# 30-kW Maintenance-Free Solar Dish Engine

## DOE Solar Programs Annual Review

### Infinia FOA Program

Austin, Texas
April 22, 2008

# Thanks and Congratulations for the Rebirth of Dish Stirling CSP!

- The viability of dish Stirling CSP was demonstrated in the 70's and 80's – then it died ……
- Thanks to the persistence of a few folks at DOE, a number of true believers, and .... energy costs and climate change ... It has revived and helped all below
  - Sandia and NREL have weathered the storm and are helping on many levels
- Congratulations to SES
  - Breaking their own long-standing efficiency record
  - Raising $100M+ to support GW+ installations
- Recent Infinia capital investment of $60M+

# Presentation Overview

- Infinia Background
  - Company overview
  - Free piston Stirling engine (FPSE) offers long-life maintenance-free operation
  - 3-kWe solar dish product
- 30-kWe engine demonstration plans
  - Dish Stirling advantages
  - Technical approach

# We are…

- A solar-thermal / energy technology company


- Backed by leading venture capitalists & private equity investors

khosla ventures
venture assistance, strategic advice, venture capital

glg.

Idealab.
THINK AHEAD

EQUUS

VULCAN Capital

WEXFORD
Wexford Capital LLC
Independent Thinking • Opportunistic Investing

Power Play Energy

- Located in Washington state

Pacific Northwest National Laboratory

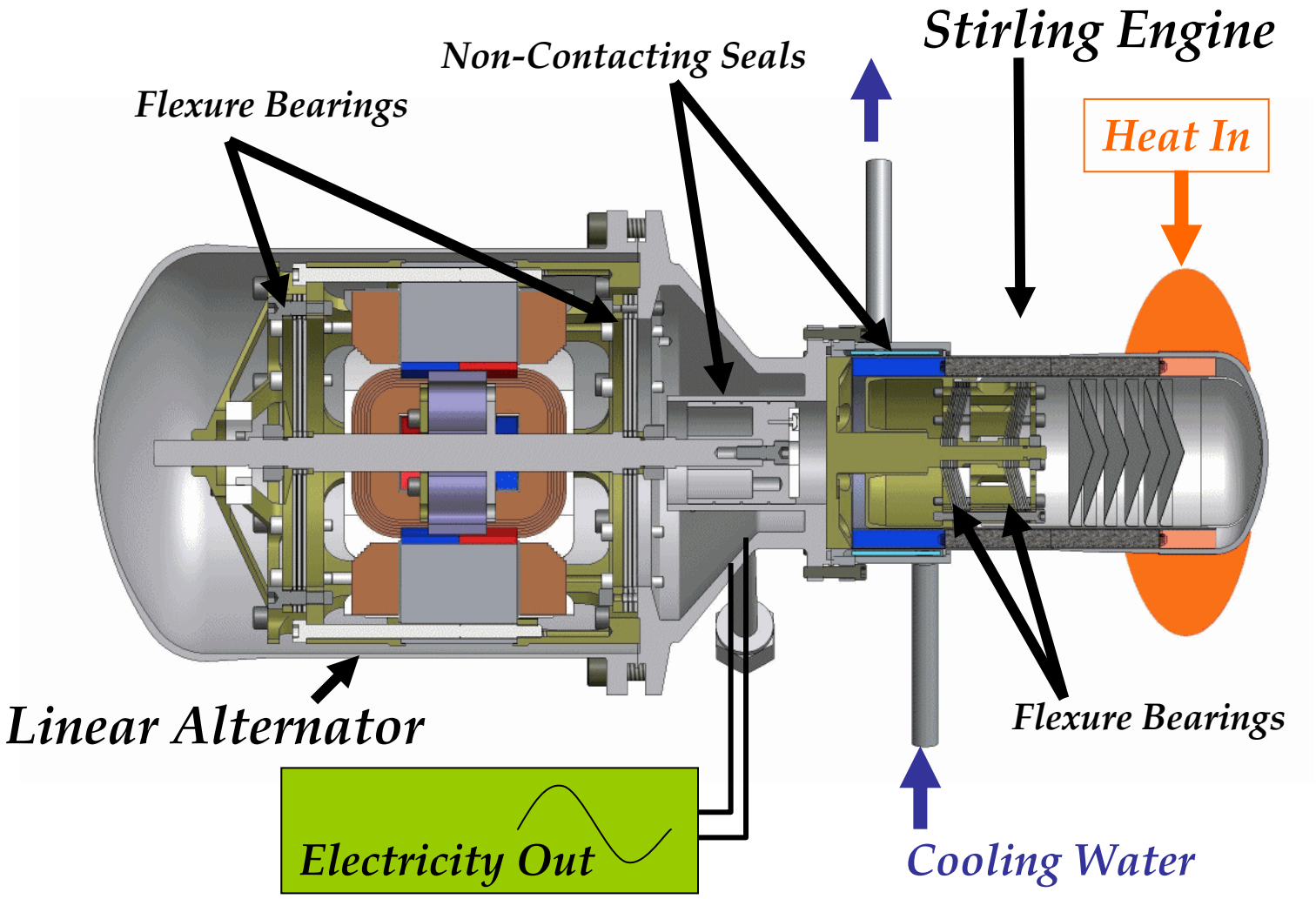
# Our Long Life Stirling Engine Enables…

