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News & Highlights

Is There a Bright Future for Solar Power from Space?

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Late in the evening of May 22, 2023, a team of researchers at the California Institute of Technology (Caltech) in Pasadena, CA, USA, measured a faint beam of microwaves emanating from a solar-powered satellite 550 km overhead [1]. Satellites send signals to Earth all the time, but this occasion was different. The satellite carried a unique transmitter developed by the Caltech researchers, a 30 cm by 30 cm array of polyimide and copper designed to be lightweight and flexible [2]. Using that transmitter, the satellite became the first spacecraft to direct solar power captured in space to the Earth's surface [3,4].

The feat "was a terrific demonstration of technology," said John Mankins, a former program executive at the US National Aeronautics and Space Agency (NASA) who now heads the technology management consulting firm Artemis Innovation Management Solutions LLC, based in Nipomo, CA, USA. And it might be the beginning of something much bigger. Mankins and other advocates have long argued that solar power captured in space and beamed to Earth can provide a large share of the planet's electricity. But the approach was always too expensive [5]. Now, said Mankins, thanks to improved technologies and plunging launch costs, "we are dramatically closer" than ever before to having a solar power station operating in space, with a handful of companies and countries rushing to develop and deploy these plants. The first prototypes could be launched later this decade [1,6], and in just over 10 years orbiting solar arrays could be feeding gigawatts of power into the grid [6–8].

Space-based solar would provide a baseload, or a standard amount of electricity regardless of the weather and time of day, said David Homfray, chief technology officer at Space Solar. The company, based in Harwell, UK, hopes to launch its first generating satellite in less than 6 years. Solar power from space would complement, not replace, terrestrial renewable sources, Homfray said. "Space solar is critical for renewables, and renewables give it time to come in."

Still, engineers have their work cut out for them to make the technology functional and commercially viable. For one thing, they will need to boost the amount of energy it delivers. The satellite in the Caltech demonstration transmitted 200 mW, too little to heat a cup of coffee [1]. On Earth, researchers have managed to send 30 kW, but only across a distance of 1.6 km [9]. Tapping this energy source will also require designing and constructing massive space solar arrays or satellites that are more than 100 times larger than any human-made objects now in space [10]. And if those challenges were not enough, space solar will also have to provide power reliably and cheaply enough to compete with terrestrial energy sources.

The concept of trapping solar energy in space and dispatching it to Earth dates back at least to a 1941 short story by science fiction master Isaac Asimov [6]. Asimov's story may have been visionary, but it was short on technical specifics. In 1968, mechanical engineer Peter Glaser of the Cambridge, MA, USA-based consulting firm Arthur D. Little detailed how the approach would work, calculating that a collecting array of nearly 23 km^2 that relayed the energy it gathered as microwaves could meet the power needs of the entire northeastern United States [11,12]. "The basic physics of space solar power were proven in the 1960s," said Mankins.

During the energy crises of the 1970s, this power source started to look very attractive. NASA helped perform terrestrial tests of power beaming [9] and in 1979 published a study that envisioned a space generating system with as many as 60 orbiting solar arrays, each of which would be up to 50 km^2 in area and yield as much as 10 GW of electricity [13]. However, the gigantic facilities would have required an investment of 250 billion USD before they could furnish any electricity to users; that astronomical cost, along with falling energy prices in the early 1980s, doomed the idea [13].

Space solar power remains appealing today because it offers several potential advantages over Earth-bound clean energy sources [10]. The most obvious benefit is that a space-based array in geosynchronous orbit is continually exposed to sunlight and free from the vagaries of weather [6,10], allowing it to generate power more than 99% of the time. The figure is not 100%, Mankins noted, because such an array would be in the Earth's shadow for a few hours each year around the vernal equinox in March and the autumnal equinox in September. He said that any electrical grid relying on space solar power would need a backup, such as batteries, for these periods.

Harvesting sunlight in space could also help reduce the immense land requirement of conventional solar and wind power [10,14]. Microwaves from space attenuate little as they travel through the atmosphere, but they spread out, requiring large, net-like receivers known as rectennas to catch them [15]. Space Solar calculates that each of its rectennas would be about 8 km by 13 km [16]. But one of them would still take up only 8% as much area as a wind farm in the United Kingdom that supplies the same amount of power, the company estimates [16].

