International Academy of Astronautics Results of the First International Assessment of Space Solar Power

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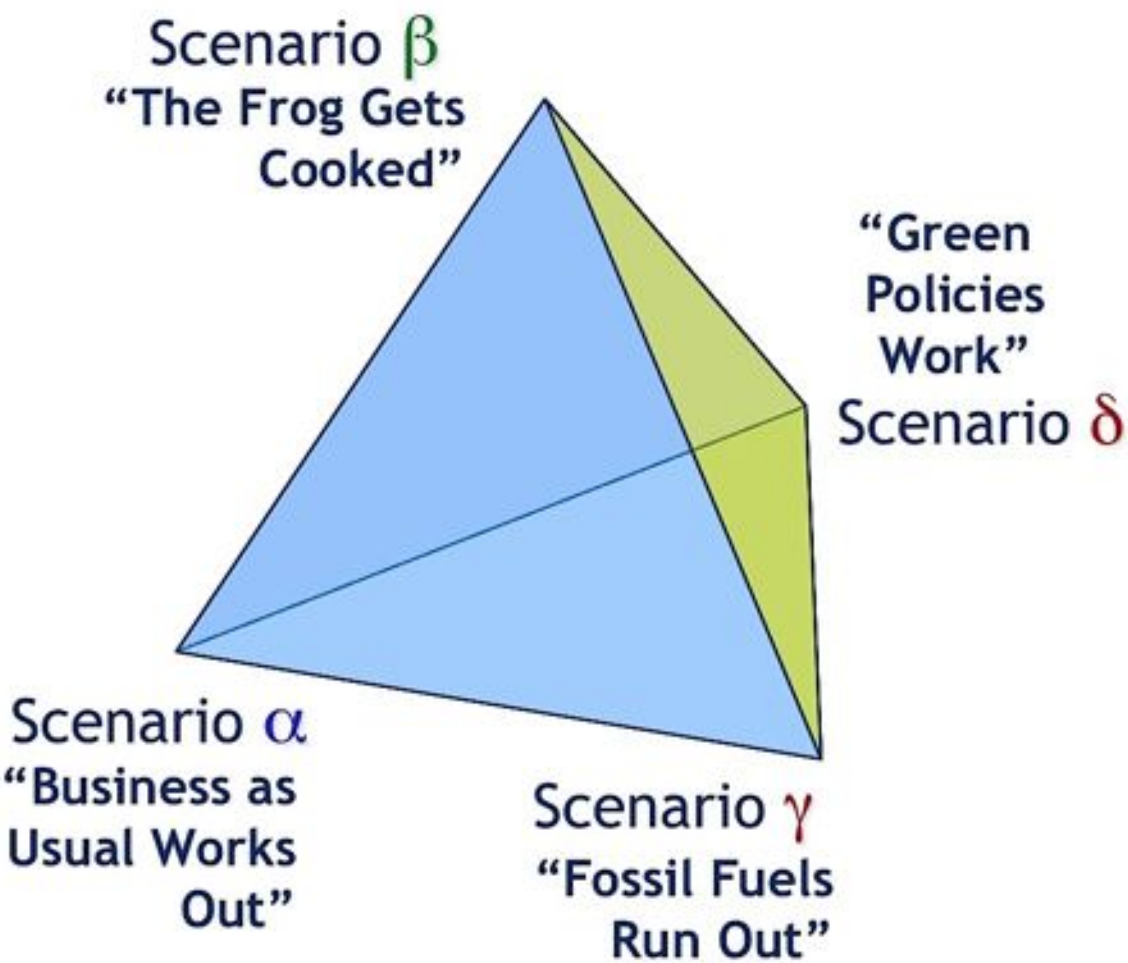
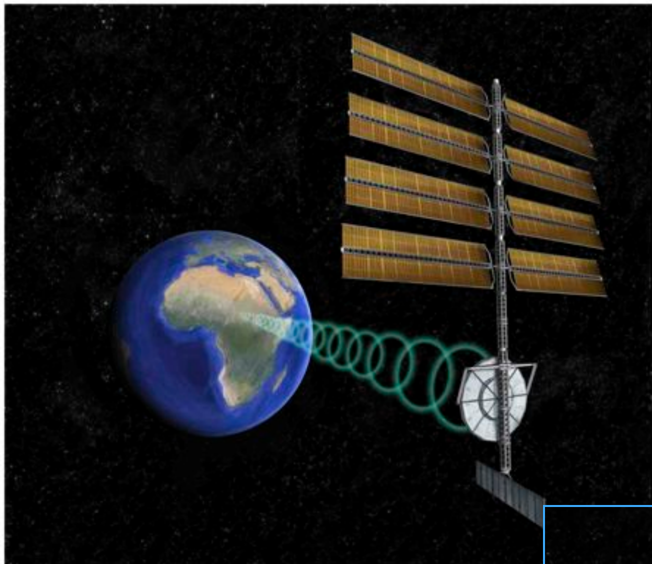
IAA – First International Assessment of SSP OVERVIEW

