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TWO LAUNCHES TWO COMPANIES TWO BILLIONAIRES

New Glenn's partial success could give Blue Origin new momentum in its competition with SpaceX. Should gradatim ferociter get the credit? PAGE 22

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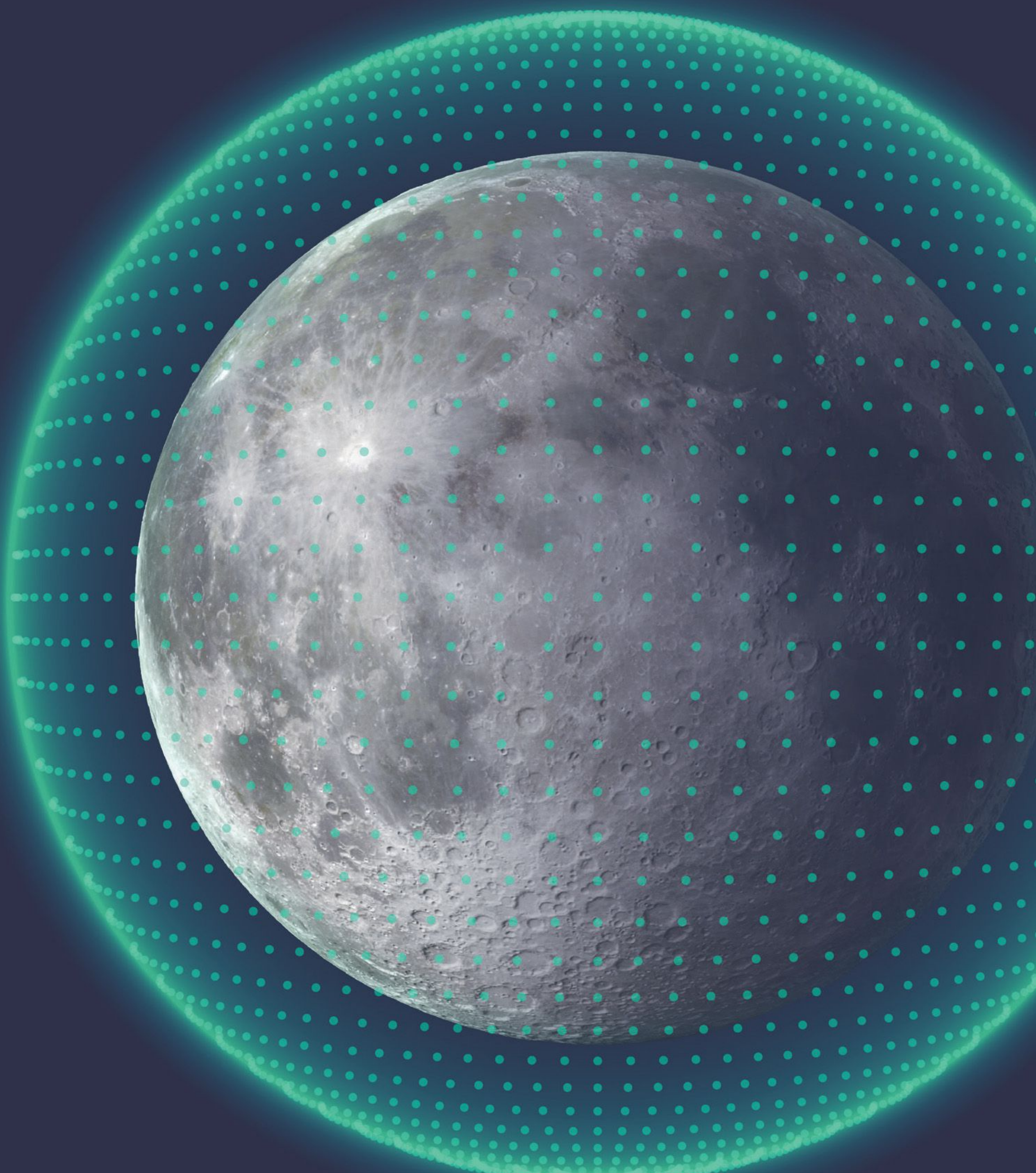

Beating the fear of darkness

A constellation of space-based solar power satellites in lunar orbit could, as soon as 2028, be ready to wirelessly power lunar landers and rovers through the grueling cold of the long lunar night. Paul Marks tells us about the progress to date.

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In Isaac Asimov's 1941 short story "Reason," the narrative unfolds on a sprawling, kilometers-long spacecraft stationed near the sun, its role being to convert solar energy into a power beam that it transmits to Earth. In other words, it was Asimov who first conceptualized space-based solar power stations, a technology that China, Iceland, Japan and the United Kingdom are considering fielding in the next decade. These stations would harvest solar power on kilometer-scale arrays, convert it to microwaves and beam gigawatts of it to grid-connected antennas on Earth, from geostationary orbit.

