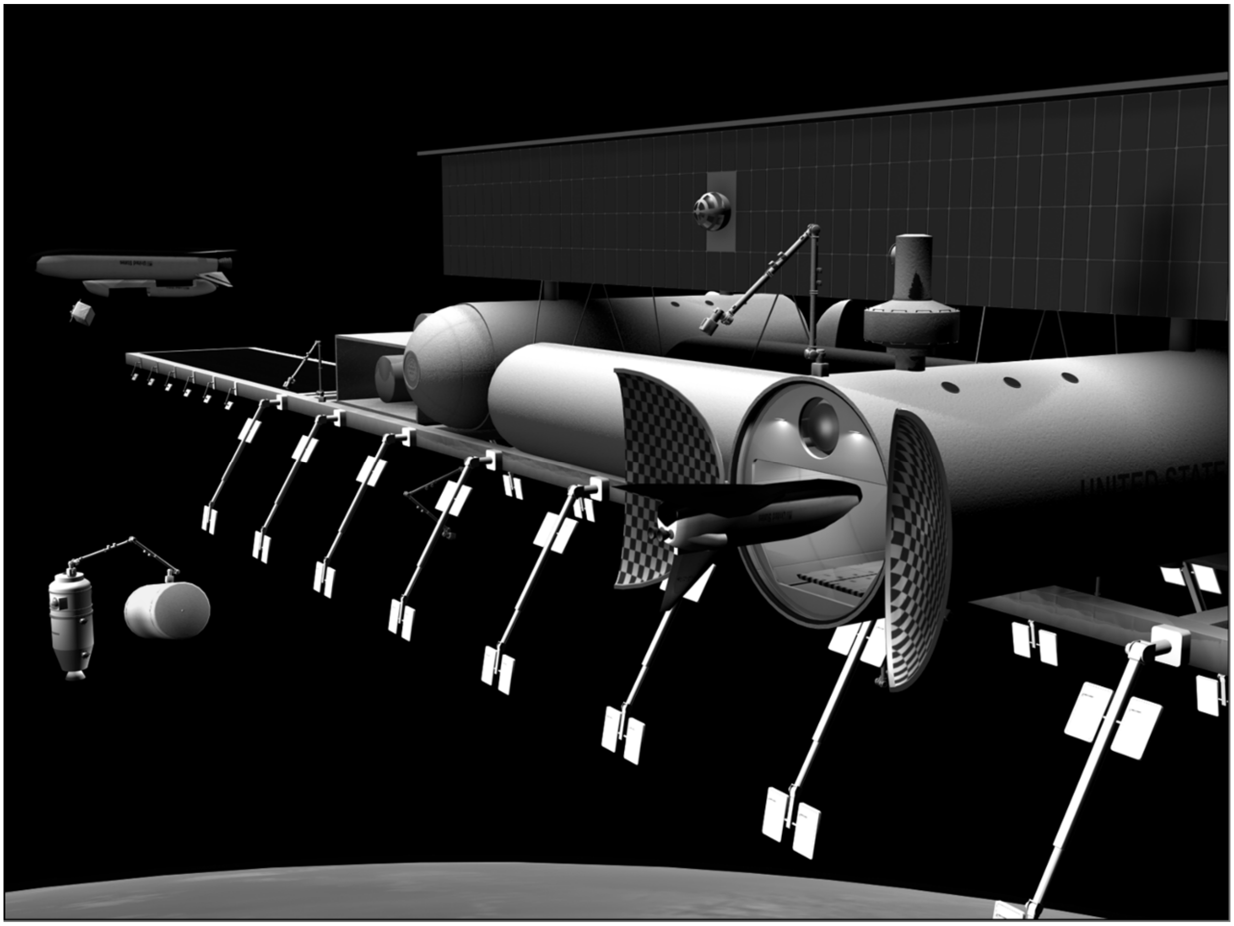

Space-Based Solar Power Study

Spacefaring Logistics Infrastructure Breakout Session Summary

Introduction

Any form of industrial scale space-based or space-derived energy first requires the establishment of an integrated logistics infrastructure enabling safe and routine operations by humans and robotic systems throughout the Earth-Moon system. The logistics infrastructure breakout session of the space-based solar power (SBSP) study focused on defining these spacefaring logistics infrastructure capabilities.

