The Edge of Electric Generation

By John Benson

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1. Introduction

Forbes has many specialized news-letters, and I subscribe to a weekly post called Forbes Current Climate.

Occasionally my cup runneth over, and I have too many good leads for articles. Then something else comes in. Although I have various methods for capturing this content for later digestion, the simplest (for emailed content) is to just leave it in my in-box. I did that with an issue of Current Climate in early January (after capturing a few leads), and then came back to it in early-February (as I'm writing this). I found two really good leads about crazy-edge generation technologies. These quickly developed into this paper.

2. Generator-to-Earth

We need visionaries.

2.1. Back Story

In the 1941 short story "Reason," science fiction author Isaac Asimov described a future where electricity was generated in space and then beamed down to Earth. It took nearly three decades for engineers to first describe a workable way to potentially make such an orbiting power plant work. This week, nearly 50 years after that first engineering proposal and over 80 years after the short story, Caltech has made a big step in making that science-fiction idea a reality: on Tuesday, its experimental orbiting solar power satellite was launched into orbit…[1]

Note that excerpt immediately below is from over a year ago, and thus predates the above (and further below) described launch.

Orange County's billionaire real estate developer Donald Bren has donated at least $100 million to a Caltech project that aims to generate solar power in space and beam it back to earth.[2]

The Southern California News Group has learned that in 2013, Bren agreed to a 10-year commitment to Space Solar Power Project at the Pasadena institute. The years-long effort will reach a milestone in the coming months when it launches the first space test of technology that could change how the world creates and distributes electricity.

"I have been a student researching the possible applications of space-based solar energy for many years," said Bren, chairman and owner of Irvine Co. and a lifetime trustee at Caltech. "My interest in supporting the world-class scientists at Caltech is driven by my belief in harnessing the natural power of the sun for the benefit of everyone."

[1] Forbes Current Climate, Jan 7, 2023 Issue.

[2] The Orange County Register, "$100M gift from Irvine Co.'s Bren powers Caltech space electricity idea," July 30, 2021, https://www.donaldbren.com/2021/100m-gift-from-irvine-co-s-bren-powers-caltech-space-electricity-idea/

And, guess what:

For about as long as engineers have talked about beaming solar power to Earth from space, they've had to caution that it was an idea unlikely to become real anytime soon. Elaborate designs for orbiting solar farms have circulated for decades—but since photovoltaic cells were inefficient, any arrays would need to be the size of cities. The plans got no closer to space than the upper shelves of libraries.[3]

That's beginning to change. Right now, in a sun-synchronous orbit about 525 kilometers overhead, there is a small experimental satellite called the Space Solar Power Demonstrator One (SSPD-1 for short). It was designed and built by a team at the California Institute of Technology, funded by donations from the California real estate developer Donald Bren, and launched on 3 January—among 113 other small payloads—on a SpaceX Falcon 9 rocket.

"To the best of our knowledge, this would be the first demonstration of actual power transfer in space, of wireless power transfer," says Ali Hajimiri, a professor of electrical engineering at Caltech and a codirector of the program behind SSPD-1, the Space Solar Power Project.

Let's see, a crazy Sothern California Billionaire funds the creation of a "Space Solar Power Demonstrator." Who else would he tap to launch it but another crazy California Billionaire with a Southern California Rocket Company (who wants to colonize Mars)? By the way, the California Institute of Technology (Caltech) is in Pasadena, also in Southern California.

One other side story:

The Martian Way is a science fiction novella by American writer Isaac Asimov. It was first published in the November 1952 issue of Galaxy Science Fiction…[4]

I would think that both young Elon and Donald might have read "The Martian Way," and perhaps "Reason" (see subsection 2.1). SciFi is a good way to inspire young minds.

2.2. Technology

Although SPPD-1 actually works, powering objects from space is not its main job. It is testing various advanced technologies to make this concept work. These include:

DOLCE (Deployable on-Orbit ultraLight Composite Experiment): *A structure measuring 6 feet by 6 feet that demonstrates the architecture, packaging scheme and deployment mechanisms of the modular spacecraft that would eventually make up a kilometer-scale constellation forming a power station;*[5]

ALBA: *A collection of 32 different types of photovoltaic (PV) cells, to enable an assessment of the types of cells that are the most effective in the punishing environment of space;*

