

A SPACE SOLAR POWER INDUSTRY FOR \$2 BILLION OR YOUR MONEY BACK

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ABSTRACT

A system of prizes to develop space solar power (SSP) is proposed. If successful, a one or two billion dollar investment could kick-start a vigorous SSP industry, which in turn could provide humanity with essentially unlimited quantities of clean electrical energy. If unsuccessful, the money is returned to its source. The prize is structured to subsidize the construction of nine SSP satellites by at least three different entrants using different designs. The prize is aimed at developing small SSP systems delivering a few tens of megawatts to utilities on the ground. Under some reasonable assumptions, the prize money is sufficient to make one or perhaps two of the satellites profitable and provide a significant subsidy to the other seven. Once small SSP systems have been successfully developed, producing large systems that can make a real difference to global energy production will be much easier. While \$2 billion is a great deal of money, should this effort be successful, it is reasonable to hope that Earth's energy and greenhouse gas problems could be solved.

INTRODUCTION

Space solar power (SSP) is a high risk, huge payoff potential energy industry. Long term, SSP can supply massive amounts of electrical power to Earth with no greenhouse gas emissions and no dependence on foreign energy sources. The basic idea: gather solar energy in space and transmit it to Earth. In space, solar energy is available 24/7 in extremely large quantities. SSP has been studied for 40 years and all the major elements proven in use or experiment. Most satellites use solar power routinely, the physics of power beaming are well understood, and power beaming has been demonstrated (Globus, Towards an Early Profitable PowerSat, 2010). However, SSP requires construction of satellites much larger than any built so far and power beaming at distances and power levels never before accomplished.

SSP is not currently economically viable because operating in space is very expensive. These costs could be greatly reduced by improved technology and the economies of scale¹ successful SSP could provide. For example, launch costs are a critical factor for SSP development and today there are around 100 launches per year. The people of Earth use roughly 16 terawatts (trillion watts) of power continuously. For SSP to supply one of those terawatts would require around 40,000 launches of the largest vehicle ever designed (Globus, Paths to Space Settlement, 2011), the Sea Dragon intended to lift 500 tons per flight². Such a high flight rate would revolutionize the cost space operations by radically reducing the cost of delivering satellites to orbit.

Furthermore, building hundreds or even thousands of more-or-less identical satellites to provide large amounts of power to Earth should be much less expensive, per satellite, than building one-of-a-kind systems or even the small constellations (a few tens) of communication satellites we have today. It is reasonable to expect SSP can be economic once high volumes are achieved, because the costs of space operations will drop dramatically as we ascend the learning curve and put infrastructure in place. The problem is how to get from here to there. The key is at least one, ideally several, profitable SSP systems of any size.

It is tempting to suggest a large government-run technology development and infrastructure project to bring SSP to economic viability, but there may be a much better way. In recent years prizes have been successfully used to develop important technologies and even entire industries. For example,

1. The \$10 million Ansari X prize started a sub-orbital space tourism industry that has collected many times that figure in customer deposits.
2. The DARPA Grand Challenge spurred important advances in driverless cars.
3. The \$30 million Google Lunar X Prize has spurred substantial development in private spacecraft designed to operate on the surface of the Moon.

Prizes have some important properties relative to SSP:

1. If no one delivers the desired results, the prize money goes back to the sponsor.
2. Typically, far more is spent chasing the prize than the prize is worth. For example, the winner of the Ansari X Prize is rumored to have spent three times the purse in development³. Of course, the losing entries represent a substantial additional investment as well.
3. As there are frequently many entries, around 30 currently in the case of the Google Lunar X Prize, even the losing efforts help develop expertise that can be tapped if an industry develops.

¹ It is important to remember that the phrase 'economies of scale' refers to doing the same thing over and over again, not necessarily building something very large.

² For comparison, the Falcon 9 lifts about 10 tons per flight (Space Exploration Technologies Corporation).

³ Although Scaled Composites, Ltd, the winner, spent perhaps \$30 million to win a \$10 million prize, other income generated by the project apparently netted a small profit.

A much more expensive SSP prize system was proposed by this author in 2007⁴. That prize chose \$21 billion dollars as the prize amount because the Japanese proposed a traditional government R&D program of that size. Since then, the advent of SSP designs based on thin-film solar cells, solar sails, infra-red power beaming and fiber lasers suggest that much less expensive SSP systems can be built so a much smaller prize may be sufficient (Globus, Bararu, & Popescu, Towards an Early Profitable PowerSat, Part II, 2011).