Purpose

Current U.S. National Space Policy states: "In this new century, those who effectively utilize space will enjoy added prosperity and security and will hold a substantial advantage over those who do not. Freedom of action in space is as important to the United States as air power and sea power. In order to increase knowledge, discovery, economic prosperity, and to enhance the national security, **the United States must have robust, effective, and efficient space capabilities**." (Emphasis added)

Developing space-based or space-derived energy to meet the United States' needs for assured energy availability is one example of how space may be more effectively utilized in the coming decades. To be able to successfully utilize space, however, the nation's current shortfall in achieving "robust, effective, and efficient space capabilities" must first be corrected. The purpose of the logistics infrastructure breakout session was to identify near-term technical concepts and an implementation strategy to provide American space enterprises with the needed robust, effective, and efficient space operational capabilities.

Assumptions

1. The development of an integrated spacefaring logistics infrastructure is part of a general national space strategy to establish mastery of operations in space and transform the United States into a true spacefaring nation. This will require, over several decades, national investment to strengthen and expand the nation's aerospace industry and associated capabilities.
2. While supporting the development, deployment, and operation of space-based solar power, the spacefaring logistics infrastructure will also be used by all American spacefaring enterprises.
3. The infrastructure will be developed as a public-private partnership emphasizing competitive commercial products and services to provide assured national spacefaring logistics capabilities. Following the establishment of baseline capabilities, the commercial extension and expansion of these commercial spacefaring logistics capabilities will be encouraged.
4. The central function of the integrated spacefaring logistics infrastructure is to transport, sustain, and service American space enterprises, both governmental and commercial, throughout the Earth-Moon system, by 2030, and throughout the central solar system by 2050.
5. The development and deployment of the spacefaring logistics infrastructure will be undertaken in phases. The time phasing of the development and deployment of the phases will be scheduled such that later phases "bootstrap" off of earlier phases.
6. Emphasis will be placed on employing Technology Readiness Level 6-9 technologies to establish the initial operational capability of each phase and then to use pre-planned product improvements to introduce improved systems with more advanced technologies leading to improved safety, performance, and operability.
7. Spacefaring operations, while emphasizing the practical use of robots, will necessarily remain a human activity to oversee the construction and operation of both the spacefaring logistics capabilities as well as SBSP systems. The spacefaring logistics infrastructure must provide suitably safe living, work, and transportation capabilities for humans traveling to and living and working in space.
8. The development of both the spacefaring logistics infrastructure and the SBSP system will each be a major national undertaking. As such, these will have access to the necessary national resources for their development, production, and operations.
9. While the initial elements of the SBSP satellites will be constructed entirely on the Earth or in space from terrestrially-supplied components, later SBSP satellites may be substantially constructed in space from extraterrestrial materials. Later phases of the spacefaring logistics infrastructure architecture will provide the capabilities to establish, maintain and support such future SBSP satellite construction methods.
10. All new habitation and transportation systems used by humans will be fully-reusable and will be certified as airworthy through appropriate acceptance inspection and both ground and flight testing prior to placement into service.
11. The start date for the full scale engineering development of the initial Phase 1 elements of the spacefaring logistics infrastructure is 2009 following preliminary organizational and engineering activities being undertaken in 2008.

Infrastructure deployment phases (2009 - 2050)

1. Establish routine access to low earth orbit (LEO).
2. Establish LEO space logistics depots.
3. Extend routine transportation throughout the Earth-Moon system.
4. Support the initial space-based solar power satellite demonstrations, assembly, and operations in geostationary orbit (GEO).
5. Support increased human and robotic resource survey missions to the Moon.

6. Expand LEO capacity to support the increased assembly of SBSP satellites.
7. Establish permanent lunar surface capabilities to support the extraction of resources.
8. Establish Earth-Moon Lagrangian logistics capabilities to support in-space SBSP component manufacturing using extraterrestrial resources.

Capabilities and example infrastructure concepts deployed during the first three phases

1. Phase 1 - Establish routine access to low earth orbit (LEO):
   a. Capability:
      - Establish routine Earth-to-orbit transport for passengers and cargo with “aircraft-like” safety and operability
      - Establish spacelift for heavy and oversize cargo

   b. Strategy:
      - Develop new, fully-reusable two-stage, rocket-powered space access systems (aerospaceplanes) for passenger and cargo transport
        – Generation 1 aerospaceplane followed by Gen 1.5 aerospaceplane
      - Develop Shuttle-derived systems as a near-term transport replacement for the Space Shuttle and to provide future heavy spacelift
        – Generation 1 Shuttle-derived spacelifter followed by Gen 1.5 spacelifter and then Gen 2 spacelifter

