National Aeronautics and Space Administration

# NASA Strategic Roadmap Summary Report

May 22, 2005

# Strategic Roadmap Summary Report

## May 22, 2005

# EXECUTIVE SUMMARY

## Introduction

On January 14, 2004, President George W. Bush announced the Vision for Space Exploration. The Vision's fundamental goal is to advance U.S. scientific, security, and economic interests through a robust space exploration program. To support this goal, the Vision stipulated that the U.S. would:

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- Develop the innovative technologies, knowledge, and infrastructure both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further United States scientific, security, and economic interests.

## Roadmap Teams Commissioned

In response to the Vision, NASA commissioned strategic and capability roadmap teams to develop the pathways for turning the Vision into a reality. The strategic roadmaps were derived from the Vision for Space Exploration and the Aldrich Commission Report dated June 2004. NASA identified 12 strategic areas for roadmapping. The Agency added a thirteenth area on nuclear systems because the topic affects the entire program portfolio.

To ensure long-term public visibility and engagement, NASA established a committee for each of the 13 areas. These committees — made up of prominent members of the scientific and aerospace industry communities and senior government personnel — worked under the Federal Advisory Committee Act. A committee was formed for each of the following program areas:

- Robotic and Human Lunar Exploration
- Robotic and Human Exploration of Mars
- Solar System Exploration
- Search for Earth-Like Planets
- Exploration Transportation System
- International Space Station
- Space Shuttle
- Universe Exploration
- Earth Science and Applications from Space
- Sun-Solar System Connection
- Aeronautical Technologies
- Education
- Nuclear Systems

(The charter and membership of these committees are provided in the Appendix.)

**Strategic Roadmap Committee Activities and Products**
Eleven of the 13 strategic roadmap committees began meeting in early January. Formation of the Space Shuttle Committee, which was to focus on the transition from the Shuttle to a new exploration vehicle, was deferred pending the Shuttle's return to flight. Formation of the Education Committee also was delayed until the others had begun their work. The rationale was that the Education Committee would benefit from the others' discussions about long-term opportunities for educational and public outreach.

**Completed Roadmaps**
The 11 committees each met at least once between January 3 and May 17, 2005. Several committees benefited from early results and momentum from pre-existing focused planning outreach activities, and consequently, they developed roadmap before the roadmapping activities ended on May 22. Completed roadmaps are:

- Robotic and Human Exploration of Mars
- Solar System Exploration
- Search for Earth-Like Planets
- Universe Exploration
- Earth Science and Applications from Space
- Sun-Solar System Connection

The summaries presented in this volume are based on completed roadmaps in these areas. The completed roadmaps are collected in a separate Strategic Roadmaps volume.

**Provisional Committee Findings**
The remaining committees did not schedule all their meetings or complete work on their roadmaps. As a result, the summaries presented here are based on provisional committee findings and staff analyses. As such, the material from these committees here does not represent the formal findings of the chartered committees.

**Other Roadmap Committees**
Three of the roadmap areas for which committee activities were planned are not represented in this volume for diverse reasons.

The Shuttle Transition Committee was not established pending Return to Flight, and its creation has been overtaken by Agency events so no products are available in this area. The International Space Station Committee did meet, but a 60-day task force established by the Administrator has superseded its efforts and preliminary results. Finally, the first meeting of the Education Committee was deferred until preliminary findings of the other committees would be available to it, but will not now meet. As a result, there is no output from this committee.

**Informing Capabilities Roadmaps**

In addition to laying out options and decision points for implementing the Vision's goals, an important objective of the strategic roadmap development process was to inform the development of the capabilities roadmaps. Because development proceeded in parallel, this was accomplished iteratively. The Agency will use the findings of the two roadmapping efforts to ensure that NASA's long-range plans for technology development support the major flight programs.

Dr. Marc Allen, Team Lead
Strategic Roadmap Committees



# Exploration Transportation System Strategic Roadmap Summary Report

May 22, 2005

# Roadmap Summary

- **NASA objective to which transportation roadmap responds:**
  - Develop an exploration transportation system to deliver crew and cargo from the surface of the Earth to exploration destinations and to return the crew safely to Earth.

- **Connection to Vision for Space Exploration:**
  - Roadmap outlines decision pathways to meet the transportation requirements enabling the Vision for Space Exploration.
  - Roadmap cuts across nearly all other strategic roadmaps, particularly International Space Station, lunar, Mars, and solar system exploration.

- **Top-level summary of anticipated achievements:**
  - An operational crew exploration vehicle, post 2010
  - An operational launch vehicle for the Moon, post 2015
  - An operational launch vehicle for Mars, post 2030
  - A demonstration of nuclear propulsion, post 2015
  - An operational, crewed planetary descent/ascent capability, post 2015

# Roadmap Anticipated Achievements

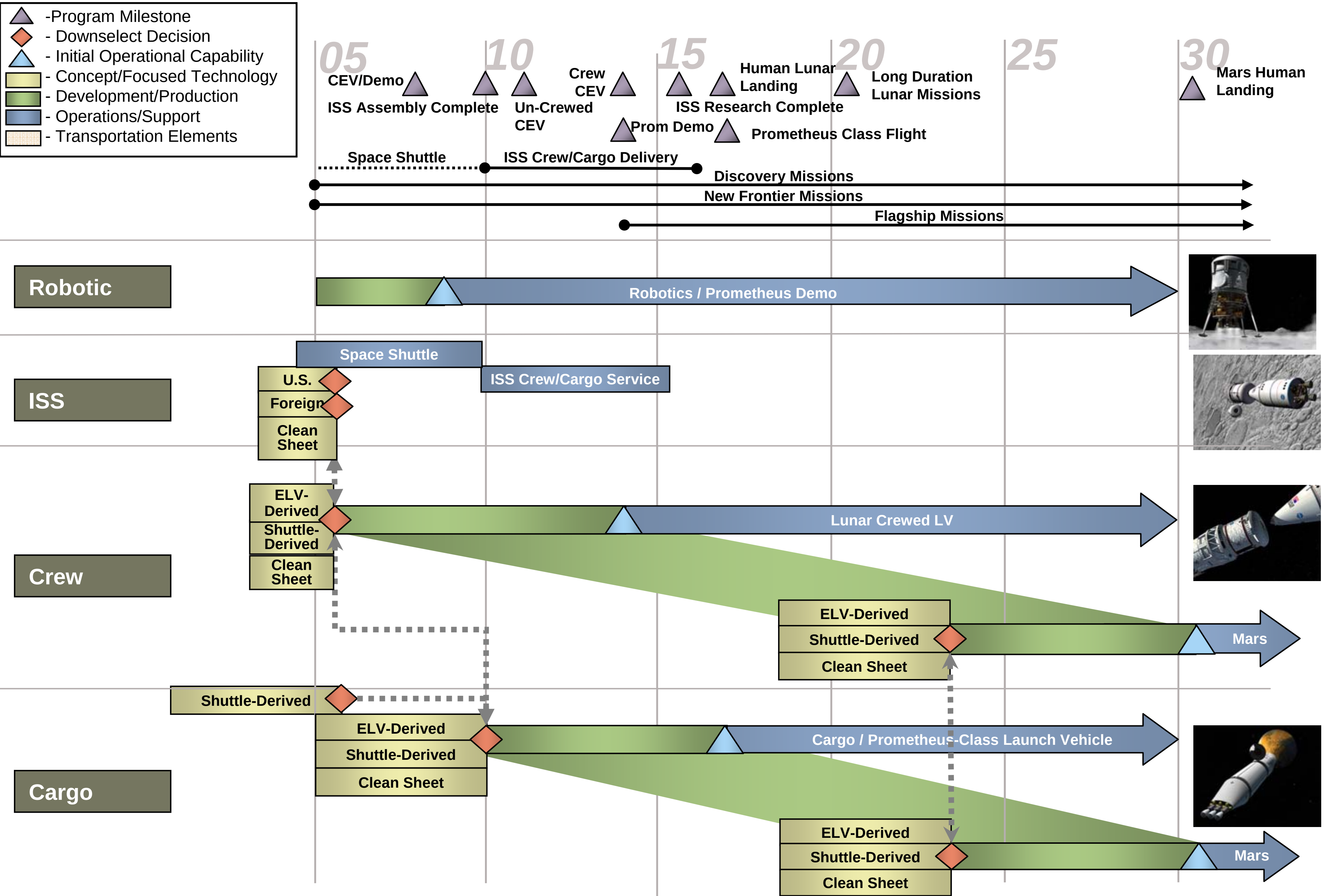
| *Roadmap Goals* | Phase 1: 2005-2015 | Phase 2: 2015-2025 | Phase 3: 2025-2035 |
|---|---|---|---|
| **Earth-to-Orbit Transportation** | - Move from Shuttle to new ISS-compatible crew and cargo systems<br>- Develop, test, and operate crew exploration vehicle and associated launch vehicle<br>- Develop lunar cargo launch vehicle | - Operate lunar cargo launch vehicle<br>- Develop crewed Mars launch vehicle<br>- Develop Mars cargo launch vehicle | - Develop, test, and operate Mars crewed launch vehicle<br>- Develop, test, and operate Mars cargo launch vehicle |
| **In-Space Transportation** | - Demonstrate nuclear electric propulsion<br>- Develop propulsion alternatives (chemical/solar electric propulsion/aero-assist, solar sails, tethers)<br>- Select lunar trajectories | - Operate nuclear electric propulsion for robotic missions<br>- Operate lunar crew and cargo propulsion systems<br>- Select Mars trajectories | - Operate Mars crew and cargo propulsion system (crew and cargo could be different systems)<br>- Develop and operate Mars crew systems (life support, deep-space radiation protection, artificial gravity) |
| **Ascent/Descent Transportation** | - Develop and initially operate robotic ascent and descent systems | - Operate lunar descent and ascent systems (crew and cargo) | - Operate Mars descent and ascent systems (crew and cargo) |
| **Earth Capture and Reentry** | - Operate robotic Earth capture and reentry systems<br>- Operate crew exploration vehicle reentry systems | - Operate lunar-crewed Earth capture and reentry systems | - Operate Mars-crewed Earth capture and reentry systems |

# Roadmap Graphic Guide

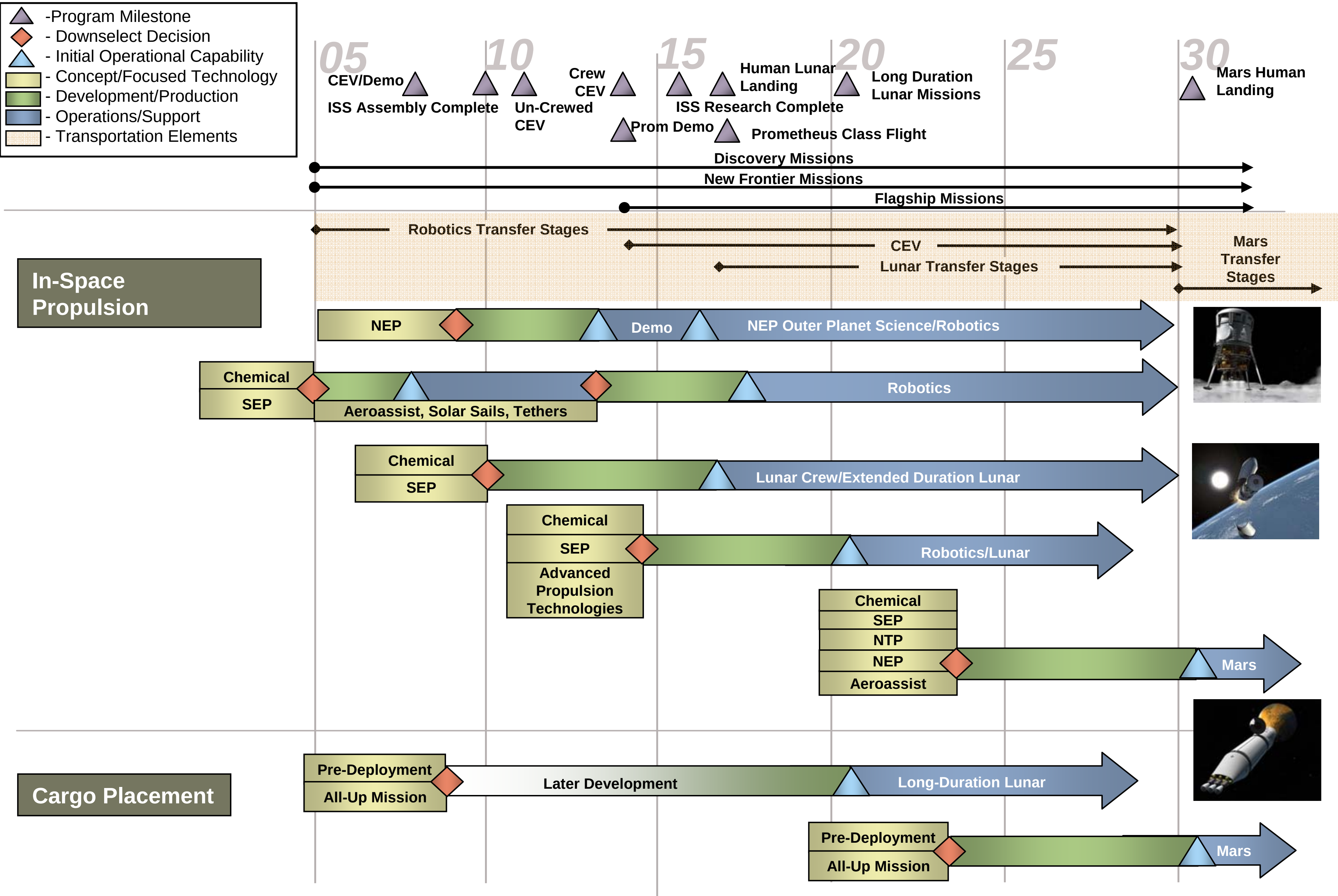
- **The scope of the Transportation Systems Roadmap is based on committee discussions at the first meeting. Note that the committee's activities ended before the committee could approve a complete and consistent product. The material presented in this package represents the results as of meeting #2 (April 18-19, 2005).**
- **The Transportation Systems Roadmap is divided into the following categories:**
  - Earth-to-orbit (1 chart)
  - Transfer to and orbital operations (2 charts)
    - Included as part of the "in-space transportation" goals and roadmap overview decisions summary
  - Ascent/descent (1 chart)
  - Destination orbital operations and transfer from (2 charts)
    - Included as part of the "in-space transportation" goals and roadmap overview decisions summary
  - Earth capture and reentry (1 chart)
- **The Transportation Systems Roadmap:**
  - Includes transportation for crew, cargo, and robotic missions.
  - Addresses the next 25- to 30-plus years, focused on the out years.
  - Identifies key decision points and the alternative options for implementation of each decision.
- ***Note*: The Transportation Systems Roadmap is a simplified and limited representation of a large and complex decision space.**
  - An intricate web of interdependencies exists between questions, decision points, and milestones that is too complex to be represented on a few charts.
  - Many decision points are not "either/or," but may be a combination of the available options.

NASA For Official Use Only

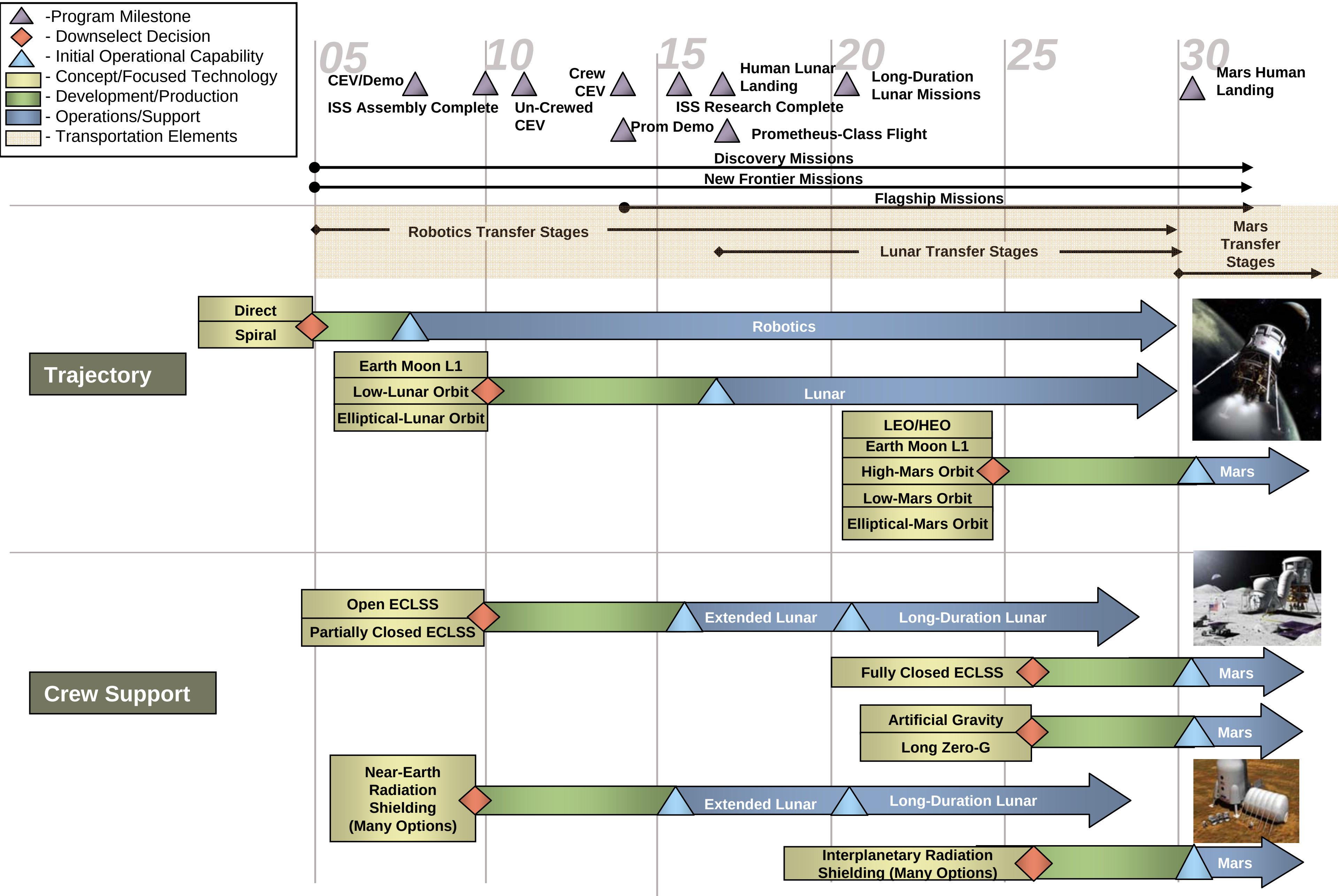
# Earth to Orbit Roadmap



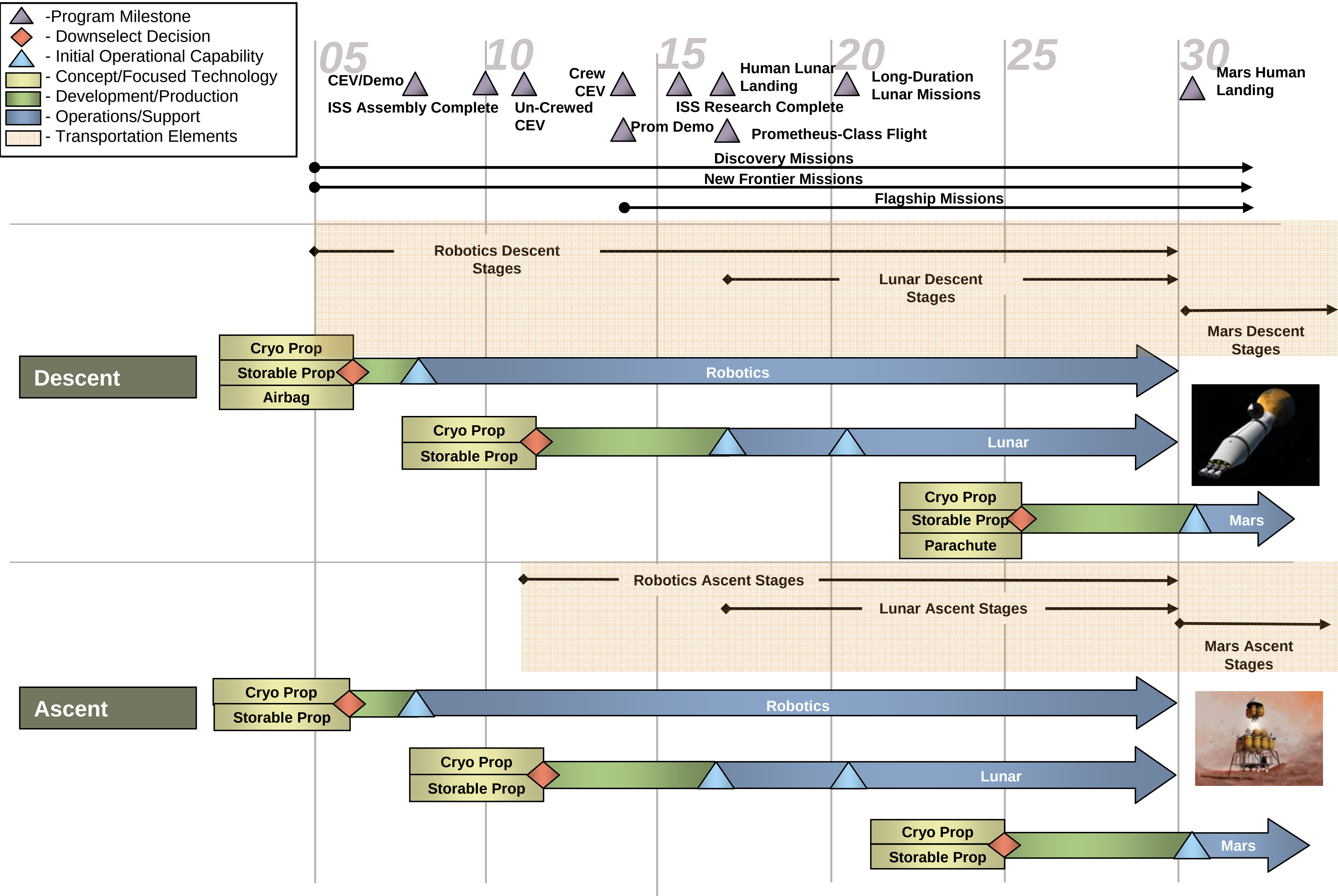
# Transfer To and Orbital Operations Roadmap



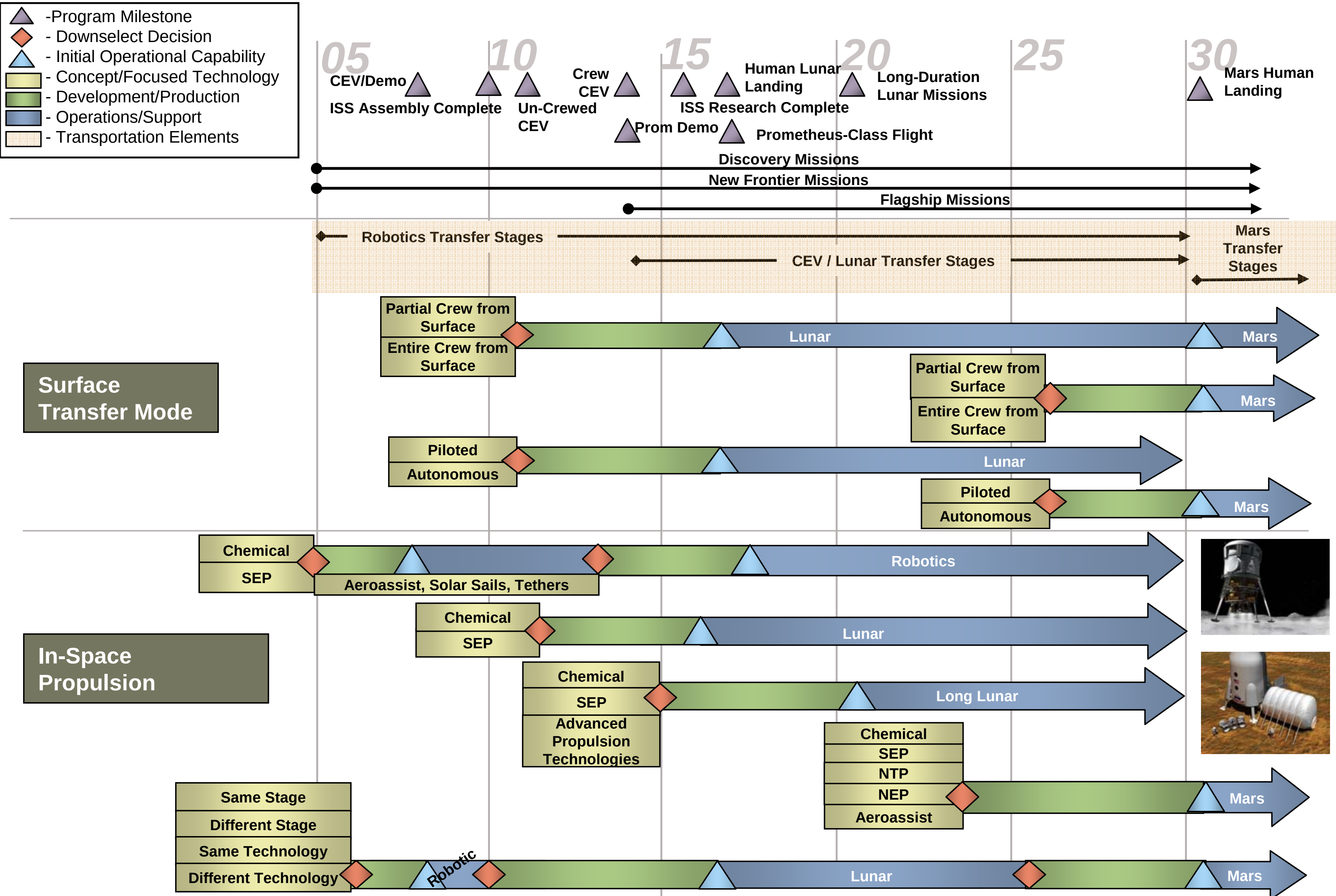
# Transfer To and Orbital Operations Roadmap (cont'd)



