The University of Alabama in Huntsville
Propulsion Research Center
UAH 2000-01

Space Solar Power Exploratory Research & Technology (SERT) Technical Interchange Meeting 2

SERT TIM 2
Executive Summary

Submitted to

Joe Howell, COTR
Grant No. NAS8-H-32056D
Mail Code FD02
Marshall Space Flight Center, AL 35812

Prepared by

Jim Sanders
and

Dr. Clark W. Hawk
Propulsion Research Center
The University of Alabama in Huntsville
March 17, 2000

List of Acronyms

AAT	Architectural Assessment Tool
ASAP	As Soon as Possible
ACT	Advanced Communication Technology
ACRE	Advanced Chemical Rocket Engine
AIAA	American Institute of Astronautics and Aeronautics
amp/cm^2	Amperes per square centimeter
AU	Astronomical Unit (Distance from the Earth to the Sun)
ARC	Ames Research Center
B	Billion
BOL	Beginning Of Life
CDS	Conception Definition Study
C&DH	Control and Data Handling
CMG	Control Moment Gyro
COTS	Commercial-Off-The-Shelf
COTR	Contracting Officers Technical Representative
CS	Civil Service
CSA	Canadian Space Agency
DASA	German Aerospace
dB	Decibels
DC/RF	Direct Current Radiation Frequency
DOE	Department of Energy
DOS	Department of State
EMF	Electromagnetic Frequency
EMI	Electromagnetic Interference
EP	Electrical Power
EPRI	Electrical Power Research Institute
EOL	End of Life
ESA	European Space Agency
ETO	Earth to Orbit
EVA	Extra Vehicle Activity
Ex ante	Preexisting
FMCA	Functional Mission Concept and Architecture
FR	Frequency Range
FY	Fiscal Year
GEO	Geostationary Earth Orbit
GHz	Giga Hertz
GN&C	Guidance, Navigation, and Control
GPS	Global Positioning Satellite
GRC	Glenn Research Center
GRC	General Research Corp
GW	Giga watts
HALO	Earth-Sun L-2 Orbit (1.5 Million km from Earth-see figure page 58)
HEDS	Human Exploration & Development of Space
HET	Hall Effect Thruster
HFET	
HRST	Highly Reusable Space Transportation
HTS	High Temperature Superconductor
IAAM	Integrated Architecture Assessment Model
IPT	Integrated Product Team

IR	Infrared IRR Internal Rate of Return
ISP	In-Space Propulsion
Isp	Specific Impulse
ISS	International Space Station
ITAR	International
ITU	International Technical Union
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
kg	Kilograms
KSC	Kennedy Space Center
km	Kilometer
kW	Kilowatts
kWe	Kilowatts Electrical
kWh	Kilowatt Hours
LaRC	Langley Research Center
LCC	Life Cycle Cost
LDC	Less Developed Countries
LEO	Low Earth Orbit
MBG	Multiple Band Gap
MEO	Medium Earth Orbit
mm	millimeter
MPD	MagnetoPlasmaDynamic
MSC	Model System Category
MSFC	Marshall Space Flight Center
MWe	Megawatt electrical
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NASDA	National Aeronautics and Space Development Agency (Japanese Space Agency)
NRA	NASA Research Announcement
NRC	National Research Council
OMV	Orbital Maneuvering Vehicle
OTA	Office of Technology Assessment—US Congress now defunct
PMAD	Power Management and Distribution
PRC	Propulsion Research Center
POD	Point of Departure
POP	Perpendicular to Orbit Plane
POST	Trajectory Model
PV	Photovoltaic
R&D	Research and Development
RF	Radio Frequency
RLV	Reusable Launch Vehicle
RMS	Root Mean Square
R&T-WG	Research & Technology Working Group
R&T	Research and Technology
RTG	Radioisotope Thermal Generator
SAIC	Science Applications International Corp
SAIM	System Analysis Integration & Maintenance
SD/PV	Solar Dynamic versus Photovoltaic (power generation)
SE&I	Systems Engineering and Integration
SEPS	Solar Electric Propulsion System
SERT	Space Solar Power Exploratory Research & Technology
Si	Silicon
SiC	Silicon Carbide
SI-WG	Systems Integration Working Group
SMSM	Self-Mobile Space Manipulator
SMSA	Standard Metropolitan Statistical Area

SOTA	State-Of-The Art
SMOC	Senior Management Oversight Committee
SPS	Space Power Satellite
SSM	Space Segment Model
SSP	Solar Space Power
STUS	Space Transportation Upper Stage
TBD	To Be Determined
TIM	Technical Interchange Meeting
TPS	Thermal Protection System
TRL	Technology Readiness Level
OOMV	Tug Orbit to Orbit Maneuvering Vehicle
UAH	University of Alabama in Huntsville
UNESCO	United Nations
US	United States
V-ac	Volts alternating current
V-dc	Volts direct current
V/m	Volts per meter
VRC	Virtual Research Center
Vs.	Versus
WHO	World Health Organization
W/m^2	Watts per square meter
W/kg	Watts per kilogram
WPT	Wireless Power Transmission

Abstract

The University of Alabama in Huntsville's (UAH) Propulsion Research Center hosted the Space Solar Power Exploratory Research & Technology (SERT) Technical Interchange Meeting (TIM) 2 in Huntsville, Alabama December 7-10, 1999 with 126 people in attendance.

The SERT program includes both "in-house" and competitively procured activities, which are being implemented through a portfolio of focused R&D investments—with the maximum leveraging of existing resources inside and outside NASA, and guided by these system studies.

Axel Roth, Director of the Flight Projects Directorate NASA MSFC, welcomed the SERT TIM 2 participants and challenged them to develop the necessary technologies and demonstrations that will lead to Space Solar Power (SSP) International implementation.

Joe Howell, NASA MSFC, reiterated the SERT TIM 2 objectives:

1) Refining and modeling systems approaches for the utilization of SSP concepts and technologies, ranging from the near-term (e.g., for space science, exploration and commercial space applications) to the far-term (e.g., SSP for terrestrial markets), including systems concepts, architectures, technology, infrastructure (e.g., transportation), and economics.

2) Conducting technology research, development and demonstration activities to produce "proof-of-concept" validation of critical SSP elements for both the nearer and farther-term applications.

3) Initiating partnerships Nationally and Internationally that could be expanded, as appropriate, to pursue later SSP technology and applications (e.g., space science, colonization, etc.).

Day one began with the NASA Centers presenting their SERT activities summary since SERT TIM 1 and wound up with a presentation by Masahiro Mori, NASDA, titled "NASDA In-house Study for SSP Demonstration for the Near-Term.

Day two began with the SERT Systems Studies and Analysis reports resulting from NRA 8-23 followed by presentations of SERT Technology Demonstrations reports resulting from NRA 8-23. Day two closed with John Mankins presentation on "Technology Roadmapping" and the delivery of the charge to the Work Breakout Sessions.

Day three began with the eleven Work Breakout Session which was the major function of this TIM 2 and day three ended with reports by the Chairs of the eleven Work Breakdown Sessions.

Day four began with the six Integrated Product Team (IPT) meetings and ended with closing plenary panel sessions.

Background and Introduction

The University of Alabama in Huntsville's (UAH) Propulsion Research Center hosted the Space Solar Power Exploratory Research & Technology (SERT) Technical Interchange Meeting (TIM) 2 in Huntsville, Alabama December 7-10, 1999 with 126 people in attendance.

Dr. Kaya demonstrated Wireless Power Transmission at the beginning of SERTS TIM 2, which was the same demonstration as at the July 1999 IAF.

Axel Roth, Director of the Flight Projects Directorate at NASA MSFC, welcomed the SERT TIM 2 participants and challenged them to develop the necessary technologies and demonstrations that will lead to Space Solar Power (SSP) International implementation.

Day 1

SERT TIM 2 Objectives

Joe Howell, NASA MSFC, provided the following SERT TIM 2 objectives:

1) Refining and modeling systems approaches for the utilization of SSP concepts and technologies, ranging from the near-term (e.g., for space science, exploration and commercial space applications) to the far-term (e.g., SSP for terrestrial markets), including systems concepts, architectures, technology, infrastructure (e.g., transportation), and economics.

2) Conducting technology research, development and demonstration activities to produce "proof-of-concept" validation of critical SSP elements for both the nearer and farther-term applications.

3) Initiating partnerships Nationally and Internationally that could be expanded, as appropriate, to pursue later SSP technology and applications (e.g., space science, colonization, etc.).

SERT Program Overview

John Mankins, NASA Headquarters, presented the SERT Program Overview:

During 1999-2000, NASA is conducting a SERT program which will conduct preliminary studies and strategic technology research and development across a wide range of areas to enable the future development of large multi-megawatt SSP systems and wireless power transmission (WPT) for government and commercial markets (in-space and terrestrial).

