National Aeronautics and Space Administration

Exploration Enterprise Workshop:

FY 2011 Enabling Technology Development & Demonstration (ETDD) Point of Departure Plans

Moody Gardens Conference Center/Hotel

Galveston, TX

May 25, 2010

Disclaimer

This chart set was presented by the Enabling Technology Development and Demonstration Team on May 25, 2010 at the NASA Exploration Enterprise Workshop held in Galveston, TX. The purpose of this workshop was to present NASA's initial plans for the potential programs announced in the FY2011 Budget Request to industry, academia, and other NASA colleagues. Engaging outside organizations allows NASA to make informed decisions as program objectives and expectations are established.

The Enabling Technology Development and Demonstration (ETDD) presentation provides a high level overview on the following topics: the objectives and approach of the proposed program, how it would relate to other exploration programs, and the basic program structure. The presentation goes on to explain the selection rationale for demonstration programs and goes into some depth about the priority technologies and capabilities desired for demonstration. The charts show a notational integrated schedule for the initial demonstration projects and goes over the RFI that was released on May 10, 2010. The ETDD presentation identifies 10 Foundational Technology Domains that develop long-range, exploration-specific technologies to feed future demonstration projects and outlines the near term priorities for each. The presentation concludes with at discussion of a notional acquisition strategy and potential next steps over the summer.

DISCLAIMER: The following charts represent at "point of departure" which will continue to be refined throughout the summer and the coming years. They capture the results of planning activities as of the May 25, 2010 date, but are in no way meant to represent final plans. In fact, not all proposed missions and investments fit the in budget at this time. They provide a starting point for engagement with outside organizations (international, industry, academia, and other Government Agencies). Any specific launch dates and missions are likely to change to reflect the addition of Orion Emergency Rescue Vehicle, updated priorities, and new information from NASA's space partners.

Outline

- Program Objectives
- Approach
- Relationships to Other Programs
- Program Structure
- Initial Demonstration Projects
  - Overview
  - Schedule
  - Request for Information
- Foundational Technology Domains
- Notional Acquisition Strategy
- Next Steps
- Summary

Enabling Technology Development & Demonstration Objectives

Develop, mature, and test enabling technology for human exploration

- Develop and demonstrate prototype systems to feed the Flagship, robotic precursor, and other missions of opportunity.
- Develop long-range, critical technologies to provide the foundation for a broad set of future exploration capabilities.
- Provide infusion path for promising, game-changing technologies developed by Space Technology Program.
- Assess the feasibility of system and operational concepts resulting from architectural studies by building and testing proof-of-concept systems.
- Develop exploration technologies that may also have terrestrial applications for clean energy and protecting the environment.

