Background Material & Summary Prepared by the National Space Society on the

International Academy of Astronautics Report On Space Solar Power

The First International Assessment of Space Solar Power: Opportunities, Issues and Potential Pathways Forward

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http://iaaweb.org/iaa/Studies/sg311_finalreport_solarpower.pdf

What is the need: It is crucial for the world to identify, research, develop, demonstrate, commercialize and deploy affordable and sustainable new energy sources. This need is driven by various factors; three of the most important are: (1) demand for energy to enable economic growth for a still-increasing global population, (2) concerns regarding the long-term accumulation in Earth's atmosphere of fossil fuel-derived greenhouse gases, and (3) the prospect that during the coming decades annual production of petroleum (and possibly other fossil fuels) will peak and begin to decline.

Continuing economic progress will require a four-fold increase in annual energy use by the end of the century. If carbon dioxide (CO2) emissions into the atmosphere are to be constrained during the same span, by 2100 some 90% of all energy used must be from renewable or nuclear sources. Notwithstanding optimistic claims to the contrary, it does not appear that there is at present a solution to these concurrent challenges.

Substantial renewable energy now comes from hydropower sources, and a much smaller amount from geothermal power; however, these remain a modest fraction of the total. Also, a wide variety of aerospace technologies – including photovoltaic arrays, fuel cells, and wind turbines –have been applied during the past three decades in newer renewable energy systems. Certainly, these already-existing "green" technologies can be expected to make substantial contributions to meeting long-term energy challenges faced by the global economy. However, these technologies are unlikely to provide the huge amounts of new and sustainable energy that will be needed in the coming decades.

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A New Energy Alternative: In the late 1960s, Dr. Peter Glaser of Arthur D. Little invented a fundamentally new approach to global energy: the Solar Power Satellite (SPS). The basic concept of the SPS is quite elegant: a large platform, positioned in space in a high Earth orbit continuously collects and converts solar energy into electricity. This power is then used to drive a wireless power transmission (WPT) system that transmits the solar energy to receivers on Earth. Because of its immunity to nighttime, to weather or to the changing seasons, the SPS concept has the potential to achieve much greater energy efficiency than ground based solar power systems (in terms of utilization of fixed capacity).

The SPS concept has been the subject of numerous national systems studies and technology development efforts during the 40 years from 1970 to 2010. These have included several intense, but episodic efforts in the US, Canada and Europe, as well as steady technology research and development (R&D) activities in Japan, and recent activities in China and India. There have also been a number of national and international conferences, workshops and symposia addressing the SPS concept – most steadily, the International Astronautical Federation (IAF) organized SPS sessions as part of the annual International Astronautical Congresses (IAC). Despite these activities, up until the past several years, there has never been a comprehensive international assessment of the SPS concept.

The IAA Study of Space Solar Power

The International Academy of Astronautics (IAA) has conducted the first broadly based international study of the concept of space solar power. This assessment was conducted under the auspices of IAA Commission 3 (Space Technology & System Development) and involved participants from the Academy, a wide variety of other organizations, and diverse countries. The goals of the study were to determine what role space solar power (SSP) might play in meeting the rapidly growing need for abundant and sustainable energy during this century, to assess the technological readiness and risks associated with the SSP concept, and (if appropriate) to frame a notional international roadmap that might lead to the realization of this visionary concept.

Because significant advances in space solar power could have profound benefits for human and robotic space exploration capabilities as well as other space applications, the study also identified such opportunities and evaluated the potential for synergies (if any) between these benefits for space missions and space solar power for terrestrial markets. Finally, there have long been discussions of the potential role that extraterrestrial resources might play in solar power satellite architectures; as a result, the study attempted to identify these opportunities and assess potential connections between international lunar exploration programs now being undertaken and SSP systems. The IAA study was initiated in Spring 2008 and concluded in Fall 2010 with the completion of this report.

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A Study Results Summary is provided at attachment 1.

