Technological and Business Challenges of a Modular Process Technology – Case Study

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for global good

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Keys to a Successful Technology Commercialization

Feasibility
Innovative Technology

+

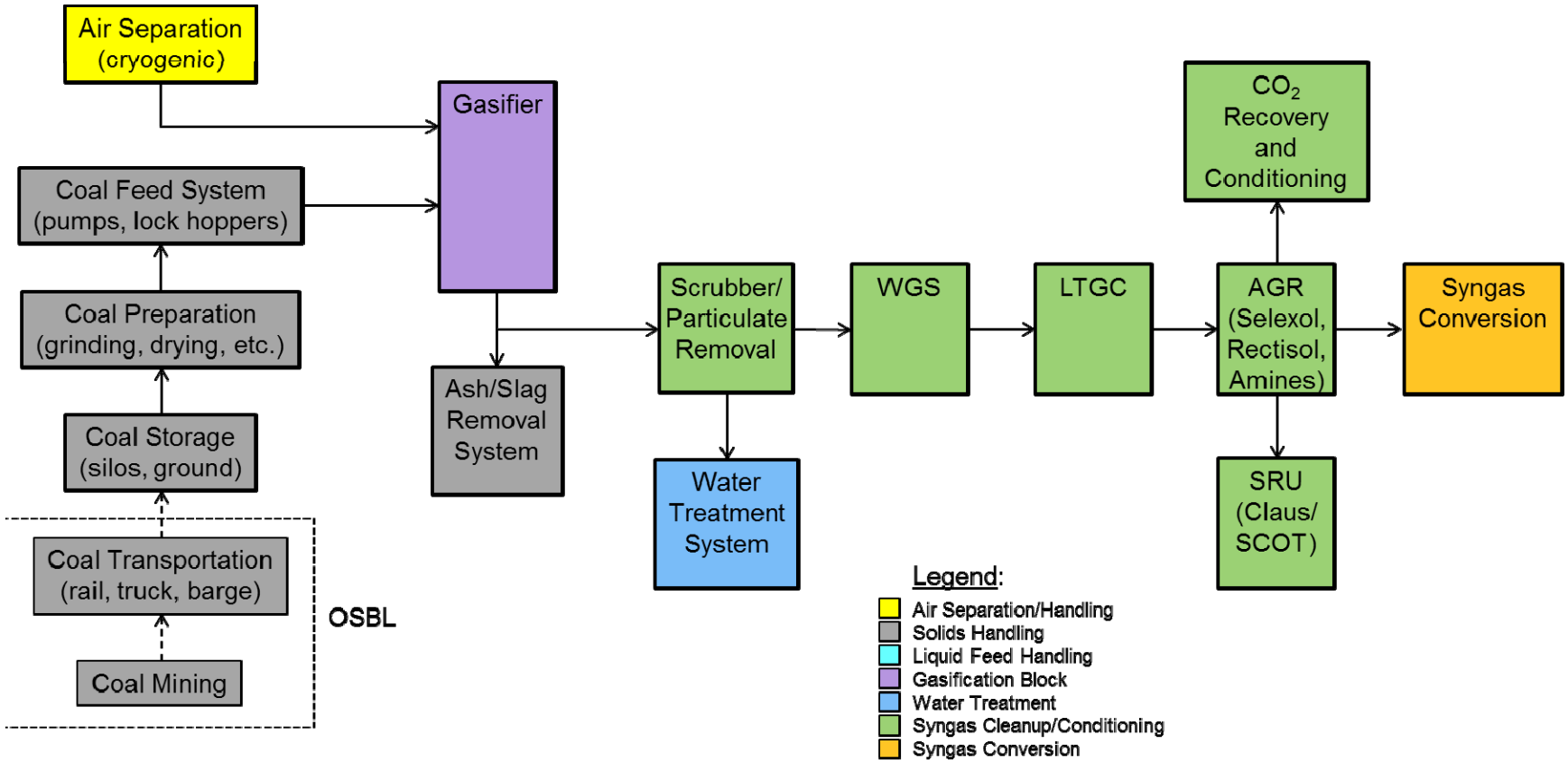
Viability
Economically Competitive

+

Desirability
Profitable Business Model

Successful Commercialization of Technology

Conventional Coal Gasification

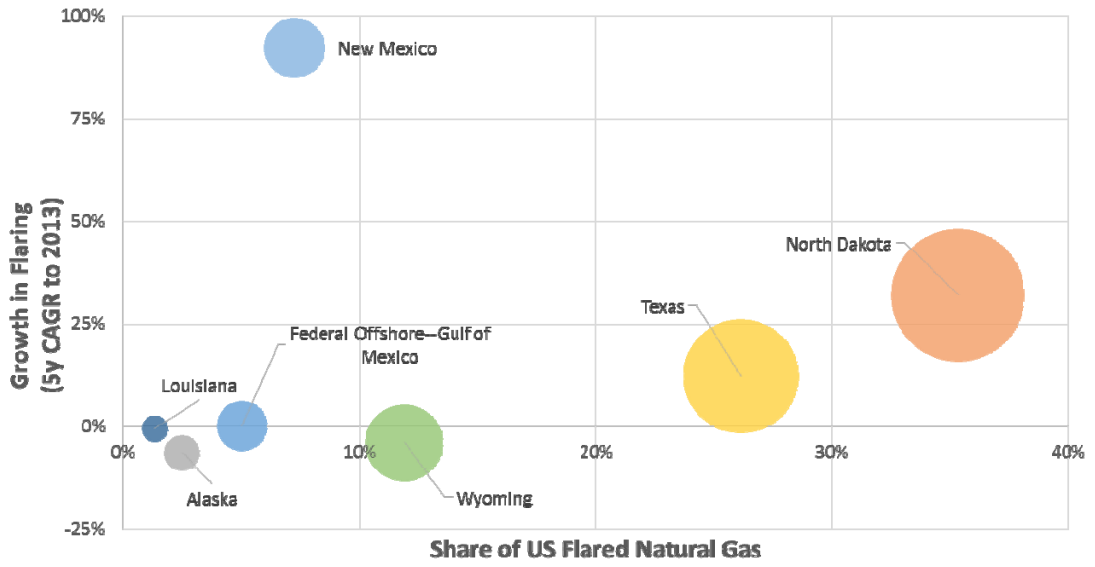


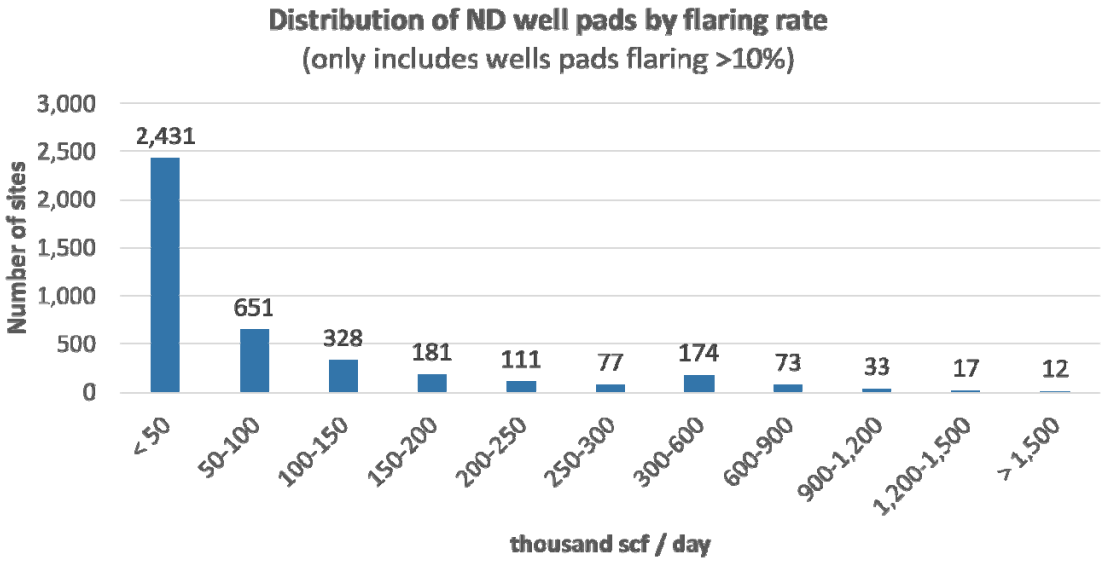
How to Reduce Costs and Economy of Scale?

- Eliminate or reduce solids handling
- Reduce number of specific equipment pieces
- Reduce footprint/size of specific equipment pieces
- Explore process intensification
- Reduce number/size/cost of expensive equipment units, such as compressors, heat exchangers, etc.