This program will allow informed decisions regarding future SSP and related R&D investment by both NASA management and prospective external partners. In addition, the SERT program will guide further definition of SSP and related technology roadmaps including performance objectives, resources and schedules; including "multi-purpose" commercial missions, Earth and Space science, exploration, and other government applications, such as national defense.

The SERT program currently includes both "in-house" and competitively procured activities, which are being implemented through a portfolio of focused R&D investments—with the maximum leveraging of existing resources inside and outside NASA, and guided by system studies. The Portfolio consists of three complementary elements:

1) System Studies and Analysis
2) SSP Research and Technology
3) SSP Technology Demonstrations

SERT Integration, Analysis and Modeling

Connie Carrington, NASA MSFC, and Harvey Feingold, SAIC, presented the status of the "SERT Integration, Analysis, and Modeling" which included the following:

Overview of Systems Integration Working Group (SIWG)
Points of Departure (POD)
Alternate Concepts (PODs)
Modeling/Analysis Status and Selected Results
Identified Issues and Technology Needs
Accomplishments and Status

NASA Centers Activities Summary

Next the NASA Centers presented their SERT activities summary since SERT TIM 1:

Ames Research Center (ARC) presentation was made by Han Thomas, who used a computer generated presentation and he did not leave an electronic copy nor a hard copy. All efforts to contact Hans Thomas have been unsuccessful to date; but these efforts to contact Hans Thomas will continue until his material is in hand!

Shelia Bailey made the Glenn Research Center (GRC) presentation and she included:
- Power Management and Distribution Activities
- SiC High Power and High Temperature Electronics Research

The Status report by Professor Krishna Shenia, University of Illinois at Chicago, was moved from Day 2 to Day 1 due to a previous travel commitment. The title of Professor Shenia's presentation was "Defect Engineering and Reliability Study of SiC High Power Devices.

Steve Kant made titled "SSP Platform Systems" the Goddard Space Flight Center (GSFC) presentation.

The following people made the Jet Propulsion Laboratory (JPL) presentations:
- Wireless Power Transmission (WPT) by Richard Dickinson
- Inflatable Structures Technology Development by R. Freeland
- Space Power Robotics by Gregory Hickey
- Science Applications by Henry Harris (Actually Presented by Richard Dickinson)

The following people made the Johnson Space Center (JSC) presentations:
- Microwave System Analysis for the 5.8 GHz Wireless Power by Dickey Arndt
- Robotic Assembly, Maintenance and Servicing by Chris Culbert (Do not have a copy of Chris's presentation as of to date).

The Kennedy Space Center (KSC) did not participate in SERT TIM 2, but we included Carey McCleskey's SERT Technology Mini-Workshop conducted at NASA Headquarters November 9-10, 1999.

The Langley Research Center (LaRC) presentation was given by Chris Moore and was titled "Structures, Materials, Controls, and Thermal Management.

The following people gave the Marshall Space Flight Center (MSFC) presentations:
- Ground Power Systems by George Kusic
- Space Transportation Infrastructure by John Olds
- Functional Mission Concepts & Architecture by Lanny Taliaferro
- Environmental Safety and Health by Marvin Goldman
- Space Solar Power Applications by David Smitherman

An Economic Assessment of Satellite Solar Power Technology as a Source of Electricity for Space Based Activities

John Fini, Strategic Insight, presented "An Economic Assessment of Satellite Solar Power Technology as a Source of Electricity for Space Based Activities".

NASDA In-house Study on SSP Demonstration for the Near-Term

Day 1 wound up with a presentation by Masahiro Mori, NASDA, titled "NASDA In-house Study on SSP Demonstration for the Near-Term.

Day 2

SERT Systems Studies and Analysis reports resulting from NRA 8-23

Day 2 began with the following SERT Systems Studies and Analysis reports resulting from NRA 8-23:

1) System Studies and Analysis by Jay Penn, Aerospace Corp.
2) Systems Studies and Analysis by Seth Potter, Boeing
3) Power With Out Wires (POWOW) by Henry Brandhorst, Auburn University
4) Advance Design Concepts for SSP by Geoffrey Landis, Ohio Aerospace Institute
5) Application of SSP Technology to Space Transportation for HEDS Missions by Steve Hoffman, SAIC.
6) Market Analysis & External Factors by Carie Mullins, Futron
7) Assessment, Outreach, and Future Research of Environmental and Safety Factors Related to SSP by Margo Deckard, Space Frontier Foundation
8) AIAA Assessment: (1) International Cooperation, (2) Applicability to Terrestrial, Civil Space, and Military Space Programs, and (3) Technololgy by Jerry Grey, AIAA
9) Economic and Market Analysis to Ascertain the Potential Impact of SSP on a Specific Locale by John Fini, Strategic Insight

SERT Research & Technologies resulting from NRA 8-23

Day 2 continued with presentations of SERT Research & Technologies resulting from NRA 8-23:

1) Advanced High-Voltage Solar Array Design Guidelines from Soar Tile Testing by Brian Reed, Boeing
2) Multi Band Gap High Efficiency Converter (Rainbow) by C. William King, Essential Research
3) Effects of Hypervelocity Impacts on High Voltage Soar Arrays by Henry Brandhorst, Auburn University
4) Low Mass Phased Array Antenna for Wireless Power Transmission by James McSpadden, Boeing Phantom Works
5) Development of Inflatable Space Frame by Dilip Darooka, ILC Dover, inc.
6) Innovative Deployable Radiator for Space Solar Power Systems by Roger Giellis
7) Fabrication of Very High Efficiency 5.8 GHz Power Amplifiers using AlGaN HFETs on SiC Substrates for Wireless Power Transmission by Gerry Sullivan, Rockwell Science Center
8) High-Voltage, Modular, DC-to-DC Converter by David Fox, Hamilton Sundstrand Aerospace
9) Rectenna Development for Wireless Power Transmission by Bernd Strassner, Texas A&M University
10) 5.8 GHz Circular Polarized Dual Rhombic Loop Antenna for Space Power Applications by Bernd Strassner, Texas A&M University

SERT Technology Demonstrations resulting from NRA 8-23

This was followed by presentations of SERT Technology Demonstrations resulting from NRA 8-23:

1) Wireless Power Transmission for Science Applications by James Benford, Microwave Sciences, Inc.
2) Ultralightweight Fresnel Lens Solar Concentrators for Space Power by Mark O'Neill, ENTECH, Inc.
3) Skyworker Assembly, Inspection, and Maintenance of SSP Facilities by Red Whittaker, Carnegie Mellon University
4) Space Solar Power Technology Demonstration for Lunar Polar Applications by Mark Henley, Boeing

"Technology Roadmapping" and delivering the charge to the Work Breakout Sessions

Day 2 was closed with John Mankins presenting "Technology Roadmapping" and delivering the charge to the Work Breakout Sessions which begin tomorrow (day 3). John Mankins presented the following technology challenges for SSP:

- Solar Power Generation
- Wireless Power Transmission
- PMAD
- Structural Concepts, Materials, and Dynamics
- Thermal Materials and Thermal Management
- Controls and Operations cannot be worked as yet
- In-Space Transportation, propellant availability and cost are unresolved issues

John Mankins presented the following Model System Concept 1 (MSC 1) fundamental decision points assuming that MSC 1 POD is launched for testing in the 6-7 year timeframe:

- Near-term decision points
  - Mission and capabilities
    - Delta V
    - Payload
    - On-board utilities
  - Solar power generation
    - PV versus Solar Dynamic (current recommendation is PV of some sort)

- Mid-term decision points (in the next 2-3 years)
  - System configuration
    - Single spacecraft or mother/daughter
    - Program/system cost goals/constraints
  - Solar array type
    - Planar
    - Thin film
    - Concentrator (e.g., POD 1.1 or POD 1.2)
  - Wireless power transmission
    - Frequency?
    - If microwave

        - 2.45 GHz; 5.8 GHz? Other RF
    - If visible
        - IR; green; other?
    - Power management and distribution: Operational voltage
        - 300 V or higher?
        - Energy storage on board?
    - Structural concept, materials and dynamics
        - Mix of structural concepts
            - Integrated, erectable, deployable, inflatable
        - Platform systems
            - Autonomy and operations approach: Traditional or intelligent systems
        - Earth-to-orbit transportation and infrastructure
            - One launch or several
            - One element or several with in space assembly
        - In-space transportation and infrastructure
            - Space transportation R&T goals?
                - On-board propulsion (primary? and/or an experimental package?)
        - Robotic assembly, maintenance and servicing
            - Assembly approach
            - Use of International Space Station or not?
            - Astronaut compatibility?

- Later decision points (prior to CDR)
    - System configuration
        - Lifetime
        - Number of MSC 1 units and/or flights
    - Wireless power transmission
        - Microwave or visible?
            - If microwave
                - Solid state
                    - Magnetrons
                    - Klystrons
            - If visible
                - Lamps and reflectors (spot light approach)
                - Lasers?
- Power management and distribution
    - If energy storage, what type?
- Structural concepts, materials and dynamics
    - GN&C/attitude control design (e.g., momentum wheels? Station-keeping?)
- Robotic Assembly, maintenance and servicing
    - Resident robots or not? Roles?