# Descent / Surface Operations / Ascent Roadmap

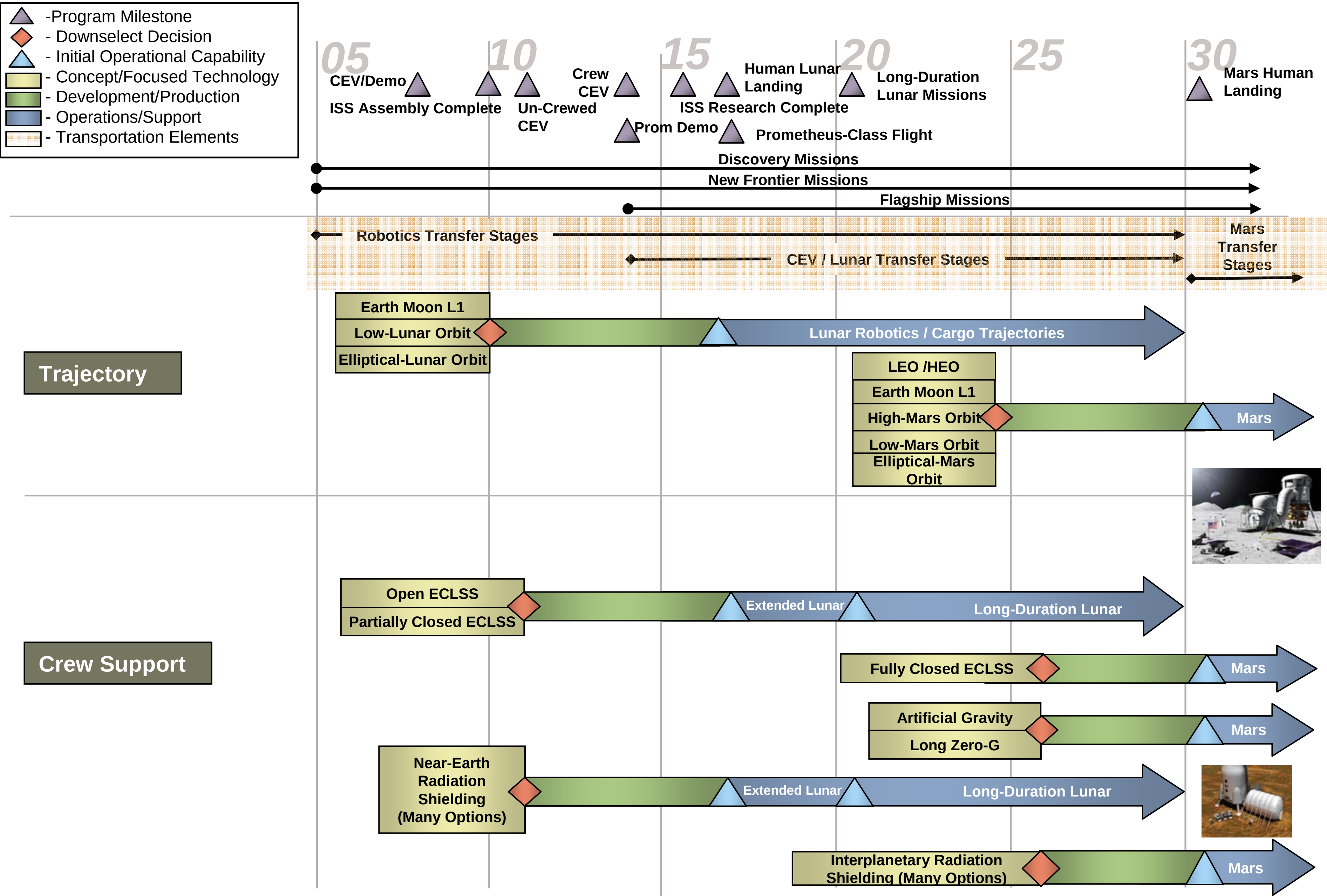


# Destination Orbital Operations and Transfer From Roadmap

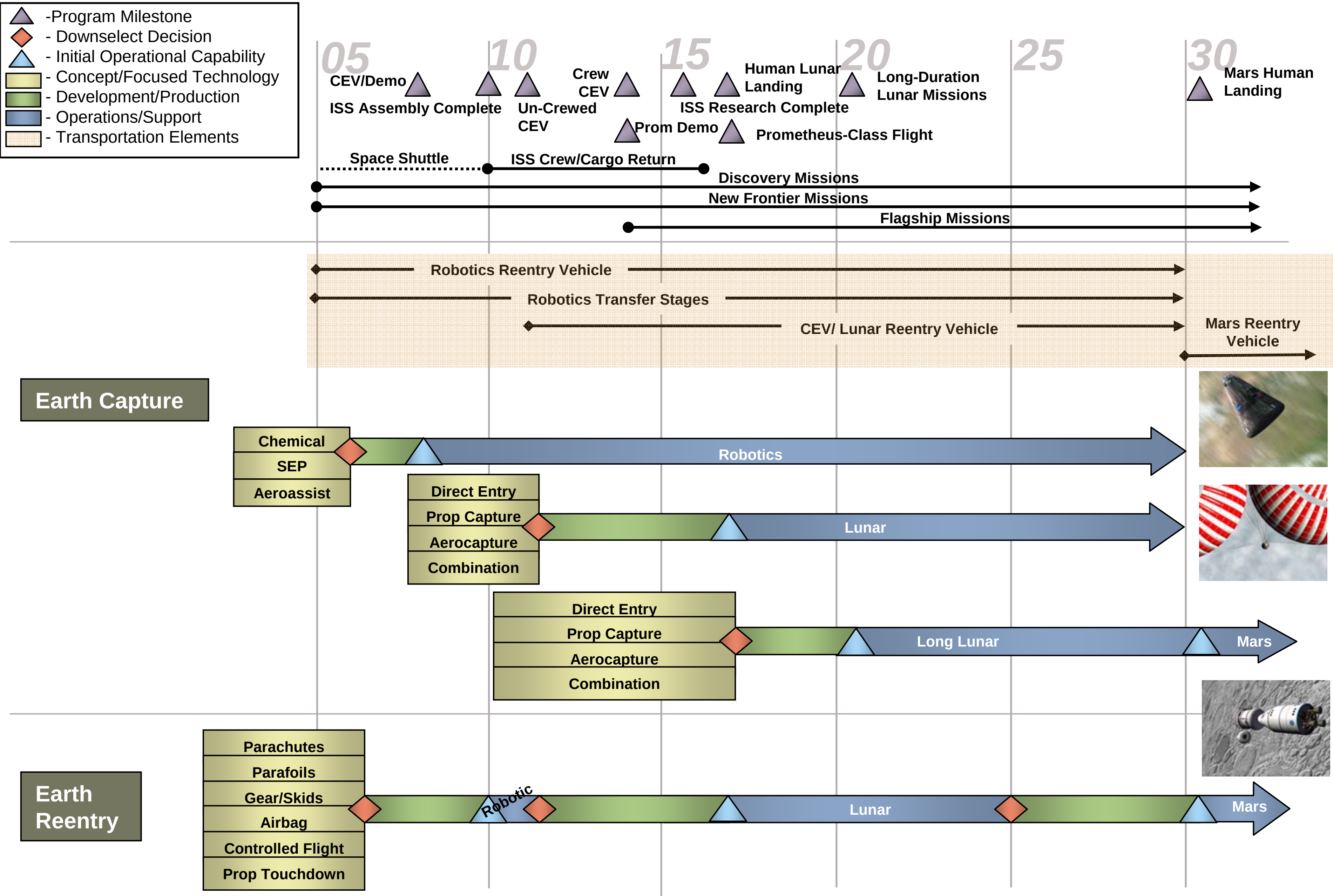


# Destination Orbital Operations and Transfer From Roadmap (cont'd)

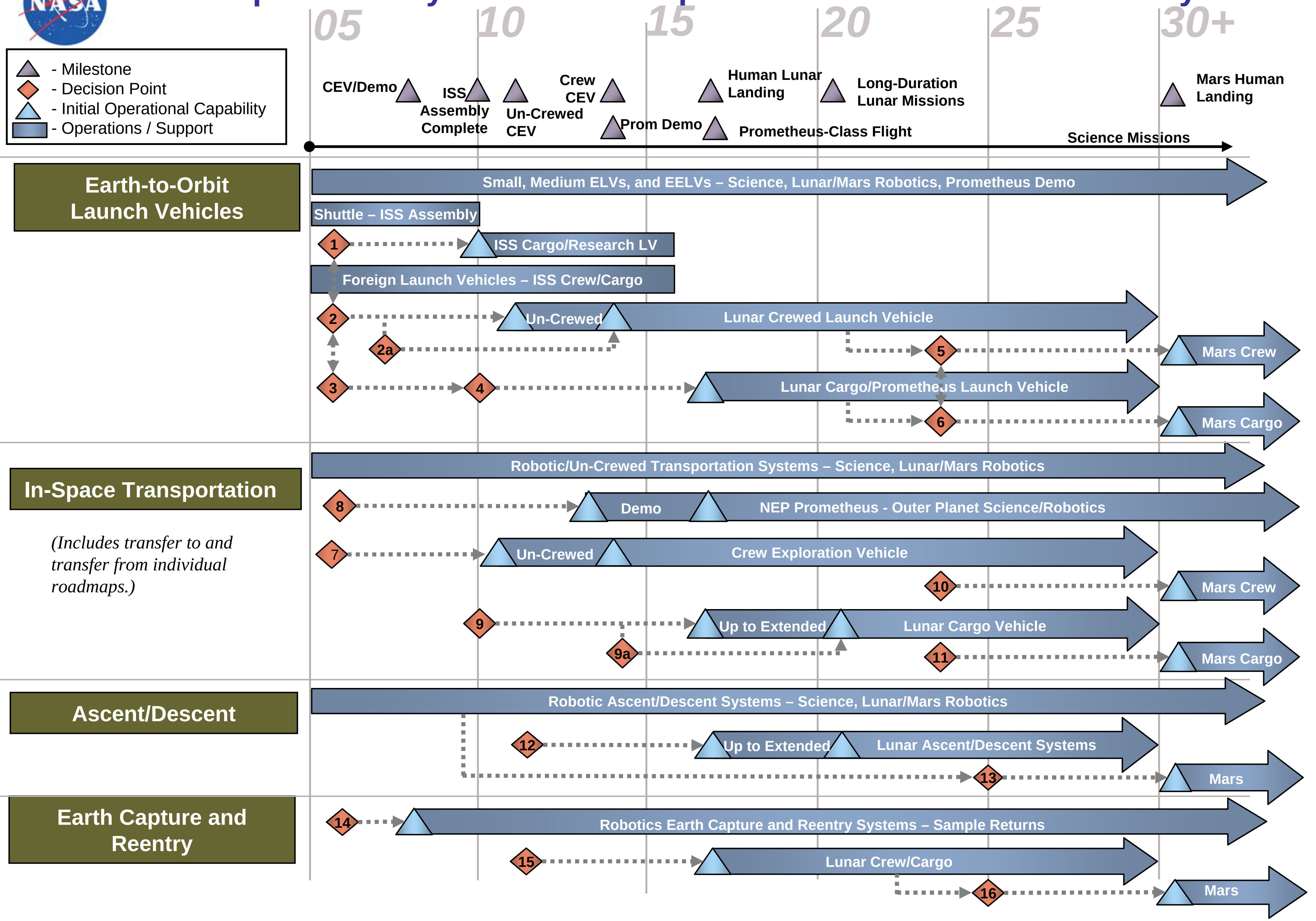
NASA For Official Use Only



# Earth Capture/Reentry Roadmap



# Transportation Systems Roadmap Overview - Decisions Summary



# Launch Vehicle Decision Points from Roadmap Overview

| Decision Point | Decisions<br>• Option Space | Other Considerations |
|---|---|---|
| 1 | Cargo launch vehicle for ISS post-Shuttle retirement?<br>•Expendable Launch Vehicle (ELV)/commercial, Shuttle-derived, rely on foreign vehicles, clean sheet? | Commonality or expansibility to crew exploration vehicle (CEV) or lunar cargo launch vehicles? |
| 2 | Launch vehicle for crew exploration vehicle?<br>•Shuttle-derived, ELV-derived, clean sheet? | Should the un-crewed CEV be the same as the crewed CEV?<br>Commonality with cargo launch vehicles?<br>Expansibility for Mars?<br>Role of commercial/role of international? |
| 2a | Launch vehicle for crewed CEV?<br>•Shuttle-derived, ELV-derived, clean sheet? | Commonality with cargo launch vehicles?<br>Expansibility for Mars?<br>Role of commercial/role of international? |
| 3 | Launch vehicle for lunar cargo?<br>•Preserve Shuttle-derived or not? | Degree and timing of heavy lift?<br>Commonality with crew launch vehicles?<br>Extensibility for Mars?<br>Autonomous rendezvous and docking?<br>Role of commercial/role of international? |
| 4 | Launch vehicle for lunar cargo and “Prometheus-class” science mission?<br>•Shuttle-derived, if preserved in 3, ELV-derived, clean sheet, commercial/entrepreneurial? | Degree and timing of heavy lift?<br>Commonality with crew launch vehicles?<br>Autonomous rendezvous and docking?<br>Expansibility for Mars?<br>Role of commercial/role of international? |
| 5 | Launch vehicle for Mars crew?<br>•Shuttle-derived, ELV-derived, clean sheet? | Commonality with cargo launch vehicles?<br>Role of commercial/role of international? |
| 6 | Launch vehicle for Mars cargo?<br>•Shuttle-derived, ELV-derived, clean sheet? | Commonality with cargo launch vehicles?<br>Autonomous rendezvous and docking?<br>Role of commercial/role of international? |

# In-Space Decision Points from Roadmap Overview

| Decision Point | Decisions<br>• Option Space | Other Considerations |
|---|---|---|
| 7 | Select crew exploration vehicle design concept? | Function and destination of crew exploration vehicle and other crewed vehicles? |
| 8 | Develop nuclear electric propulsion for science/robotic missions? | Nuclear electric propulsion? |
| 9 | Trans-lunar and return cargo vehicle short-duration?<br>•Solar electric power?<br>•Chemical? | Commonality of transfer stage and upper stage? Commonality of cargo and crew?<br>Spiral departure from low-Earth orbit? Staging points? Parking orbits?<br>Pre-deployment or al- up mission? Propellant depot?<br>Autonomous rendezvous and docking?<br>In-situ resources?<br>Role of commercial/role of international? |
| 9a | Trans-lunar and return cargo vehicle long duration?<br>•Solar electric power?<br>•Chemical?<br>•Advanced propulsion? | Commonality of transfer stage and upper stage? Commonality of cargo and crew? Spiral departure from low-Earth orbit? Staging points? Parking orbits?<br>Pre-deployment or all-up mission? Propellant depot?<br>Autonomous rendezvous and docking?<br>In-situ resources?<br>Role of commercial/role of international? |
| 10 | Mars crew in-space vehicle propulsion?<br>•Chemical?<br>•Nuclear thermal propulsion?<br>•Nuclear electric propulsion? | Gravity assist? What propulsion is needed for capture maneuvers?<br>Artificial gravity?<br>Fully closed environmental control and life support systems? Radiation shielding?<br>In-situ resources?<br>Propellant depot? On-orbit refueling and fluid transfer?<br>Role of commercial/ role of international? |
| 11 | Mars cargo in-space vehicle propulsion?<br>•Chemical? Aeroassist?<br>•Solar electric power?<br>•Nuclear thermal propulsion?<br>•Nuclear electric propulsion? | Nuclear thermal propulsion?<br>Gravity assist? Propulsion needed for capture maneuvers?<br>Pre-deployment? Propellant depot?<br>On-orbit refueling and fluid transfer?<br>Role of commercial/role of international? |

# Ascent/Descent, Earth Capture/Reentry Decision Points from Roadmap Overview

| Decision Point | Decisions<br>• Option Space | Other Considerations |
|---|---|---|
| 12 | Lunar ascent and descent systems?<br>•Cryogenic propellant, storable propellant? | Down mass/return mass?<br>Is the descent stage reusable?<br>Crew and cargo separate? Crew abort options?<br>Engine out capability required?<br>Landing systems? |
| 13 | Mars ascent and descent systems?<br>•Cryogenic propellant, storable propellant, parachute? | Down mass/return mass?<br>Is the descent stage reusable?<br>Crew and cargo separate? Crew abort options?<br>Engine out capability required?<br>Aerocapture, entry, descent, and landing systems? |
| 14 | Robotic Earth capture systems?<br>•Chemical, solar electric power, aeroassist?<br>•Robotic reentry systems?<br>•Parachutes parafoils, gear-/skid-controlled flight, prop touchdown? | Return mass? |
| 15 | Earth capture for lunar crew and cargo?<br>•Direct entry, prop capture, aerocapture?<br>•Combination?<br>•Earth reentry system?<br>•Parachutes parafoils, gear-/skid-controlled flight, prop touchdown? | Return mass?<br>Expendable or reusable system? |
| 16 | Earth capture and reentry systems for Mars crew and cargo?<br>•Direct entry, prop capture, aerocapture?<br>•Combination?<br>•Earth reentry system?<br>•Parachutes, parafoils, gear/skid, controlled flight, propulsive touchdown? | Return mass?<br>Expendable or reusable system?<br>Ablative and non-ablative high-temperature materials or active cooling? |

# Capability Roadmap Interdependencies

| Capability Roadmap | Capability Applicable for Transportation Systems |
|---|---|
| **High-Energy Power and Propulsion** | Nuclear electric propulsion, nuclear thermal propulsion, solar electric propulsion |
| **In-Space Transportation** | Autonomous rendezvous and docking, aerocapture at Earth, on-orbit refueling, fluid transfer, tethers |
| **Communication and Navigation** | High-bandwidth communication |
| **Human Planetary Landing Systems** | Efficient entry and landing system |
| **Human Health and Support Systems** | Life-support systems, information systems (video, internet), exercise and health-management systems, spacesuits |
| **Human Exploration Systems and Mobility** | In-space assembly, deployment, and servicing |
| **In-Situ Resource Utilization** | Reduction of launch mass to low-Earth orbit and beyond; use of lunar regolith or ice for transportation propellants |
| **Autonomous Systems and Robotics** | Rendezvous and docking, repair and servicing, deployments, health monitoring, control and operation of systems, operations planning, and scheduling |
| **Advanced Modeling, Simulation, and Analysis** | Integrated simulation of long-term human missions |
| **Systems Engineering Cost/Risk Analysis** | Required to ensure an outcome and/or optimize performance within engineering, budget, and scheduling constraints |
| **Transformational Spaceport** | Ground-based infrastructure, launch frequency, vehicle mass, volume and processing, range capabilities, safety, and interface with national airspace |
| **Nanotechnology** | Ultra-high strength, lighter and multifunctional materials, high-temperature structural materials, damage-tolerant, self-healing materials, advanced power and propulsion materials, micro-electronics, highly miniaturized spacecraft systems, engines, airframes, and energy generation and storage |

# Other Information

- **The Transportation Roadmap Committee received a summary of the Department of Defense's space launch-related plans.**
  - Assure access with two extended expendable launch vehicle (EELVs) providers.
  - Fly the remaining Delta II and Titan IV vehicles and transition to EELVs through 2020.
  - The existing Delta IV and Atlas V launch vehicle families meet all identified national security space launch requirements.
  - There is potential need for operationally responsive access to space.
  - Dependence on space for national security is becoming apparent.
- **The Transportation Roadmap Committee recognized that on-going commercial entrepreneurial endeavors need to be considered.**
  - A key issue is to balance pursuit of new paradigms versus the Agency's tolerance for risk.
  - Consider unorthodox business terms, modular architecture with open standards, and balancing research investments against development activities.
- **International participation and maintenance of a viable infrastructure were identified as critical issues, but the roadmap activity ended before specific recommendations could be made.**

# Nuclear Systems
# Strategic Roadmap Summary Report

May 22, 2005

# Roadmap Summary: NASA Objectives

NASA Strategic Objective #13: **Demonstrate power, propulsion, life-support capabilities for long-duration, more distant human and robotic missions**

- **Also potentially addresses the following NASA Strategic Objectives derived from the Vision for Space Exploration:**
  6. Undertake lunar exploration to support sustained human and robotic exploration of Mars and beyond
  7. Series of robotic missions to Moon by 2008 to prepare for human exploration
  8. Expedition to the lunar surface as early as 2015, but no later than 2020
  9. Use lunar activities to further science and test approaches (including lunar resources) for exploration to Mars and beyond
  10. Conduct robotic exploration of Mars to prepare for future expedition
  11. Conduct robotic exploration across the solar system to search for life, understand history of universe, search for resources
  14. Conduct human expeditions to Mars after acquiring adequate knowledge and capability demonstrations

# Roadmap Anticipated Achievements

- The Nuclear Systems Committee did not reach consensus on a strategic roadmap.
  - This package documents the interim products of the Nuclear Systems Roadmap.
  - Only committee materials through the end of meeting #2 (April 5-6, 2005) are reported.
  - A government-based working group generated most of the available “product material.”
- Unlike scientific/exploratory roadmaps in which discovery-based decisions are typical:
  - Key elements of the nuclear systems infrastructure are path-dependent limited resources that generally permit only serial (versus parallel) efforts requiring long development times.
  - Decision points for this Nuclear System Roadmap are generally requirements driven rather than “discovery” driven.
  - Activities in the nuclear part of nuclear systems are the statutory responsibility of the U.S. Department of Energy.

# Roadmap Options and Alternatives: Key Questions Under Deliberation

The Nuclear Systems Committee did not reach a formal consensus. The following summarizes topics of deliberation at the time of the committee's termination.

(This does not reflect an exhaustive list of issues for nuclear systems)

- The committee had identified the following topics:
  - Radioisotope Thermoelectric Generator/ Radioisotope Power Sources
  - Fission (space-based power, surface power, nuclear electric propulsion)
  - Nuclear Thermal Propulsion
  - Outreach (public engagement and continued NASA support)
- … about which the committee asked the following questions (list is not exhaustive) before the activity stopped:
  - What is the relevant history of the topic?
  - What activities are currently underway?
  - What are the design considerations?
    - Do safety standards exist or do they need to be developed or modified?
    - Do design standards exist, need to be developed or modified (including lifecycle, operations, disposal)?
    - Where are the logical breakpoints (power levels where a technological approach is no longer practical)?
    - When should this technology be used (surface, space, human, robotic)?
    - What capabilities are required to support activity (facilities, production systems, launch vehicles, test chambers, etc.)?
    - Do analogs (ground-based, space-based, or historical) exist and are they relevant?
    - What are the associated costs (consider only relative or at most or order of magnitude)?
  - Which mission classes do the various technologies enable or enhance?
  - Regarding the roadmap, what decisions need to be made and when (technology development, fuel tests, fuel production, materials, launch systems, safety systems, etc.)?
  - How effective is NASA planning?

# Key Roadmap Decisions

The Nuclear Systems Committee did not reach a formal consensus. The following summarizes possible “key decisions” that likely would appear on a Nuclear Systems Roadmap:

- Determination of first use for fission systems
  - Surface Power
  - Nuclear Thermal Propulsion
  - Nuclear Electric Propulsion (Jupiter Icy Moons Orbiter-type)
  - Nuclear Electric Propulsion (reduced capability)
- Determination of the need for nuclear thermal propulsion in a Mars transportation architecture
- Determination of the practicality of large-scale Radioisotope Power Source (RPS) systems for early surface architectures
  - Primarily: Does the Pu-238 fuel infrastructure support large-scale RPS use (such as for a habitat application)?

# Strategic Roadmap Interdependencies

| Roadmap | Relationship |
|---|---|
| **Robotic and human lunar expeditions** | Nuclear Systems Roadmap receives technical requirements and schedule arising from the lunar planning. The roadmap may provide systems for sustained power generation irrespective of illumination. Possible in-space propulsion contributions for cargo transport. Lunar Robotic and Human Exploration Roadmap may provide opportunities for technical demos. |
| **Sustained, long-term robotic and human exploration of Mars** | Nuclear Systems receives technical requirements and schedule arising from Mars planning. The roadmap may provide systems for sustained power generation irrespective of illumination. Possible in-space propulsion contributions for human and cargo transport. |
| **Sustained program of solar system exploration** | Nuclear Systems receives mission class requirements. The roadmap may provide power and propulsion systems to enable or enhance exploration of outer solar system, interstellar space, near-sun environments, and multi-body tours |
| **Develop an exploration transportation system** | Transportation architectures drive possible nuclear system deployment architectures. Nuclear-based propulsion systems may contribute to the space transportation repertoire. |
| **Complete assembly of the International Space Station and focus utilization** | Possible relevant on-orbit assembly experience from the International Space Station (ISS) may be applied to on-orbit assembly of nuclear systems (depending upon launch vehicle capabilities). |
| **Safely transition from Space Shuttle to new exploration-focused launch systems*** | Safety and risk management policy development at Kennedy Space Center (KSC) likely would affect launch of nuclear systems. National Environmental Policy Act and launch approval processes tightly couple the launch system with the nuclear spacecraft launched. |
| **Explore the origin, evolution, structure, and destiny of the universe** | Nuclear Systems receives mission class requirements. The roadmap may provide power and propulsion systems to enable or enhance exploration of outer solar system, interstellar space, and multi-body tours |
| **Explore Sun-Earth system to understand effects on Earth and implications for human exploration** | Nuclear Systems receives requirements for power sources in near-sun missions. The roadmap may provide power and propulsion systems to enable or enhance exploration of near-sun environments |
| **Educate students and public, and expand national technical skills and capabilities** | Nuclear Systems poses unique education challenges and opportunities. The Education Roadmap focus may contribute to national technical skills in support of Nuclear Systems activities. |

# Strategic Roadmap Interdependency Details (1 of 2)

- **Transportation notionally provides to Nuclear Systems:**
  - Launch capability for Jupiter Icy Moons Orbiter-type missions by 2017 (incidental from lunar launch vehicle requirements to surface power lift by 2019-2020
- **Nuclear Systems notionally provides to Transportation:**
  - Nuclear electric propulsion (NEP) in-space transportation capability
    - Initial robotic mission demonstrates NEP capability in 2014 (planned JIMO precursor at the time of roadmap development)
    - Robotic missions to outer planets by 2017 (planned JIMO mission at the time of roadmap development)
  - Nuclear thermal propulsion in-space transportation capability
    - Cargo and piloted missions to Mars in 2025-2035 timeframe (per Mars roadmap)
- **Other notional synergies/interactions between Nuclear Systems and Transportation:**
  - Launch approval of nuclear power systems (radioisotope and fission) on existing and future launch vehicle systems
  - Human rating of nuclear in-space transportation systems
  - Architecture decision, including nuclear in-space transportation systems

The long development timeline of any nuclear system (surface or space) necessitates a stable and strong mission-class pull, otherwise the development will not come to fruition.

# Strategic Roadmap Interdependency Details (2 of 2)

- **Nuclear Systems notionally provides to Lunar:**
  - Landing locations flexibility
    - Not defined
      - Equatorial most likely = 14-day lunar night
      - Uniquely supports permanent shadowed region
    - Decision in 2010-2012 (established by Lunar Roadmap)
  - Robotic science power flexibility
    - Miscellaneous long-term surface science
  - High-power orbiting assets:
    - Communications, navigation, synthetic aperture radar /notional opportunities
  - Habitats
    - 30kWe by 2020 (first over-night human presence per Lunar Roadmap)
  - Rovers
    - Short haul: radioisotope power source (RPS) may enhance, but not required
    - Long haul: 1-5 kW- class RPS may enable
  - In-situ resource utilization (ISRU) — dependent on architecture
    - ISRU Testbed = 10kW
      - Option A: 2020-2022 (1-2year lag from first habitat assumed 2020)
    - ISRU Pilot = 50kW ("mostly thermal")
      - Option A: post 2025 (ISRU pilot per Lunar Roadmap)
    - ISRU Baseline = 50 to 100 kW ("mostly thermal")
      - Option C: 2017-2022 (pre-placement of ISRU ahead of humans)
    - ISRU Production >100kW ("mostly thermal")
      - Option C: post 2025 (extension of above)

- **Lunar Transport**
  - Chemical only – no nuclear in-space transport assumed

The long development timeline of any nuclear system (surface or space) necessitates a stable and strong mission-class pull, otherwise the development will not come to fruition.

# Salient Points Arising in Committee Deliberations (1 of 2)

The Nuclear Systems Committee did not reach a formal consensus. Below are significant points that one may reasonably infer from the committee deliberations. They are not in priority order.

- Strong and sustained mission pull is a requirement for space nuclear system development.
  - Focus on a deliverable engineered product is critical to program success.
- Key elements of the nuclear systems infrastructure are path-dependent limited resources that generally permit only serial (versus parallel) efforts that would require long development times.
- The U.S. has no fast flux-reactor test capability, necessitating use of foreign facilities for fuel test of in-space fast-flux reactors.
- The U.S. Department of Energy indicated that expansion of Pu-238 production and processing would be insufficient to support a radioisotope power source-based lunar surface power architecture.
  - Changes in U.S. policy and an extraordinarily large infrastructure investment would be required to support even a first use at 30kWe.
  - Current estimates of Russian Pu-238 supply are insufficient to support 30 kWe use.
- Significant differences may exist in mission classes (human versus robotic, in-space versus surface, mobile versus stationary). This may lead to significant differences in corresponding nuclear systems designs.
  - Nuclear system design relies heavily on requirements. One design for all applications should not be assumed.
- Expectations of "extensibility" of a nuclear system need to be tempered with practicality.
  - One hundred percent plug-and-play extensibility on the full-system level is unlikely.
  - Likelihood of extensibility increases at lower levels of integration (i.e. subsystem to component to material levels).
- The available human resources for nuclear systems development are very limited.
  - Enrollment rates in nuclear fields reached an all-time low in 2000.

# Salient Points Arising in Committee Deliberations (2 of 2)

The Nuclear Systems Committee did not reach a formal consensus. Below are significant points that one may reasonably infer from the committee deliberations. These are not in priority order.

- Existing nuclear thermal propulsion (NTP) infrastructure and knowledge base is an actively fading resource.
  - Reclamation of physical facilities, design media, and "corporate memory" will be more effective if initiated sooner than later.
- The main mission-class application for NTP is crew transport to Mars.
  - The role of NTP in lunar applications (crew and/or cargo) and Mars cargo applications is programmatically uncertain.
  - Human rating and systems operations remain open questions.
- Public perception of risk and accountability for safety is a complex issue that transcends memoranda of understanding between agencies.
  - The public most likely would hold NASA accountable for any incident pertaining to a space-nuclear system, regardless of time, statute location, or phase of development.
  - The relative roles of NASA and the U.S. Department of Energy in areas of safety, risk assessment, and risk mitigation are currently not clear to the public.
  - The degree and scope of analyses and testing needed to instill public trust in NASA's stewardship of nuclear systems have yet to be fully determined and may not be determined strictly by technical decisions.
- Launch safety and safety of space nuclear systems are tightly linked.
- The design, development, and operational challenges of a surface nuclear-reactor system are not as well understood as those of in-space reactor systems.
  - That includes concepts of operations, landing, future human interactions on the site of the power system and decommissioning

# Cooperation Opportunities

- International cooperation was discussed without resolution.
  - International cooperation regarding nuclear systems is not a straightforward matter (e.g., International Traffic in Arms Regulations, export control, etc.)

- Government (U.S. Department of Energy) cooperation was discussed.
  - The Energy Department's involvement is both required by statute and provides required expertise to develop nuclear systems.