- High performance / low-cost solar power
  - 70% overall conversion efficiency (thermal & electric)
  - 24% net electric efficiency
  - Automotive-scale production cuts costs

- Affordable home heating and power appliances
  - 90% thermal efficiency (electric & hot water)
  - 40% reduction in greenhouse gas emissions
  - Licensees: Rinnai (Manufacturer), Bosch and ENATEC


- Biogas-fired village power systems – EBI
  - Electricity, heat improve lives in undeveloped regions
  - Uses locally available fuel in anaerobic digestors
  - Enables sustainable economic activity

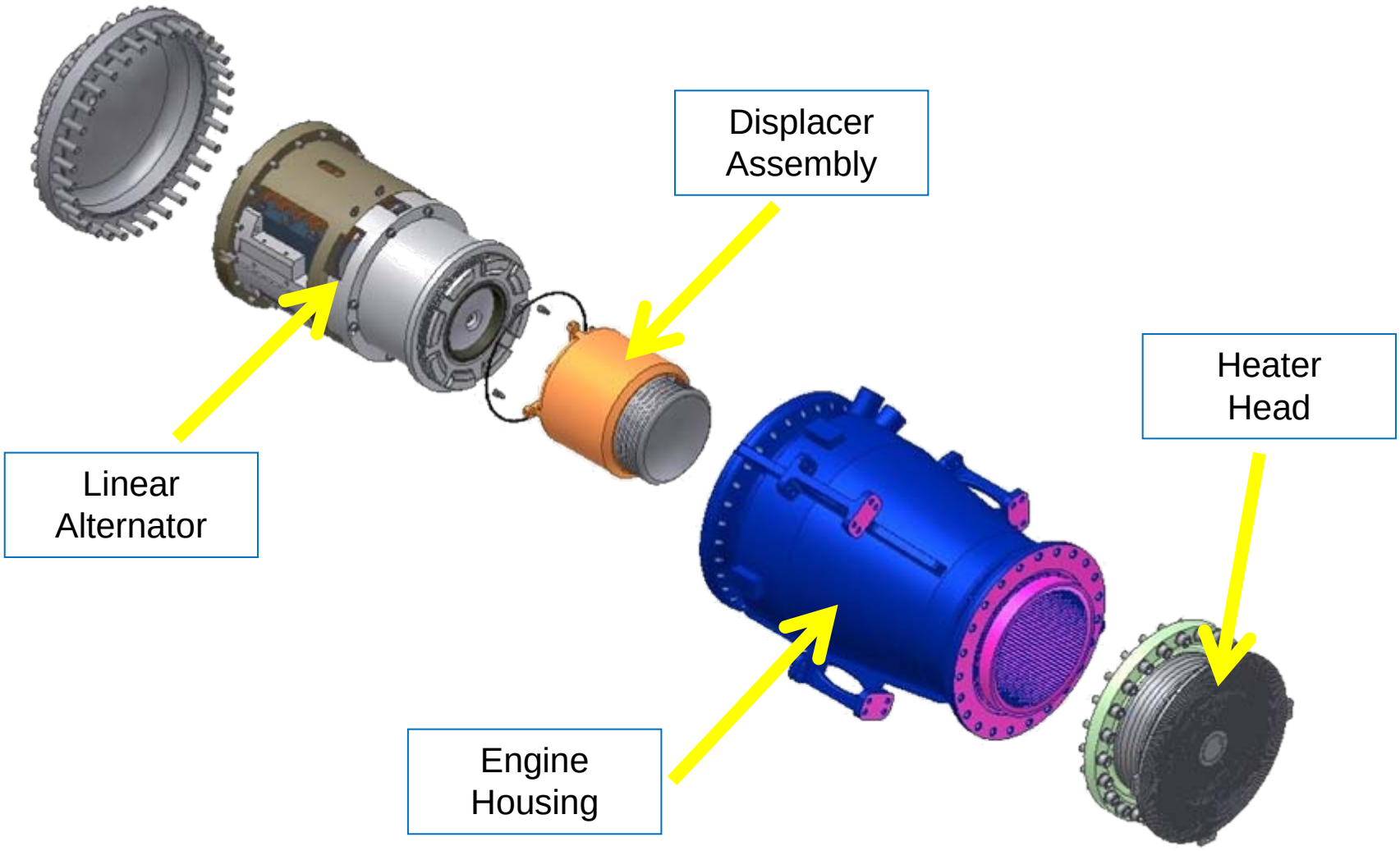
# Flexure Bearing Engine Topology



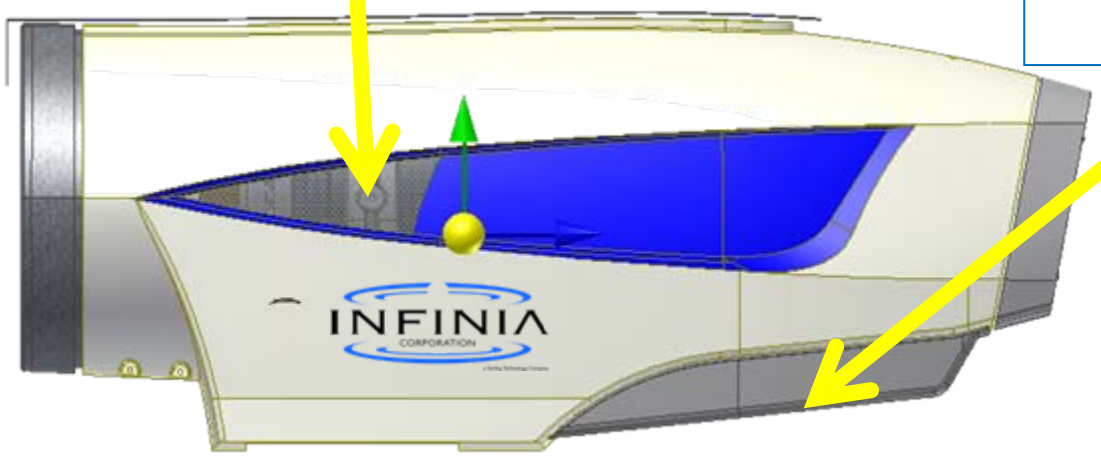
# Infinia Engine Hours are Unrivaled

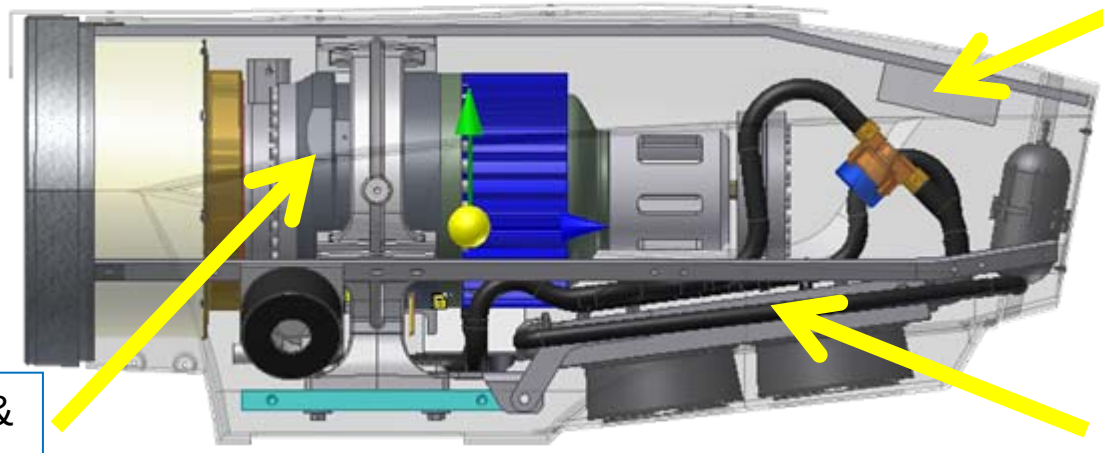
| | 10 watt (?) | 55 watt (NASA) | 350/450 watt (comm'l) | 1 kW (comm'l) | 3 kW (comm'l) Solar | Total |
|---|---|---|---|---|---|---|
| Units | 10 | 30 | 20 | 84 | 2 | 146 |
| Longest test | 100,000 | 35,000 | 30,000 | 25,000 | 300 | N/A |
| Cumulative test time at Infinia | 160,000 | 30,000 | 24,000 | 40,000 | 500 | 254,500 |