- Modularization/standardization/mass production to reduce equipment costs (including advanced manufacturing)
- Advanced technologies/designs that reduce cost and/or improve efficiency (efficiency improvements help reduce overall plant costs)
- Advanced catalysts and sorbents to improve efficiency of syngas cleanup and conversions

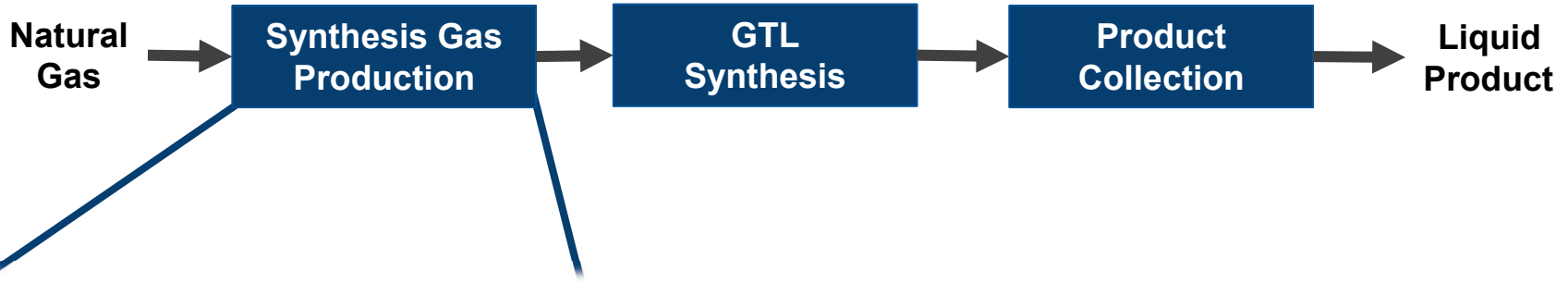
Case Study --- The Flaring Problem

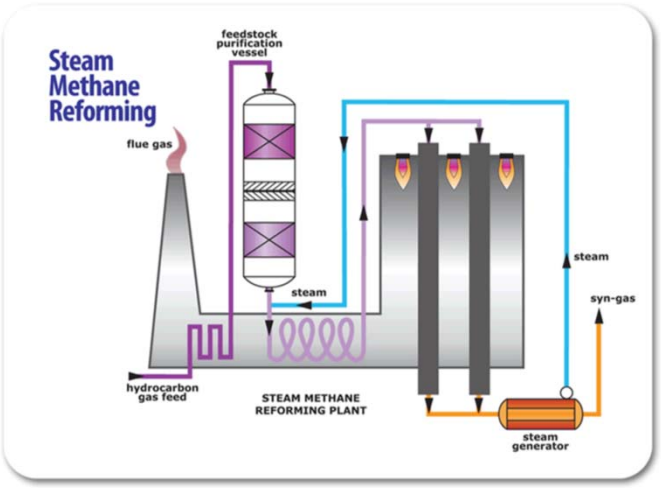
- Over **5.5 tcf per year** of natural gas is flared worldwide.
- In 2014, over **288 bcf** of natural gas was flared in the US.
  - More than the consumption of Maryland and Washington DC.
- A large proportion of ND well pads flare relatively **small amounts of gas**.
- In addition to flaring **other sources of natural gas** are typically distributed and small such as bio-gas.



