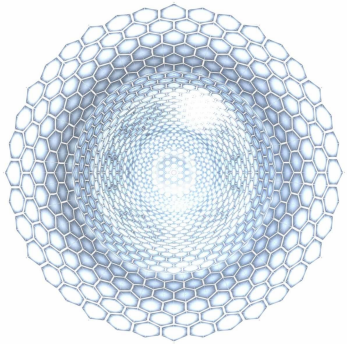

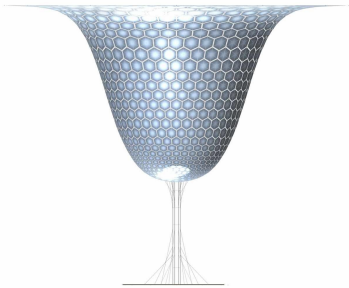

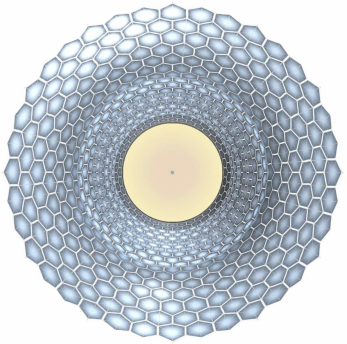

NASA Innovation Advanced Concepts (NIAC) Program

SPS-ALPHA

The First Practical Solar Power Satellite (SPS)
via Arbitrarily Large Phased Array

27 March 2012

John C. Mankins

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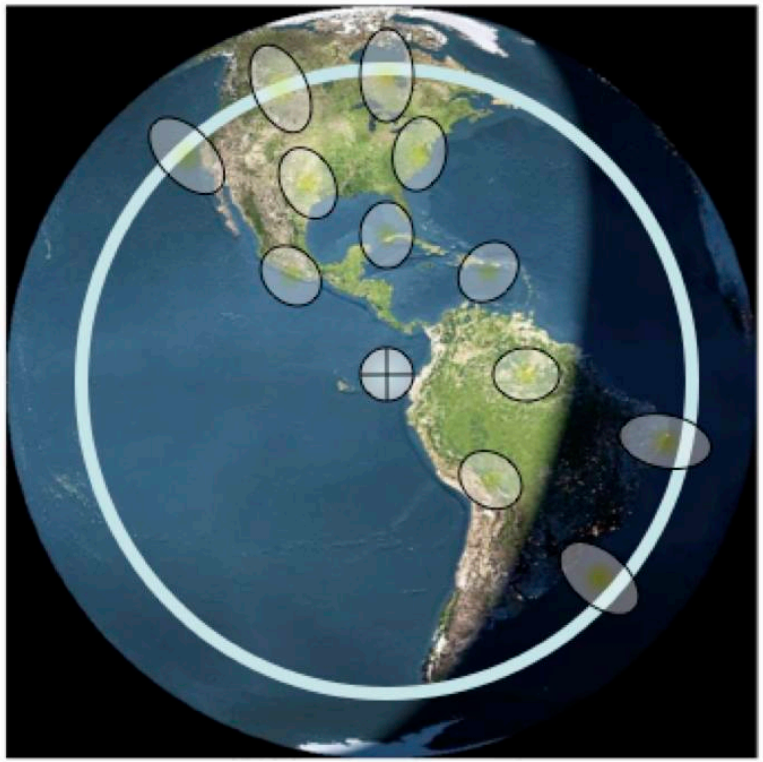
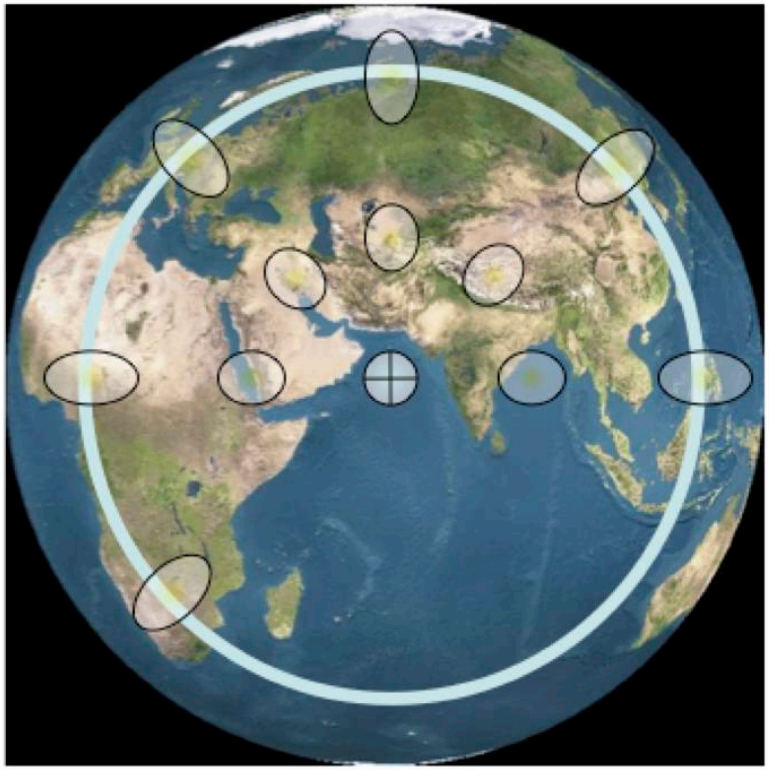
http://www.artemisinnovation.com

NIAC Program Summary

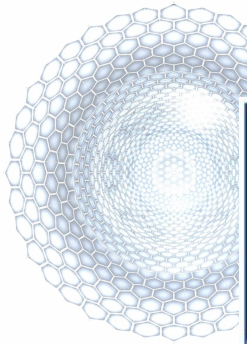
- The NASA Innovative Advanced Concepts (NIAC) program invests in low Technology Readiness Level (TRL) research in support of the Office of the Chief Technologist (OCT) Early Stage Innovation Division
- NIAC will be focused on early studies of visionary aerospace concepts; these may be architecture, mission, or system concepts, roughly TRL 1-3 in maturity, aiming 10 or more years in the future
- NIAC supports innovative research through two phases of study
  - The Phase I projects will be one-year efforts to explore the overall viability and advance the TRL of visionary concepts. NASA funding for Phase I projects will be up to $100K over 12 months
  - Follow-on Phase II proposal call will later be released to eligible recipients of Phase I awards, past and present, to further develop the most promising Phase I concepts for up to two years (with increased funding) and explore potential infusion options within NASA and beyond
- International organizations may participate in NIAC projects, but cannot receive NASA funding (funding must come from appropriate other sources)
- On 8 August 2011, NASA announced the initial Phase I NIAC projects
  - See: http://www.nasa.gov/offices/oct/early_stage_innovation/niac/index.html
  - See: http://www.nasa.gov/offices/oct/early_stage_innovation/niac/2011_phase1_selections.html
- One of the selected NIAC 2011 projects was "SPS ALPHA"

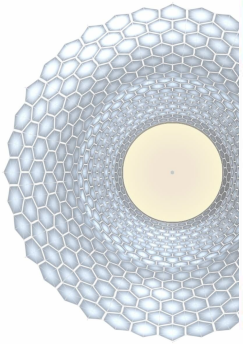
The SPS Vision
Affordable / Dispatchable Solar Energy 24-7