   c. **System 1 - Gen 1 aerospaceplanes**:
      - Mission: Transport passengers and cargo with “aircraft-like” safety and operability
      - Configuration: Two-stage, fully-reusable, rocket-powered
      - Current TRL: 6-9
      - Gross weight: ~3 million lbs (1,400 m-tons)
      - Net cargo weight: 25,000 lb (11.4 m-tons) to 51.6°@ 270nm (500 km) circular (cargo carried externally)
      - Passengers: 10 using passenger spaceplane carried externally in lieu of cargo container
      - Deploy two design-independent types for assured space access; 4 operational systems per type for 8 total systems
      - Average turn-around time: 4 weeks (IOC); 2 weeks (FOC)
      - Annual fleet flight capacity (FOC): ~20 per system; ~160 for fleet
      - Recurring mission cost (FOC): ~1,100/lb or $2,400/kg (net) or ~$26M (cargo); ~$36M (passenger)
      - Operate from Kennedy Space Center and Vandenberg Air Force Base
      - IOC year: 2018 (nominal with 2009 start); 2016 (accelerated with 2009 start)

   d. **System 2 - Gen 1.5 aerospaceplanes** (block update of Gen 1):
      - Mission: Transport SBSP satellite modules/components
      - Configuration: Two-stage, fully-reusable, rocket-powered optimized for the SBSP cargo payloads
      - TRL 6-9 availability date: 2015; focused on increased engine life, increased thermal protection system durability, decreased recurring operational costs, and decreased turn-around time
      - Net cargo weight: 30,000-50,000 lb (13.6-22.7 m-tons) delivered to 28.5°@270 nm circular
      - Deploy two design-independent types for assured space access; 10 operational systems per type for 20 total operational systems
      - Annual fleet flight capacity (FOC): ~80 per system; ~1,600 or more for fleet
      - Annual fleet cargo capacity: ~32,000 tons (29,000 m-tons) at 40,000 lb per mission

- Recurring mission cost (FOC): ~$225/lb ($500/kg) (net) or less, or ~$9M or less per mission
- Operate from 5 or more sites worldwide
- IOC date: 2023 (nominally 5 years after Gen 1 aerospaceplane nominal IOC of 2018); 2020 (accelerated 4 years after Gen 1 aerospaceplane accelerated IOC of 2016)

e. **System 3 - Passenger spaceplane**
   - Mission: Transport passengers to and from the space construction station, space logistics base, and space habitat
   - Configuration: 10-passenger mini-orbiter carried as payload on, first, the Gen 1.5 Shuttle-derived spacelifter and, then, on the Gen 1 aerospaceplane
   - Approximate weight: ~40,000 lbs (18.2 m-tons)
   - IOC year: 2016 (nominal with 2009 start); 2014 (accelerated with 2009 start)

f. **System 4 - Gen 1 Shuttle-derived spacelifter** (example: Jupiter 120 described at directlauncher.com):
   - Mission: Replace Space Shuttle for transporting astronauts and cargo to the International Space Station and other LEO locations; provide astronaut transport using crew capsule
   - Vertically-stacked, unmanned version of the present Space Shuttle
   - Current TRL: 7-9
   - Gross cargo weight: ~32 to 64 m-tons into low elliptical orbit
   - IOC year: 2014 (nominal with 2009 start); 2012 (accelerated with 2009 start)

g. **System 5 - Gen 1.5 Shuttle-derived spacelifter**
   - Mission: Modification to the Gen 1 spacelifter to improve human transport and to enable the deployment of the initial Phase 2 space construction station
   - Configuration: Modified configuration to accommodate a single passenger spaceplane (10 passengers) and to carry an upper stage to place the Phase 2 space construction stations into LEO
   - Delivered payload weight: ~140,000 lb (64 m-tons) to 51.6°@ 270 nm circular
   - IOC year: 2016 (nominal); 2014 (accelerated)

h. **System 6 - Gen 2 Shuttle-derived spacelifter**
   - Mission: Replace Gen 1.5 to support larger payloads and higher flight rates; used to launch the modules to assemble the Phase 2 space facilities and to launch large SBSP modules that cannot be carried on the Gen 1.5 aerospaceplane
   - Configuration: Vertically-stacked configuration using two fly-back boosters based on the Gen 1 aerospaceplane booster, a new core propellant tank using updated/lower cost manufacturing processes and designed for on-orbit reuse, and, possibly, a new core disposable engine with increased performance over the rocket engines to be used for the Gen 1 spacelifter
   - Delivered payload weight: ~200,000-250,000 lb (90-114 m-tons) to 51.6°@ 270 nm circular
   - Annual flight rate: 12 (nominal); 24 (max)
   - IOC date: Same at Gen 1 aerospaceplane (2018, nominal; 2016, accelerated)