John Mankins also presented the above type of material for MSC 2 and MSC 3 as part of his charge to the eleven Work Breakout Session groups.

Day 3

Work Breakout Sessions meeting

Day 3 began with the eleven Work Breakout Sessions meeting in parallel until 3:00 pm

1) Systems Integration, Analysis, and Modeling co-chaired by Harvey Feingold and Connie Carrington.
2) Space Transportation and Infrastructure co-chaired by David Way and Mike Nicks

3) Wireless Power Transmission co-chaired by Richard Dickinson and Jim McSpadden
4) Platform Systems co-chaired by David Maynard and Seymour Kant
5) Robotics, Assembly, and Servicing co-chaired by Chris Culbert and Red Whittaker
6) Structures, Materials, Controls, and Thermal co-chaired by Chris Moore and Mike Gilbert
7) PMAD and Ground Power Systems co-chaired by Jim Dolce and Tom Lynch
8) Solar Power Generation co-chaired by Shelia Bailey and Nick Mardesick
9) Environmental and Safety Factors co-chaired by Marvin Goldman and Gayle Brown
10) International Issues and Opportunities co-chaired by Jerry Grey and Mark Henley
11) SSP Applications co-chaired by David Smitherman and Ken Cox

The Work Breakout Session reports

Day 3 ended with reports from the eleven Work Breakdown Session chairmen.

Work Breakout Session 1 Report

The Work Breakout Session report from group 1, Systems Integration, Analysis & Modeling, chaired by Connie Carrington and Harvey Feingold was as follows:

Objective:

- Address the SIWG role in achieving the near to long term goals of SERT and SSP
- Update and/or develop technology roadmapping products for the SERT systems function (WBS element B.12)

Session results:

- New "Bubble Chart" created
  - Uses modified version of technology roadmap template
  - Chart driven by systems information that must be provided to RTWG's, leading to required system studies and analyses.
  - Identified product is system level characterization and documentation of performance, cost, schedule and risk for defined candidate concepts.
  - Will be used to update last years Systems Integration "Bubble Charts"
- Reviewed MSC 1 and MSC 3 decision points
  - Tried to determine if the system level information or analyses would be needed to support the identified configuration or technology decisions.
  - Decision points can be used to develop system integration, analysis and tool development schedules analogous to technology development schedules that lead to MSC 4.
  - Cost of identified systems support still to be determined.

SIWG recommendation on MSC 1 fundamental decision points:

- Near-term decision points during SERT
  - These decisions depend upon the particular mission scenario, and the mission and technology development objectives. An additional decision point should be added: If microwave, what frequency is suitable.
- Mid-term decision points within the next 2-3 years:
  - Technology breakthroughs may determine solar array type. WPT decisions will depend on the mission scenario, as does the GN&C approach, on-board propulsion demo status, and the assembly approach. We recommend that the transmitter technology decision be made in mid-term, since it is a design driver for configuration and subsystems. We prefer 300 V solar arrays to direct drive SEP thrusters, with the capability to use DC-DC conversion only if lower S/S voltages (120 V) can be achieved. The decision about the need for on-board energy storage will depend upon the selected configuration and mission application. Structural technology decisions should be based on lifetime cost considerations, rather than mass (unless mass is a showstopper). The decision on traditional versus intelligent systems should be

based on the state-of-the-art at this time (off-the-shelf technology). We recommend scaling the mission to minimize the number of launches, and would use in-space assembly only if absolutely necessary. We do not recommend use of ISS or astronaut compatibility for assembly or maintenance.

Later decision points prior to CDR

Lifetime decisions should consider follow-on applications, perhaps commercial, after the primary mission objectives are met. Microwave vs. laser decisions will be greatly influenced by international policy. The transmitter technology decision should be made earlier, since it is a driver for many other decisions and will delay development if deferred. The decision on robotic demonstrations should also be made earlier, since it will impact configuration and mission design as well as operations, and the decision should depend on cost impacts to the program. Energy storage technology, in any, will depend on the selected mission scenario. GN&C design decisions should be made earlier, although sensor selection could be made at this latter period.

SIWG recommendations on MSC 3 fundamental decision points:

Near-term decision point within the next 4-5 years

These decisions should use knowledge determined from system studies and the MSC 1 program. We expect to have more insight into technology readiness levels, high voltage issues, and cost impacts of technology decisions. We will have a better understanding of the concepts, and insights into spin-off applications and commercial applicability. We hope to have a better understanding of projected launch rate capabilities, and insight into future launch infrastructures.

Mid-term within next 8-9 years and later pre-CDR decision points

These decisions should be made from lessons learned during the MSC 1 program. At the same time, they should address the critical technology needs fro MSC 4 (with implications that many decisions on MSC 4 will have to be made concurrently). As in MSC 1, the technology selection for WPT should be made in mid-term rather than later, since it is a primary driver for many other subsystems, configurations, mission scenario, operations, kind regulations/safety requirements. Propulsion technologies should also be made in mid-term since it is a primary driver for MSC 3 configurations.

Work Breakout Session 2 Report

The Work Breakout Session report from group 2, Space Transportation and Infrastructure co-chaired by David Way and Mike Nix was as follows:

Charge from John Mankins

What data needs to be exchanged between teams?

What data will need to be provided in the near future?

Database, structured properly, could address needs

Data (documented with assumptions of what is included in estimates

Modeling results

Algorithm

Problem: Some teams do not have even basic information needed to start analysis

E.g., Structures team does not have loads

Concept proposers should take responsibility for providing schemes for assembly, component packaging, etc.

Assembly complexity vs ETO launch sizing (do we need to optimize?):

Currently assuming 20 to 40 MT per launch (5 lb/cubic foot) for transportation
Larger payload units could simplify assembly, but launch vehicle availability is a consideration
Transfer vehicle could become part of on-orbit structure
How fast does transportation need to provide materials? Driven by economic considerations
High flight rate is better, from transportation point-of-view
SIWG can provide number of launches per satellite (Current assumption is one SSP per year, but economic considerations will require a fleet of SSP satellites in perhaps a 5 year period of time

Recommendations:

1) Get SIWG, transportation, structures, and robotics teams together ASAP to establish assembly philosophy baseline.
2) Decide ASAP on a LEO-GEO transportation philosophy baseline

Interactions between Systems and Transportations Teams:

Questions:

Do we need a depot for storing materials, tools, etc?

Does each package deliver itself to GEO (maybe higher, due to GEO station keeping considerations), or do we have tug deliver launch packages?

1) Deploy SSP arrays for LEO-GEO transportation (load on structures, degradation, PMAD, and high voltage considerations, etc.)
2) Transportation has traded expendables, reusable, and autonomous SEP approaches for transportation considerations only
3) Autonomous SEP approach appears favorable to transportation, but oversizes/overdesigns the on-orbit SSP configurations, structures, PMAD, etc.

Do we need LEO transportation nodes?

1) May need three for orbit phasing considerations
2) Will need equatorial launch sites (build our own island?)

What is the lifetime of this system?

What transportation needs from SIWG?

Density and dimensions of the payloads
Launch rates
Payload mass
Assembly sequence
Maintenance estimates

Information needed by Systems and transportation teams from the following other teams:

Propulsion needs

Efficiency vs specific impulse vs propellant type
Specific mass of propulsion unit

Solar array needs

Specific power with or without structure
Degradation (thermal and radiation)
Efficiencies (BOL and EOL, to aid in lifetime estimates)

Robotics needs

Robotic capability for assembly
Reliability
Mass and cost including all support
Type of robots

Wireless Power Transmission (solid state, magnetrons, klystrons, lasers)

Characteristics: Mass, configuration, performance with assumptions
Efficiency chains (space segment, atmospheric, ground rectenna)

Platform Systems needs

Reliability data for all hardware (SSP satellites, robotics, ground systems)
Mass and cost data for platform systems with all assumptions
Communications and computers with all assumptions

- Structures needs
  - Mass estimate for solar arrays, transmitter array, reflectors/bearings, integrating structure
  - Number of control actuators and sensors, mass, power, and cost estimates
  - Assembly approach and deployment
  - Packaging
  - Thermal mass, radiator configurations and locations
- PMAD Needs
  - Voltage levels, AC or DC, radiator temperatures
  - Mass distribution of components for configuration, design recommendations
  - PV to SEP switching information
- SSP applications
  - Missions
  - Requirements
  - Spin off applications that could impact systems and transportation decisions, such as lifetime
- Environmental, safety and health needs
  - Allowable power densities
  - Stake holders such as exclusion zones and cost impacts

Missing element in Work Breakout Sessions
- Operations
  - Command and control (ground and space)
  - Hierarchy, control sites, etc
  - Role of government and private industry

