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# Technology Applications that Support Space Exploration

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## Abstract

**Several enabling technologies have been identified that would provide significant benefits for future space exploration. In-Space demonstrations should be chosen so that these technologies will have a timely opportunity to improve efficiencies and reduce risks for future spaceflight. An early window exists to conduct ground and flight demonstrations that make use of existing assets that were developed for the Space Shuttle and the Constellation programs. The work could be mostly performed using residual program civil servants, existing facilities and current commercial launch capabilities. Partnering these abilities with the emerging commercial sector, along with other government agencies, academia and with international partners would provide an affordable and timely approach to get the launch costs down for these payloads, while increasing the derived benefits to a larger community.**

**There is a wide scope of varied technologies that are being considered to help future space exploration. However, the cost and schedule would be prohibitive to demonstrate all these in the near term. Determining which technologies would yield the best return in meeting our future space needs is critical to building an achievable Space Architecture that allows exploration beyond Low Earth Orbit. The best mix of technologies is clearly to be based on our future needs, but also must take into account the availability of existing assets and supporting partners. Selecting those technologies that have complimentary applications will provide the most knowledge, with reasonable cost, for future use**

**The plan is to develop those applications that not only mature the technology but actually perform a useful task or mission. These might include such functions as satellite servicing, a propulsion stage, processing lunar regolith, generating and transmitting solar power, cryogenic fluid transfer and storage and artificial gravity. Applications have been selected for assessment for future consideration and are addressed in this paper. These applications have been made available to the various NASA study groups that are determining the next steps the Agency must take to secure a sound foundation for future space exploration**

**The paper also addresses how follow-on demonstrations, as launch performance grows, can build on the earlier applications to provide increased benefits for both the commercial and scientific communities. The architecture of incrementally building upon previous successes and insights dramatically lowers the overall associated risk for developing and maturing the key enabling technologies. The goal is to establish a potential business case that encourages commercial activity, thereby reducing the cost for the demonstration while using the technology maturation in developing readiness for future space exploration with overall less risk.**

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[2] NASA/JSC/Space Shuttle Program, Advanced Studies- retired

## Acronyms

| | | |
|---|---|---|
| *BETD* | = | Beamed Energy Transfer Demonstration |
| *GEO* | = | Geosynchronous Earth Orbit |
| *HAT* | = | Human Architecture Team |
| *ISS* | = | International Space Station |
| *ISRU* | = | In-Situ Resource Utilization |
| LEO | = | Lower Earth Orbit |
| *MMSEV* | = | Multi-Mission Space Exploration Vehicle |
| *OTV* | = | Orbital Transfer Vehicle |
| *SBSP* | = | Space Based Solar Power |
| *SEP* | = | Solar Electric Power |
| *SDHLV* | = | Shuttle Derived Heavy Lift Launch Vehicle |
| *SSP* | = | Space Shuttle Program |
| *TAAT* | = | Technology Applications Assessment Team |

## I. Introduction

As the Space Shuttle Program comes to a close many questions have been asked on how the NASA can capitalize on the tremendous skill base and inventory of flight hardware and the infrastructure created and perfected during shuttle operations. The first consideration was to continue to utilize those assets in developing a shuttle derived heavy-lift launch vehicle (SDHLV) that could satisfy the immediate launch needs following shuttle retirement. These ideas were suggested alternatives presented to the President's transition team and the Norm Augustine team as considerations but rejected as following short of the heavy lift launch performance needed for future exploration. In reviewing this option additional questions came up as to the need for an intermediate capability so soon. The program addressed early manned flights and cargo flights that could mature technologies that would be needed in the future. NASA managers felt it best to let the Marshall Space Flight Center (MSFC), the Center responsible for developing launch systems, develop the launch vehicle needed for exploration with support from the Shuttle Program as required. However it was felt prudent to allow a small shuttle staff to continue to evaluate technologies that could be demonstrated soon that may be helpful down the road.

The Technology Applications Assessment Team (TAAT) was set up to identify and assess candidate technologies that could be affordably demonstrated soon, two major guidelines were mandated to keep the cost down- 1). Make the maximum use of existing shuttle assets and 2). Partner wherever possible to share the cost. The team was allowed to use shuttle skills on a non-interfering basis with existing shuttle duties to staff the team. TAAT was formed beginning in FY 2011 and has been meeting weekly, periodically providing progress status with the Shuttle Program.

A summary of the work TAAT has performed along with suggestions for follow on assessments are discussed.

## II. Team

The TAAT members varied based on needed skills and availability. The core team is around a dozen civil servant engineers from the Space Shuttle Program (SSP) and the JSC Engineering Directorate. Other NASA Centers support as needed and a couple of Shuttle support contracts are used for special tasks and administrative support. Other support is requested when needed to expand the team's knowledge on a particular application based on their shuttle experience. More importantly all the work is on a non-interfering basis with ongoing shuttle work and at no added cost.

## III. Objectives

The primary objective for TAAT is to select some promising technologies that can be demonstrated relative soon that would advance the technology readiness level (TRL) needed to enable the space exploration architectures. Technologies that support multiple customers and a variety of applications are preferred. Technology demonstrations that can be done soon, are affordable and can be partnered with others are the most desirable. Also, performing demonstrations that make use of existing assets, e. g. facilities, flight hardware and software, skills help keep the cost down and can be done sooner. The selected technologies should correspond to those technologies identified in the Space Technology Roadmaps (ref. 1) developed by NASA's Office of Chief Technologist (OCT). It is important also, that these technologies would conform to a Commercial Space Model (Fig. 1) that would encourage commercial participation and development.

Sufficient ground and flight testing are a necessary prerequisite to a flight demonstration. This utilizes existing skills and facilities that will not only lower the cost but increase the confidence. The International Space Station (ISS) makes an excellent test platform and provides two important connections: 1.) it uses the ISS to advance technologies needed for exploration and 2.) it facilitates the international partners to participate in the testing and bonds a partnership for exploration. The Technology Application Roadmap (Fig. 2) shows some examples for what technologies could be tested on the ISS.