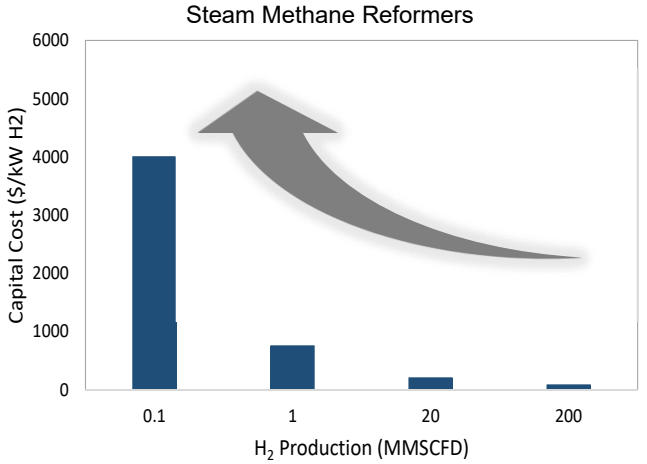


Conventional Conversion Technologies





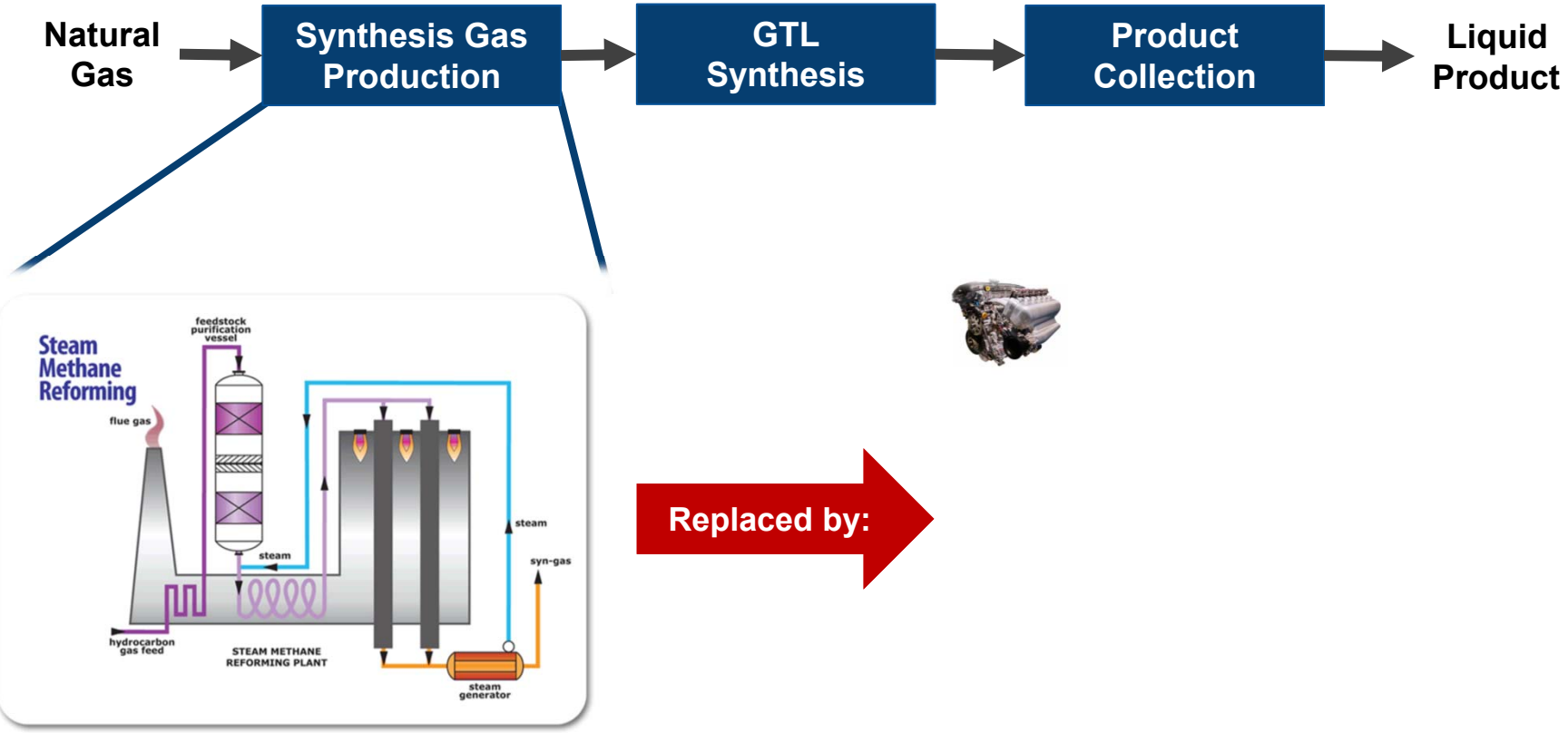
* Picture from www.eajv.ca, June 17,2015



