ADVANCING COMBINED HEAT AND POWER DEVELOPMENT THROUGH INNOVATIONS

2014 Staff Workshop
Combined Heat and Power to Support California's Energy and Environmental Goals

July 14, 2014
Hearing Room A, 1516 Ninth Street, Sacramento, CA

Renewable Energy and Advanced Generation RD&D

Goals and Strategies

Overall Goal

- Advance the science and technology, reduce barriers and increase market penetration of combined heat and power (CHP)/combined cooling, heating and power (CCHP)

Strategies:

- Expand CHP/CCHP while developing innovative energy supply based on reliability, affordability and environmental attributes
  - CHP as the most efficient form of DG and qualifies as first in the loading order
  - Minimize pollutant formation during combustion processes
  - Maximize heat utilization and waste heat recovery (i.e., increase energy efficiency)
  - Upgrade the thermodynamic quality of fuels
- Develop hybrid generation, fuel-flexible systems and other energy efficient and low emission CHP technologies
- Develop and demonstrate diversified applications that use renewable resources

RD&D Innovations Supporting the Development of CHP in California

Some Technical and Cost Challenges	Research Solutions
▪ Ability to meet state and local air emissions requirements - e.g. CARB 2007 and SCAQMD's Rule 1110.2 ▪ Fuel flexibility to benefit from renewable and alternative fuels ▪ Hybrid generation –benefit from synergistic combination of advanced technologies ▪ Systems integration, dispatchability and controls, including ability to integrate with microgrid ▪ Overall performance and cost improvement	***Technology developed and being developed cuts across these challenges.*** **Examples of innovations:** • Duel oxidation catalyst (DE Solutions/Tecogen) • Homogenous Charge Compression Ignition – HCCI (Makel Engineering) • Air-independent internal oxidation (ZERE) • Premium power CHP system (Tecogen) • Boiler burner energy system technology –BBEST (Altex) • Tri-generation energy system technology –TRIEST (Altex) • Integrated microturbine with ultra-low NOx burner (GTI) • Fuel-flexible microturbine (UCI) • Partial oxidation gas turbine (GTI) • Free piston engine technology (EtaGen)

Example Technology – Hybrid POGT-ICE for CHP

Fuel-Flexible Hybrid Partial Oxidation Gas Turbine (POGT) – Internal Combustion Engine (ICE) Combined Heat and Power

- **Goal**: Develop and demonstrate a Partial Oxidation Gas Turbine system integrated with an IC Engine to reduce emissions to new, lower levels that must be met by January 2016 at less than one half the capital investment than required with SCR.
- **Features of the POGT-ICE Approach**
  - Can use biogas or natural gas for hydrogen production
  - Does not introduce new requirements for biogas or natural gas clean-up
  - Produces additional electrical energy and heat that can be used onsite
  - Does not require any catalysts
  - Unlike SCR, the system will increase power output, potentially improve the engine efficiency and increase overall CHP efficiency