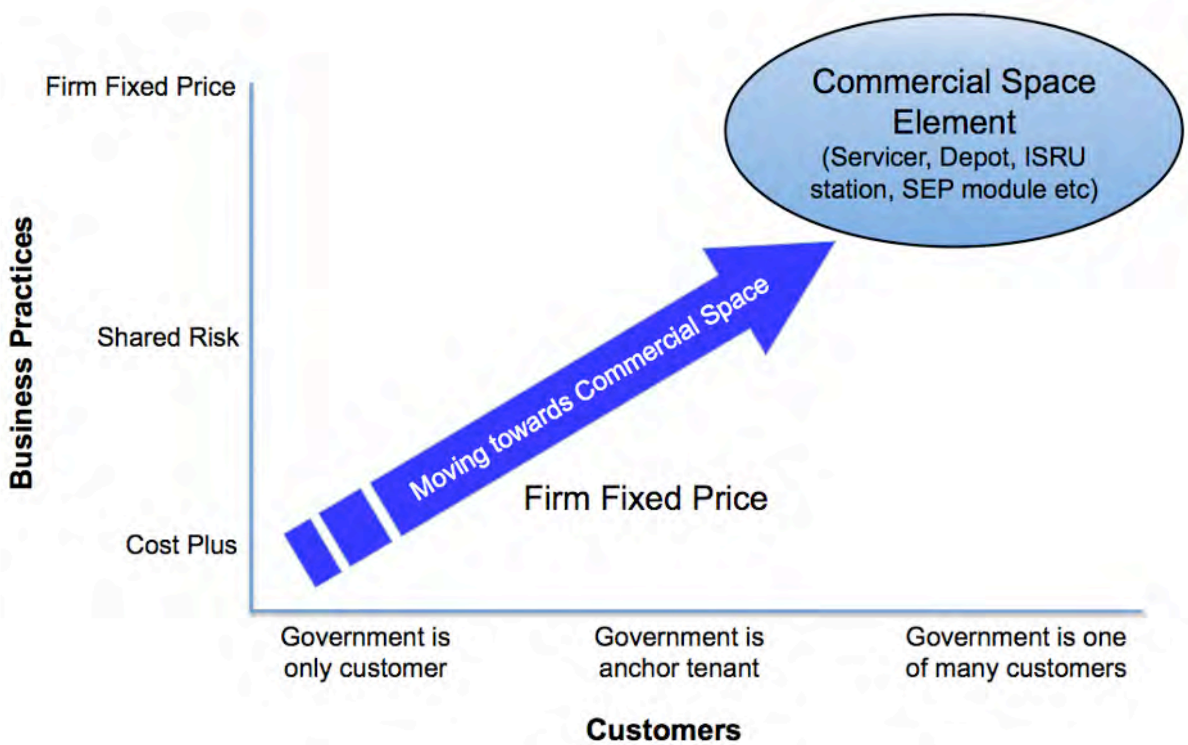



**Figure 1. Commercial Space Model**

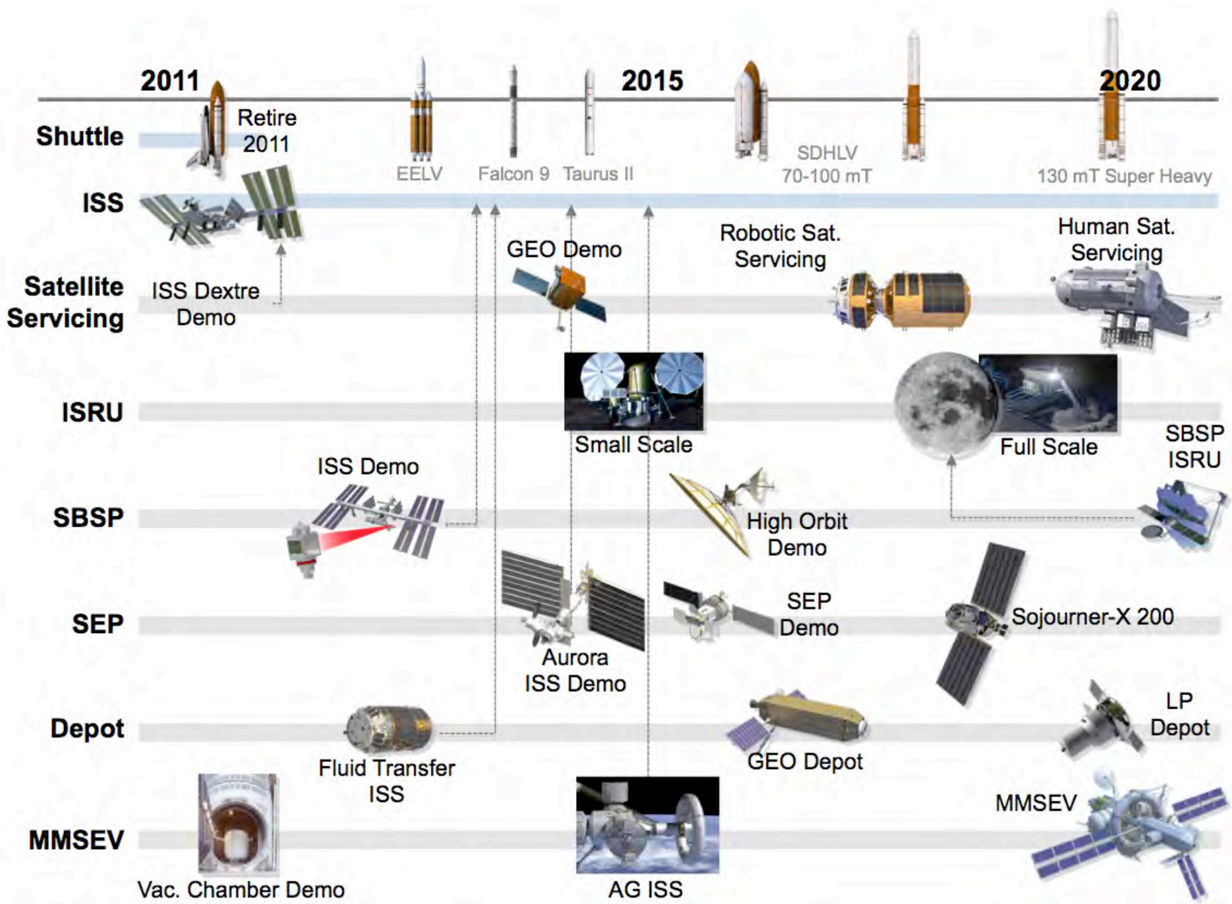



**Figure 2. Technology Applications Roadmap**

## IV. Technology Applications

Initially six broad technologies were selected for preliminary assessment: 1.) Satellite Servicing, 2.) In Situ Resource Utilization (ISRU), 3.) Space Based Solar Power (SBSP), 4.) Solar Electric Propulsion (SEP), 5.) Depots and 6.) Multi-Mission Space Exploration Vehicle (MMSEV). The selections were based on the criteria discussed in the objectives, the skills available to support the team and management interests. A lead was assigned for each application and was requested to describe the technology to be demonstrated and develop a preliminary concept definition plan (Fig. 3). This included identifying partnering opportunities with other NASA Centers, government agencies, internationals, contractors and academia (Fig. 4). Interfaces with existing teams were established that had common functions to not only avoid duplication but also to strengthen the overall support (Fig. 5).

A brief description, challenges and key risks for each application were addressed in the assessment analysis. The technologies needed for each application were crossed referenced to supporting paragraphs provided in the Space Technology Roadmap documents (Fig. 6) to ensure that these were important technologies needed for space exploration.

## Applications Concept Definition Plan

- Brief description of the Application, including a quad chart
- Identify launch systems and existing assets being used
- Concept of Operations and Design Reference Mission
- Design description including configurations, main subsystems, and performance sensitivities
- Identify Challenges and key risks
- Identify Partnering Opportunities: Other Centers, Contractors, Government Agencies, Internationals, etc.
- Identify which Space Technology Roadmaps are supported
- Define a rough development schedule, including the projected first flight date and a Development cost "Swag"

**Figure 3. Applications Concept Definition Plan**

| | Centers | Industry Partners | TAAT Partners | Existing Assets |
|---|---|---|---|---|
| **Sat Serv.** | HQ, JSC, JPL, GSFC, LaRC | Commercial, DoD, IP (JAXA, CSA) | GSFC, DARPA, CSA, JAXA | Falcon 9, EELV (D-IVH, Atlas 511), Delta IV U.S, Modified HTV elements, DEXTRE/Ranger (UMD), FREND, LIDAR, Air Table |
| **ISRU** | HQ, JSC, GRC, ARC | Commercial, Academia, IP (JAXA, CSA, ESA) | Resolve, KSC/MSFC, USRA | LRO/LCROSS Data Sets |
| **SBSP** | JSC, JPL, GRC, LaRC | Commercial, DoD, DOE, Academia, IP (JAXA, CSA, ESA) | GRC, Henry PV, AFRL, JAXA, NRL | SOLAROSA, Atlas V |
| **SEP** | HQ, JSC, JPL MSFC, GRC, LaRC | Commercial, DoD, IP (JAXA, CSA, ESA) | GRC, JPL, DARPA | VASIMR facilities, HALL/Ion Thrusters, Mini Air Can, TRIDAR, LRO Bus, FAST/SOLAROSA |
| **Depot** | HQ, JSC, MSFC, GSFC, GRC, LaRC | Commercial, DoD, IP (JAXA, CSA, ESA) | FISO, DoD/DARPA (robotic servicing vehicle), Commercial (Tanker, Future ops), International (Service Protocols & Interfaces) | EELV (Launch), Existing bus technology and hardware |
| **MMSEV** | HQ, JSC, KSC, MSFC | Commercial, DoD, IP (JAXA, CSA, ESA) | JPL, ARC, GRC, GSFC, ISS, HEFT, LaRC | Orbiter Airlock, HTV |

**Figure 4. TAAT Partners**

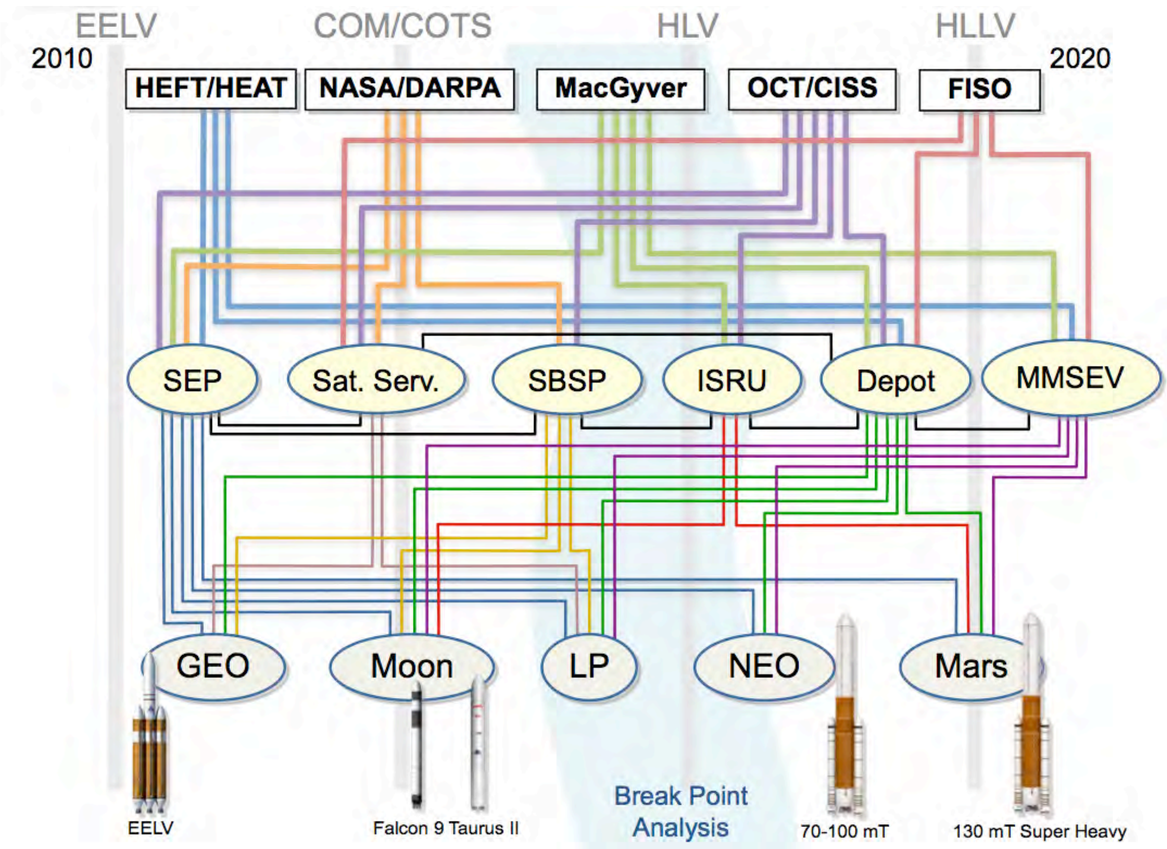
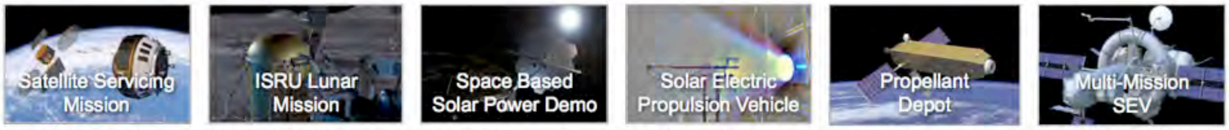



