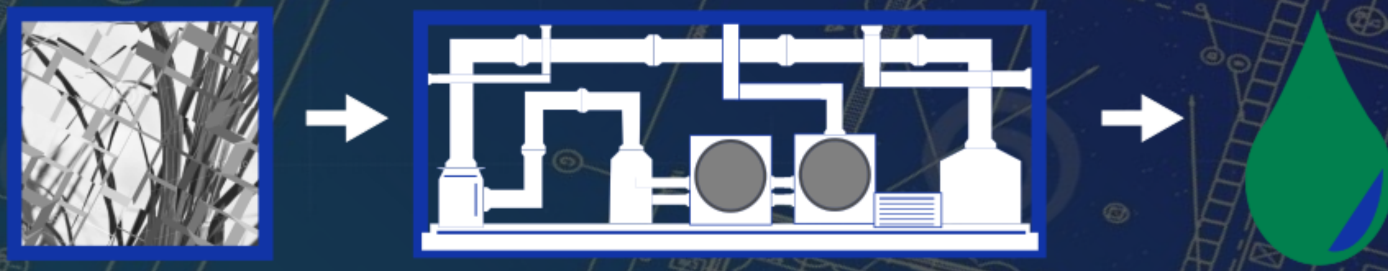


Fuels and chemicals

Five Focus Areas

1. chemical conversion processes
2. next-generation, low-energy separations
3. standardized modular “plug and play” unit operation – designing interconnected and mass produced economically
4. integrated sensors, and controls; and
5. tech to market activities – regulatory requirements, safety codes, resource logistics and market analyses.

Chemical Conversion via Modular Manufacturing: Distributed, Stranded, and Waste Feedstocks



December 2-4 Sheraton Westport Plaza Hotel St. Louis, Missouri

WORKSHOP OBJECTIVES

- Understand conversion technologies for processing distributed, stranded, and waste feedstocks at suitable scales;
- Synthesize the current state of the field in modular manufacturing;
- Identify bottlenecks and gaps that will enable technology developers, feedstock owners, and modular manufacturers to produce fuels and chemicals from these underutilized sources;
- Ascertain the potential of emerging technologies and ways to accelerate market transformation;
- Define a shared vision and determine a path forward.

WORKSHOP EXAMINED

- Distributed carbon opportunities
  - Waste owners and converters
- Venture capitalist requirements
  - Reduce risk for financing
- Manufacturing approaches
  - How to increase flexibility

WASTE IS ABUNDANT

Major Sources	Million Dry Tons Per Year (USA)	Percent
Animal Wastes	335	55
Food Processing	113	19
Pulp and Paper	149	25
Municipal Wastewater	7	1
Total	604	100

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Animal Wastes

Animal Type	Amount, millions dry tons per year	Percentage of all Biomass
Cattle	253	42
Swine	31	5
Poultry	51	8
Total	335	55

Only about 3.6 million tons per year is subject to energy recovery today.