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A third possible upside of space solar facilities is that they could beam power directly to places where it is needed, thus providing electricity for remote areas that are hard to connect to the electrical grid [10]. That ability could also potentially reduce the need for transmission lines, which are expensive to install, require large amounts of raw materials, and can cause wildfires [10,17].

Space solar power stations were feasible in 1979, but they were not practical. Three developments have changed the equation, said Mankins. Technological advances in materials and manufacturing allow production of lightweight, low-cost components for space structures. Another contributor, he said, is improvements in robotics. NASA's 1979 study assumed that astronauts would assemble the orbiting power stations [13], an expensive strategy that would entail risk for human crews. In contrast, all current plans for space solar arrays assume that robots will perform the construction work [6].

But the most important factor, the experts agree, has been the dramatic decrease in launch costs, largely because of cheaper rockets from SpaceX (Hawthorne, CA, USA) [18]. The company can deliver a kilogram of cargo into low-Earth orbit for as little as 1500 USD, a decrease of 90% over the going rate just two decades ago [18]. "We can make space hardware cheaply, we can put it together robotically, and we can launch it inexpensively—that is the technical trifecta," said Mankins.

That combination has made space solar competitive with other forms of energy, according to a pair of reports commissioned by the UK government and the European Space Agency [19,20]. The UK report projected that if the first solar satellite was deployed in 2040, it would deliver power at a levelized cost—the electricity price necessary to cover the expense of building and operating the system [21]—of about 61 USD per gigawatt. Although conventional solar power and wind are cheaper, space solar power would beat the energy sources that have to fill in when those renewable sources cannot produce power. For instance, the levelized cost for a new gas turbine plant with carbon capture would be 101 USD per gigawatt [19]. Moreover, designing, building, and launching the first satellite is the most expensive step. As companies gear up their assembly lines and manufacture more satellites and other system components, the levelized cost would decline substantially, said Ian Cash, Space Solar's chief system architect.

A variety of ambitious, innovative, and sometimes exotic blueprints for space solar arrays is on the drawing board [6]. The proposal from Mankins, known as SPS-ALPHA (short for solar power satellite via arbitrarily large phased array), would capture solar energy with several thousand adjustable, thin-film mirrors mounted on a cone-shape framework up to 6 km in diameter (Fig. 1) [22]. The mirrors would direct sunlight onto a central platform about 1.7 km in diameter that has solar cells on one side and microwave transmitters on the other.

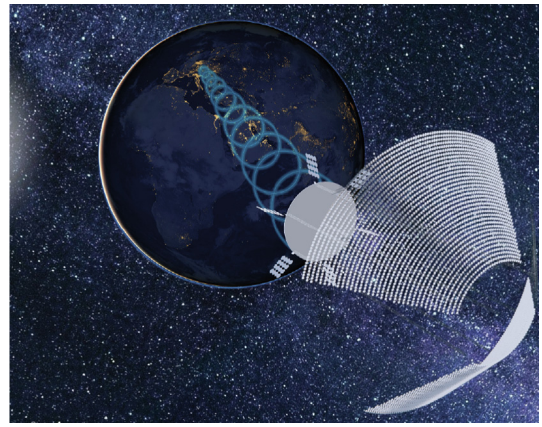

Fig. 1. The SPS-ALPHA designed by John Mankins envisions a cone-shaped solar-collecting satellite up to 6 km across. Mounted on a framework are thin-film mirrors, each of which is about 190 m^2. The mirrors continually adjust their orientation to direct sunlight onto the photovoltaic layer on the circular central platform. Transmitters on the Earth-facing side of the platform beam microwaves to the surface. Credit: John C. Mankins, with permission.

