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Dish Engine Research and Development

Performing Organization: Sandia National Laboratories (SNL)

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DOE FY 2008 Budget: $1,000K

Industry Partner CY08 budget $160M estimated

Objectives

- Improve the reliability and reduce the cost of dish/engine components and systems.
- Support industry in the commercialization of the technology.
- Perform research and development on dish/engine system components and systems.
- Test, evaluate, and improve the performance of dish/engine components and systems.
- Develop tools for industry to characterize their systems and components

Accomplishments

- Continued to operate, maintain, and improve the Stirling Energy Systems (SES) six-dish model power plant, characterizing performance and identifying development opportunities.
- Participated as a key member of the SES commercial product design team.
- Developed real-time mirror characterization prototype system for 100% inspection of mirrors on assembly line
- Developed engine simulator for development of modern engine control hardware and software
- Coupling of optical and structural models led to a weight savings of about 6000 pounds
- Began installation of 4 production prototype SES dish Stirling systems at Sandia
- Significant mentoring of new solar engineers through Sandia programs and at industry partners
- Developed tradeoff study of facet performance and cost to guide commercialization efforts
- Assisted Infinia in optical design and systems design of 3-kW FPSE dish system
- Enhance CIRCE2 model to support finite element analysis-modeled deflections.
- Participated in FOA team for dish Brayton system

Future Directions

Primary activities in FY 2009 will support industry's efforts toward commercialization:

- Continuing to evaluate the reliability of the model-power plant.
- Identifying and resolving operational and reliability issues.
- Installation and commissioning of 4 pre-production dish systems at Sandia National Laboratories
- Retrofit and commissioning of 6 MPP dishes with production units
- Development of highly automated rapid alignment system for production dishes
- Continue to participate on commercial product design team
- Installing two next-generation Infinia dish systems at SNL.
- Continuing to support Infinia's commercialization effort
- Evaluate possible additional dish/engine products as needed

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1. Introduction

Staff carrying out the U.S. Department of Energy's (DOE) dish-Stirling activities in the Solar Energy Technologies Program work closely with industry to improve system performance and reliability and to support industry deployment in the near term. Both of these are explicit goals of the *DOE Solar Program Multi-Year Program Plan*, section 4.2.5.3. While we continued to gain operational experience with the SES 6-dish Model Power Plant (MPP) at SNL, our primary focus this year was on next-generation system design, with an emphasis on manufacturability. In addition to SES, we supported Infinia in its first product development and deployment effort.

The SES system is derived from the successful McDonnell Douglas Corporation (MDC) system, redesigned to improve the cost. SES's objective is to put this system into production in the next year; the target market is bulk power production in the southwestern United States. Preproduction prototypes have begun deployment at SNL, and incorporate improvements in manufacturability, as well as addressing reliability and serviceability opportunities identified in the testing at SNL.

SES is pursuing the large-scale deployment of 25-kW dish-Stirling systems for bulk power generation. SES hardware is based on the tried-and-true MDC design, with refinements to reduce manufacturing costs. SES is working closely with an SNL engineering team to maximize the possibility of success.

SES has signed agreements with Southern California Edison for up to 850 MW of power and with San Diego Gas and Electric for up to 900 MW of power. Operational improvements identified and/or implemented in the MPP are critical in the design process for these deployments. SES has made significant progress in developing site plans for the plants. The MPP at SNL enabled successful partnerships to be made with utilities and with companies developing the site plans.

This year, the emphasis regarding SES has been to convert the prototype system design deployed at MPP to a manufacturable design that facilitates the logistics of deployment and service. A team approach with suppliers was further developed, and key suppliers were involved in the design process. SES has moved all components through their design review process, and many parts are already in manufacturing. SNL has provided significant consulting input to the design process, particularly in the optical and performance design and analysis areas.

Infinia, previously Stirling Technology Corporation (STC), has developed a system around a 3-kW free-piston Stirling engine. This system is hermetically sealed and requires no maintenance. Infinia plans both large and small deployments and has targeted photovoltaics as a competitor. Sandia National Laboratories was involved in the conceptual design, the detailed design, and the deployment of the first prototype systems. SNL developed an innovative facet profile design tool to aid in the concentrator optics design to provide a desired flux pattern on the receiver. SNL has entered into a memorandum of understanding with Infinia to support several Infinia staff on SNL premises. A prototype dish was set up at Sandia National Laboratories, and optically characterized, providing feedback to the facet manufacturer.

2. Technical Approach

SES plans to achieve cost reductions by rapidly moving to high production rates in support of bulk power production. This approach, when compared with smaller prototype installations spread out at many locations, has the advantage of lower cost through production automation early in the product design cycle and lower operations and maintenance (O&M) cost through the consolidation of O&M resources.

SNL has provided office, test lab, field, and infrastructure facilities to SES at the SNL National Solar Thermal Test Facility, which provides direct access to technology transfer and expertise and allows the engineers daily hands-on access to the dish systems. This is critical to accelerating the development and deployment path and to rapidly training new SES solar engineers. SNL has also played a key role in design meetings throughout the design life cycle.