[3] Ned Potter, IEEE Spectrum, "Caltech Tests Space-Based Solar Power Using a satellite as testbed for wirelessly beaming power from orbit," Feb 6, 2023, https://spectrum.ieee.org/solar-power
[4] Wikipedia Article on "The Martian Way," https://en.wikipedia.org/wiki/The_Martian_Way
[5] Robert Perkins, Caltech, "Caltech to Launch Space Solar Power Technology Demo into Orbit in January," Jan 2, 2023, https://www.caltech.edu/about/news/caltech-to-launch-space-solar-power-technology-demo-into-orbit-in-january

MAPLE (Microwave Array for Power-transfer Low-orbit Experiment): *An array of flexible lightweight microwave power transmitters with precise timing control focusing the power selectively on two different receivers to demonstrate wireless power transmission at distance in space.*

An additional fourth component of SSPD is a box of electronics that interfaces with the Vigoride computer and controls the three experiments.

Note that *A Momentus Vigoride spacecraft carried aboard the SpaceX rocket on the Transporter-6 mission carried the 50-kilogram SSPD to space.* [6]

2.3. Why "Space" Solar, and How

Ten years ago, Caltech formed the Space Solar Power Project, which culminated in the Jan. 3 launch milestone. Weeks later, its three lead researchers are still musing on the achievement, enthusiastically talking about how it all works. They're hopeful about the future of a technology once deemed technically possible but economically infeasible.[7]

Each are experts in a discipline integral to space solar power: Dr. Harry Atwater, Otis Booth Leadership Chair of the Division of Engineering and Applied Science, heads the Project's photovoltaics research, the solar cells converting sunlight into electricity. Dr. Ali Hajimiri, Bren Professor of Electrical Engineering and Medical Engineering, leads the wireless power transfer technology which would beam harvested energy down to earth. And Dr. Sergio Pellegrino, Joyce and Kent Kresa Professor of Aeronautics and Professor of Civil Engineering, heads the design of lightweight spacecraft that could one day carry the technology in orbit. Hajimiri illustrated some of the benefits of space solar power.

"When you are in space, compared to photovoltaics on the ground, there is about 8 to 9 times more power because of the fact that you don't have day and night, you don't have seasons, you don't have clouds," he explained.

With rocket launches costing multiple dollars per gram of cargo, economics has remained a hurdle to space solar power. Caltech's team took a new approach to the challenge with their design, cutting down on the mass and footprint of their proposed satellites.

The Project team designed a flat sandwich of components: a thin, photovoltaic cell on one side, a circuit-board in the middle, and an array of transmitters on the other side, all flexible. These sandwiches look like large, flimsy, plastic drink coasters. Combined into panels, they can be suspended in thin, flexible spacecraft, producing lightweight, foldable satellites.

While the orbiting demonstrator is only a series of experiments testing key technologies, the team hopes someday to see thousands of these satellites orbiting the earth.

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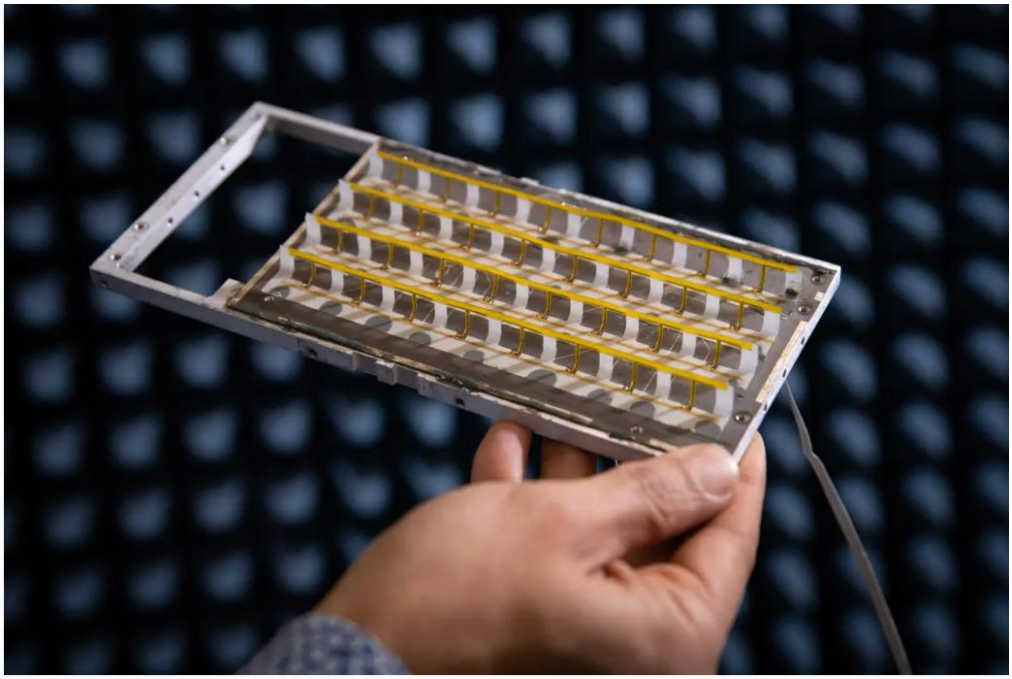
[6] Vigoride is a space tug that is under development by Momentus Space in Santa Clara, CA (in Silicon Valley, SF Bay Area). Momentus space lists plans to offer "space infrastructure" services, including space transportation, on-orbit refueling, and on-orbit services of satellites. Space transportation in the form of space tugs is particularly emphasized. https://momentus.space/