# Lunar Exploration Strategic Roadmap Summary Report

May 22, 2005

# Roadmap Summary

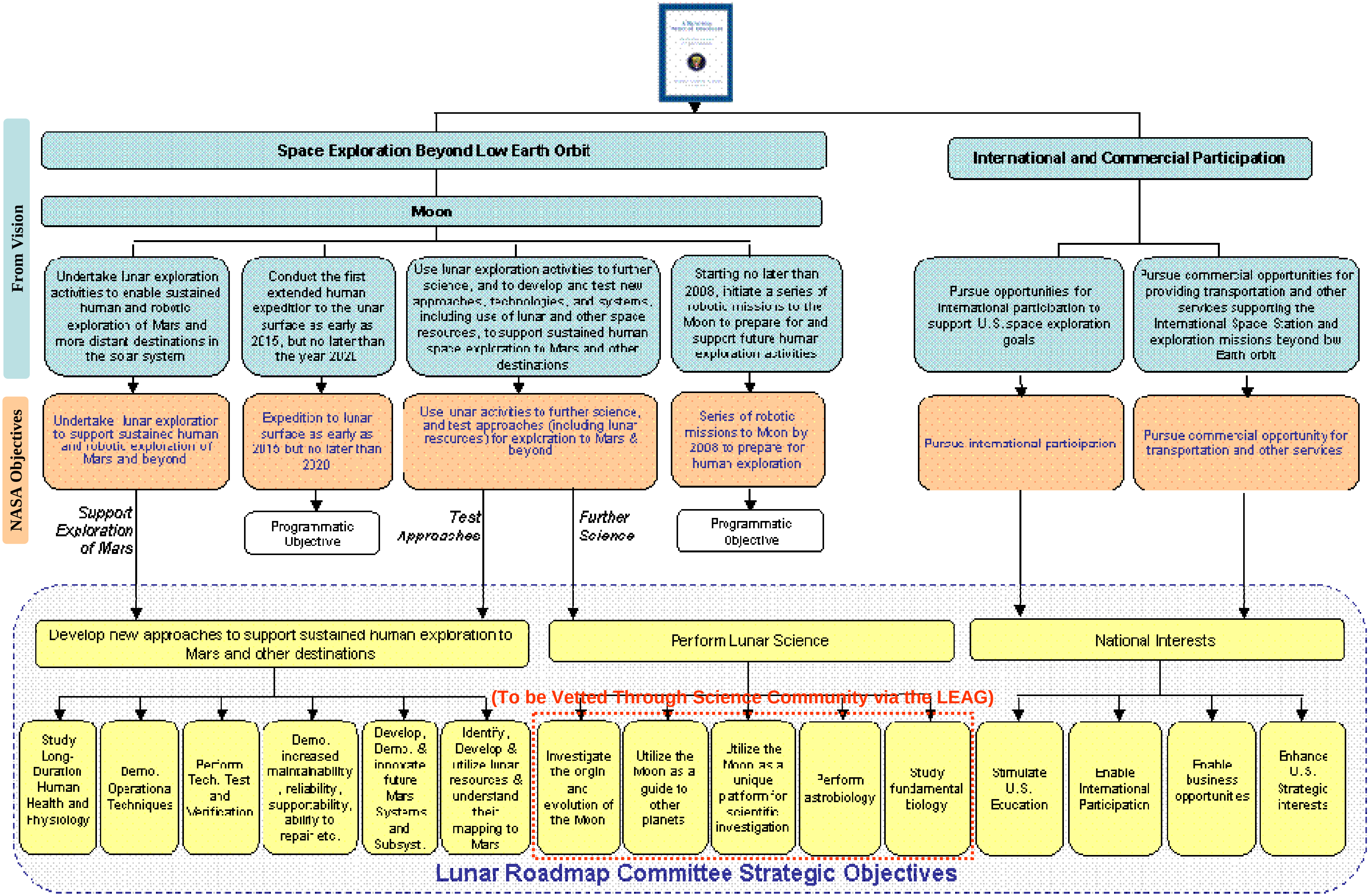
**NASA Objective:**

*"Conduct robotic and human lunar expeditions to further science and to test new exploration approaches, technologies, and systems that will enable future human exploration of Mars and other destinations."*

**Anticipated Accomplishments:**

- Two robotic precursor missions (one orbiter and one lander) between 2008-2012
- Demonstration of lunar transportation systems in low-Earth orbit around 2014
- Lunar sortie missions around 2017 (up to 7-day missions)
  - Outpost site selection
  - Transportation system test and verification
  - Surface system development
  - Apollo-class science investigations
- Single site lunar outpost around 2021 (up to 90-day missions)
  - Short-duration Mars simulations
  - Mars flight crew training and selection
  - In-depth scientific investigations
  - Initial in-situ resource utilization investigations (ISRU), proof-of-concepts, small-scale incorporation
- Extended duration outpost around 2025 (up to 1-year missions)
  - Long-duration Mars simulations
  - Mars flight crew training and selection
  - In-depth scientific investigations enhanced with long-distance surface mobility
  - ISRU
- Wide range of options to allow transition to Mars exploration

# Roadmap Objectives – Trace to the Vision for Space Exploration



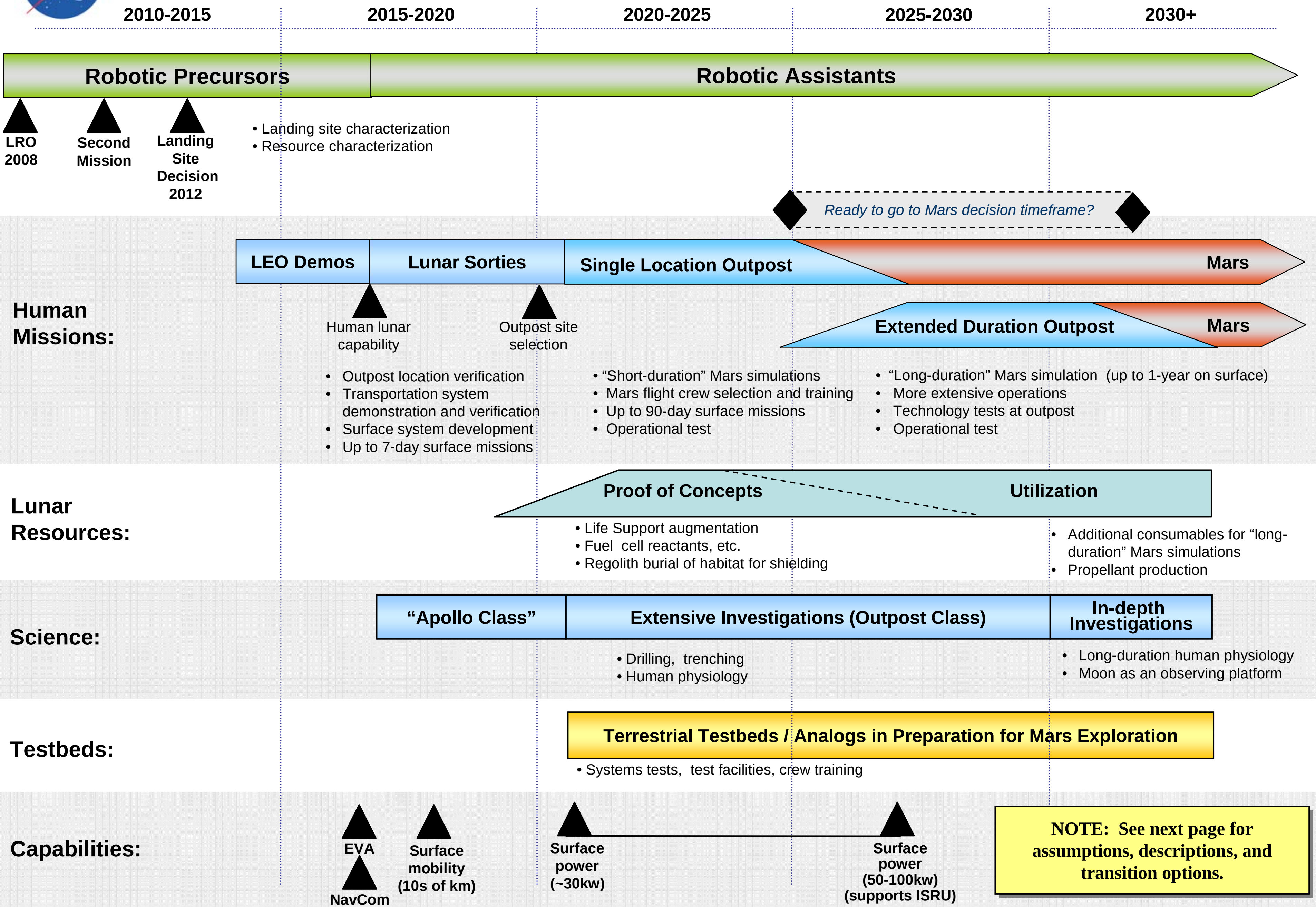
# Roadmap Anticipated Achievements

| Roadmap Goals | 2015-2020 | 2020-2025 | 2025-2030+ |
|---|---|---|---|
| **Develop new approaches to allow sustained human exploration of Mars and other destinations** | • Demonstrate and validate surface mobility designs and systems<br>• Develop a proficiency with off-Earth spacecraft launch and landing operations<br>• Demonstrate advanced chemical propulsion<br>• Build partnerships with industry, government, and academia<br>• Develop methods for managing organizational complexity (project management, program management, systems engineering,international partnerships)<br>• Develop risk management methods for human exploration of deep space | • Understand long-term human adaptation to planetary environments (physiological)<br>• Develop countermeasures to maintain crew health (eg., exercise in a microgravity environment)<br>• Understand the effectiveness of radiation shielding, biological interaction, human response.<br>• Validate food systems, nutrition, and long-term storage<br>• Validate and demonstrate medical diagnosis and treatment equipment<br>• Develop and understand bio-isolation systems.<br>• Develop and understand ISRU fundamentals<br>• Develop regolith-excavation technology<br>• Test and demonstrate test power systems.<br>• Test and demonstrate closed life-support systems<br>• Demonstrate and validate habitat design/systems.<br>• Develop and understand logistics, maintenance, and repair capabilities<br>• Develop and understand dust-mitigation techniques<br>• Demonstrate nuclear power for human systems on Mars (if required)<br>• Develop propellant storage and transfer capability to support surface refueling<br>• Develop experience in planetary surface operations | • Understand long-term system reliability<br>• Conduct psychosocial behavioral observations investigations<br>• Select and train Mars crews |
| **Advance scientific knowledge** | • Investigate the origin and evolution of the Moon<br>• Use the Moon as a guide to other planets<br>• Perform astrobiology<br>• Study fundamental biology<br>• Use the unique features of the Moon as a platform for scientific investigation | | |
| **Advance national interests** | • Enable business opportunities<br>• Enhance strategic interests<br>• Stimulate U.S. education<br>• Promote international participation | | |

NOTE: Objectives were identified for the three lunar goals that appear in the far left column; however, only those for the first row were time-phased. This was due to committee acceleration.

NASA For Official Use Only

# Graphic Representation of Roadmap
## Option A: Lunar Evolution – Focus on Mars Preparation



# Description of Roadmap
# Option A: Lunar Evolution – Focus on Mars Preparation

**Assumptions**:
- Lunar sortie crews perform final site verification and characterization before selecting outpost location.

**Description**:
- Emphasizes preparation for Mars exploration.
- Follows current Exploration Systems Mission Directorate baseline approach.
- U.S. government provided and managed.
- Extended lunar-sortie phase helps defer outpost development costs.
- Science opportunities grow as capabilities expand from sorties, to an outpost, and to a potential extended-duration outpost.
- Once a single location is found, lunar resource use is gradually included, leading to utilization.
- Modest surface mobility concentrates on a central site.

**Transition Options:**
- Decision point around 2025: *Are we ready to go to Mars?*
  - Phase out lunar outpost; complete test-bed/preparedness activities – focus on Mars.
  - Sustain outpost at appropriate levels to support more extensive Mars test-bed activities.

# Roadmap Options and Alternatives – Graphic Depiction

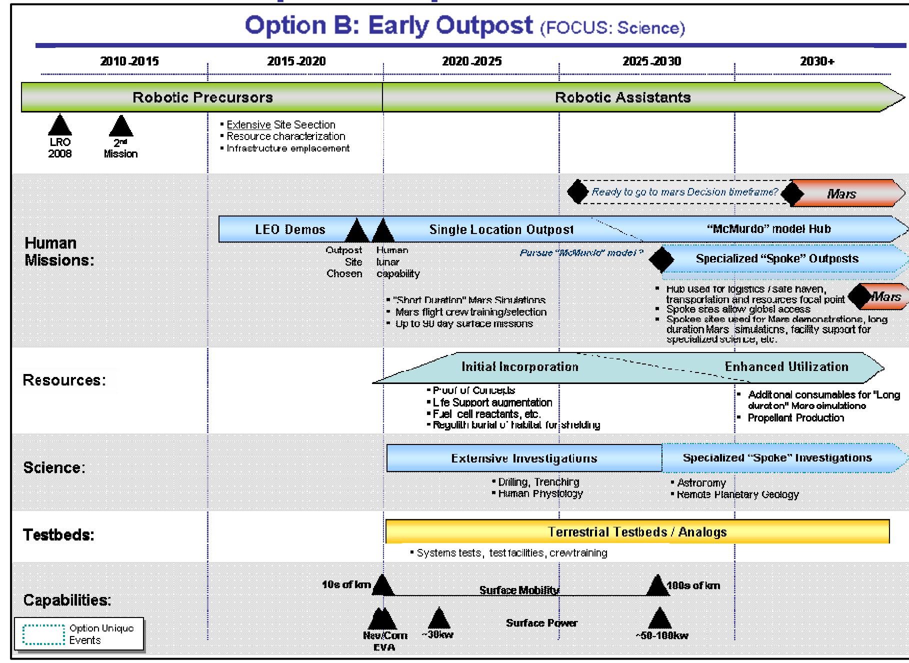
## Three Additional Options:

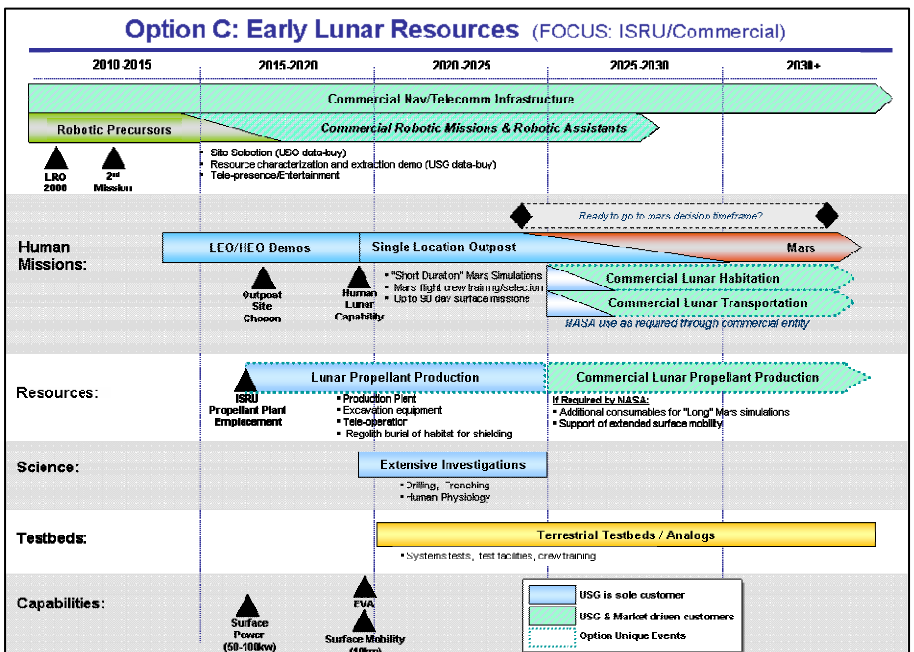
(B) Early outpost (focus on science)

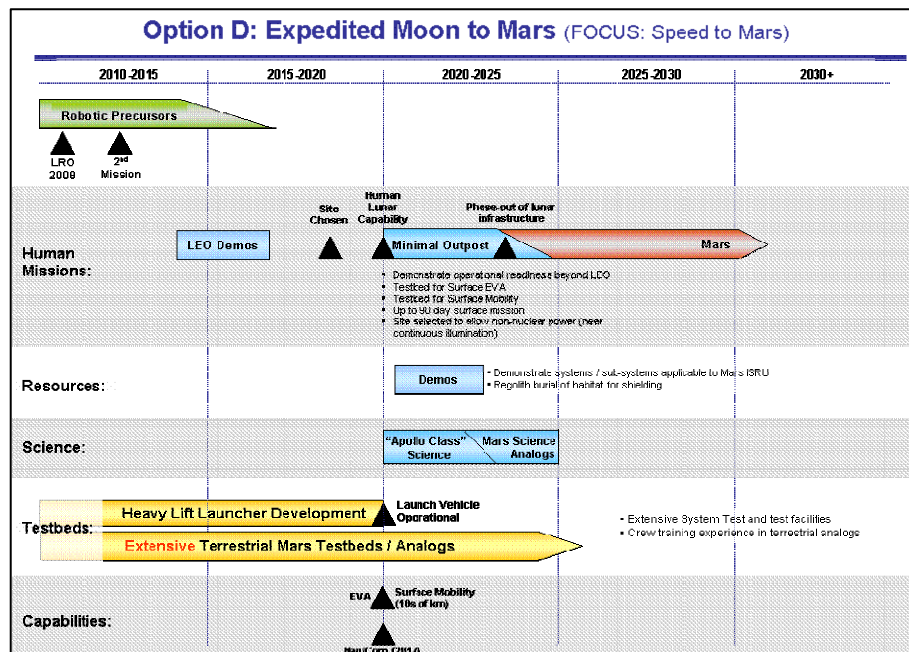
(C) Early lunar resource utilization

(D) Expedited moon to Mars

**NOTE: See next page for assumptions, descriptions, and transition options for each alternative.**



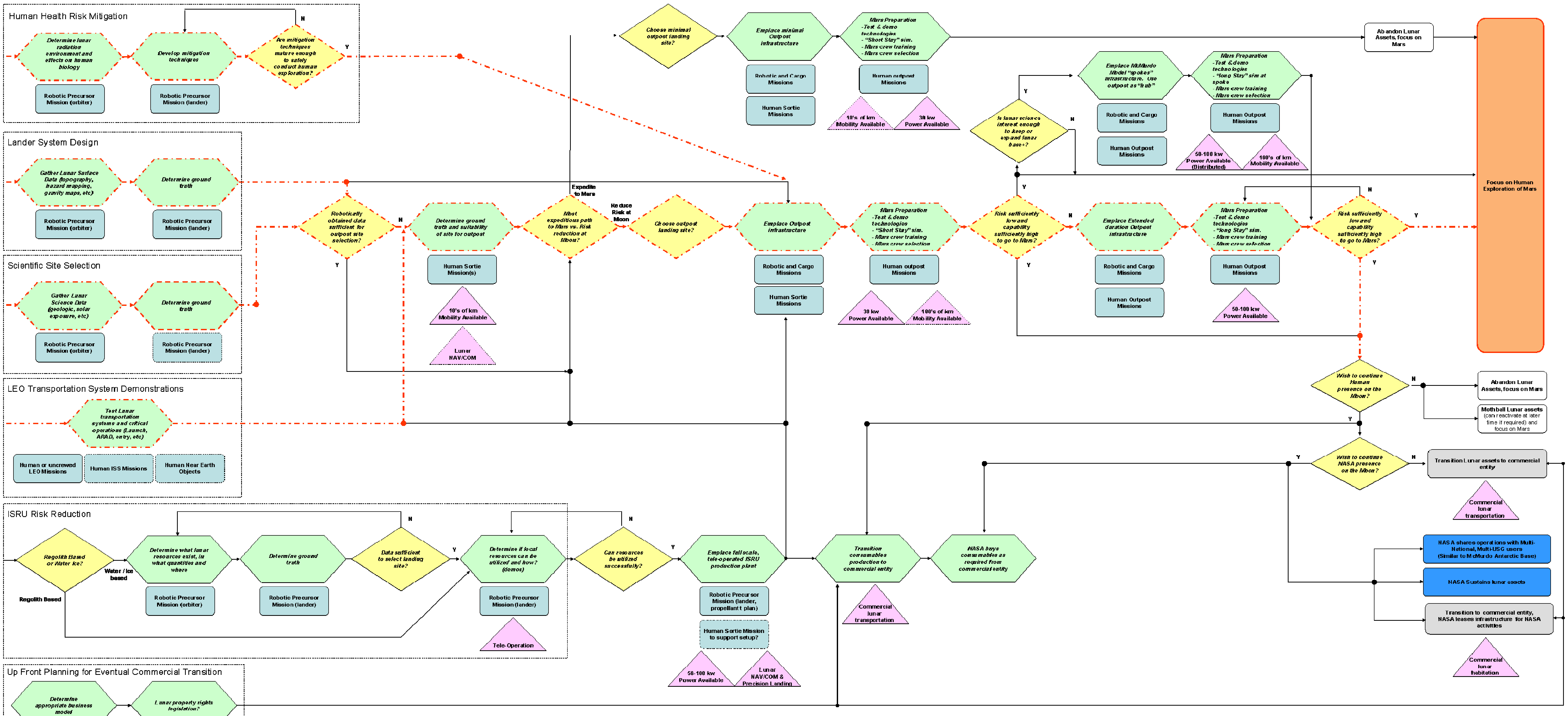



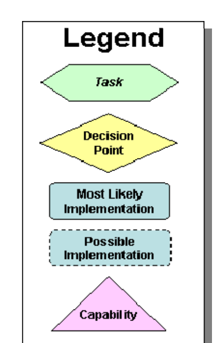
# Roadmap Options and Alternatives - Descriptions



| | Option-B | Option-C | Option-D |
|---|---|---|---|
| **Assumptions** | • Robotically obtained data is sufficient for selecting outpost site.<br>• Assumes sortie phase is not required. | • Assumes the term "commercial" means a viable business case exists where NASA is not the sole customer. (Although NASA may provide "guaranteed buys" at the start to initiate the market.)<br>• Assumes commercial lunar navigation/telecommunication infrastructure to support commercial lunar robotic missions<br>• Assumes U.S. government data-buy from commercial robotic missions<br>• Assumes robotically obtained data is sufficient for site selection<br>• Assumes that robotically obtained data is sufficient for propellant-scale resource extraction<br>• Assumes resource extraction and propellant production are initiated through tele-operation before the crew's arrival<br>• Assumes lunar transportation system designed at outset to most efficiently leverage lunar-produced propellant<br>• Assumes propellant production and habitation are established with goal of "privatization"<br>• Assumes commercial nav/telecomm, propellant production, habitation, and reduced transportation costs because lunar resources are sufficient to enable commercial lunar transportation | • Assumes that a decision to send humans to Mars is made early; influencing the launch vehicle decision<br>• Assumes limited commitment to a lunar presence.<br>• Assumes a minimal set of robotic missions because the use of resources and/or a sustained presence are not the objectives |
| **Description** | • Emphasizes science<br>• McMurdo "Hub & Spoke" model for expanded science/technology utilization accessed through surface mobility<br>–Astronomical instruments<br>–Long-duration Mars simulation facility<br>–Other specialized remote facilities<br>–Enhanced surface mobility for support – enabled by ISRU?<br>–Gradual incorporation of lunar resource utilization once single location determined<br>• Outpost allows for Mars simulation and operational test<br>• Differences from Option-A:<br>–Requires no sortie missions<br>–Outpost is not decommissioned but rather becomes the "hub" of a McMurdo (Antarctica)-type model<br>–Exploration of Moon and Mars occurs in parallel in the out years | • Emphasizes early use of lunar resources<br>• Leverages commercial markets<br>• Maximizes use of lunar resources<br>• Maximizes use of commercial capabilities<br>• Outpost allows for Mars simulation and operational test<br>• Differences from Option-A:<br>– Requires up-front commitment to ISRU<br>– Outpost is not decommissioned but rather transferred to commercial entity | • "Basic" habitation capability – not necessarily extensible to long-duration Mars systems<br>• Only selected surface systems and operations (EVA, surface mobility, etc.) and key transportation systems (precision landing, etc.) tested in lunar environment<br>• Extensive terrestrial and ISS test beds for habitation, life support, crew physiology, etc.<br>• Demonstration of key ISRU subsystems only – no major utilization<br>• Differences from Option-A:<br>– No sortie missions<br>– Delays first human lunar landing to allow development time for Mars systems (Mars systems will be used to the largest extent possible for lunar mission)<br>– Outpost is only designed to last long enough to complete required tests for Mars exploration |
| **Transition Options** | • Decision point in 2025 time frame: *Are we ready to go to Mars?*<br>• If NASA emphasis is on Mars, then second decision point is whether U.S.government should pursue a McMurdo model under an National Science Foundation-style operation | • Decision point in 2025 time frame: *Are we ready to go to Mars?*<br>• Commercial operation of lunar transportation, habitation capabilities; allows NASA to continue lunar presence, if required or desirable, as a tenant | • Decommission lunar outpost – focus on Mars as early as 2023<br>• Decision point around 2023: *Are we ready to go to Mars?* |

# Key Roadmap Decisions




- The figure above represents the basic lunar exploration decision tree
- Lunar Option-A (baseline) is depicted by the red dashed path
- The three alternative roadmaps each represent a different path through the decision tree

# Criteria for Pathway Selection

These questions must be answered before selection of a pathway is possible:

**What is the objective for lunar exploration?**

- What is the definition of “sustained” exploration as applied to the Moon in the Vision for Space Exploration (e.g., Moon to stay or Moon as a stepping stone)?
- Is “sustained” an objective for returning to the Moon or a figure of merit?

**What is the transition strategy?**

- How should NASA transition from a lunar focus to a Mars focus once lunar objectives are achieved (including operationally, budget, workforce, vehicles, infrastructure, etc.)?
- How do we build in a transition strategy from the beginning, particularly for commercial interests?

**What are the other concerns?**

- How long do astronauts need to stay on the lunar surface to understand how well they adapt psychologically and physiologically to planetary environments? (e.g. reduced gravity, etc.)
- How should terrestrial analogs be used in conjunction with lunar activities?
- What is the best approach for international collaboration?

# Strategic Roadmap Interdependencies

| Strategic Roadmap | Dependency to Lunar Strategic Roadmap |
|---|---|
| Exploration Transportation | -Cargo and crew transport |
| Nuclear Systems | -Power, energy storage and propulsion<br>-Mission duration, safety, human factors |
| Mars Exploration | -Scientific and engineering test beds (robotic)<br>-Operations concepts (robotic)<br>-Mars human exploration precursor needs |
| Sun-Solar System Connection | -Human health and safety<br>-Space environment for operations (forecasting and “now-casting”) |
| Space Station | -Space environment<br>-Human health and physiology, subsystem test (e.g., ECLSS) |

# Capability Roadmap Interdependencies

| Capability Roadmap | Capability Available for Lunar exploration |
|---|---|
| High-Energy Power and Propulsion | Energy storage; surface power, surface nuclear power (demo/ops) |
| In-Space Transportation | Autonomous rendezvous and docking; lunar descent/ascent systems |
| Communication and Navigation | Communications relay architectures; autonomous navigation systems; precision navigation systems and algorithms; tele-operations |
| Robotic Access to Planetary Surfaces | Lightweight, high-performance chemical landing systems; impact attenuation; precision landing and hazard avoidance; subsurface exploration techniques; surface mobility; sample acquisition and handling; techniques for landing large masses; surface systems that can survive in harsh environments (e.g., dust, thermal, etc) |
| Human Planetary Landing Systems | Precision landing and hazard avoidance; lightweight landing propulsion; landing systems (vehicles) |
| Human Health and Support Systems | Habitats and safe havens — in space and on surface; life-support systems, food, water; thermal control; dust management; information systems; spacesuits |
| Human Exploration Systems and Mobility | Robotic adjuncts; mobility systems (including rovers) |
| Autonomous Systems and Robotics | Traverse planning and hazard avoidance; repair and servicing; deployments; health monitoring, control and operation of systems; descent, landing and ascent; operations planning and scheduling |
| Scientific Instruments/Sensors | Landing site selection; resource assessment for ISRU |
| In-Situ Resource Utilization | Use of lunar regolith and ice for construction, oxygen & propellant; scalable demos for validation of Mars techniques |
| Advanced Modeling, Simulation, Analysis | Integrated simulations of exploration architectures; science/engineering data processing and fusion |
| Systems Engineering Cost/Risk Analysis | Required for all complex engineering/scientific initiatives |
| Nanotechnology | Ultra-high strength, lighter, multi-functional materials, low power/mass electronic, human health monitoring,and life support; environmental monitoring; Biomimetic materials; Robotics; instrument systems |

# Commercial Opportunities for Lunar Exploration[1]

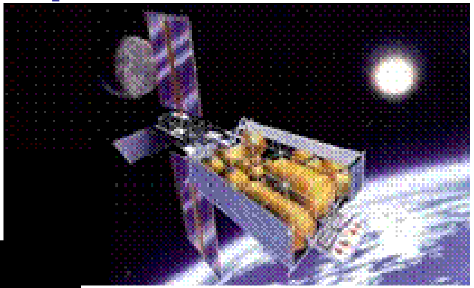
**To develop the public-private frontier:**

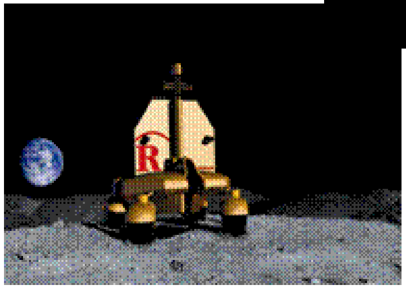
- **NASA is the catalyst**

- **Public and private stakeholders**
  - **Builders of the infrastructure**
  - **Users of the infrastructure**
  - **Benefactors from the use of the infrastructure**

- **Path to a sustainable frontier**
  - **Long term: all infrastructure owned commercially**
  - **Now: Mixed use projects; e.g., private rover, commercial payload, NASA science instruments**

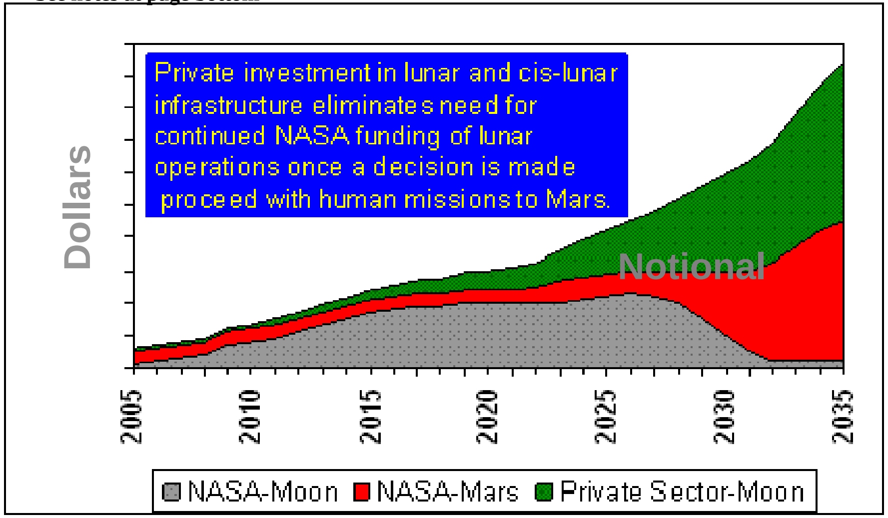
- **Needed:**
  - **Welcoming attitude toward commerce**
  - **Appropriate, nurturing regulations**
  - **Planned transfer of management/ownership to private sector**
  - **Start as soon as possible, including lunar robotic missions**





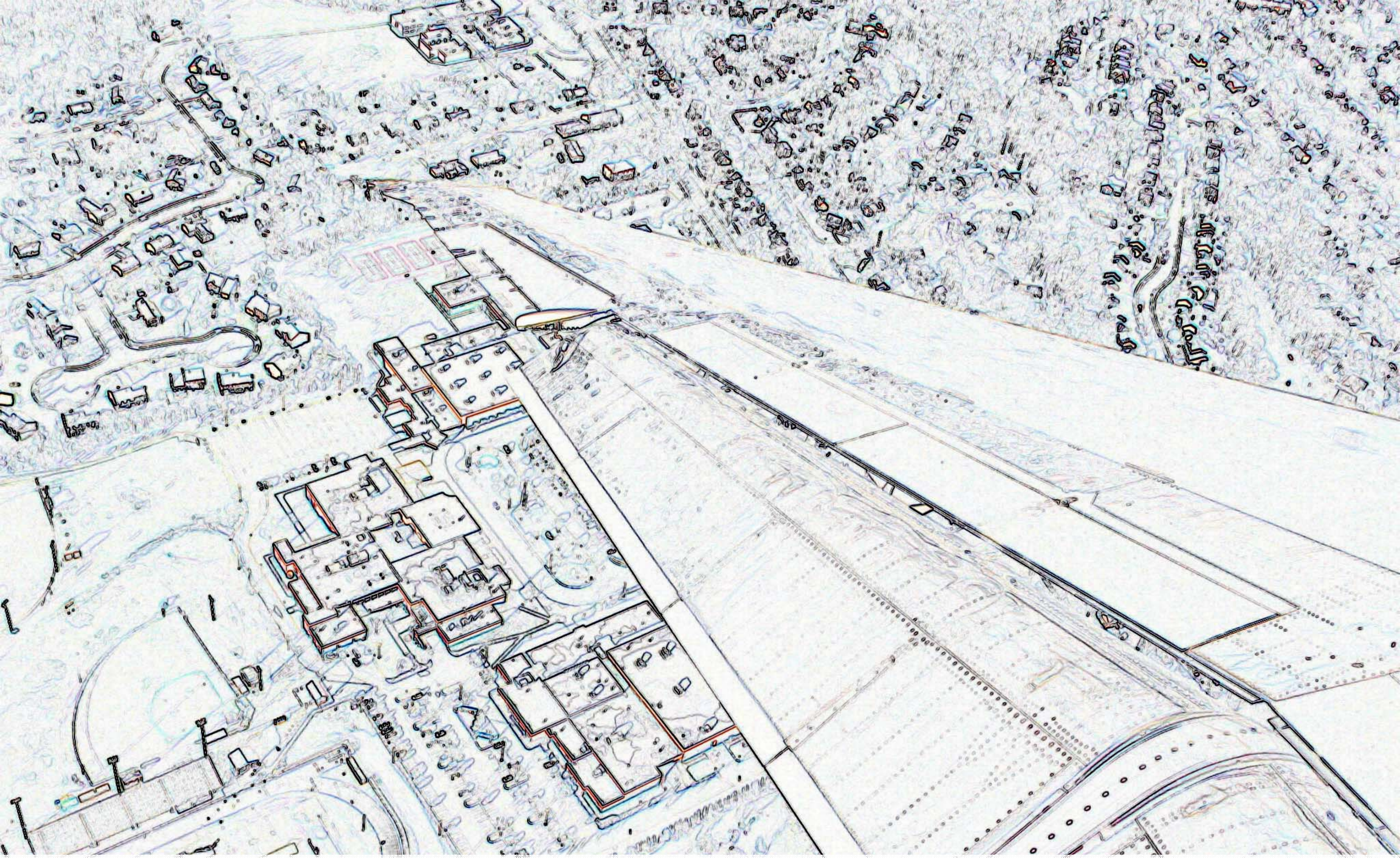
**Potential products and services:**
- **Propellant**
- **Satellite repair**
- **Power**
- **Tourism**
- **Communications**
- **Advertising**

** See notes at page bottom




**No delay in humans to Mars;**
**Private sector takes over lunar operations**

[1]Chart provided by invited commercial panel chaired by Dr. Geoff Taylor (Univ. Hawaii) on behalf of Lunar Roadmap Committee
[2]Radio Shack™ is a trademark of the Tandy Corporation and is not affiliated with NASA



# Aeronautical Technologies
# Strategic Roadmap Summary Report

May 22, 2005

# Roadmap Summary and the Vision

National goal (from the Vision for Space Exploration):

- Advance U.S. scientific, security, and economic interests through a robust space exploration program.