Study Findings and Recommendations

Overview

The successful development and market-competitive deployment of any major new energy technology requires decades to accomplish. Historical examples include coal, oil, electricity, natural gas, etc. It is likely that space solar power (SSP) will be no different. As noted, the original invention of SPS occurred in the late 1960s, and the advancement of specific (e.g., wireless power transmission) and relevant technologies (e.g.,reusable launch vehicles) has continued during the subsequent 40 years. As of 2010, the fundamental research to achieve technical feasibility for the SPS was already accomplished. Whether it requires 5-10 years, or 20-30 years to mature the technologies for economically viable SPS now depends more on (a) the development of appropriate platform systems concepts, and (b) the availability of adequate budgets. Based on the results of the IAA assessment of the concept of solar energy from space, the Academy study group makes the following findings and offers the associated recommendations regarding the concept of future space solar power for markets on Earth.

Findings

Finding 1: Fundamentally new energy technologies clearly appear to be needed during the coming decades under all examined scenarios – both to support continued (and sustainable) global economic growth, and for reasons of environmental/climate concerns. Solar energy from space appears to be a promising candidate that can contribute to address these challenges.

Finding 2: Solar Power Satellites appear to be technically feasible as soon as the coming 10-20 years using technologies existing now in the laboratory (at low- to moderate- TRL) that could be developed / demonstrated (depending on the systems concept details).

Finding 2a: There are several important technical challenges that must be resolved for each of the three SPS systems types examined by the IAA study.

Finding 2b: The mature (high-TRL) technologies and systems required to deploy economically viable SPS immediately do not currently exist; however, no fundamental breakthroughs appear necessary and the degree of difficulty in projected R&D appears tractable.

Finding 2c: Very low cost Earth to orbit transportation is a critically needed supporting infrastructure in which new technologies and systems must be developed to establish economic viability for commercial markets.

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Finding 3: Economically viable Solar Power Satellites appear achievable during the next 1-3 decades, but more information is needed concerning both the details of potential system costs and the details of markets to be served.

Finding 3a. SPS do appear economically viable under several different scenarios for future energy markets, including potential government actions to mediate environment/climate change issues.

Finding 3b. The economic viability of particular Solar Power Satellite concepts will depend upon both the markets to be served, and the successful development of the technologies to be used (including required levels of performance (i.e., key figures of merit for SPS systems).

Finding 3c: The potential economic viability of SPS has substantially improved during the past decade as a result of the emergence both of government incentives for green energy systems, and of “premium niche markets”.

Finding 3d. Establishing the economic viability of SPS will likely require a step-wise approach, rather than being achieving all at once –in particular SPS platform economics, space transportation economics, in-space operations economics, integration into energy markets, etc., will likely require iterative improvements to build confidence and secure funding for further developments.

Finding 3e. Given the economic uncertainties in developing and demonstrating SPS technologies and systems and the time required, it is unlikely that private sector funding will proceed alone; i.e., government involvement and funding support is likely needed.

Finding 4: An in-depth end-to-end systems analysis of SSP/SPS is necessary to understand more fully the interactions among various systems / technologies for different concepts and markets; however, no such study has been performed since the conclusion of NASA’s Fresh Look Study in 1997.

Finding 4a: Scenario-based study approaches can be extremely useful in examining prospective markets for visionary future systems such as SPS, but must provide sufficient detail to enable one to distinguish from among various SPS systems options.

Finding 4b: Special attention appears needed to refresh understanding of prospects for space applications of SSP systems and technologies, with attention to the enabling role that low-cost electrical power in roughly the megawatt range could play for ambitious future space missions and markets.

Finding 5: Low-cost Earth-to-orbit transportation is an enabling capability to the economic viability of space solar power for commercial baseload power markets.

Finding 5a: Extremely low cost ETO transportation systems appear to be technically feasible during the coming 20-30 years using technologies existing in the laboratory now (at low- to moderate- TRL) that could be developed / demonstrated (depending on the systems concept details). However, the technologies required for this future space capability are not sufficiently mature for system development to begin at present.

Finding 5b: Acceptable ETO systems for future SPS must be "environmentally benign" – i.e., space transportation infrastructures to launch the satellites cannot result in harmful pollution of the atmosphere.

Finding 6: Systems studies are not enough. Technology Flight Experiments (TFEs) to test critical technology elements and Technology Flight Demonstrations (TFD) that validate SPS systems concepts to a high level of maturity ("TRL 7"‡) appear to be essential in order to build confidence among engineers, policy makers, and the public and allow space solar power technology maturation and SPS deployment to proceed.

Finding 6a: The International Space Station (ISS) appears to represent a highly attractive potential platform at which various SSP and related technology flight experiments (TFEs) could be performed.

