PROTOTYPE DEMONSTRATION OF AN INTEGRATED SOLAR CONCENTRATOR SYSTEM AND CARBOTHERMAL REACTOR USING SOLAR ENERGY TO EXTRACT OXYGEN FROM REGOLITH.

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Introduction: Obtaining oxygen in-situ enables space commercialization and exploration through dramatic reduction of the mass cost associated with lunar launch, landing, and propellant supply for missions beyond Earth orbit. Carbothermal reduction is one method to extract oxygen from lunar regolith [1]. Sierra Space developed a flight forward Carbothermal Oxygen Production Reactor (COPR) through a NASA funded Tipping Point program. COPR was successfully tested in the relevant lunar thermal and vacuum environment using NASA JSC facilities in 2024, elevating this reactor system to Technology Readiness Level (TRL) 6 through NASA's Carbothermal Reduction Demonstration (CaRD) project. The CaRD project continued development of a deployable solar concentrator capable of tracking the sun, gas analysis system, and a solar concentrator control system consisting of avionics and software. These subsystems were developed by multiple NASA centers. The COPR hardware was integrated with the solar concentrator system at NASA JSC and performed testing in summer 2025 using ambient sunlight in Houston, Texas. This testing demonstrated successful extraction of oxygen from lunar regolith simulant using concentrated solar energy as the heat source.

Carbothermal Reduction Reactor with Scalable Flight Forward Architecture: COPR demonstrates a mass efficient, low electrical demand, scalable architecture for oxygen extraction sized for a lunar technology demonstration mission. A prior Carbothermal Oxygen Production (CTOP) program demonstrated an architecture capable of mass production of oxygen from lunar regolith simulant [1]. The technologies that enabled mass production were miniaturized from the CTOP program and integrated into COPR (Fig. 1). This produces a design that demonstrates the technologies required for mass production in a small flight package.

Direct Energy Approach and Thermal Control: The COPR design uses a direct energy processing approach where concentrated light is applied directly to the lunar regolith simulant surface. The insulating properties of the regolith are used to isolate the molten material from all hardware. This approach allows for a completely passive thermal control system where high temperature (>1650°C) carbothermal reduction is performed without requiring exotic materials, complex cooling systems, or consumables.

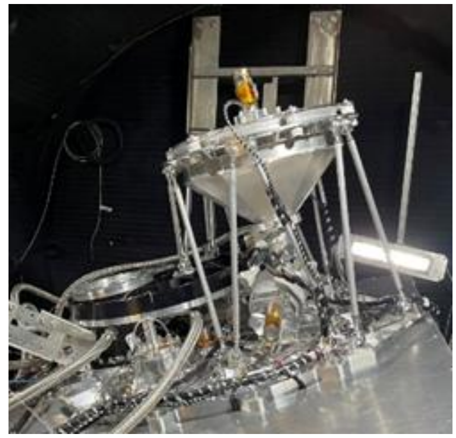

Fig. 1 COPR Carbothermal Reactor in TVAC

The COPR hardware includes an automated material handling system. This system controls the movement of regolith into the pressurized reactor volume, manages the material for the carbothermal reaction, separates and removes the processed slag from the regolith. Processed material is then removed from pressurized volume using a regolith tolerant valve design which has been demonstrated to 10,000 cycles[1]. Sierra Space has demonstrated repeated, automated material handling processes with the regolith simulant in the lunar thermal vacuum environment.

While laser energy is employed in the laboratory environment, direct solar energy was utilized for integrated testing in 2025 using GreenSpar 250 lunar highlands simulant. The carbothermal reduction process was also demonstrated using direct solar energy at the 2010 International Lunar Surface Operations field test at Mauna Kea, Hawaii. This previous testing used local volcanic tephra as the regolith material instead of a tailored lunar regolith simulant.

Integrated Solar Concentrator System: The full integrated solar concentrator system and carbothermal reactor shown in Figure 2 was developed across multiple NASA centers and with industry partners. The solar concentrator system was developed at NASA GRC. The concentrator was designed to be stowed for a launch environment and configuration, then deployed on the lunar surface. It utilized a crossed dragone configuration of composite mirrors to direct horizontal sunlight onto a target 90° from the incoming sunlight. This configuration is optimal for polar locations, but other designs can be utilized for equatorial operation.