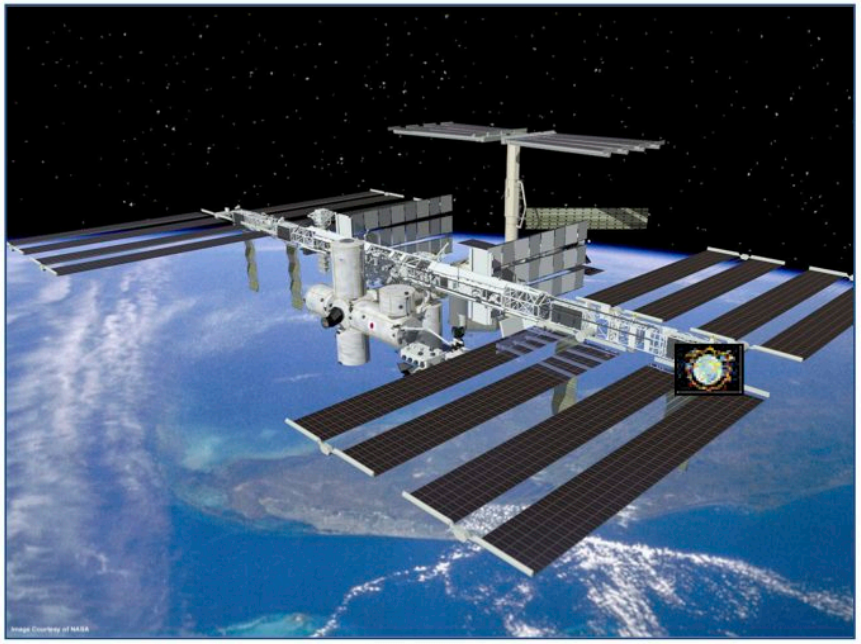


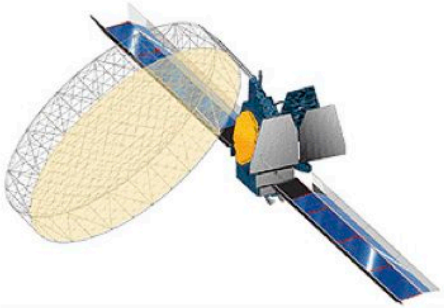


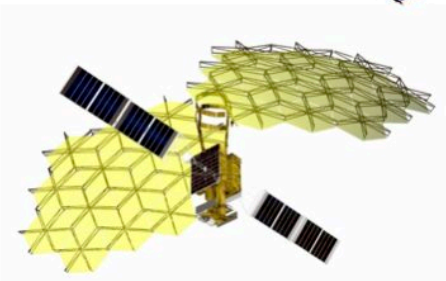
How is it Done Today?
Current Space Systems Architectures



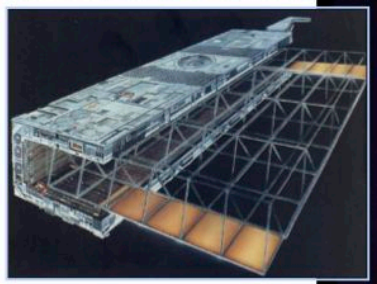


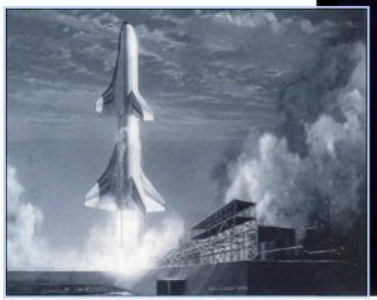


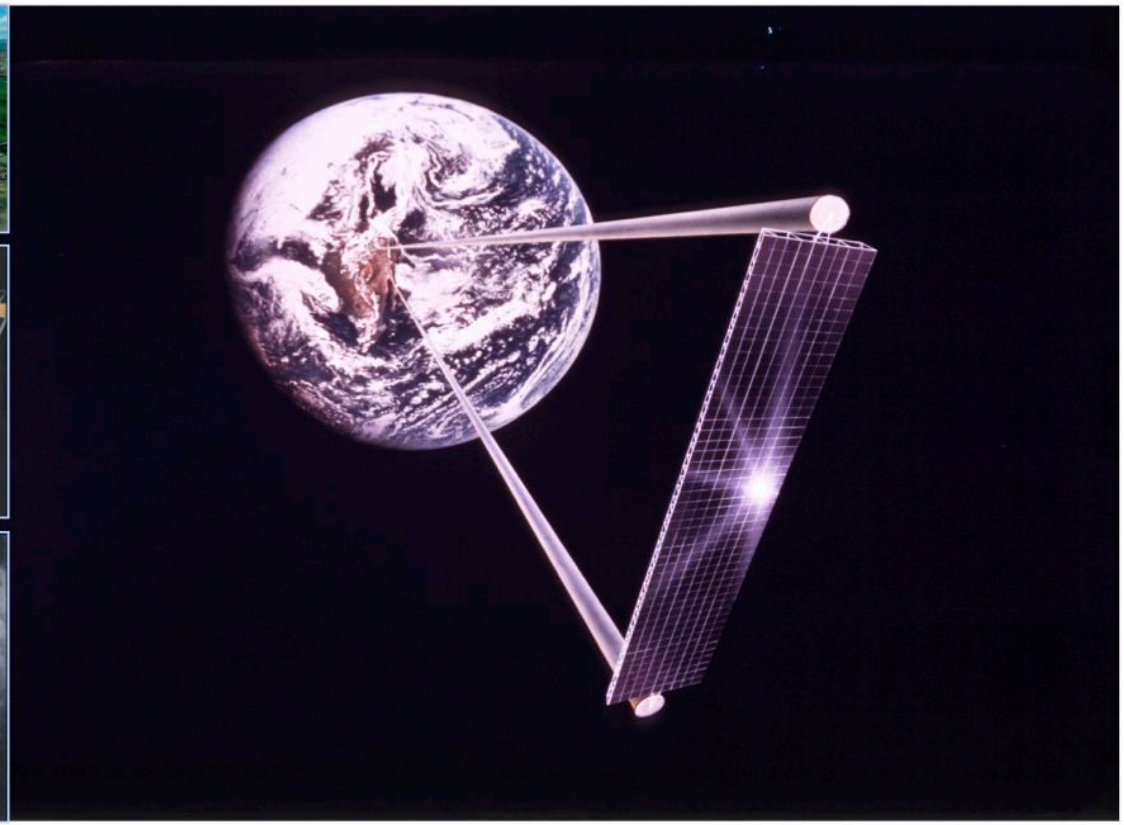




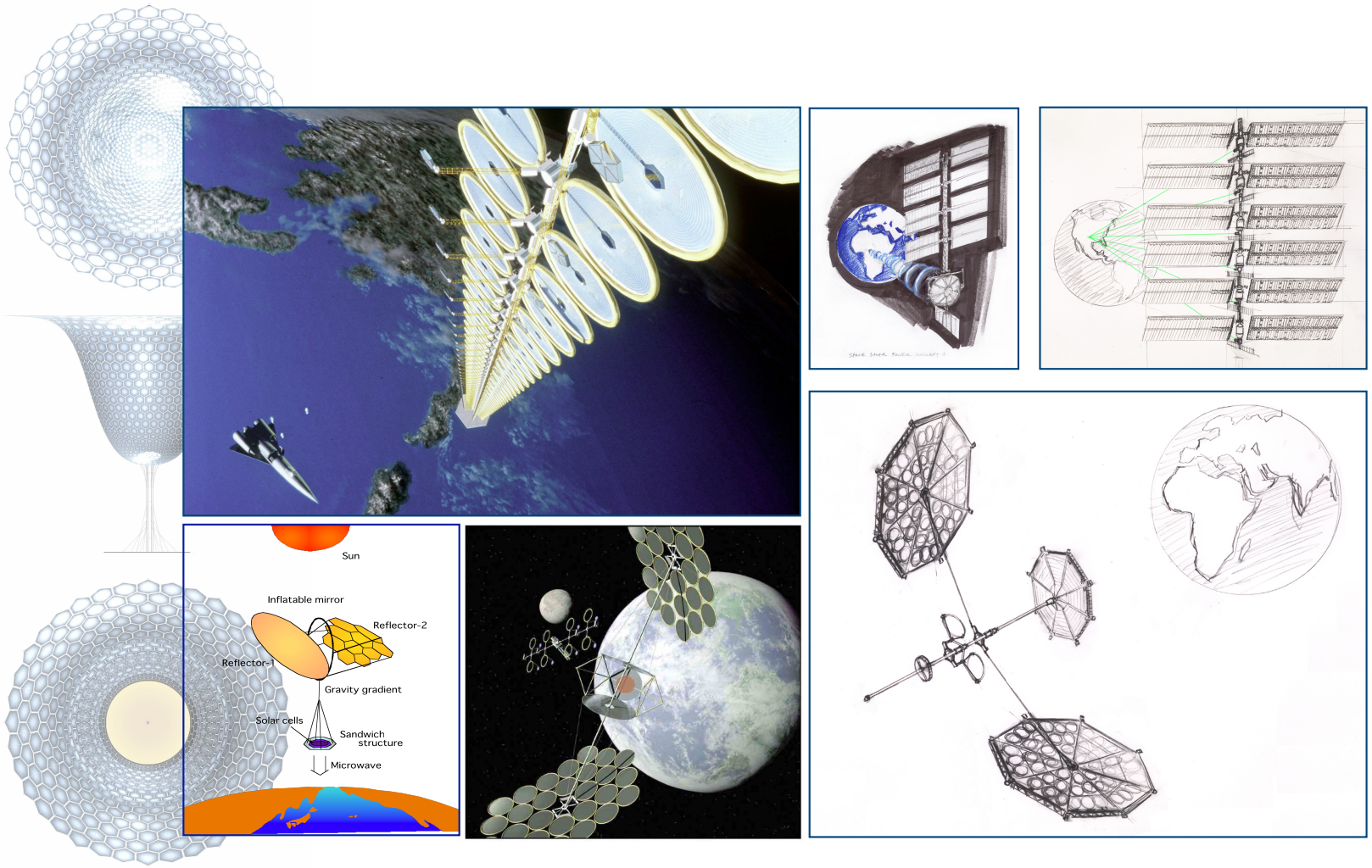
"How is it Done Today"?
1979 SPS Reference Concept in GEO