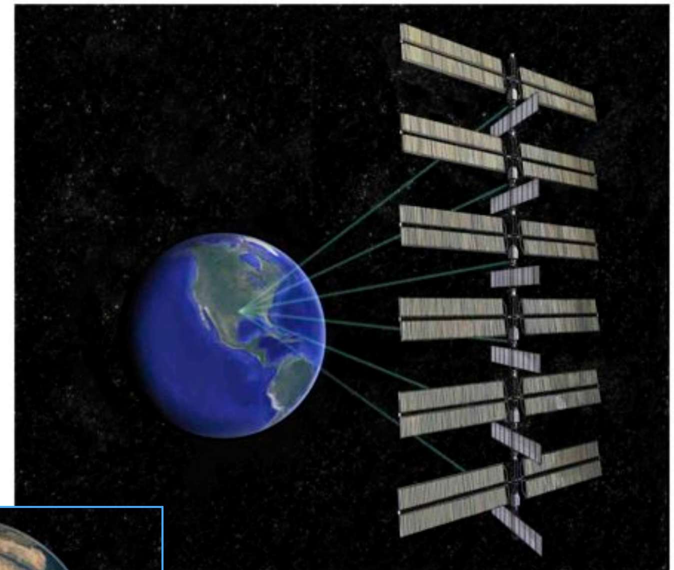
- During 2008-2010, the International Academy of Astronautics conducted the first International Assessment of the concept of Space Solar Power
- Primary Goals…
  - Determine what role solar energy from space might play in meeting the rapidly growing need for abundant and sustainable energy during the coming decades,
  - Assess the technological readiness and risks associated with the SSPS concept, and (if appropriate) …
  - Frame a notional international roadmap that might lead the realization of this visionary concept.
- In addition…
  - Identify and evaluate opportunities for synergies (if any) between the prospective benefits of SSP technology and systems for space missions and SSPS for terrestrial markets.
  - Identify the opportunities to introduced extraterrestrial materials into an SSPS industry and assess potential connections between international lunar exploration programs now being undertaken and SSPS.

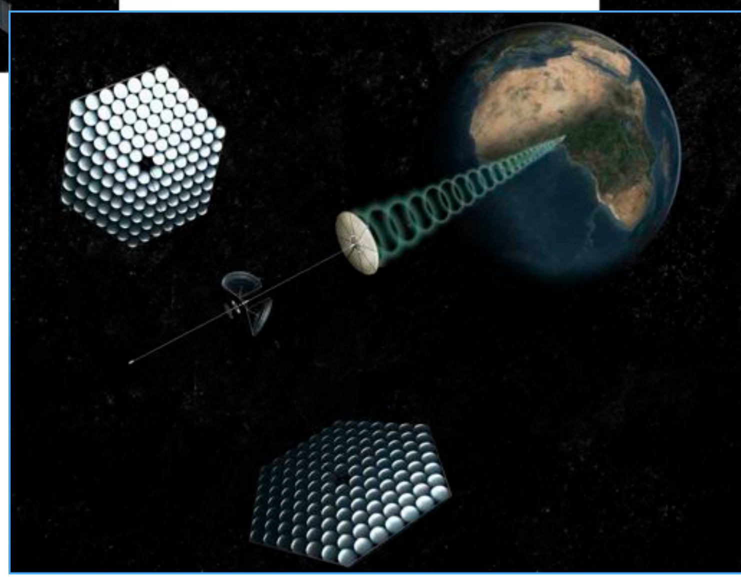
IAA Study: Space Solar Power
GLOBAL ENERGY/ENVIRONMENT SCENARIOS



IAA Study: Space Solar Power
THREE CASES







Artwork:
SpaceWorks Engineering Inc.

Summary Evaluation of SPS Concept Types
TECHNICAL CRITERIA

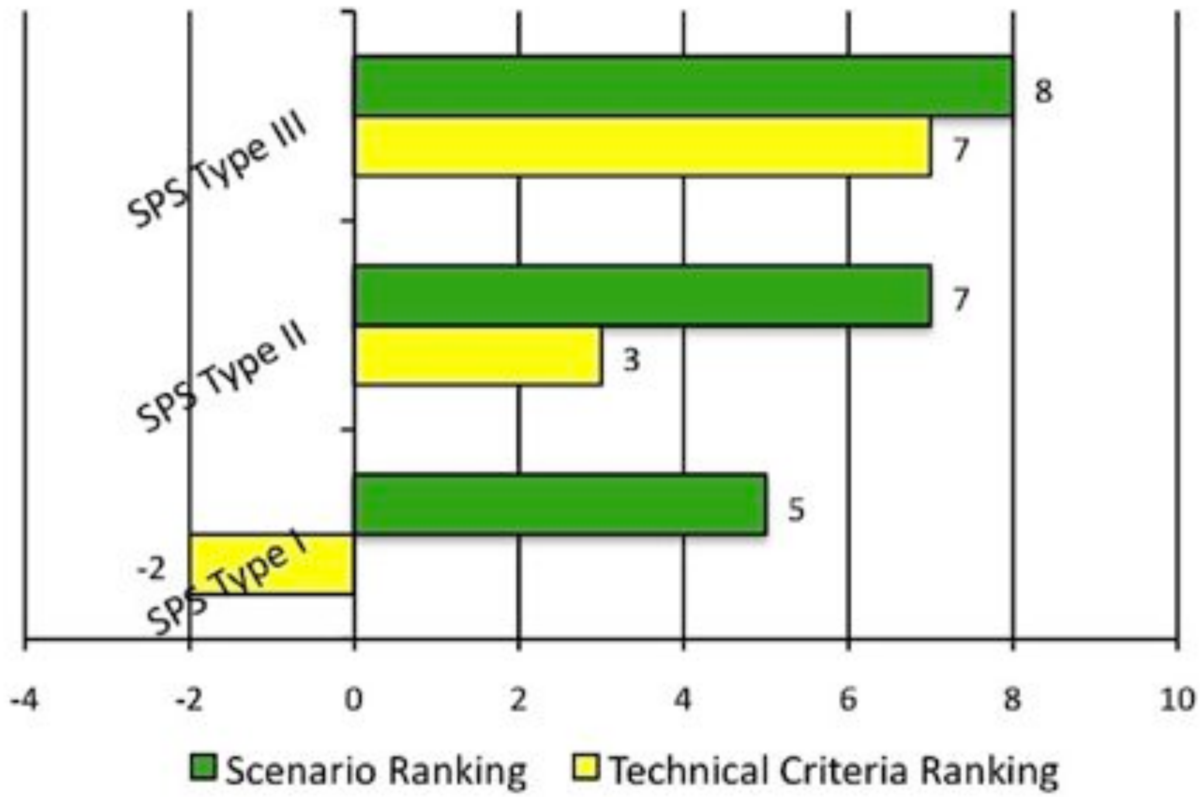
		SPS Type I	SPS Type II	SPS Type III
TECHNICAL CRITERIA		"RF Classic"	Modular Electric Laser	RF Modular Sandwich
1	Cost to First Power	-2	+2	+1
2	Life Cycle Cost / Economic Prospects	+2	0	+2
3	Technology Readiness / Risk	-1	+1	+2
4	Expected Ease of Tech. Maturation	0	+1	+2
5	Policy Issues (Scope Difficulty)	-1	-2	-1
6	Non-SPS Applications (Variety/Benefit)	0	+1	+1
	Summary Assessment	-2	+3	+7