| Cumulative test time at Clients | 90,000 | 120,000 | 42,000 | 30,000 | n/a | 282,000 |
| Total Test Time | 250,000 | 150,000 | 66,000 | 70,000 | 500 | 536,500 |

# 3 kW modular free-piston Stirling engine



# 3-kW Heat Drive includes…



Solar Receiver

Cooling Air Inlet

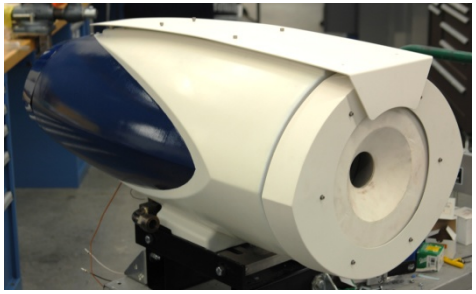
Cooling Air Outlet

Power Electronics

Stirling Engine & Generator

Closed-loop Cooling System

# 3-kW Solar Product



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**Engine**

- *32% net efficiency*
- *Modular design*
- *Low cost production*
- *Automotive suppliers*

**Concentrator**

- *86% net reflectivity*
- *EuroDish Design*
- *300 Suns*
- *Auto Tracking*

**System**

- *24%* net efficiency*
- *985 lbs total*
- *120/240VAC , 1Ø, 3Ø*
- *-25°F to 130°F*

** After Inverter & System Parasitics*

RICARDO

EWI

designconcepts

Rinnai

WMS

Sandia National Laboratories

NREL

ButlerSunSolutions

EDTEK

Schlaich Bergermann und Partner

Concentrating Technologies

Underwriters Laboratories Inc.