NASA objective:

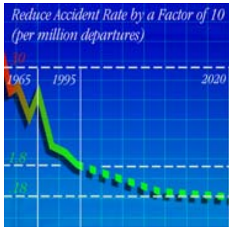
- Develop innovative technologies, knowledge, and infrastructure to explore and to support decisions about the destinations for human exploration.

Aeronautical technologies objective:

- Provide advanced aeronautical technologies to meet the challenges of next-generation systems in aviation, for civilian and scientific purposes, in our atmosphere and in atmospheres of other worlds. Specific research objectives follow.

This roadmap was canceled after one meeting. The committee, therefore, did not complete deliberations on significant areas, including workforce and facilities requirements.

# Aeronautics Research - *Objectives*




**Protect air travelers and the public**

Decrease the aircraft fatality rate, reduce the vulnerability of the air transportation system to hostile threats, and mitigate the consequences of accidents and hostile acts.


**Protect the environment**

Protect local and global environmental quality by reducing aircraft noise and emissions.

**Increase capacity and mobility**

Enable more people and goods to travel faster and farther, with fewer delays.

**Partnership for national security**

Enhance the nation’s security through partnerships with Department of Defense, Department of Homeland Security, and other U.S. or international government agencies.

**Explore revolutionary aeronautical concepts**

Create novel aeronautical concepts and technology to support science missions and terrestrial and space applications.

# Roadmap Anticipated Achievements

| | **2005 – 2015 Digital Era** Network Enabled Optimizations for State-of-the-Art Systems | **2015 – 2025 Sentient Era** Proactive, Reconfigurable Systems for New and Enhanced Capabilities | **2025 – 2035 Nano/Bio Era** Revolutionary Systems for Human Societal Evolution |
|---|---|---|---|
| ***Protect Air Travelers*** | •Global integration of existing sensors for real-time global situational awareness (security, safety, and capacity) | •Integration of next-generation global sensors and communications for perspective situational awareness – seamless national defense integration<br>•Inclement weather-proof systems<br>•Embedded, multi-fault-tolerant security and safety systems, including self maintenance and repair | •Regenerative and highly reconfigurable hybrid organic structures and systems for real-time optimization, hazard avoidance, and security threat mitigation |
| ***Protect the Environment*** | •Evolutionary reductions of emissions and noise for current state-of-the-art systems | • Revolutionary zero-emission power density and storage capabilities<br>•Total elimination of some emission classes and significant reductions in noise | •Total elimination of direct, unwanted emissions and noise |
| ***Increase Capacity and Mobility*** | • Automation enhancements of business-as-usual-operations | • System-level automation with controlled zones of autonomous operations<br>•Seamless National Airspace System unmanned aerial vehicle (UAV) fleet operations for a range of missions with controlled zones of autonomous operations | •Collaborative autonomous systems (no human labor) for commercial, private multi-modal transportation and UAV operations<br>•Ubiquitous, robust sensor nets and communications |
| ***Public Partnership for National Security*** | •Global integration of existing sensors for real-time global situational awareness (security, safety, capacity) | •Integration of next-generation global sensors and communications for perspective situational awareness — seamless national defense integration<br>•Embedded, multi-fault-tolerant security and safety systems, including self maintenance and repair | •Regenerative and highly reconfigurable hybrid organic structures and systems for real-time optimization, hazard avoidance, and security threat mitigations |
| ***Explore Revolutionary Aeronautical Concepts*** | •Robust hypersonic and quiet supersonic operations demonstrations<br>•Operational High Altitude, Long Endurance UAVs; Prototypes for autonomous cargo, firefighting, rescue, and other missions | • Regular hypersonic and supersonic operation, with seamless integration involving military and, as appropriate, launch operations | • Micro Travel — individual flight gear or suits for urban, neighborhood, and nature hike-type excursions as well as entertainment and construction or operations-type activities |
| ***Cross-Cutting*** | •Automation enhancements of business-as-usual-operations<br>•Highly accurate predictive systems (safety, security, capacity, environment, and aircraft/infrastructure systems) for real-time human decision-support systems | •Micro- and nanotechnology structure, power, and control-surface enhancements to enable new vehicle classes and augmentation to existing vehicle fleets<br>•Semi-reconfigurable, pro-active, on-demand systems (safety, security, capacity, and environment), subsystems (intelligent engines, gate robotics, and intelligent maintenance systems) | •Highly distributed, with dynamic real-time system and vehicle optimizations |

# System Performance Metrics

| Year | Activity | Goal |
|---|---|---|
| | Objective: Protect Air Travelers and the Public | |
| 2010 | **Reduce the aviation fatality rate per FY 90-96 average** | **50%** |
| 2010 | **Reduce aircraft vulnerability (exposure)** | **35%** |
| 2012 | **Identify and resolve air transportation system real-time risk and vulnerability** | **—** |
| | | |
| | Objective: Protect the Environment | |
| 2007 | **Reduce NOx emission per the 1996 International Civil Aviation** | **70%** |
| | **Organization (ICAO) standard.** | |
| 2010 | **Reduce aircraft community noise** | **10db** |
| 2010 | **Reduce Carbon Dioxide greenhouse emissions per 2000 SOA** | **25%** |
| | | |
| | Objective: Increase Mobility | |
| 2009 | **Increase terminal area throughput** | **5%** |
| 2009 | **Enable short-flied take-off and landing, and high-speed cruise capability** | **—** |
| 2009 | **Increase en route throughput per 1997 NAS capacity** | **10%** |
| 2013 | **Provide key enabling capabilities for a low cost, easy-to-fly personal air vehicle** | **—** |
| | | |
| | Objective: Partnership for National Security | |
| 2007 | **Transfer technology with the Department of Defense** | **—** |
| 2010 | **Reduce air transportation system vulnerability via partnership with the Department of Homeland Security and Transportation Security Agency** | **—** |
| | | |
| | Objective: Explore Revolutionary Aeronautical Concepts | |
| 2010 | **Enable un-inhabited air vehicle** | **14 day @ 60,000 ft. and 200kg payload** |
| 2010 | **Enable planetary flight vehicle technologies for exploration** | **—** |
| | | |

# Roadmap for Safety

| *Fatal accident rate vs. 1990-96:* | *-50%* | *-70%* | *-90%* | *-98%* |
|---|---|---|---|---|

2005 2010 2015 2020 2025 2030 2035

**Aircraft self-protection and preservation**

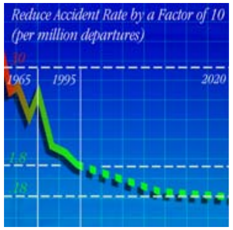
- Large-scale Homeland Security integration and Department of Defense (DoD)
- Global/seamless security/DoD integration
- Advanced bio/nano personal protection systems
- Reactive risk-mitigation systems that lessen abnormal operations
- Proactive risk-mitigation systems based on risk precursor identification
- Reactive risk-mitigation systems that lessen system failures
- Real-time learning/adaptive risk-mitigation systems
- Highly reconfigurable systems

**Environmental hazards awareness and mitigation**

- Detection of natural hazards that compromise safe operations in the National Airspace System (NAS)
- Impervious to environmental hazards through real-time, in-flight, self-healing and self-repairing systems
- Mitigation of the effects of detected natural hazards that compromise safe operations in the NAS
- Highly robust materials systems resistant to environmental hazards

**Human error avoidance**

- Recovery from unsafe flight situations due to human error
- Onboard autonomous advisor — electronic co-pilot
- Recovery from unsafe flight situations due to the breakdown of the human/machine interface
- Recovery from unsafe flight situations due to machine error
- System-wide autonomous advisor – sentient NAS




**Foundation Technologies-**TRL 1-3, R&D with technology transition to mid-TRL programs

Digital Era | Sentient Era | Nano/Bio Era

# Roadmap for Security

*Reduction in vulnerabilities:* *-35%* *-60%* *-90%* *-99%*

2005 2010 2015 2020 2025 2030 2035

**Hostile act intervention and protection**

- Protection of critical assets from hostile aircraft takeovers
- Protection from man-portable air defense systems, other projectiles, and explosive devices
- Protection from electromagnetic effects/cyber attacks
- Protection of aircraft systems for information flow against hostile disruption
- Isolation, containment, and elimination of communicable diseases and chemical and biological agents aboard aircraft and in airports

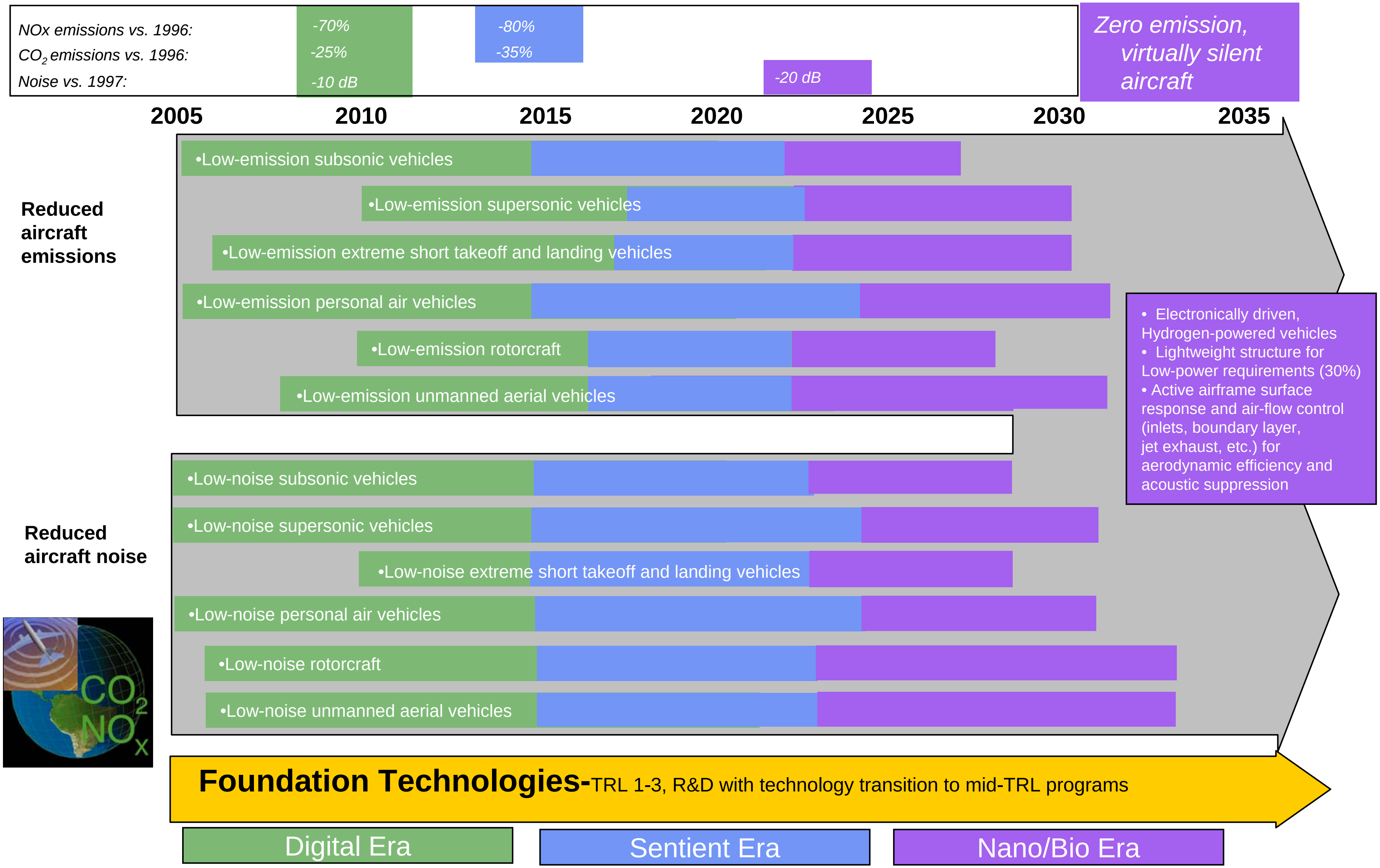
**System vulnerability discovery and management**

- Detection and mitigation of deviations from flight path with hostile intent
- Discovery of potential security breaches at airport breaches at airports – Intelligent Sensors – Self replication sensor grids
- Data mining and detection of potential cargo threats
- Sensing of communicable diseases and chemical and biological agents aboard aircraft and in airports

**Foundation Technologies-**TRL 1-3, R&D with technology transition to mid-TRL Programs

Digital Era | Sentient Era | Nano-Bio Era

# Roadmap for Environment



# Roadmap for Capacity

ATS Capacity vs. 1997: 2.05 (x 1997) | 2.5 (x 1997) | 3 (x 1997) | 4 (x 1997)

2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035

**Efficient traffic flow**

- Increase en-route commercial operations in the NAS
- Full system capability for general aviation during peak demand
- Full system capability public service aircraft during peak demand

**System-wide operations**

- Minimize system-wide disruptions from external events (thunderstorms, etc.)
- Harmonize equipment and operations globally

**Aircraft/ airport productivity**

- Increase arrival and landing rates at commercial airports — advanced terminal, gate, and ramp automation as well as dynamic/reconfigurable airport structures
- More commercial operations from small and underused airports
- Commercial operations with short or no runways

**Fully integrated automated optimized National Airspace System (NAS)**

- Automated optimization of four-day flight path for all commercial aircraft
- Transparent integration of general aviation, public services, and unmanned aerial vehicles
- Air traffic management procedures tailored to individual aircraft characteristics
- High-level optimization of system performance and full integration of en-route and terminal operations
- System impervious to disruptions from any source

**Foundation Technologies-**TRL 1-3, R&D with technology transition to mid-TRL programs

Digital Era | Sentient Era | Nano/Bio Era

# Roadmap for Mobility

Goal: Continuously expanding choice of efficient air transportation

2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035

**Optimized flight with reduced or no human intervention**

- •Efficient subsonic vehicles
- •Efficient low-boom supersonic vehicles
- • Air traffic management for unmanned aerial vehicles and other vehicle types (supersonics/hypersonics)
- Micro Travel — individual flight gear/suits for local neighborhood/urban/entertainment excursions
- •Quiet and efficient all-weather extreme short takeoff and landing vehicles
- •Efficient all-weather rotorcraft
- • Highly configurable subsystems for continuous optimization of entire flight profile
- • Real-time transformation systems for continuous optimization of the entire flight profile
- •Low-cost, efficient, easy-to-fly personal air vehicles
- • Autonomous personal air vehicles
- • Reconfigurable personal multi-modal modular vehicles

**Optimized ground ops and maintenance with reduced or no human intervention**

- • Highly accurate predictive decision-support systems for human operations
- • Intelligent, proactive maintenance support systems
- • Self-healing and regenerative systems

**Foundation Technologies-**TRL 1-3, R&D with technology transition to mid-TRL programs

Digital Era | Sentient Era | Nano/Bio Era

# Roadmap for New Missions

**UAV Operation**

- **14 days @ 60,000 ft., carrying 200-kg payload**
- **100 days @ 60,000 ft., carrying a 150-kg payload**
- **100 days @ 60,000 ft., carrying a 3,000-kg payload**

**2005 2010 2015 2020 2025 2030 2035**

**Autonomous long-endurance unmanned flight**

- Autonomous, high-altitude, long-endurance unmanned aerial vehicle technologies aerial vehicle technologies
- Planetary flight vehicle technologies
- Innovative applications of autonomous unmanned vehicles

**Robust, re-useable demonstration vehicles and systems**

**Operational vehicles**

**Next-generation operational vehicles**

**Hypersonic atmospheric flight**

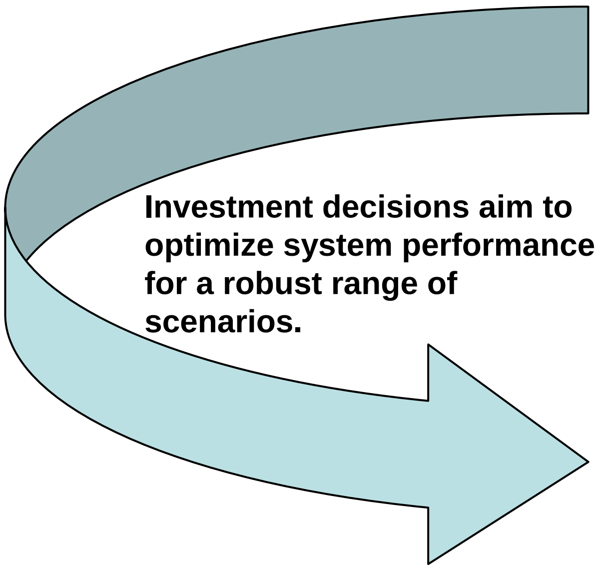
- System research and development for propulsion and vehicle options for efficient air-breathing hypersonic flight
- Earth launch assist system of systems
- Hypersonic cargo/sample return un-crewed return
- Global rapid response systems

**Foundation Technologies-**TRL 1-3, R&D with technology transition to mid-TRL programs

Digital Era | Sentient Era | Nano/Bio Era

# Scenario Options for Elements of the National Airspace System

| *Passenger/Cargo Demand* | *Fleet Mix/ Aircraft Types* | *Business Model/ Schedule* | *National Airspace Space Capability* | *Disruptions /Weather* |
|---|---|---|---|---|
| 1) Current<br>2) Terminal area forecast (TAF) growth to 2014 and 2025<br>3) 2X TAF-based constrained growth<br>4) 3X TAF | 1) Current scaled<br>2) More regional jets<br>3) New vehicles:<br>• Micro jets<br>• Uninhabited air vehicles<br>• ESTOL/RIA<br>• Supersonic Transport (SST) | 1) Current (mostly hub and spoke)<br>2) More point-to-point and regional airports<br>3) Massive small airport utilization | 1) Current<br>2) 2014 Operation evolution plan (OEP)<br>3) Increased capacity of landside, surface runways, terminal en-route<br>4) Systemic CNS, SWIM, and weather prediction | 1) Good weather (Wx)<br>2) Bad<br>• Airport IFR<br>• En-route<br>• 7 Wx days<br>3) Disruption<br>• Sudden shutdown of an airport or region |



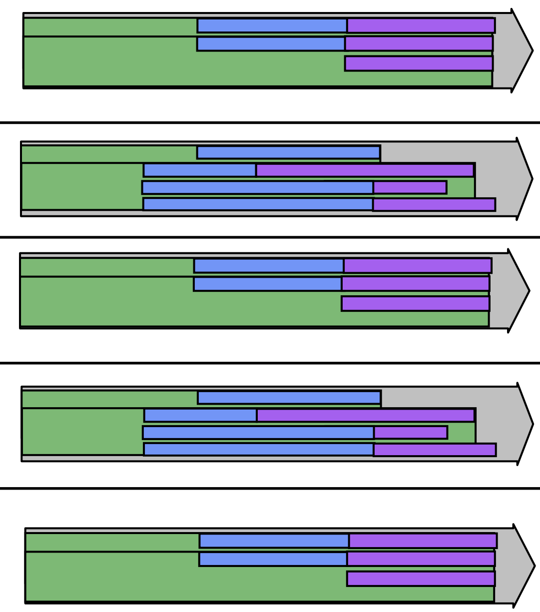

*Protect air travelers and public*

*Protect the environment*

*Increase capacity and mobility*

*Explore revolutionary aeronautical concepts*

*Create a partnership for national security*



# Strategic Roadmap Interdependencies

| Roadmap | Relationship |
|---|---|
| **Sustained, long-term robotic and human exploration of Mars** | The roadmap receives technical requirements and schedules. It provides technologies for atmospheric flight on Mars. |
| **Sustained program of solar system exploration** | The roadmap receives technical requirements and schedules. It provides technologies for atmospheric flight on other worlds and for hypersonic/ unmanned aerial vehicle (UAV) sample and return to Earth . |
| **Develop an exploration transportation system** | The roadmap receives technical requirements and schedules. It provides technologies for atmospheric flight for both launch services and hypersonic/UAV reentry vehicles. |
| **Safely transition from Shuttle to new exploration-focused launch systems** | The roadmap receives technical requirements and schedules. It provides aero-assist launch technologies. |
| **Determine how the living Earth system is affected by internal dynamics and understand the implications for life** | The roadmap receives technical requirements and schedules. It provides a range of UAV technologies, including long-duration, high-altitude, robust atmospheric vehicles for data gathering as well as oceanic sensor deployment, water sample collection, and other Earth-monitoring and autonomous sampling missions. |
| **Explore Sun-Earth system to understand effects on Earth and implications for human exploration** | The roadmap receives technical requirements and schedules. It provides a long-duration, high-altitude, robust atmospheric vehicles to help carry out research and development on space weather forecasting and monitoring. |
| **Educate students and public, and expand national technical skills and capabilities** | The roadmap offers opportunities for students and the public to follow advanced technology systems and to augment math and science skills. |

# Capabilities Roadmap Interdependencies

| Roadmap | Nature of the relationship: What the Capability Roadmap Provides for Aerospace |
|---|---|
| **High-energy power and propulsion** | •Energy storage |
| **Communication and navigation** | •High-bandwidth communication<br>•Secure inter-aircraft and ground and satellite command and control links |
| **Autonomous systems** | •Health monitoring and control and operation of systems<br>•Control of aircraft on the ground<br>•Air traffic control |
| **Transformational spaceport/range** | •Range safety<br>•Interface between national airspace system and space range |
| **Advanced modeling/simulation** | •Advanced computational fluid dynamics techniques<br>•Advanced end-to-end system modeling |
| **Systems engineering** | •Required to ensure an outcome and/or optimize performance within engineering, budget, and schedule constraints for all enterprises<br>•Enable large system of systems (NAS) to transform |
| **Nanotechnology** | •Ultra-high strength, lighter, and multifunctional materials (100 times stronger than steel)<br>•Micro-electronics 100 times smaller and less power consuming<br>•Highly miniaturized avionics and instrument systems<br>•Efficient electrical power systems |

# Earth Science and Applications Strategic Roadmap Summary

May 22, 2005

# Roadmap Summary

- NASA objective to which roadmap responds:
  - Advance scientific knowledge of the Earth system through space-based observation, assimilation of new observations, and development and deployment of enabling technologies, systems, and capabilities, including those with the potential to improve future operational systems.

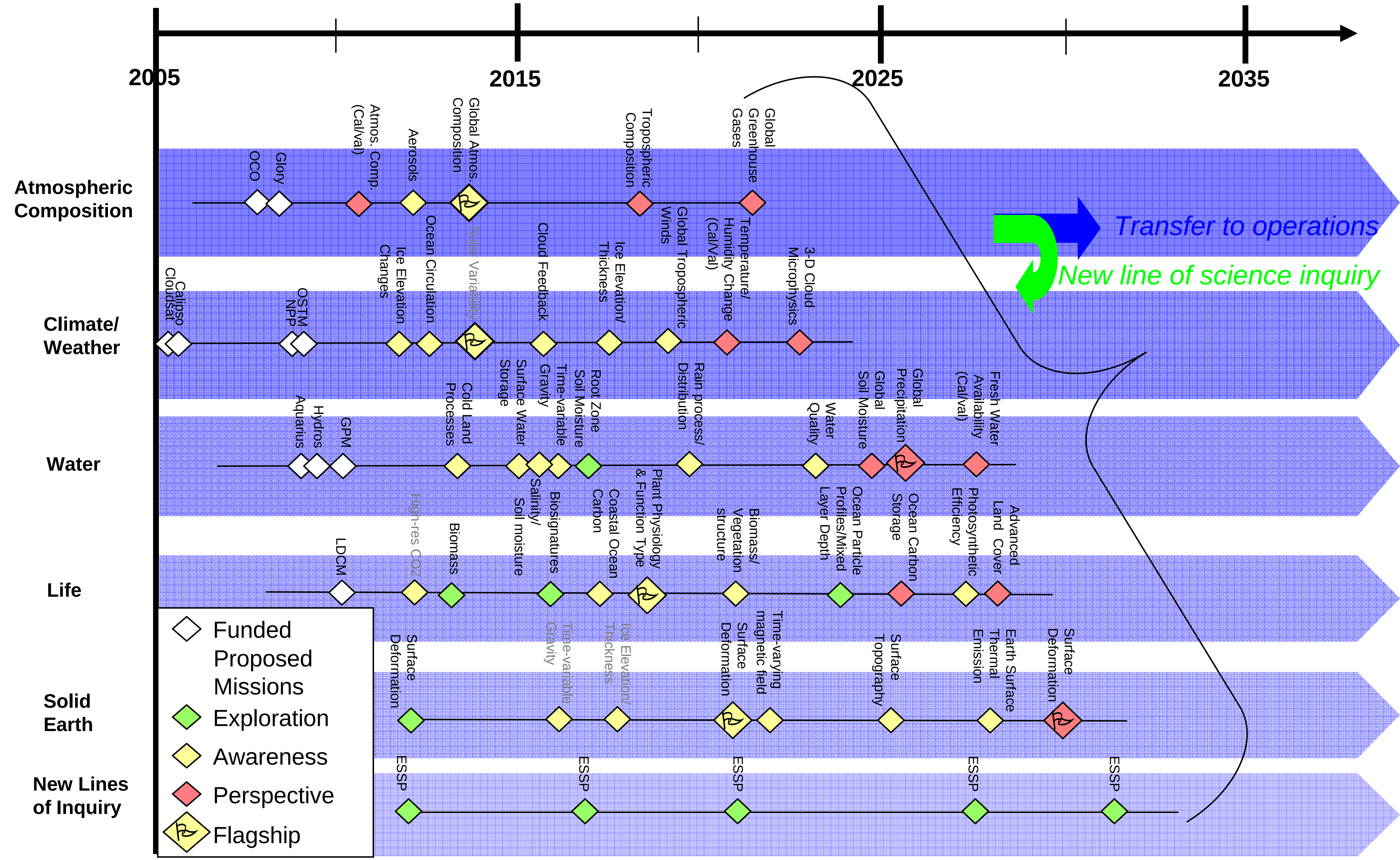
- Connection to NASA vision:
  - "To Improve Life Here"
  - Responds to multiple presidential initiatives and directives, including Climate Change Research (June 2001), Global Earth Observation (July 2003), and Collaborative Oceans Research (December 2004)

- Top-level summary of themes:
  - Predictive understanding of the Earth as a system of interacting natural and human systems
    - Atmospheric composition: how the atmosphere protects and sustains us
    - Climate and weather: how climate and weather are evolving
    - Water: what controls the availability of water on the planet
    - Life: how life influences and responds to environmental processes
    - Solid Earth: what controls the changes to the Earth's surface and interior
  - Synergistic integration of Earth observations and models (sensorweb/modelweb)
    - Exploration and discovery: new investigations using new insights, technologies, capabilities, and vantage points to explore unknown aspects of the Earth system
    - Continuous awareness: prompt recognition and adaptive observation of dynamic events through the networking of distributed observing and modeling systems for new scientific understanding of dynamic processes and to demonstrate the potential to improve future operational systems
    - Developing perspective: integration of sustained and comprehensive observations and models to understand long-term Earth processes and trends