Work Breakout Session 3 Report

Work Breakout Session group 3, Wireless Power Transmission, co-chaired by Richard Dickinson and Jim McSpadden report follows:
- Solid State needs
  - Two filters per element, many filters, large volume and large mass
  - Establish EMC requirements
    - Currently large uncertainty
  - More emphasis in laser systems area
  - Effects of weather on system
- MSC 1 R&T goals (launched in 6-7 years timeframe)
  - Free flyer furnace
  - Photon sail
    - Microwave and laser
  - Micrometeoroid arc
  - Beam turner mirror with slew tracking
  - Pilot beam steering
  - Safety beam de-phasing, etc.
  - Two to three years more study of options for flight in 6-7 years
- MSC 3 R&T goals (launched in 15 years timeframe)
  - More and bigger MSC 2
  - $300 Million

Work Breakout Session 4 Report

Work Breakout Session group 4, Platform Systems, co-chaired by David Maynard and Seymour Kant report:

High level task functions
- Reliability methodology
  - Goals
    - Identify methodologies and risk mitigation techniques to support mission assurance

Identify failure modes
Predict lifetimes of year 2020 configurations
Determine lifetimes of new technologies (MTBF >30-40 years)
Derive maintenance requirements
Approach
Identify components reliability drivers
Include damage modes
Define functional relationships of subsystems
Characterize uncertainties
Apply probabilistic failure assessment methodologies
System monitoring and health management
Goals
Define satellite communications requirements
Incorporate high bandwidth telecommunications
Provide high capacity computing and data management
Determine communications subsystems
Evaluate command and control linkage (C&DH)
Accommodate for robotic systems and operations
Approach
Identify operational and situational factors
Define communication frequency domains
Construct communications subsystems and apply to concept architectures
Configure hierarchical operations decisions tree
Provide "hot" change-out of components
Technology sharing
Goals
Capture advantages of current and emerging technologies
Employ technologies to minimize mass and cost ($100-$200/Kg)
Approach
Identify opportunities for utilizing technology
Development from other programs (NASA, other agencies and industry)
Map technology insertion opportunities
Facilitate synergisms of function and integration of operations
Consider alternative configurations for SSP components, subsystems and systems
Evaluate interfaces and identify areas requiring emphasis
Leverage on-going activities to minimize effort duplications
Focus on critical elements
Concept architectures, technology, integration and emerging R&T needs
Alternate architectures
Thermal analysis
Goals
Define heat rejection requirements
Evaluate heat transfer and radiator concepts
Approach
Define environmental and structural factors
Characterize SSP operation affecting thermal design (transient, load rejection, and shadowing)
Compare candidate thermal subsystems (efficiency, mass, maintenance, cost, etc)
Controls
Goals
Define control schemes for each MSC
Develop two-tier, ultra-high precision, extremely large flexible-surface control technology
Required surface flatness /40RMS/20RMS
Subarray tilt angle to within 2 arc –minutes RMS

Subarray size to 4MX4M
Applicable FR frequency to 500 M diameter range to 5.8 GHz
Applicable antenna size

Approach

Identify performance criteria for concepts structures
Define control approaches for various configurations
Characterize multifunctional control for thrust/non-thrust modes, antenna, control, and solar array drives

Work Breakout Session 5 Report

Work Breakout Session Group 5, Robotics, Assembly, and Servicing, co-chaired by Chris Culbert and Red Whittaker report:

Robotics Technology Challenges

- Maintenance during continuous operations
- Environmental issues (robot operating conditions)
  - Micrometeorite impact, heat, RF and high voltage
- Stick to/grasp anything (minimize scarring)
- Walk/manipulate softly
- Wiring, plumbing, and connecting work
- Coordinated operations with ground (levels of autonomy)
- Satellite to robot power and communications
- Robot state assessment
- "Migrant" construction robots?
- Inspection approaches
- Extended operations for autonomous robots (MTBF of robot)
- New and/or unique robot physiologies
- Simulation and studies
- Cooperative robots (coordinated activities)
- Material logistics

Interfacing challenges

- Facility mobility
  - Hardpoints, grapple, etc
  - Spots to minimize reaction forces
- Facilitate reaction control
- Facilitate maintenance
  - Design for robot only maintenance
  - Smart structure, self-diagnosis, and component changeout
- Clearance and accessibility (pathways)
- Location/marking/components bar-coding
- Communication and data (diagnostic facilities)
- Robotic infrastructure/toolshed, or warehouse

Robotics Technology Demonstration Opportunities

- General philosophy: Develop basic technologies through ground demos leading to specific capabilities demonstrated on-orbit in MSC 1 through MSC 4
- Ground demonstrations
  - Robotic component to inspect and calibrate a ground phased array structure
  - Robotic assembly of a ground based array structure
  - Grappling and manipulation tests (to develop grasp anything concepts)
  - Basic environmental studies (heat and EMF affects on robots)
  - Connectors and plumbing fittings handled by robot
  - Develop extended operations concepts and procedures
  - Autonomous robot docking, self-charging, and self-maintaining

- Mobility approaches that lead to "walking softly"
- Cooperative control of multiple robots; information sharing
- Robot state awareness capabilities

Flight demonstrations
- Robotic assembly techniques
- Environmental tests
- Zero g mobility tests
- Automated rendezvous and docking
  - MSC 1
    - Well suited for inspection demonstration and simple maintenance
    - Onboard inspection system capable of traversing and inspection the vehicle and providing status information to the ground
  - MSC 3
    - Begin testing initial assembly concepts. Target areas such as plumbing connections, wiring routing, etc.
    - Demonstrate full-scale inspection and maintenance
    - Once core vehicle mission has been completed, use robotic maintenance to keep sub-elements functional over an extended period of time.
  - MSC 4
    - Demonstrate significant portion of robotic assembly capability, including coordination between multiple robots.
    - Refine inspection and maintenance approaches
    - Demonstrate long-terms operational processes

Short Tem Future Work
- Study to characterize robotics assembly and maintenance activities and visualize scenarios
- Integrated project to demonstrate cooperating robots performing assembly with visual service as needed
- Study "stick-to" approaches (Van de Waals forces, etc
  - Non-goopy, sticks to glass, in vacuum, under thermal variance

Work Breakout Session 6 Report

Work Breakout Session group 6, Structures, Materials, Controls, and Thermal co-chaired by Chris Moore and Mike Gilbert report:

- SSP Inflatable Structures Roadmap
  - Develop a database of properties for rigidizable materials
  - Characterize structural performance of inflatable columns
  - Develop inflatable truss concept with scaling laws
  - Build and test proof-of-concept trusses
  - Integrate inflatable in prototype SSP structures
- Logic diagram for multifunctional structures
  - Structural/thermal load carrying panels with embedded heat pipes
  - Structures/PMAD load carrying PMAD backbone
  - Interconnects
    - Mechanical
    - Thermal
    - Electrical
  - Demos
    - Structural/PMAD
    - Thermal/WPT
    - Antenna module
  - Module assembly
- Thermal logic diagram
  - High k materials
    - TPS

- Nanotubes
- c-f
- Loop heat pipes
  - High temperature wicks
  - Liquid metals
- Advanced radiators
  - Carbon-carbon, etc
  - Deployable
  - Heat pipe radiators
  - Coatings
  - Louvers
  - Electrochromic
- Demos
  - Integrated heat pipe/radiator
  - Central thermal bus
  - Waste heat regen
    - Heat engine
    - TPV
    - Thermoelectric cooling

Control
- Architecture
- Control algorithm
  - Modeling
  - Design
  - Simulation
- Sensors and actuators
  - Attitude
  - Structural sensing
  - Metrology
  - Momentum actuators
  - Strain actuation
  - Differential GPS
  - Networking communications
  - Avionics
- Inflatable structural control
- Demos
  - Integrated structural/attitude control

Technology needs for ABACUS concept
- Structures
  - Modular rigid abacus structure
  - Lightweight deployable solar arrays
  - Modular antenna structure
  - Lightweight RF reflector
  - Integrated structure/PMAD/thermal
  - 500 meter rotary bearing
  - Autonomous modular assembly
  - In-space manufacturing
- Thermal management
  - Lightweight deployable radiators
  - High-temperature loop heat pipes
  - Management of viable thermal loads
- Control
  - Distributed attitude control and structural control
  - Pointing of RF reflector
  - Shape control of RF reflector (1.3 mm accuracy)
  - Solar array tracking

Work Breakout Session 7 Report

Work Breakout Session Group 7, PMAD and Ground Power Systems, co-chaired by Jim Dolce and Tom Lynch report:

PMAD design risks

100 KV operation: Test prototype transfer and cable segment to validate design baseline

MTBF for 30 years: Evaluate design for thermal/voltage stress and other factors

HV shielding: Test design concept in ground test facility

Failure detection and recovery: Analyze design concept for subsection failure by shorting. Can design withstand failure and stop propagation?

High temperature electronics: Develop program parts list suitable for 200 C to 300 C operation. Find and characterize candidate parts. Predict MTTBF for these parts.