Finding 6b: Free flying spacecraft appear to be an attractive option for selected SSP TFEs and systems level demonstrations.

Finding 7: Architectural approaches that most efficiently and seamlessly integrate energy delivered from SPS into existing terrestrial energy networks are likely to be the most successful. (The same is true for any transformational new energy technology.)

Finding 8: The SPS concept is sufficiently transformational and entails enough technical uncertainties such that major systems level in-space demonstrations will be necessary to establish technical feasibility, engineering characteristics and economical viability before any organization is likely to proceed with full-scale development.

Finding 8a. The likely investment in technology maturation, hardware development and system deployment for a very low-cost, highly reusable space transportation (HRST) system will require some 10s of billions of dollars ($, US). If the SPS concept is the sole – or even a significant – market justification for such a development, then it is likely that a large-scale, pilot plant type demonstration of the SPS to be launched will be required prior to a government and/or commercial commitment to fielding HRST systems or supporting infrastructure.

Finding 8b. In-space systems and infrastructures that will support SPS deployment, assembly, servicing, etc. will be intimately related to the detailed designs and characteristics of the SPS platform, and to the design of supporting ETO systems (see Finding above). Such in-space systems will likely need to be developed and demonstrated in tandem with, if not prior to, the implementation of an SPS pilot plant demonstration.

Finding 9: A variety of key policy-related and regulatory issues must be resolved before systems-level demonstrations – particularly space based tests – of SPS and WPT can be implemented.

Finding 9a. Spectrum management is an issue of particular importance that must be addressed early due to the time-consuming international processes that are in place vis-à-vis use of the electromagnetic spectrum and orbital slot allocations.

Finding 9b. A number of operational issues that are related to international cooperation and coordination, including WPT transmission safety requirements, orbital debris generation and management, etc., must also be addressed early.

Finding 9c. Policy related and regulatory issues will require considerable time to resolve, making the need to begin discussions in a timely way very pressing, particularly for SPS and related technology in-space tests and demonstrations.

Recommendations

Based on the results of the IAA study group assessment of the concept of space solar power, the Academy offers the following recommendations for the consideration of the international community.

Recommendation 1: Both government-supported and commercially funded SSP systems analysis studies should be undertaken that have sufficient end-to-end breadth and detail to fully resolve the R&D goals and objectives that must be achieved to establish the viability of SSP.

Recommendation 1a: Where possible, SSP and related systems analysis studies recommended should be coordinated among various countries and between industry and government agencies.

Recommendation 1b: It is recommended that focused and rigorous market studies should be included in future integrated /end-to-end SPS systems studies; a scenario-based approach should be considered as a key element of such studies. In addition, such studies should include more detailed analysis of "premium niche markets" in various countries and/or for specific customers.

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Recommendation 1c: Future systems analysis / market studies should examine explicitly the potential integration of SPS / WPT concepts into existing (or projected) terrestrial energy networks. These studies should involve additional non-aerospace sector experts (for example, from the energy and utility sectors).

Recommendation 1d: Future systems studies should examine in greater detail the comparison of SPS with other energy technologies for various market opportunities, including both nearer-term technologies (such as ground solar) and farther term technologies (such as fusion).

Recommendation 1e: Future systems studies should address a range of detailed issues, including policy and economic considerations, GEO orbital slot availability, operational issues (e.g., in-space assembly / infrastructure, SPS reliability and failure considerations), and orbital debris. These studies should examine Earth-to-orbit and in-space transportation issues carefully.

Recommendation 1f: Future systems studies should place appropriate emphasis on better life cycle cost (LCC) estimates of SPS, including examining the impact of new models of large volume production of space systems.

Recommendation 2: Future economic analyses should examine the potential role of non-space related government and international funding agencies in contributing to the development of SPS.

Recommendation 3: Government and commercial organizations should consider undertaking SSP and related technology R&D, including platform systems and supporting infrastructures (e.g., ETO, in-space transportation, in-space operations).

Recommendation 3a: The International Space Station (ISS) should be considered as a potential platform on and from which a number of useful SSP and related technology flight experiments and tests could be performed.

Recommendation 3b: Specific space solar power technology R&D activities – such as ground demonstrations and technology flight experiments – should be planned so as to best advance the overall state-of-the-art for SSP, and the results communicated as broadly as possible (consistent with restrictions due to intellectual property or government regulations).

