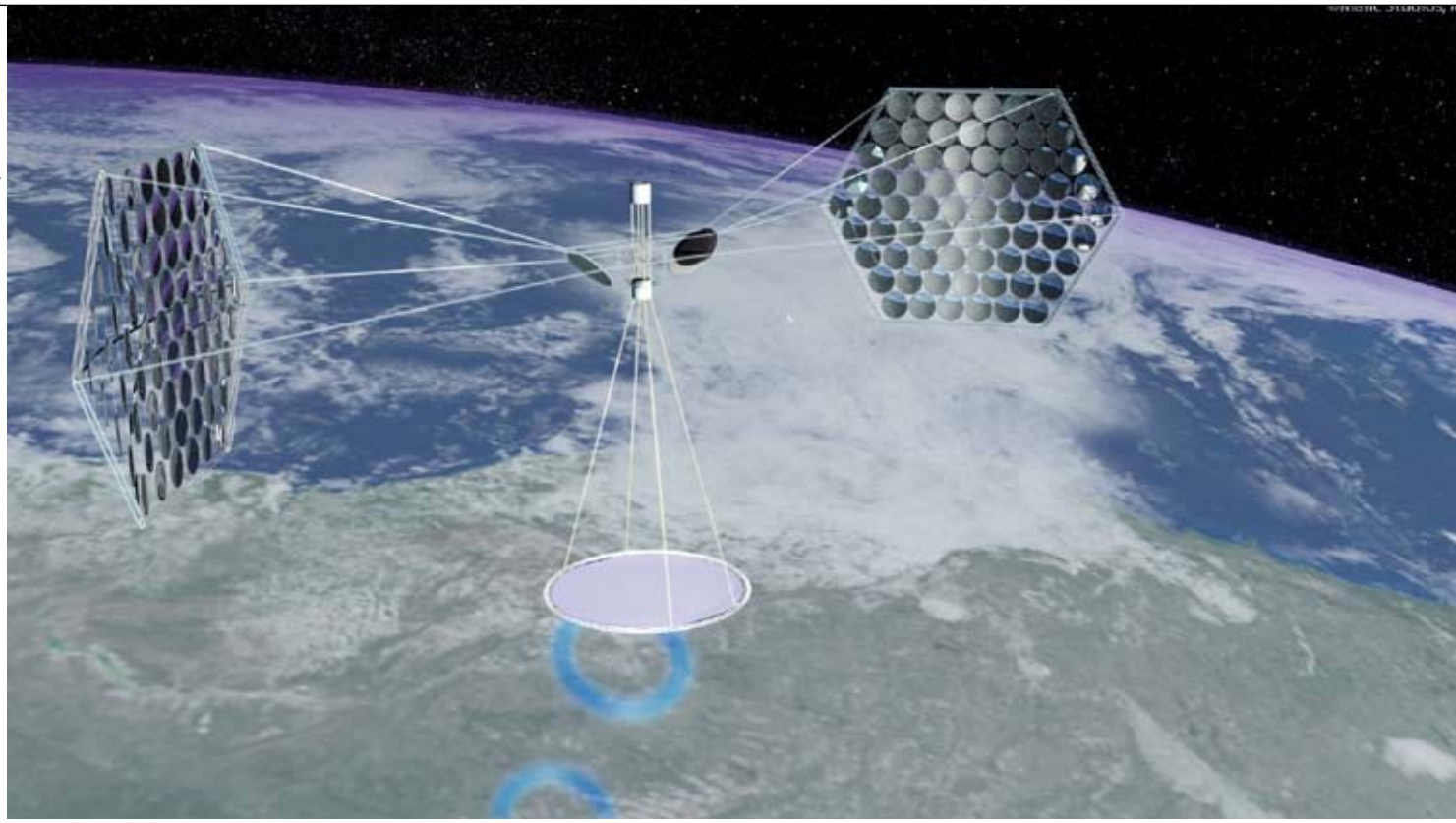


Graphic: Mafic Studios, Inc.

