
Space Solar Power: Achievable in a Generation?

The Vision of Abundant & Affordable Green Energy from Space



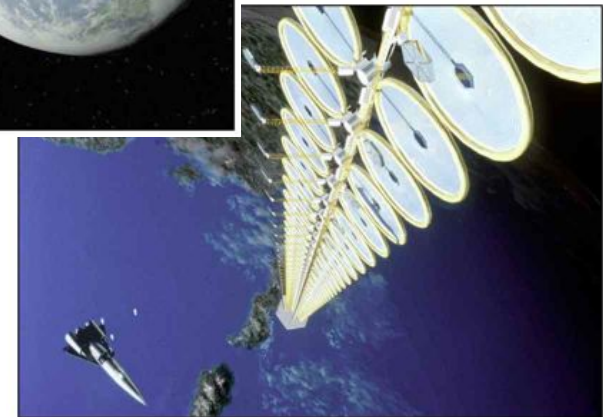
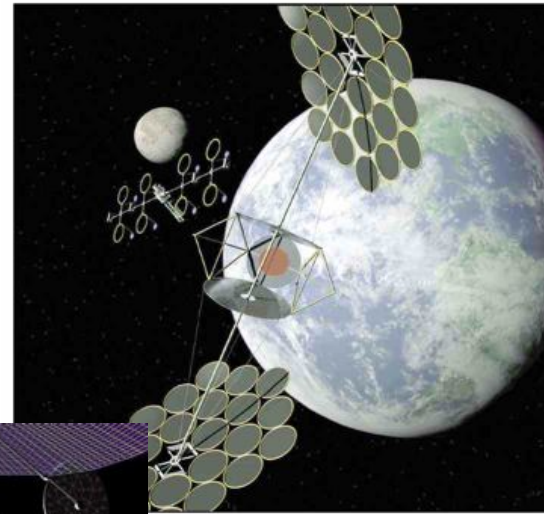
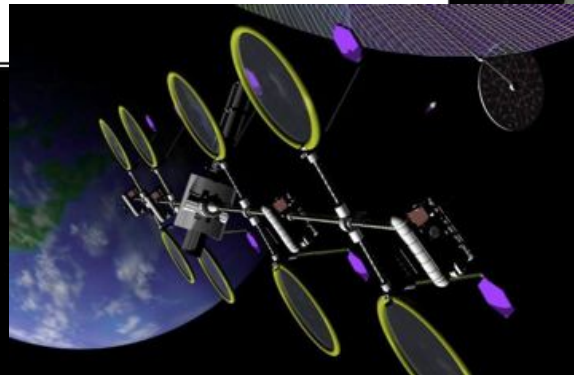
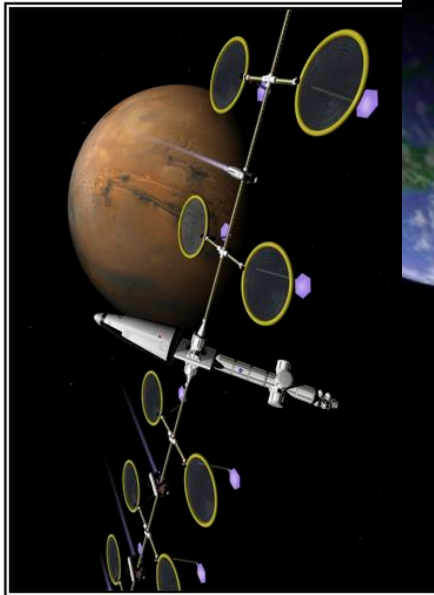
31 October 2010

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The Vision of Space Solar Power

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



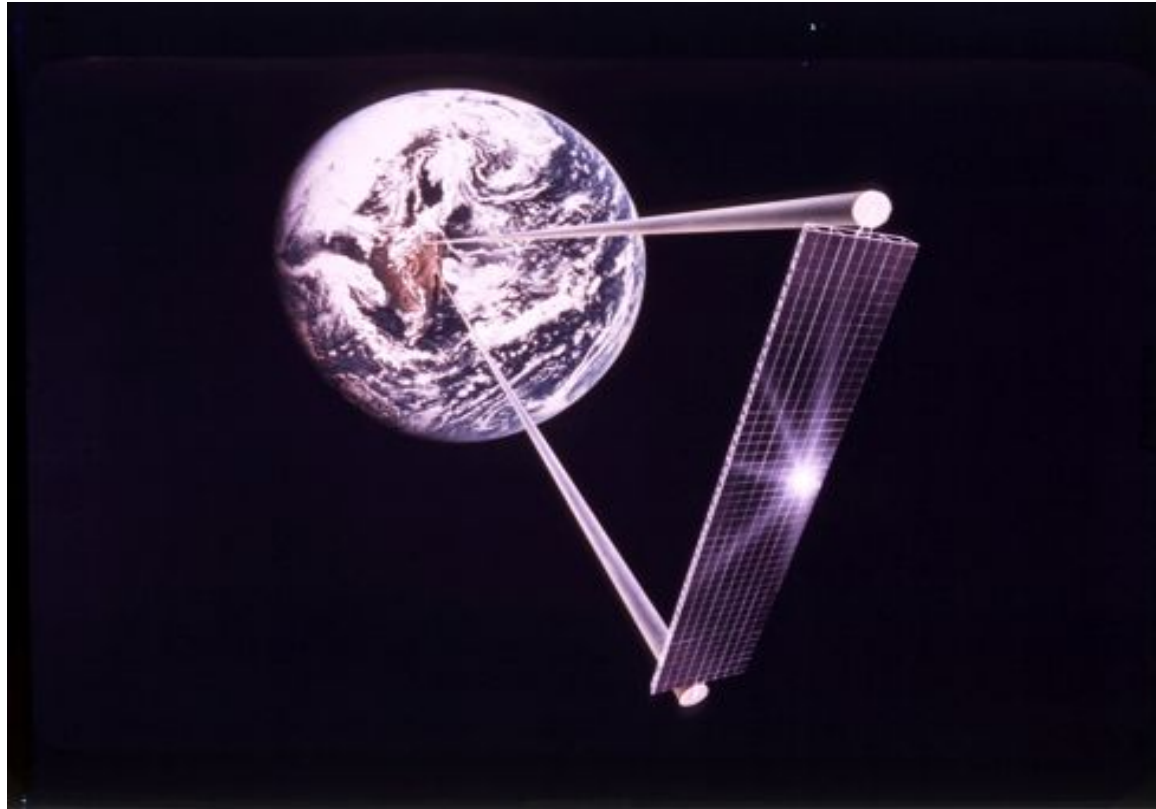
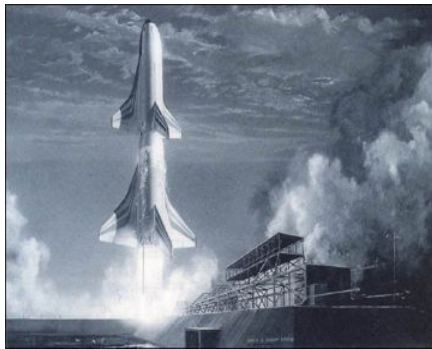
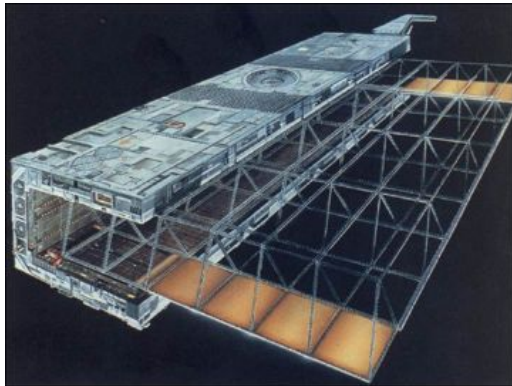
*Clean, safe, affordable and
virtually limitless solar energy
On Demand, 24/7*