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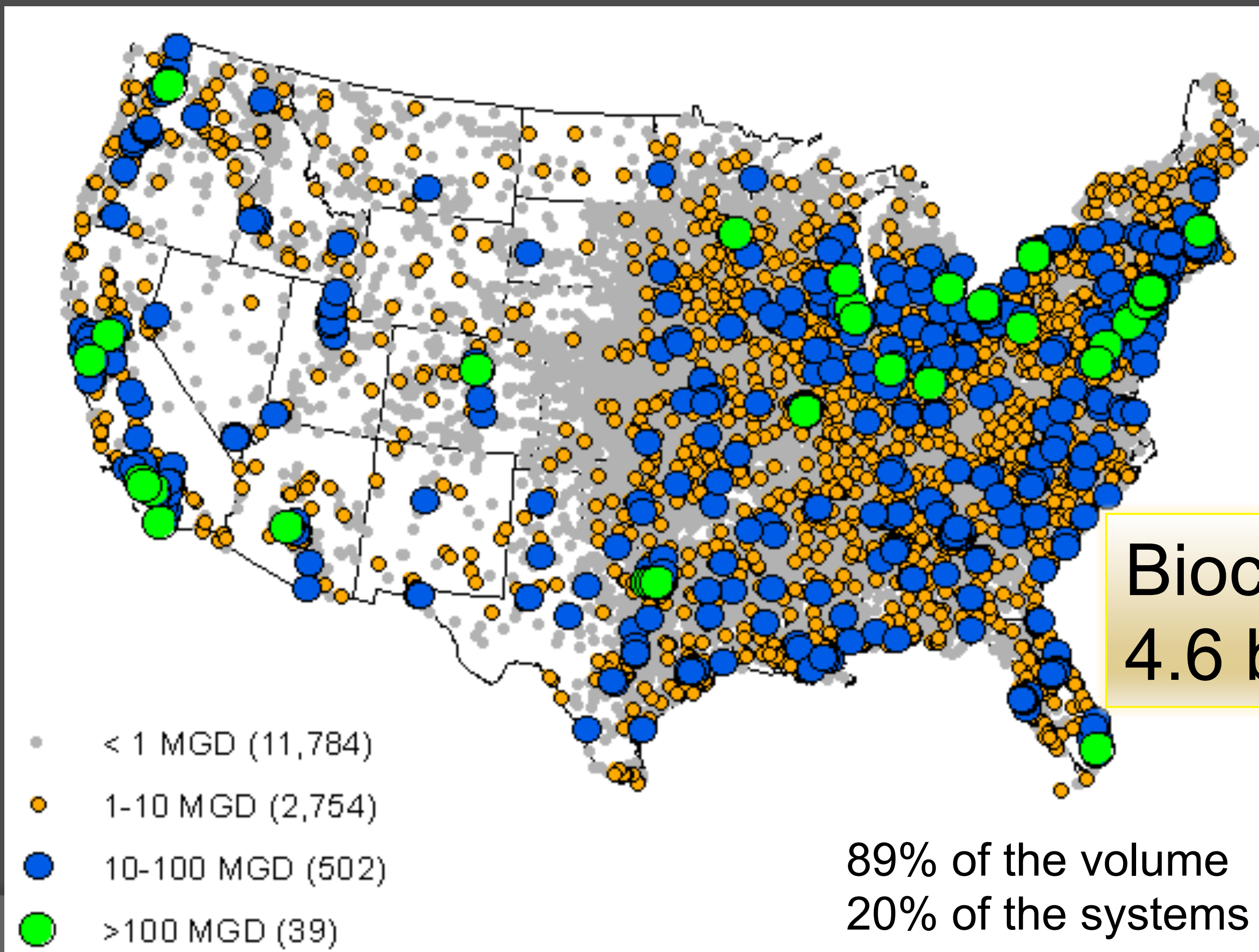
If all residual biomass from agriculture and human activities could be collected and converted into useful energy, this would meet ~ 25% of the societal demand worldwide.

Wastewater Treatment Plants

75% of the total US population is served by more than 16,000 publically owned treatment works, which treat nearly 32 billion gallons of wastewater every day.



