INFINIA

FOCUS YOUR ENERGY

Innovative Application of Maintenance-Free Phase-Change Thermal Energy Storage for Dish Engine Solar Power Generation

Contract Number DE-FC36-08GO18157

February 9, 2010

Objectives

- Demonstrate the practicality of integrating thermal energy storage (TES), using a thermal salt phase-change material (PCM), with a dish-Stirling system
- When developed the TES module is expected to lower the overall LCOE of the system
- Provide preliminary design for 1-hour demonstrator and LCOE estimate by the end of Phase 1
- Build and demonstrate 1-hour on-sun prototype by the end of Phase 2
- Deliver and field test a statistically significant number of 4-6 hour storage systems by the end of Phase 3

Phase 1	Phase 2	Phase 3
• Develop a preliminary design of the TES module • Develop preliminary interface design for existing 3-kW CSP system • Conduct manufacturing cost analysis • Assess the impact of TES on the LCOE of a 3-kW CSP system • Determine residual technical barriers and revise the Phase 2 and Phase 3 task details accordingly	• Complete Design Documentation • Develop test plan • Complete prototype TES/CSP fabrication and assembly • Test and evaluate TES/CSP prototype on-sun • Complete increased dish capacity design • Develop refined LCOE analysis	• Complete design refinement • Complete larger dish integration • Manufacture field units • Install and commission units • Conduct field endurance testing • Verify TES functionality o Round trip efficiency (>93%) o Cost (<$15/kWhT) o Dispatchable power o Expanded operational time • Conduct final LCOE analysis based on manufacturing data

Timeline and Milestones

Phase	Task	2009												2010												2011							
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
1	1-TES Preliminary Design																																
	2-Engine Interface Design																																
	3-System Integration Design																																
	4-LCOE Analysis																																
	5-Project Management and Reporting																																
2	1-Detailed Integrated Design																																
	2-Fabricate, Integrate TES/CSP System																																
	3-Increased Dish Capacity Design																																
	4-Test and Evaluate TES/CSP Prototype																																
	5-LCOE Refinement																																
	6-Project Management and Reporting																																
		2010												2011												2012							
3	1-Refine TES Design, Integrate Large Dish																																
	2- Produce Field TES/CSP Sytems																																
	3- Install and Commission Field Systems																																
	4- Field/Endurance Testing																																
	5-LCOE Verification																																

Completed Milestones

- Phase 1
  - Completed all activities, end of September 2009
- Phase 2
  - Continuation Application go ahead November 2009

Phase 1 Background:

- Task 1: TES Preliminary Design
  - Identify target storage capacity and efficiency for demonstrator and field units: *1 hr. demonstrator, 4-6 hr. field unit; round trip thermal efficiency >93%*
  - Salt selection by trade study from 83 initial candidates: considered melting temperature, cost, size, weight, material impact – down selected to one salt
  - TES Design Considerations:
    - Infinia and Thermacore conducted two workshops at Infinia and brainstormed concepts for further evaluation; trade-offs of cost, weight, technical challenges
    - Thermal analyses were conducted to evaluate salt melting/freezing characteristics
    - Began material compatibility investigation for TES components
    - Developed 11 TES field system concepts - Considered all options
    - Evaluated how to control heat transfer into TES from solar concentrator and out of TES to engine at various times
    - Trade off study of cost, weight, technical challenges, configurations
    - Weight of TES versus additional structural requirements
    - TES container material compatibility with salt versus costs
    - Controlling heat transfer during different conditions
    - Cost and efficiency of insulation versus heat storage duration