Three Snapshots of Space Solar Power

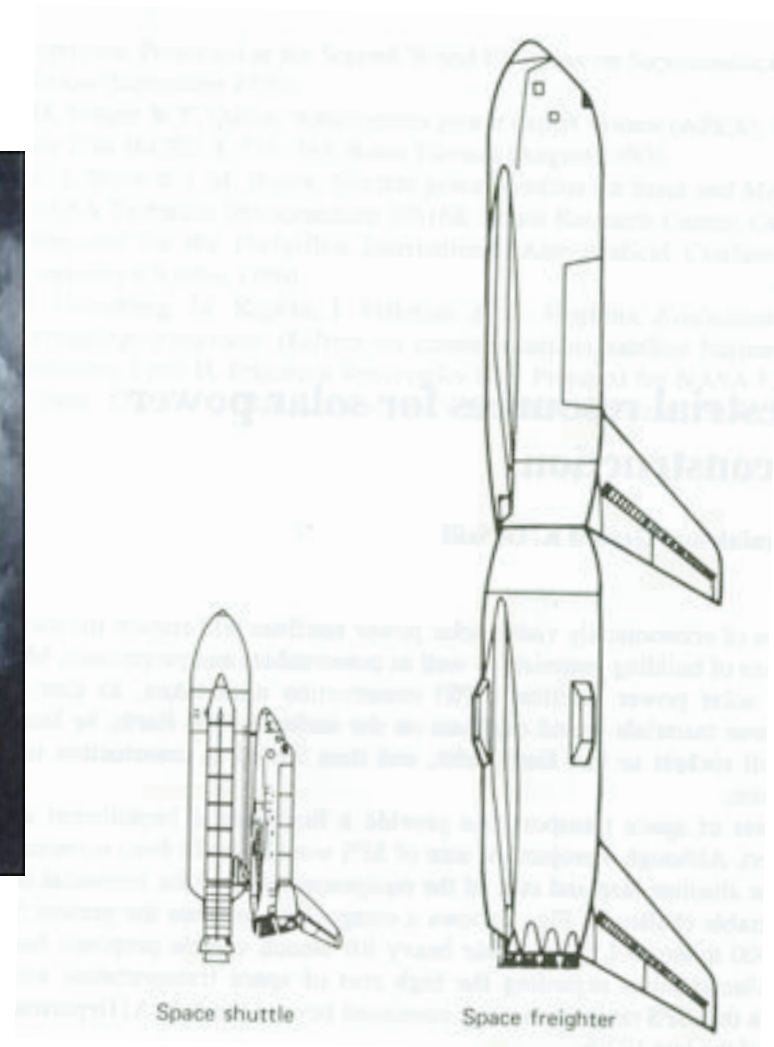
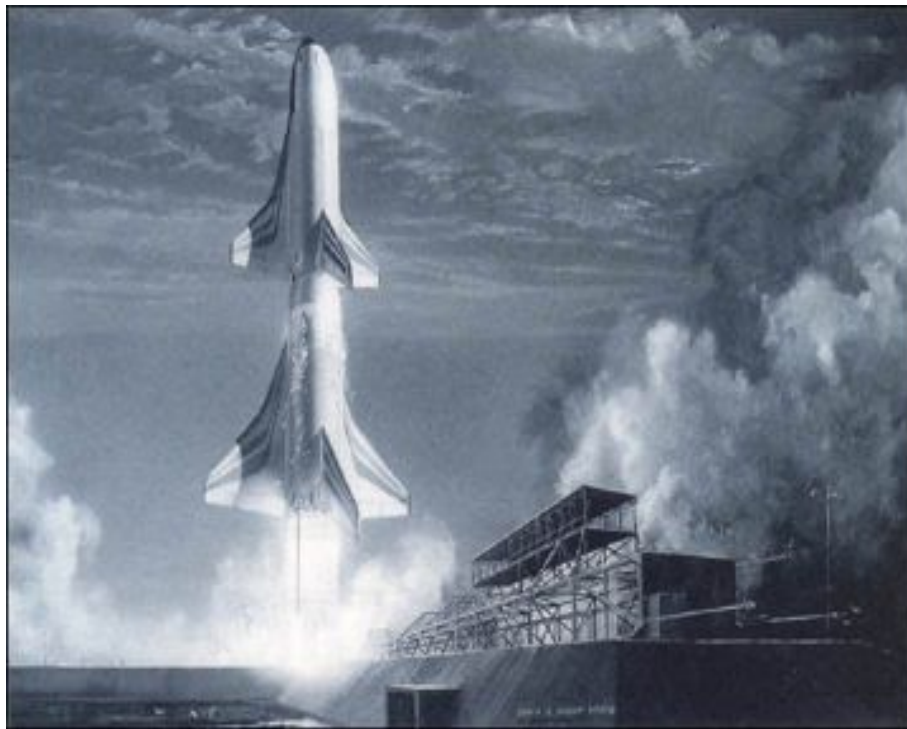
- ***Foundations: 1979-1980***
 - Revival: 2000-2001
 - Update: 2010
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SSP Foundations: 1980 1979 SPS Reference Concept in GEO