**Figure 5. TAAT Interactivity**




**TA04 TA05** | **TA07** 2.2.1, 2.2.2; **TA14** 2.1 | **TA03** 2.2.1.3, 2.2.3.2 | **TA02** 2.2.1; **TA07** 2.2.2; **TA14** 2.1 | **TA14** 2.1, 2.3 | **TA05**; **TA07** 2.2.2, 2.2.3

**Technology Area 02 "In-Space Propulsion Technologies"**
Section 2.2.1 "Electric Propulsion"

**Technology Area 03 "Space Power and Energy Storage"**
Section 2.2.1.3 "Solar Power Generation"
- Systems with high efficiency and dust tolerance ,
- Systems with low intensity/low temperature and high radiation tolerant capability, high voltage and
- High specific power array capability, etc.

Section 2.2.3.2 "Wireless Power Transfer"
- High efficiency beaming techniques, receivers, energy storage, system with high distribution voltage, etc

**Technology Area 04 "Robotics, Tele-Robotics & Autonomous Systems"**
- Sensing, Manipulation Technology, Human Systems Interface, Autonomy, and AR&D, etc..

**Technology Area 05 "Communication and Navigation Systems"**
- Optical Communication and Navigation Technology: Large aperture for ground reception, optical acquisition and tracking
- Position, navigation, and timing: Precision landing, formation flying, cooperative robotics and proximity operations, autonomous approach and landing, ultra wide-band (high bandwidth) communication and navigation.

**Technology Area 07 "Human Exploration Destination Systems"**
Section 2.2.1 "In-situ Resource Utilization (ISRU)"
- Resource Acquisition
- Consumable Production: regolith fluidization and mixing, 2-phsae separations, etc.
- Manufacturing and infrastructure emplacement: microwaves, ionic liquids, excavation equipment, etc.

Section 2.2.2 "Sustainability & Supportability"
- Logistics Systems: consumable storage, transfer & delivery, food production & preservation, reuse and recycle
- Maintenance Systems: Contamination control & cleanup, Robotics systems for maintenance. Etc.

Section 2.2.3 "Advanced Human Mobility Systems"
- EVA Mobility: EVA mobility aids & tools, Human-2-telerobotic system
- Section 2.2.5 Mission Operations & Safety: Environmental Protection, remote Mission Operations, planetary safety

**Technology Area 14 "Thermal Management Systems"**
Section 2.1 "Cryogenic Systems"
- Pass thermal control: large scale multi-layer insulation, MMOD Protection, low conductivity tank, etc.
- Active Thermal Control: 20K Cryo-coolers for propellant management, Cryo-pumps, thermal energy storage, etc.
- System Integration: Radiation Shielding for storage tanks

Section 2.3 "Thermal Protection Systems"
- In-space TPS repair
- Self-diagnosing/self repairing TPS

**Figure 6. Space Technology Roadmap Applications**

## V. Assessments

The assessments for each technology application vary considerably depending on the connectivity with other groups and skills available. A brief summary of the preliminary analysis has been presented to the Shuttle Program management and the assessment results captured on compact disk (ref. 2), available on request. The results and status on each assessment are summarized below:

**Satellite Servicing** The satellite servicing (Fig. 7) assessment was in support of work being conducted at the GSFC (Ref. 3) and for one of the special NASA/DARPA studies for Manned GEO Satellite Servicing. Several things were hoped for by developing this capability. First to demonstrate a robotic capability to refuel or repair satellites in a geostationary orbit (GEO) to extend the life of very valuable satellites, relocate failed satellites to a safe orbit freeing up a GEO slot and eliminating a source of debris. These capabilities provide an attractive business case. Once the capability has been demonstrated and the investment risks mitigated, private companies would be encouraged to own and operate the service. Later a manned tended capability could be added providing an additional dimension for servicing satellites. Providing and implementing these capabilities now would mature and utilize technologies needed for exploration.

**Figure 7. Satellite Servicing**

The team did several trade studies to determine the best methods for servicing and getting to GEO satellites. Cost trades using existing and evolving launch vehicles showed that the larger vehicles, 70-80mt, increased the number of satellites that could be serviced with one launch and consequently had a better return on investment. Propellant depots would provide similar cost benefits. In getting fuel or humans to GEO brought different requirements for getting from a low Earth orbit (LEO) to GEO. Getting fuel to GEO normally not time critical and could be transferred with an Orbital Transfer Vehicle (OTV) using Solar Electric Propulsion (SEP) in a slow spiral once beyond the Van Allen radiation belt. However delivering a work crew to GEO needs to be done faster with chemical propulsion to reduce radiation exposure and minimize life support durations. Therefore the team suggests that a reusable hybrid OTV would be better. Later the OTV could be updated with aero breaking for added efficiency (Fig. 8).

Currently the team is evaluating options for a satellite servicing demonstration that may excite commercial interest and supporting both GSFC and NASA/DARPA satellite servicing studies on request. The team plans to follow on with work on the hybrid OTV.

