

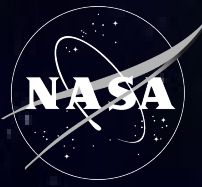


Space Technology Mission Directorate Game Changing Development Program

Aaron Paz| Jeff Michell| FY23 Carbothermal Reduction Demonstration Annual Review Presentation | 09.19.23
Aaron.paz-1@nasa.gov

CaRD

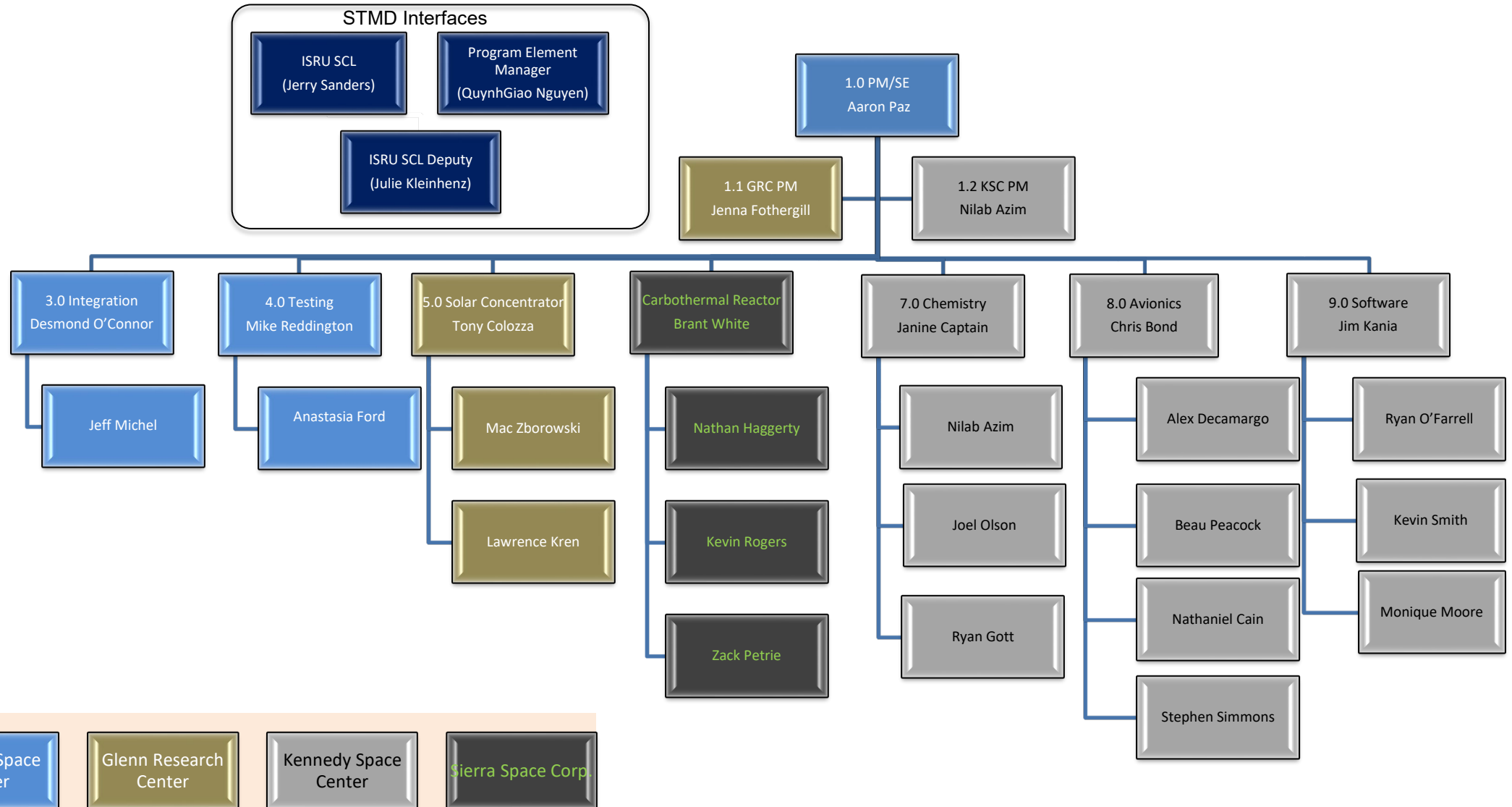
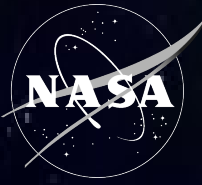
Technology Goals & Project Objectives



