Technology Study: Project Update

the Energy to Lead

Low Emissions via Hydrogen Enrichment

Cost-Effectively Achievement of Compliance with SCAQMD Rule 1110.2 **NO_X** Levels

without Catalytic After-treatment or Biogas Clean-up

Wednesday May 28, 2014

California Energy Commission PON 11-507

GTI Project: PIR-11-028

VRONAY ENGINEERING SERVICES

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Project Team

- California Energy Commission – Project Sponsor
- Gas Technology Institute - Prime Contractor
- San Bernardino Municipal Water District – Host Site / co-funder
- AlturDyne Power Systems, Design and Construction of POGT
- Vronay Engineering Services Corp, Technical Lead and System Integrator
- Southern California Gas Company / Emissions Testing Support and Co-Funder
- SCAQMD – Co-funder

Introduction

- Challenges of POTW's meeting Rule 1110.2 NO_x Levels
- SCR can be technically effective but the technology is expensive and in the case of digester gas / landfill gas applications also requires considerable clean-up of the gas.
- Gas clean-up can be equal to or more expensive than the SCR system
- Gas clean-up also introduces new costs for carbon-like filter media renewal and/or electrical power for gas drying equipment
- Need an emissions reduction technology that can eliminate the need for gas clean-up, not require additional fuel or power, is simple and can be cost-effectively retrofitted to existing engines.

The Challenge of meeting 1110.2

- Rule 1110.2 Requires SI Internal Combustion Engines to maintain emissions levels of **11 PPM NO_x, 250 PPMv CO & 30 PPMv HC**

- Biogas fueled RICE engines produce low emissions of NO_x and CO by Operating Lean of Stoichiometric

– Actual: NO_x 25-30 PPMv, CO ≤ 160-200 PPMv
– Permit: NO_x 36 PPMv, CO ≤ 250 PPMv

- Engines already operate near the lean limit ≈ 8% exhaust O2, lambda ≈1.6-1.8

- Operating leaner produces dramatically lower NO_x emissions levels since the peak combustion temperature drops with leaner air/fuel ratios and NOx formation reduces exponentially with combustion temperatures

- **If we could extend the lean limit, we could further reduce NO_x**

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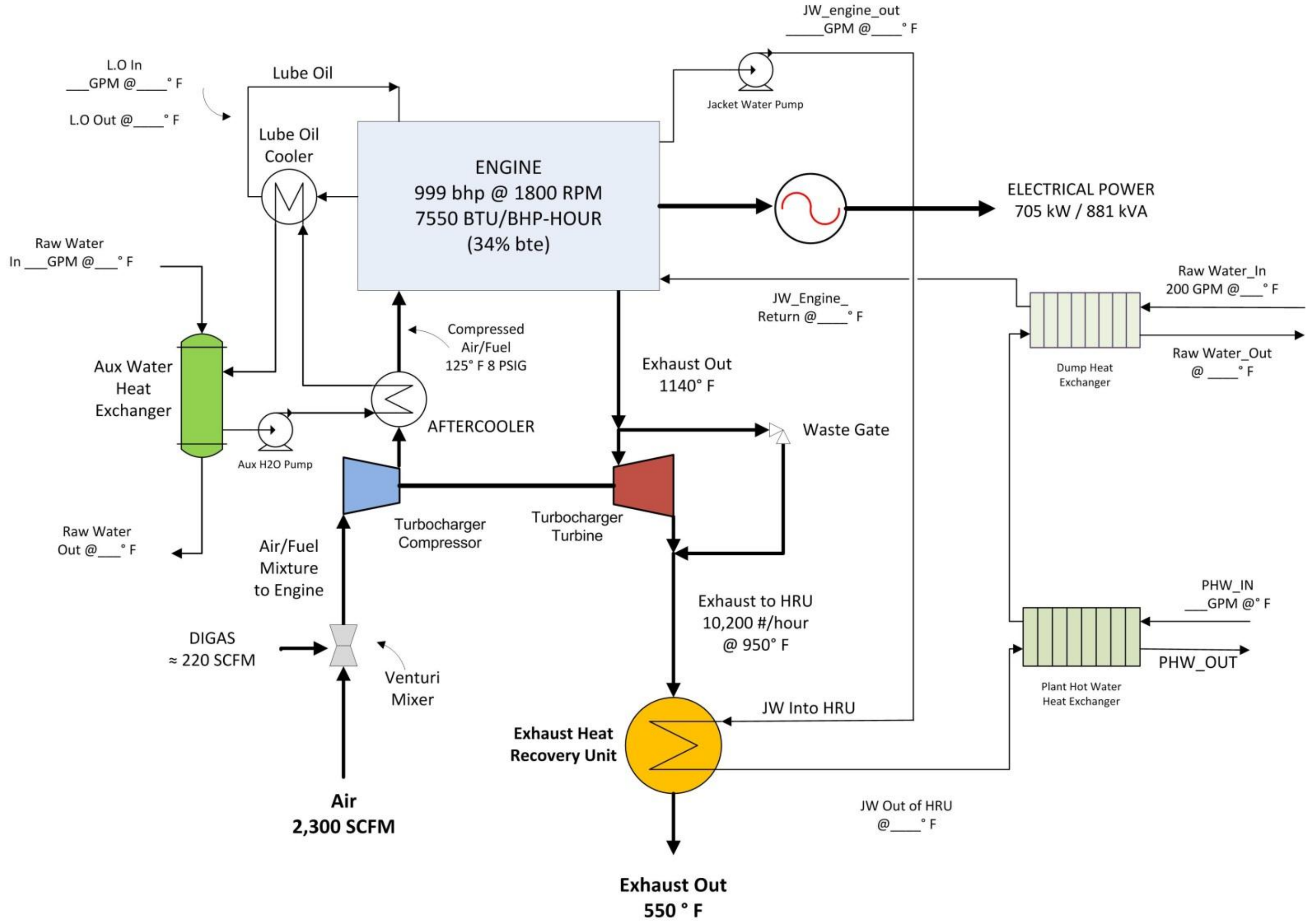
Assisted Lean Operation (HALO)

