High-Temperature Thermochemical Storage with Redox-Stable Perovskites for Concentrating Solar Power

CRADA Number: CRD-14-554

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Cooperative Research and Development Final Report

In accordance with Requirements set forth in Article X. Reports and Publications A.(2), of the CRADA agreement, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information (OSTI) as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Colorado School of Mines (CSM) and the National Renewable Energy Laboratory (NREL)

CRADA number: CRD-14-554

CRADA Title: High-Temperature Thermochemical Storage with Redox-Stable Perovskites for Concentrating Solar Power

Joint Work Statement:

The NREL efforts in the project included: (i) NREL assisted CSM in developing and specifying the perovskite material as solid particles for thermochemical energy storage in a CSP system; (ii) led the development of thermal/chemical computational fluid dynamics (CFD) model for the reactive receiver design based on NREL's near-blackbody (NBB) receiver technology; (iii) guided the system design, integration, modeling, and conceptual fluidized-bed heat exchanger design, and provided major components' techno-economical inputs.

The Period of Performance for this effort 24 months. The first phase is 12 months in duration. The deliverables will be evaluated and a next phase entered into based on success of first phase. Modification #2 puts in place the Phase II work. Phase II is 12 months in duration.

Joint Work Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$ 109,999.00
Year 2 or Modification #	$ 319,817
Year 3 or Modification #	$ .00
Year 4 or Modification #	$ .00
TOTALS	$ 429,870.00

Abstract of CRADA Work:

This project was funded by a Federal Opportunity Announcement (FOA) Award. The project was led by Colorado School of Mines (CSM) to explore and demonstrate the efficacy of highly

reducible, redox-stable oxides to provide efficient thermochemical energy storage for heat release at temperatures of 900°C or more. NREL supported the material development for its application in a concentrating solar power (CSP) plant. In the project, NREL provided its inventive system design, chemical looping for CSP, and use it as a platform to accommodate the chemical processes using a cost effective perovskite materials identified by CSM. NREL designed a 5-10kW particle receiver for perovskite reduction to store solar energy and help the development of a fluidized-bed reoxidation reactor and system integration. CSM and NREL developed the demonstration receiver for on-sun test in the 5-10 kWt range in NREL's high flux solar furnace. NREL conducted system analysis and provided techno-economic inputs for the overall system configuration.

Summary of Research Results:

The project, which was part of DOE's Concentrating Solar Power: Efficiently Leveraging Equilibrium Mechanisms for Engineering New Thermochemical Storage (CSP: ELEMENTS) funding program, explored the use of highly reducible oxides (perovskites from earth abundant elements) to store concentrated solar energy both in heat and chemical bonds. The technology has the potential to allow concentrated solar power plants to utilize stored energy for continued plant operation through the night or other periods of low solar insolation. NREL used its development in a particle thermal energy storage system for the success of the development to be applied in a CSP plant. NREL provided its high flux solar furnace as the test bed for on-sun testing to verify the solar energy conversion and the solar thermal/chemical processes. This technology has the potential to enable solar power to displace fossil fuel plants and provide reliable and fully dispatchible renewable energy for future generations.

This project investigated the technical feasibility of redox cycles with low-cost, perovskite oxides for direct high-temperature (> 900 °C) solar heating and thermochemical energy storage (TCES) in a concentrated solar power system. This project was built upon advances in an enclosed particle receiver design at NREL and the respective material expertise at CSM on characterization of the redox-stable materials and on system process design and techno-economic evaluation. The subsequent energy release to a power cycle can be sustained by oxide re-oxidation in air with a fluidized-bed reactor and heat exchanger. Perovskite selection was based on reducibility, redox stability, spectral absorptivity, and costs were determined by experimental characterization and model development at CSM. These material models have been integrated into NREL's particle receiver and fluidized-bed models to assess solar receiver efficiencies and TCES with selected oxides. From these efforts, a sub-scale (5-10 kW_t) particle receiver reactor device was tested at NREL's solar furnace facility in conjunction with a re-oxidation reactor to validate models and provided a basis for commercialization with complete techno-economic analysis.

Figure 1 shows the small-scale planar cavity receiver prototype that has been tested at NREL solar furnace. A SolTrace model has been developed in predicting the solar flux distribution based on NREL HFSF concentrating solar flux. The solar flux was used as the thermal boundary conditions for the thermal model to predict the temperature distribution and thermal performance. The leading edges of the receiver panel are cooled by liquid for higher heat transfer coefficient than the particle heat absorption to maintain adequate heat transfer when subject to direct incident solar flux. The panel shape was selected and characterized to provide optimum flux spreading on the panel wall (the left graph in Figure 1). The flux distribution is tried to match the particle heat absorption capability. The thermal model simulated the temperature distribution for this purpose.