PMAD experiments

Cable usage at high current density: Determine realistic SSP guidelines for individual wires in 0 K space environment. Can 160 A per square cm be exceeded?

Transfer-to-antenna heat load isolation: Test thermal isolation capability of transformer to antenna with candidate insulation technique.

Protection switch for 25KA at 80 V: Design and fabricate turnoff switch for 25 KA. Determine sharing, extendibility, power density for candidate design.

Transfer operation at 100 KV: Design and fabricate 10 KW transformer for 100:1 ratio at 10 KHz and 1000 V peak drive. Test for corona, dielectric stress and leakage inductance.

Cable transient response: Fabricate test model and measure step response with simulated drive and load. Develop analytic simulation model from test data.

Ground power issues

Utility grid acceptance of SSP power: Less than 20 GW must transport DC power to remote grid. Federal government controlled/

Power drop out: Site specific alternate power sources. Alternate SSP.

Grid fault, Rectenna operations: What happens to Rectenna voltage and SWR?

Site selection: Desert, volcano caldero,

Shielding

Protection of cable and distribution

R&T needs:

High current breakers

SiC power devices for high temperature

AC cable drive

AC rectifier/transformer

LAN communication tower and antenna

Superconductor: Cryogenic in space with MTBF

High temperature passive components

Thermal management and recovery

High power: Near term 10-100 KW, midterm 1-10 MW, and far term 1-10 GW

Power density: Near term 50 W/Kg, midterm > 100 W/Kg, and far term > 200 W/Kg

Low cost: $1-$2

Long life: MTBF > 20-30 years

HV switching: 25,000 A at 1-5 KV

AC HV cable: 100 KV at 10 KHz

HV solar array: 6,000 V

Hot change of PMAD

PMAD Risks

HV switching (1 KV-5 KV); Forced to new components

Mass (1 Kg/KW) Configuration dependent

High voltage (100 KV) Distribution and component risks

Lifetime (MTBF) Temperature and thermal transients affects life; forced to new materials

Beam power control: PMAD? LAN control? S/A dissipation?
Superconductor: MTBF of refrigerator pumps, vacuum quality without out gassing affects insulation, and assembly servicing of cable segments.

Work Breakout Session 8 Report

Work Breakout Session 8, Solar Power Generation co-chaired by Shelia Bailey and Nick Mardesick report.

Size-Graded Self-Assembled Quantum Dot Solar Cell

Definition

A Si quantum dot cell utilizes the solar spectrum from 1.1 eV to 4.1 eV representing 80% of the solar emission spectrum.

Accomplishments

Size graded Si quantum dots have been fabricated and characterized.

Future

Optimize laser ablation parameters for sized graded dot arrays
Characterize optical properties to determine absorption range
Determine size distribution
Build prototype devices

Solar Dynamic Power Generation

Near term priorities

Evaluate PMAD impacts associated with SD (high voltage AC)

Address spacecraft integration issues; i.e., pointing and tracking, power distribution, attitude control (torque), and electric propulsion operations

Continue to develop/refine concentrator designs; i.e., largest mass, highest cost, greater uncertainty.

Proposed tasks

SD PMAD architecture design for SSP

In-house SD integration studies

Refractive secondary concentrator development
Refractive secondary hot test
Concentrator pointing test

Demonstrate overall concept feasibility-design, build (CY2000, and test (CY2001) a 100 watt, fully integrated SD power system with advanced concentrator and Stirling converter

Ultra Lightweight High Efficiency Thin Film Cell Growth Using Low Temperature Processing

Objective is to produce high power-to-weight ratio photovoltaic solar arrays on flexible substrates.

Task Descriptions

Develop and screen single source precursors
Optimize low-temperature thin-film deposition on flexible substrates
Demonstrate >5% AMO thin-film solar cells
Demonstrate pre-pilot production deposition of thin-film solar array materials
Keep related industries informed for eventual technology transfer

Milestones/Products

July 1999 Optimized single source precursor for $CuInS_2$

August 1999 Low-temperature deposition of ZnO, CdS, Cu(In, Ga)(S, Se)

September 1999 Synthesize thin-film heterojunction solar cell on flexible substrate

November 1999 Install and test precursor analysis and characterization too

January 2000 Produce 5% efficient prototype small-area cells

Future Plans

Develop and screen single source precursors for the low-temperature deposition of $CuInSe_2$, Cu (In, Ga) (S, Se)

Produce 5% efficient thin film prototype small area solar cells with each of the above absorber materials

Complete a design study for a multi-junction high-efficiency solar cell

Produce a 10% efficient thin film solar cell on a flexible substrate

Rainbow

Accomplishments

Assemble prism assembly

Prototype mirror/prism/cell assembly test

Prototype 35% AMO prism/cell

Future Plan

Test mirror/prism/cell

Fabricate and test five cell array

Fabricate and test prism/cell array system

Test system with mirror and/or lens

Design and fabricate 28 volt array

Demonstrate system design requirements

Advanced High Voltage Solar Array Design Guidelines from Solar Tile Testing

Accomplishments

40 Volt solar tile available for plasma testing

Begun prediction analysis and test plan

Designed solar cells for 500 volt title

Contract Completion

500 Volt solar tile tested in vacuum-plasma

Developed general design guidelines for high voltage solar arrays

Follow-on Suggestions

Design, build and test a 1,000 volt solar tile (higher voltage & higher efficiencies

Thermal cycle 500 volt & 1000 volt titles

Crack cover slide and test again

Develop updated guidelines

Develop arc detection and mitigation technologies

Cross-technology development design/build/test 500 volt concentrator array

Stretched Lens Aurora

Accomplishment

Module test 25% AMO and 28% AMI

Aurora Integration (Array)

Current Performance

>300 watts/square meter

>300 watts/Kg panel

>150 watts/Kg array

Future Performance
- >400 watts/square meter
- >1000 watts/Kg panel
- >500 watts/Kg array

Follow-on Possibilities
- High voltage receivers demonstration
- Start next generation R&D (1000 watts/Kg)
- Larger Ground test panel (LaRC)
- Array integration
- Rainbow Receiver

Work Breakout Session 9 Report

Work Breakout Session group 9, Environmental and Safety Factors co-chaired by Marvin Goldman and Gayle Brown report:

- Critical path environmental analysis
  - Ionosphere
  - Atmosphere
  - Orbital space
  - Beam safety
  - Long term exposure
  - Ecology
  - Orbit slot allocation
  - Environment impact statement process
  - Frequency allocations
  - Rectenna
  - Large scale demos
- Prioritize research needs for future years
  - Dual site use (rectenna)
  - Identify environmental costs
  - Power density vs site
    - Land use
    - Safety
    - Ecological costs
    - Quality of life
  - Exposure issues
  - Debris mitigation

Work Breakout Session 10 Report

Work Breakout Session group 10, International Issues and Opportunities, co-chaired by Jerry Grey and Mark Henley report:

- ITAR constraints
  - Action is needed to mitigate constraints on SSP technical interchange
    - NASA needs an umbrella SSP technologies list
    - NASA needs to submit a rational for technical SSP interchange as a research activity for Department Of State approval via headquarters.

- International cooperation mechanisms
  - Create International Working Group (IWG) on SSP (our preference is a sub committee of the IAF Power Committee)
    - The IWG will identify demo projects, some of which may need international agreements.

- Companies seeking joint efforts will apply for Technical Assistance Agreements (TAAs)
- The IWG will seek to mitigate current ITAR constraints
- UNESCO World Solar Program
  - Identify specific need of developing countries (e.g., SPS-2000)
  - Promote SSP as a supplement to terrestrial solar systems
- Energy demand projections
  - Seek long-term energy demands scenarios from all sources

Address International Issues (non-technical)
- The IWG will create an "action" agenda to address each of the issues identified at Unispace 3

Mechanisms for International Information Exchange
- Set up SSP International Wing of VRC (Badged access, but on ITAR sensitive information) to publish and review work in all countries.
- Alternative: Create international Internet communication network using VRC-like software.