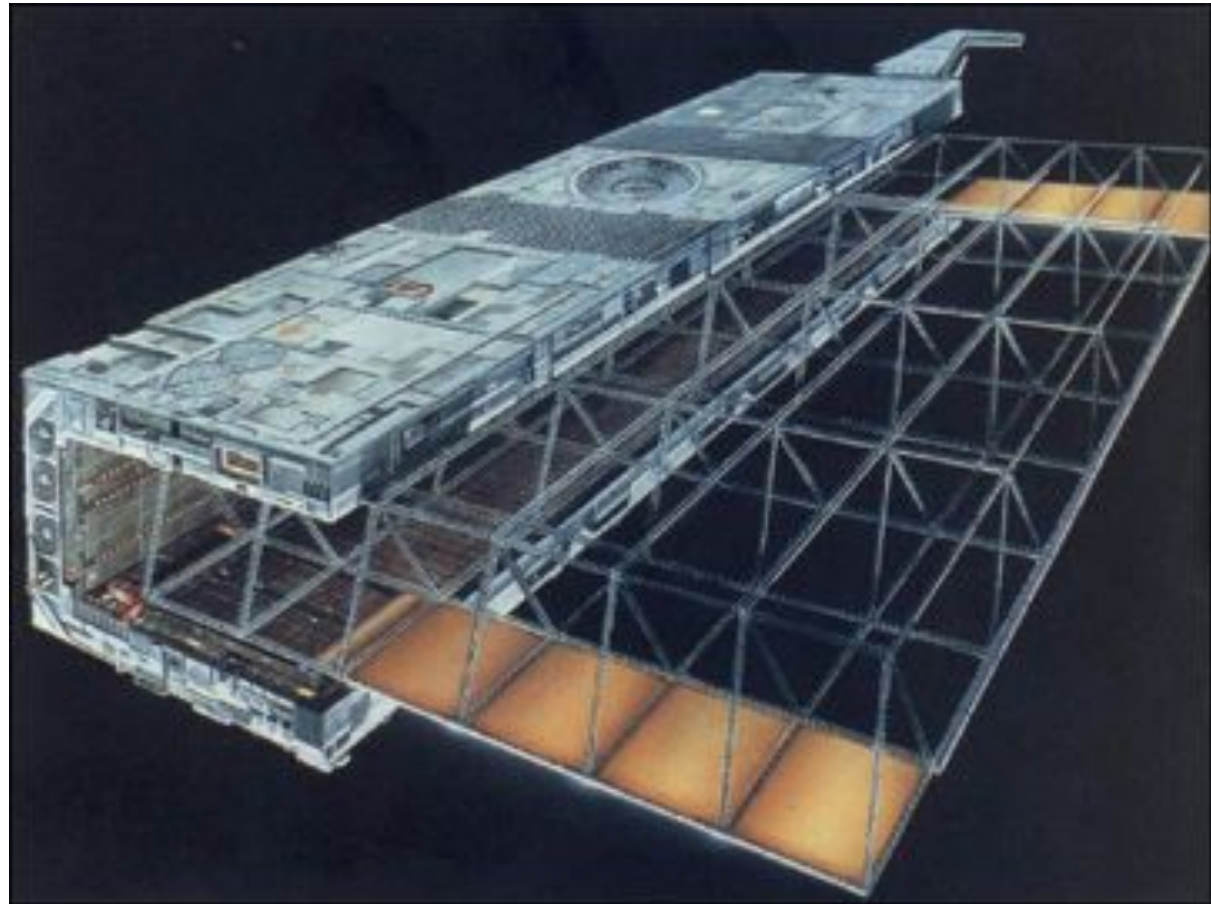
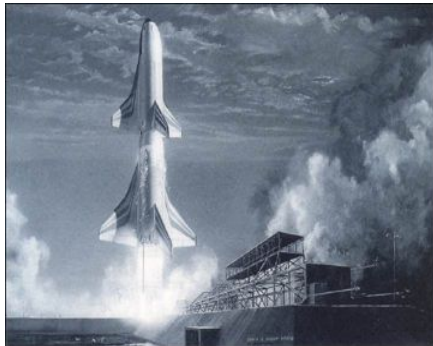


SSP Foundations: 1980

Infrastructure: Earth to Orbit Transportation



SSP Foundations: 1980 Infrastructure: In-Space Assembly



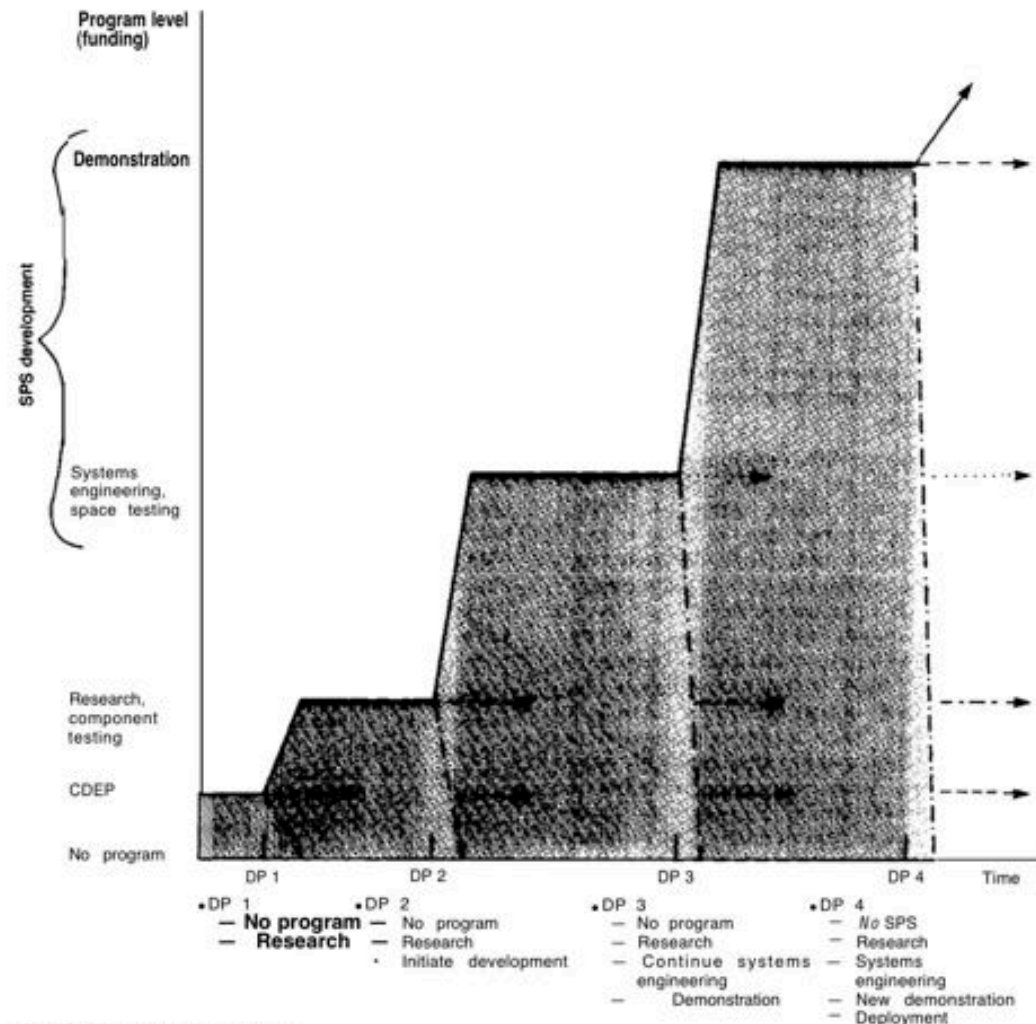
Others

SSP Foundations: 1980

The “Official Plan Forward” (per OTA/NRC)

- A single, monolithic, highly integrated U.S. National Project (ala Apollo)
- Several Cut-Off / Decision Points
- Notional Date for “Beginning of Deployment” (cited for Utilities Planning: ~20 yrs)
- Total Cost to “First Demonstration” in GEO ~ \$60-\$80 B