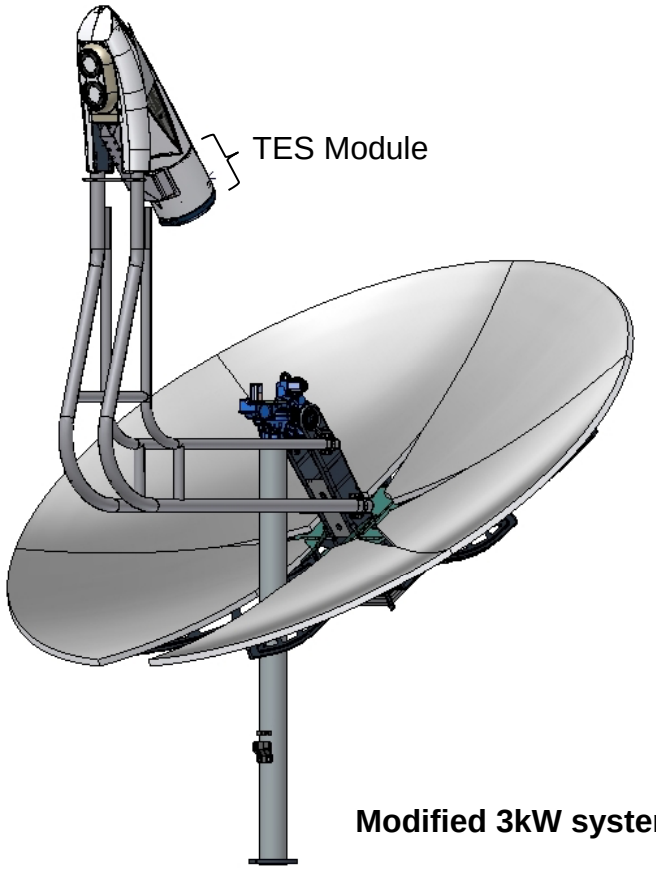
Phase 1 Background Continued:

- Task 2: Engine Interface Design
  - Engine and TES mounting and support; heat transfer to engine heater head
- Task 3: System Integration Design
  - Heat drive mounting and dish
- Task 4: LCOE Analysis
  - High volume manufacturing analysis
- Task 5: Project Management and Reporting

Demonstrator Prototype Design

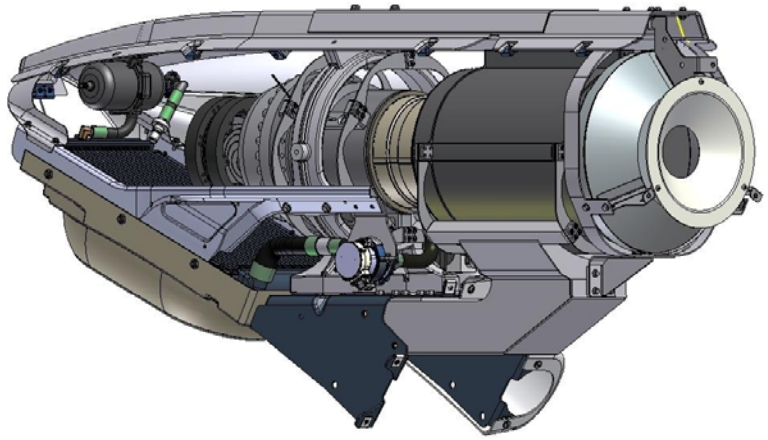
- Demonstrator is based on a modified Infinia commercial 3kW CSP system
- TES module is integrated with the Stirling engine