2. Phase 2 - Establish LEO Space Logistics Depots:

   a. Capability: Establish the first two Earth-orbiting space logistics depots that will be the primary destinations for the initial surface-to-LEO transportation systems, the base of operations for LEO logistics servicing support, and the base of operations for transportation within the Earth-Moon system.

b. Depot systems: Each space logistics depot will be initially comprised of the following (in order of deployment): space construction stations, space tugs, space logistics base/space dock, space propellant/power stations, and 100-person space habitat.

c. Orbital location: The first space depot is located at 28.5° and the second at 51.6°. The depots are placed in circular orbits at altitudes that achieve a repeating ground track. For the 28.5° depot, this is at approximately 260 nm (481 km) altitude, while the 51.6° depot is at approximately 269 nm (500 km) altitude. The facilities are "flown" in a string-of-pearls arrangement along the orbital path separated by 10-20 nm (18-36 km). The repeating ground track provides near daily access to each depot from the primary launch site at KSC.

d. **System 1 – Space construction station**: A Skylab-like space station, housing a work crew of 10, designed to support the assembly of the larger depot space facilities. Two stations are deployed to each depot using either the Gen 1.5 or the Gen 2 spacelifter.

e. **System 2 – Space tug**: a moderate size spaceship used for material handling and space search and rescue. The space tugs are transported to orbit using either the Gen 1 spacelifter (if needed earlier) or the Gen 1 aerospaceplane. The space tug includes provisions for a crew of 3 operating for up to 4 day missions. The space tug is primarily used to receive cargo transported to LEO by the aerospaceplanes and to help maneuver space facility modules during assembly. The space tug is capable of retrieving a disabled passenger spaceplane or space tug. It has an ideal ΔV of approximately 5,500 ft/sec (1.7 km/sec).

f. **System 3 – Space logistics base/space dock**: a large space station configured for logistics support operations including space facility, large spaceship, and SBSP satellite assembly; spaceship berthing; satellite and spaceship maintenance, repair, and upgrade support; and personnel housing. The primary logistics features of the space logistics base are the two large (33 ft or 10 m diameter) space hangars that enable pressurized shirt-sleeve support for satellites, passenger spaceplanes, space tugs, and space ferries, and an 850 ft (260 m) long space dock that enables the assembly of large space facilities, such as the 100-person space habitat, and large SBSP satellite assemblies. The base houses a work crew of 20-30 personnel in a zero-g environment.

g. **System 4 – Space propellant/power station**: a space construction station modified to store and dispense propellants used for in-space propulsion and auxiliary fuel cell power systems.

h. **System 5 – Space habitat**: a 100-person combination space hotel, office building, and logistics support facility that provides expanded in-space housing and work areas to support the assembly of SBSP satellites. The space habitat rotates to produce modest levels of artificial gravity. It has approximately 29,000 ft^2 (2,700 m^2) of useful floor area as well as two large space hangars for receiving cargo and passengers. The space habitat is assembled at the space logistics base's space dock using large modules transported to LEO by the Gen 2 spacelifter. The space habitat can be expanded to accommodate up to 300 people.

3. Phase 3 – Extend routine transportation throughout the Earth-Moon system:

a. Capability:

- Establish routine passenger and cargo transport throughout the Earth-Moon system
- Provide on-site logistics servicing support throughout the Earth-Moon system
- Provide emergency search and rescue of humans throughout the Earth-Moon system

b. **System 1 – Space ferry**: a medium size, fully-reusable spaceship capable of transporting payloads of aproximately 30,000 lb (13.6 m-tons) to GEO, Earth-Moon Lagrangian points, and lunar orbit. The space ferry is also used to transport passengers and cargo between the LEO space logistics depots and destinations in the Earth-moon system, and to perform limited in-space logistics servicing.

c. **System 2 – Space transport**: a large, fully-reusable spaceship that serves as a mobile space logistics base to provide temporary on-site logistics support for satellite assembly and operations. The space transport incorporates a large space hangar, similar to those at the LEO space logistics base, to enable both pressurized and extra-vehicular logistics support operations to be performed. When operating as a mobile space base, operating crews, supplies, and logistics support materials are transported to the space transport using space ferries. The space transport is assembled at the space logistics base's space dock using components transported to LEO using the Gen 2 spacelifter.