But here's the thing: Earth might not be the first recipient of power from a working space-based solar power system. Spacecraft on the surface of the moon could be first to benefit, and potentially as soon as 2028.

That's the aim of the Canadian startup Volta Space Technologies. This small company in Montreal plans to fly a constellation of between three and 30 sunlight-harvesting satellites in lunar orbit, each of which would beam infrared laser power to lunar rovers, landers, crewed habitats and science platforms.

The reason? If spacefaring nations are going to learn to live on the moon, explore it thoroughly and mine resources like water ice in some of the deepest, darkest polar craters, they must overcome one of the celestial body's lesser-known and least attractive talents: its unfortunate propensity for killing lunar surface missions after two weeks.

At issue here are the unique lunar dynamics. The same side of the moon always faces us on Earth, but the moon rotates relative to the sun, which is why night slowly creeps over its surface each month. No spot receives more than about 14 Earth days of sunlight before it's plunged back into darkness (and permanently shadowed regions of the craters around the south pole never receive sunlight).

And therein lies the problem. As the lunar night sets in, temperatures plummet from daytime's approximate peak of 120 degrees Celsius to a decidedly frigid minus 133 degrees. In the permanently shadowed regions of some craters, it's minus 246 degrees, night or day. At such temperatures, spacecraft batteries and electronics embrittle and fail and cannot survive unless enough electrical power is kept in reserve to power "WEBs" — warm electronics boxes — for thermal control.

But extra power means extra batteries, and at a cost of $1 million per kilogram of payload delivered to the moon, that is a rarely available luxury, says Paolo Pino, chief technology officer and a co-founder of Volta, who spoke to me by video.

"When that long lunar night comes, you start having trouble. Temperatures are so low that everything freezes," he says. "All of the missions that have been to the moon recently, with very few exceptions, have struggled with that, and they have died. So, you have this $200 million asset landing on the moon and then dying in two weeks."

He's referring to the three robotic landers that touched down on the moon between August 2023 and January 2024: India's Chandrayaan-3; Japan's Smart Lander for Investigating Moon, or SLIM; and Texas-based Intuitive Machine's IM-1. Chandrayaan-3 and IM-1 perished immediately as the sun set, while SLIM held on for a time, reviving at sunup three times before its systems succumbed to the punishing cold.

Pino and his colleagues believe it doesn't have to be this way. In October at the annual International Astronautical Congress in Milan, they revealed that Volta has been building and ground testing technology for a moon-specific variant of space-based solar power technology.

Plans call for the constellation, named LightGrid, to initially comprise three 300-kilogram smallsats, rising to as many as 30, with all of them orbiting the moon at an altitude of 100 kilometers. Each smallsat would harvest solar energy with low-cost, commercial off-the-shelf solar panels.

These satellites would track the positions of any surface rover or lander that requested a power injection and then transmit energy via a steerable infrared laser to the LightPort, a Volta-built photovoltaic power receiver, fixed on top of it. The energy received then would help drive surface operations, keep critical electronics warm and/or charge batteries, rather than letting the machine freeze and fail.

Powering lunar assets this way, says Pino, has advantages over using heat from decaying nuclear power sources in a radioisotope thermoelectric generator, as NASA's Curiosity and Perseverance

▲ The first spacecraft to land near the lunar south pole, India's Chandrayaan-3 lander, operated on the lunar surface until night enveloped it 12 days after landing. The lander was photographed by the rover it deployed to measure the composition of lunar rocks and dust. Volta plans to beam light to future landers and rovers so they can survive the night.

Indian Space Research Organisation

In this illustration, a laser beam (depicted in violet and blue tones) strikes one of Volta's LightPort receivers. In actual operation, the infrared laser would be invisible because its light does not have the energy to stimulate photoreceptors in the human eye. Volta has conducted multiple tests with 10-by-10-centimeter versions of LightPorts but plans to attach larger versions to surface landers and rovers.

Volta Space Technologies

Mars rovers do. First, the LightPort offers five times the specific power — that is, power per unit mass — of an RTG, and provides "many hundreds of watts" against the 110 watts from a freshly fueled RTG. Second, because RTGs require controlled nuclear materials, they face supply-chain problems, handling restrictions, regulatory challenges, safety issues and the need for radiation shielding on the spacecraft, says Pino.

"It's a great tech, but it comes with a lot of limitations," he says of RTGs.

That's not to say that Volta's alternative doesn't present a raft of multifaceted engineering challenges for its research and development team. These include developing the energy-beaming laser capable of producing a nondiverging infrared power beam; an accurate tracking system capable of pointing the laser at lunar surface assets from a fast-moving satellite; and development of the LightPort.