Biocrude oil potential
4.6 billion liters

METHANE OPPORTUNITIES

Methane has 23-86 times the global warming potential of carbon dioxide

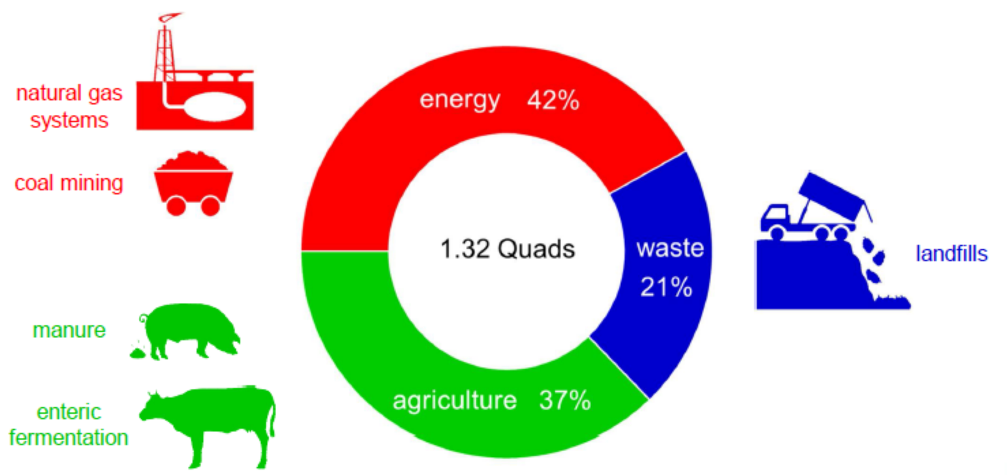
~ 630 $Mt_{CO2,eq}$

~ 10% of total GHGs

~ 1.3 Quads of energy

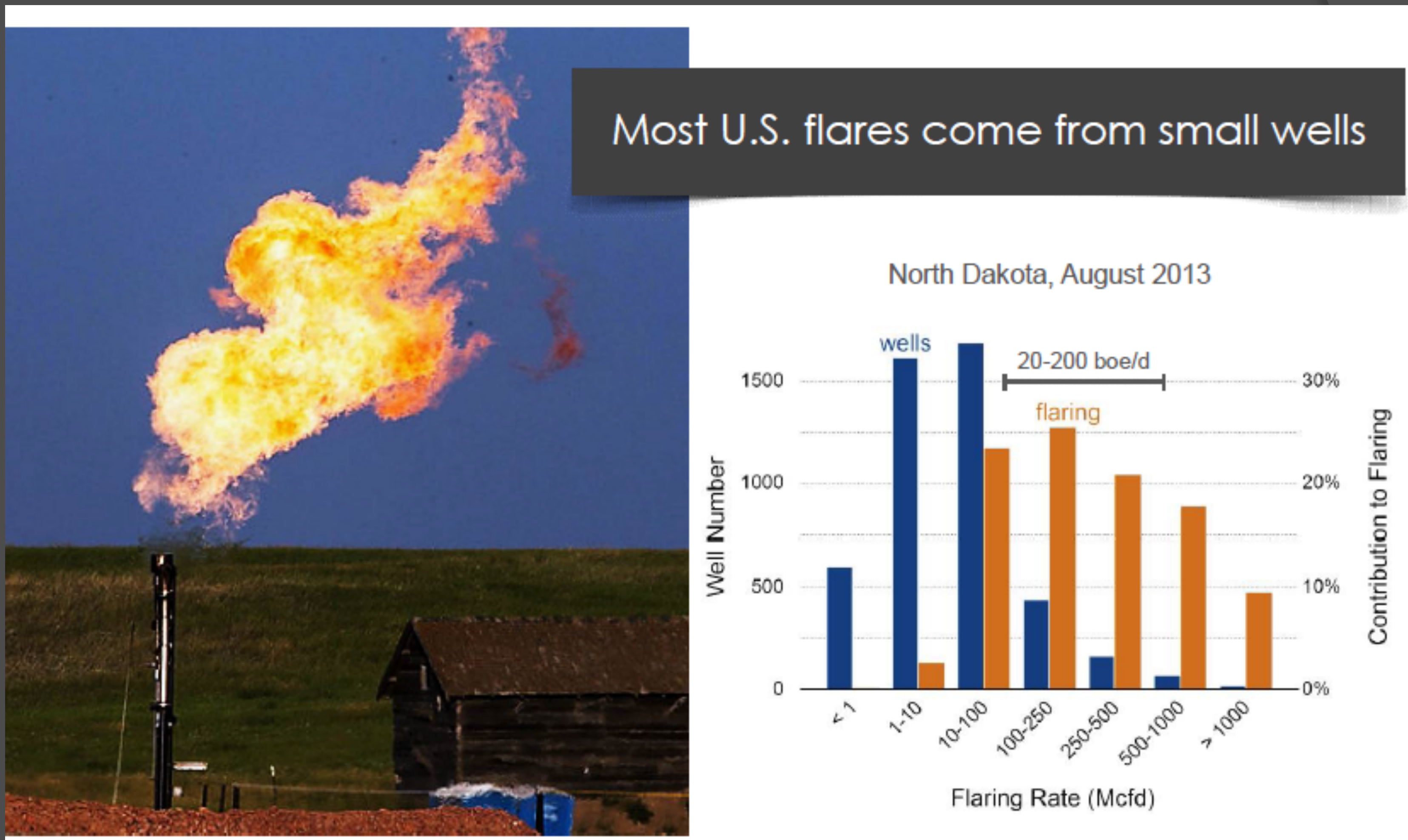
a.gov/climatechange/ghgemissions/usinventoryreport.html#fullreport

2013 U.S. Anthropogenic Methane Emissions



Source: U.S. EPA Inventories of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html#fullreport