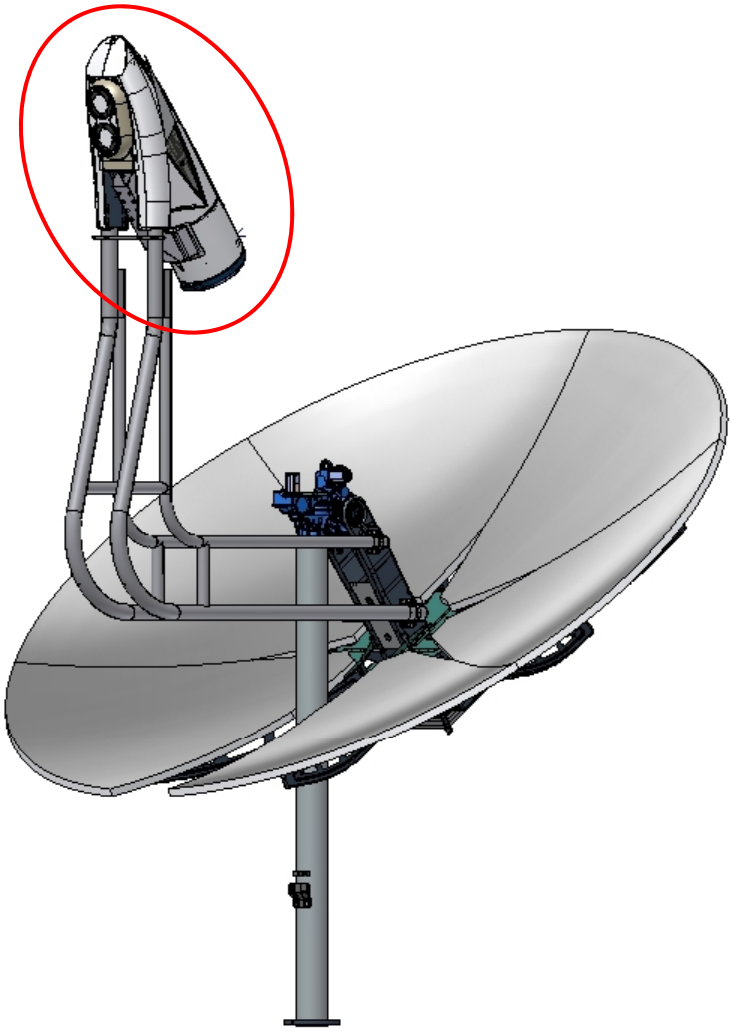
Existing 3kW system



Modified 3kW system

Demonstrator Prototype Design

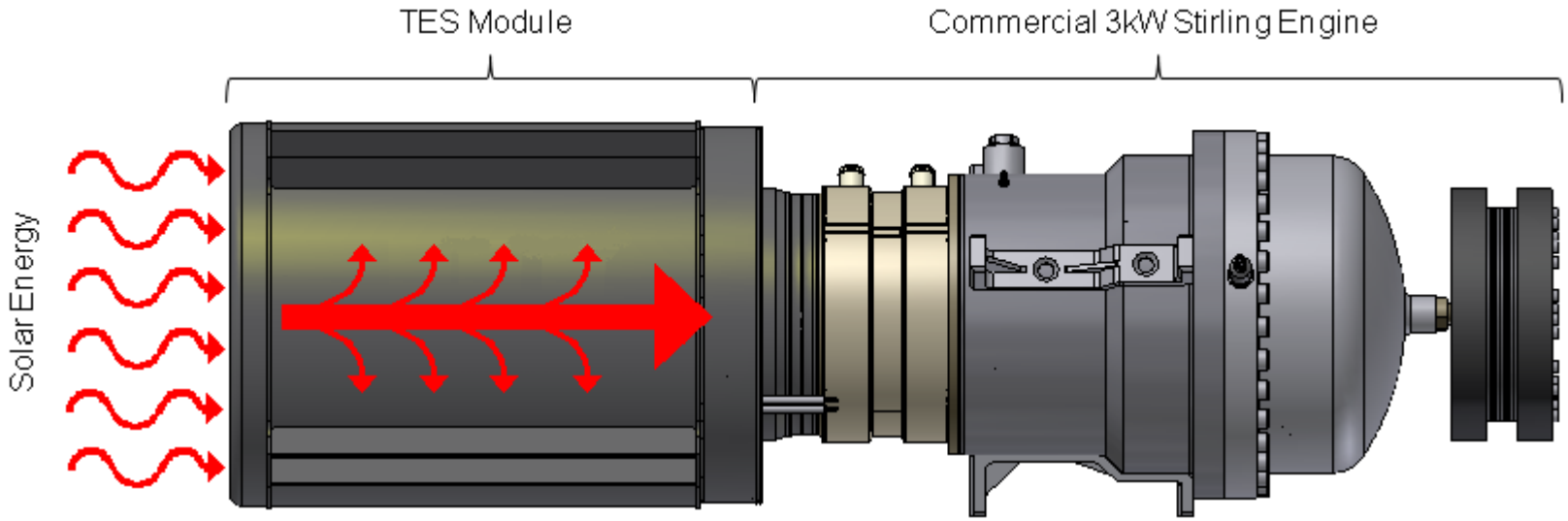




- PCM volume is sized to generate 3kWh net electric power
- Heat is delivered to, and extracted from, the salt via a system of high-temperature heat pipes embedded in the TES module.
- TES module serves as a “buffer”; excessive insolation energy is absorbed