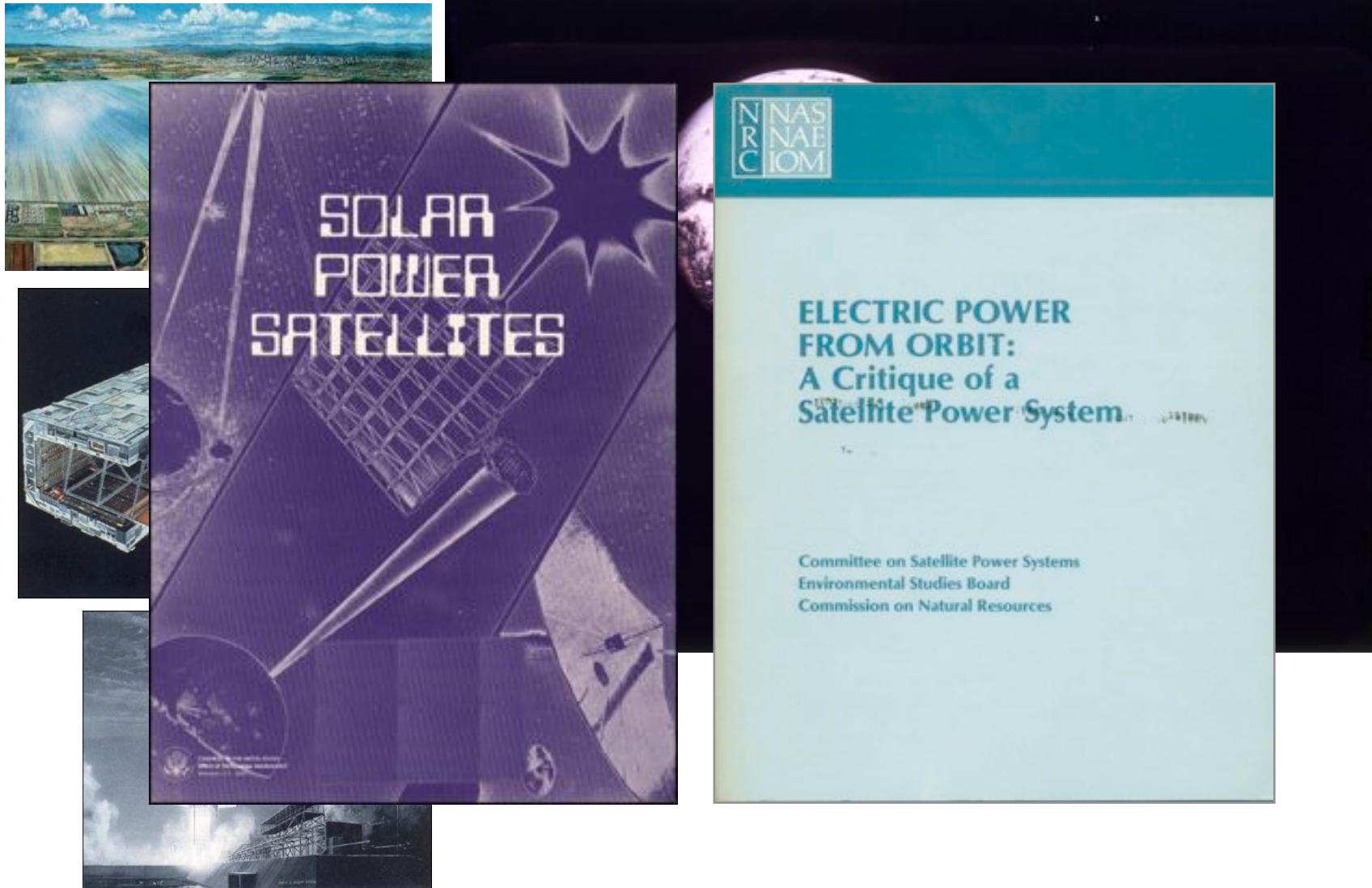
Figure 8.—SPS Program Phases and Decision Points



SOURCE: Office of Technology Assessment.

Ref: NRC Report 1980

SSP Foundations: 1980 NRC / OTA Reviews of SPS c. 1980



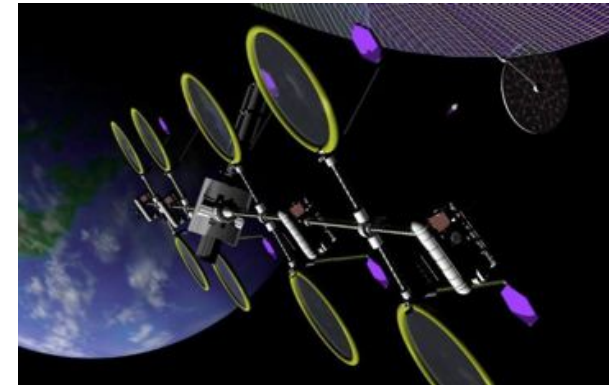
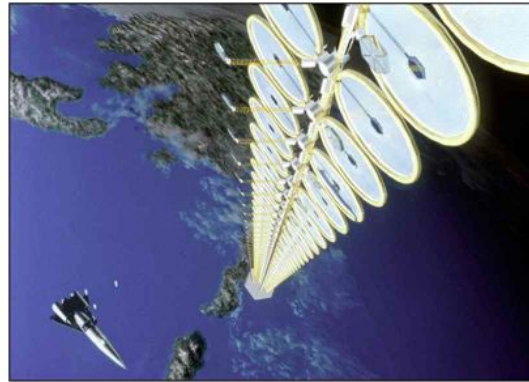


Three Snapshots of Space Solar Power

- Foundations: 1979-1980
 - ***Revival ? : 2000-2001***
 - Update: 2010
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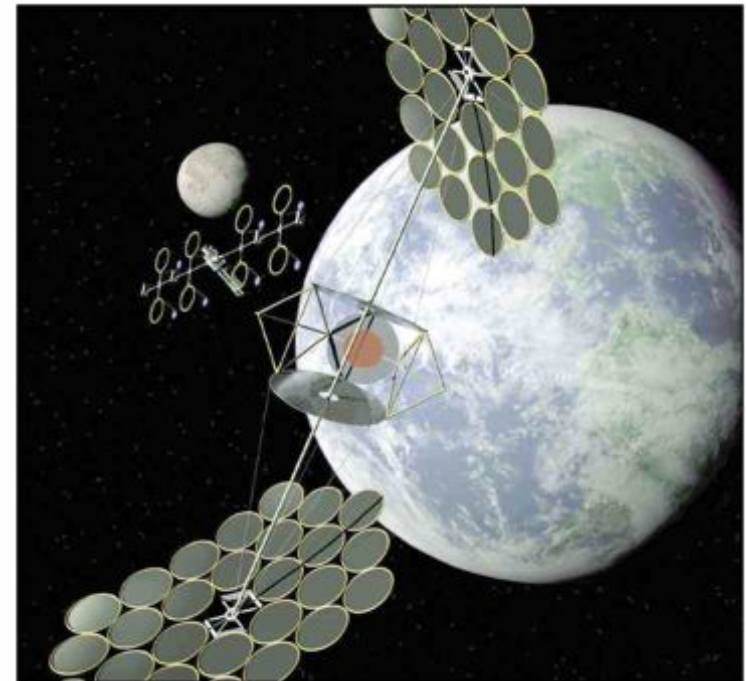
NASA Fresh Look Study / SERT Program

- Started in 1995
- Have things Changed?
- Are SPS feasible?