strategix VISION

We make technology human.™

MAGICALL

TOWNLEY TECH

# First Prototype Assembly/Test – 10/07

INFINIA CORPORATION

# 30-kW FOA Engine Program

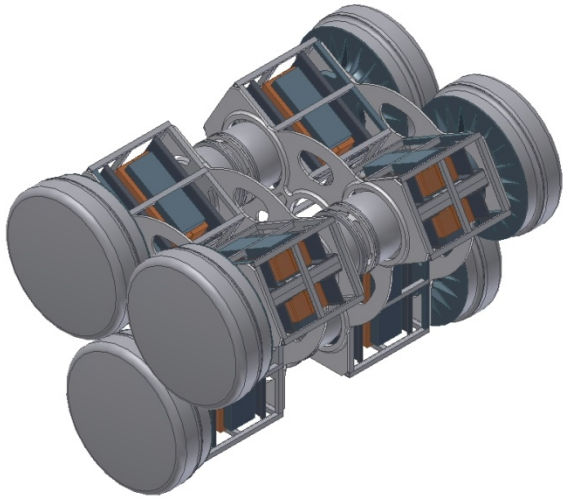
- Phase I: Preliminary design; preliminary LCOE; 9 mos.
- Phase II: Final design, fabricate and test 30-kW laboratory prototype; update LCOE; 15 mos.
- Phase III: Refine laboratory design; fabricate and test 30-kW field prototype on-sun; finalize LCOE; 24 mos.
- Dish Stirling advantages
  - Highest efficiency of any CSP option
  - Modularity enables any size stand-alone or on-grid installation
  - Uneven land is no problem, south facing slope is ideal
  - Self contained cooling enables operation without water source
  - Problem has always been engine life and maintenance
- Approach: Use innovative double-acting MCFPSE to demonstrate long-life maintenance-free 30-kW engine