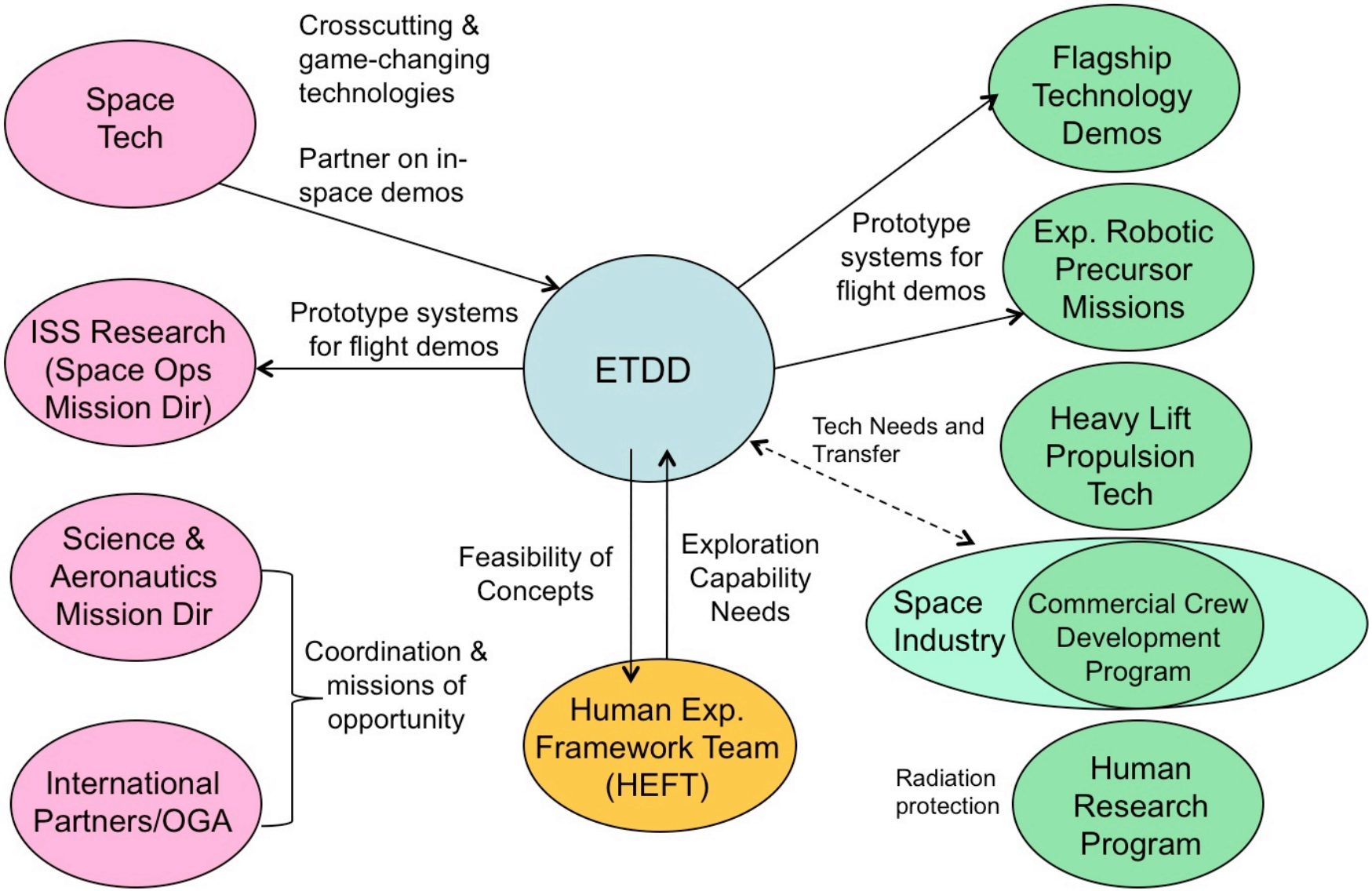
In the process of meeting these objectives, ETDD would:

- Seek opportunities to demonstrate technologies using multiple venues and platforms
- Leverage and collaborate with commercial and international partners and other government agencies.
- Promote and foster a national workforce for technical innovation by creating opportunities for engineers and scientists from NASA, private industry, and academia to gain experience in designing, building, and operating new space technologies and spacecraft.
- Support participatory exploration and education through public engagement in technology demonstrations.