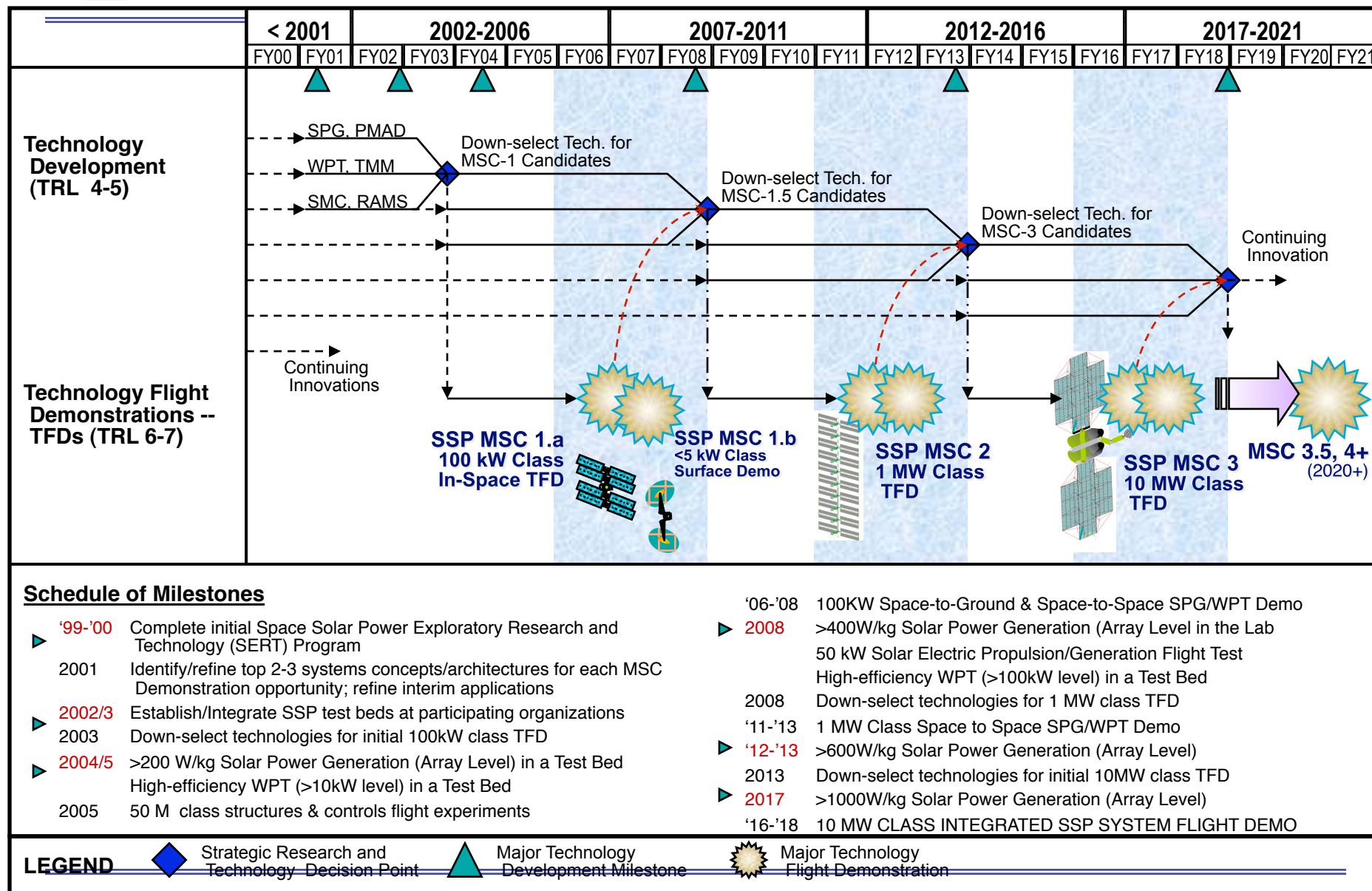


Key Elements...

- Numerous New System Architectures since 1980...
- Modular System Elements
- Robotic Construction / Self-Assembly of SPS Systems
- Improved Component Technologies
 - Particularly Solid State Devices
- Focus on Space Applications involving smaller SSP demos



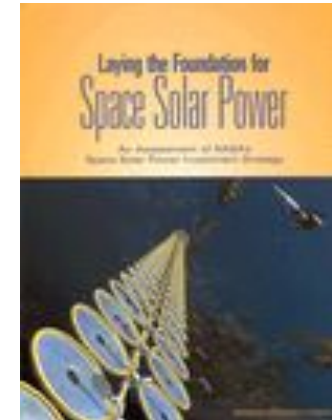
SERT SSP Research & Technology Roadmap



SSP Revival: c. 2000

Results of the US NRC SSP Review

- During 2000-2001, the Aeronautics and Space Engineering (ASEB) of the NRC assessed the technology investment strategy of the "Space Solar Power" Program to determine its technical soundness and contributed to the roadmap by...
- Selected Findings Included...
 - "SERT program has provided a credible plan for making progress toward the goal of providing space solar power for commercially competitive terrestrial electric power despite rather large technical and economic challenges
 - "Current SSP technology is aimed at technical areas with important commercial, civil, and military application
 - "Dedicated NASA team has defined a potentially valuable future program...
 - "Current SSP program is operating on minimal budget and significantly higher funding and program stability will be necessary to attain aggressive goals of program
 - "Funding plans during the first five years (leading to first flight test demonstration) are reasonable..."
 - **"Significant technical breakthroughs necessary to achieve final goal of cost-competitive terrestrial baseload power"**
 - "Ultimate success of terrestrial power application critically depends on dramatic reductions in cost of transportation from Earth to GEO
 - "Leveraging of technological advances made by organizations external to NASA must be done."