Technology Goals & Objectives

Goal #1	Design, build, and demonstrate performance and efficiency of a prototype solar energy delivery system for a carbothermal reactor.
Objective a.	Demonstrate solar concentrator deployment using prototype avionics and software.
Objective b.	Demonstrate solar tracking using prototype avionics and software.
Objective c.	Collect solar concentrator performance data at Earth operational conditions and using solar flux.
Objective d.	Produce light-weight flight-like concentrator mirrors and integrate them into a deployment and tracking system.
Objective e.	Demonstrate the ability to produce concentrated sunlight at a concentration ratio of ~4000:1 commensurate with the requirements for a carbothermal reactor.
Goal #2	Integrate solar concentrator, carbothermal reactor, and mass spectrometer to collect Oxygen from Regolith (O2FR) performance and efficiency data.
Objective f.	Collect integrated brassboard performance data under vacuum. Performance data may include thermal management of the reactor and gas analysis accuracy.
Objective g.	Analyze reaction byproducts using a mass spectrometer with hydrogen as the working fluid for carbothermal reaction.
Objective h.	Collect integrated prototype performance data using terrestrial outdoor conditions. Performance data will include optical transmission efficiency and oxygen production efficiency using natural sunlight.
Objective i.	Collect performance data of the partially integrated prototype under vacuum.

Team Members / Project Org



Collaborations & Partnerships

NASA Centers

- GRC
- JSC
- KSC

Public/Private Partnerships

- Sierra Space

SBIR/STTR

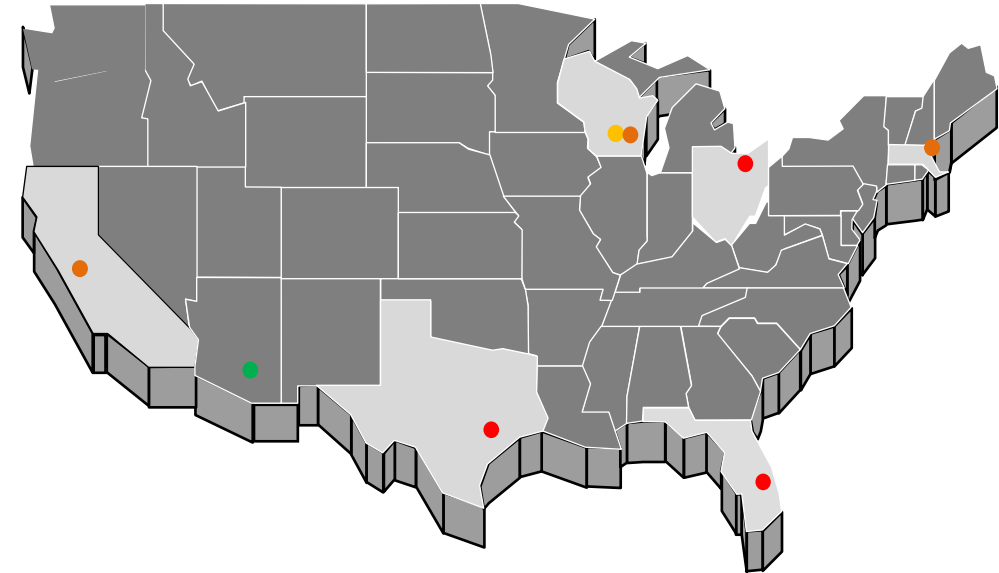
- Physical Sciences Inc.
(Phase 2 80NSSC20C0201)
- Sierra Space
(Phase 3 80NSSC20C0048)