No shading problems up here. Installation will be expensive, but Space Solar Power (SSP) is still cheaper than such star wars plans as Reagan's Strategic Defense Initiative (SDI) or Bush's National Missile Defense (NMD) concept – and it's much friendlier.

Power from Space

Space solar power: For the first time ever, a small start-up company promises to deliver solar power generated in space. Solaren signed a deal promising to supply most people in southern California with energy generated on PV satellites starting in 2016.

At the Kennedy Space Center in Florida, the National Aeronautics and Space Administration (NASA) seems to be looking far into the future. In late May, it signed a contract with the Florida Power & Light Corporation (FPL), which provides power to Florida, for almost 300,000 square meters of its land at Cape Canaveral to FPL so that the power provider can set up two separate solar farms with a total output of ten megawatts. The smaller farm is to provide one megawatt of electricity to NASA for its launching site. FPL is paying eighty million dollars to acquire the land. With this deal, the "sunshine state" has lived up to its name and is now the number two state in the Union in using solar energy.

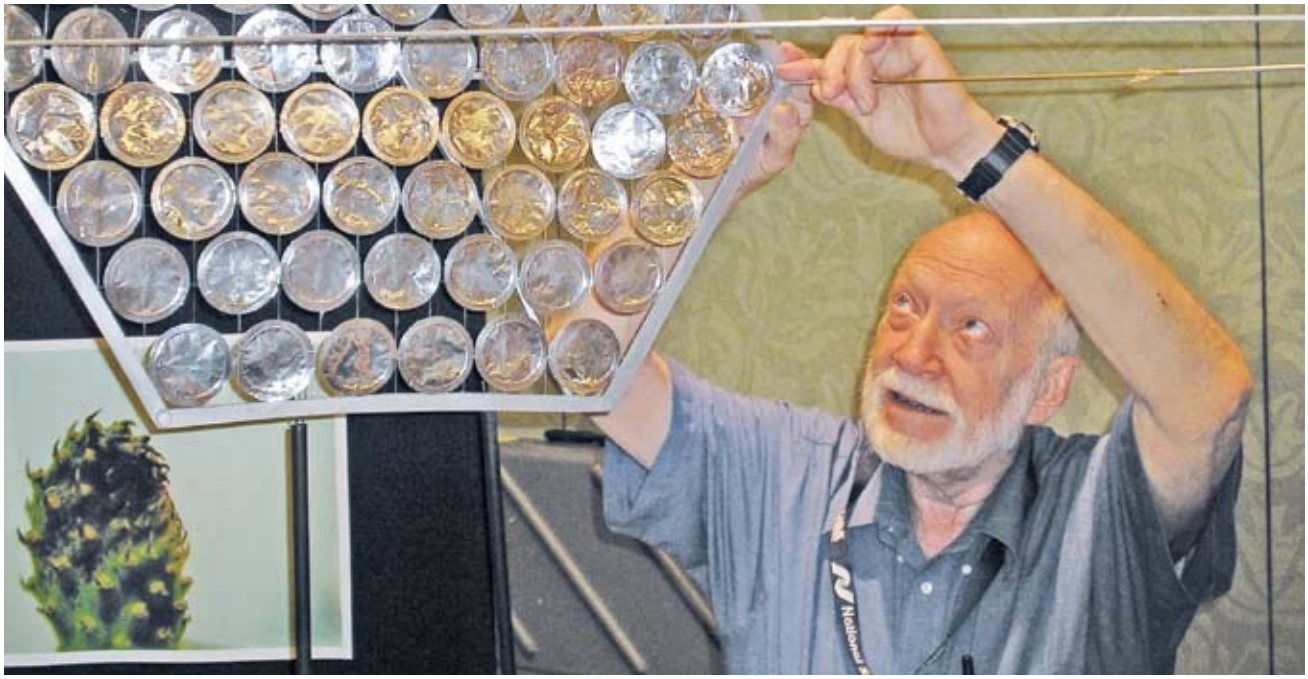
The leader, with eleven solar farms, the other sunshine state on the west coast, is also merging aeronautics with photovoltaics. Pacific Gas & Electric (PG&E), California's counterpart to FPL, is now about to take even more advantage of its sunny exposure by capturing sunlight not on the ground, but out in space.