Summary Evaluation of SPS Concept Types
SUMMARY EVALUATION – VS. SCENARIOS

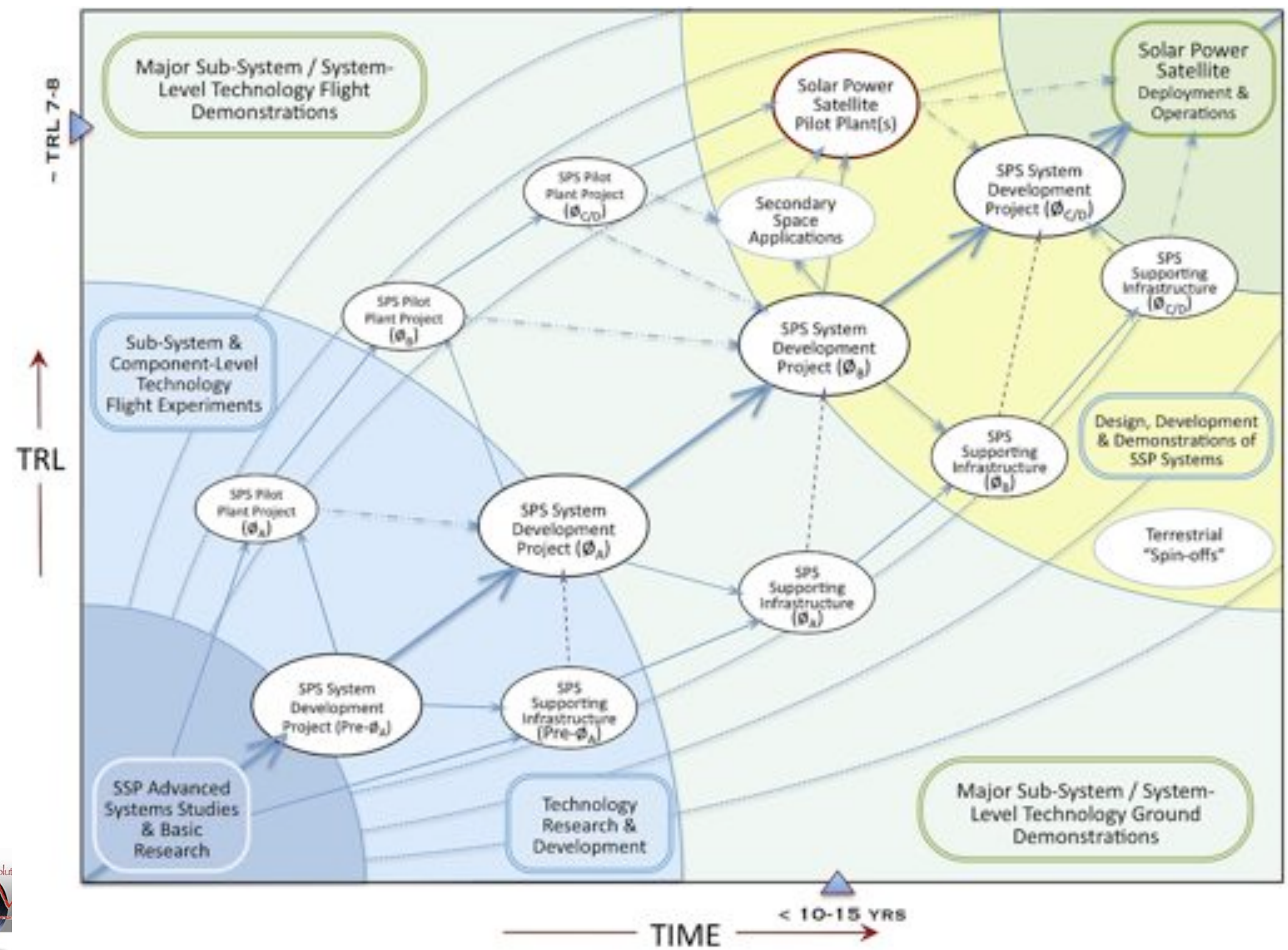
Table 7-9 Summary Comparison of SPS Concepts - Evaluation vs Scenarios