Academia

- University of Arizona

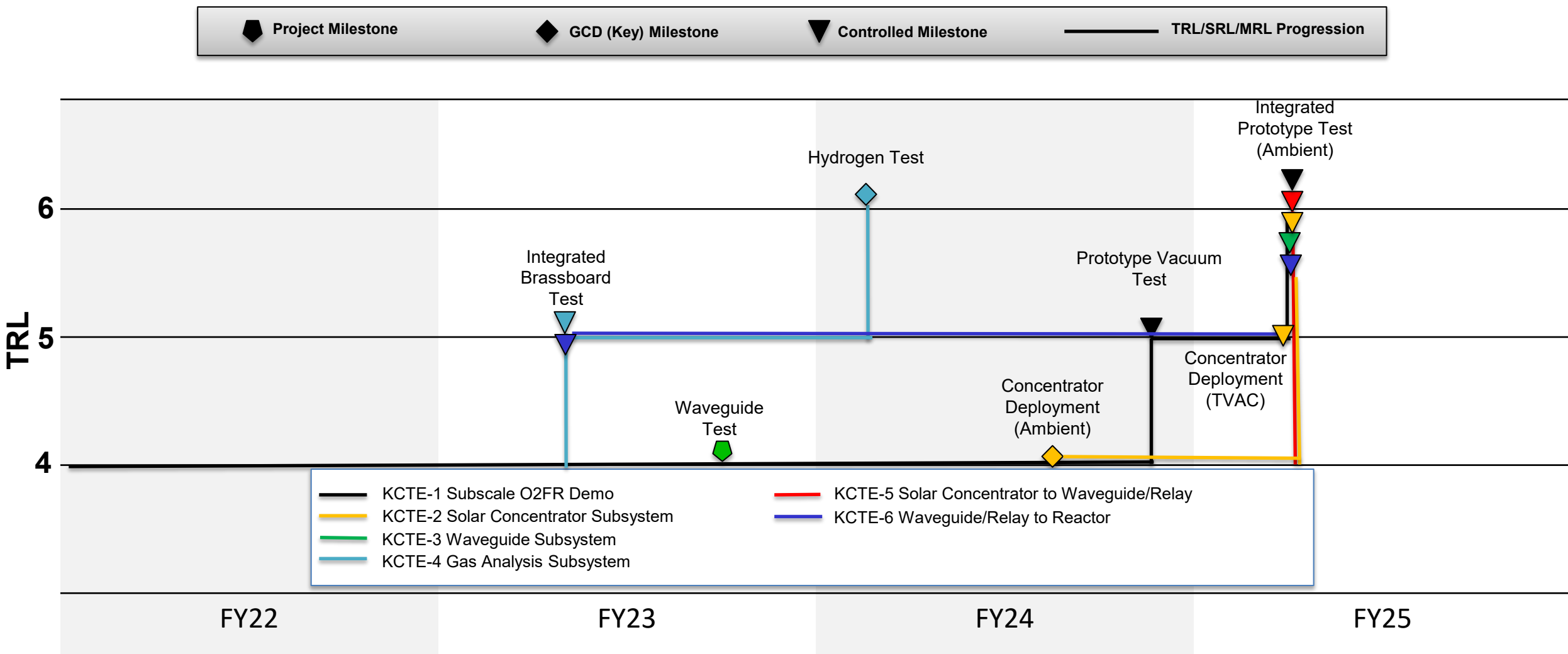
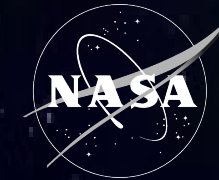
➤ Contributing partners

- Sierra Space contribution toward Tipping Point contract is ~850K.
- University of Arizona, in collaboration with Composite Mirror Applications Inc. is contributing a glass slumping mold and metrology.
- JSC Engineering has contributed ~500K.



Collaborative multidisciplinary partnerships to leverage fiscal resources, ideas, knowledge & expertise.