Space Solar has placed its bets on CASSIOPeiA (short for constant aperture, solid-state, integrated, orbital phased array), a 1.7 km-diameter craft designed by Cash that resembles two giant compact disks fastened together (Fig. 2) [16]. The disk-like structures are mirrors that reflect and concentrate sunlight, sending it onto the satellite's midsection, which is twisted and carries multiple layers of solar panels [16]. This helical shape ensures that sunlight continuously falls on the solar cells as the craft orbits the Earth, Cash said.

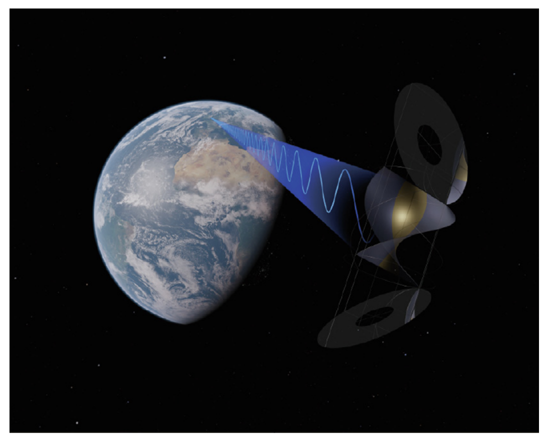

Fig. 2. The large, circular structures on the CASSIOPeiA satellite design are mirrors that collect sunlight and focus it onto the helical central portion of the craft, which carries 60 000 layers of solar panels. Unlike in the SPS-ALPHA design, the mirrors are fixed with respect to the solar panels. Credit: Space Solar Group, with permission.

The core of the approach from Virtus Solis, a company based in Troy, MI, USA, is a thin, hexagonal satellite about 1.65 m across that can produce 1 kW of power [23]. The company envisions launching bundles of 25 000 such units into orbit. Robots accompanying the bundles would unpack the panels and snap them together to make giant arrays up to 3 km in diameter that could generate 20 GW of power or more [23].

The Caltech researchers who first demonstrated power beaming from space are also looking to combine smaller components. Their plan calls for maneuvering large numbers of satellites, each of which carries a flexible photovoltaic membrane about 6 m by 6 m, into giant power-generating arrays [24]. Unlike in the Virtus Solis proposal, the craft would not be connected to each other and would instead move in unison like a flock of birds.

Despite their differences, these designs share one similarity—they focus on minimizing weight. That is because even though the launch price has fallen, it remains "the big cost for anything to do with space solar power," said Homfray. Cash designed CASSIOPeiA so that it requires no moving parts, which saves on weight by eliminating the need for motors, bearings, and other heavy components. The Caltech team is revamping the solar cells for its satellites to make them up to 40 times lighter, and the flexible transmitters the researchers tested also reduce weight [2,24].

The companies developing space solar have set very aggressive schedules. Space Solar plans to launch a satellite that can generate megawatts of power within 6 years and a gigawatt-scale satellite within 12 years, said Homfray. Virtus Solis intends to have its first prototype power station in orbit within 3 years and start feeding power into the grid by the end of the decade [1]. Countries also hope to get involved but are a bit farther behind. China's timetable is to launch a 10 kW solar satellite by 2028 and a 10 MW satellite by 2035 [25].

Whether these schedules can be met remains to be seen, since there are still substantial engineering challenges [26]. The largest human-made object in orbit is the International Space Station, which is only 109 m long [27]. Building even one CASSIOPeiA or SPS-ALPHA satellite would be the largest construction project ever undertaken in space. Space solar power companies plan to produce dozens of such craft, and the robots expected to perform the assembly work in space are untested [10]. Safety could present another roadblock. Although terrestrial power beaming tests suggest that the microwave transmissions do not harm humans and animals [9], no one has evaluated such transmissions from space-based solar power arrays [27].

Space solar power could have some downsides as well. Most companies plan to launch their satellites into geosynchronous orbit, which is already crowded. When a solar power satellite's operational lifetime is over, it could add to the large amount of orbiting junk that already threatens other spacecraft [10,28].

Before space solar power stations can start operating, said Mankins, the companies and countries pursuing this energy source need to show that they can solve the design and deployment challenges, and some will fail. "The next several years will be a proving ground for these different competing systems," he said.

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