		SPS Type I	SPS Type II	SPS Type III
SCENARIO ASSESSMENT		"RF Classic"	Modular Electric Laser	RF Modular Sandwich
Alpha	"Business as Usual Works Out"	0	2	2
Beta	"The Frog Gets Cooked"	2	2	2
Gamma	"Fossil Fuels Run Out"	2	2	2
Delta	"Green Policies Work"	1	1	2
Summary Assessment		5	7	8

Overall SPS Concept Evaluation Results



IAA Recommended SSP Technology Roadmap



FINDINGS (1 of 2)

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

FINDINGS (2 of 2)

- **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 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 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

RECOMMENDATIONS

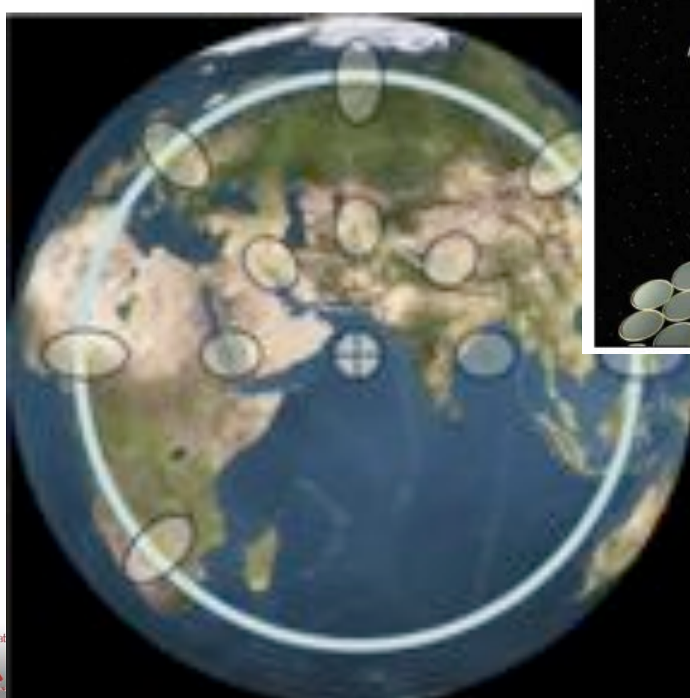
- **Recommendation 1**: Both government-supported and commercially funded SSP systems analysis studies should be undertaken that have sufficient end-to-end breadth and detail to fully resolve the R&D goals and objectives that must be achieved to establish the viability of SSP.
- **Recommendation 2**: 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 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 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

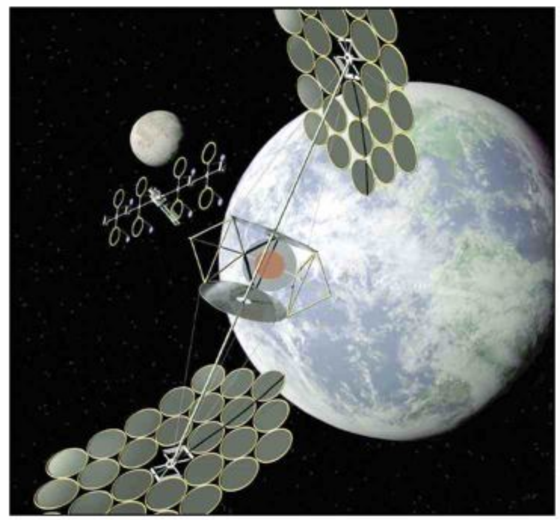
Back Up Slides

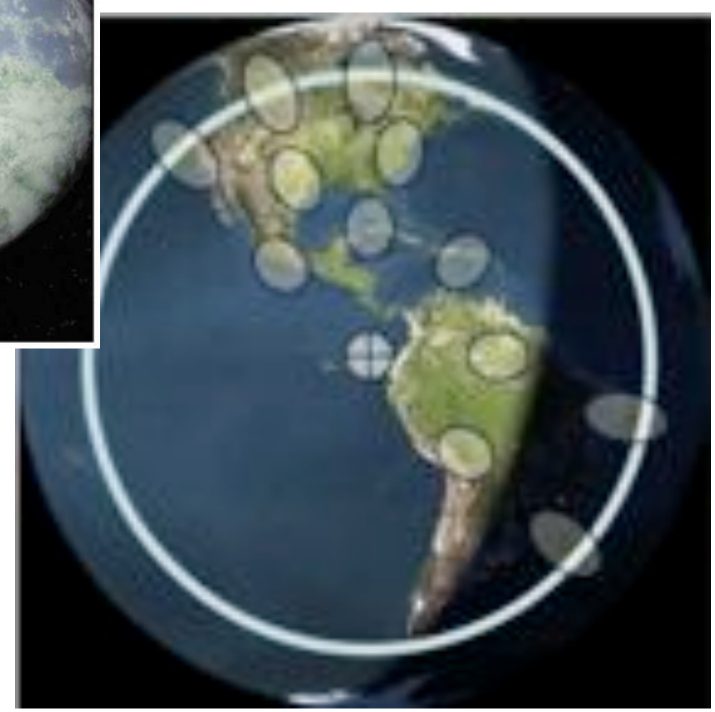
The Vision of Space Solar Power

Affordable and Abundant Solar Power in Space (Up to MW and Greater…)