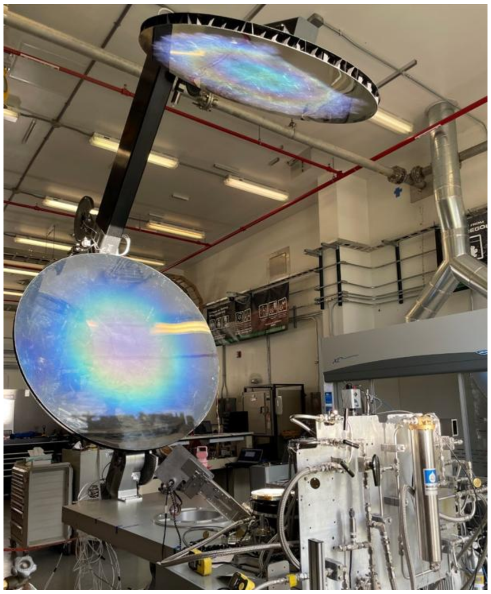

Fig. 2 Integrated Solar Concentrator System

An optical shutter and splash plate were developed by JSC for the purpose of preventing damage to the reactor while the concentrator rotates toward the sun in a deployed configuration. The gas analysis system based on the Mass Spectrometer Observing Lunar Operations (MSOLO) instrument was developed at NASA KSC and was required to determine the amount of oxygen extracted during each test. Avionics and software for the CaRD prototype were also developed at KSC and based on experience with MSOLO avionics and software. The control system was designed to stow, deploy, track the sun, and perform beam alignment of the concentrated light. Components of this system are detailed in Figure 3.

The prototype subsystems were integrated and tested at JSC Energy Systems Test Area. A heliostat was used to direct sunlight toward the prototype in a way that is representative of the sunlight conditions at the south pole of the Moon. When concentrated sunlight was focused on simulated lunar regolith within the reactor, the gas analysis team confirmed the presence of carbon monoxide gas, which confirmed that a solar carbothermal reaction took place. The prototype design successfully demonstrated end-to-end capability and further steps to achieve a flight capable system have been defined.

With lunar data, engineers would be able to design a scaled-up system capable of extracting oxygen from regolith at useful quantities for crew life support and rocket propellant. In the long term this method of In-Situ Resource Utilization could be used to drastically reduce the cost and risk of a sustained human presence on the Moon by reducing the amount of oxygen that would have to be delivered, and generate revenue as part of the developing lunar economy.

References:

[1] White B. C. and Haggerty N. P. (2023) Carbothermal Reduction System Overview and Developments in Support of the Artemis Program and a Commercial Lunar Economy. In *52nd International Conference on Environmental Systems*.

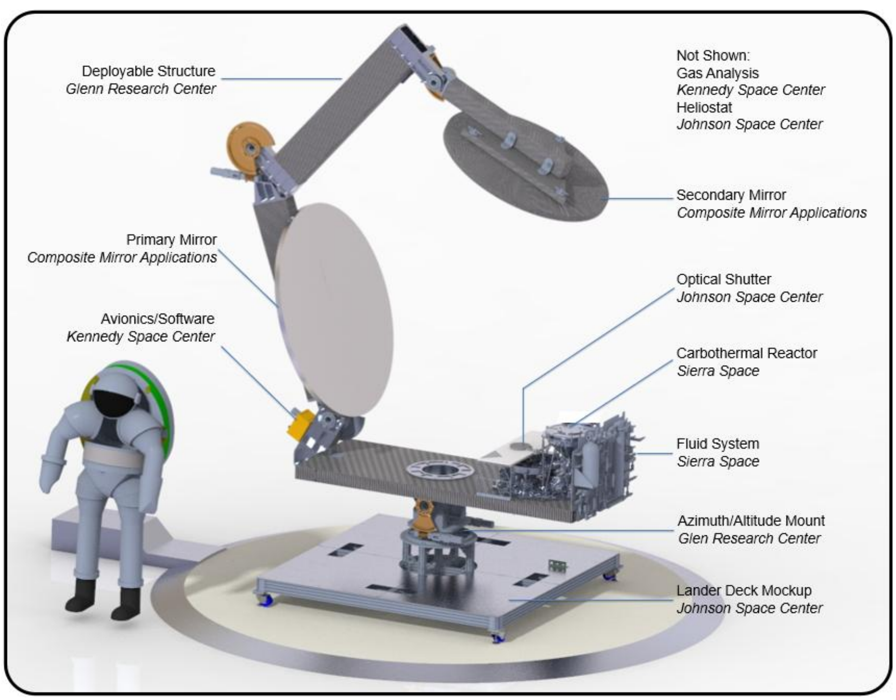

Fig. 3 CaRD Integrated Prototype