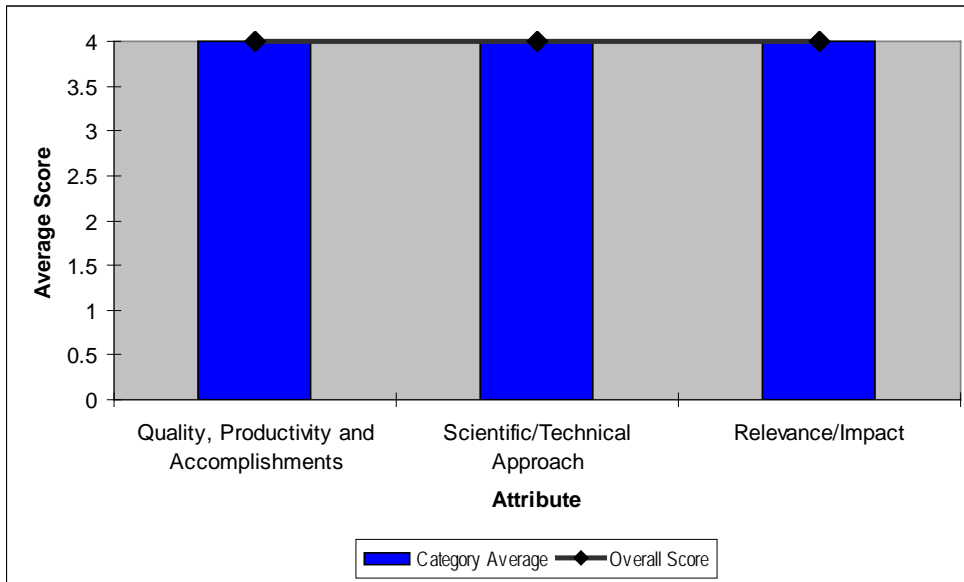


Dish/Engine Development

Principal Investigator: Chuck Andraka, Sandia National Laboratories



This review details the activities in CSP dish engine systems at Sandia National Laboratories. The program has achieved world record efficiency of 31.25% and has implemented designs that reduce total rotating weight by 34%.

Quality, Productivity and Accomplishments (Average Rating 4.0)

Rating Comments

4.0 The team participating in this project to support Stirling Energy Systems to improve the reliability and reduce the cost of its dish/engine components and systems has the required expertise and technical know-how. It is doing an outstanding job.

4.0 The composition and quality of the resources engaged for the work appears very strong. The PI has extensive (24+ yrs) experience in CSP. Other NREL and SNL resources have strong CSP experience in the areas relevant to the project (i.e. CSP, optics, heat transfer, controls, etc.). The level of technical expertise at SES and their involvement in the project is not specifically mentioned, however, the project team has worked very closely with SES. The information related to Infinia expertise and resources is too limited to make any judgment. The productivity appears to be very high. The project received several awards and notoriety including the Popular Mechanics “Breakthrough Award”, and citation from National Geographic, BBC, Discovery Channel, PBS. Achieved world record performance of 31.25%.

Accomplishments include: extensive systems, optical and thermal modeling to support design of next-generation engine and associated systems. Design process and tool development led to a total rotating weight reduction of 34% (6,000 pounds out of 17,500). Installation of production prototypes begun at Sandia. Developed and implemented engine simulator for controls development and testing, and SOFAST Mirror Characterization system for facet production inspection. Supported dish and engine controls modernization process.

SES’s AFC assessed “data adequate”. First SES production engine operational in test cell. Established and maintained ES&H controls, documentation, and training processes for entire SES team, helped in reliability improvement evaluations and root cause analysis. Assisted Infinia (3 kW dish engine) with optical and thermal design, upgrading CIRCE for facet

deformation, design process for single-facet dish.

- 4.0 An appropriate number of people, with well recognized technical credentials have been engaged in this project. The members of the team and collaborators clearly demonstrate their ability to contribute to the project. The facilities deployed on the project appear to be adequate, but limited, for the task at hand. The work under way is producing an appropriate level of accomplishment relative to the costs incurred. The project team appears to be on schedule, but the project is clearly still in progress and not yet complete. This project is outstanding. Clear benefits not only to specific design partners, but also a good focus on appropriate issues fostering technology commercialization, design for manufacturing, etc. Stirling energy systems – SES team went from 5 to 100 employees; DISH engine systems; 31.25 % sunlight hitting the system to grid ready 3 phase power record last year based on a single unit. Predict annual efficiency of about 26% for the overall systems; \$1M budget / year; SES \$100M this last and next calendar year
- 4.0 Highly experienced Sandia team in key areas, such as optics, systems, controls, materials, and system design; Dish Engine Research and Development has helped in improving the reliability and reducing the cost of dish/engine components and systems. Optical and structural coupling lead to a saving of weight by 6,000 lbs. \$100 m from SES as matching, Need to address thermal and optical issues, Control system for engine and dish, 50 systems/day. Need alignment time reduced to 20 min. Also helped Infinia with optical and thermal improvements. Fundamental change in – combined FEA with CFD (wind loading). Reduction of 4,000 lb rotating weight reduction – here the mirrors were deflected

Scientific/Technical Approach (Average Rating 4.0)