# Stirling Engine Type Characteristics

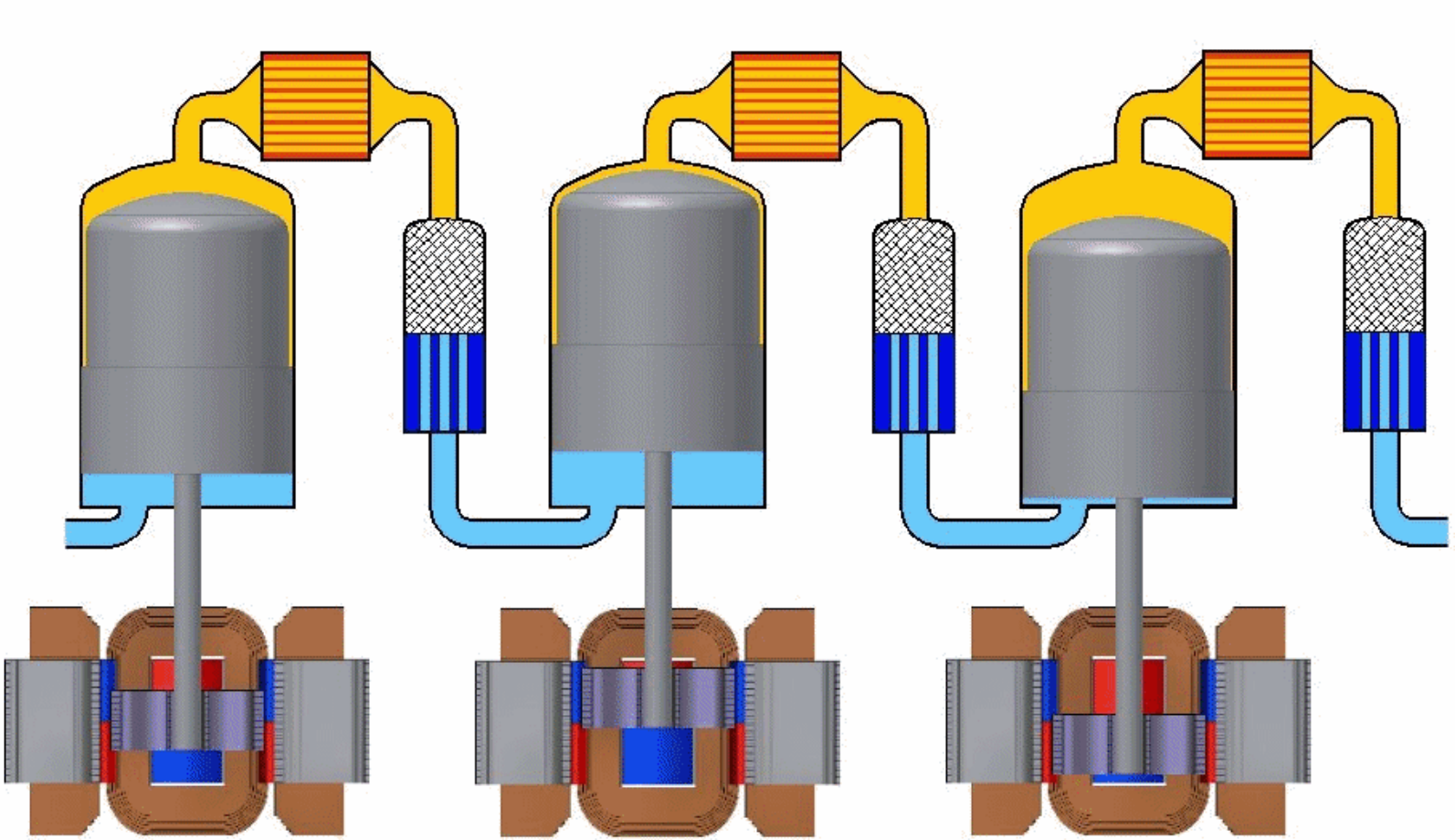
- Free-Piston Engines
  - Elegant mechanical simplicity – low parts count
  - No rubbing parts + flexure bearings → long life, high reliability
  - Single-cylinder with displacer → complex dynamic analysis
- Kinematic Engines
  - Single and multi-cylinder options, experience to 265-kW
  - Double-acting multi-cylinder has high power density
  - Oil-lubricated crankcase with crankshaft, connecting rods etc.
  - Sliding seals fundamentally limit life and reliability
- Multi-Cylinder Free-Piston Engines
  - Combines best features of free-piston and kinematic
  - Avoids limitations of both – leverages mature technology
  - Improved power density – especially 3-cylinder
  - No FPSE Displacer or Thermoacoustic Inertance Tube