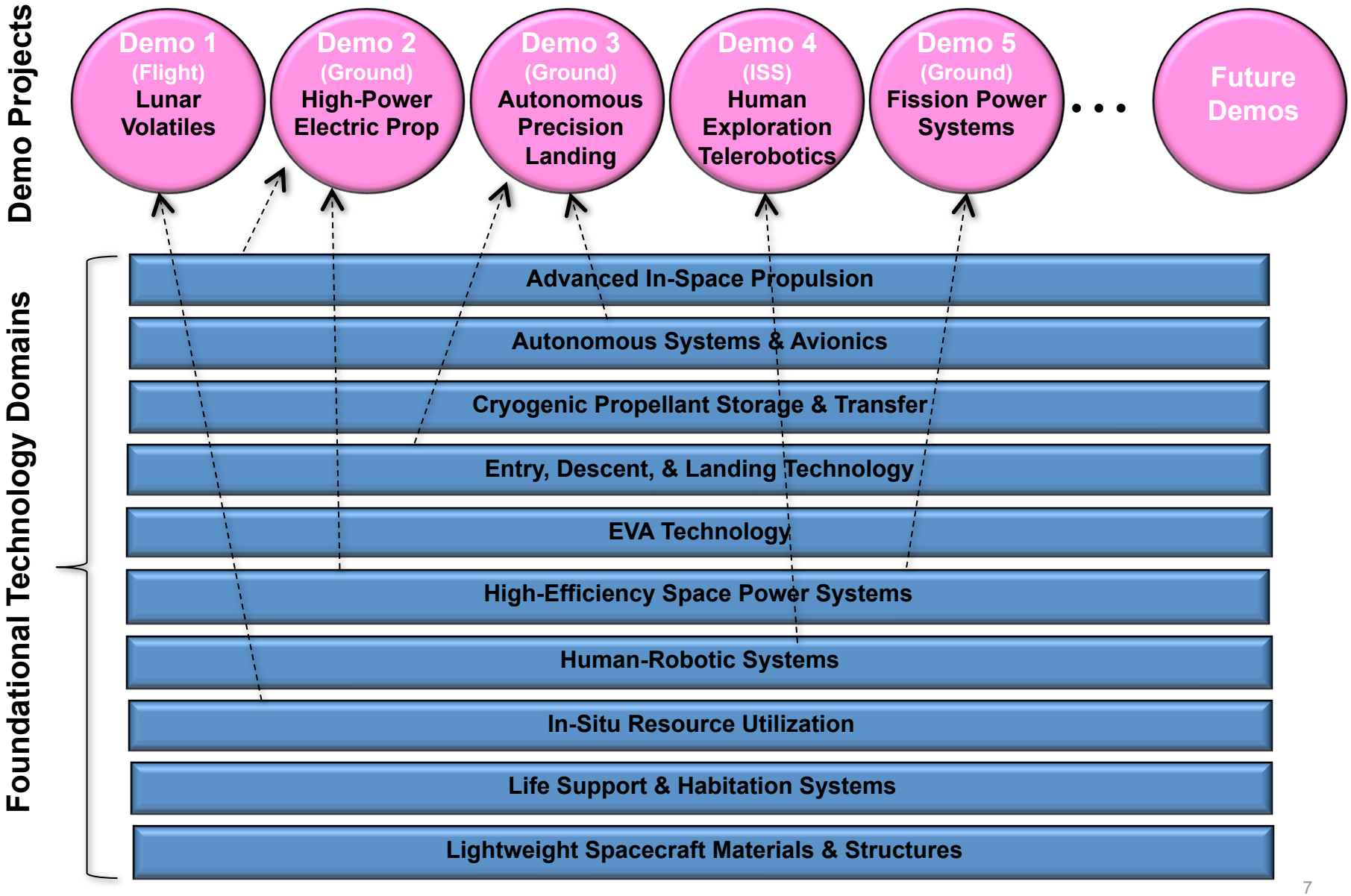
Enabling Technology Development & Demonstration Planned Approach

- Shorter duration projects (2 to 4 years) funded at $100 million or less, ranging from laboratory experiments to Earth-based field tests and in-space technology demonstrations.
- Build on technology investments within current ESMD portfolio.
- In FY11, initiate demonstration projects leading to flight experiments on Flagship, robotic precursor, or international missions around 2015.
- Provide a foundational technology base to mature technology products for future demonstration projects.
- Over 50 percent of program funding would be awarded through competition. Separate intramural and extramural competitions would be conducted so that NASA centers are not competing against their external partners.
- Projects will be designed to take full advantage of available assets, such as wind tunnels, ground-based analogues, flight test aircraft, suborbital sounding rockets, commercial reusable suborbital vehicles, robotic spacecraft, ISS, and other test platforms.

Enabling Technology Development & Demonstration Primary Relationships to Other Programs



ETDD Program Structure



Selection Rationale for Demonstration Projects

- Projects will be aligned with the critical capability needs identified in exploration architectural studies:
  - Mars Design Reference Architecture 5.0
  - Global Point of Departure Lunar Architecture
  - Review of U. S. Human Space Flight Plans (Augustine) Committee
  - Human Exploration Framework Team

- Projects will build upon current technology investments.

- Projects will demonstrate major advances in capabilities within the next five years, making the first steps on long-range, strategic technology roadmaps.