The LightGrid architecture calls for an 1,800-watt, 50-centimeter-diameter power beam, for which Volta is developing — partly with a grant from the Canadian Space Agency — an infrared fiber laser and telescopic optics to generate and collimate the beam to keep its energy tightly focused and nondiverging, says Pino.

"High-power lasers, especially in space, have had some troubles with radiation as well as with temperature extremes, so we have had to craft a system capable of dealing with those issues."

To achieve the required resilience, an optical fiber is chemically doped to cope with the thermal and radiation environments expected near the moon. A semiconductor laser diode launches infrared light into the fiber to generate the beam. In a series of ionizing radiation dose tests, which Volta undertook at "a specialized and certified radiation test facility in Europe" in 2023 and 2024, the engineering model of the laser suffered only a 5% performance degradation after exposure to 18 kilorad. That's the equivalent to a decade's worth of cislunar radiation.

The laser engineering model is now at Technology Readiness Level 6, on the scale used by NASA and the U.S. military to assess technology, says Pino. "It cleared all its major environmental tests, including radiation, shock and vibration, thermal vacuum, life test and thermal cycling."

But by late 2026, when the company hopes to run the laser in power beaming tests from a test satellite in low-Earth orbit to the ground, it will need to be at TRL 9, he says — in other words, ready for orbital action.

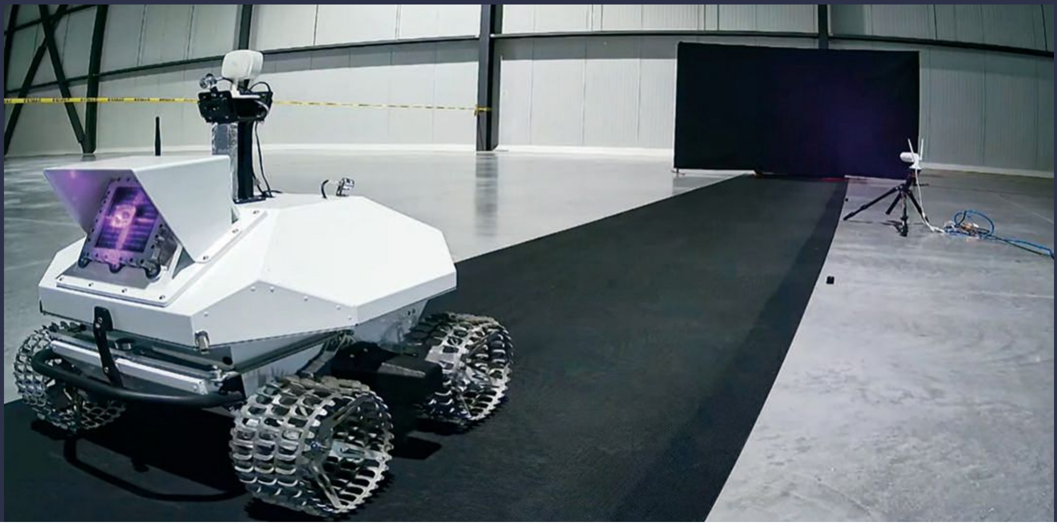
Volta in late January issued a request for proposals for the spacecraft that will fly the test laser.

"We've been talking to several satellite bus providers in the last few months, and we would like to make our decision super early in the year to partner and go ahead and fly," says Pino.

Building the laser is one thing, but aiming its 50-cm-diameter beam at the lunar surface from a moving satellite is quite another. The satellite and the laser unit will need to maneuver to do this.

"The satellite changes attitude, but our system also has an internal pointing and tracking system," Pino says.

In June, Volta began laser optical alignment tests on farmland at Saint-Michel, south of Montreal. "We tested the alignment across 800 meters, the idea being to really make sure that we can propagate and send



Among Volta's latest tests of its power-beaming technology was this one in November, in which an infrared beam was directed onto the LightPort receiver affixed to this lunar rover prototype, built by Canadensys of Ontario. The rover's batteries were able to be recharged.

Volta Space Technologies

photons with very, very good precision," says Pino.

Having learned from that how to improve the laser's optics and thermal load handling, they then attempted some limited target tracking at a lower range. The reason? "Outdoors, a bunch of factors play against power beaming as we optimize it for lunar applications, like the atmosphere, humidity and wind," Pino says. "So, we had to work at a smaller distance to see how everything behaves, accomplishing some tracking at about 170 meters with a receiver that was moving side to side, 20 to 30 centimeters, on a gantry."

In November, tests were moved indoors to an industrial warehouse at Beauharnois, southwest of Montreal. Here, a newer model of the laser projected a beam at a mini lunar rover prototype, 200 meters away, to which a 10 cm by 10 cm LightPort receiver was affixed. This experiment, using a rover built by Canadensys, an Ontario-based aerospace firm, "demonstrated the receiver could push power into the battery, recharge the battery and support operations on the rover," says Pino.