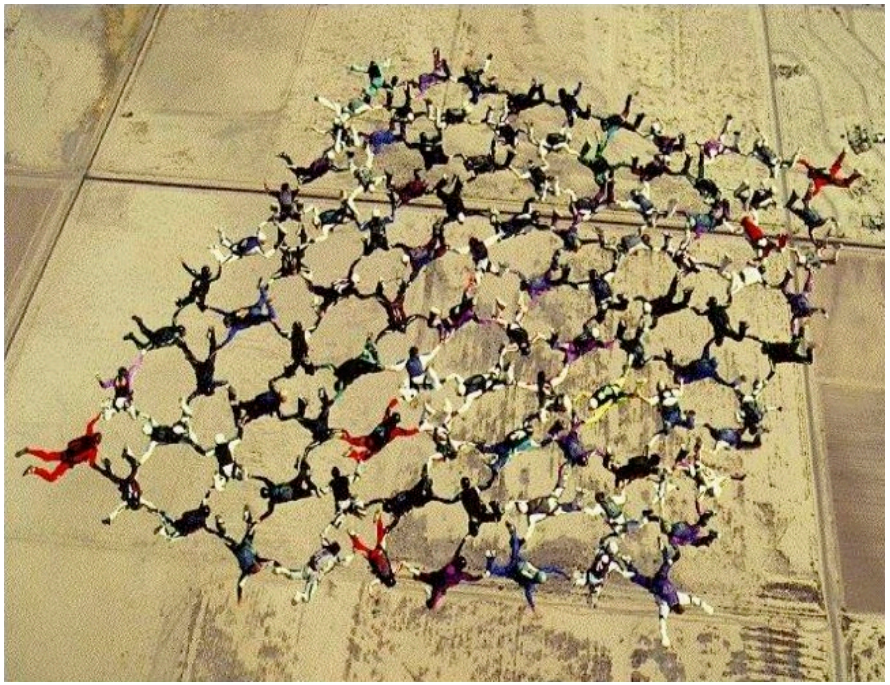


How is it Done Today?
More Recent SPS Concepts: 1997-2010



Summary Description (1 of 2)

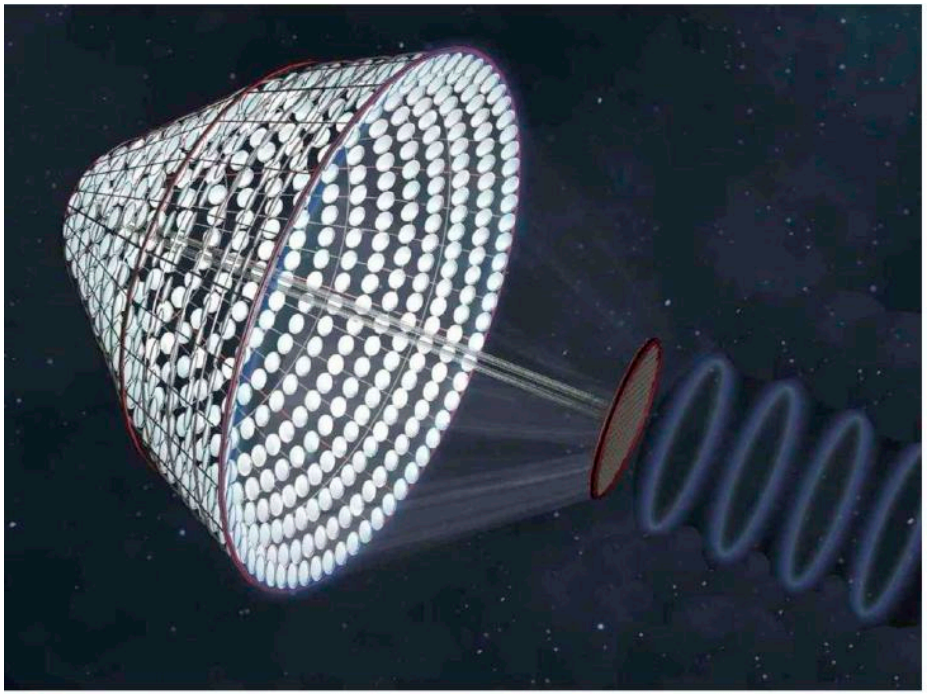
- SPS-ALPHA is a new approach to the solar power satellite: a biologically inspired architecture, analogous to a hive of bees, or a colony of ants; here, a large number of modules will be assembled to form a single enormous satellite.
- It involves no single points of failure, and is highly scalable from small prototypes to larger sizes and higher power levels.

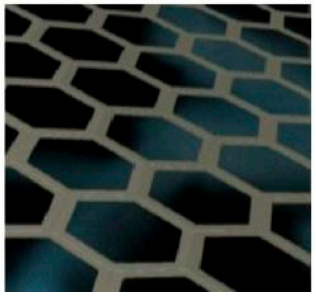


- None of the individual elements of the SPS-ALPHA will be larger than ~ 150 kg, enabling low cost through large-scale mass production

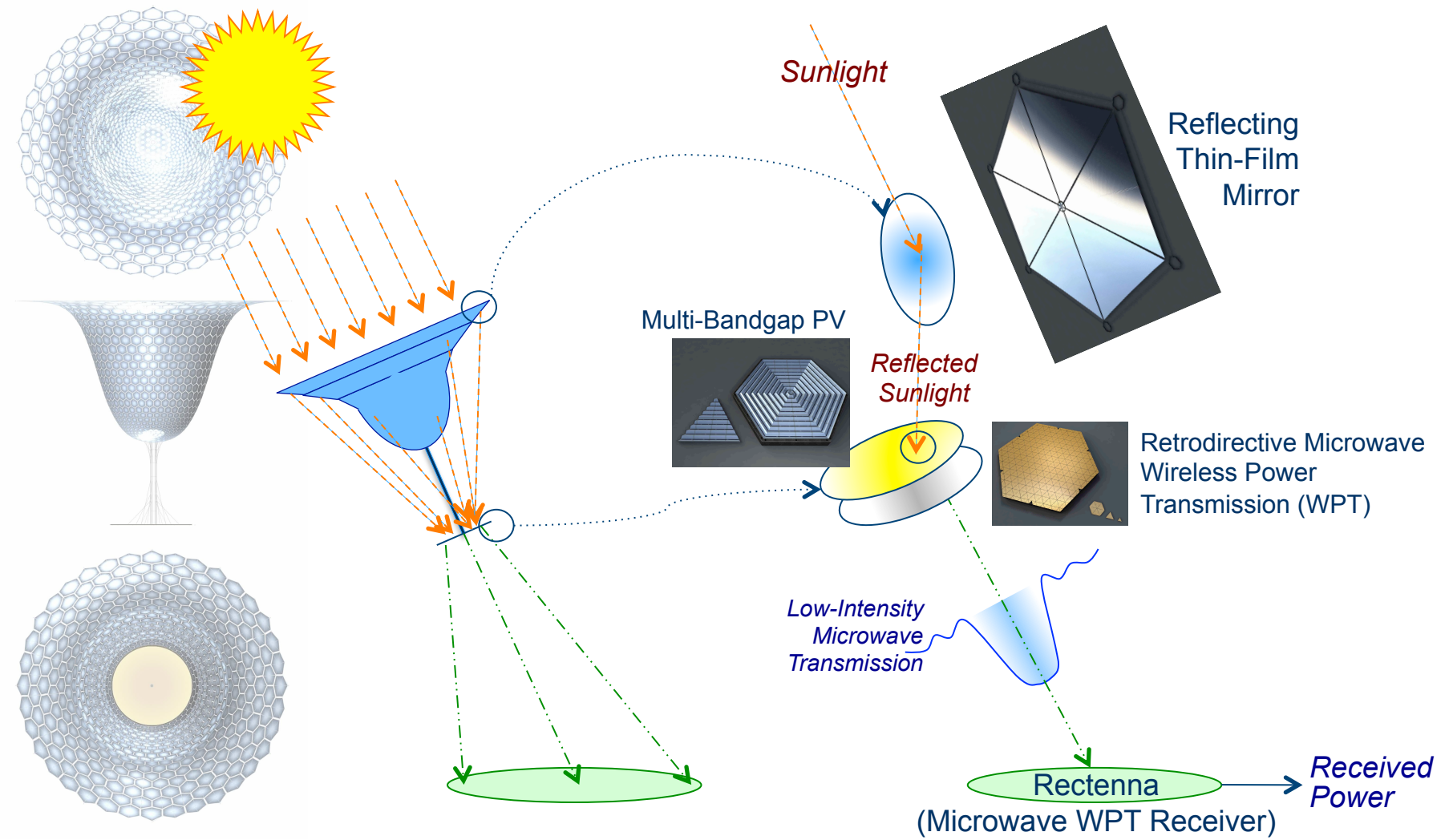
Summary Description (2 of 2)