The merits of the planar cavity receiver are multiple: it provides the atmospheric conditions for thermochemical process of the solar thermal process; it can achieve high performance at high temperature and avoids particle losses comparing to an open-cavity particle receiver. The design avoids high-temperature special coatings on the panel walls. The panel wall and whole receiver are fairly easy to be fabricated from sheet metal and can be scaled up to large scale commercial CSP plant. The further development includes verifying the particle flow and heat transfer for design optimizations.

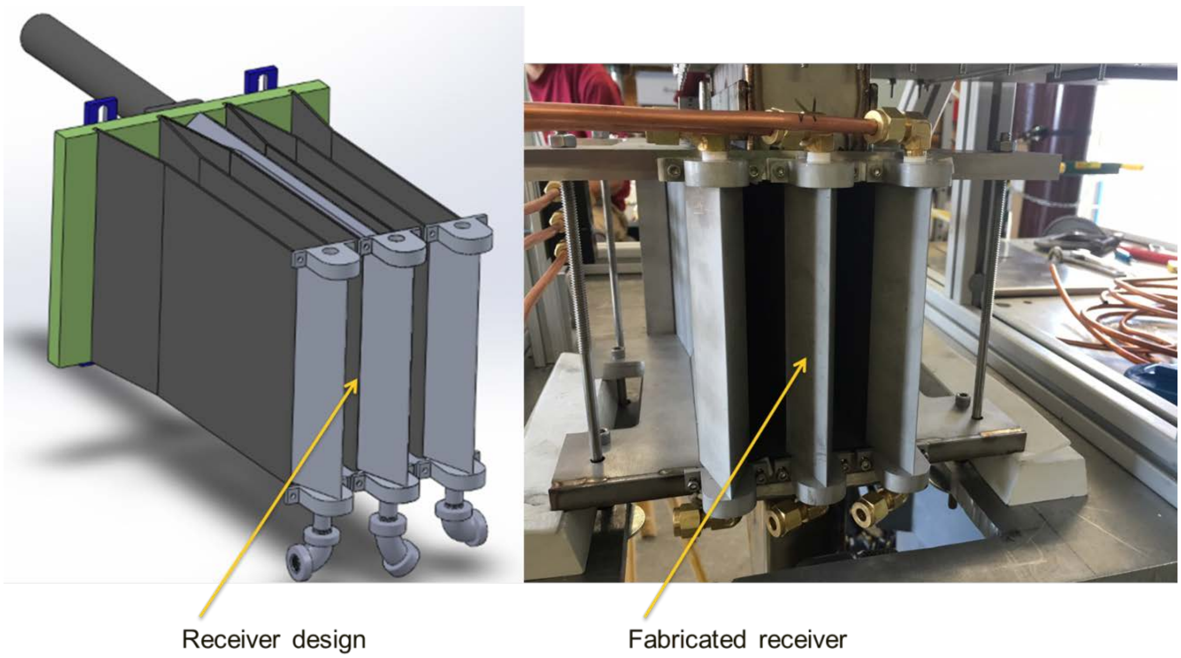

Figure 1. A small-scale planar cavity receiver has been tested at NREL solar furnace.

This project used rigorous design and modeling techniques to receiver sizing, heliostat field layout and aiming strategies to optimize the flux distribution and thermal performance of the receiver. Knowledge gained from the prototype testing can enhance certainty in sizing constraints (for example, minimum solids channel size) to enable a meaningful optimization study. Large-scale prototype testing and commercial receiver design can also be performed from the methodology developed in this project.

Subject Inventions Listing:

U.S. Application No. 15/390,690, “Receivers for Concentrating Solar Power Generation,” filed December 26, 2016.

Report Date:

April 14, 2017

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The CRADA is funded by DOE Solar Energy Technology Office, under the Concentrating Solar Subprogram. The goal of the project is to achieve the SunShot goal of 6¢/kWh, by overcoming significant barriers in existing CSP technologies. The state-of-the-art in CSP involves the use of salts for thermal energy storage and as a heat transfer fluid. NREL is developing a new CSP system utilizing solid particles for heat storage and transfer exchanger. Built upon the particle-CSP system, the material to be explored and demonstrated in this project will provide efficient thermochemical energy storage for heat release at temperatures of 900°C or more.

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