- Wide body of research has shown dramatic reductions of NO_x with the addition of 3-6% by mass with hydrogen
- Most of the work performed in the on-highway market where the technology did not gain commercial traction due to hydrogen storage issues and on-board hydrogen production costs, weight and safety issues
- A considerable amount of work on HALO has been conducted by the natural gas industry which has tested larger, natural gas engines as well as smaller, high-speed units for cogeneration applications
- Our project produces H2 Rich Gas in a balance of CH4 and Inserts using a Partial Oxidation Reactor and Energy Extracting Turbines to produce 100% of the engine fuel gas and additional electrical power.

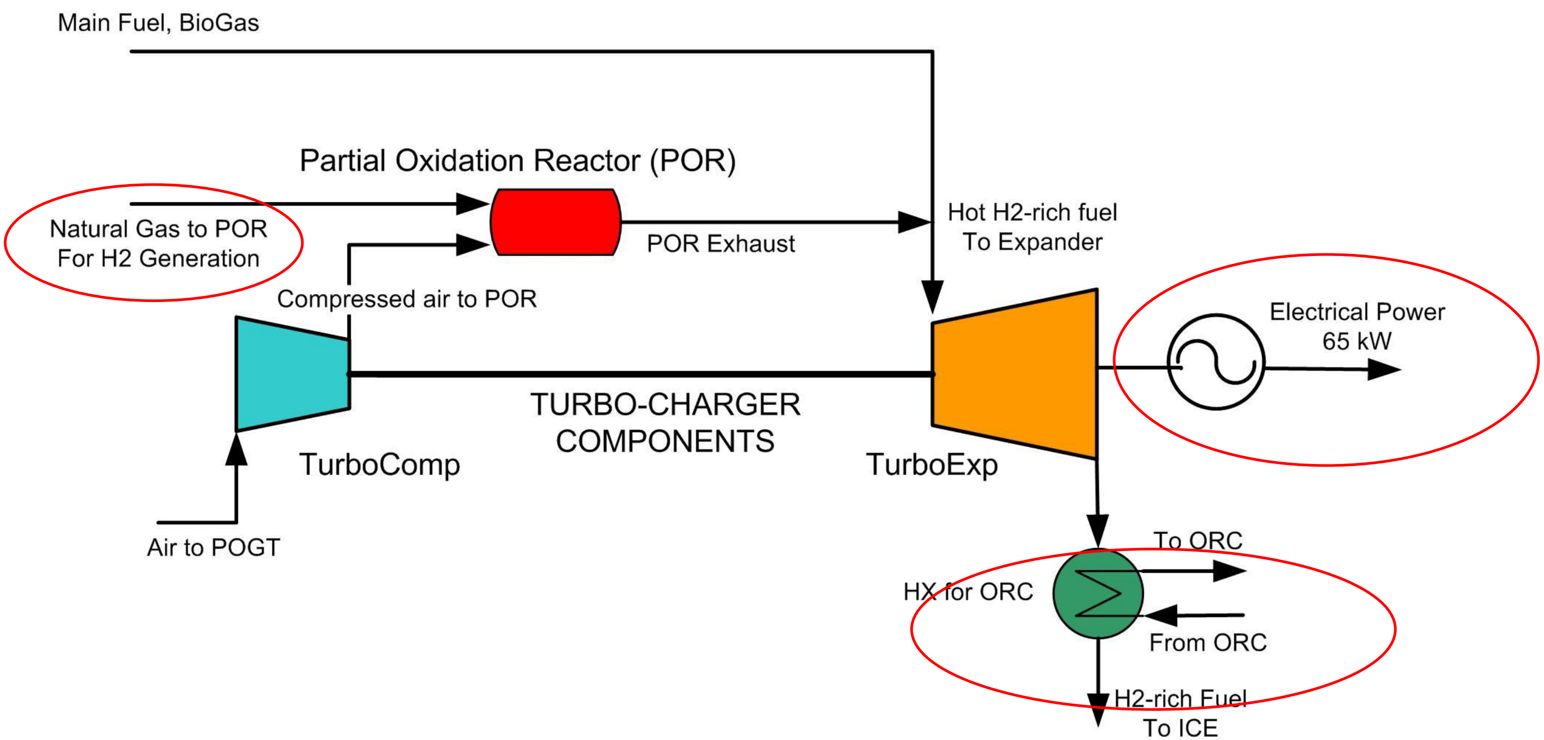
This is a Good Fit for Biogas Engines

- Use of a POR reactor to produce a hydrogen rich gas
  - Does not introduce new requirements for gas clean-up
  - Does use biogas for hydrogen feedstock
  - Does produce additional electrical energy and heat, both of which are useful for waste water treatment facilities
- Component Technologies are already at mature stage of development (…well sort of- more on this later…)
- Unlike After-treatment / SCR, the system envisioned for this project will improve the overall efficiency of the process
  - Grams/**BHP**