- SPS-ALPHA incorporates a novel optical configuration the eliminated the new for extremely large pointing mirrors (and associated "single points of failure")
- Each of the intelligent modular elements that comprise the SPS-ALPHA aperture will incorporate:
  - local solar power generation (SPG)
  - local power management and distribution (PMAD)
  - a WPT system based on the retro-directive phased array approach
  - a local thermal management system
  - a small "flat" spacecraft bus (e.g., in the form of a hexagonal panel) that hosts the above, and interconnects with others in the array





SPS-ALPHA: Overall System Concept



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SPS-ALPHA Project Team

- Principal Investigator:
  - John C. Mankins
    - ✓ Artemis Innovation Management Solutions LLC
- Co-Investigator(s):
  - Prof. Nobuyuki Kaya
    - ✓ Kobe University, Kobe, Japan
  - Dr. Massimiliano Vasile
    - ✓ University of Strathclyde, Glasgow, Scotland

- Plus… various team members and workshop participants…!

SPS-ALPHA
NIAC Phase I Project Summary

- This NIAC project will establish the technical and economic viability of the SPS-ALPHA concept to an early TRL 3 – analytical proof-of-concept – and provide a framework for further study and technology development
- The objectives of this innovative advanced concept project are:

(1) Conduct an initial end-to-end systems analysis of the SPS-ALPHA concept in order to determine its technical feasibility

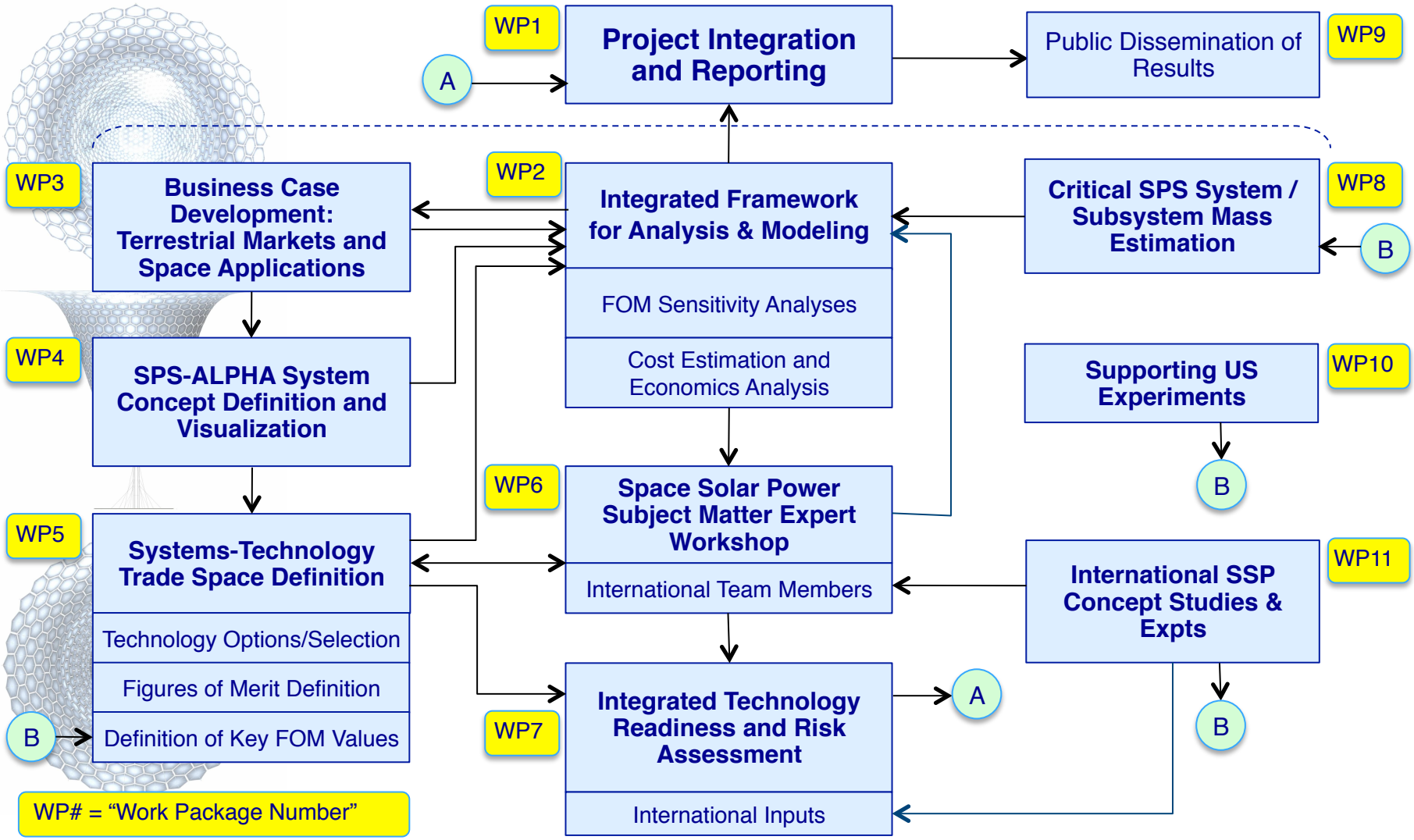
(2) Identify and assess in greater detail the key technology challenges inherent in the architecture (including figures of merit for each critical technology area)

(3) Perform selected supported technology research and development

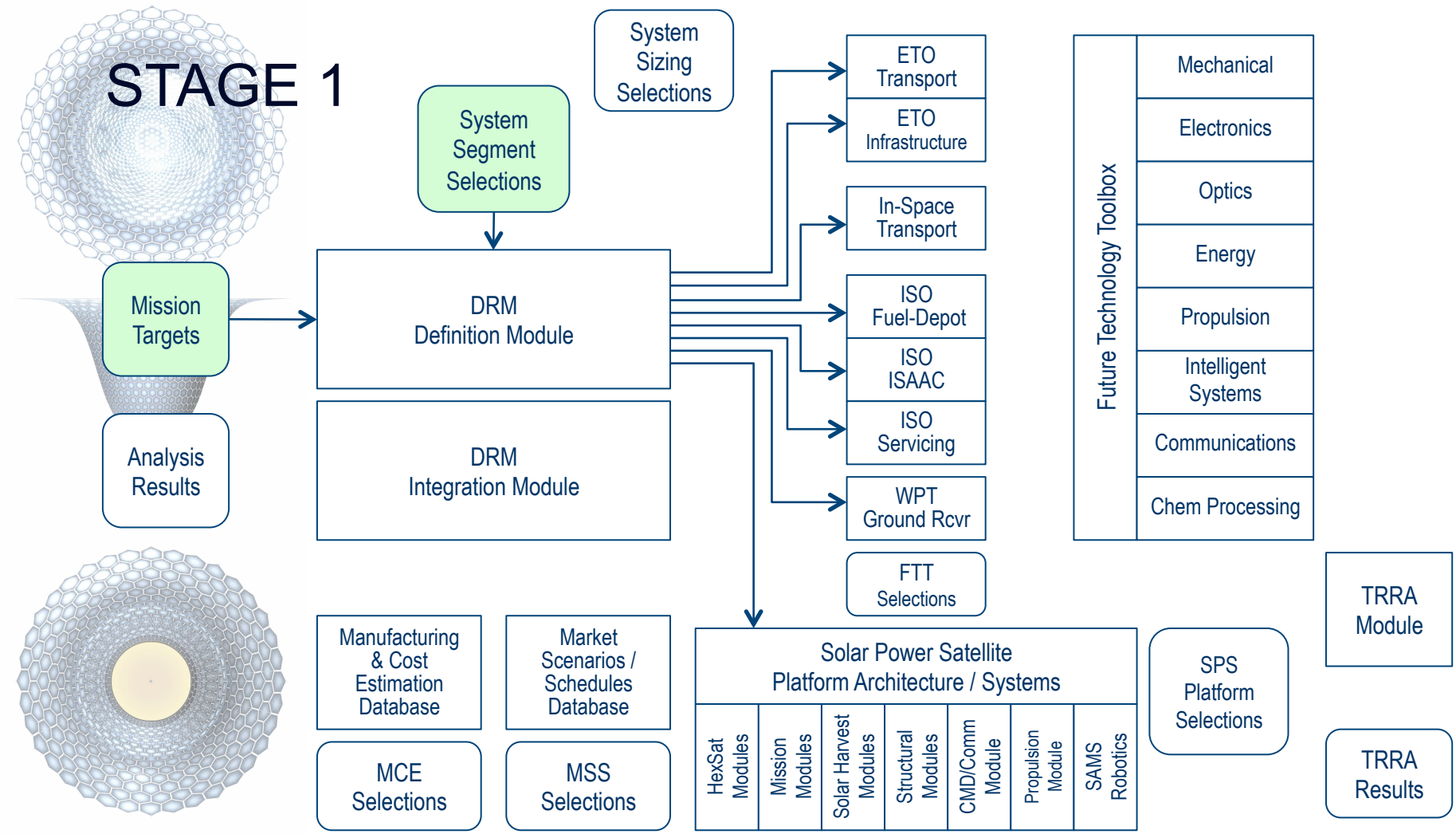
(4) Conduct an initial evaluation of the economic viability of the concept (as a function of key performance parameters)

