Free Piston Stirling Engine Based 1kW Generator

ARPA-E GENSETS Program Kickoff

21-22 October 2015

Rosemont, IL

PCI Precision Combustion, Inc.

SUNPOWER

AEROJET ROCKETDYNE

Sunpower's GENSETS Team

- **Sunpower, Inc.**
  - Team lead, FPSE lead, controls lead, prototype system integrator
  - Free Piston Stirling machine design , prototype, and low-volume production expertise
  - Free Piston Stirling controls design and prototype expertise
  - Prototype system and FPSE/combustor integration experience
  - Successful licensing of technology and technology transfer
- **Precision Combustion, Inc. (PCI)**
  - Combustor lead
  - Combustor and recuperator design and prototype development expertise
  - Combustor/FPSE integration experience
- **Aerojet Rocketdyne (AR)**
  - High temperature materials lead
  - Expertise in High Temperature (HT) materials selection, and testing
  - Expertise in HT materials processing, joining, and fabrication
  - Potential HT materials manufacturing capability

Team has an established, working relationship through this and other successful development programs.

PCI Precision Combustion, Inc.

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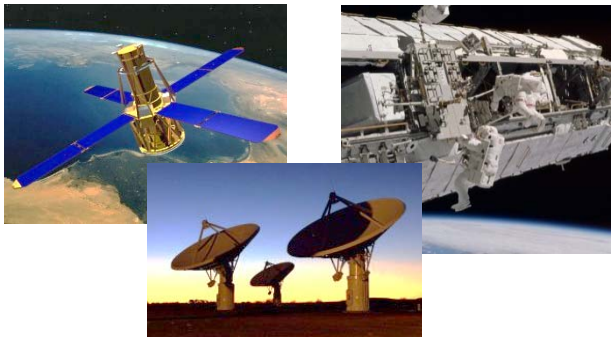
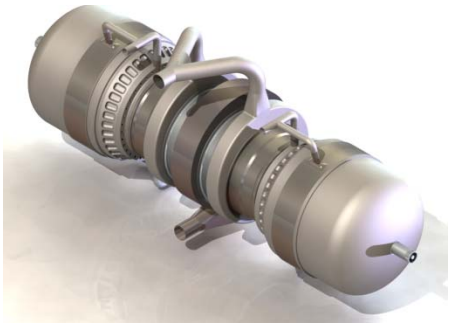
Sunpower Free-Piston Technology

Aerospace



Sunpower cryocoolers
- Space and terrestrial applications

Advanced Stirling Convertor
- 80W nominal output
- 40% average delivered efficiency



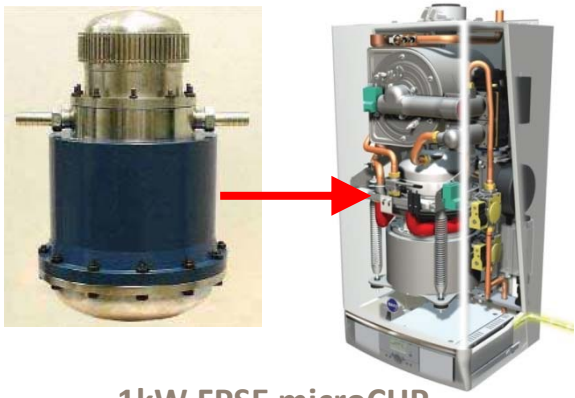
Fission Power
- 12 kW nominal output
- 27% delivered efficiency

Commercial

LG Electronics

Linear Compressors
- Licensed to LG Electronics
- Worldwide market penetration

Sunpower cryocooler manufacturing
- Industry leading performance, size, cost
- Current volume of 1000 units per year



1kW FPSE microCHP
- SP P2a design produced by SP licensee
- Tech transfer and DFM support provided
- ~10000 units sold and installed