Recommendation 3c: It is recommended that as studies and technology R&D go forward that are directed toward SPS, WPT and related applications, there should be supporting research concerning WPT health and safety issues.

Recommendation 3d: SSP technology development efforts should explicitly seek prospective nearer-term applications in support of international space goals and programs, such as space exploration.

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Recommendation 3e: Where possible, governments and commercial sector players should consider the formation of public-private partnerships to implement SSP technology development efforts; government agencies in particular should take steps to enable to encourage the formation of such partnerships.

Recommendation 4: The necessary policy and regulatory steps to enable SPS/WPT and related R&D to be conducted – leading to systems-level demonstrations – should be undertaken in the near term by government, commercial and other interested organizations.

Recommendation 4a: It is recommended that particular attention should be paid to the allocation of spectrum for WPT technology development efforts and later system applications.

Recommendation 4b: It is recommended that the formation of Public-Private Partnerships to pursue SSP technology maturation and system developments should be considered and encouraged where appropriate.

Recommendation 5: International organizations, such as the International Academy of Astronautics, should play a constructive role in fostering and guiding future SSP/SPS studies, technology developments and policy deliberations.

Attachment 1

IAA Study Results Summary

The following paragraphs briefly summarize the key results of the study, organized by the individual chapters.

Solar Power Satellite Systems Concepts (Chapter 2; SG2)

Three highly promising SPS platform concepts were examined in some detail by the IAA study; the results of this examination provide a framework for the remainder of the report, including the technology assessment, market assessment, etc. All three of the cases examined were geostationary Earth orbit-based SPS concepts; these were: (1) an updated version of the microwave wireless power transmission (WPT) 1979 SPS Reference System concept, involving large discrete structures (e.g., solar array, transmitter, etc.) assembled by a separate facility in space; (2) a modular electric / diode array laser WPT SPS concept, involving self-assembling solar power-laser-thermal modules of intermediate scale; and (3) a extremely modular microwave WPT SPS "sandwich structure" concept, involving a large number of very small solar power-microwave-thermal modules that would be robotically assembled on orbit. Several alternative SSP concepts were also identified but not analyzed, including the low Earth orbit-based "Sun Tower" SPS concept, lunar solar power, and others.

The three SPS concept types examined by the IAA study group span effectively a wide range of SSP architecture choices and options. These several systems types include a number of similarities and differences, depending on the specific topic of interest within the trade space. As a result of its assessment, the IAA study group concurs with the findings of previous groups, including the US National Academy of Sciences: Solar Power Satellites are technically feasible. There are no fundamental technical barriers that would prevent the realization of large scale SPS platforms during the coming decades. However, as noted, questions remain as to the economic viability of SPS. An early result of the IAA study evaluation of the SPS trade space was the selection of only three basic systems types for detailed examination. (The limited time and resources available to the Academy study necessitated this early down selection.) The overall results of the study suggest that this early decision was appropriate; however, alternative SPS systems / architecture concepts may warrant future consideration.

SPS Supporting Systems (Chapter 3; SG2, SG4)

There are a number of extremely important systems other than the SPS platform itself that must be pursued to provide essential support for the development and operation of SPS platforms. The supporting systems that were examined included (1) Earth-to-orbit (ETO) transportation; (2) affordable in-space transportation; (3) space assembly, maintenance and servicing; and, (4) ground energy and interface systems. A longer term supporting system option was also examined: (5) in-space resources and manufacturing.

The three SPS concept types examined together would involve a wide variety of supporting system choices and options. These systems include a range of similarities and differences, depending on the specific topic of interest within the trade space. As in the case of the SPS platform itself, the group found that there are no fundamental "show-stoppers" among the required supporting systems (i.e., no technical barriers that would prevent the realization of large-scale SPS platforms during the coming decades). However, as noted, there are key challenges in achieving the very low cost operations needed to achieve economically viable SPS. The most critical of these was the essential requirement for very low cost ETO transport.

Technology Readiness and Risk Assessment (Chapter 4; SG2, SG7)

A summary assessment was developed of the key technologies required for primary candidate SPS platform types and the associated supporting systems. This technology readiness and risk assessment (TRRA) provides the basis for the subsequent R&D roadmap (Chapter 8). The approach used to implement the TRRA was based on the technology readiness level (TRL) scale (developed by NASA in the 1970s), augmented by formal considerations of the expected research and development (R&D) degree of difficulty (R&D3), and a judgment of the systems-level importance of a particular technology advancement to a given SPS type.