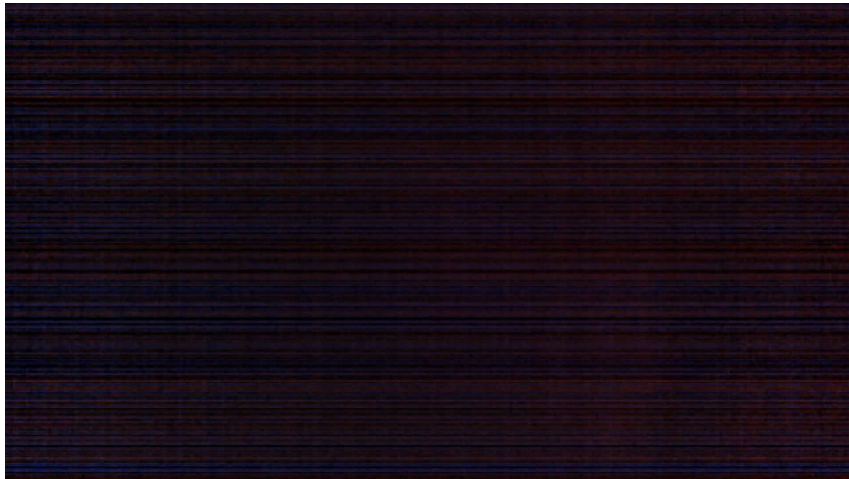
TRL Progression CaRD



Accomplishments – Integrated Vacuum Test



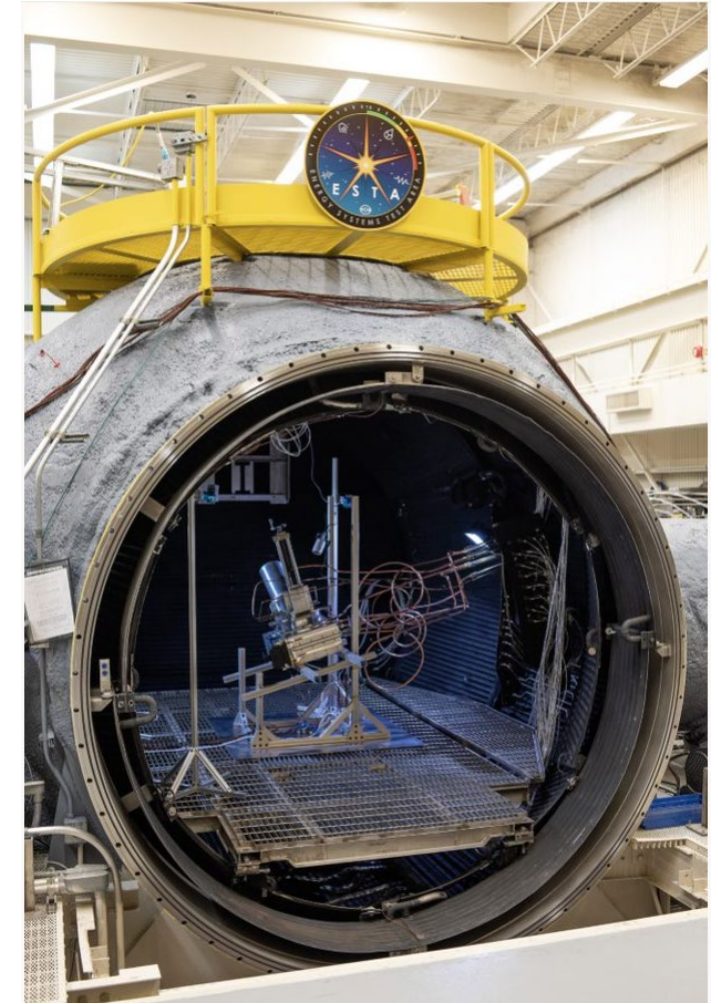
- Successfully beamed ~1.3kW of energy into a vacuum chamber to melt lunar regolith simulant.
- Successfully extracted oxygen (as CO) from lunar regolith simulant with a carbothermal reactor operating in a vacuum environment.
- Successfully quantified reaction products from a carbothermal reaction using a COTS version of a flight qualified mass spectrometer.
- **Oxygen extracted per KWh was an order of magnitude more than 2010 field demo**



Molten Regolith Simulant During Reaction
(15 sec video)