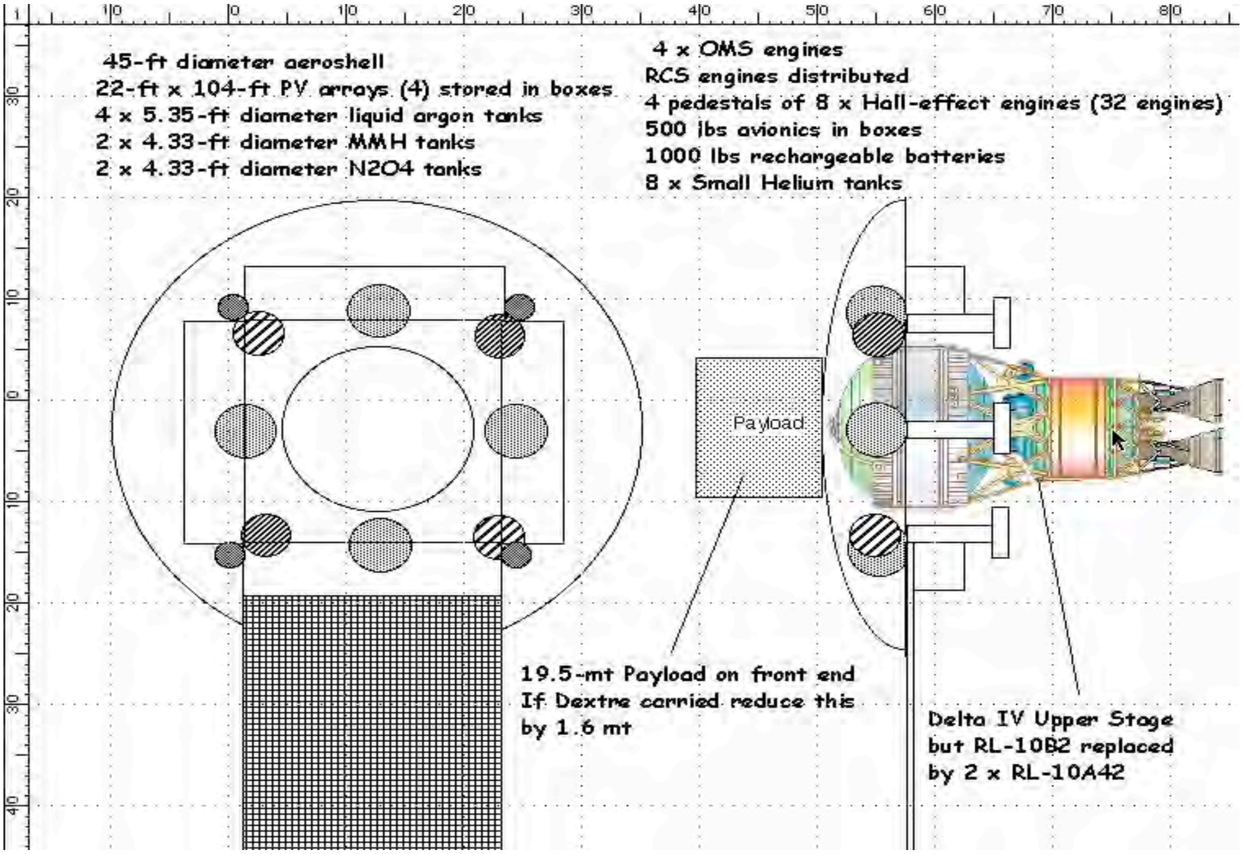



**Figure 8. Hybrid HOTV**

**In Situ Resource Utilization –** Recent findings from Lunar robotic missions (LRO, LCROSS, etc.) have indicated an abundance of water (ice) could be present at the Lunar polar regions. The benefits for space exploration for water on the Moon are huge. Not only for Lunar operations but provides a valuable in situ resource of water, oxygen, and propellant to support exploration for Lunar missions and beyond from a low gravity source. Therefore increasing our understanding on how much water, locations and the ability to process the lunar regolith to collect the ice is key to it being a viable source to support exploration and attractive a commercial interest. The team along with the Lunar Planetary Institute put together a rigorous mission (Fig. 9) that could robotically land all the elements to conduct a Lunar processing demonstration. Communications, power, rover, processor were all included on a single launch of a SDHLV. The goal was that this flight would establish the feasibility for processing water on the Moon and could result in providing a follow on production capability. Unfortunately, though doable, the demo would be too expensive near term along with an uncertainty on when a heavy lift vehicle would be available. It was decided to consider a smaller demonstration using existing launch vehicles.

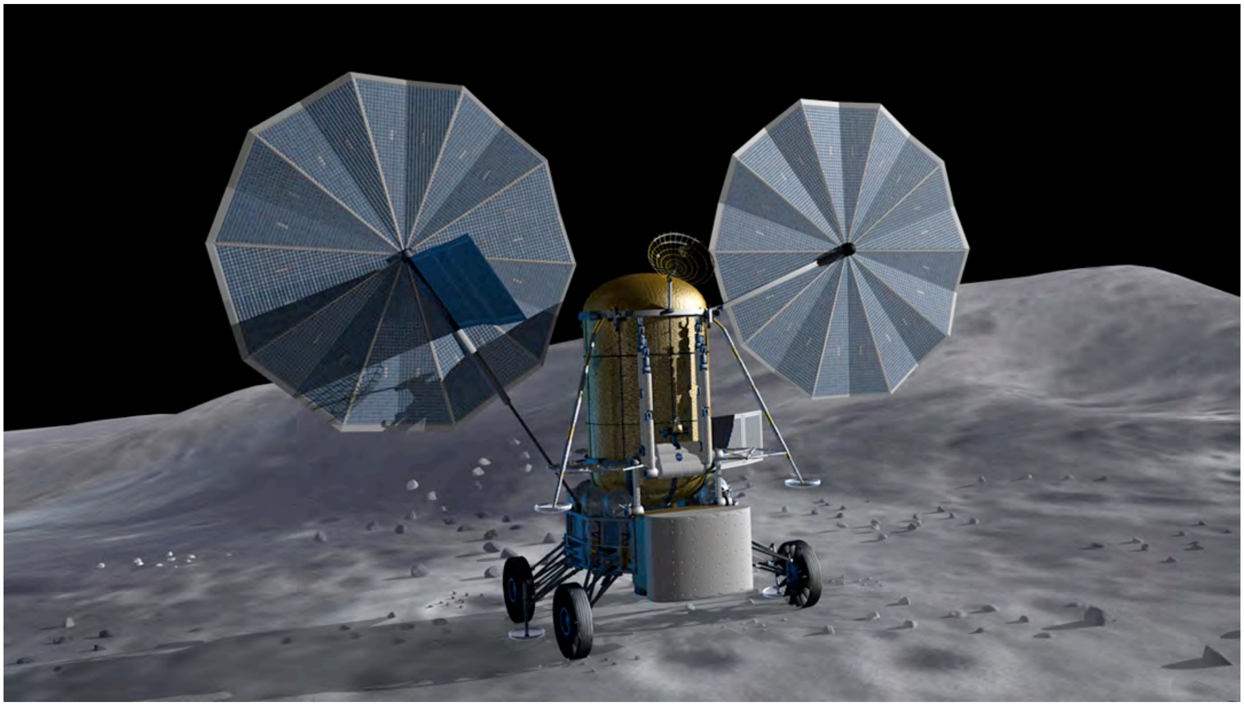


**Figure 9. ISRU Water Processing Demo**

Getting started soon is important because should water be easily available from the Moon, then it should be folded into the Human Architecture exploration plans for future early. The TAAT is working with the Cis-Lunar commercial team to perform a demo soon using commercial support and hardware that is compatible with existing launch vehicle performance. This partnership would significantly reduce the cost and could be done much sooner. Later demos could be added to prove the feasibility evolving into a production demo like the one above when funds and launch capabilities become available.

**Space Based Solar Power –** TAAT evaluated what SBSP beaming demonstration could be performed soon with existing launch vehicles. Several wireless power transmissions concepts were assessed (Fig. 10) including microwaving power from space to ground and laser power beaming power from ground to space and space to space. The hope was that a reasonable demo could be done, transferring sufficient power to the ground that might better quantify beaming efficiencies to help determine SBSP viability as a future power source for ground energy. Many variables were analyzed including a wide frequency range (5.8GHz to 94GHz), Solar Dynamic power systems, advanced photo voltaic (PV) power arrays and a range of orbit parameters from GEO to Molniya orbits. The transmitting satellite size with the available launch vehicles were too small and none of these combinations yielded sufficient received power levels on the ground to obtain a measurable result. Clearly larger satellites would be needed to get meaningful results. Once the schedule and size for follow on launch systems firms up, then maybe a more meaningful SBSP demonstration can be developed.

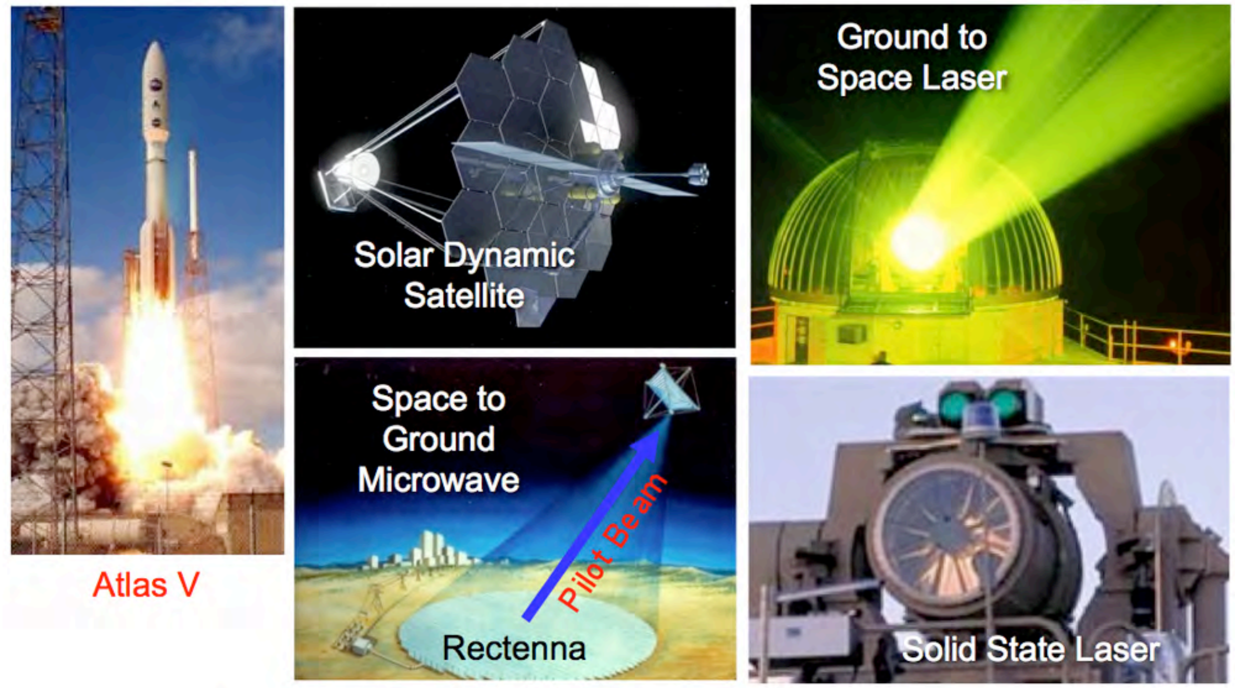



**Figure 10. Space Based Solar Power Beaming Demo**

In the mean time the team has diverted the SBSP work to working with the Glenn Research Center (GRC) on a Beamed Energy Transfer Demonstration (BETD) proposal. The plan would be to put a laser on the ISS to beam energy to one of the United States Air Force Academy's FalconSATs (Fig. 11). The laser would be delivered to the ISS on a standard resupply flight and mounted on the JEM-external facility. The FalconSAT could be delivered on the same vehicle and released on the way to the station or it could be carried on a separate launch vehicle is still to be determined. Whenever the satellite passes within range of the ISS (~500 km) the laser could beam energy (~300 W) to the FalconSAT. The laser has about a 30 sec. beam time. Primary success would be that the satellite receives the energy but secondarily the energy could be transferred to a Hall Effect thruster that could propel the satellite. The laser stay on the ISS would be at least a year so, depending on the satellites trajectory, there should be many opportunities for beaming it energy.