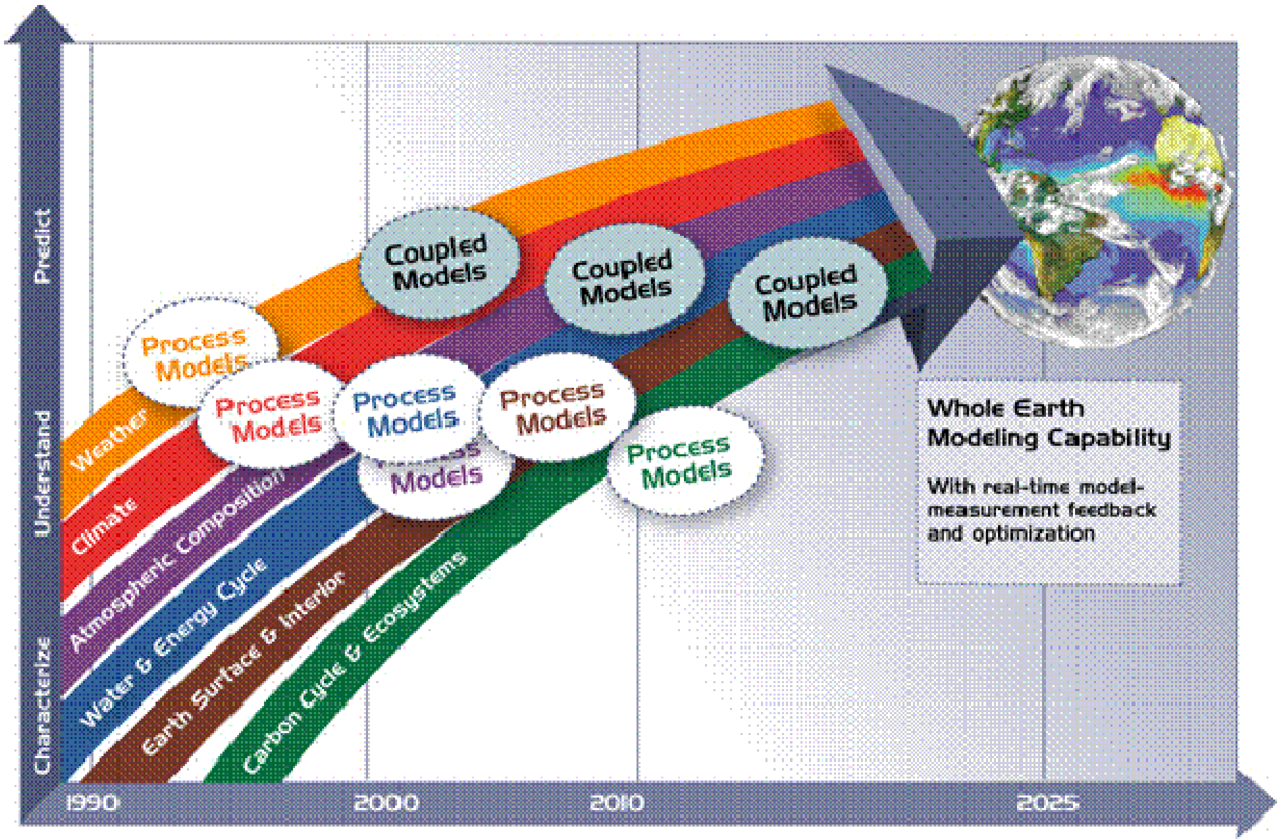
# Roadmap Anticipated Achievements

| Goals \ Achievements | 2005-2015: Building a foundation for comprehensive observing and modeling | 2015-2025: Expanding our view of Earth and benefits to society | 2025-2035 and Beyond: Fully instrumented Earth system networked to predictive models serving scientists and decisions-makers |
|---|---|---|---|
| **Exploration and Discovery:** Explore unknown aspects of the Earth system by carrying out new investigations, enhanced by new insights, technologies, capabilities, and vantage points | •Accurate assessment of carbon sequestration on land<br>•Time-dependent deformation maps of fault zones, volcanoes, slopes, and ice sheets | •Characterize water distribution in root zone; improve weather and climate prediction<br>•Upper ocean profiling to understand ocean biosphere | •Short-period magnetic field dynamics<br>•Pursuing answers to new questions, enabled by distributed autonomy, biotechnology, nanotechnology, very large apertures, etc. |
| **Continuous Awareness:** Develop new scientific understanding of the dynamic Earth process. Provide capabilities useful for decision-support tools. Provide prompt recognition and adaptive observation of dynamic events through the networking of distributed observing and modeling systems | •Improved understanding of natural and anthropogenic aerosols and their effects on climate<br>•Ice sheets changes and ocean circulation tied to predictive climate models<br>•Quantified snow deposition and water equivalent<br>•$CO_2$ flux to constrain global sources and sinks | •Quantified dynamics of major ice sheet motion<br>•Tropospheric winds over land and ocean for weather and ocean circulation models<br>•Quantified dynamics of cloud moisture, rainfall, surface and subsurface water storage, runoff, and fresh water availability<br>•Vegetation/algal type and land/ocean carbon sequestration<br>•Surface deformation dynamics, thermal/land-use changes, and surface beneath ice | •Assessment of plant and algal physiological status and productivity<br>•Improved global topography and, in conjunction with SRTM data, first global measurement of topographic change<br>•Fully integrated Earth System model and assimilation system with data distribution portals for simple, high-speed access to all aspects of the Earth System |
| **Developing Perspectives**: Enable new scientific understanding of long-term Earth processes and trends by sustaining and integrating comprehensive global observing and modeling systems | •Calibrated operational weather/climate observations for science<br>•National framework for linking Earth system models | •Reduced uncertainties in global and regional climate models through cloud feedback and aerosol forcing<br>•Models and data assimilation systems integral to the observing system and decision support systems, including future mission design | •Global water cycle, including soil moisture, precipitation, linked to climate and weather models<br>•Networked observations, models, and knowledge systems for science and operational systems |

# Strategic Roadmap Timeline



# Modeling and Computing Investment




- 2015
  - Loosely coupled global models
  - Earth System Modeling Framework implemented
- 2025
  - Fully integrated Earth system model

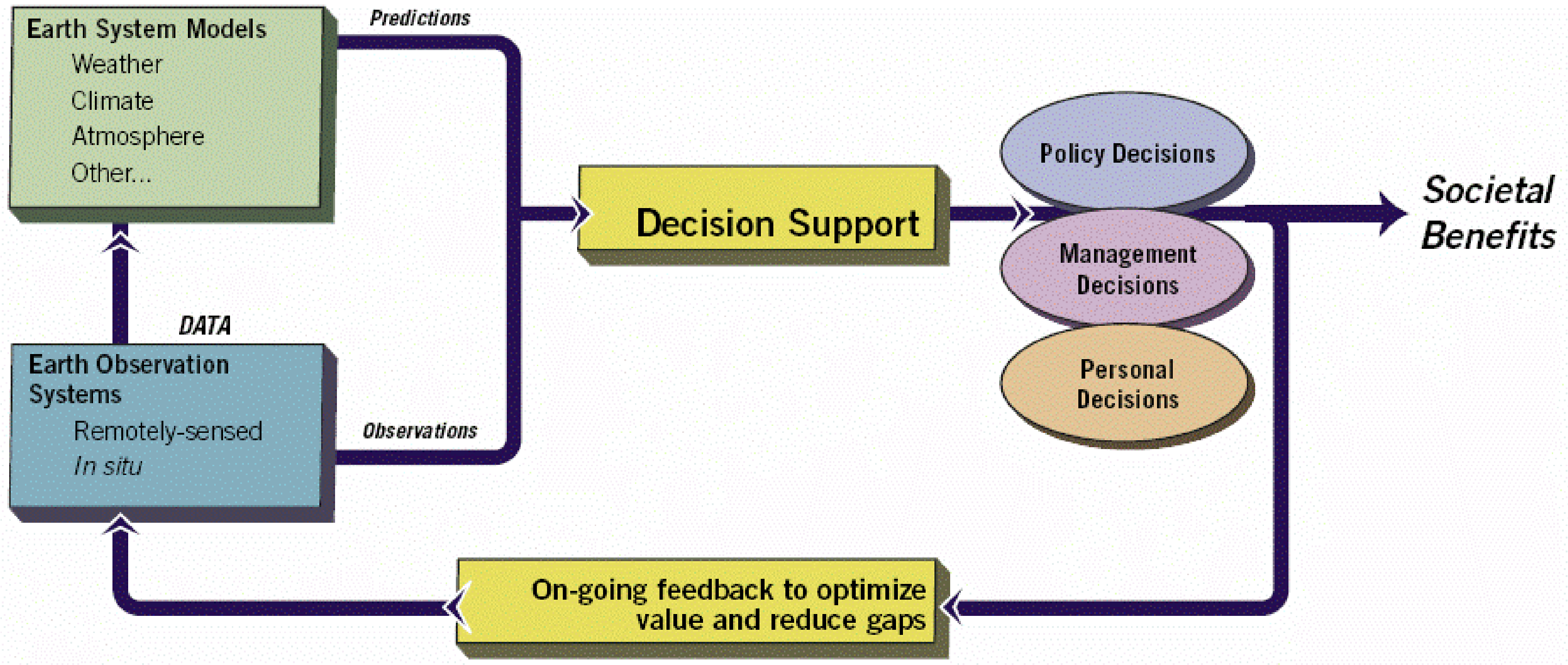
# Roadmap Interdependencies (1 of 2)

- Primary strategic roadmap linkages:
  - Shared desire with Sun-Solar System Connection Roadmap for joint investigations of the effects of solar variability on the Earth's climate and upper atmospheric chemistry dynamics.
  - Shared scientific, modeling, and observation system interests with all three exploration roadmaps (Lunar, Mars, and Solar System), Earth-like planets, and Aeronautics.
- Key required technical capabilities:
  - Sensor web/model web autonomy
  - Capacity to connect multiple observing and modeling systems to synergistic networks or system of systems, with intensive modeling and analysis
  - Innovation in Earth observation instrument and system technology, as well as the capability to rapidly, reliably, and efficiently design, build, test, and operate new instrumentation

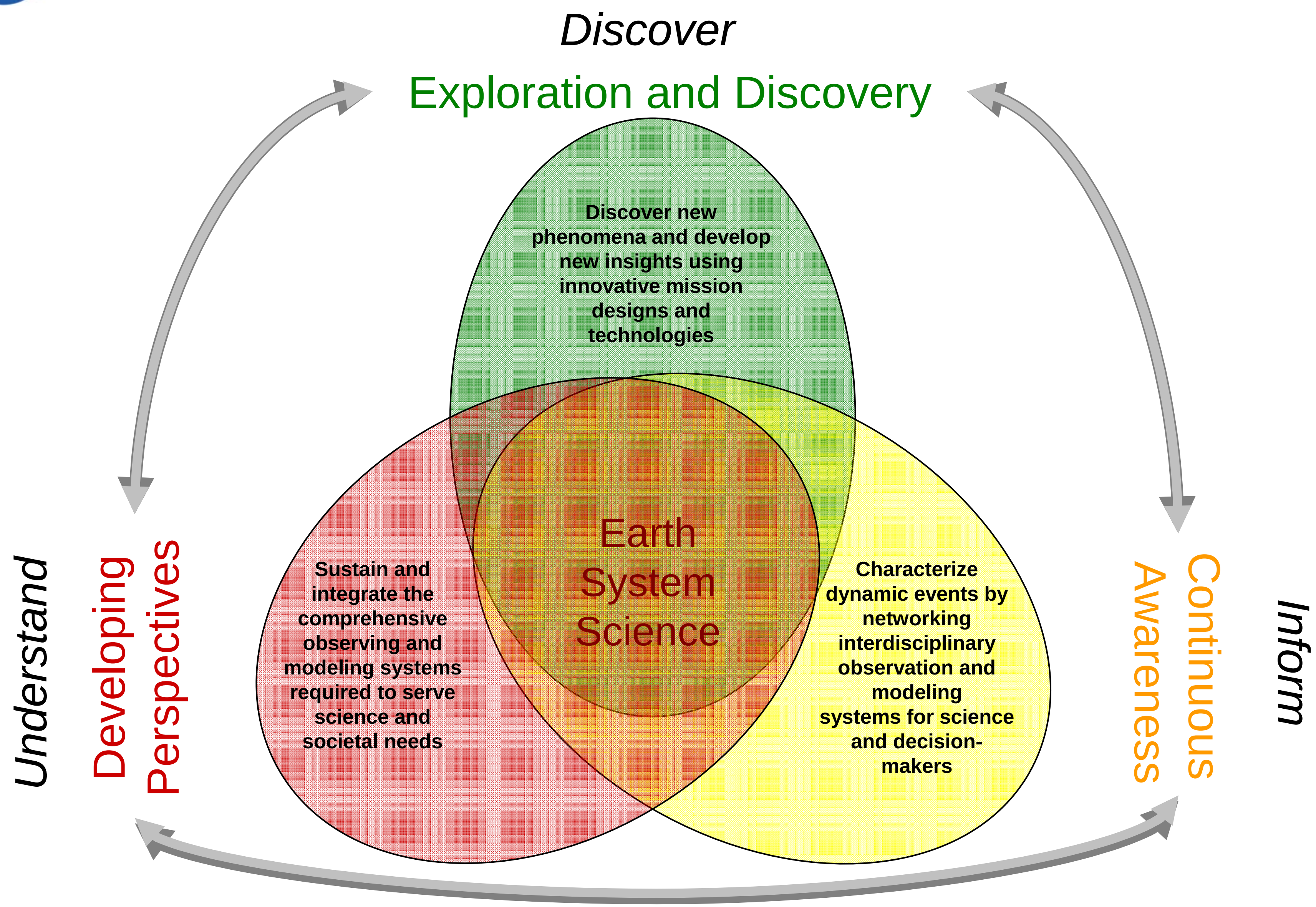
# Roadmap Interdependencies (2 of 2)

Major required infrastructure elements and facilities to support modeling and data management:

- Research and Development systems to observe all key Earth system variables and assimilate information into integrated, interacting models that include each of Earth's major subsystems: oceans, atmosphere, cryosphere, biosphere, and solid Earth
- Earth system information easily accessible via high-bandwidth portal



# Integration of Earth System Science



# Partnerships

- Multiple interagency partnerships through presidential-level initiatives:
  - Climate Change Research (June 2001)
  - Global Earth Observation (July 2003)
    - U.S. Integrated Earth Observation System
  - Collaborative Oceans Research (December 2004)

- Transition important, time-series, Earth-system data records from the research to the operational domain.
  - Global land cover operations through Operational Land Imager on National Polar-Orbiting Operational Environmental Satellite System (NPOESS)
  - Global ocean color, vegetation properties, surface temperature, and atmospheric properties through Visible/Infrared Imager/Radiometer Suite on NPOESS Preparatory Project and then NPOESS

- Bilateral international partnerships:
  - Framework of the Global Earth Observation System of Systems

- Commercial value of Earth observations:
  - Presidential space policy on commercial remote sensing
  - Benefits of competition and feedback of the marketplace

# Sun-Solar System Connection Strategic Roadmap Summary Report

May 22, 2005

# Roadmap Objective

- **National objectives (from the Vision for Space Exploration):**
  - Implement a sustained and affordable human and robotic program to explore the solar system and beyond.
  - Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations.
  - Develop innovative technologies, knowledge, and infrastructure to explore and to support decisions about the destinations for human exploration.
  - Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.
  - Study the Earth system from space and develop new space-based and related capabilities for this purpose.
- **NASA objective:**
  - Explore the Sun-Earth system to understand the Sun and its effects on:
    - Earth
    - Solar system
    - Human explorers
  - Demonstrate technologies that can improve future operational systems.
- **These national and Agency objectives drive the objectives of our science discipline, as described on the following page.**

# Sun-Solar System Connection Objectives

The Sun-Solar System Connection (SSSC) Roadmap is a plan to:

- **Develop the capability to predict space weather by:**
  - Understanding magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms.
  - Understanding the plasma processes that accelerate and transport particles throughout the solar system.
  - Understanding the role of plasma-neutral interactions in nonlinear coupling of regions throughout the solar system.
  - Understanding the creation and variability of magnetic dynamos and how they drive the dynamics of solar, planetary, and stellar environments.
- **Understand the nature of our home by:**
  - Understanding the causes and subsequent evolution of solar activity that affects the Earth’s space climate and environment.
  - Understanding changes in the Earth’s magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects.
  - Understanding the Sun's role as an energy source to the Earth’s atmosphere, particularly the role of solar variability in driving atmospheric and climate change.
  - Applying our understanding of space-plasma physics to the role of stellar activity and magnetic shielding in planetary system evolution and habitability.
- **Safeguard our outward journey by:**
  - Characterizing the environmental extremes that human and robotic explorers will encounter in space.
  - Developing the capability to predict the origin of solar activity and disturbances associated with potentially hazardous space weather.
  - Developing the capability to predict the acceleration and propagation of energetic particles to enable safe travel for human and robotic explorers.
  - Understanding how space weather affects planetary environments in order to minimize risk in exploration activities.

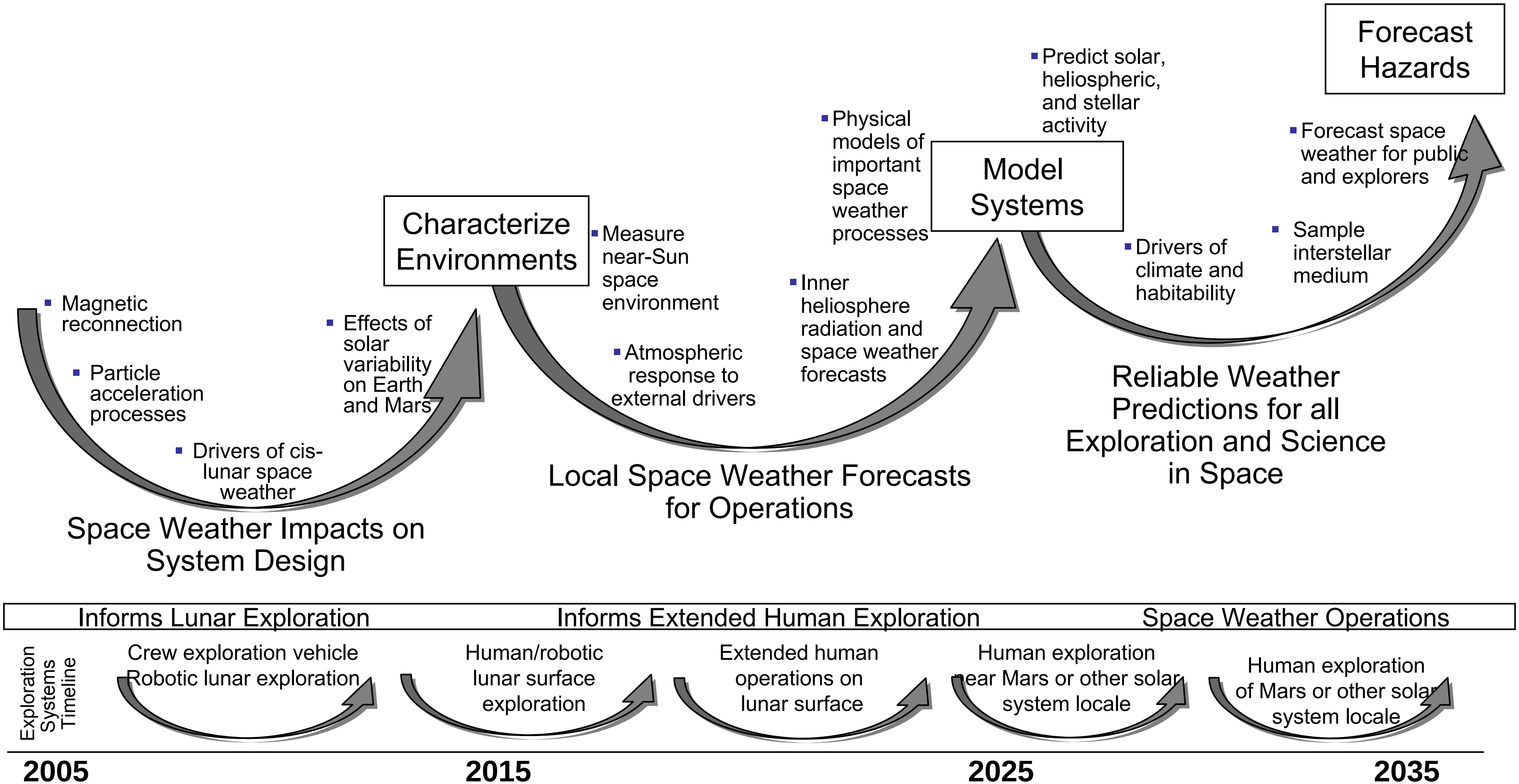
# Sun-Solar System Connection Anticipated Achievements

| Objective | Phase 1: 2005-2015 Characterize | Phase 2: 2015-2025 Model | Phase 3: 2025-Beyond Predict |
|---|---|---|---|
| **Develop the capability to predict space weather** | Characterize magnetic reconnection at the Sun and Earth<br><br>Determine the dominant processes and sites of particle acceleration<br><br>Identify key processes that couple solar and planetary atmospheres to the heliosphere and beyond | Understand the magnetic processes that drive space weather<br><br>Quantify particle acceleration for the key regions of exploration<br><br>Understand non-linear processes and couplings for prediction of the space environment and atmosphere | Predict solar magnetic activity and energy release<br><br>Predict high-energy particle flux throughout the solar system<br><br>Understand the interactions of disparate astrophysical systems |
| **Understand the nature of our home** | Understand how solar disturbances propagate to Earth<br><br>Identify how space weather effects are produced in geospace<br><br>Discover how space plasmas and planetary atmospheres interact<br><br>Identify the effects of solar variability on Earth's atmosphere | Identify precursors of important solar disturbances<br><br>Quantify mechanisms and processes required for geospace forecasting<br><br>Determine how magnetic fields, solar wind, and irradiance affect the habitability of solar system bodies<br><br>Integrate solar variability effects into Earth-climate models | Image activity in other stellar systems<br><br>Provide a scientific basis for continuous forecasting of conditions throughout the solar system<br><br>Determine how stellar activity and plasmas affect planetary formation and evolution governing habitability through time.<br><br>Predict climate change (joint with Earth Science) |
| **Safeguard our outward journey** | Determine extremes of the variable radiation and space environments at Earth, Moon, and Mars<br><br>Now-cast solar and space weather and forecast "all-clear" periods for space explorers near Earth | Characterize the near-Sun source region of the space environment<br><br>Reliably forecast space weather for the Earth-Moon system; make first space weather now-casts at Mars<br><br>Determine Mars atmospheric variability relevant to Exploration activities | Analyze the first direct samples of the interstellar medium<br><br>Provide situational awareness of the space environment throughout the inner solar system<br><br>Reliably predict atmospheric and radiation environment at Mars to ensure safe surface operations |
| | ***Develop technologies, observations, and knowledge systems that support operational systems*** | | |

# Sun-Solar System Scientific Roadmap

| Phase 1 | Phase 2 | Phase 3 |
|---|---|---|
| Sun-Earth-Moon System | Sun-Terrestrial Planets | Sun-Solar System |
| **Characterization of System** | **Modeling of System Elements** | **System Forecasting** |

Joint Sun-Earth Science



# Candidate Mission Sets

**Solar-Terrestrial Probes (STP)** — fundamental science missions:

- Auroral Acceleration Multi-Probe (AAMP)
- Dayside Boundary Constellation (DBC)
- Geospace Electrodynamics Cluster (GEC)
- GEospace Magnetosphere-Ionosphere Neutral Imagers (GEMINI)
- Heliostorm
- Heliospheric Imager and Galactic Observer (HIGO)
- Interstellar Probe (IP)
- Ionosphere-Thermosphere-Mesosphere Coupler (ITMC)
- Ionosphere-Thermosphere-Mesosphere Waves (ITMW)
- Magnetospheric Constellation (MC)
- Magnetospheric Multi-Scale (MMS)
- Magnetic TRAnsition region Probe (MTRP)
- Reconnection and Micro-scale (RAM)
- Sun-Earth Coupling by Energetic Particles (SECEP)
- Stellar Imager (SI)
- Solar Polar Imager (SPI)
- Solar TErrestrial RElations Observatory (STEREO)
- Telemachus

**Living with a Star** — missions to study the effects of space weather:

- Far-Side Sentinels (FS)
- Inner Heliospheric Sentinels (HIS)
- Ionosphere-Thermosphere Imager (ITImager)
- Ionosphere-Thermosphere Storm Probes (ISTP)
- Radiation Belt Storm Probes (RBSP)
- Solar Dynamics Observatory (SDO)

# Candidate Mission Sets

**Explorer Missions (EXP)** — openly competed smaller missions addressing timely scientific investigations:

- Aeronomy of Ice in the Mesosphere (AIM)
- Time History of Events and Macroscale Interactions during Substorms (THEMIS)

**NASA, externally funded, or other mission candidates:**

- Lunar Reconnaissance Orbiter (LRO)
- Mars Aeronomy/Mars Dynamics
- Mars Science Laboratory (MSL)
- Neptune Orbiter (NO)
- Pluto/Kuiper
- Solar-B
- Solar Connection Observatory for Planetary Environments (SCOPE)
- Solar Heliospheric and Interplanetary Environment Lookout for Deep Space (SHIELDS)
- Solar Orbiter
- Solar Probe (SP)
- Solar Sail
- Solar Wind Buoys (SWB)
- Titan Explorer (TE)
- Venus Aeronomy Probe (VAP)

# Sun-Solar System Missions Roadmap

| Phase 1<br>Sun-Earth-Moon System<br>**Characterization of System** | Phase 2<br>Sun-Terrestrial Planets<br>**Modeling of System Elements** | Phase 3<br>Sun-Solar System<br>**System Forecasting** |
|---|---|---|

## Future Mission Candidates

**Solar:**
SDO, Solar-B

**CMEs and Heliosphere:**
STEREO, Sentinels, Solar Sail Demo

**Radiation:**
RBSP, Sentinels

**Geospace Impacts:**
MMS, RBSP, THEMIS, ITSP/ITImager

**Climate Impacts:**
SDO, AIM

**Moon, Mars Awareness:**
LRO, MSL

**Interstellar Boundary:** IBEX

**Inner Boundary:**
Solar Probe

**Solar Processes:**
Solar Orbiter

**Geospace System Impacts:**
GEC, GEMINI, MagCon

**Climate Impacts:**
L1 Earth-Sun, SECEP

**Mars Atmosphere:**
Mars Aeronomy/Mars Dynamics

**Space Weather Stations:**
Heliostorm

**Solar System Space Weather:**
SEPP, Solar Wind Buoys

**Planetary Orbiters:**
Pluto/Kuiper, JPO

**Solar Processes:**
MTRAP, RAM

**Heliospheric Structure & Disturbances:**
HIGO, SPI/Telemachus

**Geospace System Impacts:**
AAMP, ITMC, ITMW

**Solar System Space Weather:**
DBC, FS/Shields

**Planetary Orbiters:**
SCOPE, NO, TE, VAP

**Interstellar Medium:**
Interstellar Probe

**Habitability:**
Stellar Imager

Characterize Environments

Model Systems

Forecast Hazards

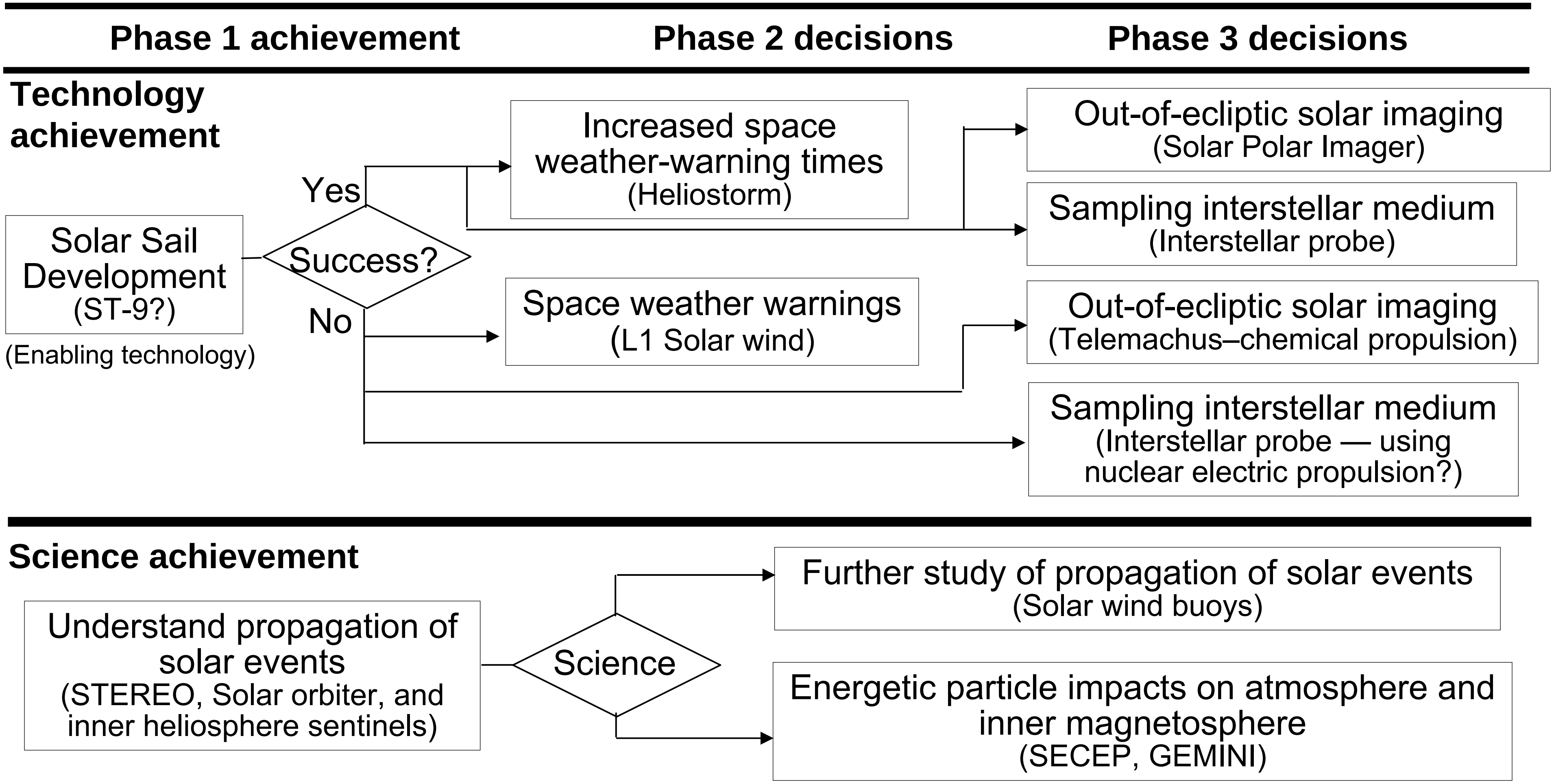
Key:
In Development;
Recommended;