# MCFPSE Validation and Evolution

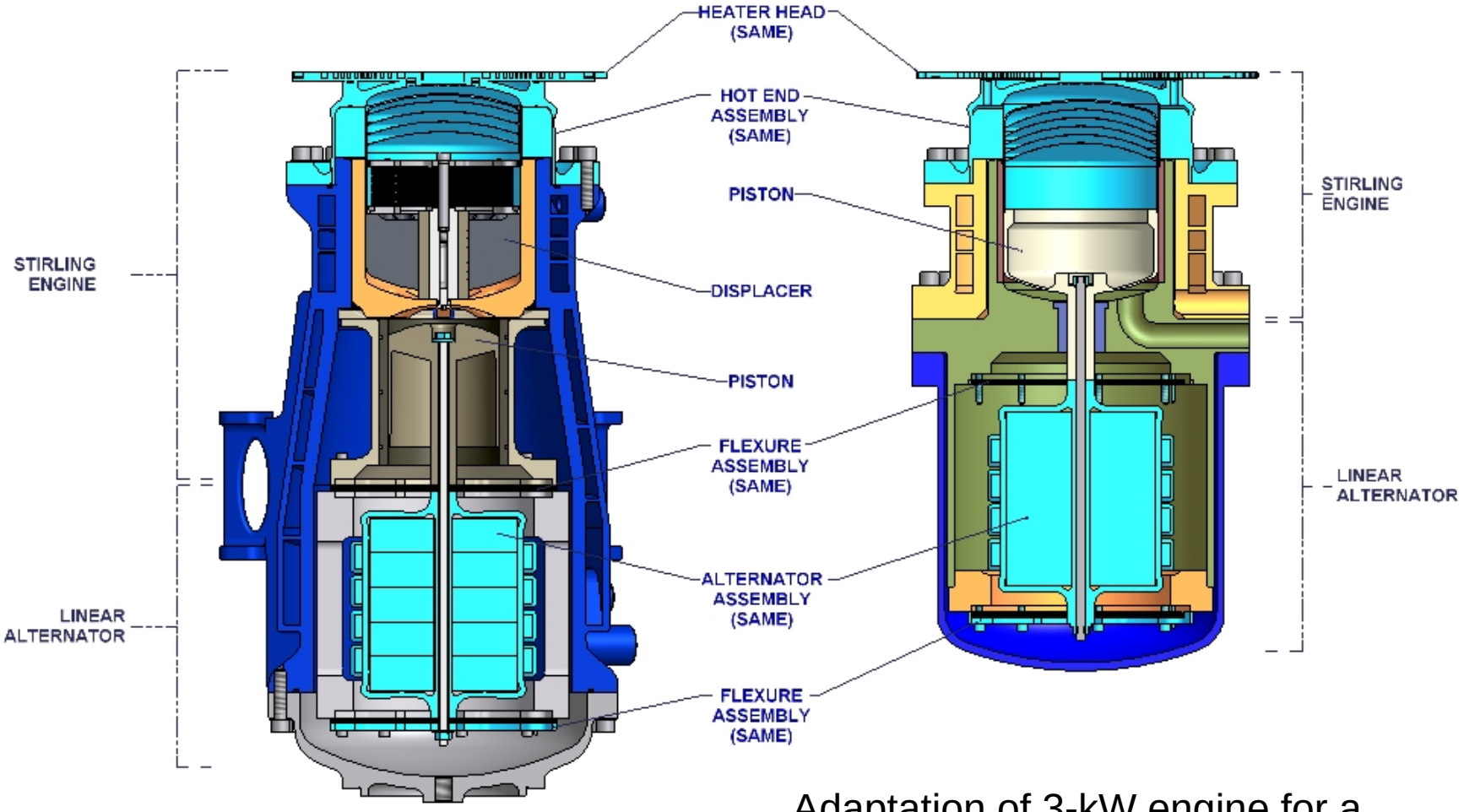
- 2004: Feasibility demonstrated
- 2006: Comprehensive patent
- Biennial peer-reviewed ISEC
  - 2005 – Concept introduction
  - 2007 – 4.2 MW conceptual design with Bechtel Bettis
  - Both received best paper awards
- 2006: DOE Phase II SBIR for high-capacity cryocooler for HTS transmission line cooling
- 2008: DOE funding for 30-kW solar dish engine