- Projects will deliver technology products in time to support the major mission milestones in the Flagship Technology Demonstration Program and the Exploration Robotic Precursor Program.

- In FY11, with Congressional passage of the FY11 budget request, ETDD would initiate five demonstration projects. Each project has been framed to address a key question for human exploration.

ETDD Demonstration Project
Lunar Volatiles Characterization

- **Key Question:** *How can we locate, access, and extract volatile resources on the moon?*

- **Objectives:** This demonstration would verify the presence of water and other volatiles on the Moon by direct in-situ measurements of the lunar regolith. The project would build upon recent field tests of in-situ resource utilization (ISRU) technology by demonstrating operation of a prototype ISRU system in a thermal vacuum chamber. A flight experiment to demonstrate lunar resource prospecting, characterization, and extraction would be developed for testing on a robotic precursor mission in 2015.

- **Top-Level Requirements:**
  - Locate sub-surface areas of elevated hydrogen bearing compounds
  - Acquire sub-surface samples for analysis
  - Analyze soil samples for mineral composition, volatile content, and bulk regolith characteristics.
  - Demonstrate the potential for volatiles and regolith utilization.
  - Must be capable of flying on a variety of lunar lander precursor missions in a polar location.
  - Overall system mass must be less than 60kg and consume no more than 200W of peak power.

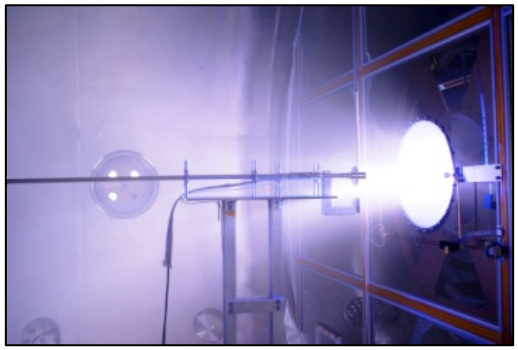
Field test of lunar volatiles prospecting system

ETDD Demonstration Project
High Power Electric Propulsion

- **Key Question:** *How can we reduce travel time and cost for human deep-space exploration?*

- **Objectives:** This demonstration would design, build, and test a complete, sub-scale electric propulsion system scalable to the power levels required to support human exploration missions. The thrusters would be integrated with a power management system and tested in a thermal vacuum chamber. This ground demonstration would support a solar electric propulsion system demonstration by the Flagship program in 2016.

- **Top-Level Requirements:**
  - Demonstrate a high power (> 100 kW), high specific impulse, electric propulsion system in an environment representative of space.
  - Electric propulsion system must be scalable to the power levels required for human exploration missions (Several hundred kWe to several MWe power)
  - 10 to 70 kg/kWe specific mass, including the power system but excluding propellant and propellant tankage
  - 3,000 to 7,000 sec specific impulse
  - > 60 to 70+% efficiency
  - Electric propulsion system lifetimes of 1 to 3 years continuous operation
  - Leverage existing high-power, high-efficiency power generation systems



Electric thruster being tested in vacuum chamber

ETDD Demonstration Project
Autonomous Precision Landing

- **Key Question:** *How can we land autonomously, precisely, and safely on a extra-terrestrial surface in uncertain environments?*

- **Objectives:** This demonstration would test an integrated autonomous landing and hazard avoidance system consisting of imaging sensors and navigation and control algorithms. NASA would develop an atmospheric flight experiment to demonstrate an autonomous precision landing and hazard avoidance system on a small lander test bed. NASA would pursue use of this system on a U. S. or international robotic precursor mission to the Moon or other planetary body around 2015.

- **Top-Level Requirements:**
  - Demonstrate autonomous landing of a robotic vehicle at any surface location certified as feasible for landing
  - Must be capable of identifying vehicle landing hazards in real-time, diverting to a selected safe landing aim point, and achieving a precise and controlled touch down at the selected location.
  - Must be capable of landing in any lighting conditions
  - Must be capable of precise and controlled landing within several meters of a landing aim point selected from the hazard map generated on-the-fly during the approach phase without using external navigational aids.
  - Must be capable of flying on a variety of lunar lander precursor missions

Small lander test bed for autonomous precision landing

ETDD Demonstration Project
Human Exploration Telerobotics

- **Key Question:** *How do we use human-robotic partnerships to increase productivity, reduce costs, and mitigate risks?*

- **Objectives:** This demonstration would simulate humans at Near Earth Objects or in Mars orbit controlling robot teams on the surface to explore and prepare for the crew landing. In 2011, this project would demonstrate teleoperation of a robot on the ground by crew on the International Space Station (ISS). In 2012, this project would demonstrate human teams operating and working with multiple robots both on the ground ("orbit to ground") and on the ISS ("ground to orbit").