by salt, and will also enable full engine output during cloud transients

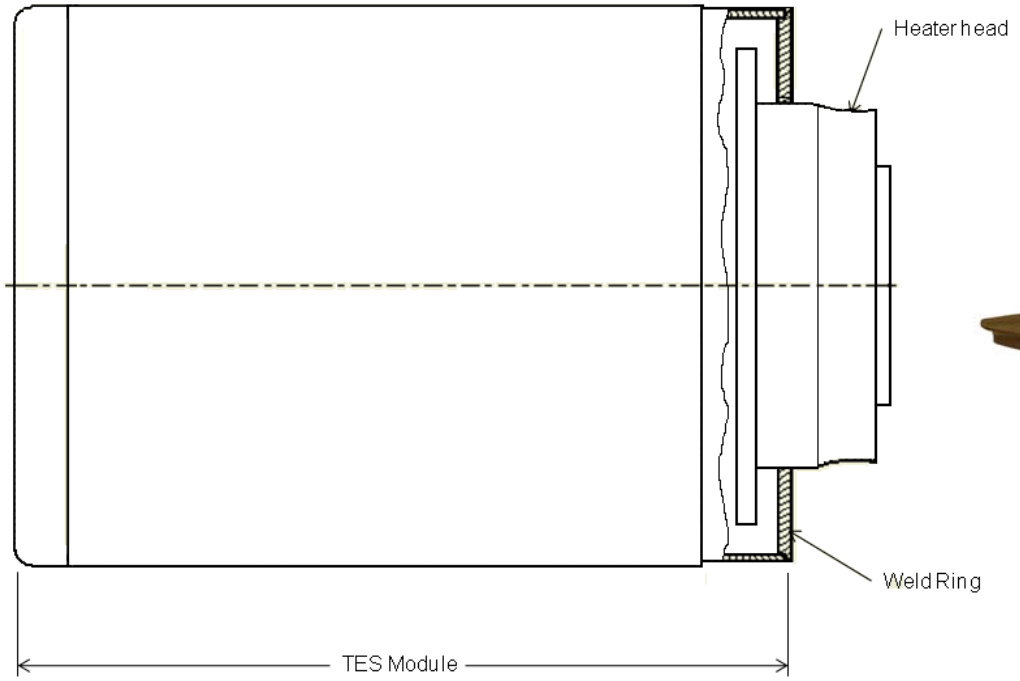
Engine/TES Module

- Heat pipe arrangement permits simultaneous operation of the engine while charging the salt as soon as solar energy is available
- TES system is passive, requiring no pumps, valves or other parasitic loads to operate
- Direct coupling to engine increases thermal efficiency