PG&E has signed an agreement with Solaren, a California start-up, for this very purpose. Solaren has undertaken to supply PG&E with solar energy harvested by space satellites starting in 2016. The principle sounds simple enough – making use of one or more satellites in a geostationary orbit around the Earth – but implementing it is likely to be a major technical challenge. At that distance – around 36,000 kilometers (or about 22,000 miles) above the Earth's surface – satellites are always at the same point in the sky, because they orbit the Earth once every 24 hours, staying in step with the Earth's rotation around its own axis. Furthermore, there's constant line-of-sight contact between a satellite and the sun up there. Solar panels mounted on such a satellite can generate electrical energy virtually without interruption and send it back to Earth as microwaves. Bad weather can't affect the process, for microwave radiation goes straight through clouds. The idea sounds too good to be true. It makes you wonder why no one put it into practice before.

Back to the future

No space agency has ever performed a space experiment of this kind, nor has any state ever budgeted enough money for it. Yet, the first proposals for a project of this type were made back in the 1970s, when President Jimmy Carter approved funds for projects to get energy from space. But before his 1979 Federal budget proposal could leave the White

Photo: Guido Meyer



Peter Kokh explains the space solar power model of the Moon Society at the International Space Development Conference in Orlando.

House for consideration by the Congress, space solar power fell victim to cost-cutting measures, and Carter cancelled it himself. "We lobbied hard at the time, trying to persuade both houses of the Congress – the House of Representatives and the Senate – of the urgency of producing alternative energy," recalls Mark Hopkins, who was then and still is a member of the National Space Society (NSS). "Unfortunately, we weren't successful." Now senior vice president of the NSS, he remembers that in the late 1970s solar energy from space had to compete with energy from coal-fired and nuclear power stations. It was no contest, he says, because no one paid any attention to the carbon dioxide emitted during the combustion of fossil fuels back then. Nor was anyone worried about the safety risks from nuclear energy. These two options were also seen as cheap, so the development of space-mounted solar panels was killed off at an early stage.

"But the times have fundamentally changed," says Hopkins happily. He is still enthusiastic today about the idea of tapping the energy of the sun while respecting the Earth's environment, and points out that the cost of developing photovoltaic cells has fallen drastically in the last four decades. They have become a mass product and are fitted to all of the Earth's artificial satellites. Important technological advances have been made in other areas as well since the 1970s, Hopkins adds. "Computers and robots are so intelligent and independent today that we could use them on their own, without astronaut assistance, to assemble the required systems in orbit."

Eureka!

Economic and ecological requirements, coupled with technical capabilities, have led to a comeback of space solar power in recent years. The models at least are now so mature that they could go into space tomorrow. One of them is made by the Moon Society, an American private interest group campaigning for a number of innovative space exploitation projects, including a return to the moon. The society's president, Peter Kokh, explains his model. "Here you have two giant solar arrays that catch the sunlight and focus it on a central collector." He presented this "solar power beaming desktop demonstrator" at the International Space Development Conference in Orlando in May. It's based on sketches, animations and drawings by NASA and the National Space Society and is intended to show that the principle works. Mirrors convey sunlight to a collector (also called photovoltaic and transmission antenna) from two sides. A conventional photovoltaic cell is used to convert the incoming sunlight into electrical voltage. This electricity is then carried by wires to a radio frequency generating device which sits on the other side of the round PV and transmission device, facing the Earth. This second device would typically be either an amplifier as they are used in mobile phones or a magnetron of the type found in microwave ovens. A very large number of these radio frequency generating devices work together to produce a large, coherent beam of radio energy – just like a radar at an airport – that is then transmitted to Earth. "Each of those devices would supply the power needs of a major metropolitan area", Kokh explains. "The idea is that up in space, where sunlight is available full strength 24 hours a day with no clouds and no haze, we could gather enough sunlight with a network of these solar power satellites to power the entire world at whatever level of energy they wanted." These are ambitious plans, but the Moon Society's model does demonstrate their theoretical feasibility. In a demonstration, the current generated causes a diode to glow. So converting light into microwaves and using those as a power conduit does work – in principle, and on a small scale.

