We could get large amounts of water from the moon by directing the sun at it

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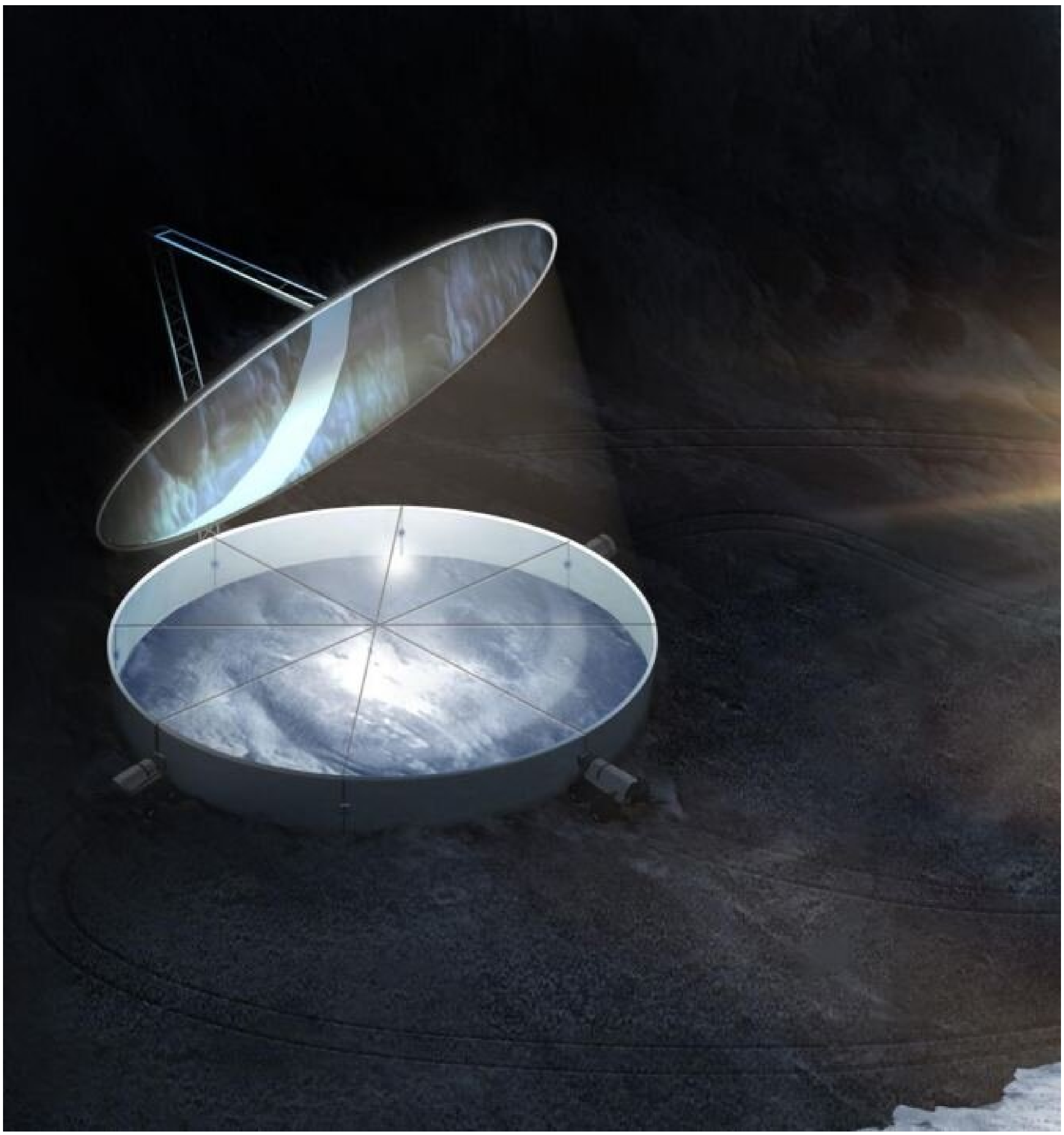

Artist's concept of a Lunar Thermal Mining Mission. Credit: Matt Olson

One of the most commonly discussed challenges when starting our species' space exploration journey is how to get the resources necessary for life off of the Earth. Typically this is thought of as two things—water and oxygen, but, luckily, oxygen can be supplied by splitting apart a water molecule, so the most critical resource we could find in space is water.

Commonly called a "volatile" in the language of space resources, water has been the focal point of many plans for in-situ resource utilization on the moon, Mars, and elsewhere. Some of those plans have been well thought out, others not. One particular showed some promise when it was selected as part of NASA's Institute for Advanced Concepts (NIAC) funding back in 2019, and here we'll take a closer look at it.

The concept, published in a report titled "Thermal Mining of Ices on Cold Solar System Bodies" but hereafter referred to as "thermal mining," is the brainchild of George Sowers, a space resource expert and Professor of Mechanical Engineering at the Colorado School of Mines (CSM). The underlying concept is surprisingly simple and familiar to anyone who played with a magnifying glass as a child.