(5) Define a preliminary roadmap for the further research and development of the SPS-ALPHA concept

SPS-ALPHA
NIAC Phase I Project – Detailed Approach



ACES (Mark-1)
Architecture Overview – October 2011



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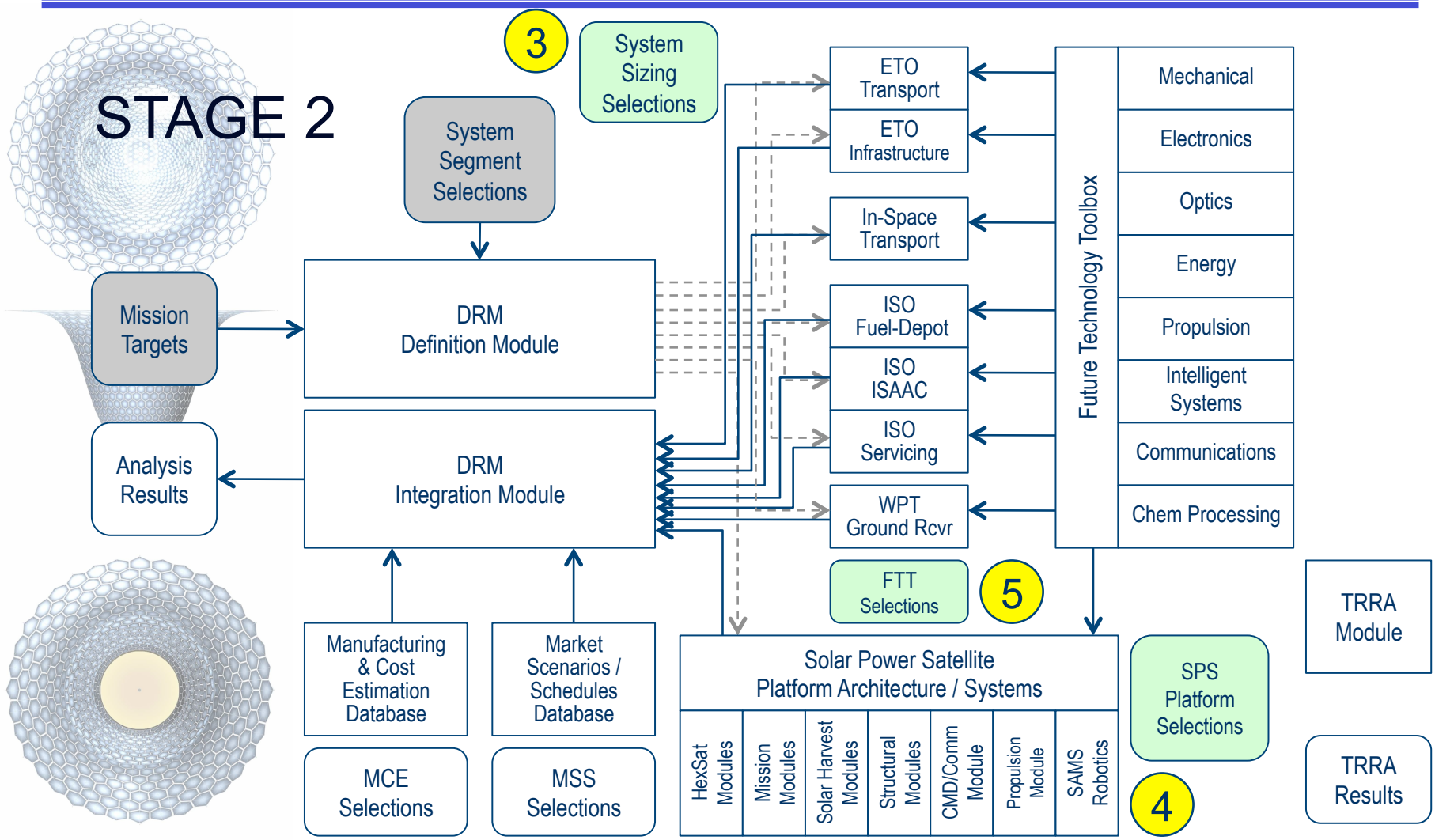
ACES (Mark-1)
Architecture Overview – October 2011



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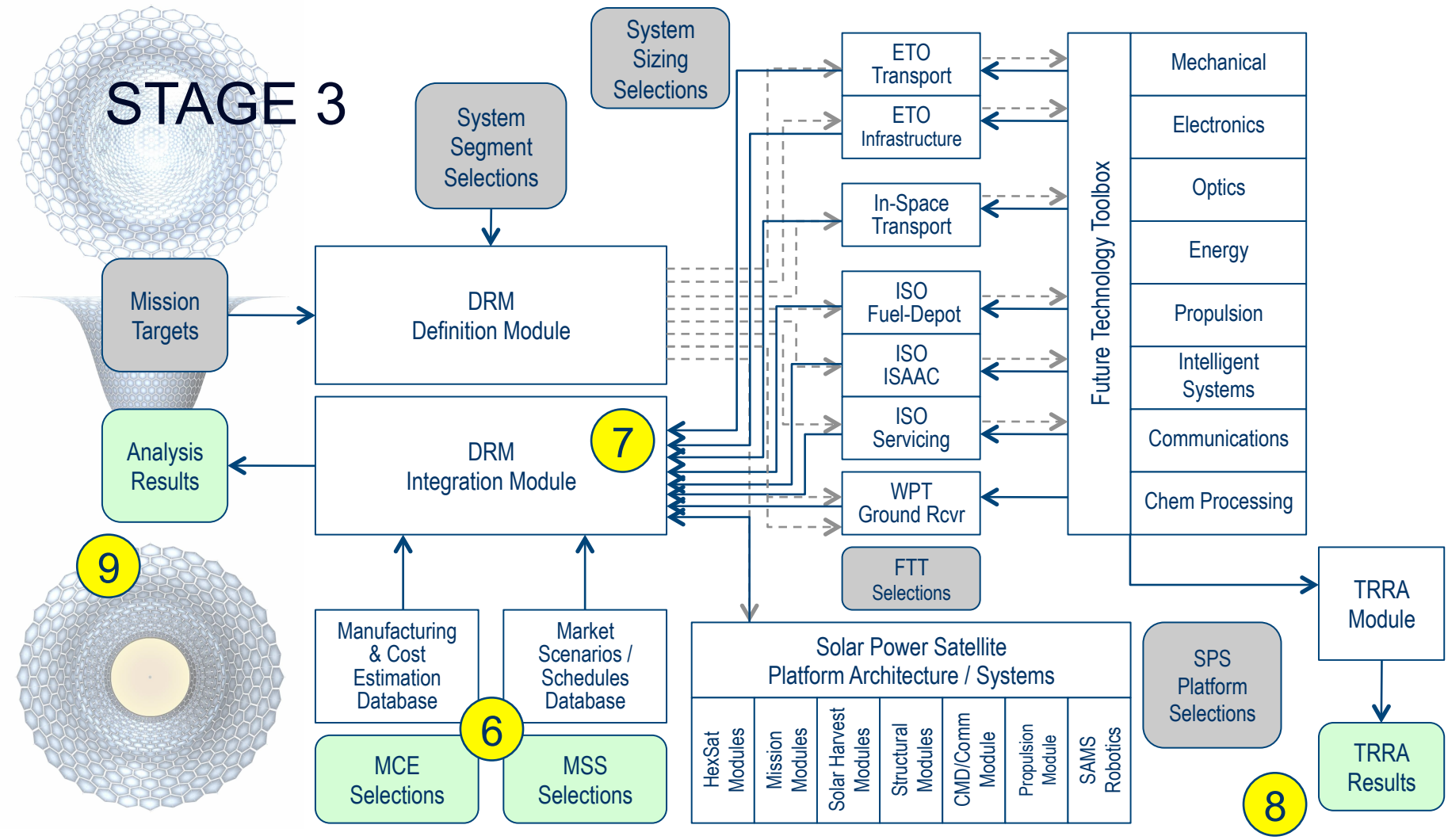
ACES (Mark-1)
Architecture Overview – October 2011