A full-size orbiting device would initially send the microwaves to a receiver on Earth, which proponents of space solar power call a "rectenna," a contraction for "rectifying antenna," analogous to a transmitting antenna. "There would be guide beams, so that if the beam started to stray off the target on Earth it would immediately cut off," explains Peter Kokh. "So it's a totally safe thing." After traveling for 36,000 kilometers, a microwave beam does not, of course, stay together completely, but instead

"frays." Just as the cone of light from a flashlight widens out as it gets further away from the bulb, microwave radiation from space spreads out to such an extent that a satellite dish wouldn't be big enough to form a rectenna: a large array of receivers is required instead. A rectenna farm would look similar to the solar farms that now capture sunlight on the ground, but instead of solar cells, the surface of a rectenna array would carry diodes to absorb the microwave radiation and convert it into either direct or alternating current. "Their size will depend on the intensity of the radiation," explains Darel Preble, chair of the Georgia Institute of Technology's Space Solar Power Workshop. If the radiation arrives at the Earth on a frequency of 5.8 gigahertz, such a farm will be five kilometers (3.1 miles) long on one side. "A weaker signal and smaller arrays would make no sense," he points out. An alternative frequency of 2.45 gigahertz that has also been approved by the International Telecommunications Union (ITU) for public use is of little interest to devotees of space solar power.

Unlike a conventional solar array, however, a rectenna array wouldn't prevent the simultaneous use of the site for other purposes. "Farming, for example, could be carried on below the receiving plane," says Preble. An example of that can be seen at Arecibo in Puerto Rico, where jungle life continues quite normally under a radio telescope more than 300 meters wide. Ferns, begonias and orchids grow ten meters down below the dish. Unlike solar collectors, rectenna receiver foils are transparent to sunlight.

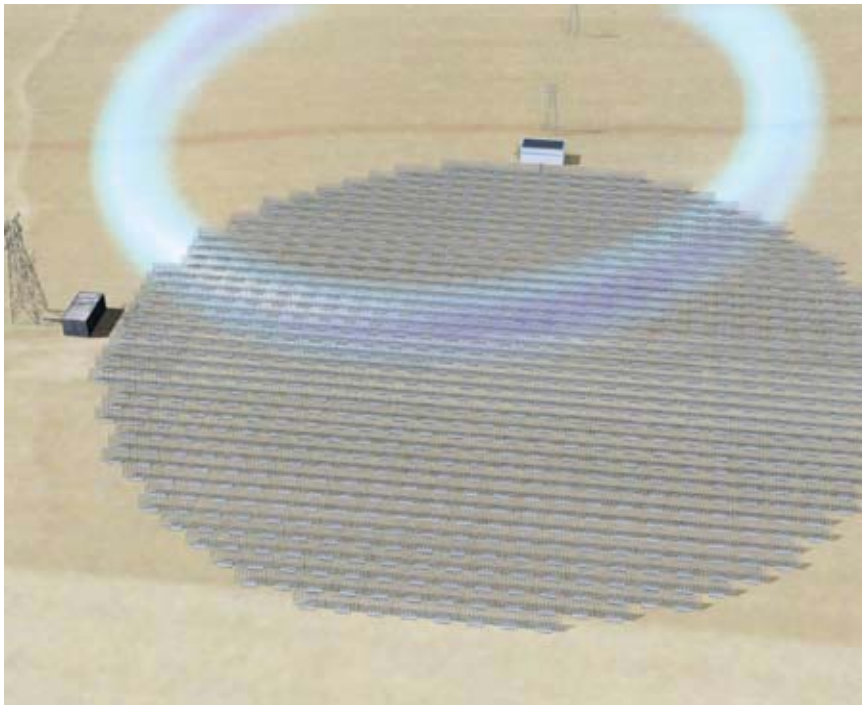
Beam me down, Scotty!