2005 2015 2025 2035

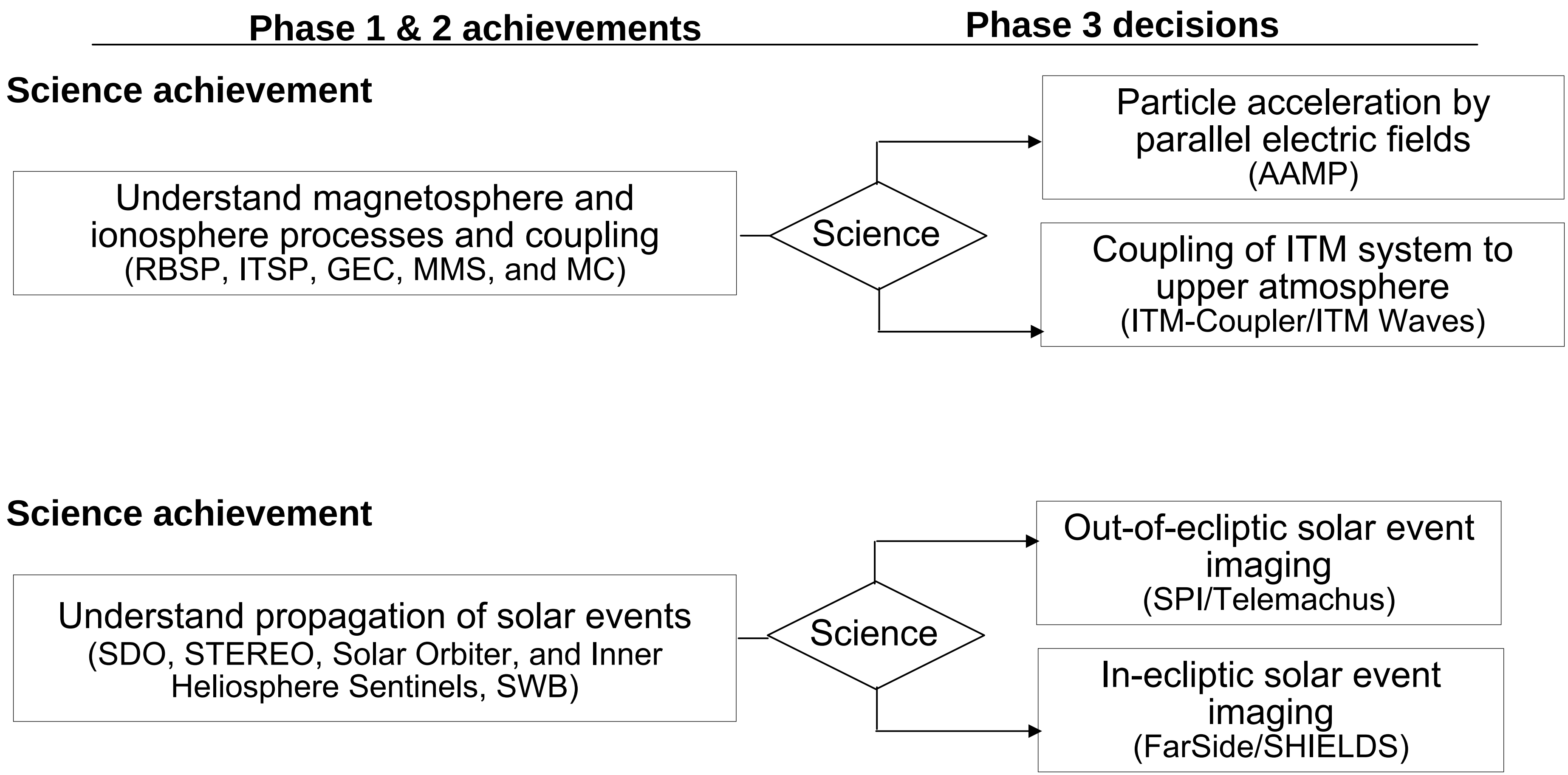
Distributed assets form an evolving sensor web to sample the vast connection from the Sun to planetary environments and beyond

# Roadmap Options and Alternatives (1)

- The roadmap is designed around scientific investigations:
  - Robust and flexible to changes in technology or new discoveries
  - Re-evaluation occurs as new understanding is achieved
  - Explorers advance knowledge to change future missions



# Roadmap Options and Alternatives (2)



# Strategic Roadmap Interdependencies

- **Lunar exploration**
  - Provide:
    - Specifications for materials and technology development
    - Forecast of solar activity and its effect on lunar environment and astronaut productivity
    - Electrostatics and dust-charging processes
  - Benefit from studying the history of solar wind through regolith-core studies
- **Mars exploration**
  - Provide:
    - Space environment specifications for materials and technology development
    - Forecast of solar activity and its effect on the Mars environment and exploration productivity
    - Data on Mars aeronomy, ionosphere, atmospheric loss, and habitability
  - Benefit from platforms for scientific investigations
- **Exploration transportation**
  - Provide:
    - Space environment specifications for materials and technology development
    - Forecast solar activity and its effect on planetary and interplanetary environments
- **Earth systems and dynamics**
  - Provide:
    - Sun/climate connection
    - Societal effects of space weather processes
- **Exploration of the universe**
  - Provide:
    - Understanding of the Sun as a magnetic variable star
    - Understanding of fundamental plasma processes

# Capability Roadmap Interdependencies

- **Answering our science questions will sometimes require measurements at unique vantage points and in non-Keplerian orbits, within and outside the solar system. Capability requirements include:**
  - Cost-effective, high-$\Delta$V propulsion and deep-space power.
    - High-energy power and propulsion — advanced radioisotope thermoelectric generators
    - In-space transportation — solar sails
    - Nanotechnology — carbon-nanotube membranes for solar sails
  - In situ measurements using clusters and constellations, combined with remote sensing (sensor webs); compact, affordable instruments and spacecraft; low-power high-radiation electronics; autonomous maintenance of precision flight formations (important for Stellar Imager mission).
    - Advanced telescopes and observatories
    - Scientific instruments and sensors
  - Low-cost access to space (secondary payloads, sounding rockets)
    - Transformational spaceport
- **Return and ingest large solar system research data sets**
  - Next-generation or follow-on to Deep Space Network
    - Communication and navigation
- **Visualize, analyze, and model space plasmas**
    - Advanced modeling, simulation, and analysis
- **New measurement techniques — compact instrumentation and imagers**
  - Next generation of Sun-Solar System instrumentation
    - Advanced telescopes and observatories
    - Scientific instruments and sensors
    - Nanotechnology

# Paradigm-Shifting Events – Needed Infrastructure and Facilities

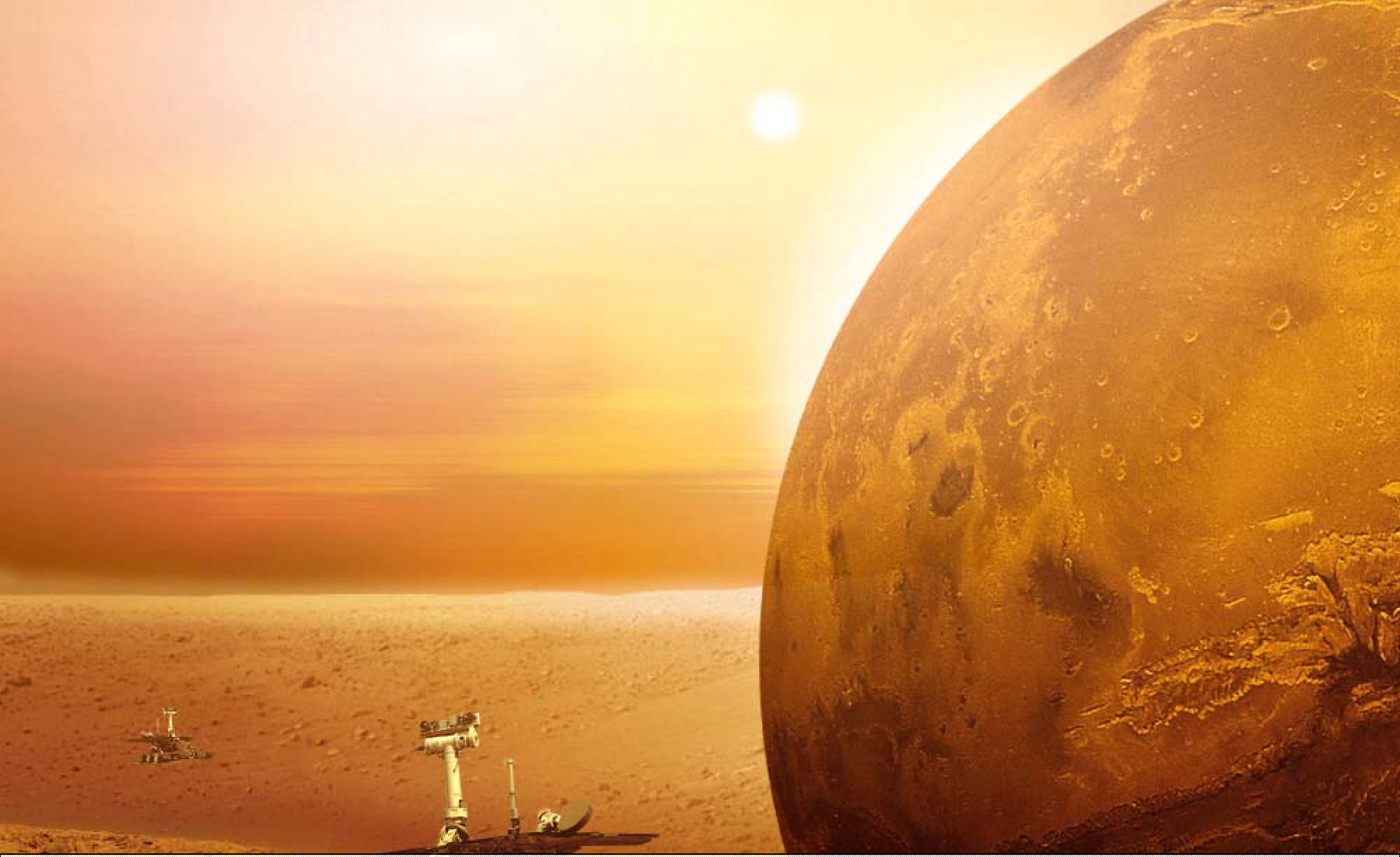
- **Paradigm-shifting events:**
  - Low-cost access to space
    - Major effects on how science experiments can be deployed
    - Revolutionize access to space
- **Infrastructure needs:**
  - Upgrade Deep Space Network to collect more data throughout the solar system
  - Supercomputing
  - Reinforce/revitalize sounding rocket/balloon program
- **Facilities:**
  - Facilities related to the development of science instruments and sensors
- **People:**
  - Develop and maintain skills through a broad range of competed funding opportunities for the scientific community
  - Outreach to attract workers to Earth-Sun system science

# Other Information

**Key cooperation opportunities**

- Partnership Forums:
  - International Living with a Star
  - International Heliophysical Year
  - International Space Environment Service
  - National Space Weather Program

- Science objectives broadly shared with national partners:
  - National Science Foundation
  - National Oceanic and Atmospheric Administration
  - Department of Commerce
  - Department of Defense
  - Department of Transportation
  - Department of Energy
  - Department of the Interior



# Robotic and Human Exploration of Mars
# Strategic Roadmap Summary Report

May 22, 2005

# Roadmap Summary

## From the Vision for Space Exploration:

- Conduct robotic exploration of Mars
  - To search for evidence of life
  - To understand the history of the solar system
  - To prepare for future human exploration
- Conduct human expeditions to Mars
  - After acquiring adequate knowledge about the planet using robotic missions
  - After successfully demonstrating sustained human exploration missions to the Moon

## The activities and investigations described in this roadmap will allow the nation to:

- Determine if Mars was ever habitable and if life ever developed there.
- Understand the climate and the geological evolution of Mars and use that knowledge to better understand the formation and evolution of the terrestrial planets and life in the solar system.
- Make informed decisions about human exploration of Mars and prepare the key capabilities required for safe and effective human missions.
- Deliver elements and infrastructure to Mars to serve as a robotic outpost prior to the arrival of human explorers.
- Undertake the first human expeditions to Mars.

# Roadmap Anticipated Achievements

| Roadmap Goals | Phase 1: 2005-2016 | Phase 2: 2016-2025 | Phase 3: 2025-2035 |
|---|---|---|---|
| **Determine if Mars was habitable and if life developed there** | - Evidence of past water and aqueous processes<br>- Habitable environments<br>- Biosignatures | - Lab study of Mars samples<br>- Subsurface exploration<br>- Intensive search for life | - Intensive search for life<br>- Discovery-driven opportunistic science |
| **Understand the climate of Mars** | - History of water<br>- Atmosphere chemistry and dynamics<br>- Polar-layered deposits | - Long-term climate change<br>- Understand and predict Mars weather | - Discovery-driven opportunistic science |
| **Understand the geological evolution of Mars** | - High-resolution surface mapping<br>- Global/local mineralogy<br>- Surface-atmosphere interactions<br>- Role of water | - *In situ* exploration of compelling sites<br>- Lab study of Mars samples | - Discovery-driven opportunistic science |
| **Prepare for human exploration** | - Search for usable water<br>- Environment, dust, surface characteristics<br>- Atmosphere variability and models<br>- Establish initial telecom infrastructure | - Downselect architectures<br>- Identify and explore candidate landing sites<br>- Confirm resources<br>- Biohazards, toxicity<br>- Validate key | - Establish robotic outpost at preferred human site<br>- Emplace infrastructure (power, ISRU, communications, etc)<br>- Develop key capabilities, build and test |

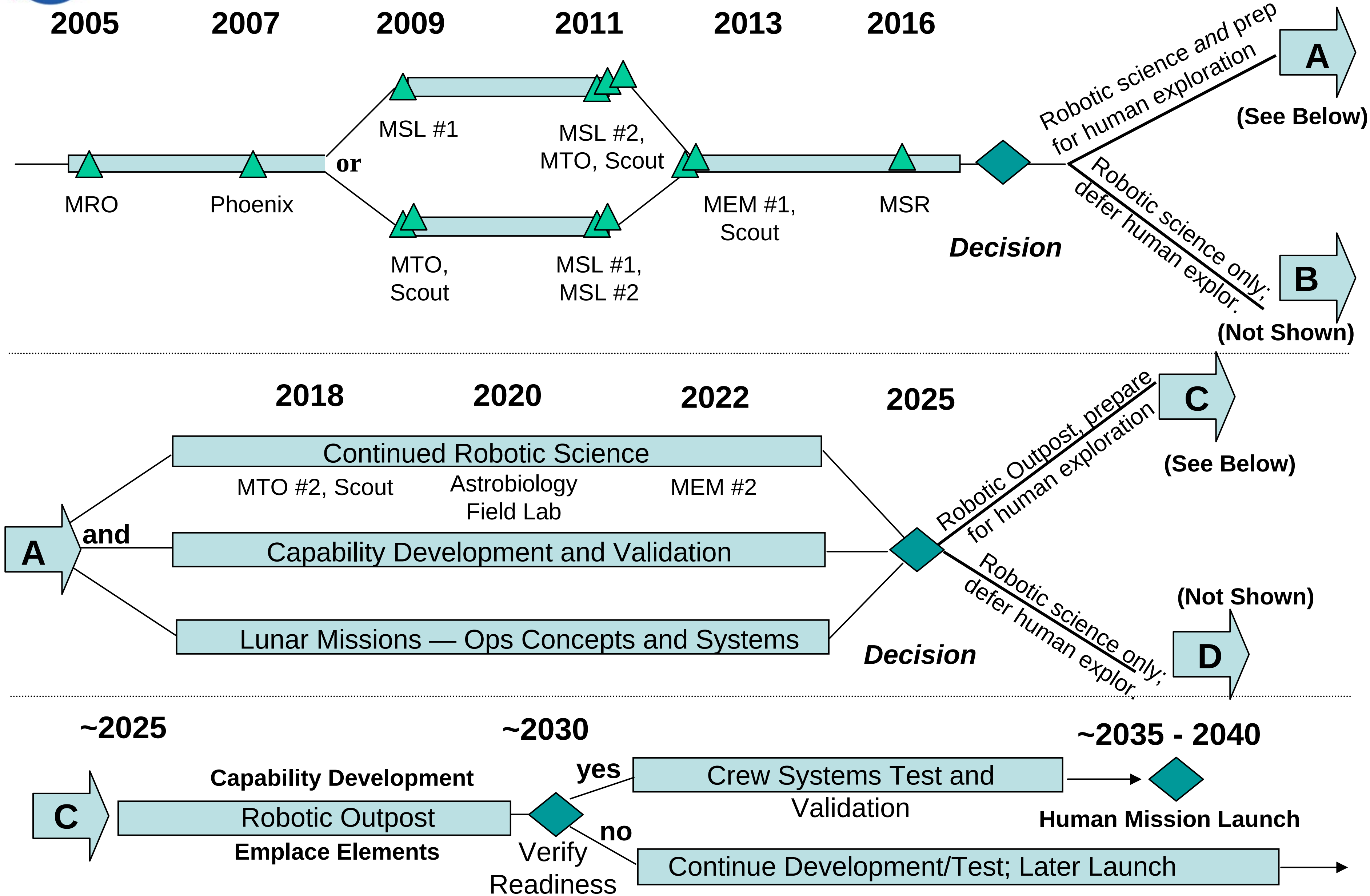
# Phase 1 Mission Recommendations

The robotic missions planned for the coming decade will revolutionize our understanding of Mars and will lay the groundwork for key decisions on future human exploration.

| Opportunity | Mission |
|---|---|
| 2005 | Mars Reconnaissance Orbiter |
| 2007 | Phoenix Lander (Mars Scout) |
| 2009 | Option 1: Mars Science Lab (MSL) #1<br>Option 2: Mars Telecom Orbiter (MTO) #1, plus Mars Scout |
| 2011 | Option 1: MSL #2, plus Mars Scout, plus MTO #1<br>Option 2: MSL #1 plus MSL #2 |
| 2013 | Mars Environmental Mission (MEM) #1, plus Mars Scout |
| 2016 | Mars Sample Return |

NASA For Official Use Only

# Mars Exploration Roadmap Schematic



# Roadmap Options and Alternatives

- As specified in the Vision, the roadmap team focused on defining priorities for a program in which robotic science missions pave the way for human explorers.
- Three natural decision points have been identified that:
  - Define the end of each phase of the roadmap
  - Determine the degree of readiness to proceed to the next series of investments leading to human Mars exploration, and
  - Are informed by discoveries, developments, and many other intermediate decisions.

**End of Phase 1 (~2016):**

- Continue with robotic science and preparation for human exploration, ***or***
- Focus on continued/expanded robotic science; defer or de-emphasize human exploration planning.

  **Decision criteria may include:**
  - Positive indications of usable sub-surface water
  - Indications that human health hazards of long-duration flight and Mars environment are tolerable and can be mitigated
  - Successful development and test of Entry Descent and Landing (EDL) technology and progress in the development of Mars surface nuclear power technology, and
  - Programmatic and budget factors.

# Roadmap Options and Alternatives (cont.)

## End of Phase 2 (~2025):

- Establish a robotic outpost for comprehensive study and emplace infrastructure at potential human landing site(s), ***or***
- Defer further planning for human Mars exploration; continue vigorous robotic exploration program.

**Decision criteria may include:**

- – Successful validation of in situ resource utilization (ISRU) capability for human consumables and propellant production
- – Analysis of first Mars samples, indicating low level of bio- or toxic hazards and continuing to enhance scientific interest
- – Successful "dress rehearsal" of major human mission elements, including entry descent and landing, ISRU, Mars ascent, and planetary protection systems
- – Satisfactory progress toward the development of human life support and habitation, surface power systems, and other key capabilities
- – Successful validation of human exploration systems and concepts on the Moon, and
- – Programmatic, budgetary, and international factors.

# Roadmap Options and Alternatives (cont.)

**Mid-Point and/or End of Phase 3 (~2030-2035):**

- Confirm readiness for human missions; continue emplacement of infrastructure, develop flight systems, and proceed toward human mission launch, ***or***
- Readiness not confirmed; continue capability development and validation, additional flight system development and test.

**Decision criteria may include:**

- Successful validation of key human flight elements
- Development of fission-power system for Mars surface
- Lunar mission demonstration of sustained human exploration systems and concepts
- Risk management
- Identification of active Mars biology in region of robotic outpost, and
- Programmatic, budgetary, and international factors.

# Summary: Key Roadmap Decision Points

**Decisions of architectural significance:**

- Select a new human Mars Design Reference Mission to guide capability investments and future mission planning.
- Select the capability of new heavy-lift launch system and determine development timeframe.
- Determine the feasibility of safely landing large (~40 metric ton) mass elements on the surface of Mars.
- Decide on the preferred method of in situ resource utilization by confirming the presence of usable subsurface water and conducting system tests and validation.
- Identify the Mars mission elements for which validation on the Moon is critical.
- Decide whether to proceed with a fission-reactor system for Mars surface power.
- Determine the nature and degree of human health hazards likely to be encountered on the surface of Mars.
- Determine the need for high-efficiency in-space propulsion based on fission power.
- Confirm the ability of humans to live and work safely in deep space long enough to travel to Mars and return to Earth.

# Strategic Roadmap Interdependencies

- **Lunar Exploration**
  - Systems and concepts for living and working in a planetary environment over an extended period
  - "Mars-like" exploration tools and concepts for use on the Moon
  - Challenge: Joint Moon-Mars program planning to identify requirements and plan for their evolution and infusion into lunar missions in an intelligent manner
- **Exploration Transportation System**
  - Heavy-lift launch capability, ~100 metric tons to low-Earth orbit for crew and cargo
    - Use on a lunar mission before using on Mars
  - Mars descent and ascent systems compatible with human mission masses
  - Possible need for high-efficiency in-space propulsion— to be determined via trade studies as a part of architecture definition and selection
- **International Space Station**
  - Knowledge of human health and performance in space
  - Fully equip and use the International Space Station to conduct physiological and biological research
  - Must support architecture decisions by ~2015
- **Nuclear Systems**
  - Surface power for human missions (~60-100 kW total, possibly in blocks of 20-40 kW)
    - Fission power appears to be the most beneficial implementation
    - Support architecture decisions by 2015; implementation readiness by ~2030
  - Surface power for robotic missions — ensure availability of improved Radioisotope Power Source systems
  - Possible need for fission power to support in-space propulsion

# Capability Roadmap Interdependencies

**Required:**

- Hypersonic parachute to allow landing Mars Sample Return-class assets at high elevations on Mars
- Human-scalable entry, descent, and landing systems capable of safely and precisely landing 40 metric tons
- Heavy-lift launch vehicle (~100 metric tons to low-Earth orbit)
- Robust ~20-40 kW power plant for use on the surface of Mars
- Validation of capabilities needed for human expeditions, using appropriate venue
  - Strategically select opportunities to validate key capabilities in relevant environments
  - Includes Earth analog environments, International Space Station, Moon, and Mars (via robotic missions)

**Possibly Required:**

- In-situ resource utilization for human consumables and propellant production
  - Downselect among candidate methods based on Mars environment knowledge (especially the presence of water), feasibility tests, and architecture studies
- Nuclear propulsion for Mars missions
  - If the cost benefit for Mars is established via trade studies, or if required by other overriding Agency/national needs

# Core Competency and Infrastructure Interdependencies

- **The NASA workforce and national talents must be energized and defined to meet the challenge of Mars exploration.**
  - Survey engineering talent and facilities to establish baseline and identify gaps.
  - Create strategic partnerships among government, industry, and academia.
- **Key areas of emphasis for workforce:**
  - Systems engineering and mission planning
  - Robotics, mobility, instrument/system integration
  - Physiological research
  - Nuclear systems
  - Atmospheric entry and dynamics
  - Planetary science
- **Key areas of emphasis for facilities:**
  - Mars sample receiving, handling, and curation
  - Atmospheric entry simulation and test
  - Nuclear systems testing (in partnership with U.S. Department of Energy)
  - Mars simulation with realistic surface material/environmental properties
  - Physiological/biological testing (radiation, gravity adaptation, etc.)
  - Testing, simulation, and modeling of large-scale complex systems
  - End-to-end in-situ resource utilization system operations in a simulated Mars environment

# Solar System Exploration
# Strategic Roadmap Summary Report

May 22, 2005

# Goals and Objective

## Agency goal from the Vision for Space Exploration:

Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore the moons of Jupiter, asteroids, and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources.

## Roadmap objectives:

1. Learn how the Sun's family of planets and minor bodies originated.
2. Determine how the solar system evolved to its current diverse state, including the origin and evolution of the Earth's biosphere.
3. Explore the space environment to discover potential hazards and search for resources that would enable a permanent human presence.
4. Understand the processes that determine the fate of the solar system and life within it.
5. Determine if there is or ever has been life elsewhere in the solar system.

# Roadmap Summary Science Threads

## How does a planetary system become habitable?

- Habitability in other planetary environments
  - Earth-like planet:
    - Venus-Earth-Mars: Venus is a baked-dry version of Earth; Mars is frozen solid.
    - Venus and Earth are the same size; when did Venus become uninhabitable?
    - Did life ever start and does life still exist on Mars?
  - Blue Moons: Habitable worlds around the giant planets:
    - Europa-Titan-Triton are another warm-to-cold trio.
    - What does organic chemistry on Titan tell us about how life began?
    - Is there life on Europa?
- Habitability in the architectures of planetary systems:
  - How do giant planets determine the arrangement of terrestrial planets near the habitable zone? (Focus on Jupiter and Neptune.)
  - Can giant planets in the habitable zones of other stars have habitable moons?
  - How were the ingredients for life supplied and when?
  - How have impacts affected the survival and evolution of life through time?

(Note: This roadmap does not include Moon/Mars flight missions.)