Public Education and Information
- Identify and publicize demos having general public interest
- Seek public participation in demo projects (e.g., control of rovers)
- Create awards, essay contests, toys, etc

Work Breakout Session 11 Report

Work Breakout Session group 11, SSP Applications, co-chaired by David Smitherman and Ken Cox report:

- Applications to Space Science Missions
  - High power laser beaming to asteroids and planetary surfaces to determine chemical content
  - Power for long duration sample return
    - Economics
      - Improved remote analysis of materials
      - Standardized high power systems
  - Power for lunar-based telescopes
  - Technologies for large space telescopes
    - Optics
    - Power
    - Propulsion
    - Structures
    - Robotics
    - WPT to interstellar probes
      - Economics
        - Continuous non-nuclear power supply
        - Common technology development path
        - Identify Earth crossing asteroids

- Application to HEDS
  - SEP stages for space transfer
  - Power plug in space
  - High power for processing raw materials
  - Surface power beaming instead of power lines
  - WPT to surface systems
    - Landers and science instruments
    - Rovers
    - Habitats
    - Power to surface solar power systems in shadow

Power beaming to cold traps in shaded areas to release water and gases
High power radar mapping for resources mapping on planetary bodies

Application to Space Infrastructure Development
High power to micro satellites
High power for electromagnetic launch systems on lunar and planetary bodies
Orbital debris removal
Power to robotic maneuvering vehicle
Deorbit by direct laser beam to debris

Dual Use Technologies
SSP Technology
PMAD
Thin film Fresnel lens
Ultra light solar arrays (efficient thin film flexible solar arrays)
High temperature RF electronics and materials (phased array to replace dish antennas)
High efficiency solar cells (terrestrial power including solar cells on roofs)
Robotics (convenience robots and construction robots)
Remote assembly
WPT and tall towers for receivers above the atmosphere
Next generation commercial aircraft and future RLVs
Space telescope lenses
Satellite solar arrays

GRC presentation at the Work Breakout Session

GRC presented 73 VUGHRAPHS at the Work Breakout Session and Pat George furnished copies of these charts for the SERT TIM 2 record and they include the following subjects:

1) High Voltage SSP Issues by Dale Ferguson
2) Application of Superconductors to SSP Satellites by James Powell
3) Solar Electric Propulsion by GRC
4) PMAD Accomplishments and Future Plans by GRC

Day 4

Integrated Product Team (IPT) meetings

Day 4 began with the following six Integrated Product Team (IPT) meetings until 11:00 am:

IPT 1, Systems Engineering, Integration, Analysis, and Modeling: Cost Estimation and Space Transportation & Infrastructure co-chaired by Harvey Feingold, Connie Carrington, and David Way

IPT 2, WPT & Reception: Ground Power Systems: Environmental & Safety Factors co-chaired by Richard Dickinson, Jim McSpadden, and Marvin Goldman

IPT 3, Solar Power Generation and PMAD co-chaired by Shelia Bailey and Tom Lynch

IPT 4, Structural Concepts & Technologies co-chaired by Chris Moore and Mike Gilbert

IPT 5, Space Platforms and Operations co-chaired by David Maynard and Greg Hickey

IPT 6, SSP Applications: Space & Terrestrial Markets, International Issues and Opportunities co-chaired by Jerry Grey, Mark Henley, Ken Cox, and David Smitherman

Day 4 ended with closing plenary panel sessions

IPT Reports

IPT 1 Report

IPT 1, Systems Engineering, Integration, Analysis, and Modeling: Cost Estimation and Space Transportation & Infrastructure co-chaired by Harvey Feingold, Connie Carrington, and David Way

- Charge from John Mankins
  - What data needs to be exchanged between teams?
  - What data will nee to be provided in the near future?

- Database, structured properly, could address needs
  - Data documentation with assumptions of what is included in estimates
  - Modeling results
  - Algorithms

- Problems: Some teams do not have even basic information needed to start analysis
  - E.g., Structures team does not have loads

- Interaction between systems and transportation
  - Concept Proposers should take responsibility for providing schemes for assembly, component packaging, etc.

- Assembly complexity Vs ETO launch sizing (do we need to optimize?)
  - Currently assuming 20 to 40 MT per launch (5 pounds per cubic foot) for transportation
  - Larger payload units could simplify assembly (but launch vehicle failure is a consideration)
  - Transfer vehicle could become part of an-orbit structure
  - How fast does transportation need to provide materials? (Driven by economic considerations)
  - High flight rate is better, from transportation point-of view
  - SIWC can provide number of launches per satellite (currently assume on SSP satellite per year, but economic considerations will require a fleet of SSP satellites in perhaps a 5-year period of time)

- Interactions between systems and transportation
  - Recommendation 1: Get SIWG, transportation, structures, robotics teams together soon to establish assembly philosophy baseline
  - Recommendation 2: Decide soon on a LEO-GEO transportation philosophy baseline

- Interactions between systems and transportation
  - Question 1: Do we need a depot for storing materials, tools, etc.
  - Question 2: Does each package deliver itself to GEO (maybe higher, due to GEO stationkeeping consider stationkeeping), or do we have tug deliver launch packages?
    - Deploy SSP arrays for LEO-GEO transportation (loads on structures, degradation, PMAD and high voltage considerations etc.
    - Transportation has traded expendable, reusable, and autonomous SEP approaches (for transportation considerations only)
    - Autonomous SEP approach appears favorable to transportation, but oversizes and overdesigns the on-orbit SSP configurations, structures, PMAD, etc
  - Question 3: Do we need LEO transportation nodes?
    - May need 3 for orbit phasing considerations
    - Will need equatorial launch sites (build our own island?)
  - Question 4: What is the lifetime of this system?

Transportation needs from SIWG
- Density and dimensions of the payloads
- Launch rates
- Payload mass
- Assembly sequence
- Maintenance estimates

Propulsion needs
- Efficiency vs. specific impulse vs. propellant type
- Specific mass of propulsion unit

Solar array needs
- Specific power with or without structure
- Degradation both thermal and radiation
- Efficiencies (BOL and EOL) to aid in lifetime estimates

Robotics needs
- Robotic capability for assembly
- Reliability
- Mass, cost including all support
- Type of robots

WPT technology needs (solid state, magnetrons, klystrons, and lasers)
- Characteristics: mass, configuration, performance with assumptions
- Efficiency chains (space segment, atmospheric, ground rectenna)

Platform System needs
- Reliability data for all hardware (SSP satellites, robotics, and ground systems)
- Mass and cost data for platform systems
- Communications and computers

Structure needs
- Mass estimates for solar arrays, transmitter array, reflectors/bearings, and integrating structures
- Number of control actuators and sensors: mass, power and cost estimates
- Assembly approach and deployment
- Packaging
- Thermal mass, radiator configurations and location

PMAD needs
- Voltage levels, AC or DC and radiator temperatures
- Mass distribution of components for configuration design and recommendations
- PV to SEP switching information

SSP Applications needs
- Missions
- Requirements
- Spin-off applications that could impact systems and transportation decisions (lifetimes etc)

Team for Environmental Safety and Health needs
- Allowable power densities
- Stake holders
  - Exclusion zones (cost impacts)

Missing Elements in WBS
- Operations

Command. Control and Data handling (ground and space)
Hierarchy. control sites. etc
Roles of government and private industry

IPT 2 Report

IPT 2. WPT & Reception: Ground Power Systems: Environmental & Safety Factors co-chaired by Richard Dickinson. Jim McSpadden. and Marvin Goldman

- Safety
  - Locate receiving stations in restricted airspace sites when possible
  - Site requirements
    - Two radars
      - One for low slow moving small airplanes
      - One for high fast moving commercial and corporate planes
    - Detectors for beam scatter
    - Tie in with FAA ATC system
    - Redundant computers
  - What do you want to protect?
    - All spaces?
    - Other (land use. medical devices. etc)
    - Need more chronic long-term exposure data
    - Satellite Protection
    - Need analysis of fleet of beaming power stations at GEO
    - Rectenna maintenance
      - Protective suits
      - Auditory effects
  - Beam pulsing possible? Probably not

- Land use considerations
  - Siting of microwave
  - Not is SMSAs
  - Need flyway corridors superimposed on beam map
    - Birds. aircraft. and other migratory animals
  - Reservations
    - Indian
    - National parks
    - Military
    - Wetlands
  - Land costs
  - Societal issues (e.g., construction worker support infrastructure)
  - Microclimate effects

  - Siting of lasers
    - 10^5-10^6 receiving sites for 1 GW
      - May require neighborhood homogeneity
    - Public comfort factor (could look like a weapon)
      - Minimal problems with birds and planes flying through beam
    - PV material scarcity

- Minority report 1
  - Economics ($/KWh) is the ultimate figure of merit for SSP. Microwave WPT at this point of time and for the next several decades is much better than laser WPT.
  - Lowest cost of electricity has been shown to be delivered from large antennas to multiple recentenas
- Minorities report 2

Laser emitters can be designed so that they deliver power at about the intensity of natural sunlight in a distributed manner.
Laser emitters can be designed so that they can not be turned into a weapon system without major changes.
Efficiencies of 36% for a high quality beam have been demonstrated.
Higher efficiencies appear accessible (upper limit is 100(1 – kT/kW)) www.osa.org

IPT 3 Report

IPT 3. Solar Power Generation and PMAD co-chaired by Shelia Bailey and Tom Lynch

- Interface Questions and Issues
  - WPT voltage level and regulation
  - Propulsion voltage level
  - Structures, control and thermal: Mass and pointable structure, grounding, thermal regulation, and housekeeping power
  - Robotics: Replacement of damaged components
  - Space environment and safety: Charge dissipation

IPT 4 Report

IPT 4. Structural Concepts & Technologies co-chaired by Chris Moore and Mike Gilbert

- IPT 4 did not meet; therefore they had no report.