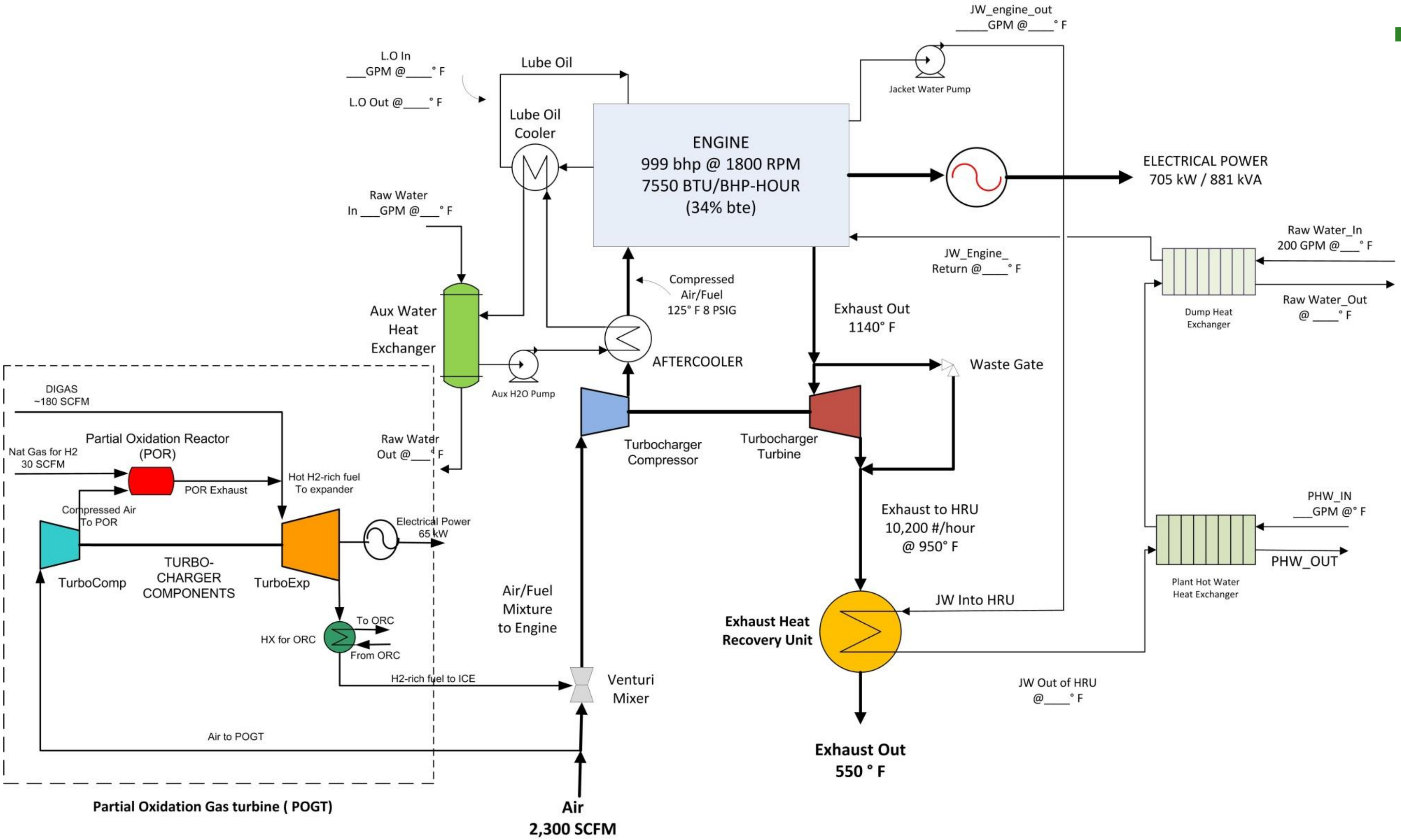
Simplified Flow Diagram - Engine



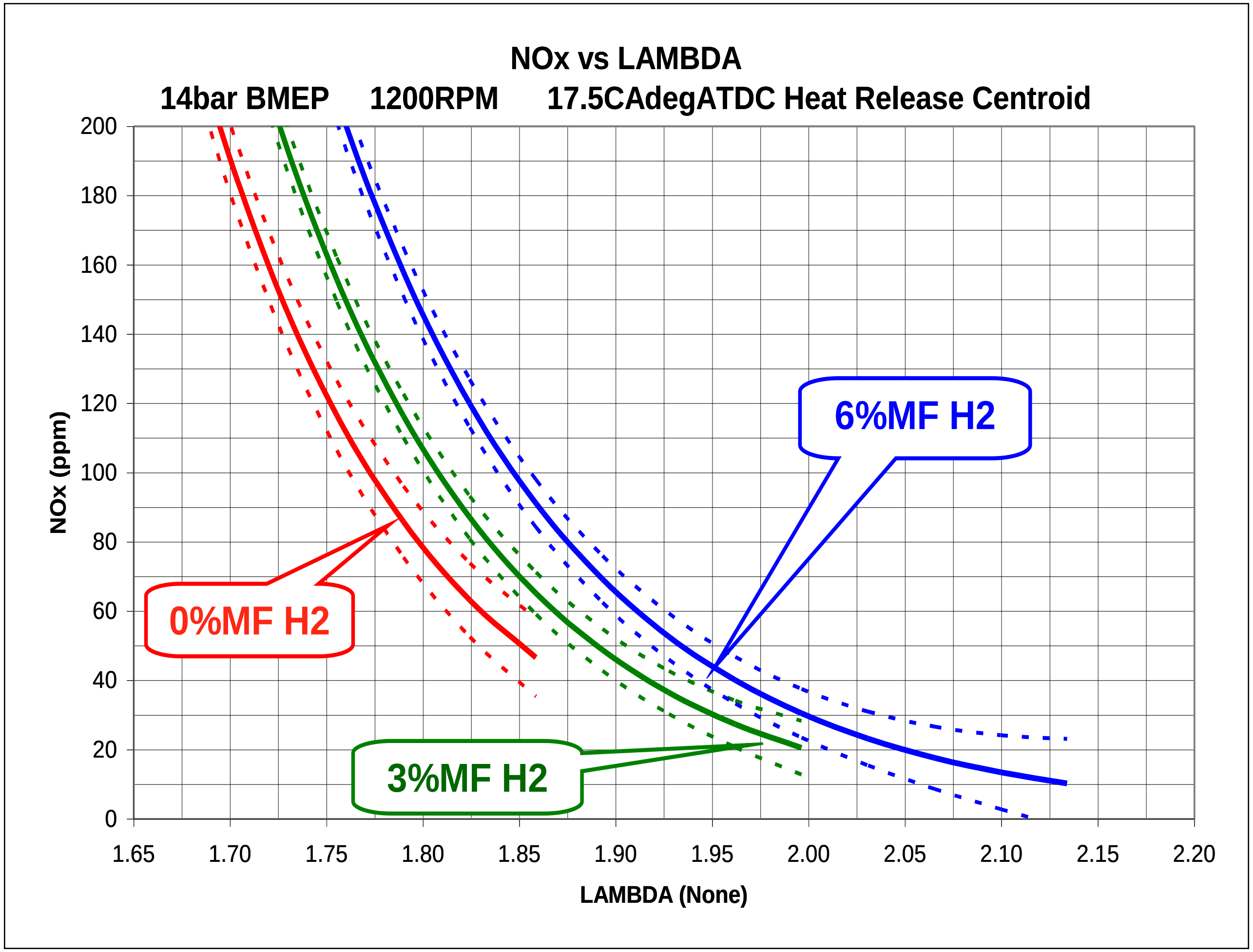