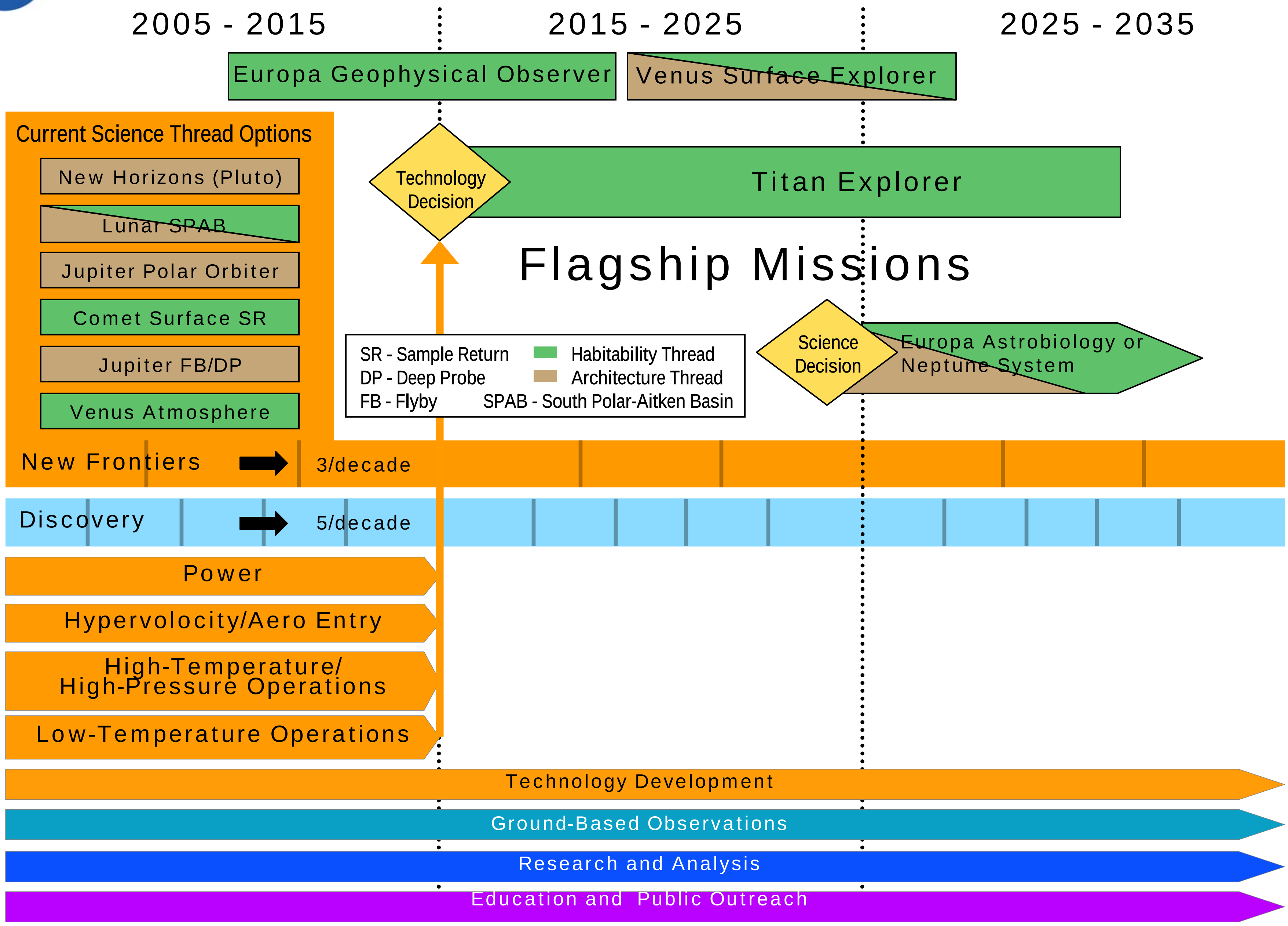
# Roadmap Anticipated Achievements

| Agency Strategic Goal: Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. | | | |
|---|---|---|---|
| **Roadmap Objective** | **Phase 1: 2005-2015** | **Phase 2: 2015-2025** | **Phase 3: 2025 - Beyond** |
| **1: Learn how the Sun's family of planets and minor bodies originated.** | a) Probe the interior of a comet (Deep Impact)<br>b) Return samples of dust from a comet's coma (Stardust)<br>c) Conduct detailed studies near a differentiated and a primitive asteroid (Dawn)<br>d) Conduct detailed studies of a cometary nucleus (Rosetta) | a) Complete the reconnaissance of the solar system with a flyby of Pluto<br>b) Explore the diversity of small bodies with such missions as multiple comet and Trojan/Centaur asteroid flybys<br>c) Study individual small bodies intensively by means of sample-return missions | a) Return cryogenically preserved samples from a comet<br>b) Characterize the diversity of Kuiper Belt objects |
| **2:Determine how the solar system evolved to its current diverse state, including origin and evolution of the Earth's biosphere.** | a) Conduct an intensive orbital study of Mercury to understand how and where it formed (Messenger)<br>b) In conjunction with the expected achievements of Roadmap objective 1, investigate the origin of Earth's water, organics, and other volatiles<br>c) Investigate the earliest life on Earth through studies of Earth's oldest rocks as well as modern analagous microbial communities | a) Land on a Venusian highland to search for granitic or andesitic rocks consistent with an early Earth-like tectonic evolution<br>b) Search for evidence of past massive oceans of water on Venus<br>c) Characterize the past and present population of asteroid impacts to understand their impact on terrestrial planets | a) Drill into various places on Venus to determine the mechanisms by which Venusian highlands were formed<br>b) Return selected geologic samples from Venus |
| **3: Explore the space environment to discover potential hazards and search for resources that would enable a permanent human presence** | a) Complete (>90 percent) the inventory of Near-Earth Objects (NEOs) larger than 1-km in diameter<br>b) Characterize potentially hazardous objects via telescopic remote sensing<br>c) Study remotely the resource potential of a sample of accessible small bodies | a) Precisely track and characterize any near-Earth object that could impact the Earth<br>b) Explore near-Earth asteroid mineralogy in situ to determine resource potential | a) Develop technologies to alter trajectories of large, potential Earth-impacting bodies<br>b) Study an L2 and NEO human-visit capability to understand the need for robotic and piloted extraction of asteroidal resources for use in space and on Earth |

# Roadmap Anticipated Achievements (continued)

| **Agency strategic goal: Conduct robotic exploration across the solar system for scientific purposes and to support human exploration.** | | | |
|---|---|---|---|
| **Roadmap Objective** | **Phase 1: 2005-2015** | **Phase 2: 2015-2025** | **Phase 3: 2025- Beyond** |
| **4: Understand the processes that determine the fate of the solar system and life within it.** | a) Determine the nature of interactions and balance of processes on/in Titan's surface, interior, and atmosphere<br>b) Quantify the nature of changes in Saturn's atmosphere<br>c) Understand the evolution of satellite surfaces and ring structure | a) Study the nature of Pluto's surface and its evolution over time<br>b) Look for clues to the origin of the Pluto-Charon system<br>c) Determine the composition of the surface of a typical Kuiper Belt object and hence understand its origin | a) Determine the range of detailed properties of Kuiper Belt objects<br>b) Quantify the composition and conditions within the giant planets, particularly Jupiter and Neptune<br>c) Determine the origin of Triton's volatiles and the origin of this body's apparent early episode of melting/resurfacing |
| **5: Determine if there is or has ever been life elsewhere in the solar system.** | a) Through the astrobiology program, determine plausible pathways for the origin of life on Earth<br>b) Determine if organics exist on Titan distinct from those made by photochemistry and whether they are accessible for study | a) Determine if material from Europa's subsurface ocean is accessible to a surface or near-surface-drilling study<br>b) Deploy a mobile platform to study the detailed structure and composition of biogenically relevant organics on Titan | a) Determine if evidence of biological activity exists in selected materials samples directly on Europa<br>b) Drill into cryovolcanic flows on Titan to search for organic material that evolved in the presence of liquid water<br>c) Explore for life throughout the outer solar system |

# Solar System Exploration Roadmap



# Roadmap Options and Alternatives

- A budget-balanced portfolio of Discovery, New Frontiers, and Flagship-class missions is the foundation for this roadmap. It also is built on robust research and analysis programs, critical technology developments, supporting ground observations, and education and public outreach.
- Three categories make up the options for flight missions:
  - **Discovery ($300M - $500M)**
    - Open, unrestricted competition to address broad solar system objectives
    - Budget projection supports flying five per decade
  - **New Frontiers ($500M - $800M)**
    - Open competition to address solar system objectives consistent with Decadal Survey recommendations
    - Budget projection supports flying three per decade
  - **Flagship missions ($800M - $1400M or $1400M - $2800M)**
    - Major campaigns to address fundamental questions in solar system exploration consistent with Decadal Survey recommendations
    - Investigations address distant and/or extreme environments
    - Budget projection supports flying two $800-1400M or one $1400-2800M mission(s) per decade

# Roadmap Mission Set Options

- **New Frontiers**
  - Kuiper Belt/Pluto
  - Lunar South Pole Aitken Basin
  - Comet Surface Sample Return
  - Venus Buoyant Station
  - Jupiter Polar Orbiter with Probes
- **Flagship Missions**
  - Europa Geophysical Orbiter
  - Venus Surface Explorer
  - Titan Explorer
  - Europa Astrobiology Lander
  - Titan Orbiter/Lander
  - Neptune Orbiter with Probes
  - Comet Cryo Nucleus Sample Return
  - Venus Sample Return

# Flagship Decision Criteria

- Decision points are influenced by the confluence of three major factors:
  - Scientific priorities and knowledge
  - Technological readiness or capability, and
  - Programmatic considerations.

- Preceding missions influence the destination(s), the campaign architecture, and the approach.

- Selected Discovery and New Frontiers missions can influence other priorities.

- A focused investment in critical technologies and capabilities will enable the missions and dictate the timetable for their implementation.

# Key Roadmap Decisions for Flagships

## 2005 - 2015

Europa Geophysical Orbiter (f)

1

**Decision 1** (2012/2013)
Start the first of two flagship missions for the period (2015-2025).
If the technology is ready, fly Titan Explorer ahead of a Venus Surface Explorer.

## 2015 - 2025

Titan (f) Explorer

Venus (f) Surface Explorer

2018/2019
Start the second of two flagship missions — a Venus Surface Explorer.

(f) = $800M - $1400M
(F)= $1400M - $2800M

## 2025 - 2035

(f) or (F)

Europa Astrobiology

Titan Orbiter/Lander

Neptune Orbiter with Probes

**Comet Cryo Nucleus Sample Return**

Venus Sample Return

2

**Decision 2** ( 2023/2024)
Start a flagship mission in the $1400M to $2800M range.

# Roadmap Technology Interdependencies

- **Highest-priority investments:**
  - Radioisotope Power Source technologies (milliwatts up to 10s to 100s of watts, high efficiency)
  - Technologies for extreme environments:
    - High radiation tolerance (Europa, Jupiter)
    - Very high (Venusian surface) and very low (Titan mid-atmosphere) temperatures
    - Extreme pressure (hundreds of bars: Venus, Jupiter, and Neptune)
    - Atmospheric entry probes for outer planets and Venus (very high heating rates in helium/hydrogen atmosphere for outer planets and high heating rates in carbon dioxide for Venus)

- **Further assessment of the following technology areas:**
  - Closer evaluation of optical communications, ultra-high bandwidth, and ultra-high pressure communication/survival technologies that could enhance and possibly enable deep giant planet probes
  - Further study to determine specific needs for technologies in autonomous systems, science instruments, nanotechnology, or advanced modeling and analysis to enhance solar system exploration missions

# Roadmap Technology Interdependencies

| Technology Links | |
|---|---|
| **Radioisotope Power Source (RPS)** | • Radioisotope power supplies are critical for missions at extreme distances or in extreme environments<br>• Ongoing evaluation of efficient RPS designs (e.g., Stirling cycle rather than Radioisotope Thermoelectric Generator)<br>• Highest-priority critical path item for Europa and future outer-planet missions |
| **Technologies for Extreme Environment**<br>- High Radiation Tolerance | • High-intensity radiation environment around Jupiter (near Europa) poses special problems<br>-Different energy and particle distribution distinct from military applications<br>-Implies need for electronics, structures, and shielding, which can provide a minimum 30-day operation to one lasting many months |
| - Extreme Temperatures<br>•High: 700K<br>•Low: 70-90K | • Extremely high-temperature technologies are needed for Venus atmosphere mission with surface access<br>- Electronics and surface mobility at ~500 degrees Celsius<br>• Extremely low-temperature technologies are needed for Comet Surface Sample Return missions and Titan Explorer |
| - Extreme Pressures<br>•Hundreds of bars | • Missions that require operations at > 100 bars<br>-Deep atmosphere of Neptune (up to one kilobar)<br>-Surface of Venus (90 bars)<br>-Deep atmosphere of Jupiter (100 bars)<br>• Implies special attention to structure and design of surface vehicles and pressure vessels in hazardous environment (hydrogen in outer-planet atmospheres, high-temperature corrosive chemicals in Venus) |
| **Technology for Outer-Planet and Venus Probes** | • Extreme entry velocity/heating rates in hydrogen/helium atmosphere for Jupiter and Neptune probes and very high heating rates in carbon dioxide atmosphere for Venus<br>-Requires extreme environment thermal protection systems and testing in relevant environments<br>• Extreme depth for Venus, Jupiter, and Neptune probe missions<br>-Requires special attention to entry probe design, including pressure vessel structure to deal with $\geq$ 100 bar pressures, and thermal management of sensors, electronics, and batteries<br>-Communications technology needed for data transfer from extreme depths<br>• Aerocapture for a Neptune and Triton Orbiter probe<br>-Requires targeting precision and extreme environments thermal protection system |

# Strategic Roadmap Interdependencies

| Strategic Roadmap | Links |
|---|---|
| **Lunar Robotic and Human Exploration** | Studying solar system processes preserved in lunar surface materials through sample analysis and field studies is critical in understanding the processes under which the solar system developed |
| **Mars Robotic and Human Exploration** | Understanding Mars from both a historical and current perspective is critical to understanding the solar system's development<br>•Understanding the current state and evolution of the Martian atmosphere, surface, and interior<br>•Determining the nature of any habitable environments on Mars and whether life exists or ever existed on Mars |
| **Earth-Like Planets and Habitable Environments** | Studying the giant planets in our solar system and understanding how they affect habitability<br>Studying extrasolar planetary systems and understanding how they become habitable |
| **Exploration Transportation** | Exploring the outer solar system will require longer transit times.To gather more sophisticated science data, instruments will require larger launch mass and volume<br>•Heavy-lift launch for high-mass robotic missions<br>•Precision entry/descent and landing<br>•In-space propulsion<br>•In-space automated rendezvous and docking (depending on design of launch and transfer vehicles)<br>•Pre-deployed surface/orbit assets (fuel, power, instruments, etc.)<br>•Surface ascent/sample return to Earth |

# Strategic Roadmap Interdependencies

| Strategic Roadmap | Links |
|---|---|
| **Sun-Solar System Connection** | Specifying and predicting space weather at solar system destinations and along interplanetary routes. Includes planetary atmospheric state (ascent, aerobraking, aerocapture, descent, landing), ionospheric state (communications, navigation), and energetic radiation morphology and spectral content (reliability of electronics and materials)<br>•Predicting, detecting, and warning of solar and galactic radiation environment<br>•Characterizing upper atmosphere (e.g., Titan, Neptune) for aerocapture<br>•Study magnetosphere around other planetary bodies |
| **Aeronautical Technologies** | Future atmospheric vehicles |
| **Nuclear Systems** | Radioisotope Power Sources are critical for missions at extreme distances or in extreme environments in providing propulsion to and from the outer solar system, communications, and for planetary surface investigations |

# Search for Earth-Like Planets
# Strategic Roadmap Summary

May 22, 2005

# Strategic Roadmap Summary

The Vision statement contains the objective:
**"Conduct advanced telescope searches for Earth-like planets and habitable environments."**

## Objectives:

- Find planets and nearby Earth-like worlds.
- Profile planetary characteristics and biomarkers.
- Understand planet formation and habitability.

## Anticipated accomplishments will answer universal questions:

- What is the number of planets around nearby stars?
- What is the location of the nearest terrestrial planets?
- What are the properties of these planets, including indicators of the existence of life?
- What is the relationship between star formation and planet formation?
- What conditions are needed for the formation of life on planets?
- What evidence is needed to determine if life exists on any planet beyond the Earth?

# Mission Set

**Planet Search and Characterization Missions**

- Space Interferometer Mission (SIM PlanetQuest), 2011: Indirect astrometric detection of planets M > 3 Earth masses
- Terrestrial Planet Finder-Coronagraph (TPF-C), 2014: Direct visible-light detection of planets and planetary systems around other stars
- Terrestrial Planet Finder-Interferometer (TPF-I), 2019: Direct infrared detection and spectroscopy of planets and their atmospheres
- Life Finder: Unambiguous signs of life around nearby stars
- Planet Imager: Multi-pixel resolution images of nearby planets

**Planet Formation and Habitability**

- Stratospheric Observatory for Infrared Astrophysics (SOFIA), 2005: Circumstellar disks, star, and planet formation
- James Webb Space Telescope (JWST), 2011: Formation of planets, stars, and galaxies
- Single Aperture Far Infrared (SAFIR): Formation of planetary systems
- Large Ultraviolet Visible Observatory (LUVO): Chemical evolution of the early universe
- Far Infrared Space Interferometer (FIRSI): High-resolution imaging of proto-planetary disks

**Competed Missions**

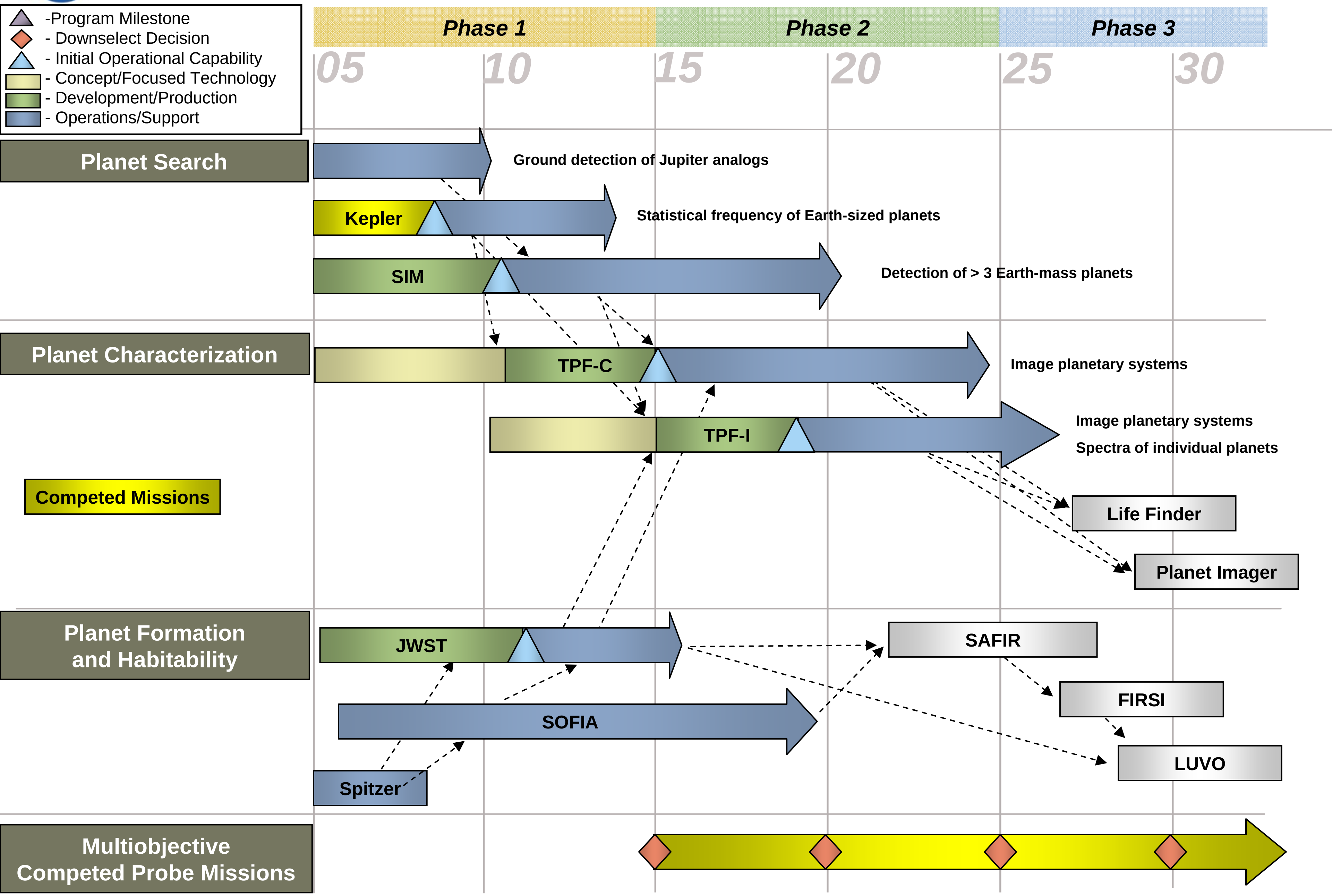
**Address focused science questions through scientist-led investigations**

- Kepler (2008): Accurate determination of the statistical frequency of earth-mass planets around solar-type stars
- Additional Origins probe missions

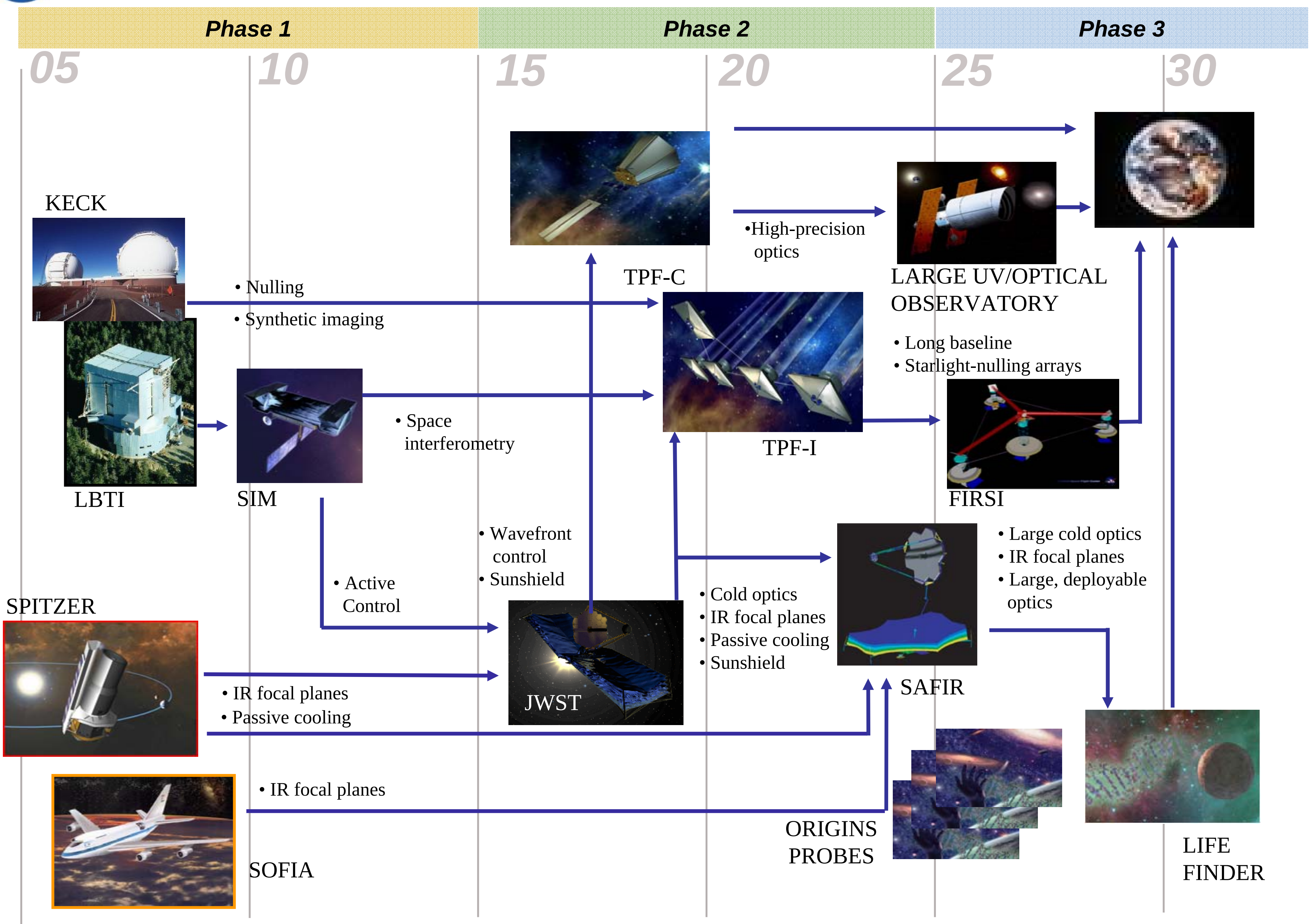
# Roadmap Anticipated Achievements

| *Conduct advanced telescope searches for Earth-like planets and habitable environments* | | | |
|---|---|---|---|
| **Objective** | **Phase 1: 2005-2015** | **Phase 2: 2015-2025** | **Phase 3: 2025 Beyond** |
| **Planet Detection** | a) Measure the frequency of Earth-like planets in a statistically representative sample [COROT, Kepler]<br>b) Radial velocity surveys detect additional Jupiter analogs and nearby planets with mass approaching10 $M_{earth}$ [Ground]<br>c) First SIM planet detections | a) Astrometric detection of M > 3 $M_{earth}$ planets in habitable zone within 10 parsecs [SIM]<br>b) Phometric detection of M > 0.5 $M_{earth}$ planets in stellar habitable zone within 10 parsecs [TPF-C]<br>c) Photometric detection of M > 0.5 $M_{earth}$ planets in stellar habitable zone within 100 parsecs [TPF-I] | a) At least an order-of-magnitude increase in the number of directly detected Earth-like planets [LF]<br>b) Detection of planetary moons in nearby extrasolar system [LF] |
| **Planet Characterization** | a) Measure atmospheric spectra of hot Jupiters seen in transiting events [Ground, HST, Spitzer, JWST]<br>b) Measure spectra of brown dwarfs and giant planets [JWST] | a) Measure planetary masses [SIM]<br>b) Measure radius and surface temperature [TPF-C+TPF-I]<br>c) Detect basic atmospheric composition and presence of clouds [TPF-C+TPF-I]<br>d) Measure gross surface properties [TPF-C, TPF-I]<br>e) Detect new classes of planets [SIM, TPF-C, TPF-I]<br>f) Detect provisional indications of life [TPF-I] | a) Confirmation of biomarkers [LF]<br>b) Search for life on a larger sample of planets<br>c) Search for variety of different metabolisms [LF]<br>d) Improved characterization of planetary systems [LF] |
| **Planet Formation and Habitability** | Observe the formation and evolution of stars, galaxies, and planetary systems from the first luminous objects to debris disks [Spitzer, SOFIA, Herschel, JWST] | Observe the development of conditions for life, from the first release of the chemical elements in the first stars, through the formation of protoplanetary disks, to the chemistry and physics of the solar system [SOFIA, JWST,SAFIR] | a) Observe proto-planetary disks with the resolution needed to detect Earth-like planets in formation [FIRSI]<br>b) Trace the chemical evolution of the early universe [Large UV/Optical Imager] |

# Roadmap Timeline



# Strategic Technology Linkages



# Key Decision – Search Strategy

- Choice of the most effective strategy to find Earth-like planets depends on whether they are common or rare.
  - The Frequency of Earth-like Planets (FEP) is currently unknown
    - Earth-mass planets fall below the detection threshold of ground-based observatories.
  - The Kepler and European COROT missions are designed to accurately determine this parameter within the next five years.
  - For planning, FEP is estimated to be at least 10 percent.

- If FEP is 10 percent or greater, the baseline TPF-C/TPF-I strategy is ideal.
  - Terrestrial Planet Finder-Coronagraph (TPF-C) and Terrestrial Planet Finder-Interferometer (TPF-I) each support roadmap objectives and are scientifically complementary.

- If FEP is close to 100 percent, performance requirements could be relaxed or detailed characterization could be emphasized because a nearby Earth analog becomes very likely.

- Although unlikely, if FEP is significantly less than 10 percent, TPF-C does not have enough target stars within its range to detect a useful sample of Earth-mass planets.

# Other Decisions

- The planned mission sequence builds knowledge acquisition logically, but other mission sequences will achieve the overall objectives.
  - Space Interferometer Mission (SIM) finds planetary systems.
    - Obtains planetary mass, which is a key physical characteristic.
    - Enriches the target set for Terrestrial Planet Finder (TPF) missions and improves their efficiency.
  - Terrestrial Planet Finder-Coronagraph (TPF-C) measures planet size.
  - Terrestrial Planet Finder-Interferometer (TPF-I) obtains planet temperature.

- The plan recognizes the possibility of setbacks
  - For various reasons, the Frequency of Earth-Like Planets (FEP) might not be successfully measured.
  - Earth-massed planets might be extremely rare — FEP ~ 1 percent or fewer.
  - Programmatic or technical difficulties could degrade the SIM.

- The following chart maps out examples of alternate architectures and the events that would trigger their selection.
  - Specific alternate paths, if needed, would be designed and evaluated based on the driving issues.

# Alternate Architectures

## Baseline Architecture

Assumes Earth-like planets occur in about 10 percent of systems — FEP ~ 0.1

## Alternates 1 & 2

1) Earth-like planets are rare FEP ~ 0.01 or COROT and Kepler fail to measure FEP

2) TPF-C fails on-orbit

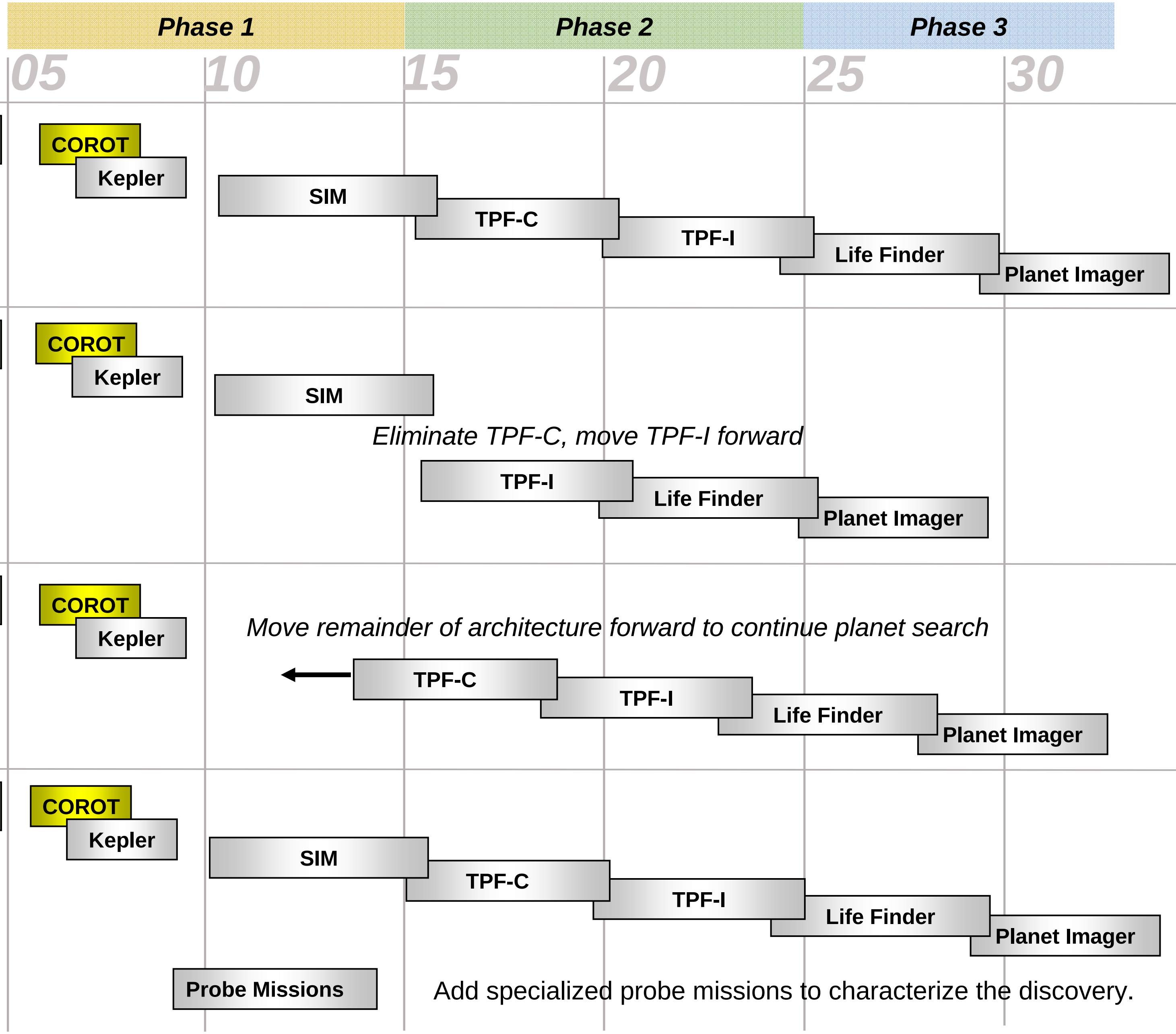
## Alternate 3

No SIM mission — cancellation or early on-orbit failure

## Alternate 4

Early discovery — a nearby Earth-like planet is found by ground-based observations or other means

European



# Roadmap Interdependencies

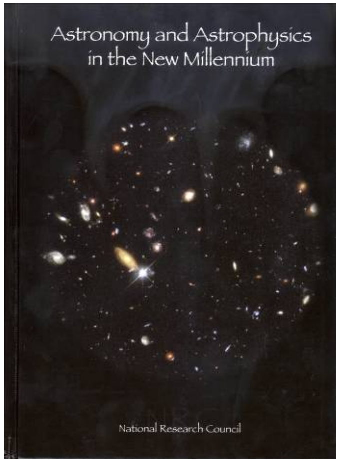
- **Science Requirements**
  - A complete set of astrometric data and visible and infrared measurements are needed to fully characterize the planets in orbit around other stars.
    - Maintaining the development pace of the Space Interferometer Mission (SIM), Terrestrial Planet Finder-Coronagraph (TPF-C), and Terrestrial Planet Finder-Interferometer (TPF-I), is key to this requirement.
- **Capability Requirements**
  - Develop the enabling detectors, optics, structures, formation flight, specialized test facilities, and model-augmented verification capabilities identified in the capability roadmaps.
    - Advanced telescopes and observatories
    - Sensors and scientific instruments
    - Advance simulation and modeling
- **Ground Data, Interagency Partnerships, and International Collaborations**
  - Use ground-based observatories to continue the discovery of planetary systems and carry out target star surveys.
  - Partner with the European Space Agency (ESA)'s active planet-finding program.
    - Explore the possibility of a joint TPF-I-Darwin mission.
  - Continue to advance large, lightweight space optics capabilities using dual-use partnerships with the national security community.
- **Future Workforce Requirements**
  - A strong technical workforce, including scientists and engineers, is critical to the sustainable future of the roadmap initiatives.
    - Encourage undergraduate- and graduate-level training in physical sciences, mathematics, and engineering.