The operation of the MPP at SNL has provided continued valuable information about the advantages and limitations of existing systems. Although several key reliability areas have been addressed in the field, a number of issues are being addressed in the DFMA process. We have teamed with the SES design team, both at SES and at their strategic partners, to ensure this transfer of findings is implemented. The issues and opportunities identified have been systematically categorized for severity and impact to the future success of the design. Key resources have been applied to the highest priority issue areas based on this approach. The remaining issues are incorporated into the design process for the production units. All of the dish system hardware is funded through SES investor financing, while SNL, through the DOE CSP Subprogram, provides in-kind engineering support, technology transfer, training, and facilities.

SES has received a significant influx of commercialization cash from NTR of Ireland. This has allowed a significant expansion of the SES team, with nearly 100 employees on role, and new hires every week. This has presented a significant training and solar mentoring role at Sandia, particularly for those employees involved in the optical portions of the design work. SES has also announced a partnership with Linamar, an automotive engine developer and manufacturer. Linamar is providing superb support in commercializing the successful SES Stirling engine. Partnerships such as this are a key part of SES's development and deployment strategy.

Infinia is taking a similar approach. They plan high-rate production to reduce the cost of the systems down to competitive levels. While initial markets are identified as small business and commercial installations, Infinia has proposed installations up to 300 MW (*Solar Paces*, March 2008).

Infinia has designed a system based on a 3-kW, single-cylinder, free-piston engine. Similar 1-kW engines have run very well with extended no-maintenance life. They have designed a composite-structure dish system with glass mirrors on a composite substrate and a steel rib backing. SNL has also provided significant design support to Infinia in the preparation of their first prototype systems.

3. Results and Accomplishments

The SES MPP dish systems have accumulated over 24,000 hours on sun. The performance of the system continues to exceed the performance of the MDC systems, primarily as a result of improved system optics, alignment, and cooling.

On January 31, 2008, SES and Sandia set a world record for sunlight to grid electricity with one of the MPP units. This new record was 31.25% net conversion efficiency, averaged over a full hour of operation. This significant accomplishment was awards a “Breakthrough Award” by Popular Mechanics, recognition of life-changing and society-changing technical accomplishments. High system efficiency is a key factor in reducing the levelized energy cost for energy produced by these systems.

SES has used the reliability data captured in the Failure Reporting, Analysis, and Corrective Action System (or FRACAS) to guide the design work during the commercialization effort. Many of the issue areas are software-related, and the solutions have been folded into the software specification. Likewise, their engine manufacturer has addressed outstanding issues in the design of the commercial engine. This formalized path from testing to final design is key to producing a highly reliable system. SES and Linamar will install a number of production engines in test cells to provide accelerated testing of the commercial package.

Continued refinement of the dish system leading to the commercial system has led to nearly 6000-lb weight reduction and resulted in a stiffer optical system. This was facilitated over the last 3 years by SNL's optical code (CIRCE2) combined with SES's structural model. SES's steel fabrication partner has designed a highly automated fabrication plant in conjunction with the redesign effort. The refinement of this design is continuing, taking into account the key environmental implications of the California sites.

The combination of CIRCE2 with the structural modeling has been a key insight by Sandia and implementation by the SES team. We have continued to refine this connection. While most of the work performed to date imposed structural deflections as rigid-body rotations of the facets, new improvements to CIRCE2 will allow the actual facets to be shape-distorted in the optical model, based on finite element model results, as well as measured facet shapes.

SNL continued the development of an alignment system suitable for high rate production. Such a system requires computer interpretation of the alignment status, and digital feedback to technicians or to actuators. We have developed an approach based on fringe reflection measurements, and we have tested key components of the software. The approach appears to be very robust within a significant range of mirror quality. The complete software embodiment will be developed in FY09.

A spinoff of the alignment tool is the successful Sandia Optical Fringe Analysis Slope Tool (SOFAST) for Mirror Characterization, also based on fringe reflection techniques. This tool accurately measures slope errors and shape errors of facets in less than 10 seconds, allowing application to the production line for quality control. A complete system has been deployed at SES's facet manufacturer and is being during the facet manufacturing process development. A key element that extends this technology is "virtual boresighting", where positional imperfections in setup of the camera, target, and facet are accounted for in the analysis software. This tool has proven useful to SES in refining the manufacturing processes for the production facets.

SNL, with the support of several graduate level interns, developed a Stirling Engine Simulator for use with the SES system. This simulator reproduces the sensor signals of an operable engine, and responds to control stimuli. This simulator is then used to characterize and test the engine control system. This has proven to be very valuable as SES has developed their production system controls, and has avoided a tremendous number of hours of hardware testing on real engines in the lab, while also avoiding risks to those engines while exploring off-normal operating conditions.

SES announced the delivery of their Application for Certification for the Solar 2 plant in California, and the acceptance of this documentation as "data adequate". This is a key document leading to the deployment of systems in California. SNL provided consultation support during the development of this document.