Source: Ogden, Intl. Energy Agency Report, 2002

Traditional NG conversion technologies do not scale down economically

Small-Scale Modular Conversion Technologies



* Picture from www.eajv.ca, June 17,2015

RTI MicroReformer

Replacing Economies of Scale with Economies of Mass Manufacture

Economies of Scale

- Cost reductions from large scale operations
  - Reduce overhead, increase efficiency, reduce personnel cost
  - Pushing to physical limits in size

CAPEX Cost:
IGCC = $3,000-$6,000/kW
Natural Gas = $1,000/kW
*eia.gov

Mass Manufacture and Scaling by Numbers

- Cost reduction from producing large numbers of short lived units
  - Reduce cost by learning, improved accuracy, faster response
  - Pushing the limits of automation and coordination

Capital Cost:
Engine = $50-$100/kW
Genset = $100-$200/kW
*survey of publically available prices

Small Unit Size

- Allows for centralized or distributed deployment

Fast Replacement Times

- Reduce business risk, and risk of obsolescence
- Gain flexibility in right-in-time deployment

Advantages of Being Small

Reliability constraints are relaxed

- Replaced by ultra-high redundancy
- Automatic fault detection and replacement

Shorter deployment times

- Faster response time
- Risk reduction

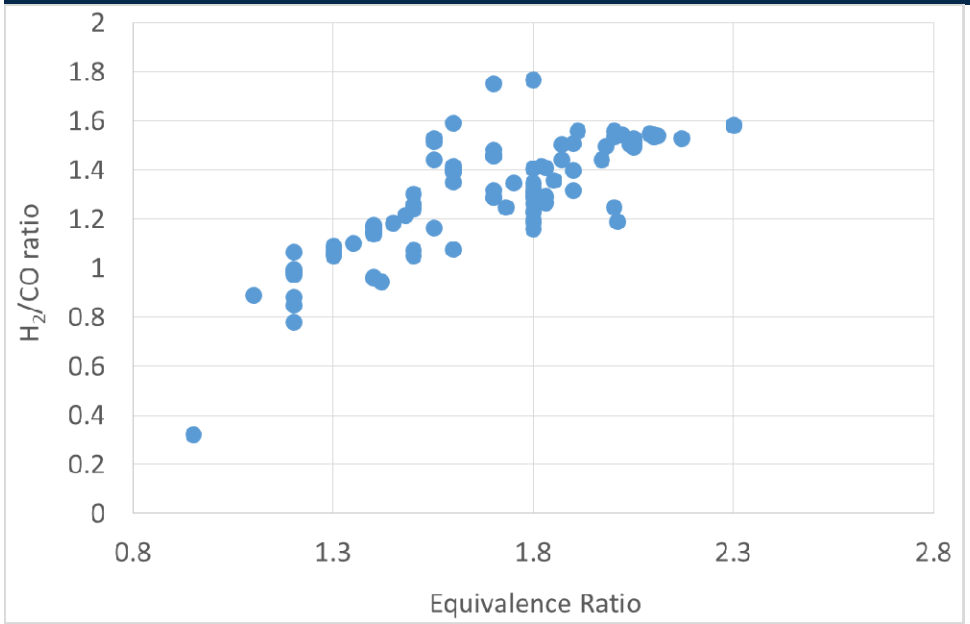
Flexibility in deployment

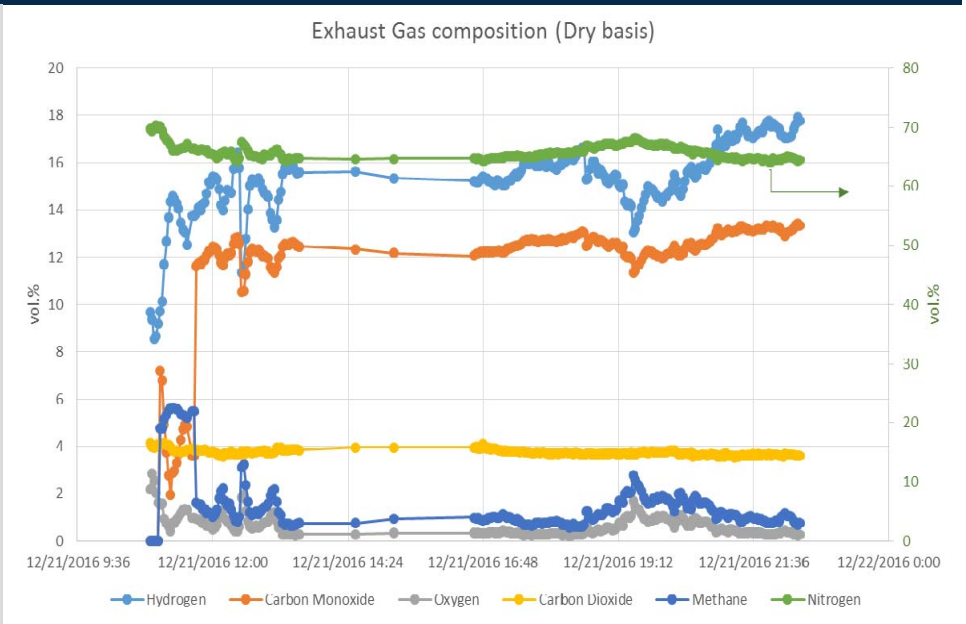
Operational life times can be shortened

- More learning, mistakes are less costly
- Reduced risk

Efficiency?