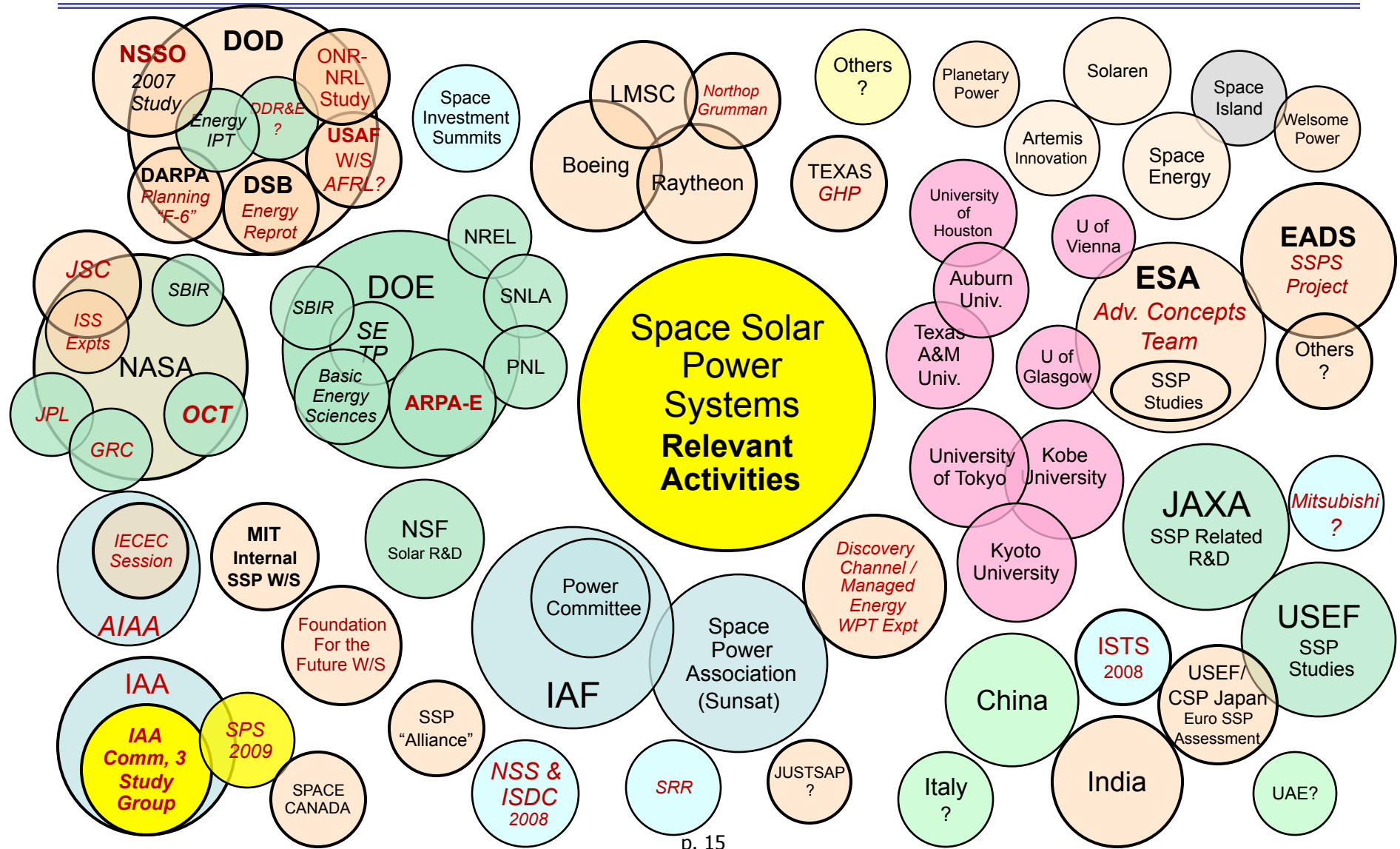
- Low-level SSP related R&D continued at NASA for several more years
 - However, despite the positive results of the NRC review c. 2000, US activities stopped again within 3+ years...
 - Various reasons...
 - Lack of interest by Bush Administration
 - Loss of Shuttle Columbia
 - New Vision for Space Exploration
 - International interest continued, with some increase, however, particularly due to changing international energy market , climate findings, etc.
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Three Snapshots of Space Solar Power

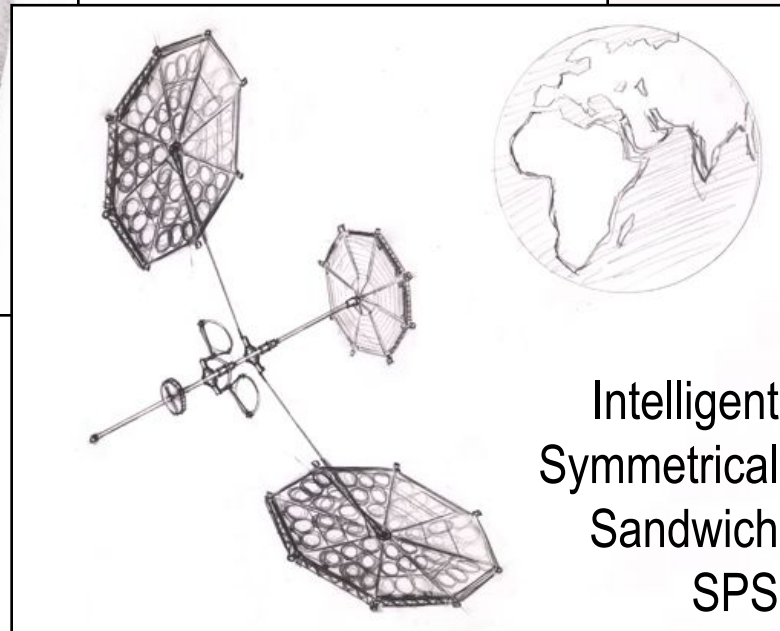
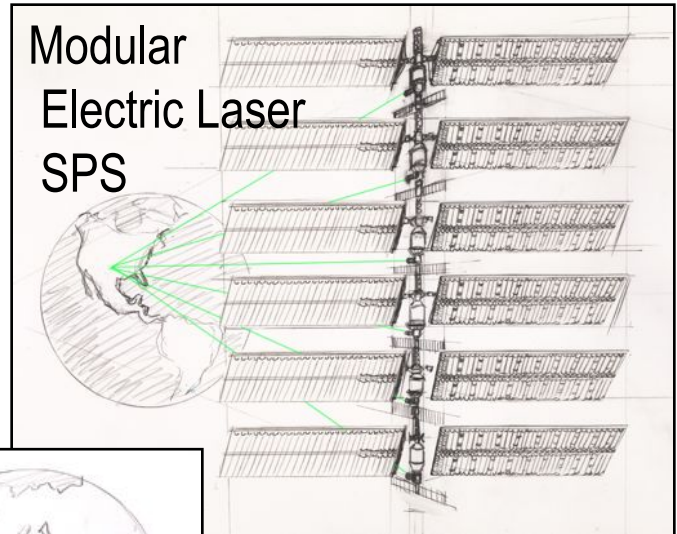
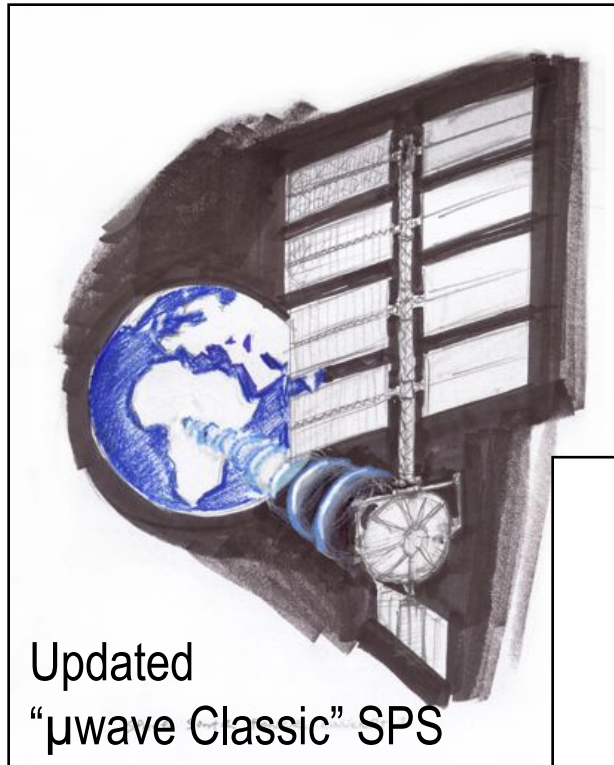
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Space Solar Power Systems and Related R&D 2007-2010 Overview of Activities Internationally