- **Top Level Requirements:**
  - Remotely operate robots to perform human exploration tasks:
    - Surface robots at high-fidelity analog sites controlled from space
    - Robots onboard space vehicles controlled from ground
  - Quantify benefits and limitations of humans in orbit controlling robots on the surface, and vice versa.
  - Demonstrate heterogeneous robots collaborating with human teams.
  - Implement large-scale participatory
  - Evaluate human-robot productivity, workload, performance, and human safety
  - Mature dexterous and human safe robotic technologies in space environmental conditions.
  - Conduct high-fidelity experiments involving ISS
  - Develop approach for maturing and infusing prototype systems into flight missions.

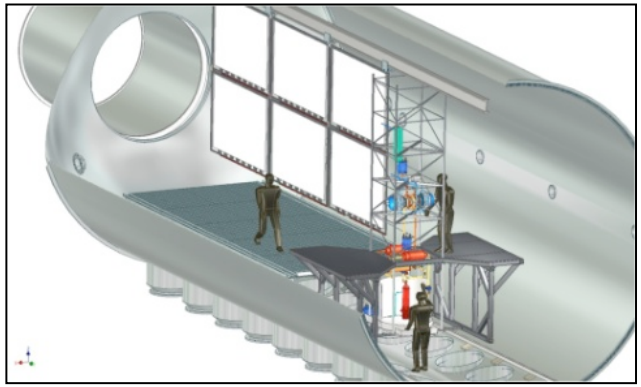
Robots on the ground would be controlled from ISS

ETDD Demonstration Project
Fission Power Systems Technology

- **Key Question:** *How do we provide abundant, low-cost, and reliable electric power for long-duration missions?*

- **Objectives:** This demonstration would test power conversion and thermal management technologies for a 40 kW fission power system. The non-nuclear test would validate the performance of an integrated system consisting of Stirling power converters, a liquid metal coolant loop, and an advanced radiator in a thermal vacuum chamber.

- **Top-Level Requirements:**
  - Must ultimately be capable of operating on Mars, the Moon, or in deep space.
  - Provide continuous power independent of location
  - Low sensitivity to environment characteristics (temperature, dust, etc.)
  - Operational simplicity (self-regulating without human control for weeks)
  - Safe during all mission phases
  - Long life (~8 years or more) with no maintenance
  - Demonstration should validate model predictions for a conceptual power system



Concept for testing fission power system in thermal vacuum chamber

Proposed Integrated Schedule for Initial Demonstration Projects

	2011	2012	2013	2014	2015	2016
Lunar Volatiles Characterization	Field Test	Vacuum Chamber Test			Robotic Precursor Mission	
High-Power Electric Propulsion				Int. System Test		Flagship Demo
Autonomous Precision Landing			Atmospheric Flight Test		Lunar Lander Flight Test	
Human Exploration Telerobotics	ISS Demo – Field Test	Teleops of R2 on ISS			Teleops of Lunar Rover	
Fission Power Systems		Pwr. Conversion Test		Int. System Test with Radiators		

Request for Information

- On May 10, 2010, NASA issued a Request for Information (RFI) for ETDD demonstration projects. The information gathered will be used for project formulation and acquisition planning.

- Ideas are sought for demonstrations, technologies, systems, and test platforms.

- Major topic areas:
  - Lunar Volatiles Characterization
    - Instruments for volatiles detection & characterization
    - Test chambers
  - High Power Electric Propulsion System
  - Autonomous Precision Landing
    - Terrestrial Free Flyer Test Bed
    - Hazard Detection System
  - Human Exploration Telerobotics
  - Fission Power Systems Technology

- Responses are due June 4, 2010.