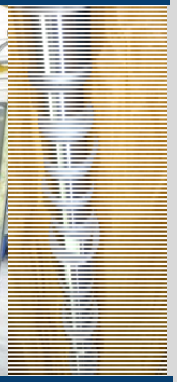
50,000 scfd MicroReformer at RTI





Engine System testing at RTI

Cam shaft



Compression increase

- Produces syngas with H_2/CO ratio at 1.4 with greater than 90% O_2 and CH_4 conversion
- Utilizes a standard mass produced engine/genset
- Modifications based on available commercial parts
- Methanol micro reactor inline for direct exhaust testing

MicroReformer as a Platform

Flexible Feedstock

Flared Gas, Stranded Gas, Bio-gas

Syngas Generation

Oxidant

Air
Enriched Air
Oxygen

Clean Up
Conditioning
Compression

Flexible Product Slate

Methanol
ARPA-E Project

FT Liquids
RTI 1 bbl/day unit

Olefins
RTI Gas-to-Olefins

Ammonia
RTI ARPA-E Proposal

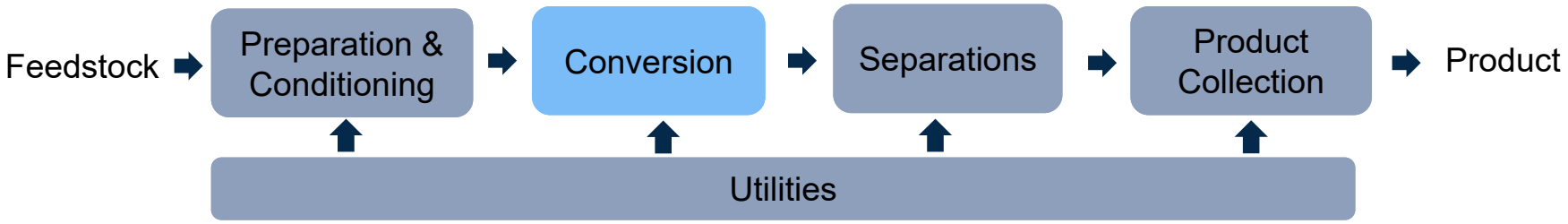
Hydrogen
Pressure Swing Adsorbers

Balance of Plant Controls

The **engine** is the key enabler for these technologies

Balance of Plant Innovation

Modular systems require development of all system components.



50% amount **Balance of Plant (BOP)** components routinely exceed 50% of equipment cost in traditional large plants.

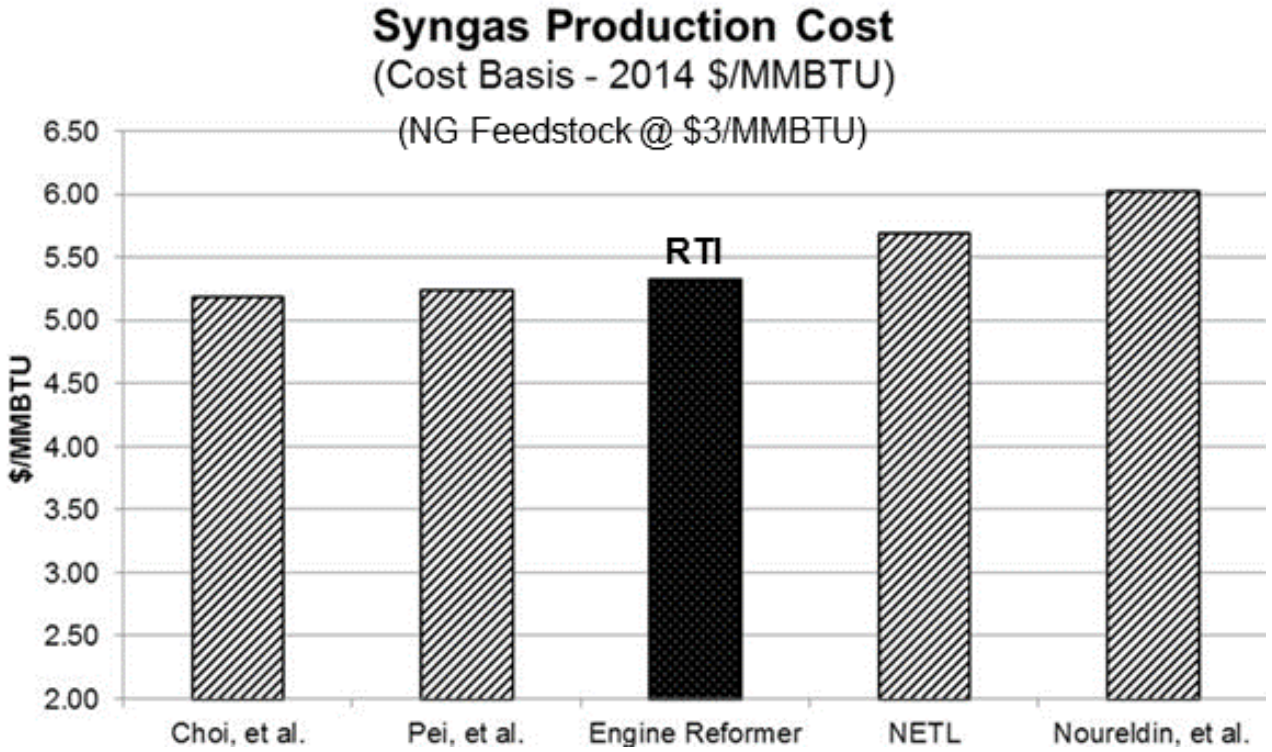
85% amount **BOP** increases to in excess of 85% of the equipment cost in our MicroReformer System

Key BOP areas for Innovation:

- Compression
- Heat Management
- Separations
- Controls

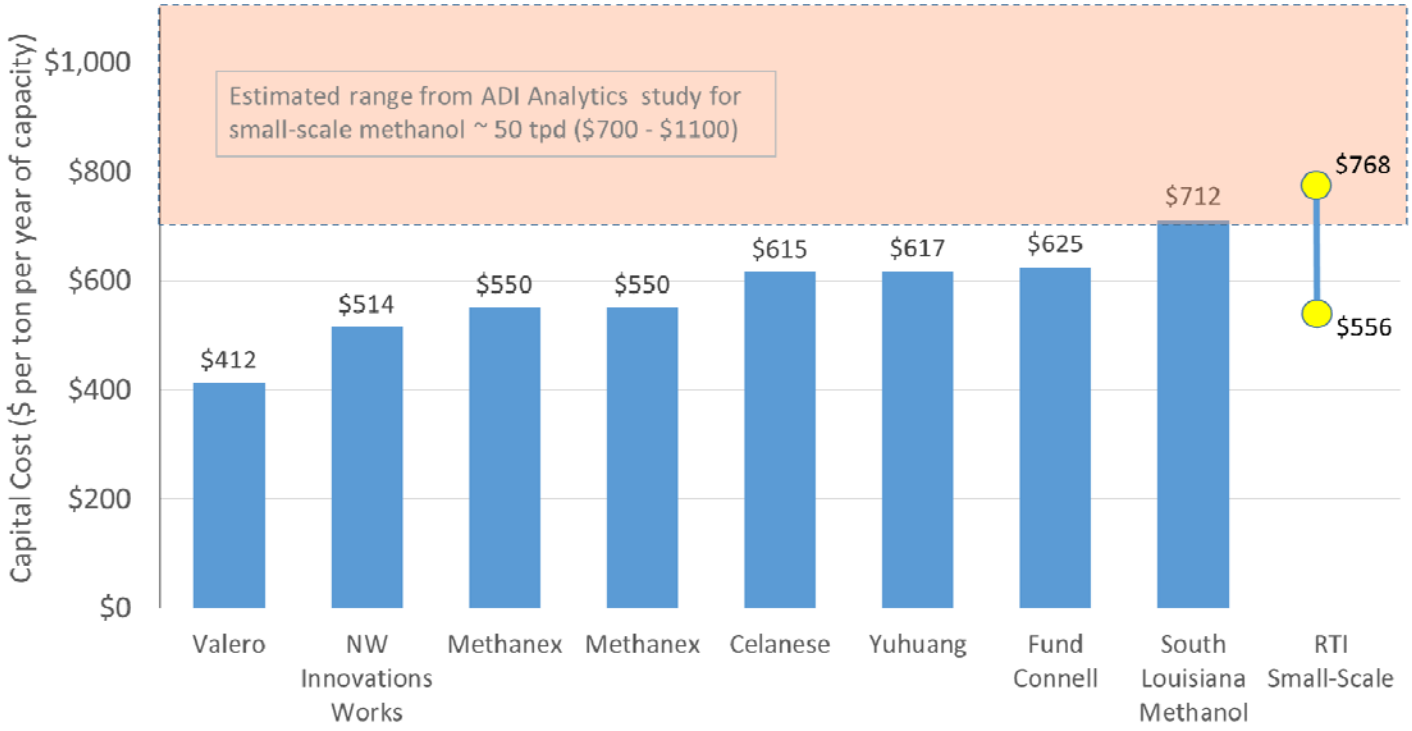
RTI MicroReformer Compares Favorably with World-Scale Production

- Syngas costs from RTI micro-reformer compare favorably with conventional reformer costs (based on $3/MMBtu NG cost).
- The RTI MicroReformer can be located at the site of low-cost stranded, associated, or landfill gas, making its potential syngas costs even more competitive.



* Data analysis from manuscript submitted for publication by RTI and Columbia University, references from other cases studies contained in manuscript

Can Small-Scale Systems be Competitive?