# 3-Cylinder MCFPSE Schematic



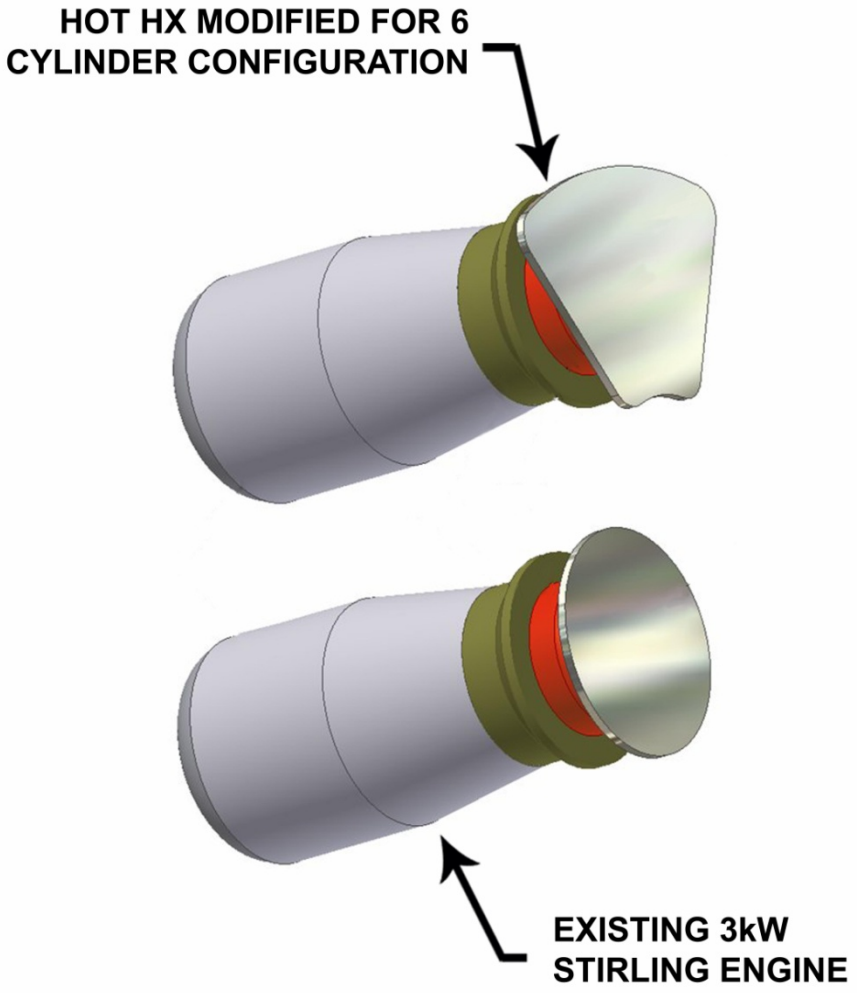
# 3-kW Engine Mods for MCFPSE

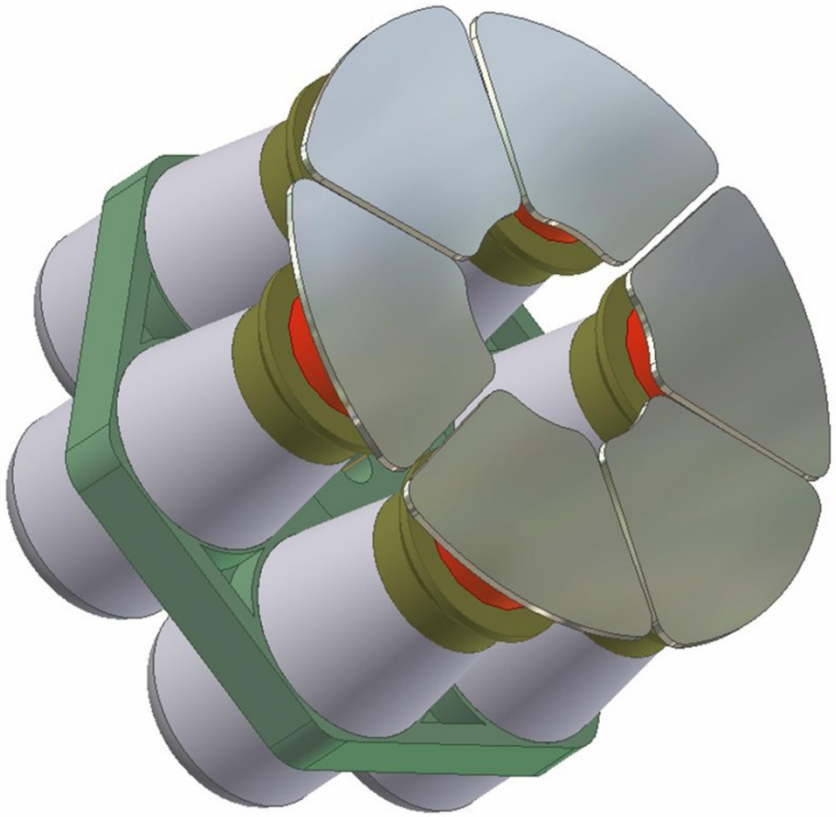



Existing 3-kW Free Piston Stirling Engine (FPSE)

Adaptation of 3-kW engine for a MCFPSE is Smaller, Simpler, Lighter and Produces up to 6 kW (Requires larger alternator)

# 30-kW Derivative of 3-kW Engine



BALANCED 30kW 6-CYLINDER CONFIGURATION

# LCOE Analysis is Key FOA Goal

- Good prospects for meeting DOE LCOE targets of 7-10 ¢/kWh by 2015 and 5-7 ¢/kWh by 2020
- 3-kW solar program provides head start
  - Intense production cost assessment with suppliers
  - Will beat ground-mount PV costs with early production
  - Few parts – mainly steel, Al, Cu, glass – that use conventional automotive class fabrication
  - Costs drop rapidly with high quantity production
  - No O&M cost for maintenance-free hermetic engine
- 30-kW engine derived directly from 3-kW
  - Double-acting configuration improves specific power
  - Economies of both size and quantity

# Conclusions

- Dish Stirling CSP offers many advantages
- Engine life and reliability have been impediments
- Infinia FPSE technology has long track record with validated long life and high reliability
- An innovative MCFPSE scales up power level and specific power to diversify applications
- The DOE FOA program offers an ideal venue to demonstrate the efficacy of a 30-kW dish engine
- LCOE is anticipated to meet DOE goals as a result of automotive scale production