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Costs, Organization, and Roadmap for SSP

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Abstract

Space Solar Power will be too expensive until it is too late to afford it. Politicians shy away from projects that last longer than they will remain in office. Governments are reluctant to fund projects where there are no short-term paybacks. Militaries will not sponsor work that cannot be used to fight wars. Corporate investment in long-term projects without a proven return are unlikely. Environmentalists, status quo defenders, and established energy interests alike will resist large-scale projects, driving up costs and costing time. There is presently no consensus on an optimal SSP architecture; nor is there an agreed-upon cost; nor is there an organization charged with achieving either. Therefore, SSP needs a miracle. By definition, miracles cannot be predicted, or counted upon. However, it is possible to prepare for miracles, so that when they do arise, action can begin immediately. This paper describes how to prepare for the miracle.

I. Introduction

The top three issues facing mankind are: (1) developing energy sources which are benign and plentiful; (2) reducing greenhouse gases and environmental contamination; and (3) nuclear proliferation. A solar powered economy addresses all three. Solar power is best collected in orbit because: (1) there is no attenuation from air, clouds, dust, or rain; (2) there is no day-night cycle at sufficient altitude; and (3) there is plenty of space. Therefore, space solar power (SSP) could be the ultimate sustainable power source for all mankind's energy needs.

The US has a long history of reactionary response. Yet, when the perceived threat diminishes, so goes the motivation for action. This is sometimes used to great effect by enemies of the US who provoke a strong response, then retreat, allowing the behemoth to exhaust its resources in overreaction. A recent, post 9/11 example is creating transportation fuels from food, kick-started by the surge in gasoline prices in 2007. Government and private funding for corn ethanol went from a peak to a trough in just two years. A similar cycle occurred in the late 1970s, also driven by gasoline prices, only to all-but-vanish by the early 1980s. Collectively, Americans are not long-term systems thinkers, preferring short-term point solutions. For these reasons, SSP will not get started in the US.

The European Space Agency (ESA) has several modest research programs in SSP. India's space agency ISRO has interest, but inadequate funding for SSP. The current center of mass for SSP is in Japan, with the recent announcement of long-term corporate investment. Japan has limited indigenous resources, leading to a strong ethic of energy conservation, so its citizenry are aware of the importance of energy. The space agency JAXA, together with the Ministry of International Trade and Industry (MITI), large corporate conglomerates, and able universities, appear to have the will and the way to achieve viable SSP satellites.

China's rapidly growing need for electric power results in projects like the Three Gorges Dam, and a regular progression of coal-fired power plants being built across the country. The environmental devastation is staggering. Yet the economic boon has helped fund China's space program, one which generates considerable national pride. China's government is also famously forward-looking. China will probably be the first country to develop SSP on a large scale.

Yet, in keeping with time-honored traditions, much basic research for SSP will come out of the US. These advances will then help China to make SSP practical and economically viable. Eventually, other nations will adopt or purchase these technologies, and SSP can begin to address the top three issues listed above. But how does the research program get started in the US? How much money should be spent, and what should be done with the money? What organization coordinates the many different approaches and technologies under the SSP umbrella into a cohesion with the chance to focus efforts sufficient to implementation? This paper outlines a common sense approach, based on established methods, by which mankind can be spared disaster by evolving to a solar powered economy.

II. Approaches

A. The Manhattan Project

The supposition that Germany might develop a bomb far more powerful than any previously possible alarmed certain scientists enough that they conveyed their concern to the President of the United States. It wasn't until Albert Einstein added his name to the list that President F.D. Roosevelt initiated the project which led to the development of the first atomic bomb. The bomb wasn't finished until after Germany surrendered. That timing might have curtailed further development if Japan was not also at war with the US. Here is a clear case of the strong US reaction to a perceived threat. The concurrence of the war with Japan provided continued motivation, sufficient to bring the project to its goal. Today, 14% of the world's electricity needs are derived from nuclear reactors.

B. The Apollo Project

The Cold War between USSR and the US was based on escalating threats of mutually-assured destruction from ever more powerful nuclear weapons. The Soviet launch of Sputnik atop an intercontinental ballistic missile, which flew across the US, and could be heard on transistor radios, provided an enormous motivation for the US. It was easy to imagine satellites and ICBMs carrying warheads capable of wiping out America at a moment's notice. Twelve years later, the US eclipsed the USSR in space proficiency with the Apollo program. The Soviet threat continued long enough for this program to reach its goal in 1969. By 1972, the moon was old news, the USSR had quit trying to one-up the US, and the Apollo program was stopped cold. NASA's budget has dropped from 2.1% of the federal budget to 0.52%. Solar photovoltaics, a technology driven largely by satellite needs, currently supplies about 0.1% of worldwide electricity demand.