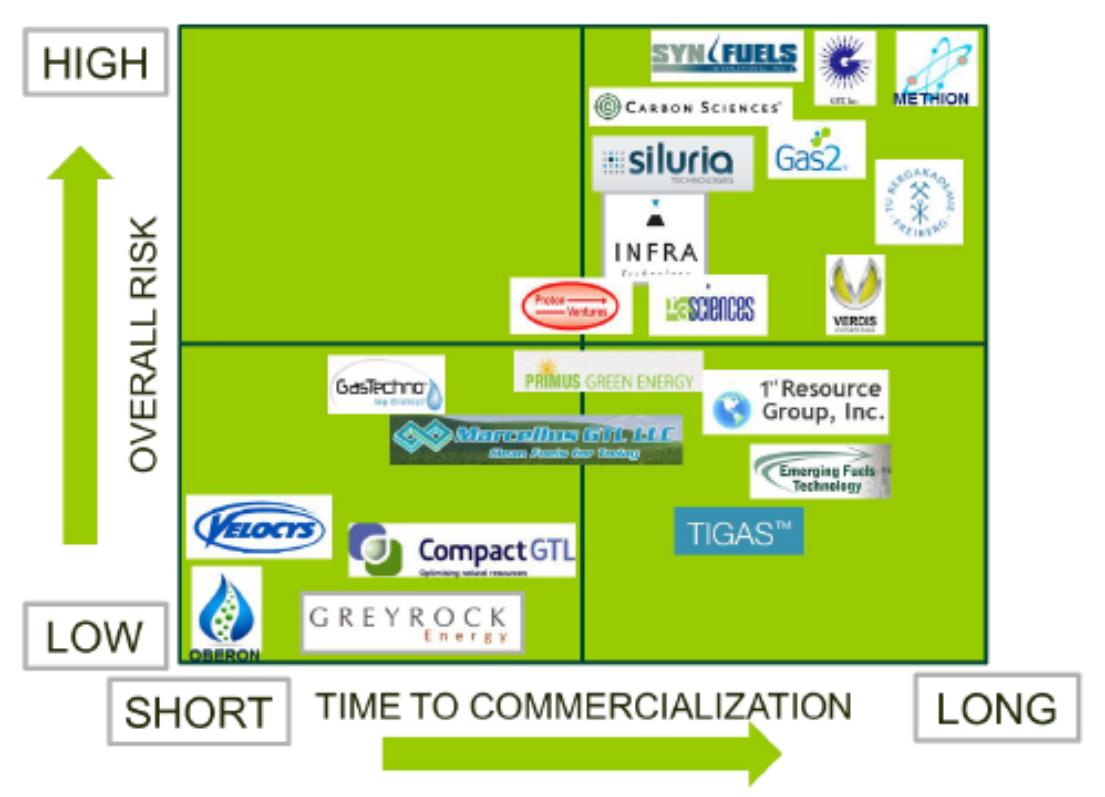


* Data (except RTI Small-scale data points) from *Natural Gas Utilization via Small-Scale Methanol Technologies* by ADI Analytics April 2015

- RTI small-scale methanol initial assessments compare favorably
  - 2,000-3,000 tpy
  - **Capital Cost $1-2M vs. $1-5B for large scale investment**
- Key driver is the mass manufactured engine cost is low
- Innovation in *balance of plant components* is critical to accelerate development and lower cost

References of Modularization in the Natural Gas Field

Natural Gas Conversions



* From T. Fleisch, (2014) "Associated Gas Monetization via miniGTL: Conversion of flared gas into liquid fuels & chemicals, Update January 2014", Global Gas Flaring Reduction Partnership.

Natural Gas Liquids Separations

PIONEER ENERGY

GTUIT

Business Model

Distributed processing of natural gas will require a new business model

- Ownership of different links of the value chain (feedstock suppliers, engine suppliers, methanol/NGL conversion, distribution, system integration, etc.)
- Geographical diversity of resources adds to the challenge
- Public-private partnerships
- Policy/regulation issues

Licensing –licenses technology to a system supplier and the system supplier runs the system, operations and is responsible for product sale & distribution.

Subscription –subscription fee for product sold by the subscriber. Technology developer sells the system to the subscriber who is responsible for operations, product sale & distribution.

Ownership – technology developer owns the entire value chain from building equipment, operating, selling and distributing the product.

Hybrid – combination of the above/new business model.

Key Insights

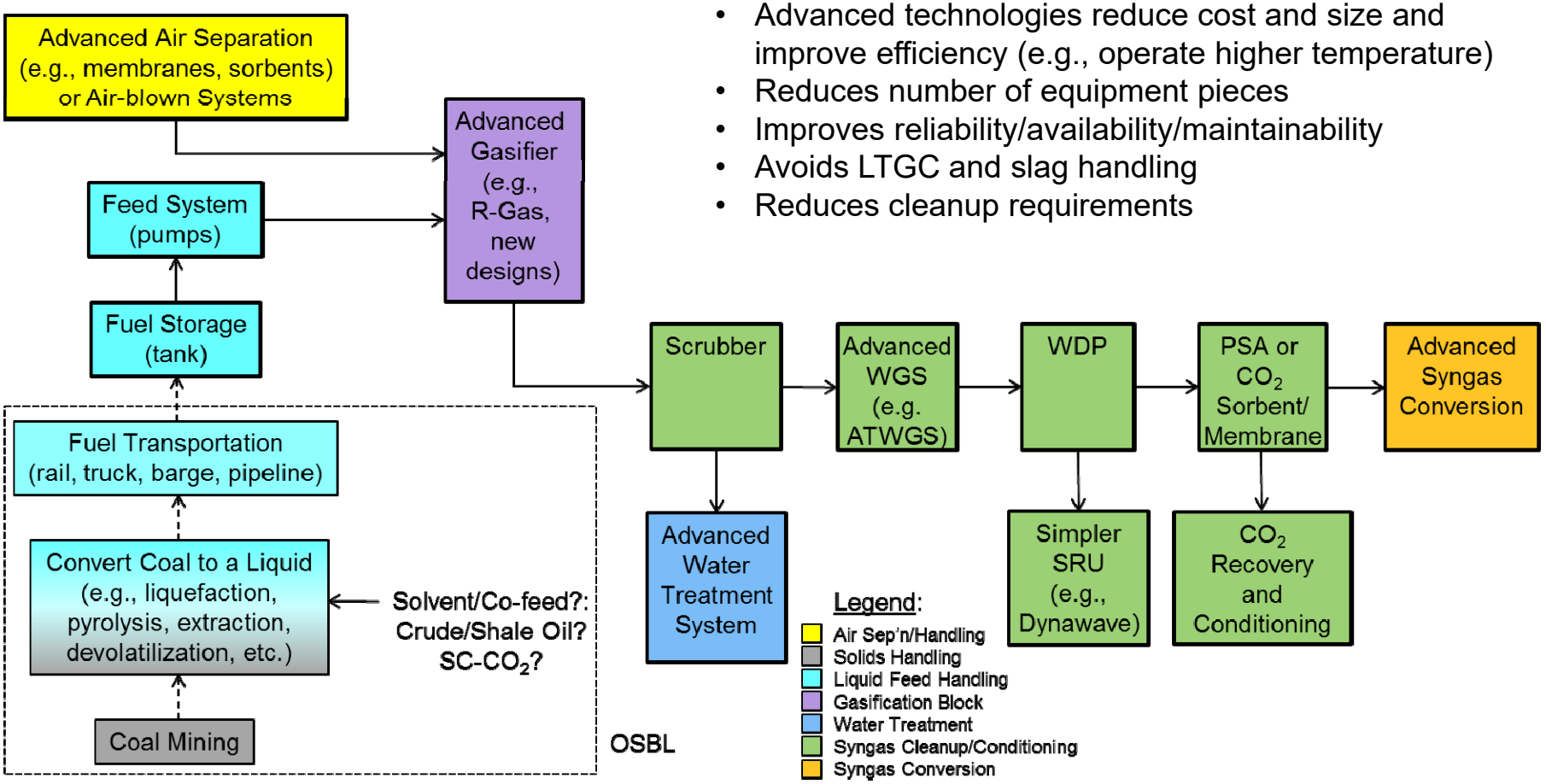
Commercializing Modular Technologies requires:

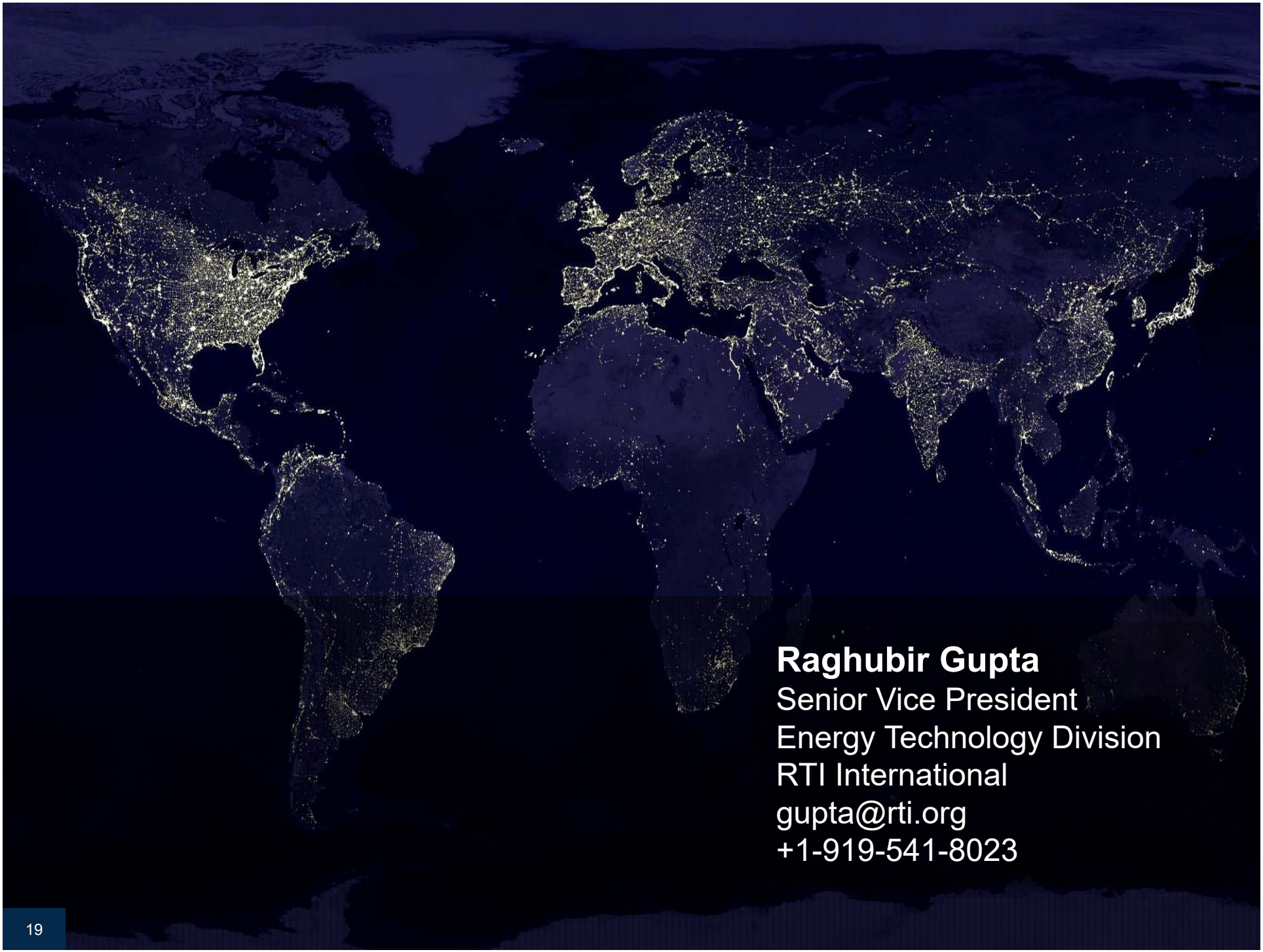
- Key innovations to challenge the economies of scale.
- Laser focus on complete technology development.
  - How do you scale-up a material or process cost-effectively?
  - How do you standardize production?
  - How to design for robustness and unique operating conditions?
  - What are the Balance of Plant issues?
  - How do you ensure safety and reliability?
  - Automation, remote troubleshooting, and data security
- Understanding of market and customer requirements.
  - New thoughts on business models/monetization beyond licensing
  - Flexible deployment to multiple segments
  - Relationship with first adopters to jump from development to commercial

Advanced Modular Coal Gasification – One Example

Improvements:

- Eliminates most solids handling
- Advanced technologies reduce cost and size and improve efficiency (e.g., operate higher temperature)
- Reduces number of equipment pieces
- Improves reliability/availability/maintainability
- Avoids LTGC and slag handling
- Reduces cleanup requirements





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