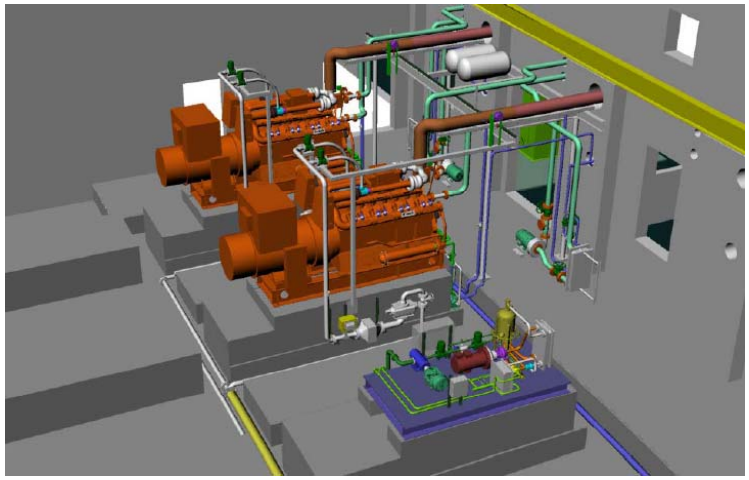
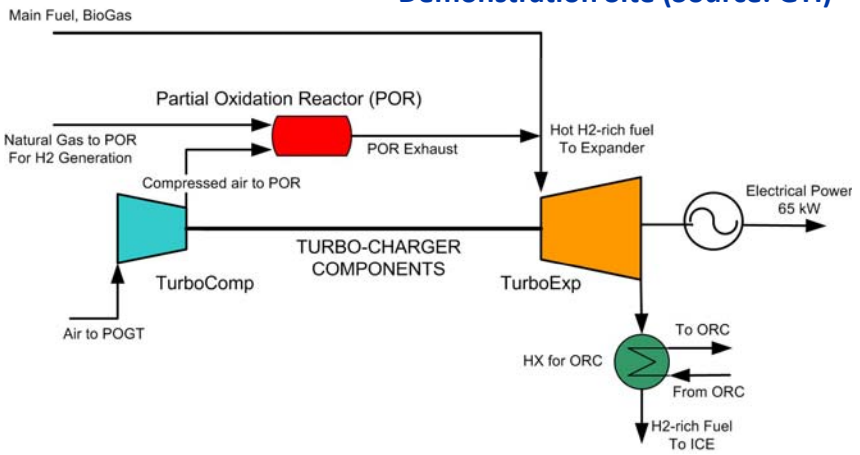


Diagram of planned hybrid POGT-ICE at the Demonstration Site (Source: GTI)



Simplified Flow Diagram – POGT (Source: GTI)

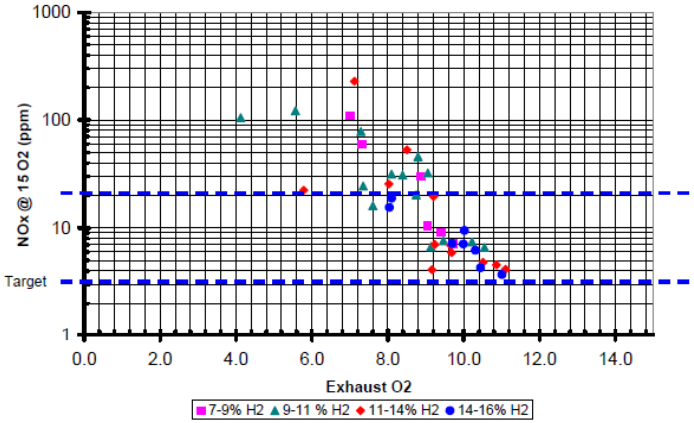
- **Contractor**: Gas Technology Institute
- **Funding**: $1,767,185 (PIER); $870,388 (Match)

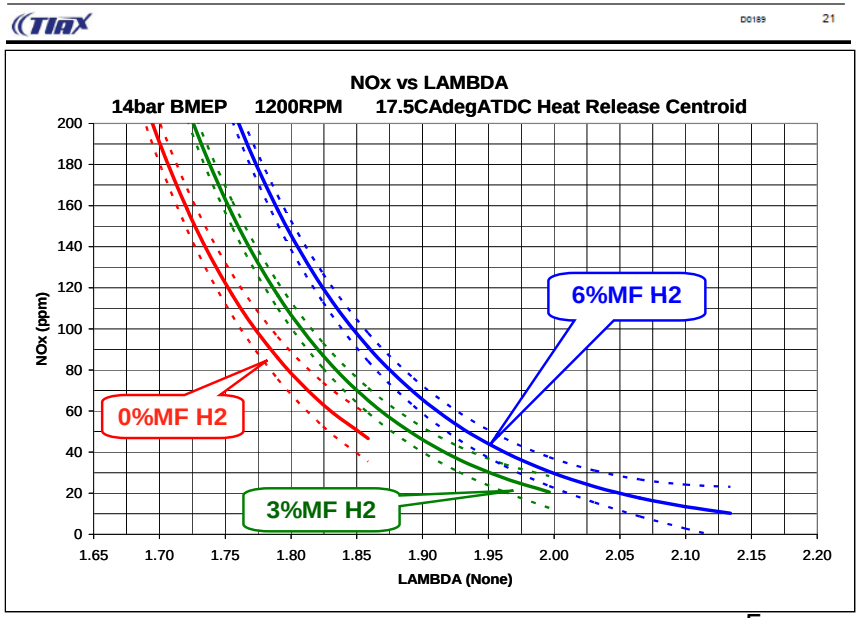
Example Technology – Hybrid POGT-ICE for CHP