[7] Collin Blinder, Pasadena Star News, Feb 5, 2023, "These Caltech scientists are trying to harness energy from outer space; Here's how they're doing it," https://www.pasadenastarnews.com/2023/02/05/these-caltech-scientists-are-trying-to-harness-energy-from-outer-space-heres-how-theyre-doing-it/



The power transmitter array in its popped-up configuration. (Photo provided by Caltech)

2.3.1. Super thin solar cells

Atwater, who speaks of his work energetically, with proud enthusiasm, designs ultra-lightweight photovoltaics, minimizing weight and maximizing efficiency.

"The key guiding principle is to lower the mass to orbit," he explained. "For a space solar cell, there are two massive elements for a conventional cell. One is that you have the active solar cell which is only a few microns thick and then it's typically on a wafer that's a couple hundred microns thick."

On top of that is a radiation shield, typically a 75- to 100-micron cover-glass, similar to a smartphone screen protector.

Atwater's team launched 32 state-of-the-art solar cells, free of wafers and capable of surviving radiation without traditional cover-glass, shedding expensive mass. He illustrated the material thicknesses. A human hair is about 50 microns thick. By removing wafer and cover-glass, the resulting photovoltaics measure around 5 to 10 microns thick.

2.3.2. Wireless power transfer

Getting energy back to earth requires converting it into microwaves that are transmitted to receivers on the ground.

Hajimiri — whose enthusiasm for the subject is exemplified by his illustrative hand gestures while describing his work — and his team will test wireless power transfer in space; not as simple as pointing antennas at receivers.

Voicing an explainer video on the Project site, Hajimiri illustrated how his team directs microwaves using wave interference.

"If you go sit next to a pond and put both of your hands down into the water and make waves at the same time, what you will probably notice is that there are areas where the

waves are much stronger and there are some areas where there are very little waves," he described.

The stronger, overlapping, "in-phase" waves are where the waves adds up. Altering the timing of the transmitters (in this example, hands in a pond) allows them to be steered and focused into a beam.

"This ability to control directions by controlling timing," Dr. Hajimiri explained, "is very critical, because it means that there are no mechanically moving parts and hence, it can be done on the timescale of electronics, at the nanosecond scale."

The pond example describes a simplified scenario with two transmitters. At full scale, Dr. Hajimiri's team would need to calculate the real time location and timing for billions of transmitters.

2.3.3. Lightweight spacecraft

The solar power panels will be suspended inside lightweight spacecraft shaped like flattened, trapezoidal picture frames, tens of meters long. Pellegrino, who has the thoughtful, precise demeanor of an engineer, is in charge of designing spacecraft that require no assembly after launch.

"Our concept does not require a robotic, in-space assembly," Pellegrino explained. "It is a series of free-flying spacecraft and they are unfolded in space individually, and then a formation is created."

His team's experiments consist of a scaled-down model observable by cameras and sensors onboard the demonstrator.

"It can be flattened and it can be folded. All of that happens elastically. We do not need any mechanical hinges," he explained.

Once the spacecraft demonstrator is unfolded in space, the team will observe the structure unfettered by gravity.

The Project team has benefitted from uncommonly long-term collaboration.

"It's a 10-year project, so that's pretty unusual in academia that a researcher gets a chance to work on something intensively for a decade," Atwater pointed out. "So there have been several chapters and in both the wireless power, the ultralight structures and the photovoltaics we've had several generations of technology development, which is pretty exciting."