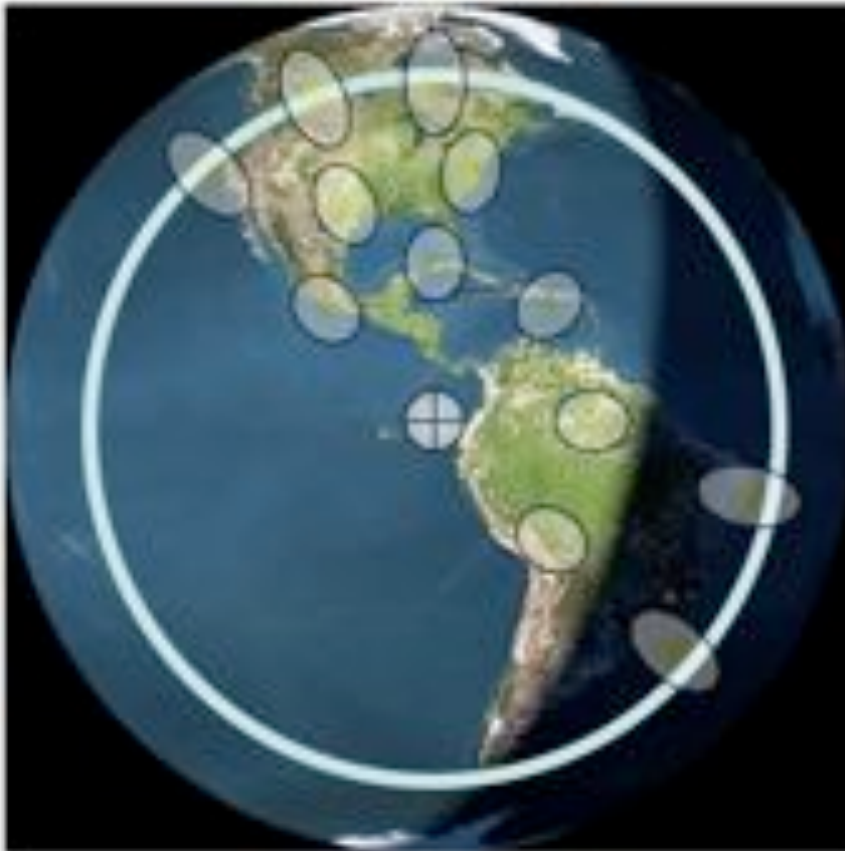
International Academy of Astronautics Study of SSP

3 Concept Types Examined...



Artwork:
SpaceWorks
Engineering Inc.

The SPS Vision Affordable / Dispatchable Solar Energy 24-7



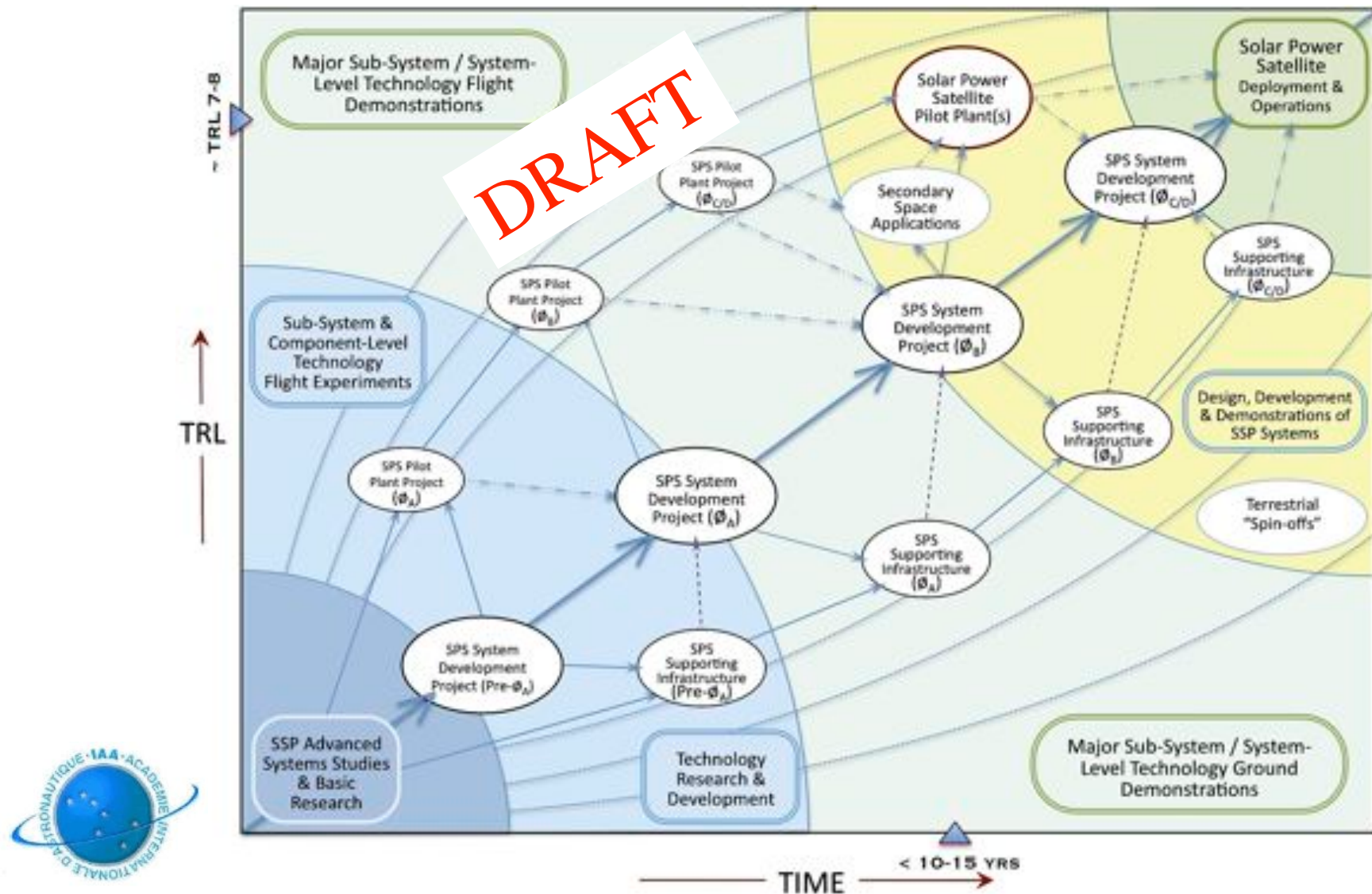
IAA Study of Space Solar Power Integrated Technology Readiness / Risk Assessment

Class A SPS SYSTEM CONCEPT SPECIFIC TECHNOLOGY REQUIREMENTS			Class B SPS PLATFORM GENERIC TECHNOLOGY RQTS	Class C SUPPORTING INFRA-STRUCTURE TECH RQTS
μ Wave Classic	μ Wave Sandwich	Laser WPT		
μ Wave Amplifiers (FET, magnetron, etc.)	FET Amplifiers	Solid State Diode Lasers	Large, Lightweight Structural Systems	Reusable Launch Vehicles (High TW Engines, TPS, Hot Structures, etc.)
High Voltage PMAD	Highly Modular Low Voltage PMAD	Mid- to High-Voltage PMAD	In-Space Assembly & Construction (Robotics / Interfaces)	Affordable In-Space Transportation (High TW Engines, TPS, EP, etc.)
High Power Rotating Couplers	Low mass Optics (w/ Reflectors)	Near-Visible Beam Expanders	Modular GN&C / Avionics	In-Space Refueling (Cryogenics, FP Fuels, etc.)
Light Weight Large Area PV	High Temperature Electronics	High Temperature Electronics	Modular CMD / Communications	
Moderate Temp Thermal Mgt	Moderate Temp Thermal Mgt	High Temp Thermal Mgt	High-Efficiency Photovoltaics	
			Radiation Tolerant Electronics	
			Radiation Tolerant Photovoltaics	

DRAFT



IAA Study of Space Solar Power International Roadmap for Space Solar Power



Summary and Closing

Space Solar Power: Achievable in a Generation?