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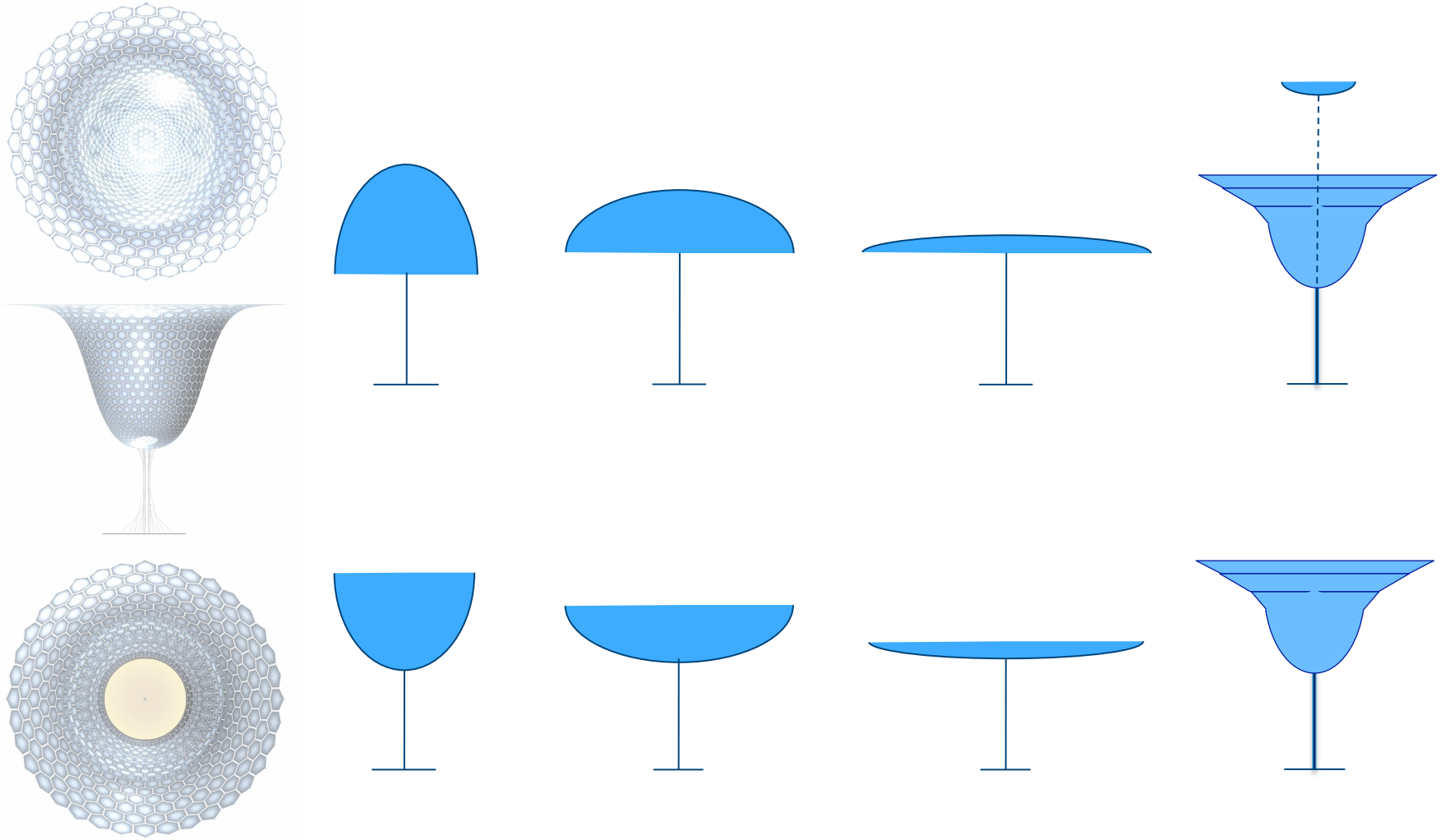
Various SPS-ALPHA Configuration Options



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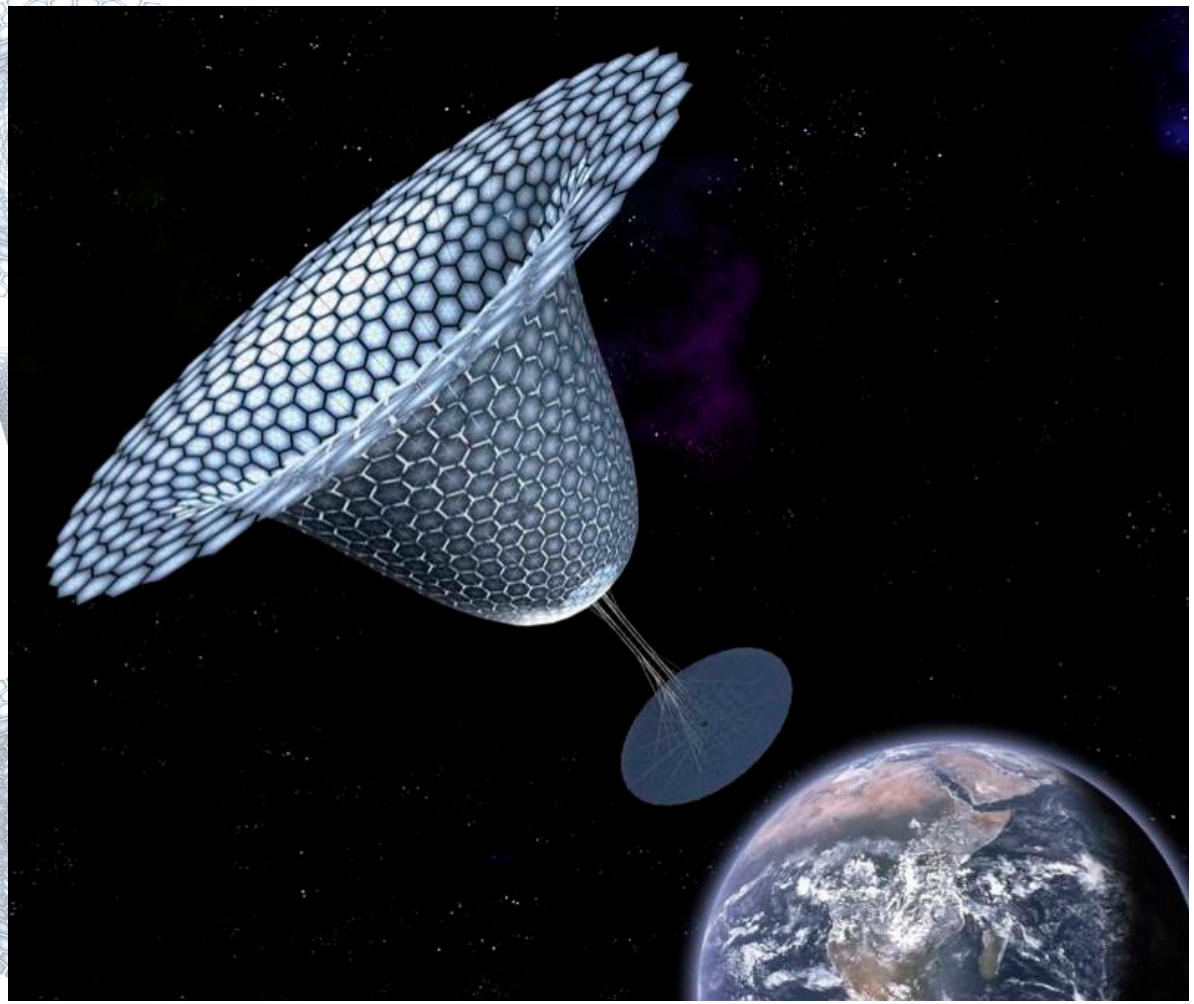
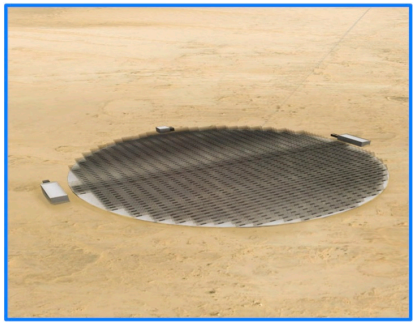
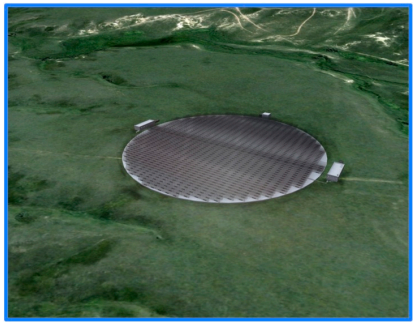
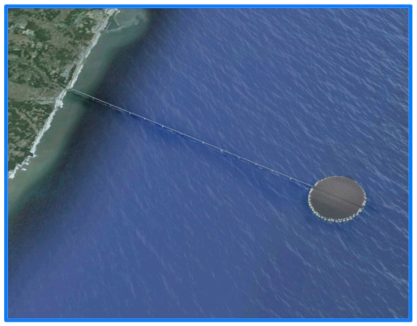
SPS-ALPHA Current Architecture Overview