Solaren has already chosen a receiving site in Los Baños, a city around 120 miles southeast of San Francisco. "We'll build a fence around the array so that no one can get in from outside and get hurt," says Carl Boerman, director of energy services at Solaren. There will be safety standards for workers at the station, he says, and regulations to ensure no one is exposed to the microwave beam for longer than ten minutes, but generally speaking, he says, the radiation coming in from space is harmless. "The heating effect of the noonday sun is seven times greater than the heating effect of our energy coming down from the satellite," so it won't even present a hazard to any birds flying briefly through the beam. Preble says the only possible side effect is that "you may have trouble with cell phones in the area, because communication interference is a major issue. We need to consider how the frequency will be filtered and whether the system would be better in remote areas away from cities where farms are typical." Receiver foils also have to be protected from lightning and strong winds.

But these problems on the ground are not the biggest challenges faced by Solaren at the moment. More than anything else, it's a question of money. The company, just eight years old, has been concentrating in recent weeks and months on getting financing for its hardware. "We are talking seriously to a couple of different groups that are more of an international flavor," says Boerman, though he doesn't mention any names. Apparently, they are mainly foundations with an interest in promoting environment-friendly projects and fostering them financially. Solaren is already thinking about means of transport into space and is quite open about the names of the two firms that may be involved. "We would buy our launch rockets from either Boeing or Lockheed or a combination of the two," says Boerman. Boeing has been successful for years with the Delta 4 series of rockets; Lockheed Martin, with its counterpart, the Atlas 5. Both firms are among the U.S.'s leading astronautics groups and regularly launch satellites and probes into space for both private companies and NASA. Solaren will probably have to dip into its pockets four times for these launches, because it wants to send four individual solar power arrays into geostationary orbit. "Those pieces will either operate independently, or we may do some automatic docking of two pieces, but it won't require any kind of manufacturing or assembling in space," says Boerman. The solar power devices shall be fitted with conventional silicon-based solar cells. For a time, Solaren also considered using thin film solar-cells. "We had to keep the weight down to make it affordable, and we had to make it as simple as we could to make it doable," is how Boerman explains Solaren's examination of alternatives before returning to the proven technology. "This is a space project, so we have to use space-qualified cells, nothing new. We are going to use the conventional solar cells that are used on satellites today, and we hope to improve their efficiency."

One step after the other?

Some experts voice doubts about the time schedule presented by Solaren and the efficiency of the system it's proposing. One skeptic is John Mankins, who led the space solar power research group at NASA from 1995 to 2001 and is now president of Artemis Innovation, a consultancy based near Washington, D.C., that advocates the promotion of new technologies, including space solar power. "There's a general con-



Graphic: Mafic Studios, Inc.

A large rectenna farm is needed to absorb the microwave beams sent by space solar power satellites.

Photo: National Space Society

Mark Hopkins: "We could use robots to assemble the systems in orbit."

sensus today that solar power satellites are now technically feasible," Mankins says. "However, they are not proven yet to be economically viable. Many of the technologies – although they exist in the laboratory – have never been integrated or deployed and tested at a systems level. The question is: can it be done with full profit?"