- There are new opportunities for Space Solar Power / Solar Power Satellites c. 2010
 - Numerous International Activities
 - Significant Changes in the Global Market
 - Continuing Advances in Technology
 - And there are continuing Challenges
 - New competitors in ground-based renewables
 - Lack of real end-to-end studies / focused technology developments & demonstrations
 - The to-be-released IAA study should provide a framework for international dialog regarding SPS...
-



Space Solar Power: Achievable in a Generation?

An Approach: Staged Investments / Accomplishments

- **1-2 Years from Today**
 - Accomplishments: End-to-End Systems Studies, Critical Proof-of-Functionality Demonstration (TRL 5)
 - Potential Cost: \$10M
- **2-4 Years from Today**
 - Accomplishments: Integrated Systems Design Studies, Supporting Technology Experiments / Demos, LEO SPS Flight Demo Designs, LEO-GEO transport Concepts, and GEO SPS Demonstration Concepts
 - Potential Cost: \$10M (Systems Design Studies), \$150M±\$50M (Remainder)
- **3-7 Years from Today**
 - Accomplishments: Further Technology Advancements, Major Ground Demos, LEO SPS Flight Demos, LEO-GEO Transport Demos, GEO SPS Demo Designs, Very Low-Cost ETO Concepts
 - Potential Cost: \$750M ± \$250M
- **7-15 Years from Today**
 - Accomplishments: Further Technology Advancements, LEO-GEO Transport Operational, GEO SPS Demonstration, Very Low-Cost ETO Designs
 - Potential Cost: ≤ \$10B
- **10-20 Years from Today**
 - Accomplishments: Development of Very Low-Cost ETO Systems, Begin Operational SPS Systems Deployment
 - Potential Cost: TBD...

No fundamental breakthroughs in Physics appear to be required for SSP – but New Approaches are Essential if Solar Power Satellites are to be Realized within a Generation...

SPS Elements: Modular, Affordable, Scalable, Manufacturable...

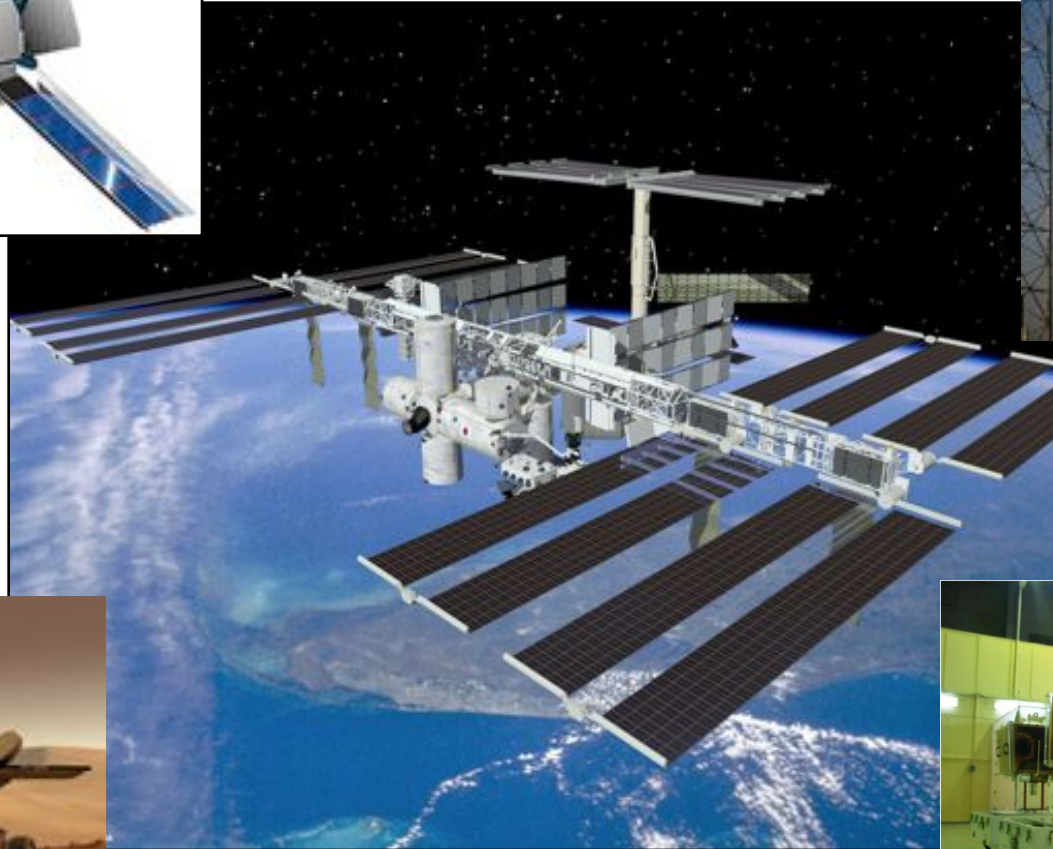
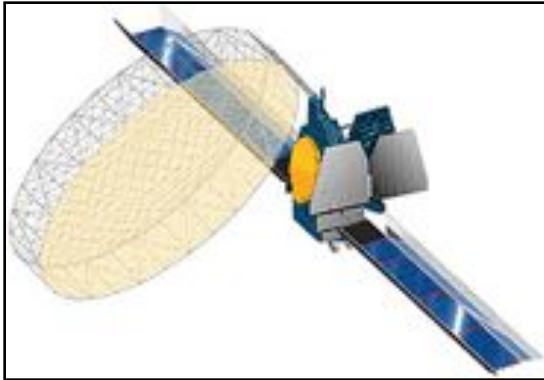
- Space Solar Power has the potential to deliver solar energy from space to global markets on a scale of up to 100s-1000s of GW
- In addition, there are strong interim market possibilities in the form of a wide range of space applications
 - Civil Space, DOD, Commercial Space
- Tremendous progress has been made in all of the key technologies, but translation from the lab to systems level tests has not yet been realized...
- The “right” roadmap will have a Portfolio of Options and Levels of Maturity
 - R&D, ground, flight tests, and systems level demos (build, test, learn)
- Key “Next Steps”
 - End-to-End Systems Studies (International, if Possible...)
 - Critical Function Demonstration at Systems Level (TRL 5+)

Back-Up Charts

Classic Space Architecture: “ENIAC-Type” Space Systems



100,000 foot view Where are Space Systems Today...?



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

