GENSETS KICKOFF MEETING

INFINIA TECHNOLOGY CORPORATION (ITC) TEAM

Sustainable Economic mCHP Stirling (SEmS) Generator

21 October, 2015

Sustainable Economic mCHP Stirling Generator

ITC/Qnergy GENSETS Team

Principal Investigator
Maury White

Stirling Engine System Integration

Project Engineer
Shane Draney

Qnergy Project Engineer
Eran Gonen

Stirling Engine Manufacturing

Manufacturing Lead
Jeff Lowe

Gas Technology Institute
Combustion System Development

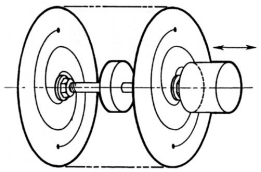
Combustion System Lead
Aleks Kozlov

Technology to Market
Mike Cocking

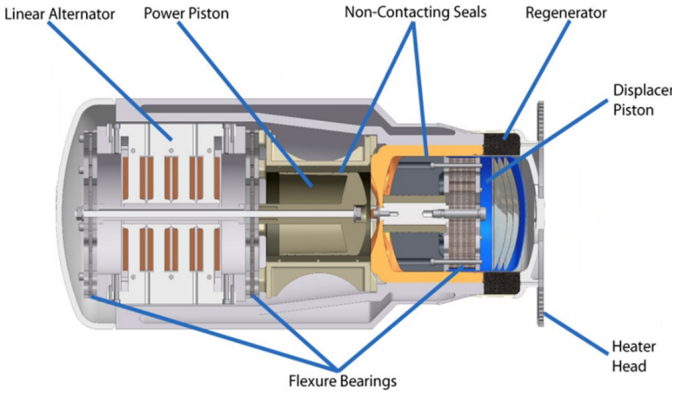
High Temperature Materials
Ron Keller

Commercialization Support
Stephen Memory

ITC/Qnergy Free-Piston Stirling (FPS) Technology Overview



Key technology differentiator for all ITC/Qnergy engines and coolers is flexural bearings coupled with clearance seals to eliminate rubbing and wear



Generic configuration of typical ITC/Qnergy engine

Basic ITC FPS Engine Topology and Operational Concept

- *Heat is supplied externally to the heater head and rejected to coolant at the cold end*
- *Displacer piston supported by internal flexure bearings creates pressure wave by shuttling helium working fluid between hot and cold regions*
- *Pressure wave drives flexure-supported power piston that runs with close clearance seal*
- *Magnet mover on piston rod reciprocates within linear alternator stator to produce power*
- *Only electrical feed-throughs penetrate the hermetically sealed pressure vessel*
- *Enables unparalleled maintenance-free life and reliability*

Sustainable Economic mCHP Stirling Generator

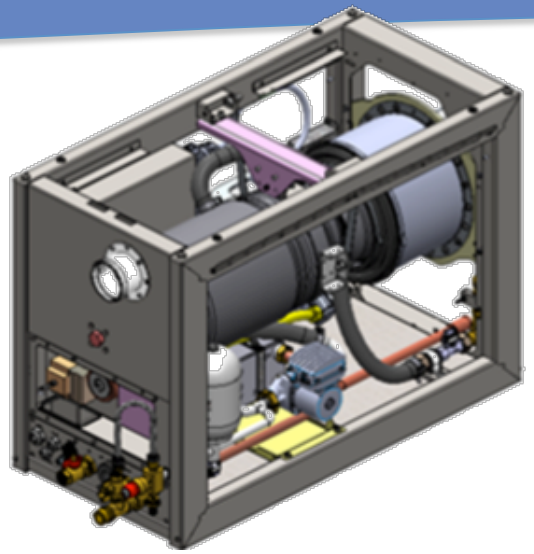
ITC/Qnergy GENSETS Approach

ITC GENSETS Project Plan

- *Design Around ITC FPS Engine Using Flexure Bearings*
- *Optimize System Performance Over Component Performance by Close Partner Collaboration*
- *Focus Development with Production Mindset Throughout*
- *Prototype 1 Fabrication Complete by End of Year 1*
- *Prototype 1 Testing Complete by End of Year 2*
- *Pre-Production Prototype 2 Fabrication Complete in Year 2*
- *Prototype 2 Testing/Delivery Complete by End of Year 3*
- *Ongoing Development of Commercialization Plan*