Clean, safe, affordable and virtually limitless solar energy On Demand, 24/7

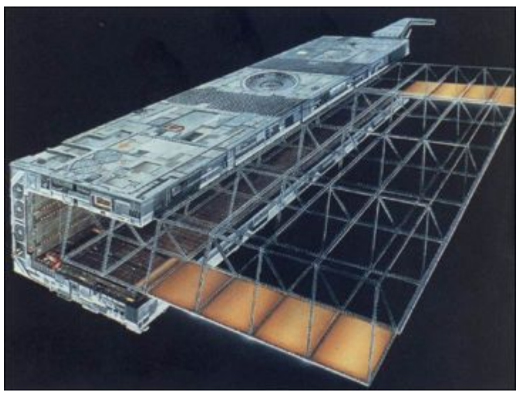


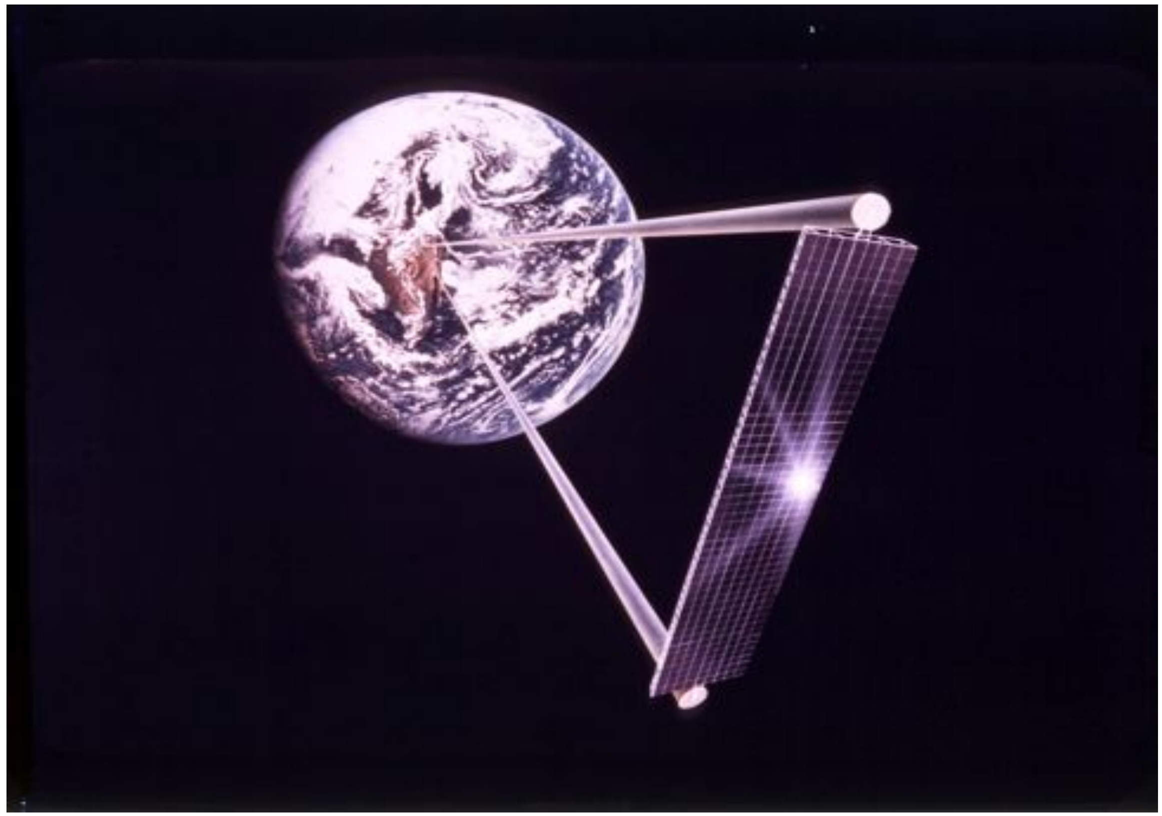




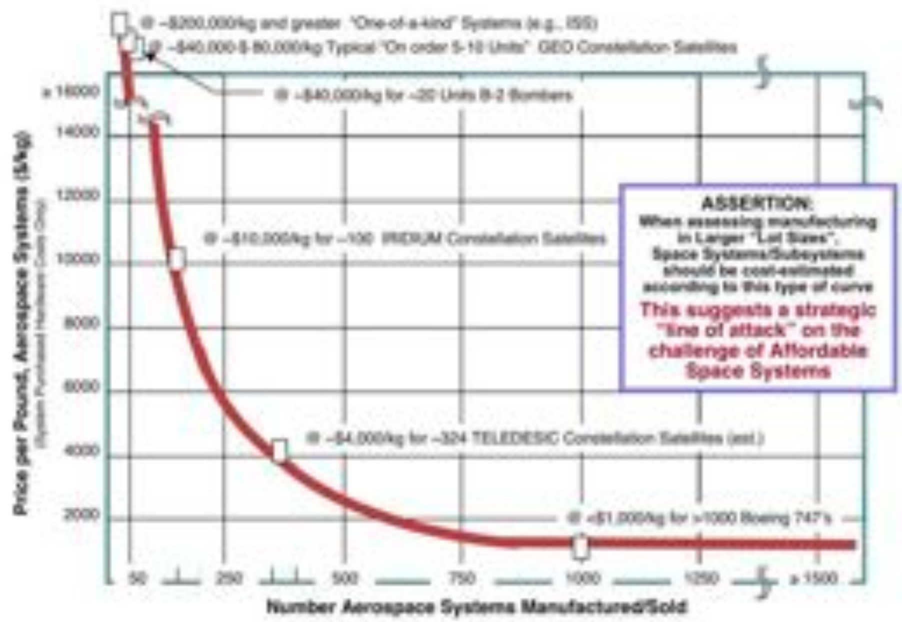
SSP Foundations: 1980

1979 SPS Reference Concept in GEO

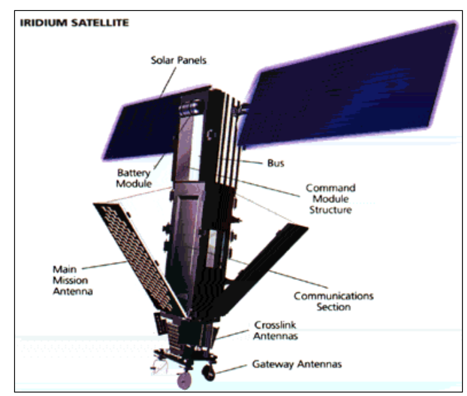




A New Approach to Large Space Systems
Mass Production of Highly Modular Elements



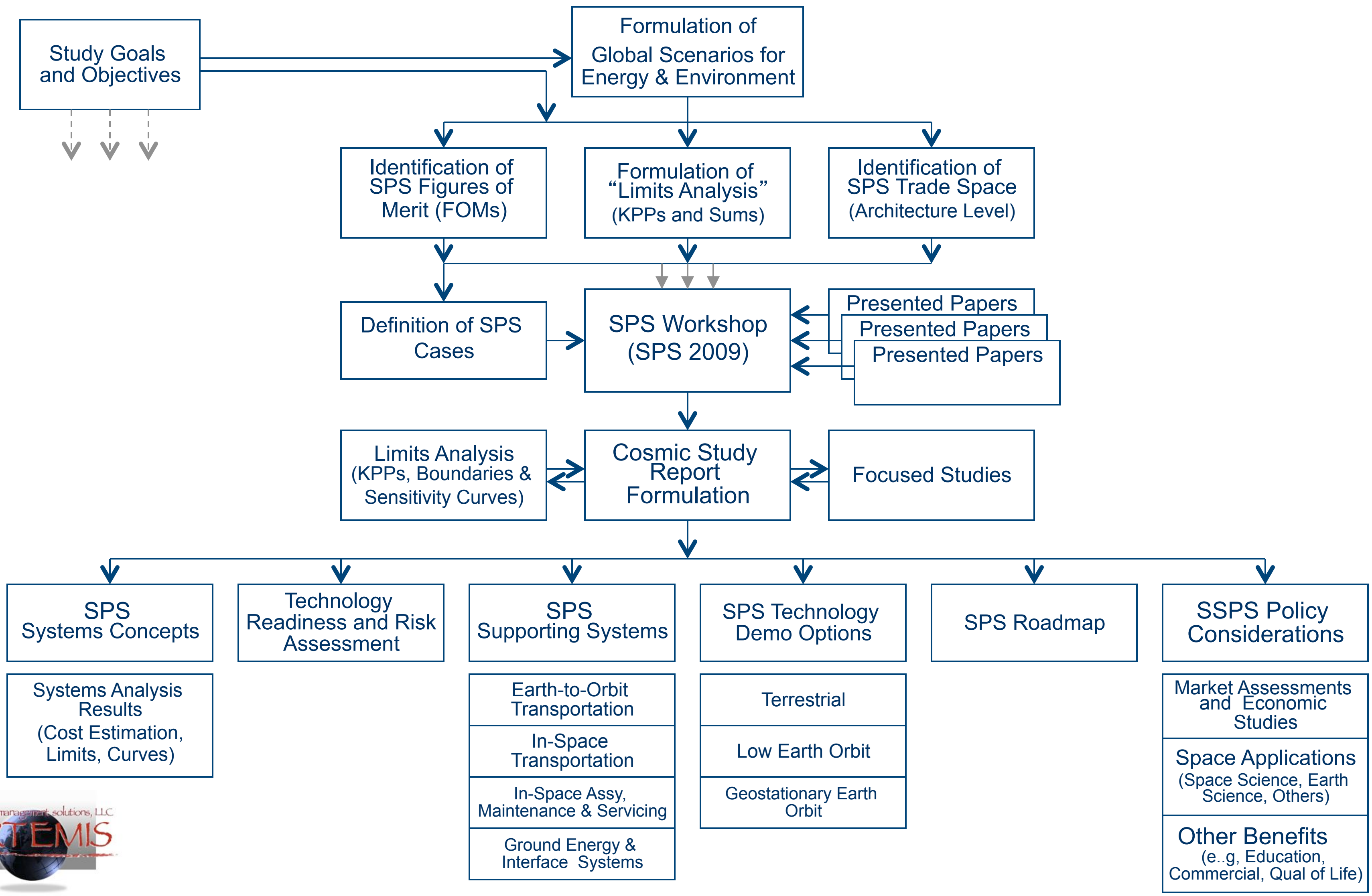
- Large systems, assembled out of identical intelligent (and reconfigurable) elements, have the potential to radically reduce the cost of space operations--for the right applications
- Assemble SPS from a small number (e.g., 5-7) of distinct systems modules, these mass produced…



innovation management solutions, LLC
ARTEMIS

Recent SSP/WPT Progress
Wireless Power Transmission Tests (2008-2010)