IPT 5 Report

IPT 5. Space Platforms and Operations co-chaired by David Maynard and Greg Hickey

- Functions
  - Hierarchy of control
    - Granularity of control
    - Command and control schemes
    - Distribution of knowledge
  - Assembly
    - Task order driven (repetitive)
    - Preventative
    - Adaptive scheduling
  - Repair
    - Highly flexible
    - Responsive
    - Do we repair everything?
  - Diagnostics/Health monitoring
    - Define needs
    - Non contact/point contact/ports
    - Smart structures

- System needs
  - Efficient highways for mobility/operations
  - Design forgiveness in system for assembly and operations
  - Modularization
    - Similarity of components
    - Similarity of subsystems
    - Common interfaces/connectors
    - Self-fastening interfaces
    - Magnitude of change out
  - Trash disposal/reutilization
- Open issues

- Computational requirements
  - Speed vs memory
  - Distribution vs non-distribution
- Thermally/electrically hot change out
- Isolation of damaged/downed systems, subsystems, and components
- Thermal management
- How is PMAD integrated into structure and its effect on assembly?
- Centralized vs distributed
  - Robotics
  - Intelligence
  - Information management

Technology challenges
- Maintenance during continuous operations
- Coordinated operations with the ground (level of autonomy)
- Platform to robot and communications
- Health monitoring system
- Ad hoc network
- Inspection approaches/definition
- Extended operations for systems
- Simulation and studies
- Material logistics

Interfacing challenges
- Facility mobility
  - Hard points, grapple, etc
  - Spots to minimize reaction forces
- Facility reaction control
- Facility maintenance
  - Design for robot only maintenance
  - Smart structure, self-diagnosis, component change out
- Clearance and accessibility (pathways)
- Location/marking/component bar coding
- Communications and data (diagnostic facilities)
- Robotic infrastructure/tool shed and warehouse

IPT 6 Report

IPT 6, SSP Applications: Space & Terrestrial Markets, International Issues and Opportunities co-chaired by Jerry Grey, Mark Henley, Ken Cox, and David Smitherman

What factors drive conversation to SSP?
- Economics
- Environmental benefits
- Fossil fuel depletion (plastic resources)
- Unique electricity markets e.g., electric cars
- Nuclear concerns

Common issues
- Terrestrial power
- Space applications

Terrestrial power
- Major market: Developing nations
- Applications: Peaking power, base loads, or niche?

Integration with utility infrastructure
How to incentivize energy companies to put SSP in their strategic planning
Would offshore oil development model work for SSP?
Space missions
Scientific exploration
Orbital debris removal
Planetary defense
Nonterrestrial materials resources

Other Subjects
Environmental effects of electric propulsion effluents (xenon)
New people in this field would benefit from 1980 DOE/NASA study: Need copies
Environmental community is a major potential ally: Review Space Frontier Foundation's presentation

John Mankins' summarization

First end-to-end review of SSP with architectures, systems, technology, and demos.
Excellent interchanges among diverse organizations and groups
Good synthesis of relationships and issues
Something else to do
Concepts>database.>R&T>applications Need to better/more explicitly document traceability of specific technology efforts to concepts
We will be inverting the matrix
Space Applications
Need to continue to work hard on this subject
Will need to engage R&T teams to broaden perspective
For Example:
Infrastructure dual-use
Technology dual-use
Alternative systems use
Information dual-use
A lot of work to do

List of Attendees

1.	Anderson, Dave	Boeing
2	Anderson, Jeffrey	NASA MSFC ED44
3	Arndt, Dickey	NASA JSC
4	Bailey, Shelia	NASA GRC
5	Balbaa, Ibrahim	Ontario Power Technologies Canada
6	Baker, William	Naval Research Lab
7	Beaudoin, Greg	Strategic Insights
8	Benford, Gregory A.	Microwave Sciences, Inc
9	Benford, James N.	Microwave Sciences, Inc
10	Blanks, Hal	United States Alliance Corp
11	Brandhorst, Henry W. Jr.	Auburn University December 7th & 8th
12	Brown, L. Gayle	University Space Research Association (USRA)
13	Brown, Gardner	Strategic Insights
14	Brown, Mike	NRL
15	Cacace, Ralph	Honeywell
16	Campbell, Jon	NASA MSFC FD02
17	Carrington, Connie	NASA MSFC FD02
18	Carroll, Kieran	Dynacon Enterprises Limited Canada
19	Charania, Ashrof	Georgia Tech

20	Christensen, David	Lockheed Martin Astronautics
21	Clark-Ingram, Marcia	NASA MSFC AD10
22	Conley, Michael	NASA JSC
23	Cox, Kenneth J.	NASA JSC
24	Culbert, Chris	NASA JSC
25	Deckard, Margo	Space Frontier Foundation
26	Dickinson, Richard	JPL
27	Dolce, Jim	NASA GRC
28	Donahue, Ben	Boeing
29	Edge, Tom	NASA MSFC ED11
30	Escher, William	SAIC
31	Farrington, Frank	Boeing
32	Feingold, Harvey	SAIC
33	Ferguson, Dale	NASA GRC
34	Fikes, John	NASA MSFC FD02
35	Fini, John	Strategic Insights
36	Fork, Richard	UAH Electrical Engineering & Computer Science
37	Gamble, Lisa	UAH Physics
38	George, Patrick J.	NASA GRC
39	Gilbert, Michael G.	NASA LaRC
40	Gilbert, Mike	NASA GRC
41	Glaese, John	bd Systems, Inc
42	Goldman, Marvin	UC Davis
43	Grey, Jerry	AIAA
44	Hawk, Clark W.	UAH Propulsion Research Center
45	Henley, Mark	Boeing
46	Hickey, Gregory S.	JPL
47	Hoffman, Steven J.	NASA JSC
48	Hollander, Sam	NRL
49	Howell, Joe	NASA MSFC FD02
50	Ijichi, Koichi	Inst. for Unmanned Space Exp. Free Flyer (USEF) Japan
51	Johnson, Gary	NASA MSFC FD02
52	Johnston, Nick	NASA MSFC ED19-F
53	Kant, Seymour	NASA GSFC
54	Kaya, Nobuyuki	Kobe University of Japan
55	Kennedy, Brett	JPL
56	King, C. William	Essential Research
57	Kuriki, Kyoichi	Inst. for Unmanned Space Exp. Free Flyer (USEF) Japan
58	Kusic, George	University of Pittsburgh
59	Lamb, David	UAH Dept. of Physics
60	Landis, Geoffrey A.	Ohio Aerospace Institute
61	Law, Glenn	Aerospace Corp
62	Lee, Gary	Boeing
63	Little, Frank	Texas A&M Univ.
64	Lynch, Tom	Boeing
65	Mankins, John	NASA Headquarters
66	Mardesich, Nick	JPL
67	Martin, Jim	Boeing
68	Marzwell, Neville	JPL
69	Mori, Masahiro	NASDA Japan
70	May, Scott	NASA MSFC
71	Moore, Chris	NASA LaRC
72	Maynard, David	JPL
73	McCaleb, Rebecca	NASA MSFC AD10
74	McDanal, A. J.	ENTECH, Inc
75	McSpadden, James	Boeing

76	Mehdi, Ishaque	Boeing
77	Moore, Chris	NASA LaRC
78	Mullins, Carie	Futron Corp
79	Muniz, Ed	Muniz Engineering, Inc
80	Nabors, Rip	NASA MSFC
81	Neudeck, Phil	NASA GRC
82	Nichols, Roger	Boeing
83	Nicodemus, Tom	University of Houston
84	Nix, Mike	NASA MSFC
85	Novara, Mauro	ESTEC ESA
86	Olds, John	Georgia Tech
87	O'Neal, Dan	NASA MSFC FD02
88	O'Neill, Mark	ENTECH, Inc
89	Patrick, Steve	Sverdrup
90	Penn, Jay	Aerospace Corp
91	Perky, Donald J.	Global Hydrology & Climate Center
92	Perkinson, Don	NASA MSFC SD71
93	Pervan, Sherry	SAIC
94	Piszczor, Mike	NASA GRC
95	Potter, Seth D.	Boeing Downey
96	Powell, Jim	DOE Brookhaven National Labs
97	Rawal, Suraj	Lockheed Martin
98	Reed, Brian	Boeing
99	Roth, Axel	NASA MSFC FD02
100	Sanders, Jim	UAH Propulsion Research Center
101	Sank, Victor	NASA GSFC
102	Schmitz, Paul	NASA GRC
103	Schnepf, Sharon	DARPA
104	Sharp, John	NASA MSFC ED26
105	Shenai, Krishna	Microsystems Res. Center Univ. of Illinois at Chicago
106	Shimizu, Kazuhiro	Kobe University Japan
107	Skiles, Jay	NASA ARC SETI Institute
108	Smith, Ron	NASA MSFC AD10
109	Smitherman, David	NASA MSFC FD02
110	Staritz, Peter J.	Carnegie Mellon University
111	Strassner, Berndie	Texas A&M University
112	Sullivan, Gerry	Rockwell Science Center
113	Taliaferro, Lanny	ALPHA Technology
114	Thompson, Zack	Volunteer
115	Trivedi, Malay	Microsystems Res. Center Univ. of Illinois at Chicago
116	Urmson, Chris	Carnegie Mellon University
117	Vassaux, Didier	CNES France
118	Watson, Judith	NASA LaRC
119	Way, David	Georgia Tech
120	Whittaker, William (Red)	Carnegie Mellon University
121	Willenberg, Harvey	Boeing
122	Willowby, Douglas	NASA MSFC ED11
123	Wilson, Sam	DARPA
124	Zhu, Sein	USRA ED47