This paper explores a \$1-2 billion prize system intended to develop the beginnings of a vigorous space solar power industry. First, the characteristics of the systems to be encouraged are discussed. Next, the monetary issues are addressed. Then the detailed rules are investigated and how investment income from the prize money in escrow might be used. Finally, we discuss potential source of the prize money.

THE PRIZE

To properly size the prize it is necessary to have an idea of what a winning entry might look like. It is not necessary that this idea be correct, only that it cost more-or-less as much as a real system. If the cost estimate is too low then no one will try for the prize, if too high the prize will be larger than necessary. This paper attempts to err on the 'too large' side.

The target system is assumed to have a mass of 100 g/m², which appears to be feasible (Globus, Bararu, & Popescu, Towards an Early Profitable PowerSat, Part II, 2011). Using underlying technologies presently available in the lab or in some cases from commercial ventures, such a system can probably achieve an end-to-end efficiency of about 2% (Globus, Bararu, & Popescu, Towards an Early Profitable PowerSat, Part II, 2011), meaning that 2% of the solar energy impinging on the satellite is converted into electrical power on the ground. Given these parameters, a satellite launched by a Falcon Heavy could deliver perhaps 7 MW to the grid for a launch cost of about \$100 million (Space Exploration Technologies, 2011) plus the cost of satellite development, operations, and ground receiving station construction and operations. Given plausible improvements in the underlying technologies, an end-to-end efficiency of about 10% could be achieved resulting in about 35 MW delivered to the ground (Globus, Bararu, & Popescu, Towards an Early Profitable PowerSat, Part II, 2011). The total non-launch cost of such a system is unknown, but it would likely be no more than \$500 million to \$1 billion for the first one and much less for the second.

Unlike, for example, the sub-orbital tourism market, there is a very large, known, and well characterized market for energy. In fact, energy is a multi-trillion dollar per year industry. Thus, there is no market risk and the cost that must be achieved is known. Typical prices are:

⁴ "Space Solar Power X-Prize," Al Globus, 2007, <http://space.alglobus.net/papers/SSPxPrize.html> in July 2011.

1. \$0.03-0.15/kwh for conventional power to the U.S. grid (U.S. Energy Information Administration, 2011).
2. \$0.34-0.38/kwh for subsidized 'green' power in some advanced nations⁵.
3. Up to \$0.50/kwh or more for power to remote locations currently dependent on diesel generators (Globus, Bararu, & Popescu, Towards an Early Profitable PowerSat, Part II, 2011).

The prize must be designed to not only produce power but to eventually bring the price down to something near competitive in at least some markets. Furthermore, for such a large market, it is desirable to develop the SSP capabilities in at least two or three companies.

Thus, the prize posed here is a bit different from some of those referenced in that it is designed to create at least three winning competitors and bring the price down to near-competitive levels over a period of time. The Google Lunar X Prize is similar in that there is a second place pot. Importantly, it is not at all clear what the best way to build solar power satellites is, so it would be advisable to support a number of different approaches.

PROPOSED PRIZE

The proposed prize pays out for each kilowatt-hour (kwh – one thousand watts of energy for one hour) of power delivered from space to an operational electrical system on Earth. To receive prize money, power must be sold to a utility or other entity on Earth at near market rates. This insures that the power is delivered in a way that can and will be used, and provides additional income to the contestants.

The prize is divided into three levels: \$1, \$0.7 and \$0.3 per kwh. This is to provide continuing incentive to develop SSP at successively lower prices on the way to unsubsidized economic viability. Furthermore:

1. To encourage the development of a competitive industry, at each level the prize money is divided such that at least three satellites are needed to capture all of the funds. No individual satellite can earn more than 60% of the prize money and no two satellites more than 90%, leaving 10% for a third satellite.
2. To encourage development of multiple approaches to SSP, each satellite earning prize money at a single level must be owned and operated by a different entity and must use a substantially different approach to SSP generation.
3. To encourage development of successively more cost-effective systems, each satellite may only win prize money at a single level.

⁵ "Should California adopt the German solar model?," Grist, 8 July 2011
<http://www.grist.org/solar-power/2011-07-06-should-california-simply-adopt-german-solar-tariffs>

Thus, this particular approach to structuring the prize will pay out all the prize money only if nine satellites are developed using at least three different approaches by at least three different companies. Table 1 describes the prize system quantitatively.

Note that the number of levels, the pricing, and the percentages are somewhat arbitrary. They are chosen to give one or two satellites a real chance at profitability and the others a significant subsidy. Obviously, there may be other sets of levels that may be more effective.