The TRRA results are summarized in Chapter 4 (Table 4-2, Table 4-3 and Table 4-4). Overall, it was found that the updated 1979 SPS Reference System is the highest risk and lowest readiness option, while the highly modular microwave "sandwich structure" SPS was the lowest risk and highest readiness. The modular electric laser SPS option was in-between the two microwave concepts. The technology readiness and risk assessment performed was highly simplified due to the scope of the overall study; a more rigorous assessment requires a detailed systems analysis of various SPS platform options, as well as various supporting systems (e.g., ETO transportation).

SSP / SPS Policy and Other Considerations (Chapter 5; SG1, SG6)

The study group examined various important policy, regulatory and legal considerations vis-à-vis SPS. One such topic is that of spectrum allocation: working through the international community of interest to secure a portion of the electromagnetic spectrum that might be used for wireless power transmission. Another topic of importance is that of identifying strategies for international coordination and cooperation in SPS development and operations.

Some of the important policy considerations examined included (1) the overall international regime (e.g., the Outer Space Treaty) that will comprise the framework for space solar power development; (2) various international legal requirements (e.g., the ITU, and space debris mitigation guidelines) with which SPS must comply; and, (3) relevant national legislation and regulations (such as ITAR in the US and similar rules in other countries).

Detailed topics examined included (1) WPT beam health and safety considerations; (2) WPT spectrum allocation and management; (3) space debris considerations; and, (4) potential weaponization concerns. None of these factors appears to be insurmountable for SPS R&D eventual deployment. However, each of these (and others) will require appropriate attention during the early phases of SPS development. This is particularly true with respect to issues related to WPT beam safety and possible weaponization. Finally, it is clear that the development of SSP technologies and systems could yield significant benefits for a wide range of non-SPS applications – in space and on Earth. Some of the novel future space applications of space solar power technologies include: power beaming to a lunar or Mars outpost from and orbital power plant; high-power solar electric power and propulsion for Earth-Moon and interplanetary transportation; and, the enabling of revolutionary new space capabilities such as robotic in-space assembly, maintenance and servicing, modular communications satellites, and others. Novel classes of Earth orbiting satellites and terrestrial applications of SSP technologies would likely also result.

SPS Market Assessment and Economics (Chapter 6; SG1, SG5)

In looking toward rest of this century, it is obviously impossible to predict with confidence how the many issues that will frame the market for SPS will unfold. In order to provide a reasonable, but not exhaustive framework, the IAA study group identified four strategic scenarios for the future that would greatly affect potential SSP/SPS markets and economics. These were: (1) Scenario Alpha – "Business as Usual Works Out" (i.e., conventional and/or available renewable energy sources prove to be capable of meeting future demand, and no adverse changes occur in Earth's climate); (2) Scenario Beta – "The Frog Gets Cooked" (i.e., the global economy does not deploy massive new renewable sources, and dramatic negative changes in Earth's climate result); (3) Scenario Gamma – "Fossil Fuels Run Out" (i.e., the global economy does not deploy massive new renewable sources and peak oil, peak gas and peak coal occurs sooner than expected); and, (4) Scenario Delta – "Green Policies Work" (i.e., the deployment of new renewable energy sources is accelerated and succeeds in forestalling changes to Earth's climate result).

Each of the four Scenarios described was intended to capture a particular possible aspect of the future – and to provide a tangible context for laying out more detailed architectures and concepts-of-operations for future Solar Power Satellites. Specific architectures for SPS (e.g., lower cost, larger-scale RF systems versus high-cost, smaller-scale laser systems) may then be compared in terms of their potential to meet the energy requirements of the several Scenarios. The characterizations of possible future energy costs presented here **are not** intended as literal / quantitative forecasts; instead they are formulated to suggest what sorts of SPS systems might be more or less profitable depending on the Scenario in question.

Based on these cases, the most dramatic increases in the cost of primary baseload power might be expected in the later term if available supplies of key fossil fuels begin to drop behind market demand earlier in this century rather than later. However, strong "green energy" policies could lead to the most favorable nearer-term environment in such primary markets. These policies would result in higher prices in the nearer term, but avoid the market risks of either fossil fuel depletion earlier than hoped (Scenario Gamma) or significant climate change (Scenario Beta) in the mid-to-latter half of the century.