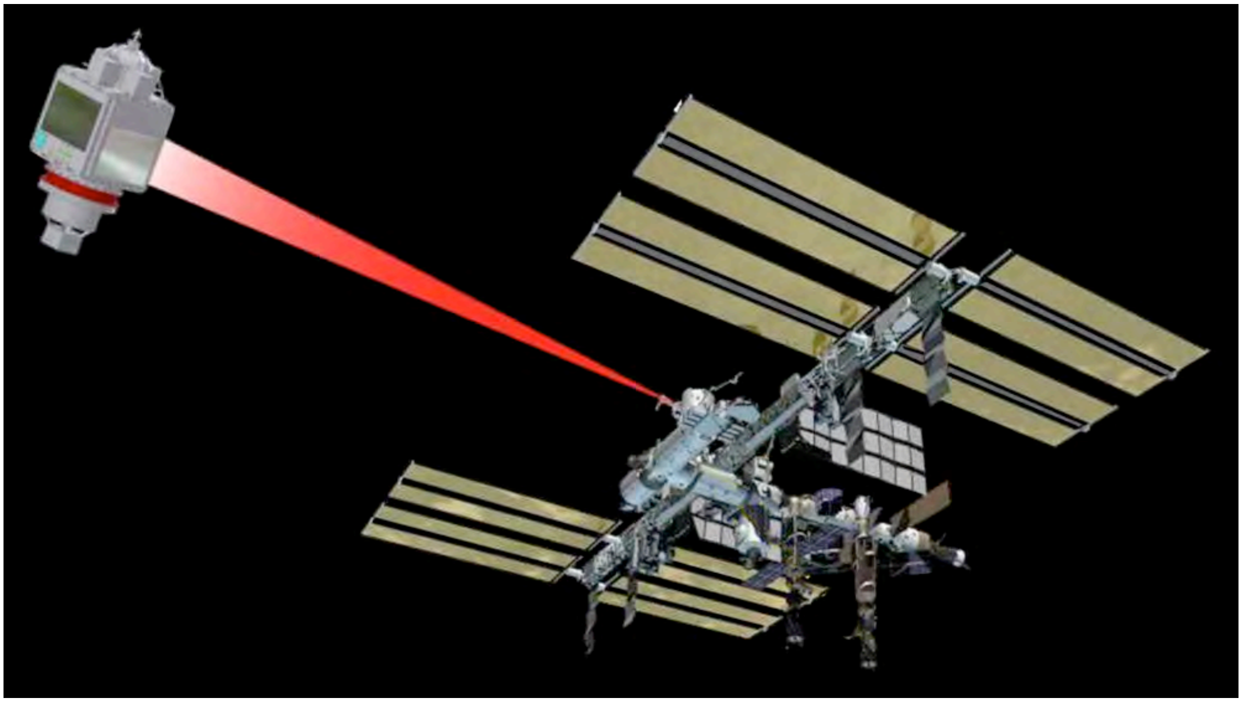


**Figure 11. ISS Beamed Energy Transfer Demonstration**

**Solar Electric Propulsion –** The team did a trade study to determine the best location for a Solar Electric Propulsion (SEP) demonstration- on the ISS or as a free-flyer (Fig. 12). The demo objective would be to demonstrate two high-powered electric propulsion engine technologies: VASIMR and a Hall or ION engine. The free-flyer demo was preferred, it allowed a dedicated environment to test and compare each type engine. However the ISS also had some advantages including a platform for long-duration testing, utilizing the ISS for its intended use for testing technologies needed for exploration and possible participation with International Partners. If affordable an ISS demo would be an excellent precursor to a free-flyer. The design, development, test and evaluation for the free-flyer demo could actually be completed in 4 years and could be launched using existing launch vehicles.


**Figure 12.  SEP Demo**

Additional work with TAAT on the SEP demo is on hold but hopefully it will continue as part of the Game Changing OCT activity. Meantime SEP is an integral part of the interplanetary highway infrastructure (Fig. 13) needed to support exploration and will be included as part of a hybrid Orbital Transfer Vehicle (Fig. 8) study TAAT is initiating.

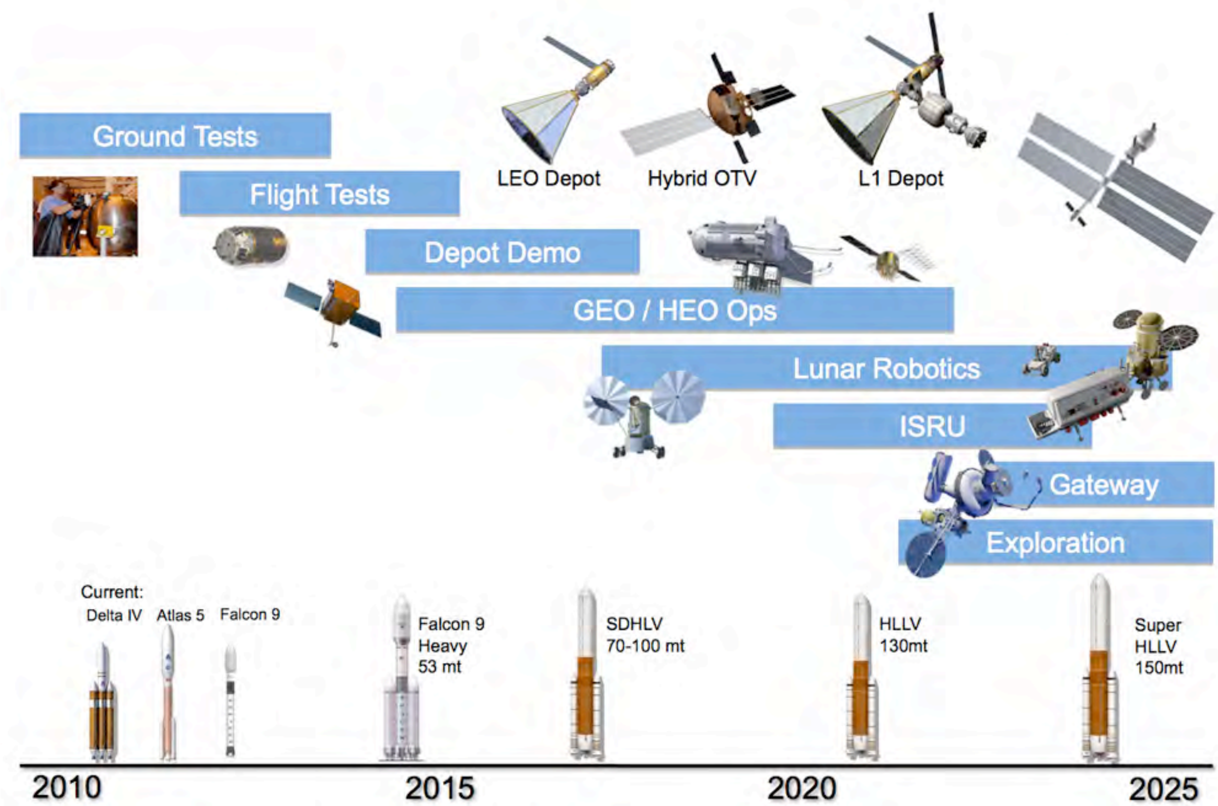



**Figure 13. Interplanetary Highway Infrastructure**

**Depot** – Most of the recent TAAT work has been developing a strategy for evolving propellant depots. Evolving a depot capability to support near term applications on servicing satellites and debris maintenance to space exploration for the long term involves all the technologies the team has been assessing. The question is where to start- ideally the sooner the better. The key is to get a commercial interest that depots can be profitable and that a good business case exists. A growing interest in servicing satellites in GEO may provide some of the near term customers needed. It is a common location for a large number of satellites, many which are at or nearing the end of their useful life. Concentrating on the larger government satellites should be profitable and once a working depot has been demonstrated other applications would expect to follow. These services would be considerably different than those needed for exploration – different propellants, different locations, different applications, etc. But establishing commercial ownership and operations would be profound. A simple GEO depot (Fig. 14) could be done relatively soon using existing launch vehicles.

