Full Spectrum hybrid photovoltaics and thermal engine utilizing high concentration solar energy

Jonathan Grandidier[1], Bill J. Nesmith[1], Terry J. Hendricks[1], Michael B. Petach[2], Emanuel Tward[2], Scott A. Whitney[2], Juan Cepeda-Rizo[1], Jordi Paredes Garcia[1], Matthew E. Devost[1], Herb Hayden[3], Nicholas Fette[3], Tyler Beeney[3] and David E. Lee[2]

[1]Jet Propulsion Laboratory - California Institute of Technology, Pasadena, California, 91109-8099, U.S.A.
[2]Northrop Grumman Aerospace Systems Redondo Beach, California 90278-1001, U.S.A.
[3]Southwest Solar Technology (SST), 820 W. Fairmont Drive Tempe, Arizona 85282, U.S.A

***Abstract* — We describe a Hybrid full spectrum solar system (FSSS) that utilizes the full spectrum available from the sun. It is designed to convert the full solar spectrum into useful electrical energy by using both photovoltaics energy conversion and thermal energy conversion combined with thermal energy storage (TES) in order to operate around-the-clock even when solar energy is not available. It is composed of a parabolic dish concentrator and a hybrid high temperature photovoltaics and thermal engine. The target efficiency of the overall system is over 35% with the AM1.5D solar spectrum as a power input.**

***Index Terms* — High Temperature Photovoltaics, Multi-junction Solar Cell, Hybrid Solar Systems, Solar Thermal Systems.**

I. Introduction

Photovoltaics can generally be used to convert energy from the sun up to the energy bandgap of the semi-conductor. Most photovoltaics materials can't convert light in the mid- to far-infrared even though a large portion of the sun's spectrum is in that region. This energy ends up being either dissipated or reflected and therefore not converted into useful electrical current. To make use of most of the solar spectrum, we are developing a Hybrid Full Spectrum Solar System (FSSS) coupled with a parabolic dish concentrator that focuses the sunlight in order to achieve a concentration of 200x.

II. Description of the System

The overall system is depicted in Fig. 1a and the FSSS is detailed in Fig. 1b. It consists of a solar receiver cavity with a flat copper plate on which concentrator solar cells are mounted. Those solar cells are designed to operate at 350°C. While solar cells usually operate at a higher efficiency at low temperature, there has been some demonstrations of photovoltaics operating over 400°C. [1,2] Waste heat from the solar cells is absorbed through the copper plate by naphthalene which is used as both a thermal energy storage (TES) and a heat transfer material. In its current form, TES can operate for 15 minutes. Naphthalene vaporizes through the evaporator section and heats a thermo-acoustic power convertor (TAPC) before liquefying back to the reflux boiler section to complete its cycle. The expected system efficiency is over 35%.

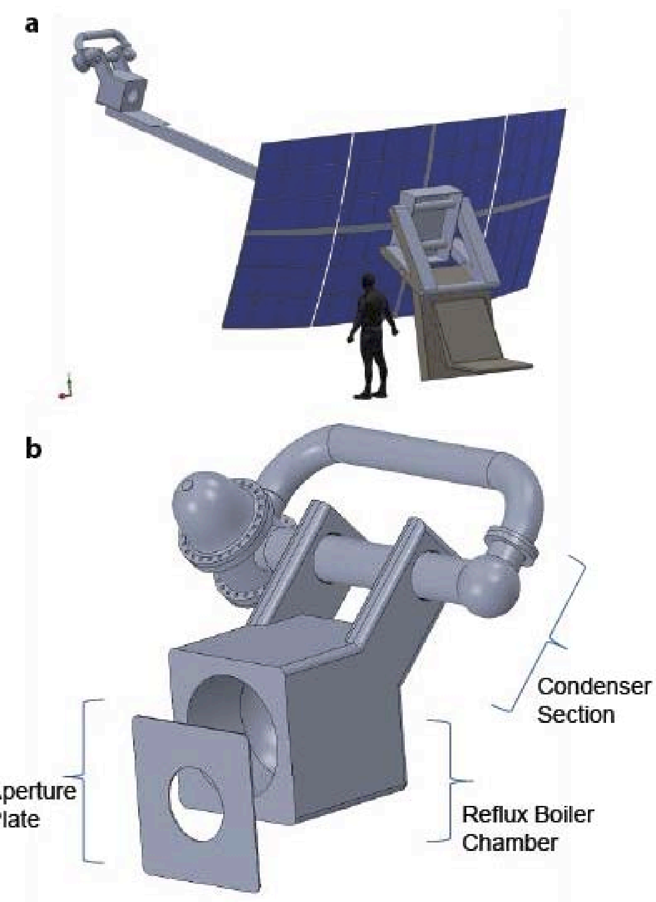

Fig. 1. (a) Overall system including parabolic dish concentrator and (b) detailed FSSS.

III. Sunlight Concentration

Solar concentration is achieved using a new parabolic dish concentrator provided by SST. The SST solar dish collector design differs from more typical point-focus solar dish systems in that the profile of the solar flux on the receiver is custom tailored to optimize the flux profile desired at the CPV input.

Figure 2 shows examples of ray tracing in Zemax of how the flux is altered from point focus to accommodate the receiver. As the system design progresses further, modifications in the dish optics may be considered, which may ultimately include two (or more) different receiver target regions in order to optimally balance energy input for the hybrid receiver.