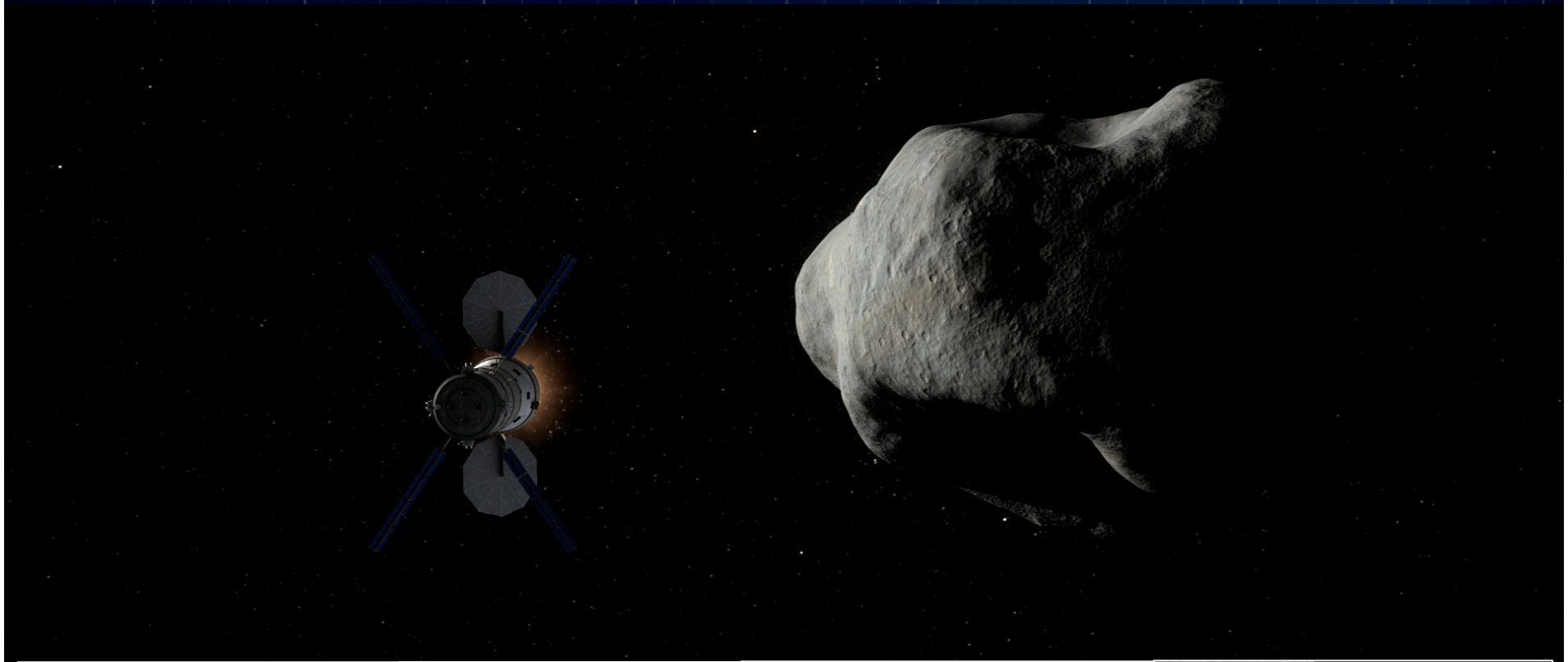
- The RFI can be found at:
  - http://nspires.nasaprs.com

- ETDD study team would like to discuss RFI responses with workshop participants in one-on-one sessions tomorrow.