SCALE IS 20-200 BOE/DAY



Need and opportunity is for conversion processes at small scale

Adventures of a Venture Capitalist

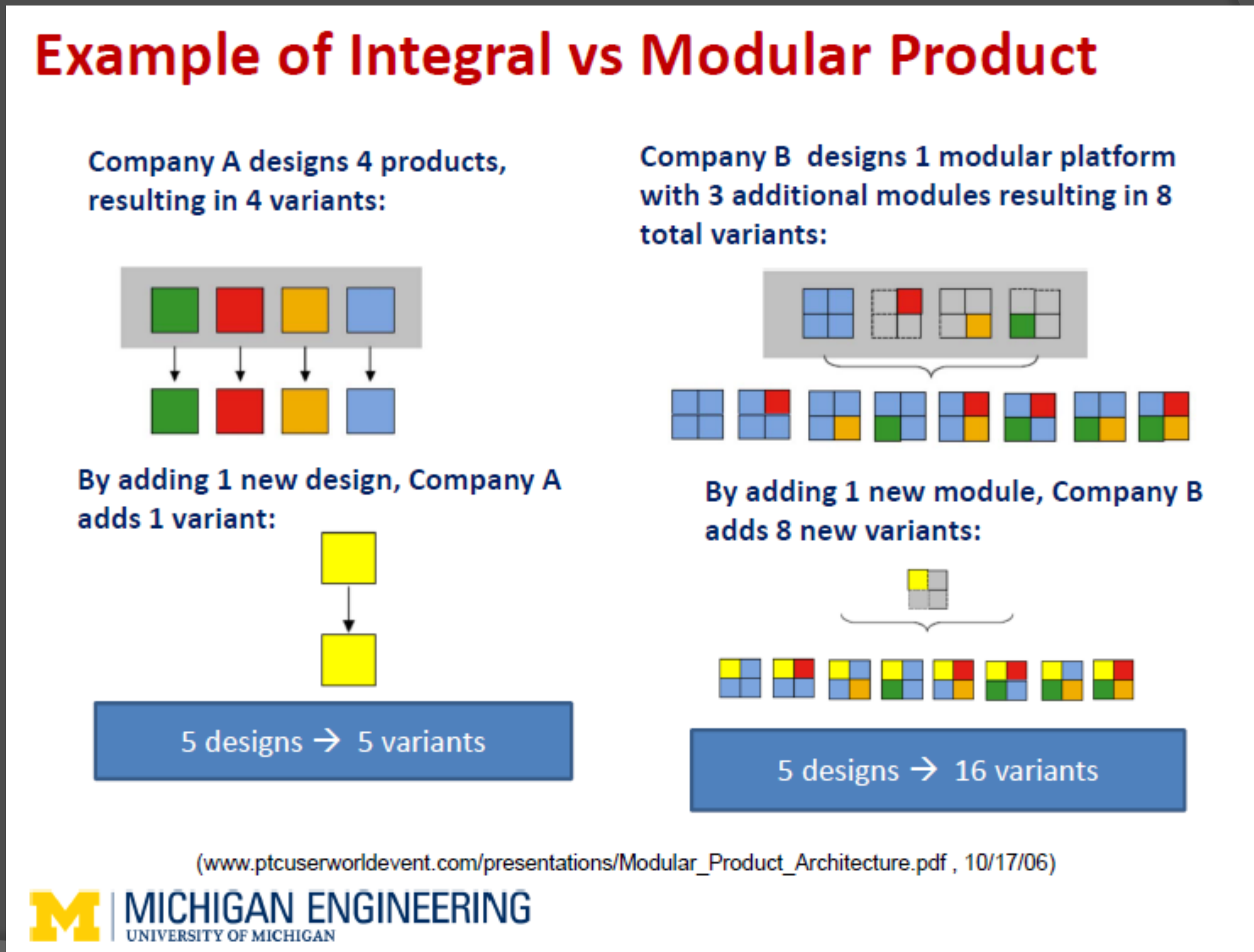
What it takes to raise money for a deployment

- Proven technology or insurance/wrap/loan guarantee
- Long-term feedstock supply and product offtake contracts with creditworthy parties
- Sound project financials with minimal volatility
- Strong independent engineering report and feedstock study
- Investment grade Engineering-Procurement-Construction (EPC) contract
- Experienced operator

(it's all about reducing perceived risks)