Simplified Flow Diagram – POR+GT



Simplified Flow Diagram - Combined



Example Performance (Raw NOx)

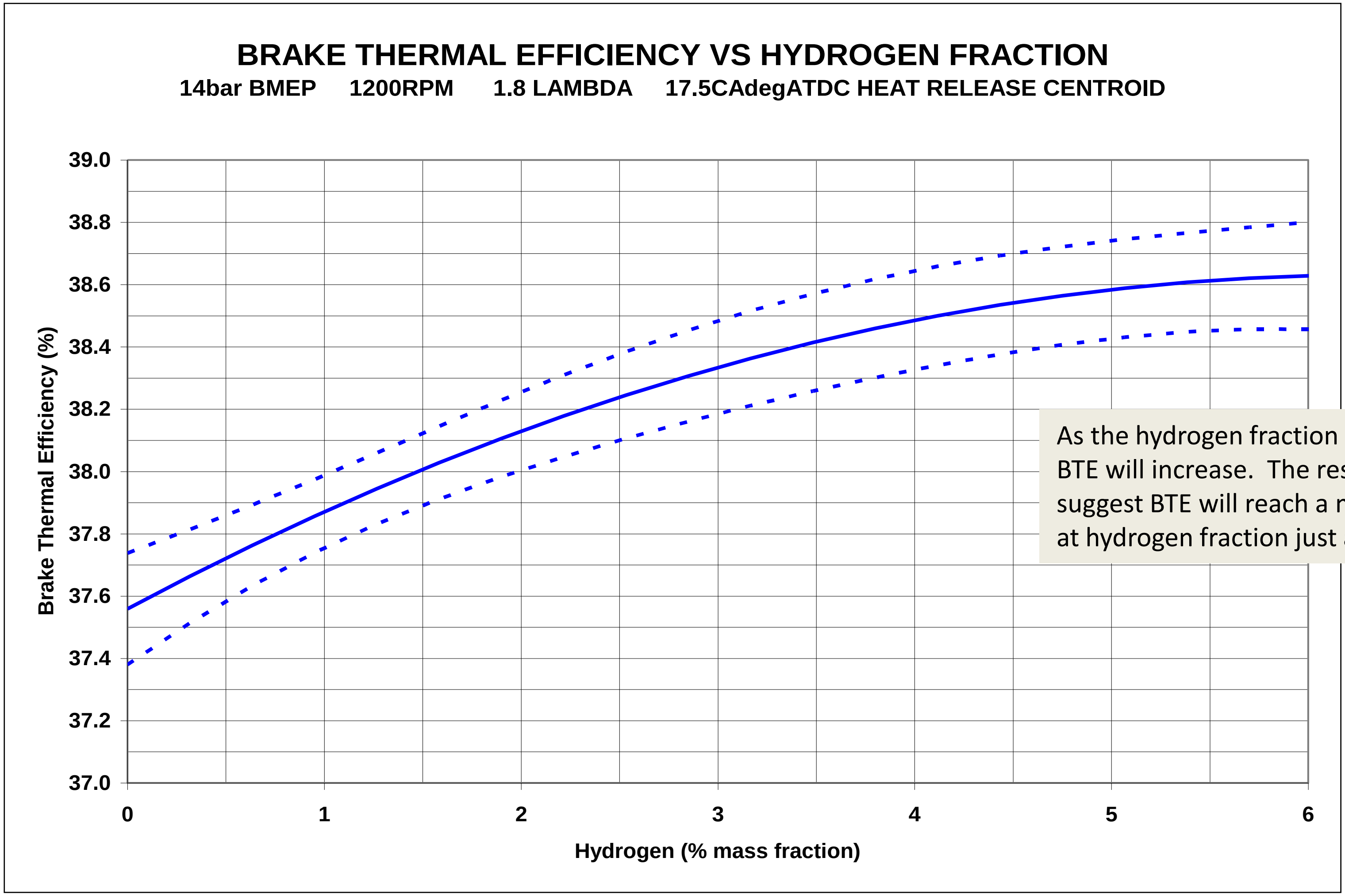


Lambda at the limit of combustion stability was observed to be as follows:

1. 0% hydrogen: 1.86
2. 3% hydrogen: 2.00
3. 6% hydrogen: 2.13

At Exhaust O2 of 11%
NOx reduced to 5.5 PPMv corr

Example Performance - Efficiency



As the hydrogen fraction increases, BTE will increase. The results suggest BTE will reach a maximum at hydrogen fraction just above 6%.

Summary of Effects of HALO

- The addition of hydrogen significantly extends the lean limit of combustion stability under LB conditions

- Lean limit is increased from Lambda of 1.85 using pure natural gas to 2.15 with 6 mass % hydrogen blended with the natural gas

- Raw exhaust NOx is reduced from 50 Parts Per Million (ppm) to 10ppm, respectively

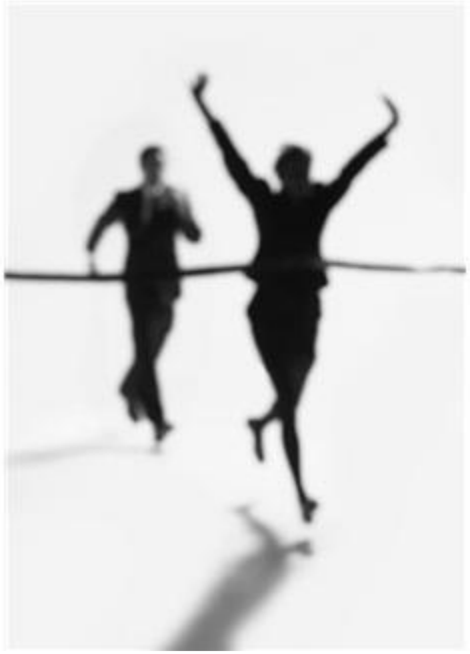
- Corrected NOx ≈ 6 PPMv

- The addition of hydrogen significantly reduces raw exhaust hydrocarbons
- 6 mass % hydrogen blended with natural gas reduced raw exhaust hydrocarbons by 22

A Little More Detail…

- HALO increases the burn velocity, with a laminar burning velocity of 2.9 m/s for hydrogen verses a laminar burning velocity of 0.38 m/s for methane.
- Improves cycle-by-cycle variations of lean-burn biogas gas engines.
- Hydrogen is characterized by a rapid combustion speed, a wider combustion limit and low ignition energy.
- These characteristics can reduce the exhaust emissions of the fuel, especially the methane and carbon monoxide emissions.
- The fuel economy and thermal efficiency can also be increased by the addition of hydrogen.

Project Status



Project Status

- POR / POGT Equipment Skid is in Final Stages of Assembly and Preparing for Testing at GTI in Chicago
- Testing of POR –GT System and GTI June 2014
- Installation of System and Integration into host site cogeneration system July 2014
- Field Test Program Commences August 2014
- Test Results Fall of 2014
- Final Report December 2014

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Some Project Challenges

- POR / POGT Equipment Complexity Increased Dramatically During the Design Stage and has been the dominant activity.

- As POGT Complexity has had a cascading Effect of Infrastructure Requirements and Construction/Installation Costs

- A key project objective, can we produce H2 rich gas containing fuel and inserts by reforming biogas –AND
  - Can this fuel enable Compliance with the target 1110.2 Emissions targets remains to determined

- There is broad interest in POR combustion across many industries for emissions reductions

Completed Work

- Design of POGT
- Installation and integration drawings @ 90%
- Application Engineering and Engine Operating Modifications
- Completed baseline testing of engine (SCAQMD Funded)
- Completed modeling + simulation of POR and POR+GT System
- Identified and Developed engine and POR_GT control strategies for AFR, load control and fuel gas composition control – i.e. H2 content

Next Steps

> Completion of POR+GT Assembly and Hot Test at APS in San Diego

> Performance and Optimization Testing at GTI

> Installation of System at Host Site

> 30-day System Optimization Testing at Site

> 6-Month Long-Term Test at Host Site


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OH
CH2
H2C

Thank-you

John Vronay, PE

john@vronay.com

www.vronay.com