Hydrogen – Assisted Lean Operation (HALO) and POGT

- Research have shown NO_x reductions and some efficiency increase in ICE with the addition of 3-6% by mass of hydrogen to extend lean limit combustion
- Considerable amount of work on HALO has been conducted on larger, stationary natural gas engines as well as smaller, high-speed units for cogeneration applications
- Principal challenge is to cost-effectively supply the hydrogen for fuel enrichment
- Proposed approach relies upon POGT technology that GTI has been developing over the past 7+ years

Higher hydrogen supplementation had the greatest impact in allowing high levels of excess air and EGR, lowering NOx emissions.





Effect of H2 addition to Natural Gas 330 kWe Engine Test Cell Data-(Raw NOx) (Source: GTI)

Example Technology: BBEST CHP

Boiler Burner Energy System Technology (BBEST) for Firetube Boilers

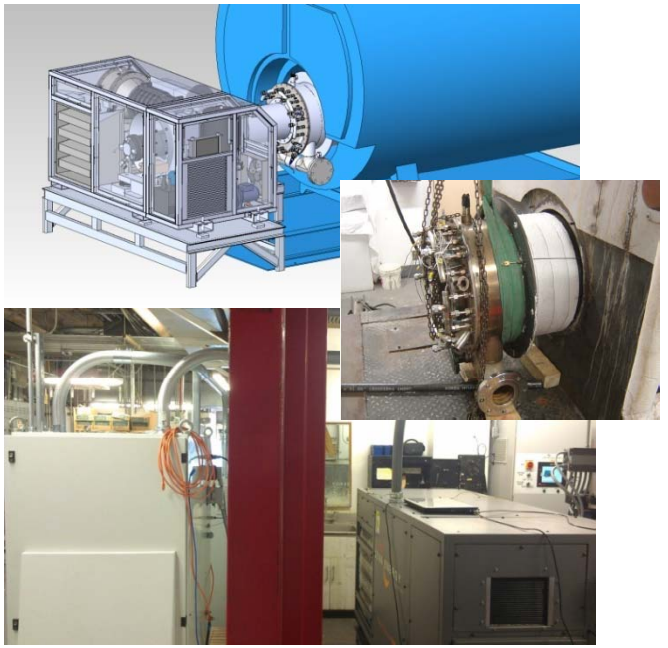
Goal: Microturbine-based Power & Heat at Lowest Possible Cost

Technology Summary:

- Engineered and integrated SCGT with an innovative boiler burner
- Tested in a firetube boiler of 10 million Btu/hr scale
- Installed at the Costa Mesa Westin Hotel and tested using applicable protocols
  - ✓ Providing heat and power since 2012
  - ✓ UL Listed as "Field Evaluated Product" at City's request
  - ✓ Meets modified AQMD Emissions Requirements
- Performance and economics of completed met initial goals

Features and Benefits

- 100 kWe Simple Cycle Microturbine
- Meets thermal need and produces power at $.065/kWh
- Reduces GHG by up to 30% versus grid
- Has improved reliability versus alternative CHP
- Two year payback
- Meet emissions limits for all CA regions