C. Imminent Threats

For a miracle to occur the US must perceive a real and on-going threat. Considering the most problematic areas listed above gives guidance on what sort of threats may arise. Environmental events may be roughly divided into regional disasters lasting days, weeks, or years (tsunamis, hurricanes, droughts); or decimating global weather shifts lasting generations (megavolcanic eruptions, ice age, runaway thermal superstorms). Either type threatens SSP. Regional disasters draw down funding coffers to provide immediate relief and possibly rebuilding; while decimations reduce commerce such that long-term, high-cost projects are no longer affordable. The same logic holds true for nuclear events, whether localized (Hiroshima, Nagasaki, Chernobyl), or widespread and generational (global thermonuclear war). Energy shortages will drive prices until economic necessity overcomes free market forces, and wars erupt. These may be regional, lasting years; or they may escalate into a third Great War over scarce energy sources. None of these options favor SSP.

Manhattan and Apollo threats were man-made. What threats could induce the US to pursue SSP? Oil shortages have failed. International climate change initiatives have so far failed. Even an attack on US soil was insufficient to change American views towards energy. Positive incentives have also failed, including Nobel Prizes and petitions by developing nations. There is presently no superpower to challenge the US, so any remaining threats are perceived as being manageable.

By process of elimination, there are no known threats or inducements which could initiate a concerted US effort to develop solar power satellites. Therefore, if SSP is to come to pass, it will require a miracle, or at the very least, an unexpected degree of good luck. As Thomas Jefferson, third President of the United States said: "I'm a great believer in luck and I find the harder I work, the more I have of it." The remainder of this paper outlines a means by which hard work can prepare the US for a SSP initiative, should a miracle occur.

III. Methods

A. Cost

The energy required to accelerate objects into orbit is enormous. The areal energy density of sunlight is low. For SSP to make a significant contribution to global energy demands therefore requires an extraordinarily large structure. Large structures require a lot of mass, and a lot of assembly time. These factors are driving a number of research efforts, such as: ultra-thin solar arrays; ultra-lightweight deployable structures; robotic assembly; lunar or asteroid processing; and space elevators. From a systems perspective, the energy required to build, orbit, and assemble huge solar arrays should be significantly less than the energy delivered to earth.

Traditional energy sources typically cost between 0.02 and 0.03 USD/kWh, such as nuclear and coal. These costs do not include environmental costs of: landscape destruction, waste disposal, groundwater contamination; or generation of atmospheric carbon in the case of coal. A consequence of the unpredictable miracle will be to somehow assign a monetary value to these hidden costs. It is not unreasonable to expect a doubling of production costs, so that the breakeven point for SSP can be taken as approximately 0.05 USD/kWh.

A solar power satellite could have an upper limit on lifetime of 15 years, although this may be optimistic. A typical power generation station is on the order of 5-8 GW. This yields a cost of between 33 and 53 billion USD for a single SSP installation. At least one study of SSP shows the potential for projects in this cost range.[13]

Federal research to generate or develop new industries varies widely. Corporate research ranges from 6% to 10% of revenues for high technology enterprises. Taking the value of a single SSP installation, amortized over its lifetime, and drawing 8% for research and development gives a reasonable research budget of 230 million USD/year.

B. Organization

At present, neither NASA, nor the US Department of Energy (DOE) conduct any appreciable research on SSP. The Defense Advanced Research Project Agency (DARPA) does not presently have any budget for SSP. Although each of these three agencies would have a significant role to play in SSP development, deployment, and security, none is currently doing so. In the case of NASA and DOE, this is largely a political issue. They cannot take on such an initiative without direction from Congress. Another consequence of the unpredictable miracle is that the US Congress must have a champion or coalition to support SSP.

A recent surge in the number of conferences, meetings, and technical tracks related to SSP show that research is being conducted in disparate locations, with different approaches, on limited budgets, and no overall cohesion.[1-11][14] It has been quipped that there are as many SSP architectures as there are principal investigators (PIs) in this field.[12-15][17] Without a central organization to guide and combine research efforts, SSP research is likely to remain fragmented and ineffective. A new organization is needed.

We propose the Organization for Space Energy Research (OSER), a 501(c)(3) not-for-profit organization located at a major Midwest university. OSER will create a board of directors consisting of those SSP PIs who are not overly zealous or intellectually rigid. This board will oversee a three part strategy: (1) gather inputs from all SSP research centers or individuals to create a complete survey of available studies, architectures, and supporting technologies; (2) guide a rigorous consensus activity to a single, achievable architecture, plus a backup architecture; and (3) allot research activities supporting the primary and secondary architectures among universities, private companies, aerospace corporations, and federal labs.