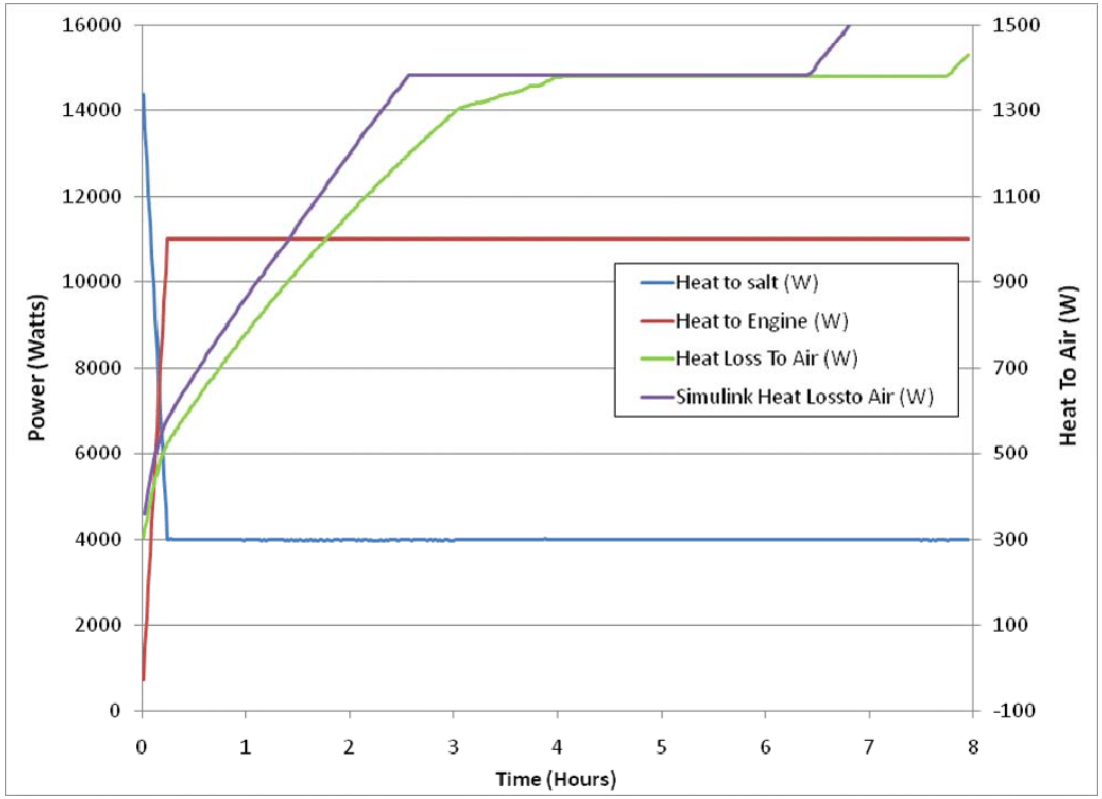
Engine/TES Module

- Commercial engine heater head modified to add a weld ring which serves as the structural interface with the TES module
- Modified heater head has been successfully prototyped