If you direct sunlight at a particular spot using a giant mirror or other technology, that spot will heat up. If you heat an area that contains ice, and it is in a vacuum, that ice will sublimate into water vapor and begin to release from the surface being heated. That water vapor can then be captured using a cold trap or similar mechanism, and the water can then be harvested for use in exploration activities, such as drinking, breathing, or even fueling rockets.

So the basic system architecture of the thermal mining idea is simple and comprises three main components. First is a large mirror (known as a heliostat) to direct sunlight to a particular area on another world. The second is a giant tent that captures the sublimated water, and the third is a cold trap/transport system that will capture the water as it escapes from the surface.

None of this is a giant technological leap—we don't need to develop fancy technologies to manufacture those three components. However, they've never been put to this use before, so it's worth some time derisking them. That's precisely what Dr. Sowers and his team did as part of their NIAC report.

First, they looked at potential places where the system might be useful. Four otherworldly bodies came out on top—Mars, where the presence of water ice has been repeatedly proven; Ceres, where there are jets of water vapor being ejected from its surface; and two main belt asteroids—24 Themis and 65 Cybele, both of whom are thought to be covered in ice due to their reflectivity. All are in the inner solar system, making them relatively easy targets for exploration and resource exploitation missions using this technique.

But the place that holds the most promise for kick-starting humanity's resource utilization in space is the moon. Dr. Sower and his team's second task was developing an architecture for use in the Permanently Shaded Regions of the moon that are thought to contain a large percentage of the 600 billion kg of water on our nearest neighbor.

The moon has some advantages over asteroids like 24 Themis for this thermal mining technique. One is that there is enough gravity to use standard rovers to transport the ice to where it's needed. Another is the lack of an atmosphere that could diminish the effectiveness of transferring solar thermal energy to the mining site. But also, it's simply much closer.

Its proximity doesn't change the overall architecture, though—the three main components are still necessary no matter where the mining site is located. As such, the third task for Dr. Sower's team was to do some proof of concept testing of the architecture they developed.

They collected lunar regolith simulant and manually shaved slivers of ice that they then turned into balls and mixed into the regolith. They put a version of this mixture, with different ice concentrations, in a vacuum chamber that was cooled by a liquid nitrogen bath. Next, they applied a heat source from a lamp meant to mimic redirected sunlight and measured the resulting weight loss of the sample, and used that to calculate how much water had sublimated.

While performing these experiments, they ran into two interesting problems—one had to do with their test setup, but another could hinder actual use on the moon.

CSM's test setup was relatively small, with the liquid nitrogen cooling system relatively near to the sample that was supposed to be sublimating. As such, much of the heat from the lamp that was supposed to be heating the sample was heating the liquid nitrogen instead, which acted like a heat sink. On the moon, this wouldn't happen, as the whole body is so cold there's no thermally conductive material under your sample that would absorb most of the energy intended to heat the water. And as such, CSM is building a larger test chamber to try to limit the effect this issue had on their experiments.

The other problem is thornier though—after a relatively short time, the thermal mining method created a desiccated layer on top of the regolith that acts as a thermal barrier to water that might be trapped further down. Not only is less heat reaching the lower levels of regolith, the desiccated layer is essentially melted into a vapor barrier, making it almost impossible for the water to sublimate into the tent and collect in the cold traps.

Such difficulties are certainly not insurmountable, and arguably one of the most important aspects of the report shows why they mind indeed be surmounted—the business case. Dr. Sower's team estimates that the total development cost for a reasonably sized thermal mining operation in the moon's PSRs is around $800M, with an additional $613M in product costs. It would also include an operating cost of about $80M annually.

Those costs come with some pretty hefty benefits—especially if it saves the cost of shipping water off the Earth to any early lunar output. By the report's calculations, the Internal Rate of Return (IRR—a measurement of how profitable a project is) would be an estimated 8% if the system operators were selling purely to commercial sources (i.e., ones that are attempting to perform other economic activities on the moon). That's a little lower than many financiers would consider investment grade, especially for an admittedly risky project. However, suppose NASA or other national space agencies become customers to support their lunar operations. In that case, the IRR jumps up to ~16%, significantly closer to where financiers might be interested.

Dr. Sowers admits that the business case is one of the riskiest parts of the overall proposal, as it requires demand, which currently does not exist since there are few to no moon operations that require water. With NASA's Artemis missions, that is bound to change in the next decade, but it is unclear whether it would provide enough demand to make the technology economically viable.

Other risks also abound, including uncertainty about the total amount and location of water on the moon. There is undoubtedly some in the PSRs, but it might be that there isn't enough close to the surface, where it can be gathered by thermal mining, to support long-term human habitation, and water and other "volatiles" have to shipped in from Ceres or elsewhere in the asteroid belt. If that's the case, there is still an argument that the underlying thermal mining technique could be useful—it just might not be profitable.

For now, the entire system is only in the planning phase, and it doesn't appear that the technology received a Phase II NIAC, and it's unclear what progress has been made in the last few years. However, the technology has been patented, and CSM offers it for licensing on their technology transfer website. And as technology more generally moves along, the idea of mining the moon will become more and more appealing. So there is a good chance that this technology will eventually come to fruition, even if it might take a while.

More information: Thermal Mining of Ices on Cold Solar System Bodies. space.mines.edu/wp-content/upl … e-I-final-report.pdf

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