For actual lunar operations, Volta plans to build a larger variant of LightPort, measuring 30 cm by 30 cm, to receive the 50 cm beam. The whole LightPort assembly has a mass of 2 kg and will initially provide power of 100 watts — more if customers want it.

As a LightGrid satellite sweeps over the lunar horizon at an altitude of 100 km, its IR laser scans the area where it expects the lunar rover or lander to be. Once triggered, the LightPort radios a "you got me" acknowledgment signal back to the satellite. The spacecraft then maintains track of that asset and begins sending a four-minute burst of power via the laser. Then, additional satellite passes provide still more power.

"We think that starting with just three satellites gives customers a charging window every 40-ish minutes or so," says Pino. "That's the minimum viable constellation, as we call it."

He adds: "The 30-satellite constellation is kind of an end vision that allows us essentially to deliver constant coverage to a particular area. A customer at the south pole, where we expect most of the activity to take place, will see a satellite at any time."

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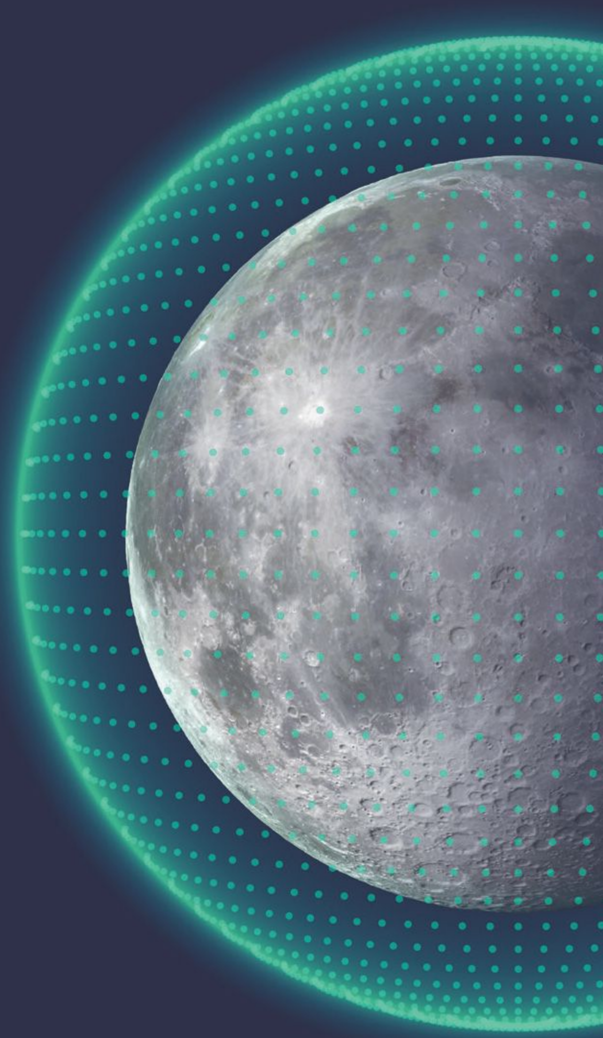
— Paolo Pino, Volta Space Technologies



Whether Volta's plans come to fruition depends in large part on customers being willing to pay for their power-as-a-service offering. The commercial signs are good, the company says. Expressions of interest have come in from companies planning to mine the permanently shadowed craters and canyons of the south polar region.

One company has also struck a firm deal with Volta: ispace-U.S. of Denver wants the LightGrid to provide a "survive the night" capability for its planned lunar surface science and in-situ resource utilization projects. Technologies that "enable survival in extreme lunar environments are crucial for a permanent human presence on the moon," says ispace-U.S. CEO Ron Garan.

Space technology consultant John Mankins of San Luis Obispo, California, who specializes in studying space-based solar power architectures, thinks Volta's technology sounds feasible.

"Their biggest dilemma is going to be their business model: A lot of companies have entered this sector, planning to offer laser power delivery from space to space, or from space to the ground, over the last four years. Can they get out in front and be first? We'll see."

First or not, the need for lunar survive-the-night technology is becoming pressing. In January, Firefly Aerospace's Blue Ghost lunar lander was launched, carrying 10 NASA instruments. Plans call for five hours of operation into the lunar night on battery power, says marketing director Risa Schnautz. "This is primarily to collect data on how the hardware performs in the lunar night environment."

"Firefly is working toward its own survive-the-night capability, and that's something we'll support as required by our payload customers," she says.

Space-based solar power is very much a live issue, 84 years after Asimov envisioned it.

"When you look into space-based solar power, what you always see are pictures of giant spacecraft requiring assembly in orbit, that require multiple launches, and on launchers that don't yet exist," Pino says. "So, what Volta is trying to do here is to switch to a different paradigm where we're saying this is really possible now.

"It's not sci-fi anymore." ★