Notes:

- Fact sheets describing each of the Phase 1-3 concepts are available. These provide illustrations and descriptions of system concepts and additional design, operations, and cost (where available) details. **The concepts described in these fact sheets and in this summary are only illustrative and meant to depict systems and capabilities that industry should be capable of providing.**
- With the exception of the Gen 1.5 aerospaceplane, the development and deployment of the Phase 1-3 systems are not tied directly to the deployment of space-based solar power. They are intended to broadly support American space enterprises. Hence, the initiation of the development of the initial Phase 1 systems can be started immediately as there are near-term (TRL 6-9) solutions.
- The Gen 1 Shuttle-derived spacelifter (also referred to as the Jupiter 120), should it be developed, will be undertaken by NASA separate from these infrastructure activities. Future versions of the spacelifter will be undertaken as part of the integrated spacefaring logistics infrastructure so that all American space enterprises have the benefit of heavy and oversize space access.

Implementation strategy

1. Assumptions:
   a. The development and deployment of the spacefaring logistics infrastructure is undertaken separately from any space-based or space-derived energy system.
   b. A new public-private partnership is established specifically for building and operating the spacefaring logistics infrastructure.
   c. The initial spacefaring logistics infrastructure is undertaken using primarily commercial product and service providers.
   d. Consistent with the need for assured space access, national freedom of operations in space, and the extension of U.S. law and regulations, title and control of the principal elements of the infrastructure will remain with the federal government consistent with other national infrastructure.
   e. Federal government organizations and agencies requiring commercial space access and logistics services will serve as anchor customers for spacefaring logistics infrastructure and its commercial operators.
   f. International participation in the development of the infrastructure will be undertaken within the obligations, constraints, and limitations imposed by ITAR or its successor legislation. International participation will be indirect; undertaken through company-to-company partnerships and agreements rather than through government-to-government partnerships and agreements.
   g. Just as the federal government provides annual appropriations for the construction and operation of national infrastructure (e.g., roads, bridges, airports, and waterways), federal

appropriations will be available to support the construction and operation of new spacefaring logistics infrastructure.

h. In establishing the operational capacity of the new spacefaring logistics infrastructure systems, growth in American space enterprises using the infrastructure will be assumed and sufficient additional capacity to encourage this growth will be incorporated. (By analogy, this means replacing an aging two-lane bridge with a new four-lane bridge.)

2. Organization:
   a. A new Federal Government Corporation will be established to organize and implement the new public-private partnership. This will be referred to as the Spacefaring Logistics Infrastructure Commission or SLIC.
   b. SLIC will be primarily an executive agency overseeing the execution of contracts to develop, produce, field, and operate the basic elements of the infrastructure. SLIC will establish internal management, technical, operational, legal, and financial expertise necessary for the effective execution of its oversight responsibilities and for the operation of the infrastructure.
   c. SLIC will not engage in technology research and development, space exploration, or, with the exception of certain safety and legal responsibilities, the operation of the infrastructure. SLIC will not build or operate SBSP systems.
   d. SLIC will partner and collaborate with other federal and state government agencies and organizations where and how needed to best execute its responsibilities.
3. Funding:
   a. The spacefaring logistics infrastructure will primarily be built using infrastructure-style funding.
   b. As part of its federal charter, SLIC will be able to raise capital funds through the sale of government-backed securities and will be able to charge user fees and lease payments for the use of the infrastructure to, with the assistance of annual government appropriations, payoff the incurred debt and operate the infrastructure.
4. Private industry participation:
   a. With the exception of specific safety and legal functions, private industry will be used to develop, produce, construct, field, and operate the infrastructure.
   b. Competitive contracting and redundant infrastructure capabilities, needed for assured space access and national freedom of space operations, will be used to maximize private industry participation by small, medium, and large companies.
   c. SLIC, through competitive contracting, will aim to maximize the growth of American space operational mastery within American private industry so as to establish the foundation of technical expertise and industrial capability needed to fully exploit the new spacefaring logistics infrastructure and promote future space enterprises.
   d. Private industry will be encouraged to commercially exploit the newly acquired technical expertise and industrial capabilities to bring new space products and services to the marketplace to replace and extend the initial spacefaring logistics infrastructure capabilities.
   e. As part of operational support contracts for government owned facilities and systems, private industry will be required to ensure that a specified percentage of the operational personnel are military reserve personnel to enable, should circumstances warrant, operation of the infrastructure under direct military control.
   f. As part of participation in the development and production of the spacefaring logistics infrastructure systems, private industry will be required to participate in programs that encourage and foster the development of the future American aerospace workforce.