A Modular System for Natural Gas Flaring Problem

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### 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.

- At this scale, traditional technologies will be expensive.
Features of Small Scale Production

- Low capital cost, fast build, use mass produced parts
- Less price risk on raw material: low volumes
- Less market risk for output, same reason

Large scale: few can finance, design, construct and operate

Small scale: democratization of the industry
  - More innovation likely in this cohort group than in oligopoly

Fast to market: size is typical of prototype plants
- Less likely to incur “Valley of Death”

Allows monetization of stranded distributed sources

Innovation in business models needed
Internal combustion engines as small-scale, inexpensive technology for converting natural gas to syngas for conversion to a liquid product (in this case methanol).

* Picture from www.eajv.ca, June 17, 2015
Micro-Reformers for Distributed GTL

Technology Concept

*Internal combustion engines as small inexpensive technology for converting natural gas to syngas for conversion to methanol*

- Small footprint syngas production and utilization
- Modular unit design
- Small scale syngas to liquids conversion (methanol)

Impact

*Enabling economically competitive, efficient use of distributed and stranded natural gas*

- Small unit size allows for centralized or distributed right-in-time deployment
- Methanol product is a viable entry into established fuels market
- Reduces greenhouse gas emissions from flaring
- Low CAPEX and fast replacement times

Innovations

- Utilizing mass produced internal combustion engines and gas conversion technology
- Integrated system combining the engine-based syngas generation with methanol production
- Small scale pilot capable of syngas production equivalent to 10 bbl/d of methanol
Why An Engine?

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

**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

**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

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**Economies of Scale**

\[
\text{Cost} = C_0 \cdot (\text{size})^\alpha, \quad \alpha < 1
\]

**Economies of Mass Manufacturing**

Cost of n-th unit:

\[
\frac{c_{2n}}{c_n} = \varepsilon
\]

Unit cost drops with production:

\[
c_n = c_1 \varepsilon^{\log_2 n} = c_1 n^{\log_2 \varepsilon}
\]

Cost of N units:

\[
= \frac{c_1}{1+\log_2 \varepsilon} \cdot N^{1+\log_2 \varepsilon}
\]

Empirically:

\[
\alpha \cong 1 + \log_2 \varepsilon
\]
Why Methanol?

- Well-established synthesis equipment
- Minimal water production/usage
- Large market can be an entry point for technology
- Large demand currently met through imports
- Interest for small-scale distributed production

*Gas-field location, gas wetness, impurities etc.
Fischer Tropsch Reactor Skid

- 1 bbl/day liquid hydrocarbons
  - On-skid wax and light liquid collection
- Flexible syngas source
  - Coal Gasification or NG POx
- High single-pass conversion
- Small footprint compact design
- Operations begin: Fall 2016
Engine Reformer

MIT Sloan Automotive Laboratory

- Bench scale engine test system
- Proof of concept demonstration of methane conversion to syngas in internal combustion engine
- Key operating parameters developed to obtain syngas suitable for chemicals synthesis ($H_2/CO \geq 1.8$)
- Air as oxidant feed, eliminating need for air separation unit
Bench-Scale Testing Data

- Bench-scale engine testing achieved syngas suitable for methanol production
- Operated at the highest reported equivalence ratio ($\Phi_{HC}$) generating the highest $\text{H}_2/\text{CO}$ ratio reported while using air as an oxidant

Engine operation at $\Phi_{HC} \sim 2.2$ with a 5% $\text{H}_2$ in the fuel feed generates a $\text{H}_2/\text{CO}$ ratio of 1.8 with 85-90% conversion of the hydrocarbon.

*Master Thesis, Emmanuel Lim, MIT 2010*
Integrated prototype system being developed

The system will:
- Process up to 50,000 scfd of natural gas
- Produce syngas equivalent to 10 bbl/d of methanol
- Generate key engineering data for development of prototype field unit
- Be a test bed of technology integration
Technical Status

Bench-scale Testing

• Proof-of-concept testing
• Sweep of engine parameters
• Optimize syngas production
• Demonstrate CH$_3$OH synthesis with syngas composition.

Achieved engine operation to generates a H$_2$/CO ratio of 1.8 with 85-90% conversion of the hydrocarbon.

Highest reported $\Phi_{HC}$ engine operation with air.

Integrated System Design & Fabrication

• Worked with engineering firms for detail design of engine and methanol systems
• Performed analysis of engine market and design specifications to select an engine
• Ongoing testing of the engine system during fabrication

Engine system capable of converting 50,000 scfd of natural gas to synthesis gas.

Engine system delivery and testing scheduled for July 2016.

Integrated System Testing

• Begin commissioning in summer 2016
• Facility prep ongoing
• Demonstrate Methanol production from engine exhaust

Syngas production at scale that would be capable of producing 10 bbl/d of methanol.

Integrated system completion scheduled for Summer 2016.
• Syngas costs from RTI micro-reformer compare favorably with conventional reformer costs (based on $3/MMBtu NG cost).

• The RTI micro-reformer 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?

- 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
Balance of Plant Innovation

- Modular systems require development of all system components.

- In traditional large plants Balance of Plant (BOP) components routinely exceed 50% of the equipment cost.

- In the engine reformer system BOP increases to in excess of 85% of the equipment cost.

Key BOP areas for innovation:
- Compression
- Heat Management
- Separations
- Controls
Implementation of these technologies requires significant understanding/interaction across the value chain.

Integrating the value chain at the modular scale may require innovative business models versus traditional petrochemical models.
RTI is developing a technology that enables competitive small-scale conversion of natural gas.

Modular technologies may need to look at non-traditional development paths.

- **Process Intensification:**
  - Requires a full system approach;
  - Must take advantage of innovation in manufacturing to provide economic competitiveness;
  - Needs to look at other fields to transfer developed technologies to new applications;
  - Should not be custom designs.