Foundational Technology Domains Address Long-Range Capability Needs for Multiple Destinations

Foundational Technology Domain	Moon	Lagrange Points	NEOs	Mars
Advanced In-Space Propulsion: Enabling low-cost and rapid transport of cargo and crew beyond LEO.	✔	✔	✔	✔
Autonomous Systems & Avionics: Extending human exploration capability by reducing workload and dependence on support from Earth.	✔	✔	✔	✔
Cryogenic Propellant Storage & Transfer: Enabling the in-space infrastructure to store and transfer propellants.	✔	✔	✔	✔
Entry, Descent, & Landing Technology: Landing large payloads safely and precisely on extra-terrestrial surfaces and returning to Earth.	✔			✔
EVA Technology: Enabling humans to conduct “hands-on” surface exploration and in-space operations outside habitats and vehicles.	✔	✔	✔	✔
High-Efficiency Space Power Systems: Providing abundant and low-cost power where it is needed.	✔	✔	✔	✔
Human-Robotic Systems: Amplifying human productivity and reducing mission risk by partnering humans and robots.	✔	✔	✔	✔
In-Situ Resource Utilization: Enabling sustainable human exploration by using local resources.	✔		✔	✔
Life Support & Habitation Systems: Enabling humans to live for long periods in deep-space environments.	✔	✔	✔	✔
Lightweight Spacecraft Materials & Structures: Enabling lightweight systems to reduce mission costs.	✔	✔	✔	✔

Long-Range Capability Needs for Human NEO Mission



Advanced In-Space Propulsion: *Enabling rapid transport*

Human-Robotic Systems: *Amplifying human productivity*

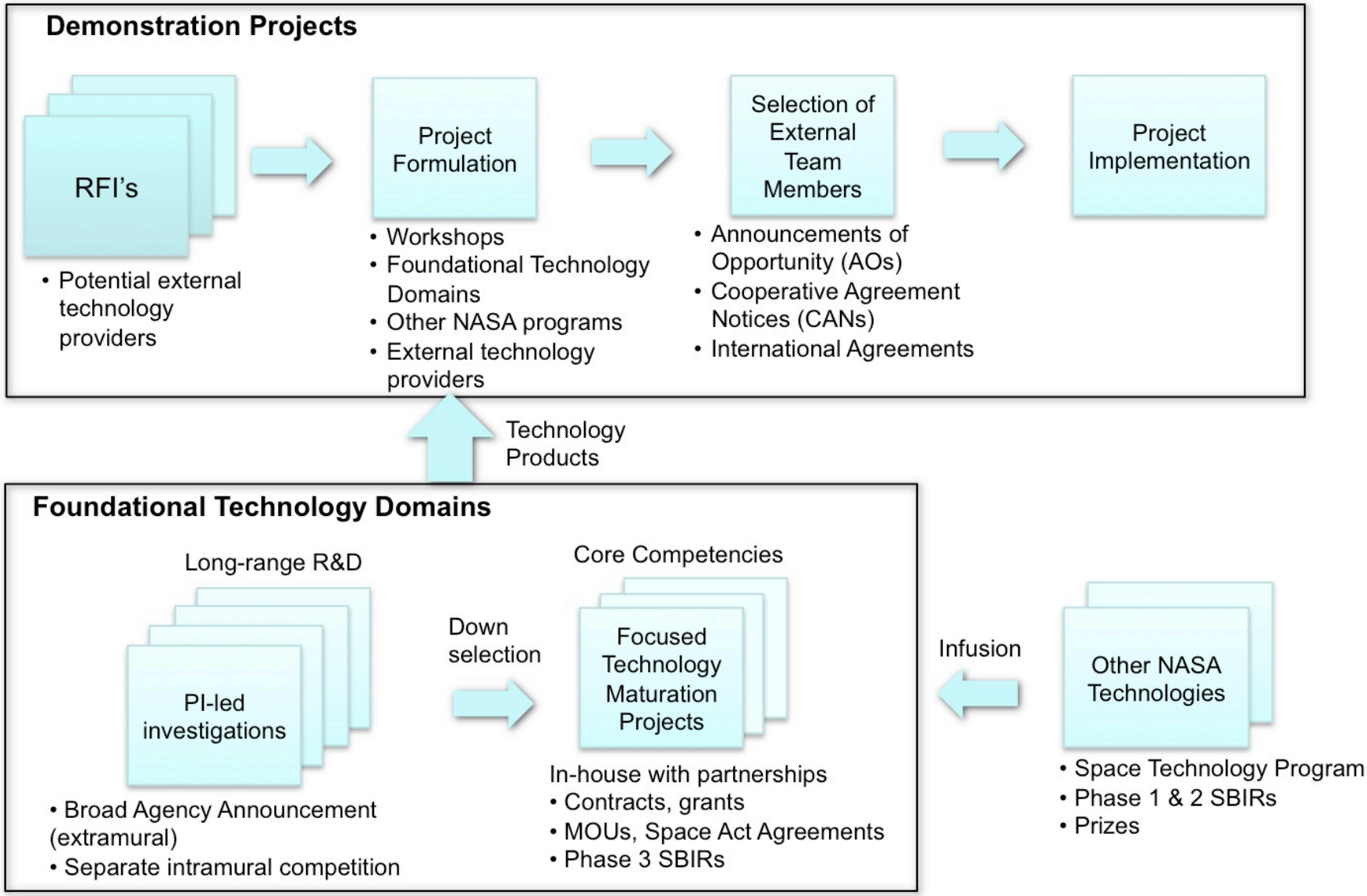
Life Support & Habitation Systems: *Enabling humans to live for long periods in deep space*