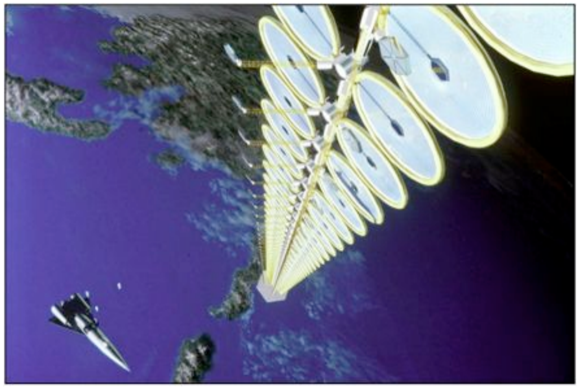
Study Approach

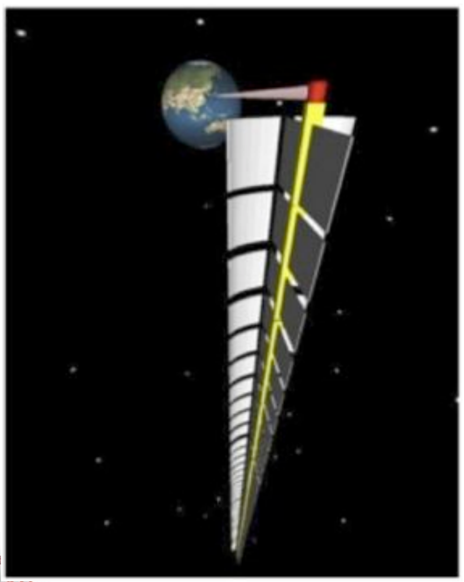


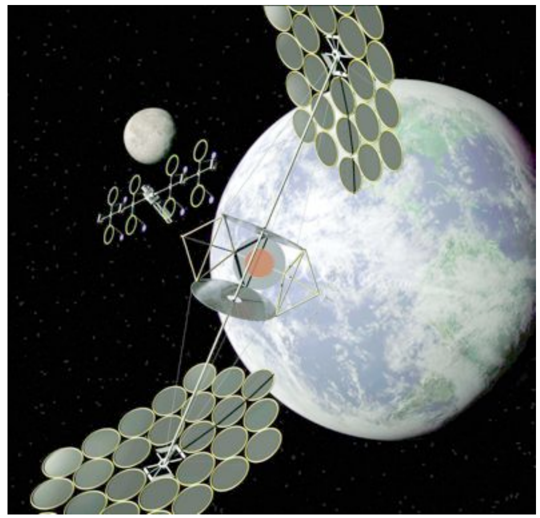
SSP Reference Mission(s)

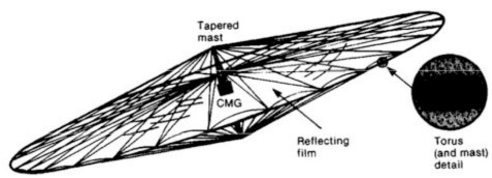
	Targeted SPS Engineering & Economic GOALS & Characteristics	SPACE SOLAR POWER REFERENCE MISSION(S)		
		SPS Reference Mission Initial Full-Scale Solar Power Satellite	**Pathway Mission 2** Solar Power Satellite Pilot Plant	**Pathway Mission 1** Sub-Scale SSP Technology Demonstration
PRIMARY GOALS	SSP System "Purpose(s)"	**Operational SPS Delivering "Baseload" Power to Earth Market**	SSP System Demo to TRL 7 Post-Demo SPS System Delivering "Niche" Power	SSP Technology Demonstration to TRL 5-6
PRIMARY GOALS	Power Delivered (from WPT Receiver)	**> 1 GW**	> 10 MW	> 10-100 kW
PRIMARY GOALS	Specific Price for SPS Energy	**10¢ - 50¢ / kW-hr**	$1.00 - $5.00 / kW-hr	N/A
SECONDARY CHARACTERISTICS	On-Board Power (to WPT Transmitter)	< 2-4 GW Power @ > 200-400 W/kg-SPS	< 20-80 MW @ 100-200 W/kg-SPS	< 100-400 kW
SECONDARY CHARACTERISTICS	Orbital Location	GEO	LEO or GEO	LEO
SECONDARY CHARACTERISTICS	SPS Hardware Systems	> 20-30 years Lifetime @ < $500-$1,500/kg	> 10-15 years Lifetime @ < $2,000-$4,000/kg	> 3-5 years Lifetime
SECONDARY CHARACTERISTICS	Earth-to-Orbit Transport (to LEO)	SPS-Specific Launcher @ < $500-$1,500/kg	Existing or New Launcher @ < $1,000-$3,000/kg	Existing ELV @ 1-3 launches
SECONDARY CHARACTERISTICS	In-Space Transport (LEO to GEO)	New Technology LEO-GEO @ < $1,000-$3,000/kg	New Technology LEO-GEO @ < $2,000-$6,000/kg	Existing Technology (LEO Maneuvering)
SECONDARY CHARACTERISTICS	In-Space Assembly / Operations	Fully Autonomous Ops @ < $500-$1,500/kg	New Technology Demo @ < $1,000-$3,000/kg	Improved SOA (Potential EVA Assist)