FLAGSHIP VENTURES

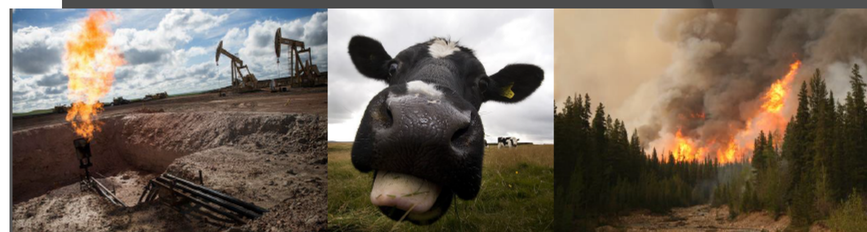
A MODULAR PLATFORM DESIGN



LEARNING FROM RENEWABLES

Economic lessons from the solar, wind, and ethanol industries

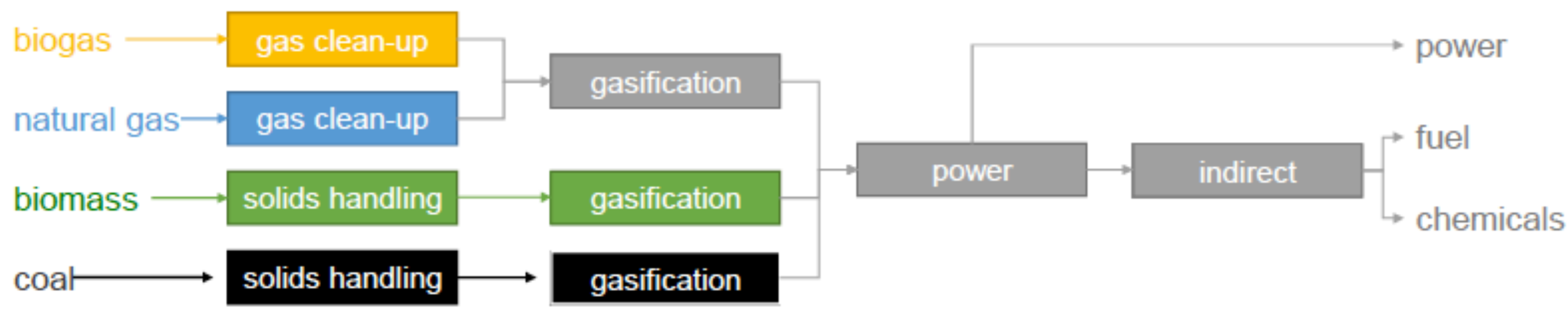
- Experience curves: every doubling of production reduces capital costs by a fixed percentage
- System optimization: operating costs decrease through learning-by-doing
- Technological innovation: improvements in efficiency and resource use reduce costs
- Manufacturing improvements: improvements in design, material use, automation reduce cost



Industries that adopt mass production have learning rates of 18% vs. 6% for economies-of-scale

Daugaard et al. 2014

MODULAR VISION FOR GASES



Modular Architecture

- Standard interfaces
- Common feed rates and compositions
- Inter-module design standard
- Plug and play protocol

Modular Platform

- Common component inventories
- Intra-module design standard
- Uniform form factor