Mankins fears that Solaren is skipping an important step by advancing from blackboard theory straight into the harshly competitive energy market, without taking time out for testing and development. "There are still some key steps to take in terms of taking the technologies, implementing them, validating them on the ground, taking them into space, doing a demonstration, before you can really say what the price of energy from a solar power satellite turns out to be." Technical feasibility and economic efficiency are both essential, he says, if energy is to be had from space. If just one of these two pillars fails, the system is not competitive. The former NASA man fears that a start-up company like Solaren, which currently consists of only ten people, can't handle a task like that. "That's millions of dollars to do ground technology, tens of millions of dollars to do system level demos, hundreds of millions of dollars to take it to space, and billions of dollars to do an initial pilot plant – a prototype."

Mankins favors international cooperation between the space agencies of the U.S., Europe and Japan, rather than having a small firm grapple with a project of this size. He says university researchers should also be recruited to the project. "It would also be a great opportunity to bring in developing countries such as India or China, which would be tremendous markets for solar energy from space," he adds. Just looking at the arithmetic convinces Mankins that Solaren won't be able to fulfill its ambitious plan of supplying 200 megawatts of electricity starting in 2016. In comparison, the International Space Station (ISS) has 16 solar sails that peak at approximately 100 kilowatts. The satellites planned by Solaren would have to be two thousand times as powerful.

In this case, Mankins puts his bets on political rather than market forces, for America's new President, Barack Obama, has expressed wholehearted support for harnessing green forms of energy. NASA hasn't yet been given any money for space solar power projects, but the situation could change soon. Obama plans to nominate Lori Garver, who was the second executive director of the National Space Society (NSS) from 1988 to 1998, as deputy NASA administrator. She is regarded as a supporter of space solar power. "We think that there's a good chance that there will be funding forthcoming in this administration," says Mark Hopkins of the NSS hopefully. Mankins is also sure that the idea of space solar power will get a boost with its new advocates in the White House and in NASA. "It could build to a national level discussion at the level of the White House or the Office of Science and Technology Policy, maybe already as soon as next year."

The Pentagon might be interested

Perhaps by that time the Defense Department, too, will have joined the ranks of the supporters of space solar power. "There is talk of some funding in the next year in the military," reports Hopkins, but he gives no further details. The Pentagon does, however, admit that it's looking for alternative energy sources. "We are concerned about things that can cause conflicts in the 21st century" is the unrevealing statement of Lieutenant Colonel Paul Damphousse, chief of advanced concepts at the National Security Space Office (NSSO). His best example? "Resource scarcity is one of those potential flashpoints that could result in conflicts." So the military is looking around for alternatives – to oil, for example. Yet there's still another, much more pragmatic and direct reason for the Defense Department's interest in space solar power: supplying U.S. troops with energy at foreign locations is difficult, expensive and dangerous. Absurdly, the U.S. has to import oil into Iraq – an oil-exporting country – to supply its troops. Terrorists welcome these incoming tanker convoys as highly explosive targets. By the time it arrives at its destination, the imported fuel is up to a hundred times more expensive than the same product at American filling stations. "We are concerned about how we get power into some of our foreign areas," Damphousse says. "So if we could do that via wireless power transmission, that's attractive to us."

His words may contain an undertone of concern in case other countries overtake the U.S. in developing this new technology. The Japanese government's new space plan funds the JAXA space agency with the equivalent of up to ten million dollars annually over the coming ten years for research into space solar power. The European Space Agency (ESA) commissioned a two-year study of the feasibility of space solar power satellites that came to a positive conclusion and is now to be extended.

Space power made in Switzerland

A company in Switzerland is already preparing to pit itself against Solaren. Schaffhausen-based Space Energy plans to launch the first of more than forty satellites into low orbit in just three years' time, initially just parking them there. The Swiss firm is also putting its money on Boeing's proven Delta 4 rocket, having made a preliminary agreement with Boeing at the International Space Development Conference in Orlando in May. Space Energy too intends to make its space solar power devices in modular form, only docking them together in space. Unlike the Solaren satellites, they are to be assembled in a near-Earth orbit

Photo: National Space Society

John Mankins: "The question is: can it be done with full profit?"

at an altitude of some 300 kilometers (186 miles), with 15 tons of materials being sent up every week and assembled by robots. After two years, each is scheduled to produce a finished device that will then set off into geostationary orbit. In all, Space Energy will have assembled 15 such stations by 2029, an average of one per year. Their dimensions look to be enormous: almost four square kilometers. "The cost of the first stations will be between 12 and 16 billion dollars and will then fall to seven to eight billion per device," says Stephan Tennsel, the Swedish founder and CEO of Space Energy. The firm will use the proceeds of the first two to finance the construction of the others.