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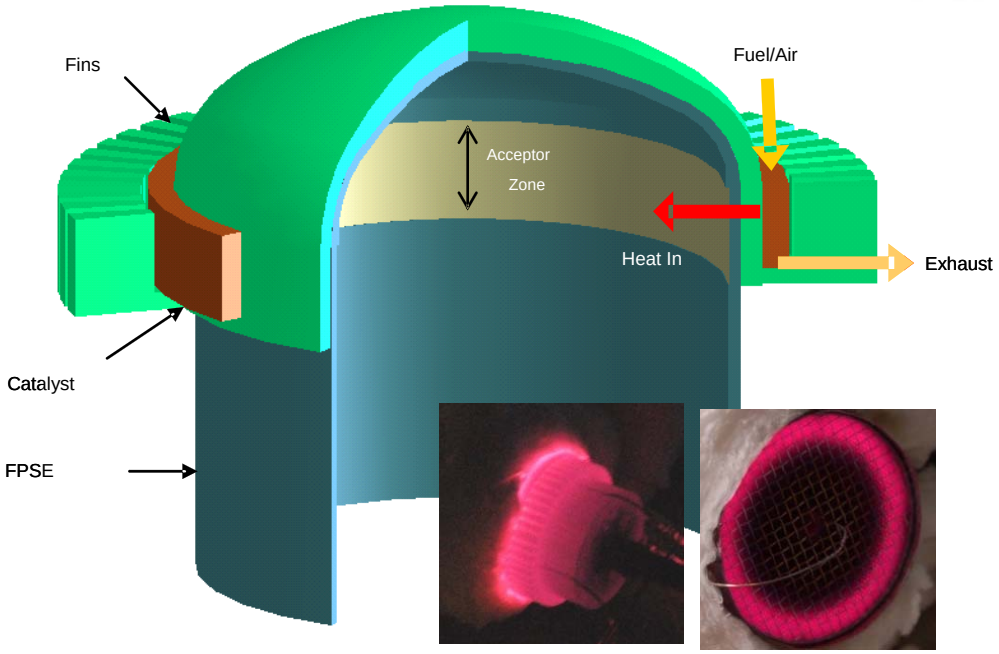
PCI Combustor

Burner Characteristics

- Flameless, catalytic design
- Integrated recuperator for high efficiency
- Low emissions and acoustics
- Glow Plug for fast startup
- >5k hr life demonstrated, poison resistant
- Significant IP protection



Challenges:

- High-temperature acceptor operation
- Suitable high temperature material selection
- High heat flux via maximized heat transfer
- Effective recuperation for minimized waste heat
- Effective fuel-air mixing and flow distribution

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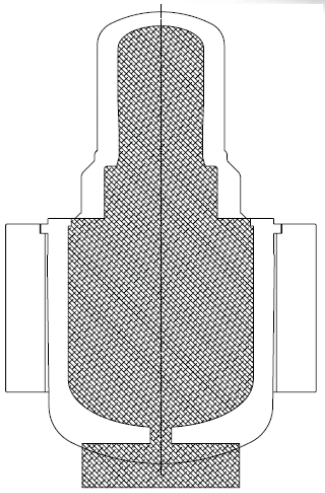
Key Challenges To Achieving GENSETS Goals

- **Low cost while maintaining performance**
  - Increasing frequency reduces physical size and cost
  - Incorporate lessons learned from previous DFM experiences
- **Increase engine*alternator efficiency**
  - High Temperature Head/Joining by Rocketdyne
  - Increase linear alternator efficiency
  - Engine improvements for efficiency
- **Increase Burner Efficiency**
  - PCI with materials/joining support from Rocketdyne
- **Market analysis and penetration**
- **High Efficiency Engine Controller**
  - Controls engine frequency and provides power to house or grid
  - Modified from existing controller architecture

Burner-Engine-Balancer Assembly (10”D x 22”H)



Proposed engine compared with commercial MEC engine

Wall-mounted GENSETS microCHP Unit

High Efficiency Controller

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