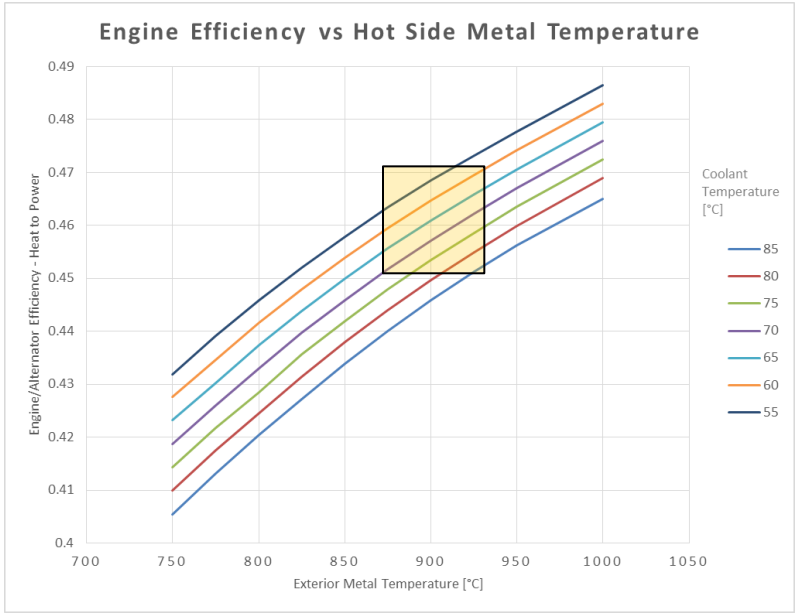
Target Performance and Approach

- *Engine/Alternator Efficiency >45% Heat to Electricity*
- *System Electrical Efficiency at 40% with TEG*
- *Key Innovations: Low-Cost, Ultra-High Efficiency, Ultra-Low Emissions Combustor, and High-Temperature High Efficiency Heater Head*
- *Ultra-Low NOx SuperPerm Staged Natural Gas Burner to Meet CARB 2007 Requirements*
- *Engine Rejector Preheats Water (Coolant Temperature), Condensing Combustor Increases It to 80C*



SEmS System Packaging Concept 14x18x28 in.

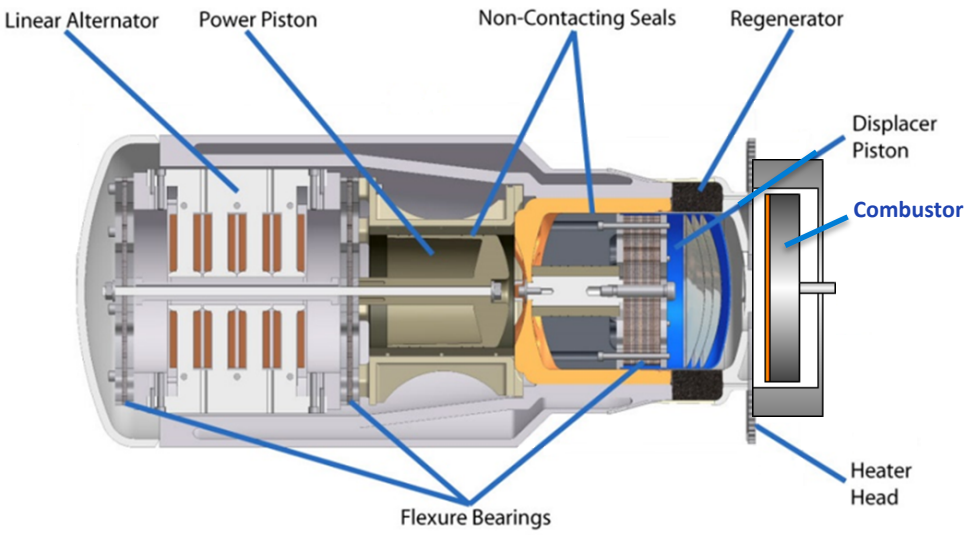
Engine/Alternator Efficiency vs. Hot & Cold Temperatures



Sustainable Economic mCHP Stirling Generator

ITC GENSETS Combustor Development by GTI

GTI Combustion System Technology Overview



- Advanced Ultra-High Efficiency, Ultra-Low Emissions System
  - High Recuperation Efficiency (~90%)
  - Advanced Condensing System
  - Low Excess Air Operation (~5%)
  - Meeting CARB 2007 Emissions Requirements

Sustainable Economic mCHP Stirling Generator

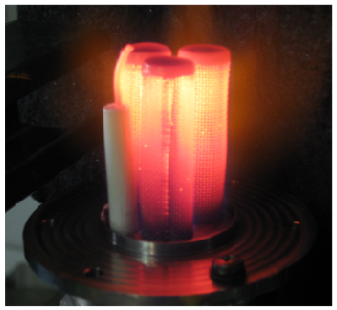
ITC GENSETS Combustor Development by GTI

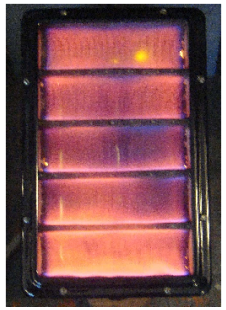
SuperPerm Burner

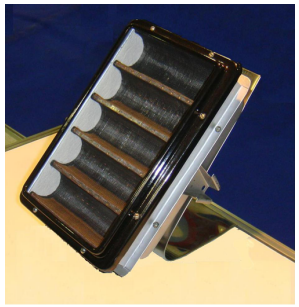
Flat Permeable Matrix Burner (4.5kW)

Volumetric Permeable Matrix Burners

(2.5 kW) **(15 KW)**







- Novel Non-Catalytic Surface Stabilized Combustion Method and Design
- Improved Combustion Chemistry and Combustion Kinetics
- High Infrared Radiation Flux
- Ultra-Low Emissions at Low (10%) Excess Air (NOx < 3vppm and CO < 12vppm Corrected to 3% O_2)
- Efficient High Temperature Operation with High Temperature Combustion Air
- Stabile Combustion at a Wide Range of Stoichiometric Ratios (from 0.35 to 1.8)
- Low Pressure Drop (~3-4 In. W.C.)
- Flexible Geometry

Key Challenges to Achieving GENSETS Goals and Mitigation Approaches

- Heater Head
  - Challenges are high temperature and low cost with long life
    - Team with Alcoa/Howmet for innovative materials and mass production approach
- Combustion System
  - Challenges are high temperature, ultra-high efficiency, ultra-low emissions, long life and low cost
    - Team with GTI for innovative combustion system
- System Integration
  - Challenge is to optimize integrated system performance
    - Assemble world-class team and closely coordinate system development