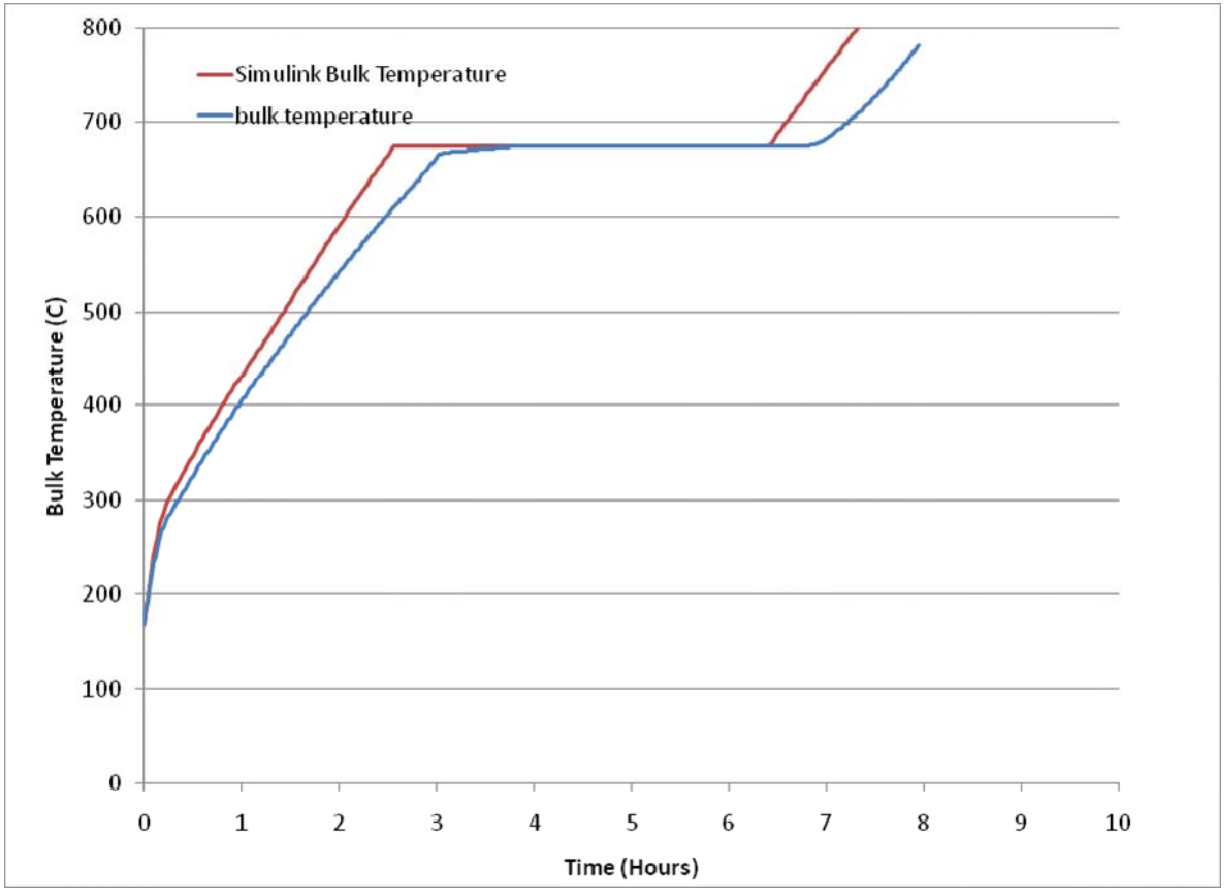
Thermal Modeling

- Computer modeling and analysis of transient thermal response performed by The Pennsylvania State University's Applied Research Laboratory
- Heat pipe configuration iterated to optimize heat transfer to/from phase change salt, and to ensure desired energy split between engine and salt mass is achieved
- Results correlate well with bulk analysis methods