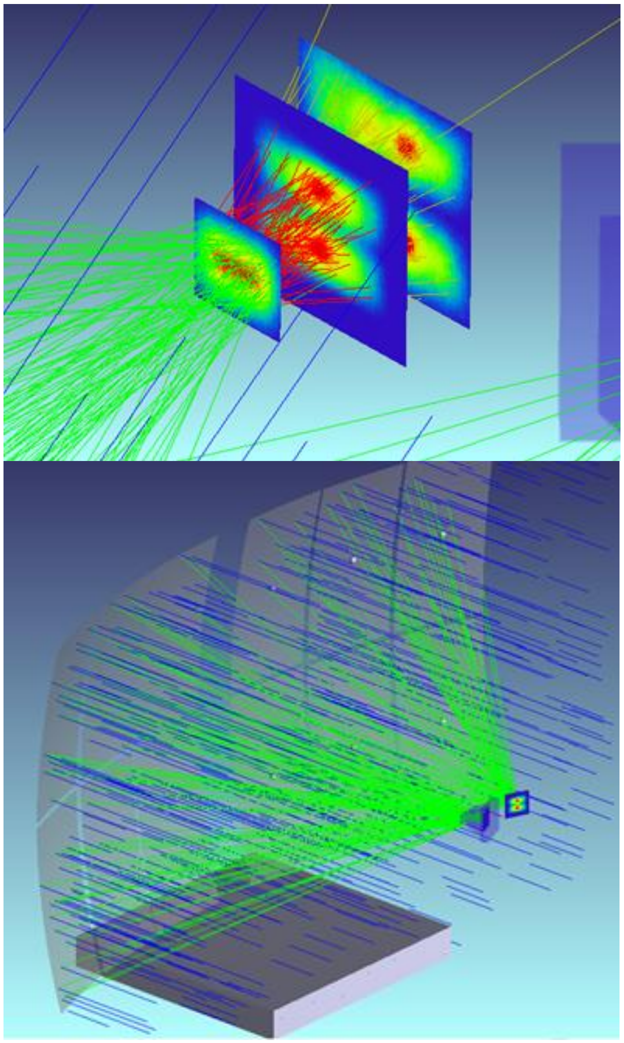

Fig. 2. Ray optics modelling of the incoming sunlight into the parabolic dish concentrator and focused into the concentrator solar cells (CPV) mounted on the copper plate.

IV. Full Usage of the Solar Spectrum

Because traditional photovoltaics don’t convert sunlight at low wavelengths, about one third of the total solar spectrum is not used. Main loss mechanisms are:

1) Reflection from the solar cell
2) Heating of the solar cell.
3) Blackbody Radiation
4) e^-/hole pair recombination

In the second case where the solar cell is heated, not only the solar energy is not converted into useful current, but it also reduces the overall performance of the solar cell as its efficiency decreases at a rate of about 0.04%/C as it heats. We present in Fig. 3 the spectrum management for full usage of the solar spectrum. We consider here a dual-junction GaInP/GaAs solar cell that converts the incoming sunlight at an efficiency over 30%. [3] Photovoltaics converts sunlight up to 1.4 eV which corresponds to the bandgap of GaAs at room temperature.

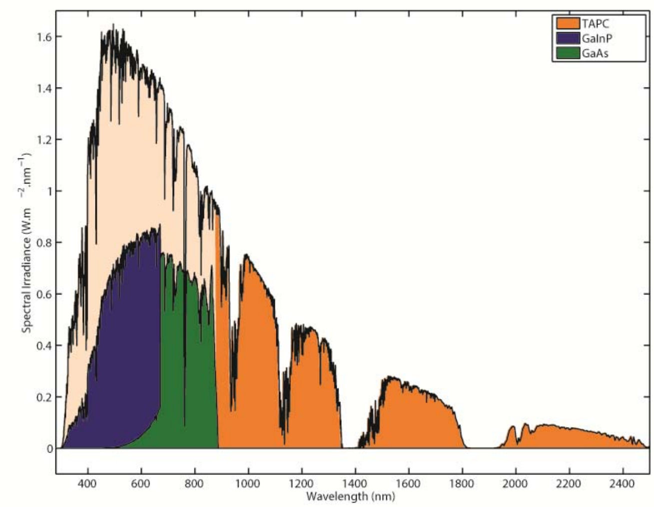

Fig. 3. Full usage of the solar spectrum with photovoltaics conversion from the solar cell and thermal energy conversion from the waste heat of both the solar cell and the mid- to far-infrared part of the solar spectrum that can’t be converted by photovoltaics.

IV. Conclusion

Using a 200x parabolic dish concentrator combined with a hybrid high temperature photovoltaics/TAPC engine, we expect to reach an efficiency of over 35%. Future work will consist of integrating the overall system with custom designed high-temperature solar cells, advanced TES and heat transfer sub-systems, advanced thermal engine designs, and measuring the lifetime of the solar cell at high temperature.

Acknowledgement

This work is supported by the Department Of Energy (DOE) through the FOCUS ARPA-E program under award #DE-AR0000466.

References

[1] G. A. Landis and K. C. Mellott, "Venus surface power and cooling systems," *Acta Astronautica,* vol. 61, pp. 995-1001, 12// 2007.
[2] A. L. Geoffrey and H. Emily, "Analysis of Solar Cell Efficiency for Venus Atmosphere and Surface Missions," in *11th International Energy Conversion Engineering Conference*, ed: American Institute of Aeronautics and Astronautics, 2013.
[3] B. M. Kayes, L. Zhang, R. Twist, I. Ding, and G. S. Higashi, “Flexible Thin-Film Tandem Solar Cells with >30% Efficiency”, Alta Devices, Sunnyvale, CA 94085, USA