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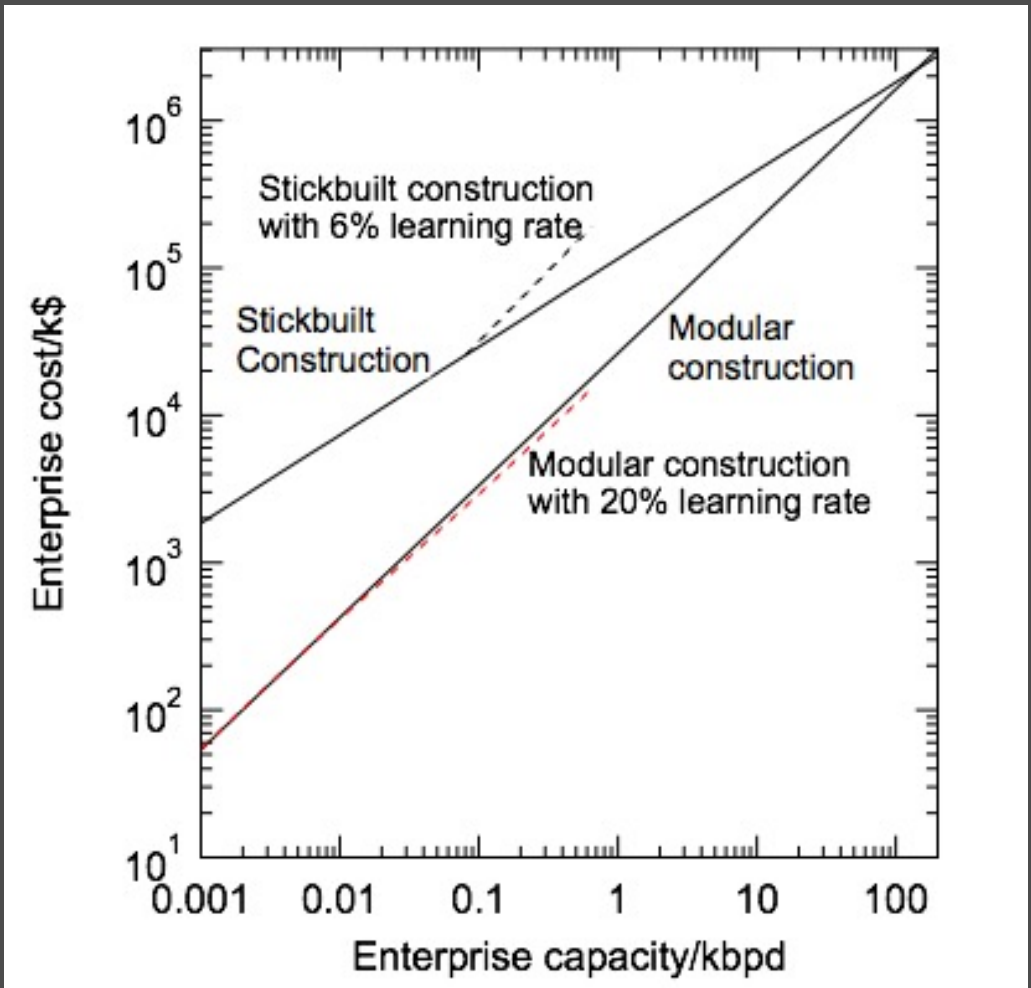
MODULAR SYSTEMS LEARNING CURVE



There are two critical issues that favor modular construction for the small scale plants:

1. It permits the pioneer plant to be constructed with a quite small amount of capital (~$50K vs $25.6M and
2. The incremental capacity is also very much lower: $23K for the the 641st modular plant versus $22.3M for the 9th stickbuilt plant.

DEMOCRATIZING TECHNOLOGIES

Technologies that democratized the world

1450	1908	1973	1977	????
Gutenburg Press	Ford Model T	Motorola DynaTAC 8000X	Commodore PET	Modular Processing
information	transportation	communication	computation	processing

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STEPS

- Identify the problem that needs to be solved
  - About 1.6 Quads and 10% GHG emissions result from flared or vented methane alone in U.S.
  - Carbon sources distributed in nature
  - Existing large scale solutions cannot address this problem
- Delineate the challenges
  - Separations and conversions-at scale
  - For methane, e.g. need a direct conversion process or a low cost oxidant
- Clarify the opportunity
  - Modular systems providing carbon for energy needs while addressing energy and environmental challenges
- Complete sanity checks
  - Do our markets fit?
  - Can costs (capital $/BOE/DOE) work?

December Workshop Identified Engineering Gaps

- Design of unit operations and the overall process, including feedstock preparation, materials of construction and EHS
- Sensors and algorithms for control
- Mixing rules for blending the products with petroleum-derived feeds: effects on rheology, combustion and emissions
- Optimization and treatment of co-products and waste streams
- TEA, logistics, scaling and learning correlations
- Site selection and preparation, training of operators and maintenance
- Business planning: Financial, Vendor/EPC, Customer coordination

December Workshop Identified Science Gaps

- Online characterization of the feed (energy content, impurity content)
- Structure-activity relations for the kinetics (rate and selectivity) of the sequence of conversions
- Structure-activity relations leading to design principles for the activity and longevity of the catalysts
- Thermodynamics and colligative properties required for the separation of the complex streams of products

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Objectives of This Workshop

- Define the fundamental scientific challenges of converting complex, variable waste streams into fuels and chemicals
- Understand the science needs for distributed refining of waste streams at small scales and in harsh environments
- Discuss emerging materials for easier processing

Thematic Areas

- Catalysis
- Separations
- Pre-designed Material Conversions
- Theory and Computation
- Process Intensification
- Characterization