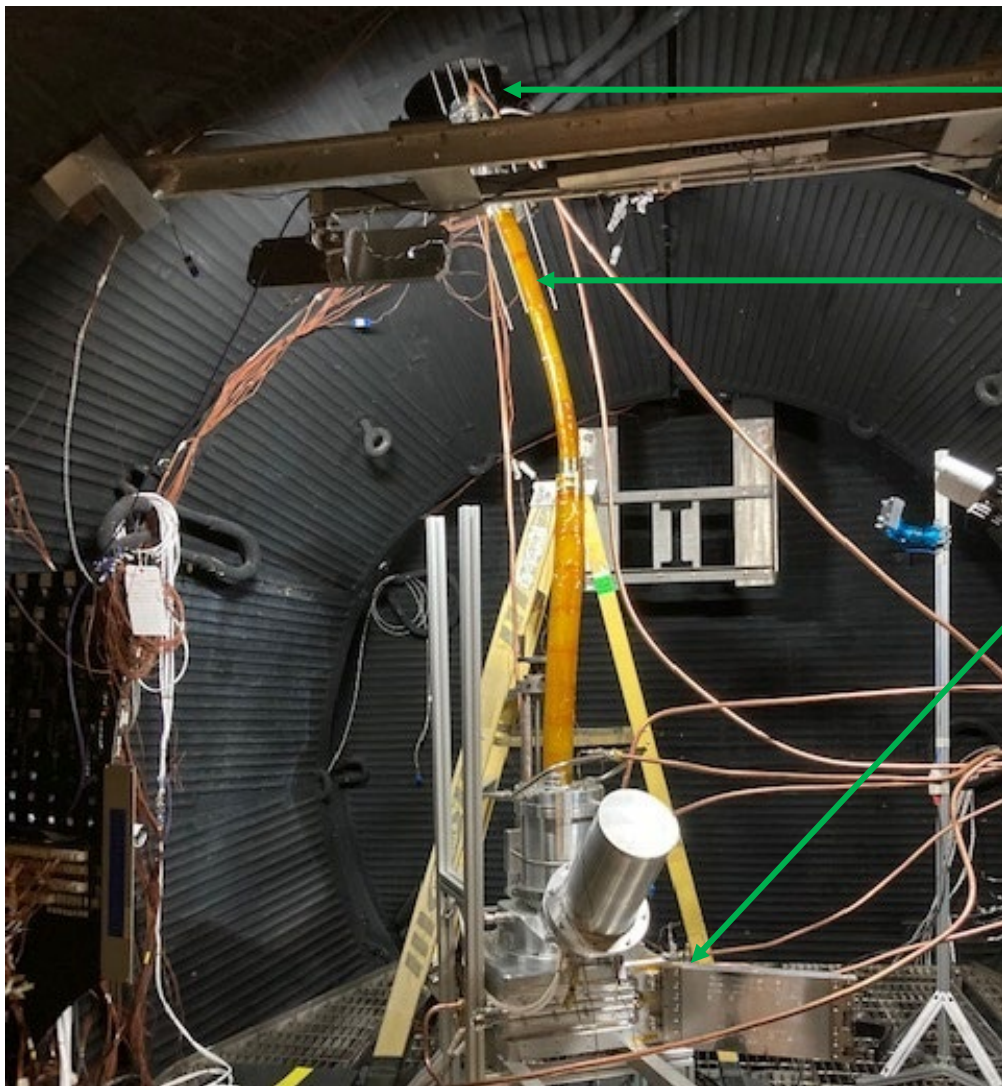


CaRD Test Team



Brassboard Reactor in 15ft Dirty TVAC
chamber at JSC

Accomplishments – Waveguide Test



Laser light enters waveguide with the same ray angles, diameter, and flux as concentrated solar energy.

Waveguide routes light into reactor through an array of water-cooled fibers.

Calorimeter (not shown) is placed inside of an open reactor to determine the amount of energy being delivered to the reactor.