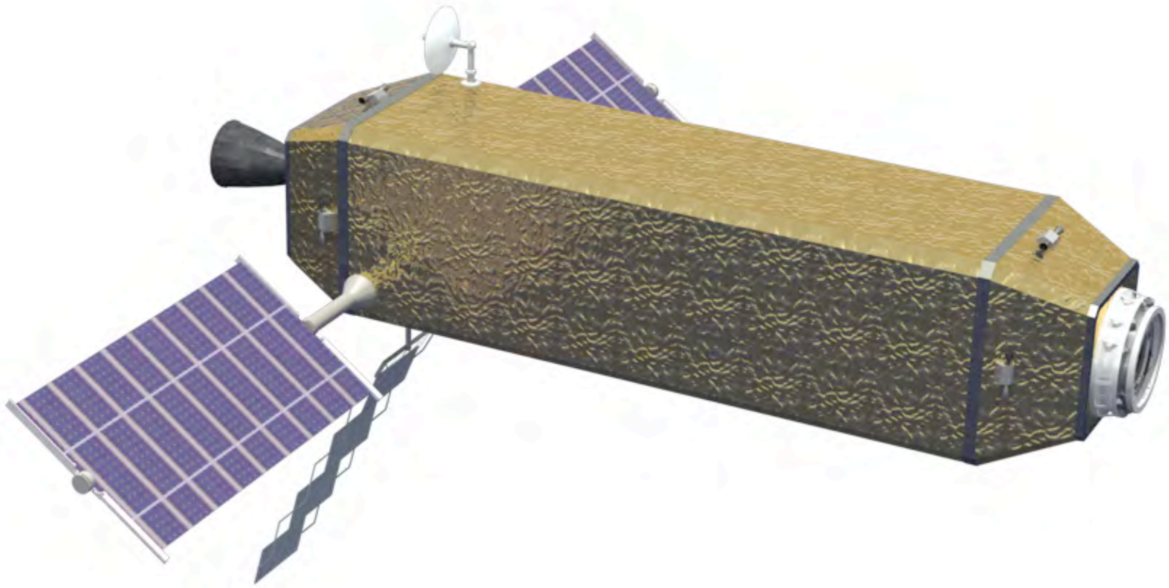


**Figure 14. Depot at GEO**

In parallel with a GEO depot a cryogenic depot should be started in LEO. This depot could be used to top-off upper stages with propellant in orbit reducing the launch performance penalty for caring the propellant to space. This capability would have two significant advantages over not using a depot. First it would enable getting more with existing launch vehicles and second it reduce the size of future launch vehicles needed to perform missions with a single launch vehicle (Fig. 15). Once this depot capability is operational larger missions can be performed, like going to the Moon, using existing launch vehicles reasonably soon.

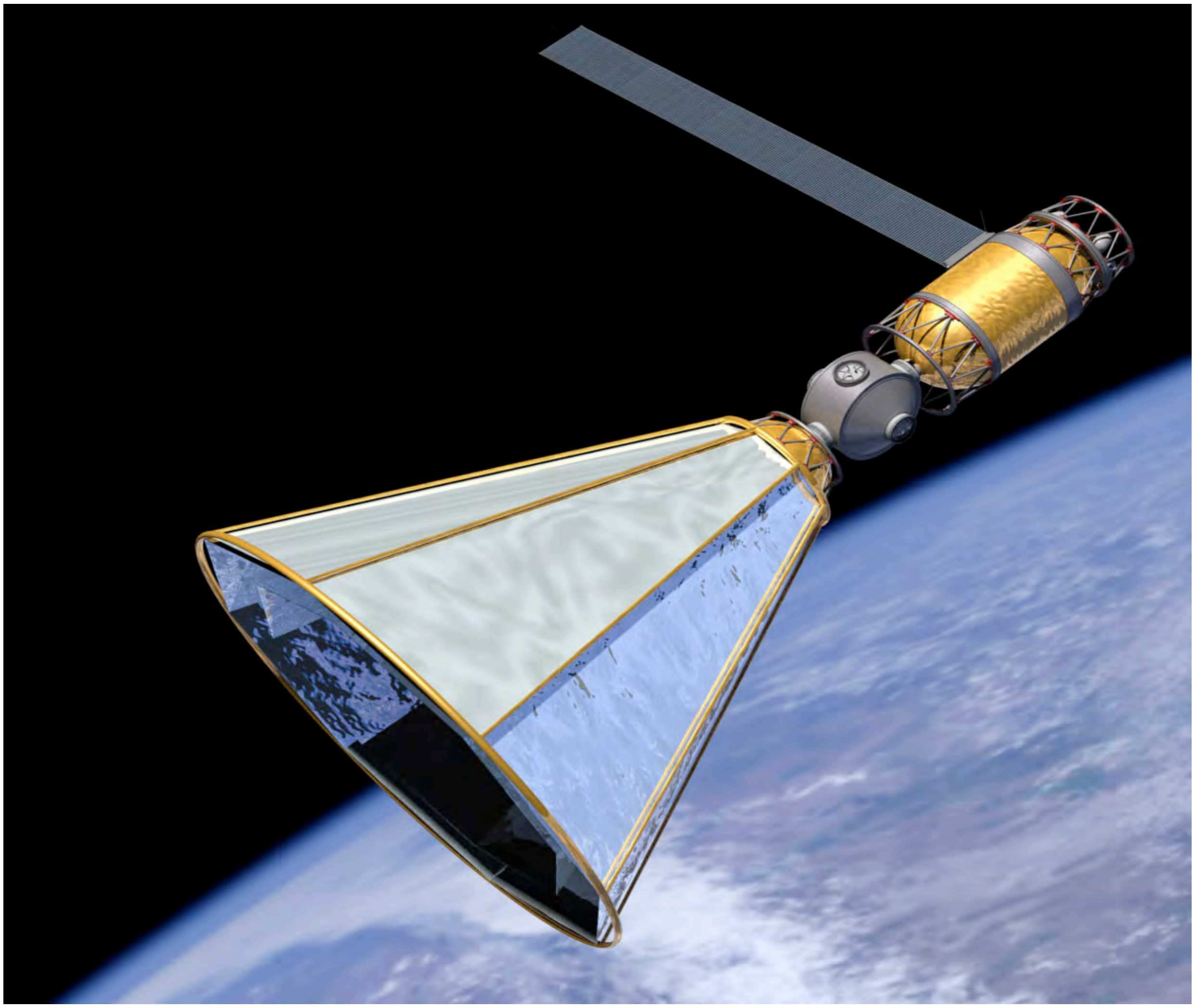


**Figure 15. LEO Propellant Depot**

A depot capability could evolve, starting with Liquid Oxygen (LOX), the heaviest propellant, adding Liquid Hydrogen (LH2) or Hydrocarbons later to increase performance. Depots could be increased in size, adding more tanks or more fuel, as needed. Once a Lunar ISRU processor has been developed (Fig. 16), a depot could be built at one of the Earth-Moon Lagrange Points. Propellant could be supplied from the Moon at a significant reduction in performance than bringing it from Earth. Later depots can be added supported by ISRU as we move out in space (Fig. 17).