The goal for OSER is to act as a central repository of the growing technology supporting commercially-viable SSP. Applied research shall be directed towards implementable strategies which can be directly converted to actionable activities within a project management plan to build, deploy, and secure a 5 GW SSP installation.

C. Roadmap

Systems of systems modeling is the approach by which assemblages of complete systems are simulated to understand complex interactions between them. This meta analysis permits optimization of a complete architecture using computational tools such as genetic algorithms, simulated annealing, or particle swarm optimization.[16] The metric by which optimization is driven must be numeric. Delivered electric power costs is a natural choice.

One of the primary tasks for OSER will be to define a standard modeling framework and interface definition which will allow harmonious interconnection of parameterized subsystem components. This approach allows a plug-and-play development environment whereby different SSP architectures can be compared on an equal footing. It will also support rapid testing of new architectures, which may only become evident when this capability is available. It may even be possible to use genetic programming, a high-level artificial intelligence tool, to develop a new SSP architecture without pre-conceived human concepts.

When a primary, and a secondary, architecture has been derived, the parameters for each subsystem will drive requirements for applied research and development. With this information, OSER can create guidance documents and provide funding opportunities. These can be sent out for competitive bidding.

The amount and timing of each OSER research project can be staged leading to incrementally more impressive demonstrations. Preference will be given to technologies which can be readily adapted to near-term business opportunities. As a 501(c)(3) entity, OSER is responsible for providing opportunities to use the benefits of this research for the public good without discrimination. These spin-offs will help fund OSER's administrative aspect, so that a greater portion of funding can be directed to advancing SSP.

When, after years of effort, a sufficient sub-population of key subcomponents have been demonstrated to a sufficient technology readiness level (TRL), and the models validated to test data, the computer models can now provide cost estimates for a pro forma. When used as part of a business case, this pro forma will provide investors the confidence they need to apply private investment to create the first large-scale SSP installation.

Once a commercial entity is delivering power to paying customers from a solar power satellite, the role of OSER will change. OSER will become an industry research house modeled after Honeywell's UOP, which provides the petroleum industry with value-added product and process improvements.

IV. Urgency

The Energy Information Agency (EIA) of the US predicts that in the time between 2004 and 2030 the world's energy demand will almost double. An extra 8,500 GW of installed capacity is needed to meet the growing energy needs of an increasingly affluent and industrialized world. This amounts to 328 GW per year of installed baseload power generation. A typical terrestrial "mega-nuclear" plant having multiple reactors produces from 5 to 8 GW, takes 8 years to build, and costs 25 billion USD, or about 3.85 USD/watt. Worldwide, the translates into 1.25 trillion USD each year on power generation facilities.

Renewable energy sources, such as hydroelectric, wind, biomass, geothermal, and solar (passive, concentrated, and photovoltaic) are limited, according to the EIA. Even if fully utilitized and cost-effective, these sources are barely capable of meeting energy needs in 2030, but inadequate to meet the projected needs in 2050. Therefore, SSP needs to become a large and growing segment of mankind's power needs by no later than 2030. The Manhattan Project took 6 years, and the first nuclear reactor came 9 years later. The Apollo project also took 6 years, and routine space travel via the STS began 12 years after that. Thus, the latest date at which SSP work must be started is 2012.

V. Conclusion

SSP is the only renewable energy technology capable of meeting the projected worldwide demand for the next generation of humans, and all of their descendants. As the present stewards of the earth, there is a great onus on the present generation to start work on the ultimate solution as soon as possible. An ancient Chinese proverb advocates that we "dig the well before we are thirsty". A law of the Native American society known as the Iroquois Nation is "In every deliberation, we must consider the impact on the seventh generation". Benjamin Franklin's advice on addressing problems before they grow unmanageable is "a stitch in time, saves nine." Grateful Dead lyrics by John Perry Barlow teach: "We don't own this place, though we act as if we did; it's a loan from the children of our children's kids." While Americans individually can recognize the wisdom of these aphorisms, for the collective US nation to act accordingly will probably require a miracle.

Should such a miracle come to pass, the cost, organization, and roadmap to commercial scale SSP has been identified herein. The Organization for Space Energy Research (OSER) will be a not-for-profit entity formed at a Midwestern engineering university directing a 230 million USD per year applied research budget. Its charter will be to identify an optimal SSP architecture and develop key enabling technologies. Started with federal fiscal year 2012 funding, OSER can demonstrate SSP viability in 6 years, and guide the first 5 GW installation to completion in 12 more years. In this way, SSP can take over an ever-increasing share of global power demand such that energy wars, climate disasters, or economic collapse can be averted or ameliorated.

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