STARMINE: A FULL-STACK LUNAR PROPELLANT PRODUCTION SYSTEM. D. A. Aden[1], G. Acosta Quiros[2], and Mihir Gondhalekar[3], [1]Starpath Robotics/Colorado School of Mines, 13030 Cerise Ave. Hawthorne CA 90250, david@starpath.space, [2]Starpath Robotics, 13030 Cerise Ave. Hawthorne CA 90250, german@starpath.space, [3]Starpath Robotics, 13030 Cerise Ave. Hawthorne CA 90250, mihir@starpath.space

Introduction: Starmine is a full-stack propellant production system scaled for industrial cislunar operations. It is the flagship system of Starpath Robotics, a venture-backed startup headquartered in Hawthorne, CA. Founded in 2022, Starpath employs fourteen fulltime employees - primarily engineers - as well as interns and Subject Matter Expert contractors/ consultants. Starpath aims to be the primary provider of propellant to the cislunar economy, as well as on the surface of Mars.

Starmine: A single Starmine unit is sized to produce hundreds of metric tons of liquid oxygen per year from icy Lunar regolith, with further scaling to the goal of kiloton-class production rates available via duplication. Each unit is sized to produce 100 mT of liquid oxygen per year, at an overall mass of 2300 kg. Starmine consists of three systems: a kilowatt-scale vertical deployable solar array, an icy regolith processing & propellant production plant, and a mining rover capable of crater traversal. The second prototype of the array and the tenth of the rover are coming online at time-of-writing, and the second prototype of the plant has just completed integrated testing.

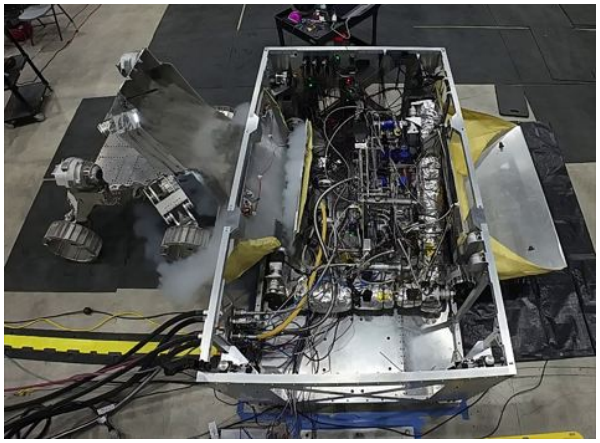

Figure 1: Rover 9.2 transferring cryogen-cooled icy regolith simulant to Plant 2 during testing. (Feb. 2025)

Rover: The Rover system is TRL 4, with in-house subsystems developed to TRL 6. The prototype currently undergoing integration will be tested to its full capability in Thermal Vacuum Chamber V-20 at NASA Marshall this summer. Starpath-developed actuators and chassis prototypes - including in-house flight computer systems - have been tested under thermal vacuum conditions and in vibration environments. Previous prototypes of the Rover system were entered into the NASA Break the Ice Lunar Challenge, a Centennial Challenges competition. Phase 2 of the Challenge required the Rover system to operate for approximately two weeks of 50% duty cycle operation, mining regolith simulant and moving it hundreds of meters to an offload point. During this test campaign, the eighth Rover prototype cumulatively traveled over a hundred miles. For Phase 3, the system was required to perform two demonstration test. The first was a traversal of a complex track that simulated Lunar terrain conditions, carrying a load of simulant at speed. The second was a gravity-offloaded mining exercise, where the Rover had approximately ⅝ of its dry weight offloaded to a crane to simulate Lunar gravity, and was given a set duration to mine icy regolith simulant. These tests were performed at-scale, in dusty/dirty conditions. The successful performances of the Rover system led to Starpath being awarded first and second place in Phases 2 and 3, respectively.

Propellant Plant: The Propellant Plant system consists of three subsystems. An intake system receives icy regolith from the Rover and extracts the water in the form of vapor. This capability was demonstrated during an integrated test at the Starpath facility in February 2025. A water cleaning & processing system was brought online in March 2025, and produced 60 grams of oxygen in its first test.

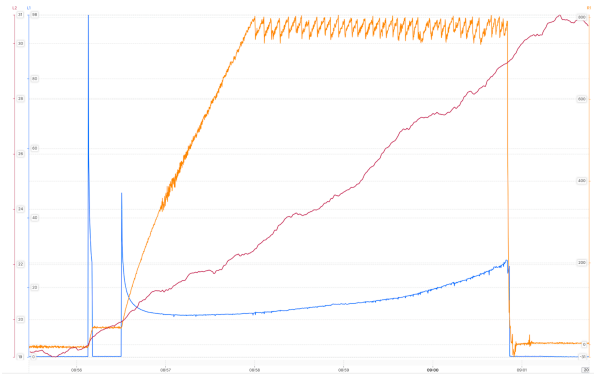

Figure 2: Data from the test campaign of the water-splitting system, showing electrolysis (blue trace) & active pressure control (orange trace). (March 2025)

An internal development program is in progress to evaluate Lunar-surface cryogenic liquefaction technology for both oxygen and hydrogen, and has included development & testing of the first prototype of a liquefaction system. Starpath also has a standing

agreement with industry experts on liquefaction for consultation and potential purchasing.

Solar Array: To power the Plant and Rover systems, Starpath is developing a vertical deployable solar array. The array for a single Starmine unit is capable of producing ~120 kW at beginning-of-life, masses 450 kg, and packs into a ~1.2 m^3 volume. It is constructed around a deployable carbon boom that Starpath has contracted with multiple industry partners to develop and shares commonalities in actuators and mechanisms with the rover. Deployed, it measures approximately 45 m tall by 16 m wide.

Actuators: Starpath has developed a set of actuators designed for common use across all of Starpath's systems to decrease space-qualification overhead and accelerate overall system development timelines, as well as decrease cost. These actuators have been successfully tested in a thermal vacuum chamber, and in a vibration/shock environment. Starpath anticipates the use of approximately 30 of these actuators for each Starmine system.

Future Work: Starpath anticipates a late-2020s landing on the surface of the Moon supplied by a commercial partner for the first flight demonstration of the Starmine system. In addition, it has begun a development campaign to identify and address early risk items — such as photovoltaics, chemical reactors, and balance-of-plant equipment — for a Martian propellant production system capable of producing oxygen, hydrogen, and methane from local materials for use as propellant.