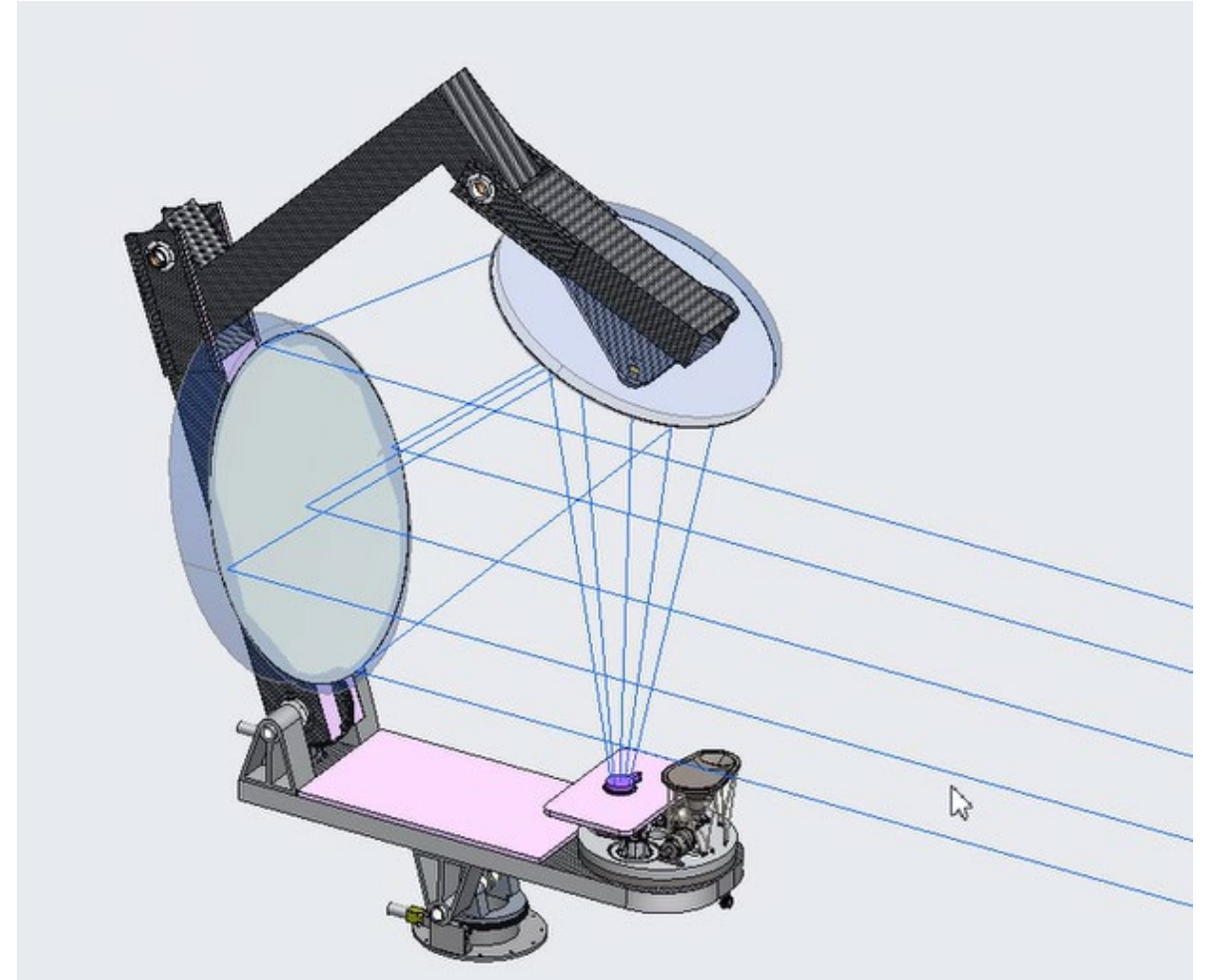
Test results showed that if this design were to be included in an integrated solar-carbothermal prototype, we would not meet the KPP threshold. The test was successful in that it helped to guide the integrate prototype design.

Waveguide Test Configuration Inside Chamber

Accomplishments – Prototype Design



- Developed preliminary design that does not require the use of a waveguide. Concentrated sunlight will enter the reactor directly.
 - More efficient
 - Lighter
 - No heat rejection system



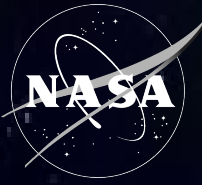
Accomplishments – Composite Mirror Construction



- Both primary and secondary mirrors have been constructed.
- Surfaces are currently being analyzed for surface accuracy.
- Upon verification of surface accuracy, mirrors are ready for optical coating.

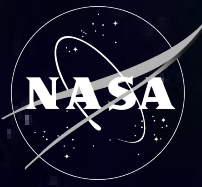


Project Assessment Summary



Project Name	Performance				Comments
	C	S	T	P	
Mid Year					Technical – Successful integrated test in vacuum. Cost – Available funds are sufficient to meet near term objectives. Schedule – Milestones revised to match approved project guideline. Programmatic -
Annual					Technical – Testing reduced the amount of unknowns and retired risks. Cost – Available funds are sufficient to meet objectives. Schedule – Near term milestones may slip, but overall schedule is still on track. Programmatic -