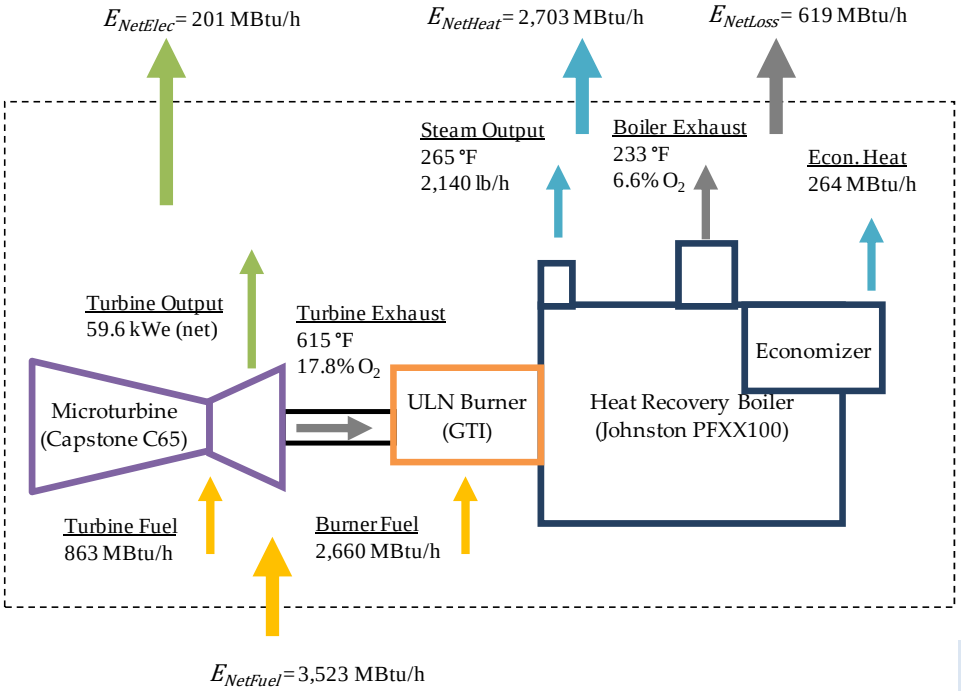
BBEST installation at Westin Hotel in Costa Mesa, CA

Contractor: Altex Technologies Corporation
Funding: $1,493,581(PIER); $473,629(Match)
Agreement No.: PIR-09-012
Term: 6/21/2010 – 3/30/2013

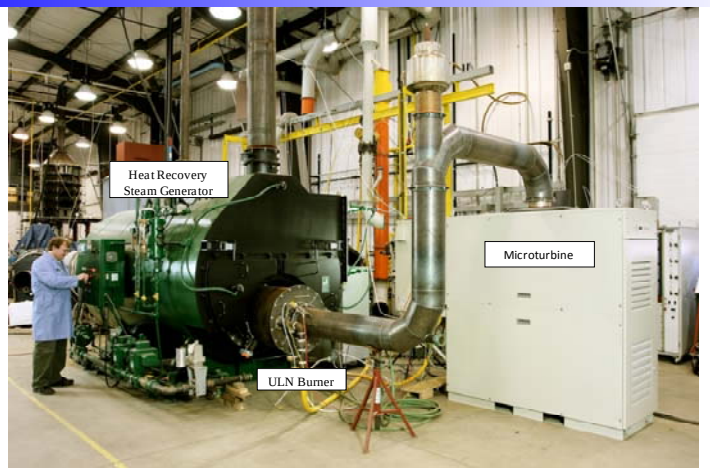
Example Technology – Gas Turbine based CHP

Integrated CHP that Reduces Costs While Meeting Emissions Standard

- **Goal**: Develop a cost-effective gas turbine based CHP system that improves overall efficiency and meets CARB 2007 emission standards without catalytic exhaust gas treatment.