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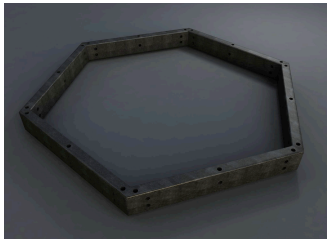
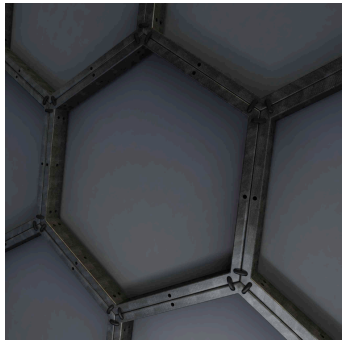
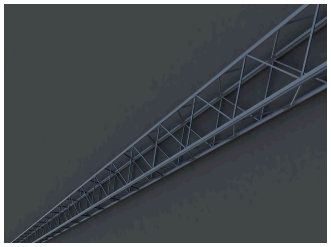
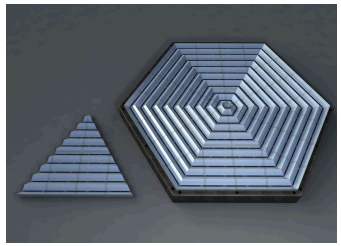
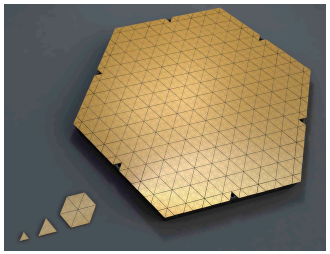
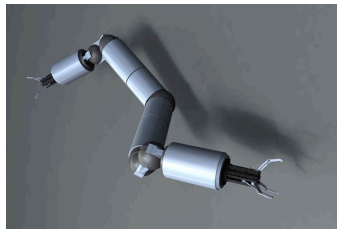
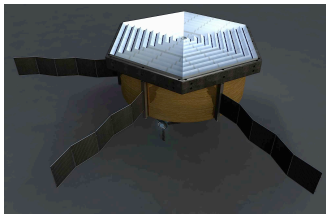
SPS-ALPHA
Key System Elements

- Principal System Elements of the SPS-ALPHA concept include the…
  - HexBus
  - Deployable Structure Boom Module
  - Solar Energy Harvesting Reflector
  - Interconnect(s)
  - Solar Power Generation (SPG) Module
  - Wireless Power Transmission (WPT) Module
  - PushMe-PullYou Bot
  - PAC (Propulsion & Attitude Control) Module

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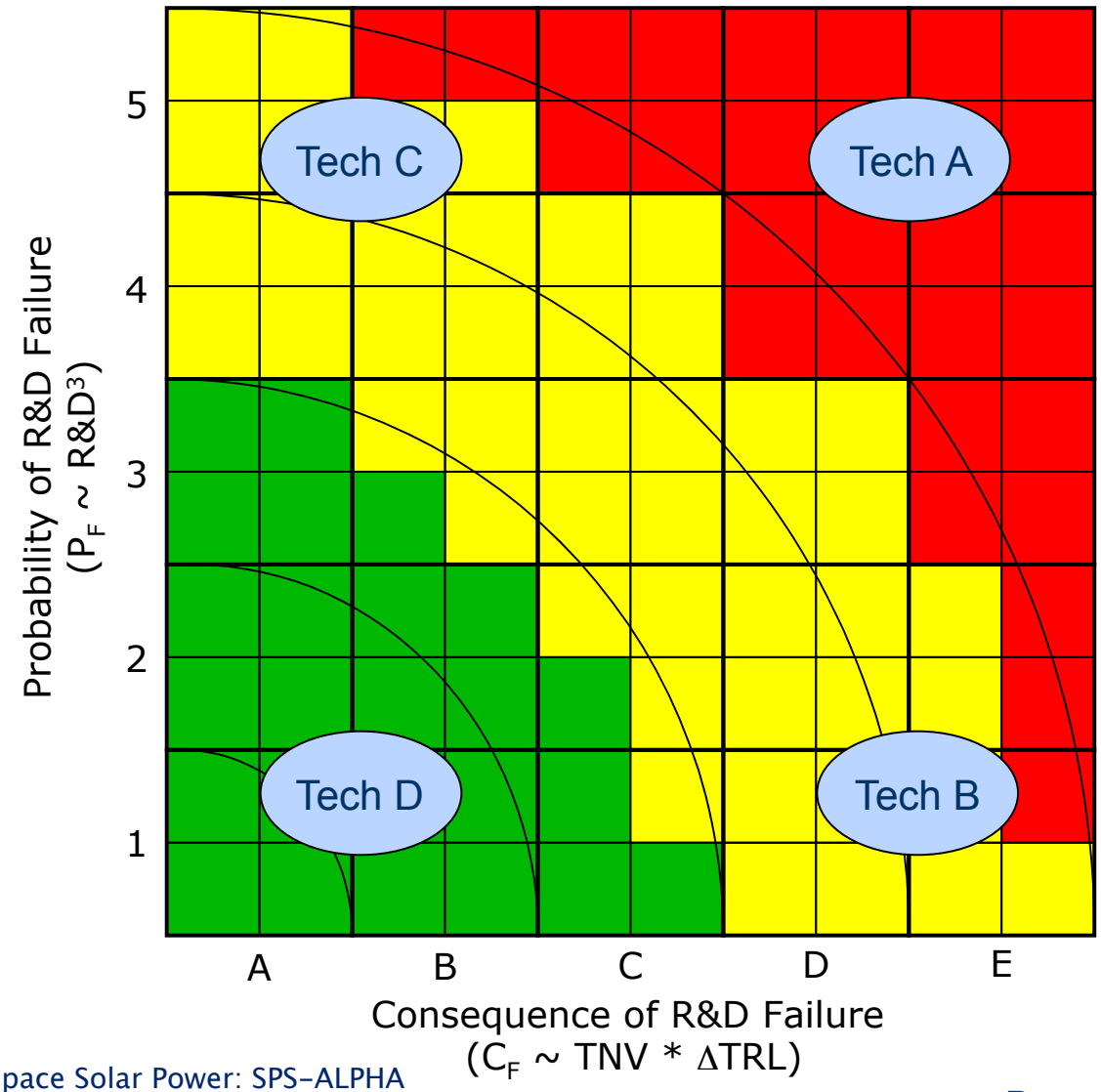
SPS-ALPHA Technology Readiness & Risk Assessment
TRL-Based Technology Risk Matrix

- Technology A
  - High Probability of Failure in R&D, High Importance
- Technology B
  - High Importance, Low Probability of Failure in R&D
- Technology C
  - Low Importance, High Probability of Failure in R&D
- Technology D
  - Low Importance, Low Probability of Failure in R&D



SSP Subject Matter Expert Workshops

- Two workshops have been held by the project
  - One in the US (Feb. 2012), and one in Europe (Mar. 2012)
- About 20 subject matter experts (SMEs) in key SSP and related technology areas have attended
- Selected results
  - **No** show-stoppers to the SPS-ALPHA approach have been raised
  - Critical Technologies for SSP have been identified and discussed
    - ✓ Wireless Power Transmission, End-to-end Power/Thermal, Systems Intelligence
    - ✓ Key systems elements include the Hexbus, Interconnects, etc.
  - Mass estimates for relevant systems and technologies have been refined
  - Elements for an SPS-ALPHA technology roadmap have been refined