In all cases, premium niche markets (PNMs) that may command higher prices for energy represent attractive options for space solar power. Remote and/or leveraged commercial markets appear particularly attractive in all cases, but especially in the case of Scenario Gamma ("Fossil Fuels Run Out") in which conventional fuels are depleted, but no special preparations are made early enough to offset the resulting energy price increases.

Preliminary Systems Analysis Results (Chapter 7; SG2, SG5)

Although the scope of the IAA study did not permit detailed modeling of the SPS concept, nevertheless some highly preliminary systems analyses could be conducted using high level relationships and selected aspects of the physics that will bound the engineering challenges to be resolved. Using this methodology, the study group conducted analyses of various SPS, and supporting systems options. The set of systems-technology considerations ranged from the physics of wireless power transmission to thermal management, from ETO launch capability to impacts of using expendable versus reusable vehicles. Some of the key SPS figures of merit (identified in Chapter 6) also were examined.

As a result, selected strategic and more detailed goals for future SSP technology R&D were identified. Each of the three SPS concepts were assessed in terms of these systems-technology considerations. At the end, it appeared that there are clear advantages for more modular, higher end-to-end efficiency systems concepts – particularly for large-scale commercial baseload power. And, the highly modular microwave WPT sandwich SPS concept appears the most attractive overall.

However, it is clear that additional, more analytically rigorous systems analysis studies are needed to better characterize the complex systems technology-market issues that space solar power entails.

International SPS Strategic Roadmap (Chapter 8; SG8)

The IAA study group synthesized a high-level roadmap for SSP/SPS that details a prospective path forward for the international space and energy community. This road map reflects the belief that several iterative stages of systems study and focused technology R&D will be necessary to enable the deployment of economically viable solar power satellites. The roadmap comprises several types of activities including:

• SSP Advanced Systems Studies and Basic Technology Research;

• SSP-Relevant Technology Research and Development;

• SSP Sub-System & Component-Level Technology Flight Experiments;

• Major Sub-System / System-Level Technology Demonstrations (including both Ground and Flight demonstrations);

• Design, Development & Demonstrations of SSP Systems (including SPS Pilot Plants, Supporting Infrastructures, Secondary Space Applications, and Terrestrial Spin-Offs); and,

• Solar Power Satellite Development, Deployment and Operations

A broad range of technical challenges must be addressed in order to establish the economic feasibility of SPS, and – if appropriate – to subsequently proceed with their development. It is possible that a single government or major company might surmount these challenges.

However, it seems more likely that timely success would result from cooperation in accomplishing R&D objectives among governments, among industry players and among a broad range of government, corporate and academic organizations. A variety of tests and demonstrations of one key SPS technology – wireless power transmission – have been performed since the 1960s. Many of these tests have involved component technologies that are not directly relevant to validating the economic viability of SSP. Moreover, selected early demonstrations have been performed by various organizations almost as a means of "getting their feet wet" – i.e., in learning the basics of WPT and/or SPS. Unfortunately, the next steps in moving higher in the TRL scale require considerably greater funding (i.e., from the lower left to the upper right in the roadmap); these key steps have not yet been taken. Timely communication of plans and results from SPS technology R&D activities is crucial to coordinated progress. The ongoing Power Symposium, organized annually under the auspices of the International Astronautical Federation

(IAF), has served a highly useful role in this regard. Similarly, periodic conferences dedicated to SPS and WPT have been held over the past 20+ years in various countries (e.g., WPT 1995, SPS 2004, etc.); these have been highly useful in promoting international dialog and coordination of SSP efforts.

As noted above, it was the consensus of the IAA study group that SSP systems are technically feasible. However, the successful development of the SPS concept – and the determination of markets might be served economically – cannot be accomplished without investments in systems level, end-to-end studies, ground and flight demonstrations at higher TRL levels, and eventually the launch of major sub-scale SPS pilot plant demonstrations. The preliminary international roadmap for SSP is not highly specific –it does not prescribe a specific budget, nor does it involve a specific schedule. However, it does provide a tractable framework for future SPS related activities by indicating a logical sequence for various steps, and the conceptual relationships among those steps. Moreover, it is the consensus of the IAA study group that significant progress could be accomplished during the next 10-15 years – leading to a large, but sub-scale SPS pilot plant.

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