A Zurich investment group has taken a stake in the project by giving start-up funding of more than 200 million euros. The first client to pay the full price is then to be the Indian government, with which Space Energy is now negotiating. An offer has been made of more than 200 billion dollars for the supply of 120 gigawatts within a period of 15 years. The contracts have not yet been signed, however. "Our satellites will be able to send their microwave beams simultaneously to various locations on the Earth and that's very useful for India, which has problems supplying energy to the population, which puts a brake on the country's progress," says Tennsel. He points out that the Space Energy design has a decisive advantage over Solaren's – lower losses. "If energy has to be laboriously transported to and fro on the ground, some of it is always lost. With our system, the electricity goes straight to the point of use."

Not all eggs in one basket

While Space Energy intends to sell its solar power to India, Solaren's will be staying in the U.S. Solaren's client, the Pacific Gas & Electric Company, intends to use the 200 megawatts promised by Solaren to supply electricity to around 150,000 households in southern California. PG&E's interest in alternative energy sources isn't entirely voluntary, but at least partly at the urging of the state of California, which has undertaken to obtain at least 20 percent of its electricity from renewable sources by 2012. Solaren won't be able to deliver until 2016, so it can't help PG&E fulfill that goal, but PG&E spokesman John Marshall points out that "Solaren is important in the much longer range of renewable energy, not in achieving that near-term goal." Even if the project with Solaren fails, he says, PG&E has still other irons in the fire. "The state wants more renewable energy, our customers want more renewable energy, and we are committed to it ourselves." Marshall won't divulge what other aces PG&E may have up its sleeve, but the company is at pains not to give the impression that it has put all of its eggs into one basket. "We're open for other proposals," says Marshall frankly. "We don't deal exclusively with one company. Dealing with Solaren doesn't mean that no other company would be viable." PG&E has signed contracts with various producers of renewable energy sources and thus backs a variety of technologies, he says. "One of our goals is to diversify both the suppliers and the technology that they represent. In the meantime we continue to aggressively contract with renewable power developers so that even if some fail to deliver we hope that others will succeed and help us achieve that goal."

In July, on the 40th anniversary of the first manned moon landing, long-serving NASA astronauts will also have their say. One such person is Rusty Schweickart, who was on the Apollo 9 mission. He says sending all of the materials needed for the construction of kilometer-sized arrays from Earth into a geostationary orbit would be far too expensive. Instead, NASA should fly to an asteroid. "You manufacture the solar cells, the photovoltaic cells, out of silicon and other elements from an asteroid – it's already up there." Astronauts or machines would only have to fly to a near-Earth asteroid, use its mineral resources to make space solar power devices, and point the devices at the Earth. "And so the whole economics of obtaining solar power in space and beaming it to the Earth changes dramatically." ◆ Guido Meyer

MORE INFORMATION

International Symposium on Solar Energy from Space
September 8-10, 2009, in Toronto, Canada
www.spacecanada.org

National Space Society
www.nss.org

Space Solar Power Workshop
www.sspi.gatech.edu

Solaren
www.solarenspace.com

Pacific Gas & Electric Company
www.pge.com

Florida Power and Light Company
www.fpl.com

Space Energy
www.SpaceEnergy.com

Artemis Innovation
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The moon society
www.moonsociety.org

For instructions on how to build a "Space Solar Power Device," write to:
president@moonsociety.org