EVA Technology: *Enabling low-gravity surface exploration*

ETDD Foundational Technology Domains: Near-Term Priorities

- **Advanced In-Space Propulsion**
  - Nuclear thermal propulsion and reactor fuel elements
  - High-power electric thrusters
- **Autonomous Systems & Avionics**
  - Crew managed autonomous operations
  - Increase reliability and capability of on-board systems
  - Increase effectiveness and reduce costs of ground-based operations
- **Cryogenic Propellant Storage & Transfer**
  - Inter-vehicle cryogen transfer
  - Capability to store and transfer liquid hydrogen
  - Support Flagship in-space propellant storage demo
- **Entry, Descent, & Landing (EDL) Technology**
  - Entry and descent of large payloads for Mars and Earth
  - Support agency aerocapture demo
- **Extra-Vehicular Activity (EVA) Technology**
  - Advanced technologies to support next generation suit demo on ISS that reduce consumables and maintenance, increase lifetime, and enable rapid egress/ingress.
- **High Efficiency Space Power Systems**
  - Energy storage – advanced batteries & fuel cells
  - Develop requirements and concepts for high-power generation systems for electric propulsion
- **Human-Robotic Systems**
  - Prototype mobility systems for lunar volatiles prospecting mission
  - Command and control approaches that allow productive work at any distance
- **In-Situ Resource Utilization**
  - Complete work on lunar oxygen production systems
  - Focus on technologies that can be demonstrated on a variety of robotic precursor missions to the moon, Mars and NEOs
- **Life Support & Habitation Systems**
  - Develop technologies to further closure of ECLSS in support of Flagship inflatable module demo on ISS
  - Radiation shielding technologies & analysis tools
  - Fire protection studies to support cargo vehicle fire demo
  - Monitoring of contaminants in recycled air and water
- **Lightweight Spacecraft Structures & Materials**
  - Large composite structures and cryotanks for future HLLV
  - Inflatable structures to support Flagship inflatable module demo on ISS

Notional Acquisition Strategy



Next Steps

- Glenn Research Center (GRC) is leading ETDD program formulation.
  - Point of contact is Tammy Harrington
- Formulation teams led by NASA centers have been established for demonstration projects and foundational technology domains.
- RFI responses will be used for project formulation and acquisition planning.
- NASA may issue additional solicitations in late summer:
  - Announcement of Opportunity for Demonstration Projects
  - Broad Agency Announcement for Foundational Technology Domains

Summary

- ETDD matures exploration technologies to the point where they can be demonstrated in small ground and flight experiments, then hands off prototype systems to Flagship, robotic precursor, and other missions of opportunity for validation of key capabilities.

- ETDD provides a path for infusing game-changing and crosscutting technologies developed by Space Technology Program into exploration missions.

- Study Team has developed concepts and top-level requirements for five proposed initial demonstration projects:
  - In-Situ Resource Utilization: Lunar Volatiles Characterization
  - High-Power Electric Propulsion
  - Autonomous Precision Landing
  - Human Exploration Telerobotics
  - Fission Power Systems

- Study Team has defined 10 Foundational Technology Domains that develop long-range, exploration-specific technologies to feed future demonstration projects.