System Performance at Full Load – Host Site



FlexCHP 65 System in Laboratory Testing at GTI

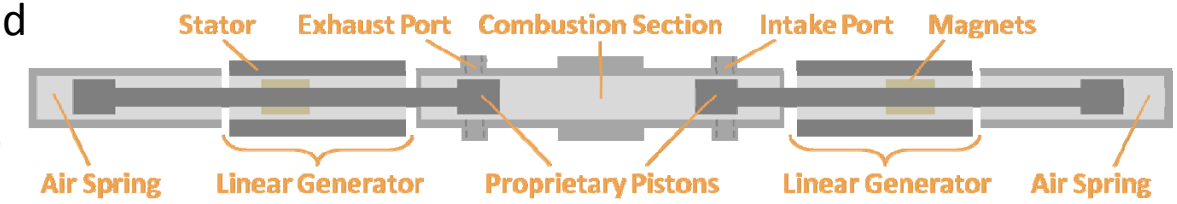
- **FlexCHP system has achieved performance objectives**
  - Achieved CARB 2007 emission standards
  - Achieved 84% (HHV) system efficiency
  - Generated a pre-engineered cost-effective CHP package employing state-of-the-art design concepts
  - Validated the system in the GTI laboratory
  - Demonstrated the system at a California host site

- **Contractor**: Gas Technology Institute
- **Funding**: $501,437 (PIER); $673,283 (Match)

Example Technology – Free Piston Engine for CHP

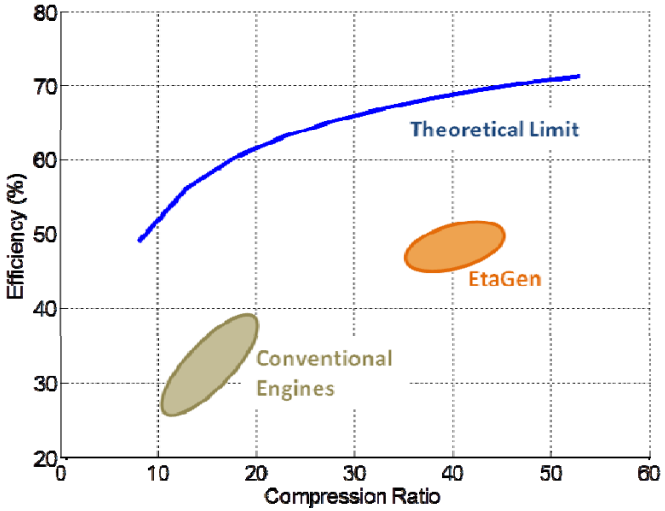
High Compression Ratio Free Piston Engine for CHP

- **Goal**: Design, fabricate, install, and test an advanced prototype high compression ratio, homogeneous charge compression ignition (HCCI), free-piston engine for CHP applications.



Cross section illustration of EtaGen's free-piston engine (Source: EtaGen).

- **Features:**
  - New engine architecture and clean piston technology that enable:
    - ✓ High-expansion operation
    - ✓ Ultra-low emissions
    - ✓ Cleaner, simpler engine
  - Low-temperature HCCI combustion
  - Linear piston motion, low side-loads, proprietary piston/bearing design
  - Standard materials and manufacturing processes
  - No oil, no spark plug