Rating	Comments
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| 4.0 | The technical approaches adopted in executing different tasks and in achieving different goals of this project are all sound, pragmatic, and effective. The results obtained in improving the technology and in helping Stirling Energy Systems to improve its dish/Stirling technologies are outstanding. |
| 4.0 | The scientific and technical approach is quite superior, which includes industry-led program that leveraged Sandia expertise in key areas (Optics, Systems, Controls, Materials, Failure analysis) in development and consultation roles along with the industry experience of SES and Infinia. Majority of the work is related to SES. Infinia's work seems to be much less than SES. The project used advanced technologies and resources (optics, controls, FEA, etc.) to accomplish the tasks. |
| 4.0 | SOFAST Mirror Characterization System; Target installation of 50 units per day need to get dwell time on alignment fixture down to about 20 minutes. First SES production system is operational in the Detroit area. DEC – Dish engine critical components. Industry led program – industry spends \$100M, gov spending \$1M. Industry is on a much different time scale than labs are used to. |

Fundamental shift in how you look at structural design of the system Couple the CIRCE model (not a ray trace) to their FE model Sunshape as a distribution convolved with mirror error distribution, project that onto the receiver. Output for fea to steer mirrors, drive the fea with cfd to look at wind loading. Peak flux on the engine to avoid melting the engine.

17500 rotating mass weight reduced to 13500 pounds, assembly line produces a mirror every 20 seconds, 500,000 points analyzed in 10 seconds – have turned around 3 generations of facets in

2.5 weeks at SES mirror simulator

- 4.0 Additional 2,000 lb reduction by changing dish shape (optical and structural coupling lead to a saving of weight of 6,000 lbs). Mirror characterization at assembly line. Working with NREL. Developed Engine simulator.

Relevance/Impact (Average Rating 4.0)

Rating Comments

- 4.0 In this early stage on the use of CSP technologies for large scale commercial applications, it is essential to avoid failures in any one of the commercial projects being promoted, since such failures may undermine the credibility of the CSP industry as a whole. In this regard, the support that Sandia National Lab is providing to SES to improve its dish/Stirling products is of the highest importance. The results that this project is delivering are outstanding and very encouraging.
- 4.0 The work is highly relevant to the CSP industry need, especially the SES work. SES has signed two major agreements with SCE and SDG&E to install over 800 MW (to be extended to over 1500 MW) in the near future. For the Infinia work, specific agreements or market has not been identified other than indicating that it will compete with PV with its small 3 kW dish. If the cost is lower than a similar size PV system, this work is likely to lead the development of an alternative for PV (3 kW), which may create a cost-competitive product.
- 4.0 Important Design Guidance: You can not give up performance to save on cost Will have 1.5 Mw in AZ by end of this year break ground late august early September, to test out assembly and deployment model, 500mw planned in California planned start install by Jan 2010. \$50,000 per unit installed cost they feel they can make a profit on the systems' Solar only system – you don't have any storage for the dish systems. Scale-up is achieved through more units in one field as opposed to increasing size of each dish, driven mostly by window loading 25-30 kw per unit with wind and seismic loading is probably about where you want to be. Two California plants are on the order of 20,000 to 30,000 units at a field. Push assembly back towards the factory. Need full trucks for weight and volume; 2 full dishes per truck with this approach vs five trucks for one dish of M-D design.
- 4.0 Sandia National Labs (SNL) has worked closely with SES and other companies to lower cost through production automation and reduce O&M costs by consolidation of O&M resources. SES will be installing up to 850 MW of power for Southern California Edison and up to 900 MW of power for the San Diego Gas and Electric. SNL has helped SES to identify and implement operational improvements, which are critical for these deployments. Annual efficiency is expected to be 26%. Improved structural design. Solar-only system (no storage), 25,000 to 30,000 units for project in CA (total 2 projects)

The project is highly relevant to the programmatic goals of the DOE Solar Program Multi-Year Program Plan.

Overall (Average Rating 4.0)

Rating Comments

- 4.0 The project is a very good example of the kind of critical and outstanding support that SNL and NREL may provide to the CSP industry. The SNL technical personnel providing that support has the required expertise and know-how. The approaches they are using to achieve the project goals are effective and pragmatic, and the results they are delivering are very well targeted, and highly valuable.

- 4.0
- Weight reduction was a great accomplishment
 - The advantages of design change from Cartesian to radial coordinate was a good discovery, which should have been intuitive to the designers long time ago. It is understandable, why they originally went for the Cartesian design.
 - AFC at CEC for SDG&E project (3200 lbs of paper) – considered data adequate.
 - SES will build a 1.5 MW demo project in Arizona, start late Aug 2009
 - 500 MW in California, start in 2010
 - Takes 4-6 hours to hand build a dish
 - Top lab efficiency of 31.25% achieved. Field efficiency, based on annual average, expected to be 26%
 - Dish design changed from Cartesian (rectangular) to radial has helped reduce cost and in other aspects also.
 - At \$50K per unit, SES can make a profit
 - O&M cost: SES thinks they have a good handle on it, but very confidential

The installation of the demonstration project (6 dishes, 1.5 MW) is absolutely essential for SES to show the public and the regulators that they are making progress and somewhat on-track with their PPA with SCE and SDG&E. That would help the company (SES) in gaining trust. Sooner they can do it better it is; would help restoring credibility.

4.0 Excellent Work. Weight reduction study was excellent.

4.0 Dish Engine Research and Development has performed component and system R&D and has supported the industry in commercialization of the technology

The 6,000 lb weight reduction for the dish system and resulting stiffer optical system is a major achievement. The SOFAST for mirror characterization is excellent tool for measuring slope errors and shape errors of facets and leading production line quality control

Announced 31% performance