Level	\$/kwh	kwh	cost \$M	total cost \$M	60%	30%	10%
1	1	1,000,000	1,000	1,000	600	300	100
2	0.7	1,000,000	700	1,700	420	210	70
3	0.3	1,000,000	300	2,000	180	90	30

Table 1: Prize levels. Each row represents one level. The second column is the prize per kwh delivered to Earth. The third is the number of kwh that will receive prize money. The fourth is the cost of each level, and the fifth the cumulative cost, both in millions of dollars. The total cost of the prize system is \$2 billion. The last three columns indicate the maximum prize income for the first, second and third satellite receiving prize money depending on the level and when it delivers the power.

If successful, this prize system would require \$2 billion, about one year’s development of the new human deep space system that might put humans on an asteroid in 2025, about the cost of a flagship deep space mission, or a little more than the cost of one shuttle launch⁶. While all of these are worthy projects, their impact pales beside the impact of a successful SSP industry. If successful, SSP could deliver essentially unlimited clean energy for a billion years and put the nations developing it in the world’s economic driver’s seat.

It should also be noted that the launch systems and other development needed for a successful SSP industry would make other space projects much easier and cheaper than they are today. In an era of limited budgets, one wonders why billions are allocated to projects of great interest but little practical day-to-day value while projects such as SSP that could revolutionize life on Earth, not to mention space development, languish with essentially no funding.

ADMINISTRATION

For investors to believe the prize will be paid out it is essential that the funds be allocated in advance and placed in some sort of escrow account. Since part of the advantage of prizes is that you get your money back if no one delivers, the prize money should be returned if none of the money is claimed within ten years. If some, but not all, is won within twenty years, any money remaining in escrow

⁶ Space News, 11 July 2011 reported that the shuttle program cost \$209 billion for 134 flights (including two failures) for \$1.6 billion per flight.

should be returned. This leaves adequate time to develop, launch and operate satellites, but the time scales are short enough to provide some urgency.

The funds in escrow should be invested in a conservative interest bearing account. With a two billion dollar fund it should be possible to get at least one percent, probably a great deal more. Even one percent is \$20 million dollar a year. The cost of administration can come out of this, but should consume no more than a small fraction. The remainder could be used to fund research and development of common interest that would be available to all competitors.

The prize will require a board and support staff to:

1. Register entries.
2. Oversee a contract to develop hardware to independently measure the energy delivered to the ground.
3. Determine the power actually delivered by contestants.
4. Determine which entries may access each level. For example, a successful company should not be able not simply sell a second satellite to another company and have two satellites of the same design accessing funds at a single level. There will be other similar issues to resolve.
5. Determine the minimum price an entrant may charge when selling prize-eligible power in a given market. The idea is to allow SSP a competitive advantage, but force the buyer to pay enough to care about using the power efficiently.
6. Award research grants.

It also may make sense to hire a single software engineer to manage a set of open source projects to develop software of common interest. Depending on the donor, this software could be available to the competitors only, or the general public.

DONOR(S)

Two billion dollars is a great deal of money. However, many governments could afford such a sum. Governments with strong aerospace industries would probably limit competitors to firms from the country itself. Nations that do not have a vigorous aerospace industry of their own might open the competition to any firm, but require that entrants move part or all of their development and operations to the donor country before prize money is awarded.

Some companies could afford such a prize. For example, Exxon made \$10.7 billion in profit this year⁷. If a company were to supply the prize money, they would probably want an ownership stake in successful entries.

⁷ CNNMoney, April 29, 2011 <http://money.cnn.com/2011/04/29/news/companies/big-oil-gas-price-response/index.htm>

Finally, there are a number of wealthy individuals who could afford to fund such a prize. In this case they might want to try a lower level, say one billion achieved by lowering the kwh per level to 500 million. In this case, of course, the donor could set policy on who may enter and have access to research results and software.

SUMMARY

Successful development of SSP would be a major positive game changer for global energy production, environmental protection, economic development, and national power. To date, SSP has received very little development funding outside of Japan, even though it is much closer to operational capability than fusion, which receives \$400 million/year from the U.S. (Department of Energy, 2010).

While it is tempting to propose a traditional government R&D program to develop SSP, a prize may be better, cheaper, and lower risk. The prize suggested here is paid out for each kwh delivered to electrical customers up to a certain level. The prize is structured to subsidize nine satellites of at least three different designs and development teams. The prize is intended to directly lead to the development of satellites delivering a few tens of megawatts as precursors to the much larger systems necessary to make a dent in global energy production.

If successful, these prizes could revolutionize our world. If unsuccessful the money is returned to its origin. What more could one want?

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