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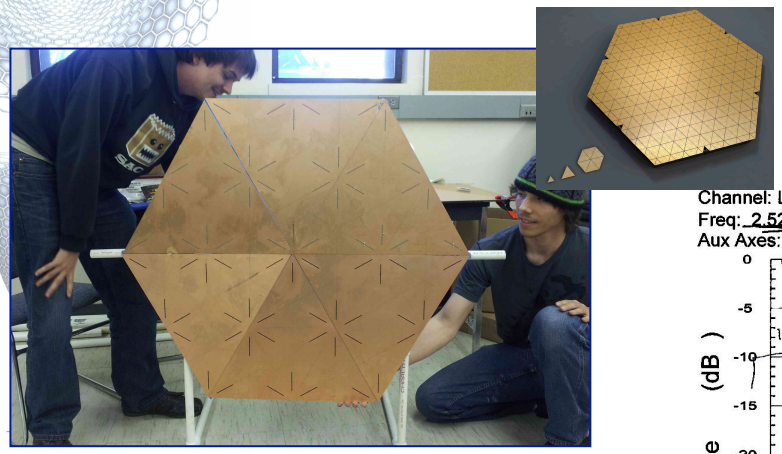
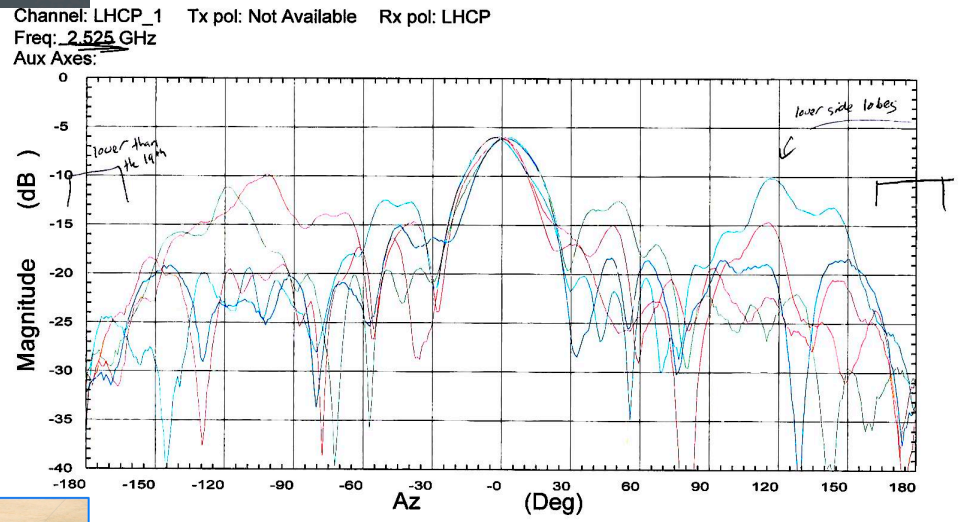
US WPT Preliminary Experiments

- Harvey Mudd College is nearing completion of an engineering clinic project to develop key WPT elements (with support from Prof. Kaya / Kobe U. & NRL / Paul Jaffe)





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SPS-ALPHA
Preliminary Systems Analysis Results

- Integrated Systems Analysis is ongoing
- Preliminary results include…
  - It does appear that SPS-ALPHA can be completely constructed from numerous small elements
  - For a 1,000 meter diameter WPT transmitter array,
    - ✓ Roughly 80,000 HexBus units will be required
    - ✓ The overall mass of the system appears good
      - ~10,000-12,000 mt
  - For system element sizing, the time between refueling operations for platform Propulsion / Attitude Control is a key parameter
- Technology Readiness & Risk assessment just getting started…
  - No significant technology risks identified for initial technology demonstrations
- During the coming months, modeling will be refined and sensitivity studies around key figures of merit will be completed (e.g., solar array efficiency, the specific mass of key elements, etc.)

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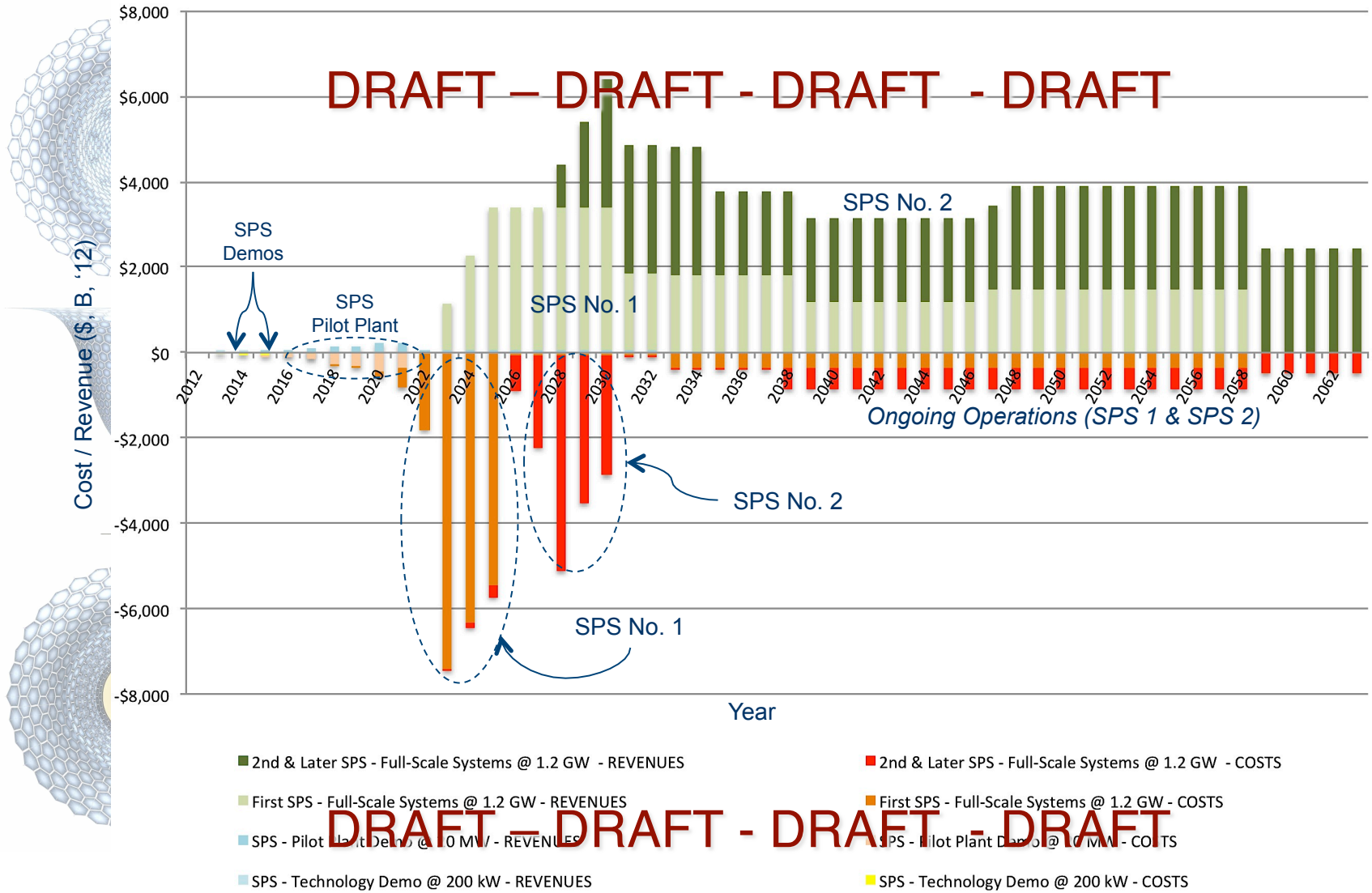
SPS-ALPHA Preliminary Systems Analysis Results

Draft Macroeconomic Modeling Example Draft



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Closing Observations

- Numerous groups have found that large-scale space solar power is technically feasible
- The successful development of SSP / SPS would compel a comprehensive transformation of global energy, energy security and space operations
- The hyper-modular approach reflected in the novel "SPS-ALPHA" concept represents an extremely strong – perhaps the strongest – current approach to realizing space solar power
- SPS-ALPHA represents a truly Revolutionary Energy, with transformational benefits possible for Sustainable Energy, Civil Space Programs, Commercial Space, and the Energy Security of the US, its friends and allies…

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