2.4. Where on Earth

Where on Earth would there be demand for energy from space? Answering this question would give the Caltech team its first customers. However, we don't want the answer for now, but for 15- to 20-years in the future, when the first "production" versions of SSPD will start to be commercialized. First adopters would be obvious:

- Isolated communities or facilities, especially those close or above to the arctic circle where ground-based photovoltaic (PV) power is not viable in the mid-winter.

- High density populations where acreage is too expensive for ground mounted PV, but tolerable for microwave antenna arrays.

Obviously the both of the above might include some places in Europe, so it isn't totally strange that the European Space Agency is also looking at SSPD technology with a project called SOLARIS.

We envision a Europe and world where clean, abundant, secure, safe and affordable energy is available to everyone.[8]

To prepare Europe for future decision making on Space-Based Solar Power, ESA has kicked-off a preparatory initiative, called SOLARIS, for which funding was approved at the ESA Council at Ministerial Level in November 2022.

The goal of SOLARIS is to prepare the ground for a possible decision in 2025 on a full development programme by establishing the technical, political and programmatic viability of Space-Based Solar Power for terrestrial clean energy needs.

It would, through a limited initial investment, undertake studies and technology developments, in partnership with European industry, to mature the technical feasibility and assess the benefits, implementation options, commercial opportunities and risks of Space-Based Solar Power as a contributor to terrestrial energy decarbonisation. SOLARIS will also address potential environmental, health and safety issues and challenges related to regulation and international space policy coordination.

Through SOLARIS, Europe will extend the technological state-of-art in a diverse set of key technologies relevant to applications both on Earth and in space, such as high-efficiency solar cells, wireless power transmission and robotic in-orbit assembly. Its aim is for Europe to become a key player – and potentially leader – in the international race towards scalable clean energy solutions for mitigating anthropogenic global warming.

Author's comment: Note that I decided to leave the above Euro/UK-spellings in place since this Euro/UK information.

3. Expired "Best-by-" Food & 750-Cows' Energy

In the energy landscape, about as far as one could get from SSPD would be some technology that has been around for decades, but is being slightly repurposed to use a different "fuel."

You may have heard about farms using anaerobic digesters to handle manure and generate electricity. The digesters also come in handy for keeping food scraps out of landfills while helping people keep the lights on. [9]

[8] SOLARIS, https://www.esa.int/Enabling_Support/Space_Engineering_Technology/SOLARIS

[9] Jeff Kart, Forbes, "Food Waste Kept Out Of Landfills And Turned Into Electricity At Family Farms," Jan 6, 2023, https://www.forbes.com/sites/jeffkart/2023/01/06/food-waste-kept-out-of-landfills-and-turned-into-electricity-at-family-farms/?ss=sustainability&sh=135d2ba93794&utm_source=newsletter&utm_medium=email&utm_campaign=currentclimate&cdlcid=628673ca6e1a1d1211f1d747

Lots of food scraps end up in landfills, from people's kitchens, retail and other sources. The U.S. Food & Drug Administration says up to 40% of the food supply is wasted; food is the single largest category of material placed in municipal landfills.

Some farms that began using manure in their digesters have started mixing in food waste. And it's helped keep their operations in the black, generating more power than manure alone.

Reinford Farms in central Pennsylvania was using manure in a digester when they got a call from a supermarket broker about feeding food waste into the system.

It was a game changer, says Brett Reinford, a partner at Reinford Farms. Inside a digester, microbes convert manure and food waste into methane gas that's captured and piped to a generator to produce electricity. Food waste produces about three times the methane that manure does.

"We realized there was something to this food waste. We were getting calls from other potential clients."

In 2017, the farm purchased a machine to separate food waste packaging from food waste that comes in, like vegetables packaged for sale that don't sell in time.

"That's opened up the doors for us to really grow exponentially," Brett Reinford says. The farm soon purchased a second, larger de-packager and built a food waste facility to house equipment.

"(In 2022), we did 35,000 tons of packaged food waste, almost 3,000 tons a month," Reinford says. "When we first started, we were happy to do 1,200 tons a year."

The Pennsylvania farm works with about 35 different food manufacturing clients, from grocery stores to warehouses, getting food waste from as far away as Georgia, but mostly from in-state, New Jersey and Maryland.

Two digesters with a total capacity of about 2 million gallons process manure and food waste to create enough electricity for about 600 homes, Reinford says.

The family also finds time to farm, with about 750 cows, but Reinford says food waste has become a nice side hustle.

"It's becoming almost equal to our dairy revenue, a lot more profitable over milking cows ... The food waste is a major part of the economics that drive our dairy farm, for sure."

Reinford also notes that the digesters operate under environmental permits…