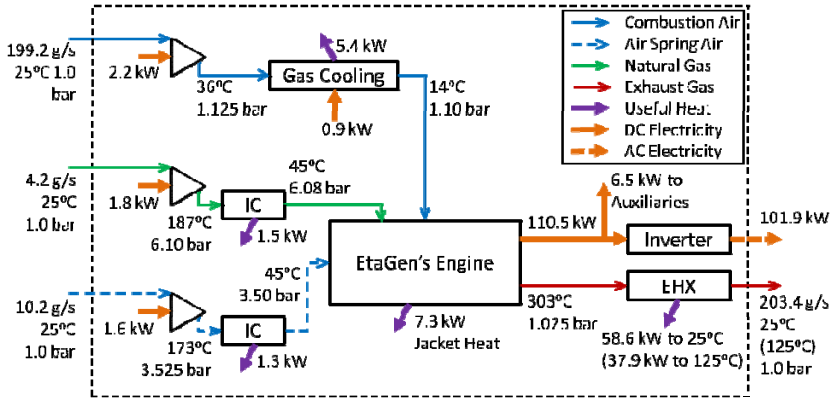
Higher expansion ratios lead to higher efficiencies (Source: EtaGen)

- **Contractor**: EtaGen, Inc.
- **Funding**: $796,247 (PIER); $1,099,580 (Match)

Example Technology – Free Piston Engine for CHP

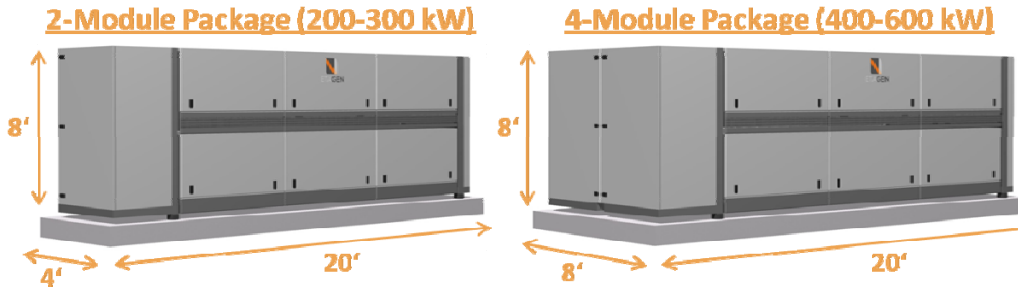
High Compression Ratio Free Piston Engine for CHP

- **Project Targets:**
  - Design and build a fully-enclosed free-piston engine with auxiliaries (the "System")
  - 4,000 cumulative hours over a 9 month period
  - Greater than 50 kW electric output
  - Greater than 40% LHV electrical efficiency
  - Greater than 80% LHV measured potential overall thermal efficiency
  - Air criteria pollutant emission less than CARB 2007 DG standard



Systems diagram of EtaGen's free-piston engine configured for CHP applications (Source: EtaGen).

- **Projected Commercial Performance Goals:**
  - Greater than 100 kW per module electric output
  - Over 45% (electrical) and over 85% (overall thermal) efficiencies (based on LHV)
  - Meets CARB 2007 emissions requirements based on electric-only output



Early concept drawings of EtaGen's commercial products illustrating modularity (Source: EtaGen)

- **Contractor**: EtaGen, Inc.
- **Funding**: $796,247 (PIER); $1,099,580 (Match)

RD&D Opportunities on CHP

Furthering CHP Development Under the Natural Gas (NG) R&D Program

- **Bottoming Cycle Solutions for Natural Gas Conservation (FY 13/14 NG Budget Plan)**
  - Support technological advances needed for wide-scale adoption of bottoming cycles for electricity generation in key California industries
- **Clean micro-scale and other novel systems for small to intermediate CHP/CCHP (FY 14/15 NG Budget Plan)**
  - Technological development and demonstration needed to enhance market deployment of micro-CHP systems of up to 50 kWe size range
  - Breakthrough clean and efficient CHP systems employing novel conversion methods and emissions control strategies
- **Cost-effective Natural Gas Power Generation with Advanced Carbon Dioxide (CO2) Capture Technologies (FY 14/15 NG Budget Plan)**
  - Improving the cost effectiveness of novel technologies for CO_2 capture
  - Opportunity for synergy with combined heat and power and other emerging technologies for carbon capture from natural gas power plants

Thank you!

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