SNL supported Infinia in the development of its 3-kW dish engine system. Significant technical support in the optical design of their dish system, ans well as in controls development, was provided. A new approach to optimize the flux distribution on the receiver was implemented in this support. Infinia has performed site prep for the installation of two prototype systems at Sandia. Infinia has completed a prototype system it its headquarters in Kennewick WA. First generation mirrors were installed and characterized at SNL.

SNL published an ASME paper that explores the relationship between facet optical performance and system economic performance. The thesis of the paper, confirmed through the analysis presented, is that you can afford to pay quite a bit for quality optics, or conversely, in high temperature systems, the cost savings of "cheap" optics is typically more than offset by revenue losses and loss of system value. This has been a key and consistent finding in the SNL dish development program, starting in the Cummins and ADDS programs.

4. Planned FY 2009 Activities

SNL and SES will continue to operate and upgrade the Model Power Plant at SNL, in order to maximize the probability of success of their large-scale deployments..

SNL will continue to support SES in its aggressive schedule for product improvement and deployment. The involvement of high-production suppliers and the national laboratories in the deployment is key to transitioning to production. SES will complete installation of 4 pre-production units at Sandia National Laboratories in order to qualify the commercial fabrication processes. After initial qualification, 6 production units will be installed, replacing the prototype MPP systems. This 10-unit MPP will be used for systems and controls studies leading to the large scale deployments.

The partnership between SNL and SES is a new way of doing business that maximizes the benefit to SES while continuing to leverage the expertise developed at the national laboratories. During FY 2009, we will accomplish the following:

- Continue to operate the MPP, evaluate performance, and identify reliability issues.
- Expand the MPP to 10 systems, and upgrade the existing 6 systems to production units.
- Characterize reliability and performance of the production prototype systems with field validation and design assistance feeding the design for manufacturing and assembly (DFMA) process.
- Develop and demonstrate optical alignment and characterization tools, applied directly to SES, but applicable to other systems: Dishes, Towers, and troughs.
- Support SES as it begins to deploy production units. SES plans a 1.5MW demonstration installation in Arizona in this CY.
- Actively participate in the DFMA process
- Develop and support development of rapid deployment component designs including

optics, foundation, dish structures, and so on, and test prototypes at SNL.

Sandia National Laboratories will also continue to support the Infinia work. At this point, Infinia plans the installation of two 3kW dish systems at Sandia, though a schedule has not been completed yet. We anticipate this occurring in FY09.

SNL anticipates having significant involvement with the two currently-active dish-engine FOAs managed by the DOE Golden Field Office for dish development activities—one with Infinia and one with Brayton Energy Systems. The tasks for the national Laboratories are not well defined yet.

5. Awards and Recognition

- Popular Mechanics "Breakthrough Award", October 2008
- ASME SED "Best Paper", 2008 Energy Sustainability 2008 conference, Jacksonville FL.
- ASME SED "Best Paper", 2007 Energy Sustainability 2007 conference, Jacksonville FL.
- Patent issued: 7,124,507, "Method of Manufacturing a Heat Pipe Wick with Structural Enhancement"

6. Publications and Presentations

Andraka, Charles E., "COST/PERFORMANCE TRADEOFFS FOR REFLECTORS USED IN SOLAR CONCENTRATING DISH SYSTEMS", ES2008-54048, Proceedings of ES2008, ASME, Energy Sustainability 2008, August 10-14, Jacksonville FL.

Andraka, Charles E. and Mark Powell, "DISH STIRLING DEVELOPMENT FOR UTILITY-SCALE COMMERCIALIZATION", Solar Paces CSP Symposium 2008, March 4, 2008, Las Vegas, NV.

Igo, John, and Charles E. Andraka, "SOLAR DISH FIELD SYSTEM MODEL FOR SPACING OPTIMIZATION", ES2007-36154, Proceedings of ES2007,ASME, Energy Sustainability 2007, June 27-30, 2007, Long Beach, California.

Andraka, Charles E., "ALIGNMENT STRATEGY OPTIMIZATION METHOD FOR DISH STIRLING FACETED CONCENTRATORS", ES2007-36177, Proceedings of ES2007,ASME, Energy Sustainability 2007, June 27-30, 2007, Long Beach, California.

Baturkin, Volodymyr, Vladilen Zaripov, and Charles E. Andraka, "DEVELOPMENT OF ADVANCED CAPILLARY POROUS STRUCTURES OF HIGH TEMPERATURE HEAT PIPES FOR SOLAR RECEIVERS FOR DISH/STIRLING SYSTEMS", 14th International Heat Pipe Conference (14th IHPC), Florianópolis, Brazil, April 22-27, 2007

Patent Application: SD-11313 Sandia Optical Fringe Analysis Slope Tool for Mirror Characterization

Patent Application: SD-10949 Closed Loop Tracking Sensors for Concentrating Solar Applications

Patent Application: SD-10565 Single Facet Solar Dish Design Optimization Method