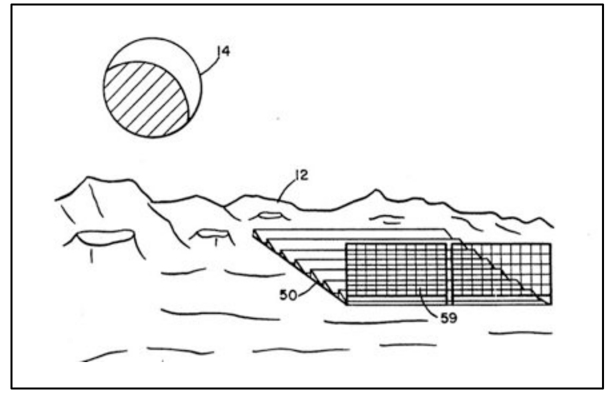
Other SSP Concepts…

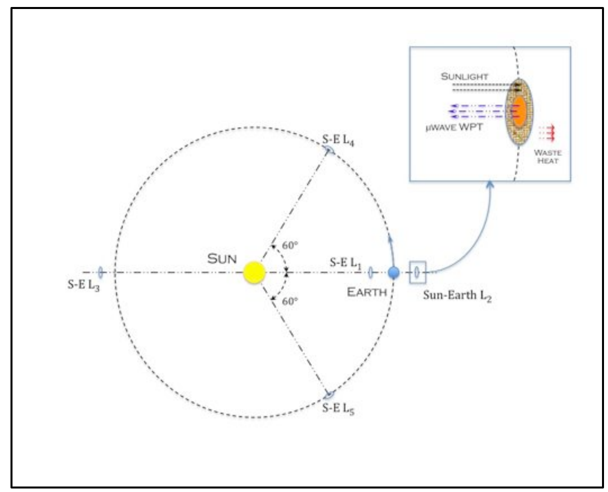




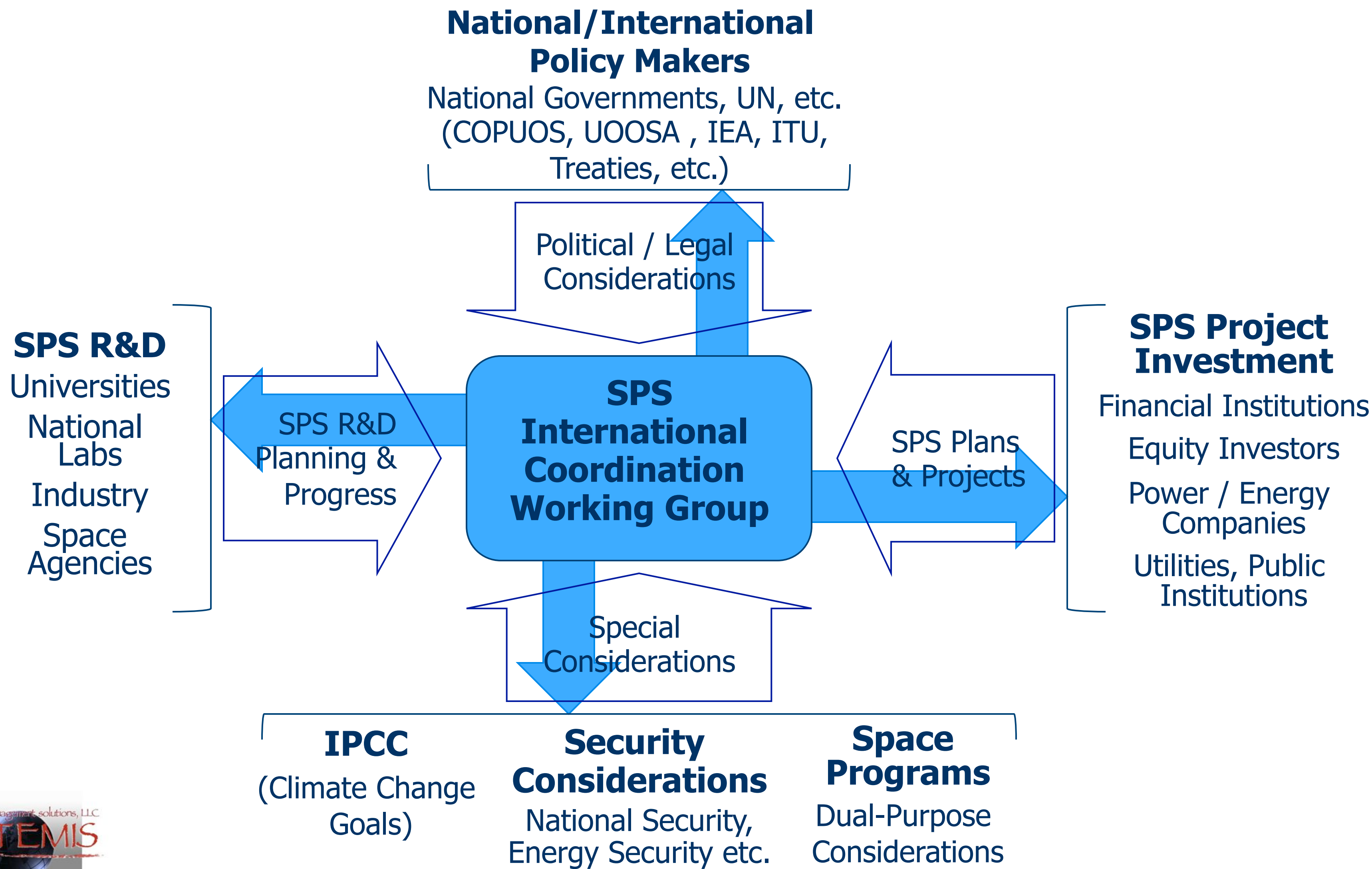








Example Concept for an SPS International Coordination Architecture



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- A.C. Charania (US; SEI)
- Raghavan Gopalaswami (India; ret.)
- Koichi Ijichi (Japan; USEF)
- Frank Little (US; TAMU)
- Shoichiro Mihara (Japan; USEF)
- Susumu Sasaki, Ph.D. (Japan; JAXA)
- Leopold Summerer (Austria; ESA)
- Didier Vassaux (France; CNES)
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- Robert Wegeng (US; Battelle Memorial Instit.)