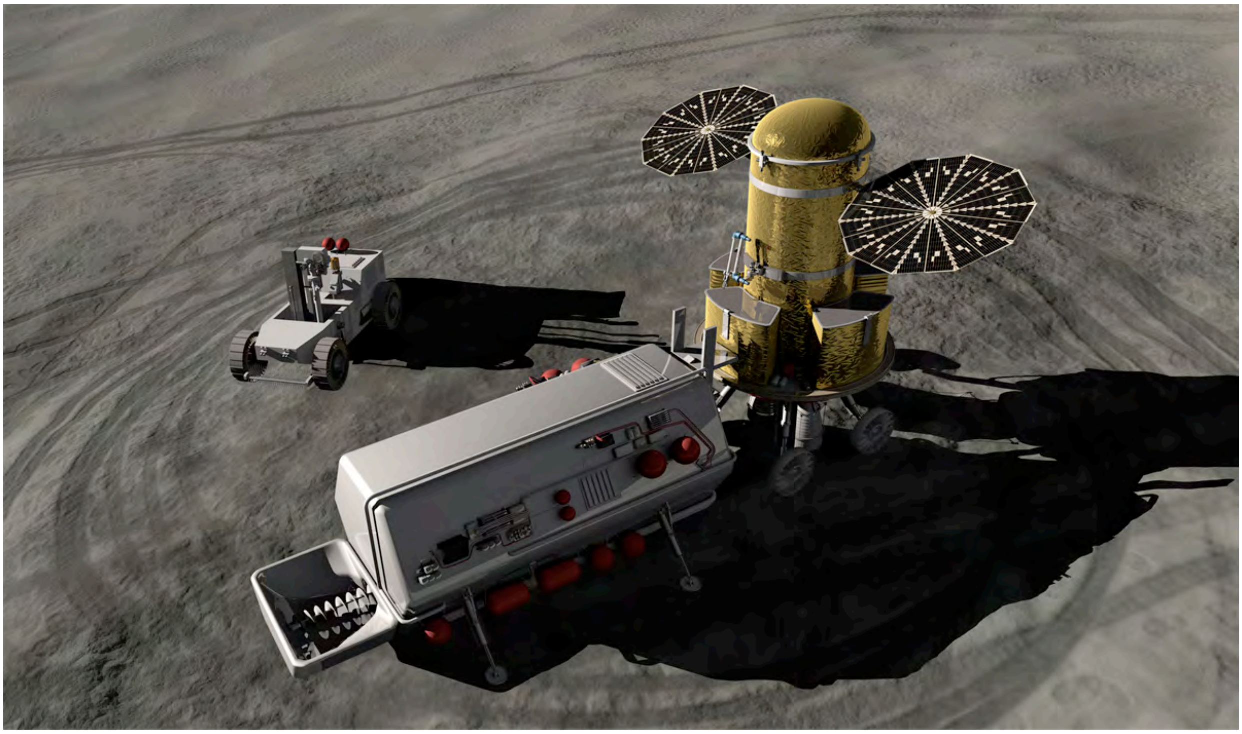


**Figure 16. Lunar ISRU**

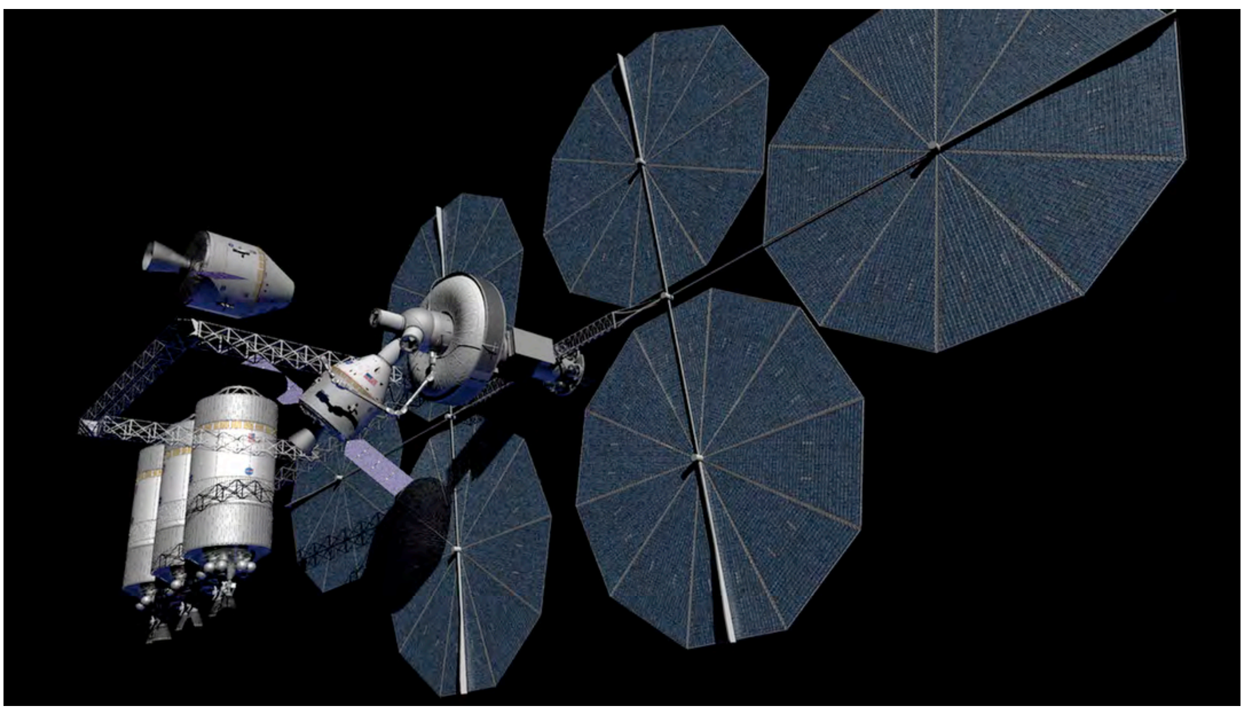


**Figure 17. Propellant Depot Evolution**

**Multi-purpose Mission Space Exploration Vehicle** The MMSEV concept (Nautilus-X) the TAAT is assessing is much different than the MMSEV being developed officially by NASA's Human Architecture Team (HAT). The Nautilus-X [Non Atmospheric Universal Transport Intended for Lengthy United Space – Xploration] manned vehicle (Fig. 18) is a design mechanism for showing how developing technologies and engineering approaches can be creatively merged. It is a multi-purpose platform that can accommodate a wide variety of missions. It integrates a number of different propulsion platforms, life support systems in a human habitat and centrifuge along with the GN&C [Guidance, Navigation & Control] system to make Nautilus-X a true departure from current spacecraft design paradigms.

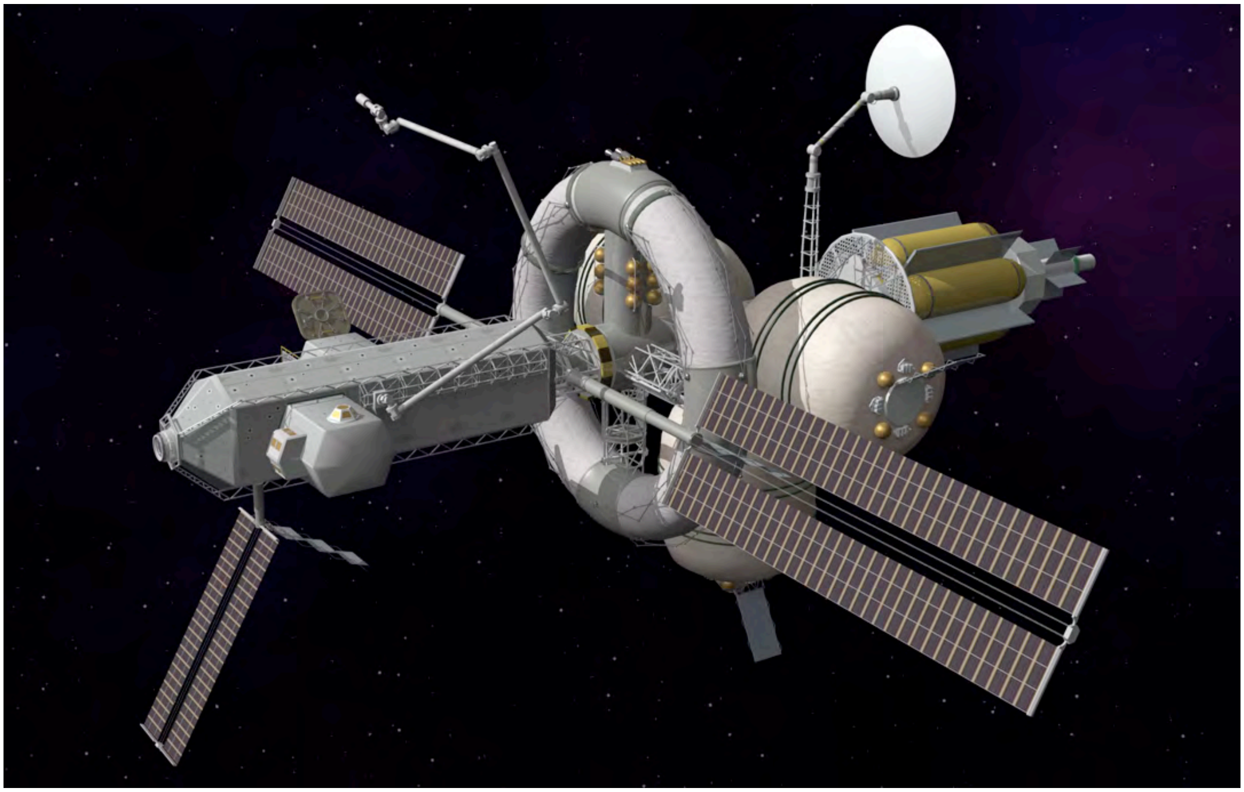


**Figure 18. Nautilus-X**

The Strategy that Nautilus-X is a part of is to develop those applications that not only mature the technology but actually perform a useful task or mission. These might include such functions as satellite servicing, a propulsion stage, processing lunar regolith, generating and transmitting solar power, cryogenic fluid transfer and storage and artificial gravity. Regarding artificial gravity, the TAAT has proposed the first demonstration of a Human-Hab Centrifuge could be done on the International Space Station (Fig. 19).