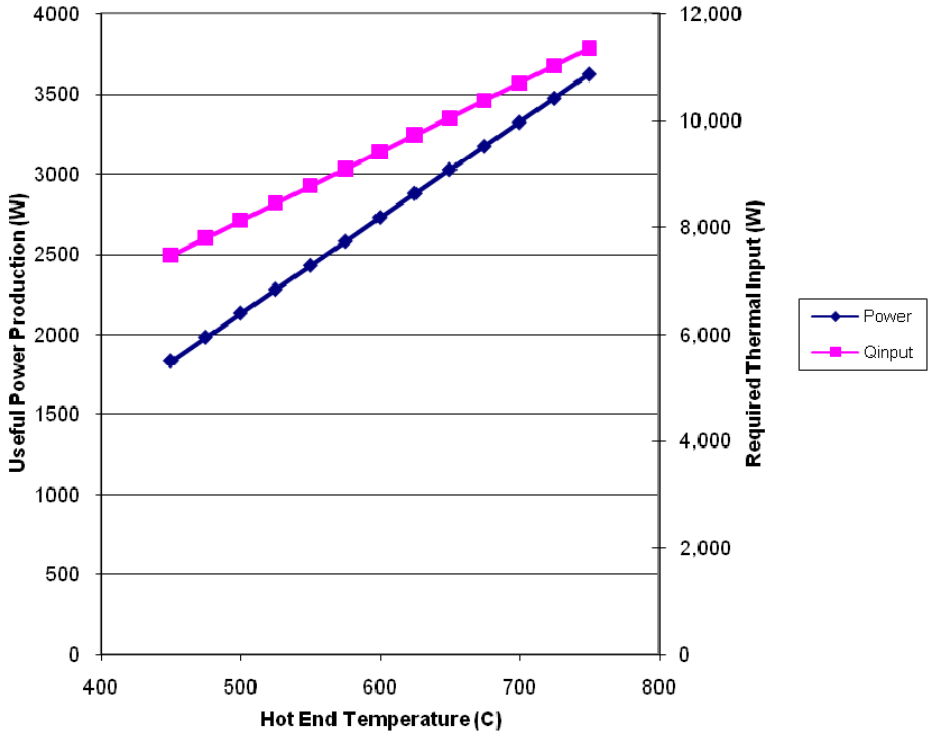
Thermal Modeling

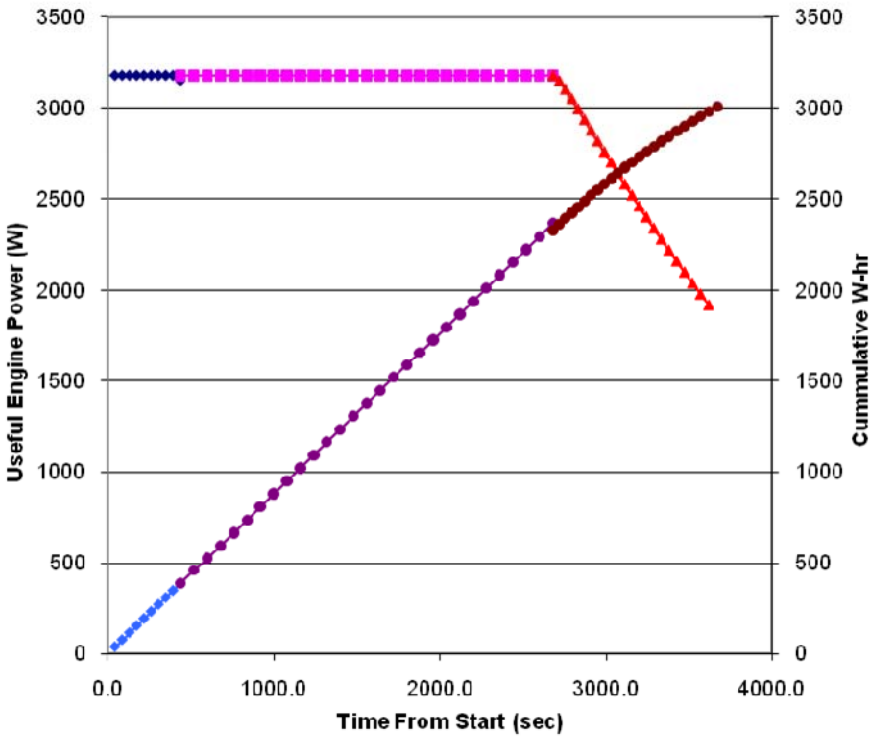
- TES module salt volume is designed to be fully charged to 700°C after approximately 8 hours



Thermal Modeling

- Analysis of Stirling engine performance as a function of hot end temperature
- Analysis of Stirling engine performance and power produced as a function of salt temperature





LCOE

- Two concepts examined at the 4-6 hour size
- Resulting LCOE drops from 15¢/kWh to 12.5¢/kWh (17% reduction in LCOE) as a result of TES addition
- Cost estimates used were conservative, but when compared to projected cost of natural gas production numbers are roughly on par with expected conventional generation.

INFINIA

Thank you

US Headquarters
6811 West Okanogan Place
Kennewick, WA 99336
www.infiniacorp.com

Albuquerque Los Angeles Madrid New Delhi Tokyo Washington DC