Agenda for Day 1

0730—0800	Registration UAH University Center UC 133	
0800—0810	Welcome/Dr. Kaya's WPT Demo	Dr. Hawk
0810—0820	Introduction	Axel Roth
0820—0830	SERT TIM 2 Objectives	Joe Howell
0830—0910	SERT Program Overview	John Mankins
0910—0950	SERT Integration, Analyses, & Modeling	Carrington / Feingold
	SERT Activities Summaries	
	ARC	
0950—1000	Intelligent Systems, Robotics, & Other	Hans Thomas
1000—1010	Environmental	Jay Skiles
	GRC	
1010—1040	Solar Power Generation	Pat George
1040—1110	PMAD	Shelia Bailey Jim Dolce
1110—1130	Defect Engineering & Reliability Study of SiC High Power Devices	Univ. of Illinois at Chicago Krishna Shenai
	GSFC	
1130—1150	Space Platforms	Jim Andary D. Maynard/Steve Kant
1150—1250	Lunch	
	JPL	
1250—1320	WPT	Richard Dickinson
1320—1340	System Activities	David Maynard
1340—1410	Science Applications	Brett Kennedy
	JSC	
1410—1430	Robotic Assy, Maint and Servicing	Chris Culbert
1430—1450	HEDS Applications and Other	Ken Cox
	KSC	
1450—1505	Spaceport Operations	Carey McCleskey
	LaRC	
1505—1545	Struct. Materials & Control, and Thermal	Chris Moore
	MSFC	
1545—1600	Ground Power Systems	George Kusic
1600—1615	Space Transportation Infrastructure	John Olds
1615—1630	FMCA	Larry Talianferro
1630—1650	Environmental & Safety Factors	Marvin Goldman
1650—1710	Commercial Applications	David Smitherman
1710—1740	Independent Economic & Market Analysis	John Fini
1740—1800	NASDA In-House Study of SSP Demo	Mori Masahiro
1740	Plans for Day 2	Joe Howell

Agenda for Day 2

0730—0800	Registration @ University Center UC 133	
	SERT Systems Studies & Analysis NRA 8-23	
0800—0830	Aerospace System Studies & Analysis	Aerospace Corp
0830—0900	SSP Systems Studies &Analysis	Boeing NA Inc
0900—0925	System Study for POWOW	Auburn University
0925—0940	Advanced Design Concepts for SSP	Ohio Aerospace Inst.
0940—0955	Application of SSP Technology to HEDS	SAIC
0955—1015	Assessment of SSP Risk & Uncertainty	Futron
1015—1035	Assessment of Environmental & Safety Factors related to SSP	Space Frontier Foundation
1035—1055	Assessment of NASA SSP Concepts, International Coordination, &Applicability	AIAA
1055—1110	Economic & Market Analysis of Specific Locale	Strategic Insights
	SERT Research & Technologies NRA 8-23	
1110—1130	Adv. High Voltage Solar Array Design	Boeing Phantom Works
1130—1145	Solar Cell Development & Array Design for RAINBOW Concentrator	Essential Research
1145—1205	Effects of Hypervelocity Impacts on High Voltage Arrays	Auburn University
1205—1300	LUNCH	
1300—1320	Low-Mass Phased Array Antenna for WPT	Boeing Phantom Works
1320—1340	Ultra-Lightweight Inflatable Boom Dev	ILC Dover
1340—1400	Innovative Deployable Radiator Design for SSP	Lockheed Martin
1400—1420	Fabrication of Very High Efficiency 5.8 GHz Power Amplifiers for WPT	Rockwell Science Center
1420—1440	High Voltage Modular DC to DC Converters	Sundstrand
1440—1500	R&D of High Gain, High Efficiency, Circular Polarized rectenna	Texas A&M University
	SERT Technology Demonstrations NRA 8-23	
1500—1530	WPT for Science Applications	Microwave Sciences
1530—1600	Ultralightweight Fresnel Lens Solar Concentrators for Space Power	ENTECH. Inc
1600—1630	Robotic Assembly & Maintenance of Solar Facilities	Carnegie Mellon Univ.
1630—1710	SSP Technology Demonstration for Lunar Polar Applications	Boeing North American
	SERT PROCESS	
1710—1740	Technology Roadmapping	John Mankins
1740	Charge to Work Breakout Sessions	John Mankins

Agenda for Day 3

0730—0800	Registration @ University Center UC 133	
0800—1500	**SERT Work Breakout Sessions**	CO-CHAIRS
UC Exhibit Hall A	Systems, Integration, Analysis, & Modeling	Harvey Feingold Connie Carrington
UC 126 C	Space Transportation & Infrastructure	David Way Mike Nix
UC 126 B	Wireless Power Transmission	Richard Dickinson Jim McSpadden
UC 126 A	Platform Systems	David Maynard Seymour Kant
UC 146	Robotics, Assembly, & Servicing	Chris Culbert Red Whittaker
UC 127	Structures, Materials, Controls, and Thermal	Chris Moore Mike Gilbert
UC Exhibit Hall B	PMAD & Ground Power Systems	Jim Dolce Tom Lynch
UC 131	Solar Power Generation	Shelia Bailey Nick Mardesick
Tech Hall S105	Environmental & Safety Factors	Marvin Goldman Jay Skiles
Tech Hall N145	International Issues & Opportunities	Jerry Grey Mark Henley
Tech Hall S301	SSP Applications: Independent Economic & Market Analysis	David Smitherman Henry Harris / Ken Cox
Tech Hall N302	Special Topics	Joe Howell
1500—1530	Break-Move back to UAH UC Exhibit Hall	
1530—1730 UC Exhibit Hall B	Reports from SERT Work Breakout Mtgs. (10 MINUTES EACH)	
	Systems, Integration, Analysis, & Modeling	Harvey Feingold
	Space Transportation & Infrastructure	John Olds
	Wireless Power Transmission	Richard Dickinson
	Platform Systems	David Maynard
	Robotics, Assembly, & Servicing	Chris Culbert
	Structures, Materials, Controls, & Thermal	Chris Moore
	PMAD & Ground Systems	Jim Dolce
	Solar Power Generation	Shelia Bailey
	Environment & Safety Factors	Marvin Goldman
	International Issues & Opportunities	Jerry Grey
	SSP Applications: Independent Economic & Market Analysis	David Smitherman
1730	Plans for Day 4	*Joe Howell*

Agenda for Day 4

0730—0800	Registration UC 133	
0800—1100	**SERT Integrated Product Team Meetings**	CO-CHAIRS
UC Exhibit Hall A	Systems Engineering, Integration, Analysis Modeling: Cost Estimation and Space Transportation and Infrastructure	Harvey Feingold Connie Carrington David Way
UC 126 B	WPT & Reception: Ground Power Systems: Environmental & Safety Factors	Richard Dickinson Jim McSpadden Marvin Goldman
UC 146	Solar Power Generation: PMAD	Shelia Bailey Tom Lynch
UC 127	Structural Concepts & Technologies	Chris Moore/Mike Gilbert
UC 126 A	Space Platforms & Operations	David Maynard Greg Hickey
UC 131	SSP Applications: Space & Terrestrial Markets, International Issues & Opportunities	Jerry Grey/Ken Cox Mark Henley David Smitherman
UC126 C	Special Topics (TBD)	Joe Howell
1100—1200	Lunch	
1200—1500 UC Exhibit Hall B	**Closing Plenary Panel Sessions** SERT Integrated Product Teams	PANEL MEMBERS
	Solar Power Generation: PMAD	Shelia Bailey/ Tom Lynch Pat George/Mark O'Neill Jim Powell
	Space Platforms and Operations	Greg Hickey Bret Kennedy Red Whittaker Seymour Kant
	Systems Engineering, Integration, Analysis Modeling: Cost Estimation and Space Transportation and Infrastructure	Harvey Feingold Connie Carrington/ Jay Penn David Way/Mike Nix
	WPT & Reception; Ground Power Systems; Environmental & Safety Factors	Richard Dickinson Jim McSpadden Marvin Goldman Gary Johnson
	Structural Concepts & Technologies	Chris Moore Mike Gilbert/ Judith Watson
	SSP Applications: Space & Terrestrial Markets, International Issues & Opportunities	Jerry Grey Mark Henley Ken Cox David Smitherman
	Special Topics	Joe Howell
1500	ADJOURN	