Plans Forward and Transition / Infusion Plan



Slide Presented by Jim Reuter at Space Resources Roundtable 2023

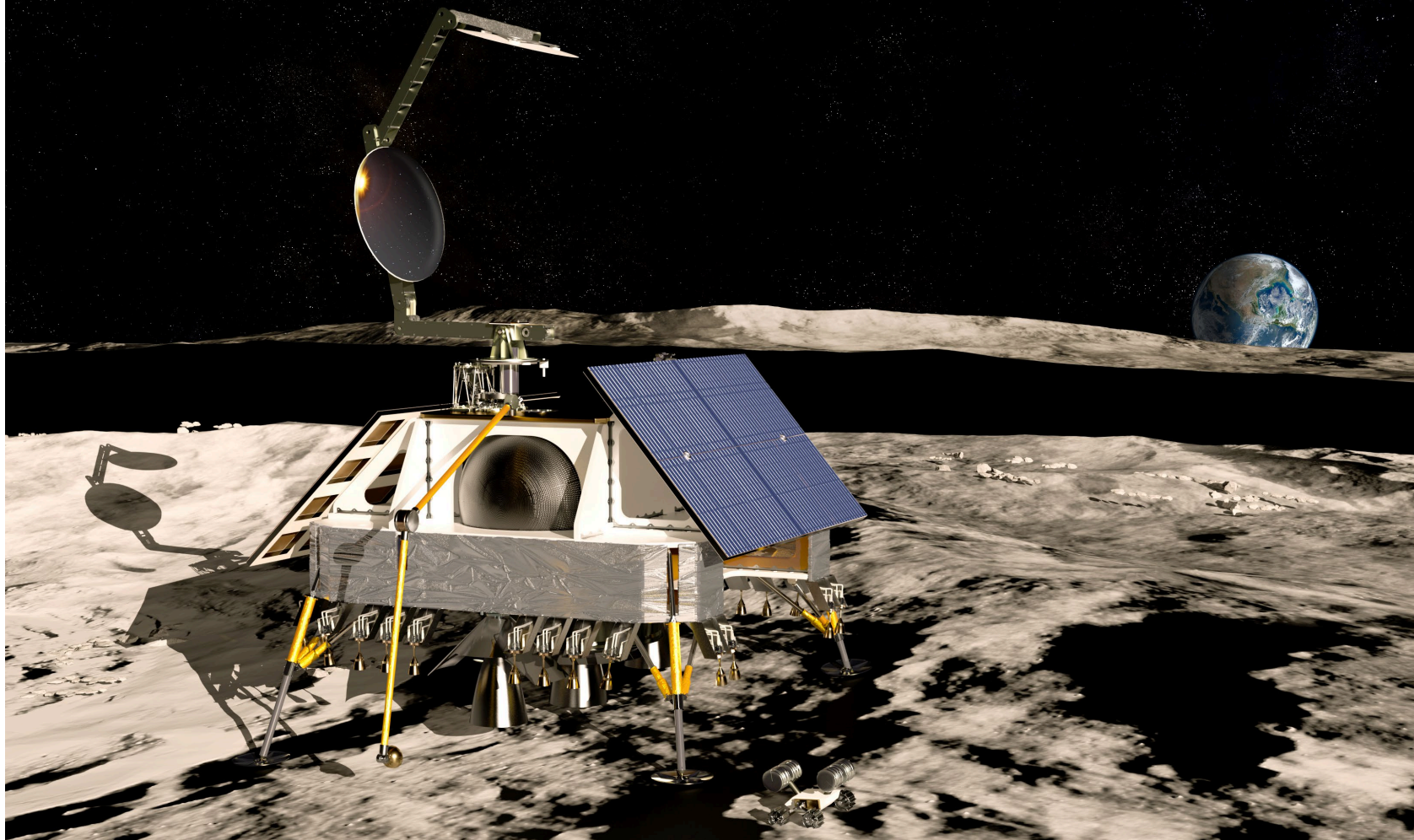


2023

2033

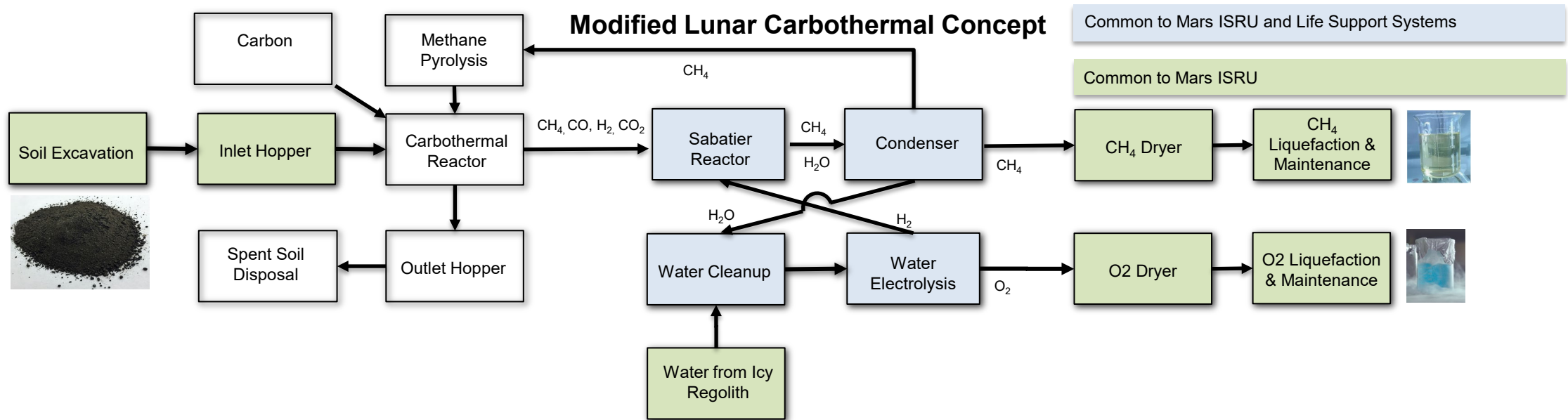
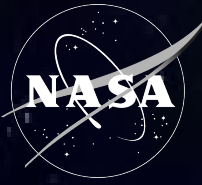
CY23	CY24	CY25	CY26	CY27	CY28	CY29	CY30	CY31	CY32	CY33
FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33
COPR-TP (Sierra Space)										
CaRD										
	CT-1 RFP?									
		CT-1 CLPS Lead Time (~3 years?)								
		CT-1 Payload Development?								
		Pilot Plant Prototype?					Pilot Plant?			

Plans Forward and Transition / Infusion Plan



Rendering of Solar-Carbothermal Flight Demo on a CLPS Lander
Image Credit: Sierra Space

Plans Forward and Transition / Infusion Plan



Long Term Infusion

- A full scale solar-carbothermal plant should be able to produce several times its own weight in oxygen, potentially saving billions of dollars per lunar launch.
- If/when water prospecting missions prove water as a reserve, water can be fed into an existing carbothermal plant, where hydrogen can be used to produce methane using the same technology as a Martian propellant production plant.
 - Methane is much easier to liquefy than hydrogen

Education/Public Outreach

EPO Involvement

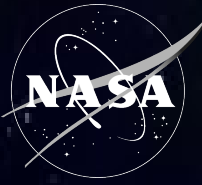
- CaRD project was presented at LSIC spring meeting
- CaRD project was presented at Space Resources Roundtable
- CaRD technology was presented at the NASA Exploration Science Forum
- CaRD PM was a guest speaker at the 1st Mexican Aerospace Forum
- Press release on CaRD testing was picked up by over 50 news organizations worldwide
- CaRD youtube video has over 30K views

EPO Calendar Outlook (High Priorities):

6 Month Look-Ahead	

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Summary



➤ Accomplishments:

- Successfully beamed ~1.3kW of energy into a vacuum chamber to melt lunar regolith simulant.
- Successfully extracted oxygen from lunar regolith simulant with a carbothermal reactor operating in a vacuum environment.
- Successfully detected reaction products from a carbothermal reaction using a COTS version of a flight qualified mass spectrometer.
- Successfully tested optical waveguide and determined efficiency.
- Developed integrated prototype design that does not require the use of an optical waveguide.
- Completed mirror construction, ready for coating upon verification of surface accuracy.

➤ Plan for FY24

- Analyze reaction productions from a carbothermal reaction that uses hydrogen as the working fluid.
- Develop ground support equipment for integrated prototype test.
- TVAC test of automated carbothermal reactor.
- Deployment of solar concentrator using avionics and software