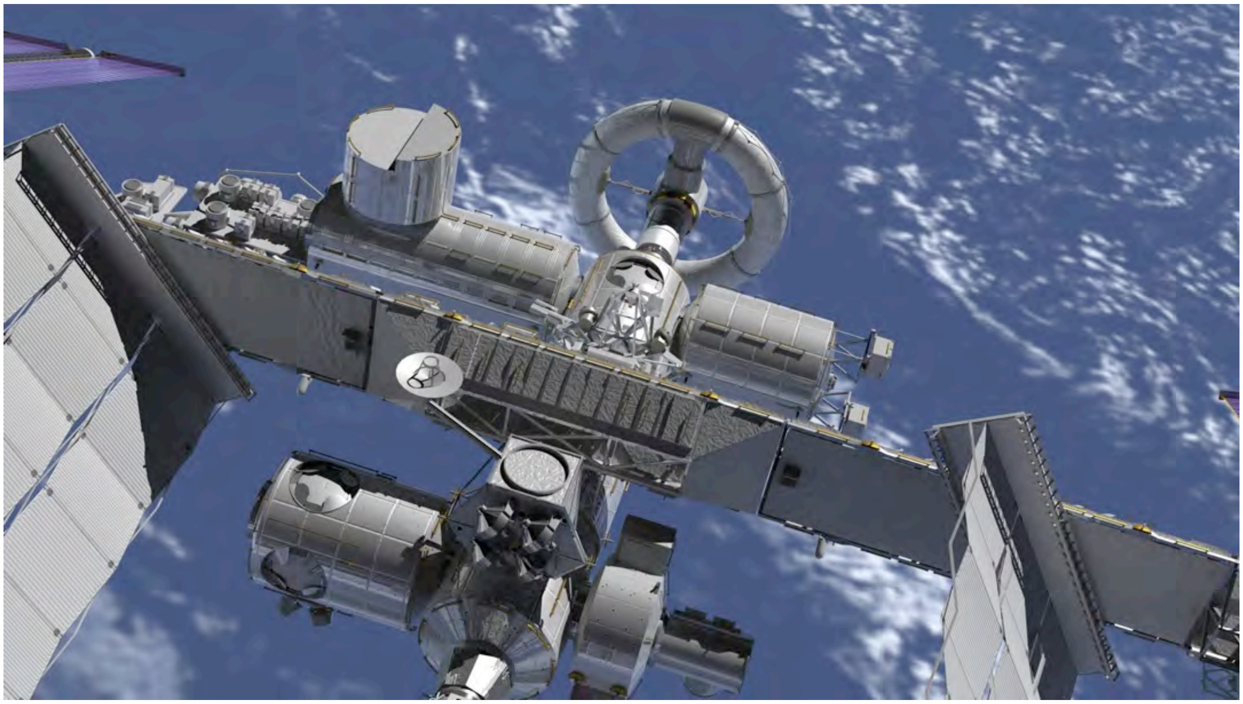


**Figure 19. Station Centrifuge Demo**

## VI. Conclusions

The technology applications the team preliminarily assessed, though selected somewhat randomly, can be linked together in a conceptual space exploration infrastructure (Fig. 20). A summary of the work the team performed on each of the technology applications assessment along with supporting trade studies has been collected on a compact disc (Ref. 2) and is available on request. Subsequently the team has been working on the ISS beamed energy demonstration and on propellant depot implementation strategy.

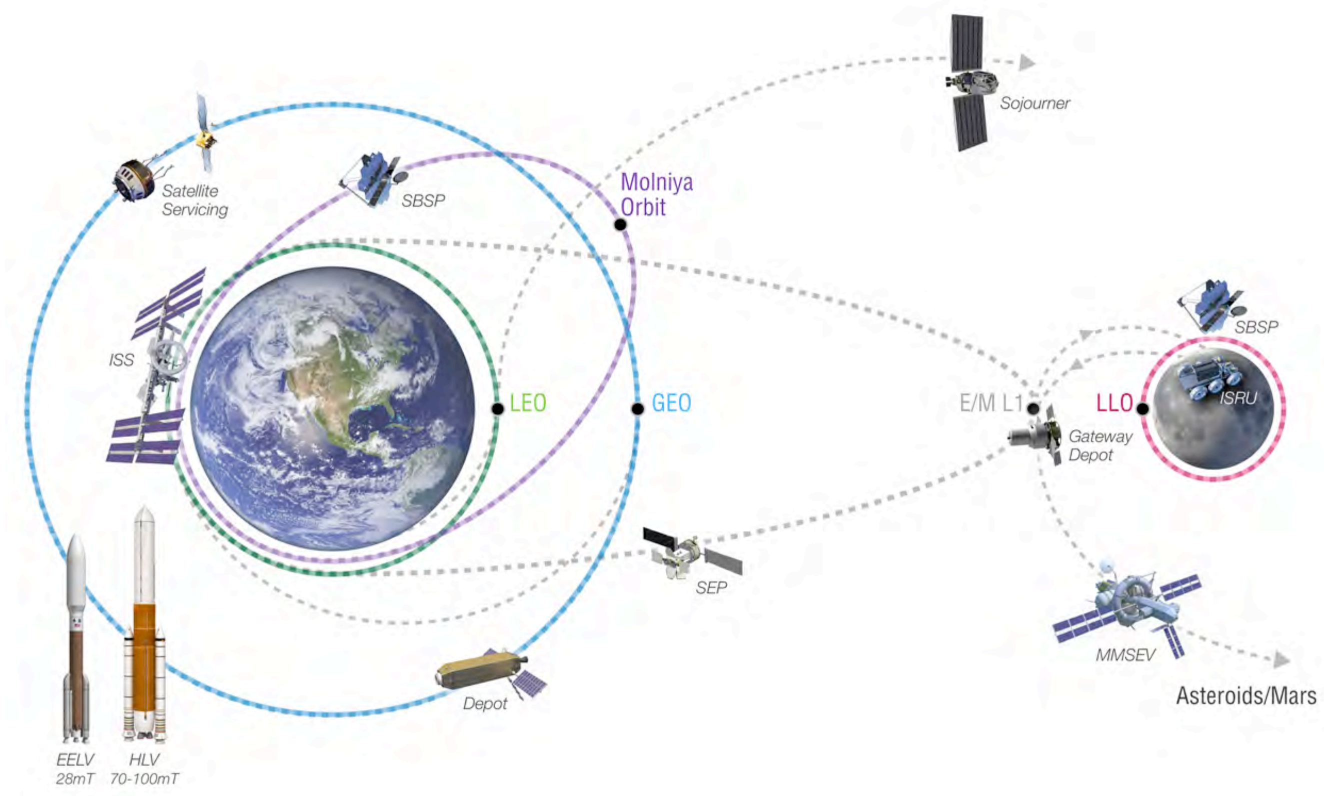



**Figure 20. Space Exploration Infrastructure Concept**

## References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2. Technology Applications Assessment Team- TAAT Plans, March 2011
3. NASA/Goddard Space Flight Center, "On-Orbit Satellite Servicing Study" October 2010, Project Report,

## Biography

Edward M. Henderson, Mack has 50 years experience with NASA in a wide variety of jobs. After his cooperative education program with the Army at Redstone Arsenal, AL, working on rocket guided missiles. Mack transferred to the NASA's MSFC, where he worked in the Aeroballistics Lab helping to define the aerodynamics used for the Saturn V. After receiving a B. S. in Aerospace Engineering at Virginia Polytechnic Institute and State University, Mack went to the Manned Spacecraft Center in Houston, TX. and worked in Mission Planning and Analysis for Gemini, Apollo and Space Shuttle programs. He was the abort subsystem design manager for the shuttle and as a Flight Design Manager, Mack lead the shuttle design work for the first Spacelab mission and the first west coast launch (which never flew). He later headed the ascent and entry flight design, owning more than 1700 software I-loads used for shuttle ascent and launch aborts.

Mack moved to the Flight Directors Office, where he was responsible for Space Shuttle and the International Space Station Program integration for the mission operations and managed the SPAN (mission control's spacecraft analysis room) for more than 50 shuttle flights. Mack moved to the Shuttle Program (SSP) office in 1990. While in the SSP, he helped set up the Space Shuttle Development office and control board that over saw major shuttle upgrade projects, designed to keep the shuttle flying to 2020. Mr. Henderson led a technical team on improvements for shuttle derived launch vehicles, significantly increasing performance at reduced cost. Once the vision for space exploration and the early retirement of the shuttle was announced, Mack helped set up the transition team charged with safely retiring the space shuttle. He led a team of project leads in an evaluation of costs and impacts for flying the Space Shuttle longer. Currently as the lead for advanced planning for shuttle applications that would help reduce risks and operations cost for future programs, Mack is the co-lead for a joint NASA and DoD team working on defining a space based solar power demonstration that could be flown up on the shuttle to the ISS for the first WPT from space.

Mr. Henderson has received some prestigious awards that include:

1983 NASA Exceptional Service Medal for his flight design leadership for the first Space Shuttle/Spacelab mission STS-9.
2001 AIAA Aerospace Maintenance Award for his work on the Space Shuttle upgrades
2007 NASA Exceptional Service Medal for his continued pursuit of improvements for shuttle flight safety
2010 AIAA Associate Fellow and Rotary National Award for Space Achievement