# Other Information

## National Academy of Sciences Decadal Survey:

- Reaffirms the high priority of the Space Interferometer Mission (SIM).
  - Decadal Survey Committees have endorsed SIM.

- Supports the search for planetary systems around nearby stars and the Terrestrial Planet Finder mission as high priorities.



# Universe Exploration
# Strategic Roadmap Summary Report

May 22, 2005

# Universe Exploration Summary

**Vision:** Implement a sustained and affordable human and robotic program to explore the solar system and **beyond.**

## Exploring Beyond

- How did the universe begin?
- How will it end?
- How did we get here?


**Objective:** Explore the universe to understand its **origin, structure, evolution, and destiny.**

## Roadmap achieves the Objective and advances the Vision

***Origin and Destiny:*** **Beyond Einstein Program**
Objective 1: Determine what powered the Big Bang.
Objective 2: Understand the properties of space, time, and matter at the edge of a black hole.
Objective 3: Investigate dark energy, the mysterious force that is driving apart the cosmos.

***Structure and Evolution:*** **Pathways to Life Program**
Objective 4: Follow the growth of the universe from its infancy to the creation of planets, stars, galaxies, and ultimately life itself.

# Universe Exploration Mission Set

**Strategic Observatories**

- Gamma-ray Large Aperture Space Telescope (GLAST), 2007: Jets from black holes and dark matter decay; signatures of first galaxies and stars
- Laser Interferometer Space Antenna (LISA), 2014: Gravitational waves from many sources; how space and time behave around black holes and constrain dark energy
- Constellation-X (Con-X), 2017: Observe matter falling into black holes and address the mysteries of dark matter and dark energy
- Competed Einstein Probes
    - Joint Dark Energy Probe (JDEM)
    - Black Hole Finder Probe (BHFP)
    - Inflation Probe (IP)
- Vision Missions
    - Big Bang Observer (BBO)
    - Black Hole Imager (BHI)

**Pathways to Life**

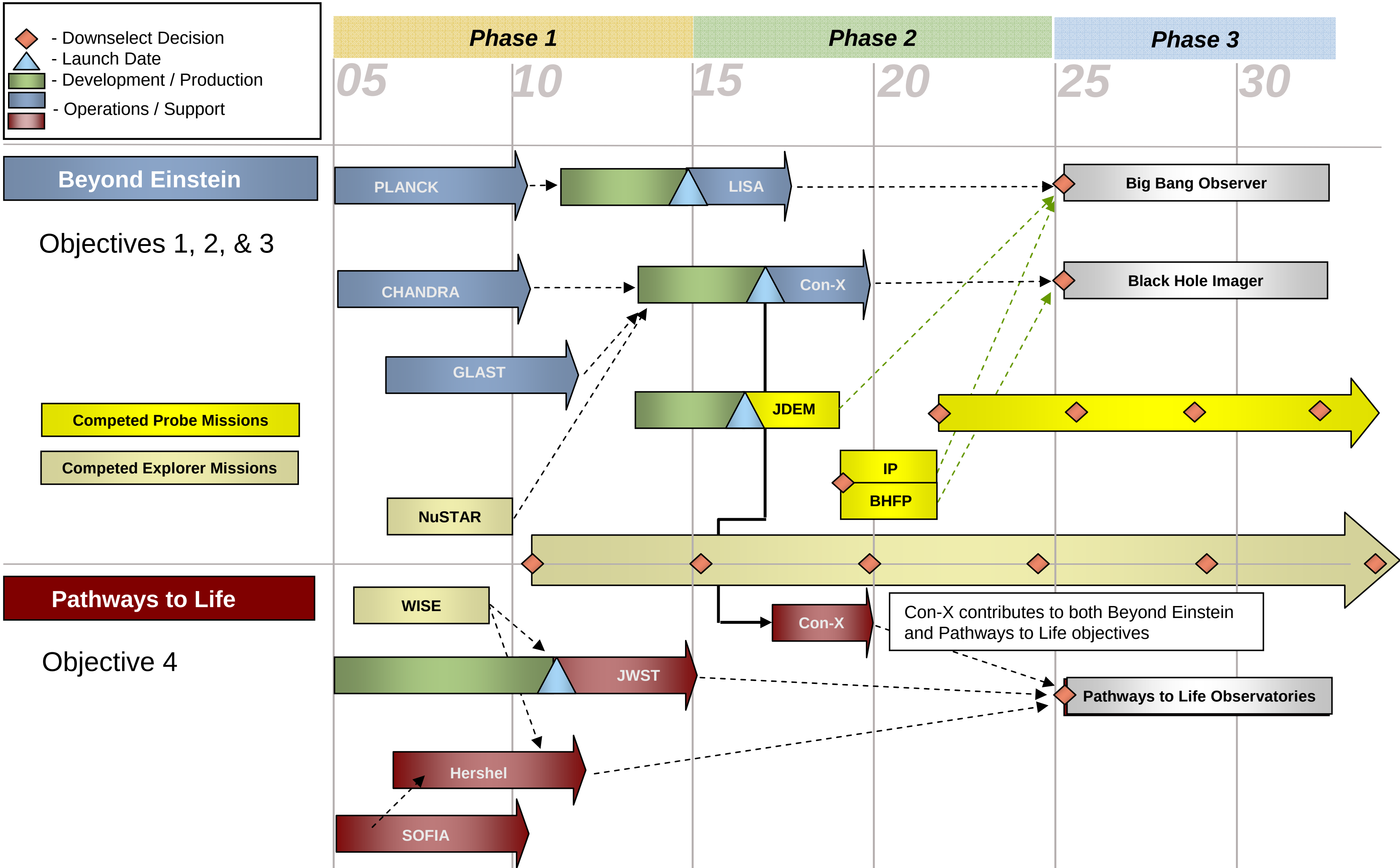
Explorers: Missions linked to universe strategic goals

- Competed Explorer Missions
- Vision Missions
    - Pathways to Life Observatories

# Universe Roadmap Goal Structure

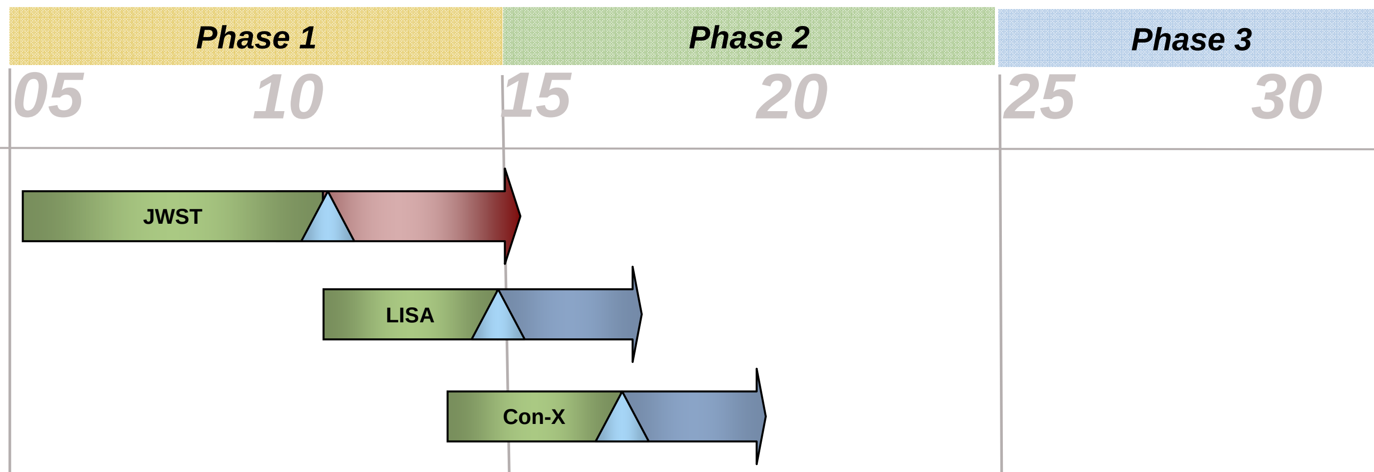
| *Agency Strategic Objective:* Explore the universe to understand its origin, structure, evolution, and destiny | | | |
|---|---|---|---|
| | **Phase 1: 2005-2015** Expected Achievements | **Phase 2: 2015-2025** Expected Achievements | **Phase 3: 2025-beyond** Expected Achievements |
| *Roadmap Objective 1:* **Big Bang** Determine the nature of cosmic Inflation by detecting its signature gravitational waves | a) Investigate alternate approaches for the Inflation Probe WMAP, and suborbital] b) Tighten constraints on inflationary models [Suborbital, WMAP, and Planck] | a) Measure gravitational waves from inflation [Inflation Probe] b) Detect gravitational waves and perhaps radiation from the first picosecond [LISA] | a) Detect all important sources of gravitational waves since the Big Bang, and directly detect quantum effects during inflation. [Big Bang Observer] |
| *Roadmap Objective 2:* **Black Holes** Validate the predictions of Einstein's Theory of General Relativity at the extremes of gravity | a) Observe acceleration processes of jets emerging from black holes [GLAST] b) Determine if General Relativity correctly describes the massive black holes at the centers of galaxies [LISA] | a) Investigate General Relativity close to black holes b) Constrain how black holes evolve [Con-X] c) Determine the number of black holes in the local universe [Black Hole Finder Probe] | a) Directly image matter falling into a black hole [Black Hole Imager] b) Investigate stellar mass black hole formation [Black Hole Observer] |
| *Roadmap Objective 3:* **Dark Energy** Determine the ultimate fate of the universe | a) Measure precise cosmological parameters, such as global curvature [WMAP] b) Ground observations constrain the nature of dark energy [HST and ground observations] | a) Increases precision of cosmic yardsticks [Con-X] b) Measure distance measurements to cosmological black holes [LISA] c) Precisely constrains the nature of dark energy [JDEM] | Measure precise absolute distances to and rates of expansion of one million cosmological binary stars, simultaneously defining both geometry and kinematics of the universe [Big Bang Observer] |
| *Roadmap Objective 4:* **Structure and Evolution:** Determine how the universe grew to contain galaxies, stars, and elements, setting the stage for life | a) Detect hot intergalactic medium (IGM) [Chandra, HST] b) Investigate protostellar disks [HST, Chandra, Spitzer, JWST, SOFIA] c) Characterize the evolution of surface activity of solar-type stars. Understand our "Sun in Time" [Chandra, XMM] | a) Confirm baryon content of hot IGM, and dispersion of heavy elements b) Probe galactic black holes c) Study stellar dynamos and stellar activity [Cox-X] d) Study star formation history [JWST] | a) Map missing baryons in the IGM b) Understand the factors critical to formation of galaxies, stars, planets, and life c) Understand the effects of stellar activity on conditions for emergence of life [Path of Life Observatories] |

# Universe Exploration Timeline



# Key Decisions and Roadmap Options

**Initial Roadmap**




Discoveries, primarily during Phase 2, will inform the direction of research emphasis and mission selection for Phase 3.

| | | |
|---|---|---|
| **Option 1** | **Unexpected detection of a cosmological gravitational wave background by LISA increases priority for the Big Bang Observer.** | Big Bang Observer |
| **Option 2** | **JWST, Constellation-X or other programs discover unexpected objects increasing the priority for Pathways to Life Observatory.** | Pathways to Life Observatories |
| **Option 3** | **Constellation-X and LISA show effects that do not follow the predictions of general relativity and increase the priority for Black Hole Imager.** | Black Hole Imager |

# Capability Roadmap Interdependencies

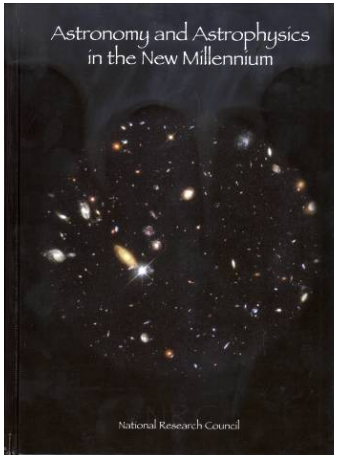
- **Capability Requirements**
  - Develop the enabling detectors, optics, structures, and formation flight capabilities identified in the capability roadmaps:
    - Advanced telescopes and observatories
    - Sensors and scientific instruments
    - Advanced simulation and modeling
  - Develop the requisite facilities required to support future universe exploration initiatives.

# Universe Exploration Requirements

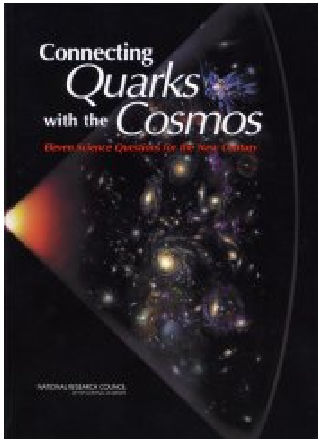
- **Interagency Partnerships**
  - A cornerstone investigation, the Joint Dark Energy Mission, is dependent on a successful partnership between NASA and the Department of Energy.

- **Future Workforce Requirements**
  - A strong technical workforce, including both scientists and engineers, is critical to the sustainable future of the roadmap initiatives.
    - Encourage undergraduate- and graduate-level training in physical sciences, mathematics, and engineering.

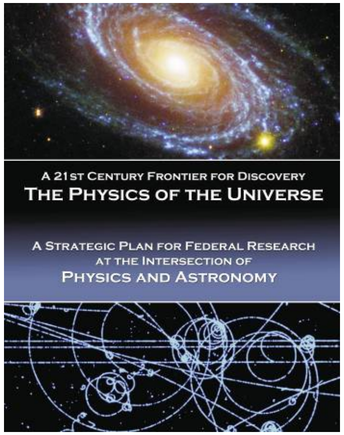
# Universe Exploration - Other Information




The National Academy of Sciences Decadal Survey identified JWST, GLAST, Constellation-X, LISA, and the Black Hole Finder Probe as high priority missions.




The National Academy Committee, chaired by Michael Turner, prepared a science assessment and research strategy for research, giving high priority to the Dark Energy Probe, Inflation Probe, Con-X, and LISA.




The White House Office of Science and Technology Policy (OSTP) Interagency Working Group (DOE, NASA, and NSF) on “The Physics of the Universe” responded to “Quarks to the Cosmos” and gave high priority to inter-agency collaboration.

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# EXPLORATION TRANSPORTATION SYSTEM
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Exploration Transportation System Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on developing a new launch system and crew exploration vehicle to provide transportation to and beyond low Earth orbit. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

Administrator                                                                 Date

MEMBERSHIP ROSTER

# Exploration Transportation System
# Strategic Roadmap Committee

<u>Committee Members</u>

**Craig E. Steidle, Admiral USN (Ret), NASA Exploration Systems Mission Directorate,** ***co-chair***
**James Kennedy, NASA Kennedy Space Center,** ***co-chair***
**Charles Bolden, Jr., General USMC (Ret), TechTrans International, Inc.,** ***co-chair***
John Campbell, NASA Goddard Space Flight Center/Wallops Flight Facility
Edward F. Crawley, Massachusetts Institute of Technology
Peter Diamandis, X-Prize Foundation
Delma Freeman, NASA (retired)
Wes Harris, Massachusetts Institute of Technology
Sydney Michael Hudson, Rolls Royce North American (retired)
Tamara Jernigan, Lawrence Livermore National Laboratory
Dave King, NASA Marshall Space Flight Center
Wayne Littles, NASA (retired)
Max Nikias, University of Southern California
Karen Poniatowski, NASA Space Operations Mission Directorate
Robert Sieck, NASA (retired)

**Mark Borkowski, Directorate Coordinator**
Dana Gould, Advanced Planning and Integration Office Coordinator (LaRC), *Designated Federal Official*

<u>Ex Officio and Liaison</u>

Lynn Cline, NASA Space Operations Mission Directorate
Doug Cooke,NASA Exploration Systems Mission Directorate
Lisa Guerra, NASA Exploration Systems Mission Directorate
Susan Hackwood, Executive Director of the California Council on Science and Technology, liaison with the Education Strategic Roadmap Committee
Colonel Jim Knauf, Secretary of the Air Force, Undersecretary of the Air Force for Launch, National Security Space liaison
Garry Lyles, NASA Exploration Systems Mission Directorate

*Final December23, 2004*
*Updated March 28, 2005*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# NUCLEAR SYSTEMS
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Nuclear Systems Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on utilization of nuclear systems for the advancement of space science and exploration. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

_________________________ ____________________

Administrator Date

MEMBERSHIP ROSTER

# Nuclear Systems Strategic Roadmap Committee

<u>Committee Members</u>

**Craig E. Steidle, Admiral USN (Ret), NASA Exploration Systems Mission Directorate,** ***co-chair***
**Chris J. Scolese, NASA Goddard Space Flight Center,** ***co-chair***
**John F. Ahearne, Sigma Xi Center, Duke University,** ***co-chair***
Doug Allen, Schafer Corporation
Ken Anderson, NASA Goddard Space Flight Center
George Apostolakis, Massachusetts Institute of Technology
Dave Bartine, NASA Kennedy Space Center
Stephen Bowen, NASA Johnson Space Center
Theron Bradley, NASA (retired)
Andy Christensen, Northrop Grumman
Tom Gavin, Jet Propulsion Laboratory
Roger Kasperson, Clark University
Andy Klein, Oregon State
Gerald Kulcinski, University of Wisconsin
Jim Mosquera, Department of Energy
Ted Swanson, NASA Goddard Space Flight Center
Earl Wahlquist, Department of Energy
Ann Whitaker, NASA Marshall Space Flight Center

Perry Bankston, Advanced Planning and Integration Office Coordinator (JPL)
**Victoria Friedensen, NASA Exploration Systems Mission Directorate,** ***Designated Federal Official***
Jason Jenkins, Directorate Coordinator

<u>Ex Officio and Liaison</u>

Dennis Berry, Department of Energy, Sandia National Laboratories
John-Luc Cambier, Air Force Research Laboratory, National Security Space liaison
Don Cobb, Department of Energy, Los Alamos National Laboratory
Bret Drake, NASA Exploration Systems Mission Directorate
Daniel Gauntner, NASA Glenn Research Center
Lisa Guerra, NASA Exploration Systems Mission Directorate
David Hill, Department of Energy, Oak Ridge National Laboratory
James Lake, Department of Energy, Idaho National Laboratory
Gary Martin, NASA Advanced Planning and Integration Office
Ajay Misra, NASA Science Mission Directorate
Joe Nainiger, NASA Glenn Research Center
Curt Niebur, Jet Propulsion Laboratory

Carl Pilcher, NASA Science Mission Directorate
Jeff Rosendhal, NASA (retired), liaison with the Education Strategic Roadmap Committee
Michael Stamatelatos, NASA Safety and Mission Assurance
Eugene Tattini, Jet Propulsion Laboratory
Ray Taylor, NASA Exploration Systems Mission Directorate
Mike Wollman, KAPL, Inc., a Lockheed Martin company

*Final 12/22/04*
*Updated3/31/05*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# ROBOTIC AND HUMAN LUNAR EXPLORATION
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Robotic and Human Lunar Exploration Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on undertaking robotic and human exploration of the Moon to further science and to enable sustained human and robotic exploration of Mars and other destinations. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________

Administrator Date

MEMBERSHIP ROSTER

# Robotic and Human Lunar Exploration Strategic Roadmap Committee

<u>Committee Members</u>

**Craig E. Steidle, Admiral USN (Ret), NASA Exploration Systems Mission Directorate, *co-chair***
**William F. Readdy, NASA Space Operations Mission Directorate, *co-chair***
**Jefferson D. Howell, Jr., General USMC (Ret), Johnson Space Center, *co-chair***
**Thomas P. Stafford, General, USAF (Ret), *co-chair***
CAPT Bruce Abbott, United States Navy, National Reconnaissance Office
Michael Duke, Colorado School of Mines
Mike Hawes, NASA Space Operations Mission Directorate
James Head, Brown University
Milt Heflin, NASA Johnson Space Center
John Horack, NASA Marshall Space Flight Center
Howard McCurdy, American University
Thomas Morgan, NASA Science Mission Directorate
Firouz Naderi, Jet Propulsion Laboratory
Bradford Parkinson, Stanford University
Donald Pettit,NASA Johnson Space Center
R. Edwin Smylie, Grumman (retired)
Paul Spudis, Applied Physics Laboratory
Tom Tate, House of Representatives Committee on Science and Technology (retired)
Jeff Taylor, University of Hawaii
Brenda Ward, NASA Johnson Space Center

**Scott Wilson, Mission Directorate Coordinator, *Designated Federal Official***
Frank Bauer, Advanced Planning and Integration Coordinator

<u>Ex Officio and Liaison</u>

Doug Cooke, NASA Exploration Systems Mission Directorate
Tom Cremins, NASA Space Operations Mission Directorate
Orlando Figueroa, NASA Science Mission Directorate
James Garvin, NASA Chief Scientist
Lisa Guerra, NASA Exploration Systems Mission Directorate
Tom Jasin, NASA Science Mission Directorate
Michael Lembeck, NASA Exploration Systems Mission Directorate
Wendell Mendell, NASA Johnson Space Center
Cassandra Runyon, College of Charleston, liaison with the Education Strategic Roadmap Committee
Charlie Stegemoeller, NASA Johnson Space Center
Richard Vondrak, NASA Goddard Space Flight Center

Jim Watzin, NASA Goddard Space Flight Center
Joe Wood, NASA Advanced Planning and Integration Office

*Final December 17, 2004*
*Updated March 28, 2005*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# AERONAUTICAL TECHNOLOGIES
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Aeronautical Technologies Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on providing advanced aeronautical technologies to meet the challenges of next-generation systems in aviation, for civilian and scientific purposes, in our atmosphere and in the atmospheres of other worlds. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________
Administrator Date

MEMBERSHIP ROSTER

# Aeronautical Technologies
# Strategic Roadmap Committee

Committee Members

**Terry Hertz, NASA Aeronautics Research Mission Directorate, *co-chair***
**Jim Jamieson, The Boeing Company, *co-chair***
Nicholas Altiero, Tulane University
Frank Cappuccio, Lockheed Martin
Randall Friedl, Jet Propulsion Laboratory
Frank Frisbie, Northrop Grumman
Richard Golaszewski, GRA, Incorporated
William Lebegern, Metropolitan Washington Airport Authority
Nancy Levenson, Massachusetts Institute of Technology
John O'Brien, Air Line Pilots Association
Col Stuart Rodgers, Air Force Research Laboratory
Nick Sabatini, Federal Aviation Administration
Roger Wall, FedEx Corporation
Terry Weisshaar, Defense Advanced Research Projects Agency

**Yuri Gawdiak, Mission Directorate Coordinator, *Designated Federal Official***
Vicki Regenie, Advanced Planning and Integration Office Coordinator (JPL)

Ex Officio and Liaison

Rich Christiansen, NASA Glenn Research Center
Tom Edwards, NASA Ames Research Center
Bob Meyer, NASA Dryden Flight Research Center
Jerry Newsom, NASA Langley Research Center
Mary Ann Thompson, Aerospace Foundation, liaison with the Education Strategic Roadmap Committee

*Draft 2/4/05*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# EARTH SCIENCE AND APPLICATIONS FROM SPACE
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Earth Science and Applications from Space Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on research and technology development to advance Earth observation from space, improving scientific understanding, and demonstrating new technologies with the potential to improve future operational systems  Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator.  The remaining Committee members will be appointed by the ADA-SI.  Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration.  Such subcommittees and/or task forces will report their findings and recommendations to the Committee.  However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

_________________________ ___________________

Administrator Date

MEMBERSHIP ROSTER

# Earth Science and Applications from Space Strategic Roadmap Committee

Committee
**Orlando Figueroa, NASA Science Mission Directorate, *co-chair***
**Diane Evans, Jet Propulsion Laboratory, *co-chair***
**Charles Kennel, Scripps Institution of Oceanography, *co-chair***
Waleed Abdalati, Goddard Space Flight Center
Leopold Andreoli, Northrop Grumman Space Technology
Walter Brooks, Ames Research Center
Jack Dangermond, ESRI
William Gail, Vexcel Corporation
Colleen Hartman, National Oceanic and Atmospheric Administration
Christian Kummerow, Colorado State University
Joyce Penner, University of Michigan
Douglas Rotman, Lawrence Livermore National Laboratory
David Siegel, University of California, Santa Barbara
David Skole, Michigan State University
Sean Solomon, Carnegie Institution of Washington
Victor Zlotnicki, Jet Propulsion Laboratory

**Gordon Johnston, Mission Directorate Coordinator, *Designated Federal Official***
Azita Valinia, Advanced Planning and Systems Integration Coordinator

Ex Officio and Liaison
Roberta Johnson, University Corporation for Atmospheric Research, liaison with the Education Strategic Roadmap Committee

*Final December 17, 2004*
*Updated March 28, 2005*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# SUN-SOLAR SYSTEM CONNECTION
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Sun-Solar System Connection Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on exploring the Sun-Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by human explorers. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________

Administrator Date

MEMBERSHIP ROSTER

# Sun-Solar System Connection
# Strategic Roadmap Committee

Committee Members
**Al Diaz, NASA Science Mission Directorate, co-chair**
**Franco Einaudi, NASA Goddard Space Flight Center, co-chair**
**Thomas E. Moore, NASA Goddard Space Flight Center, co-chair**
**Timothy Killeen, National Center for Atmospheric Research, co-chair**
Scott Denning, Colorado State University
Jeffrey Forbes, University of Colorado
Stephen Fuselier, Lockheed Martin
William C. Gibson, Southwest Research Institute
Donald Hassler, Southwest Research Institute
Todd Hoeksema, Stanford University
Craig Kletzing, University of Iowa
Edward Lu, NASA Johnson Space Center
Victor Pizzo, National Oceanic and Atmospheric Administration
James Russell, Hampton University
James Slavin, NASA Goddard Space Flight Center
Michelle Thomsen, Los Alamos National Laboratory
Warren Wiscombe, NASA Goddard Space Flight Center

**Barbara Giles, Mission Directorate Coordinator, *Designated Federal Official***
Azita Valinia, Advanced Planning and Integration Office Coordinator (GSFC)

Ex Officio and Liaison
Donald Anderson, NASA Science Mission Directorate
Alan Shaffer, Office of the Secretary of Defense, Network Information Integration, National Security Space liaison
Richard Fisher, NASA Science Mission Directorate
Rosamond Kinzler, American Museum of Natural History, liaison with Education Strategic Roadmap Committee
Michael Wargo, NASA Exploration Systems Mission Directorate
Mark Weyland, NASA Johnson Space Center

*Final 12/22/04*
*Updated 3/14/05*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# ROBOTIC AND HUMAN EXPLORATION OF MARS
# STRATEGIC ROADMAPPING COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Robotic and Human Exploration of Mars Strategic Roadmapping Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on Mars exploration, including robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future human exploration. The purview of the Committee also includes advice and recommendations on human expeditions to Mars after acquiring adequate knowledge about the planet using these robotic missions and after successfully demonstrating sustained human exploration missions to the Moon. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

## ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

## DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________

Administrator Date

MEMBERSHIP ROSTER

# Robotic and Human Exploration of Mars Strategic Roadmap Committee

## Committee Members

**Alphonso Diaz, NASA Science Mission Directorate, *co-chair***
**Charles Elachi, Jet Propulsion Laboratory, *co-chair***
**A. Thomas Young, Lockheed Martin (retired), *co-chair***
Ray Arvidson, Washington University
Robert Braun, Georgia Institute of Technology
James Cameron, producer/writer/director
Aaron Cohen, Texas A & M University
Steven Dorfman, Hughes Electronics (retired)
Linda Godwin, NASA Johnson Space Center
Noel Hinners, Lockheed Martin (retired)
Kent Kresa, Northrop Grumman
Gentry Lee, Jet Propulsion Laboratory
Laurie Leshin, Arizona State University
Shannon Lucid, NASA Johnson Space Center
Paul Mahaffy, NASA Goddard Space Flight Center
Christopher McKay, NASA Ames Research Center
Sally Ride, University of California, San Diego
Lawrence Soderblom, U.S. Geological Survey
Steven Squyres, Cornell University
Margaret (Peggy) Whitson, NASA Johnson Space Center

**Michael Meyer, Directorate Coordinator, *Designated Federal Official***
Judith Robey, Advanced Planning and Integration Office Coordinator

## Ex Officio and Liaison

Douglas Cooke, NASA Exploration Systems Mission Directorate
Orlando Figueroa, NASA Science Mission Directorate
James Garvin, NASA Chief Scientist
William Gerstenmaier, NASA Johnson Space Center
Michael Hawes, NASA Space Operations Mission Directorate
Daniel McCleese, Jet Propulsion Laboratory
Douglas McCuistion, NASA Science Mission Directorate
Firouz Naderi, Jet Propulsion Laboratory
Michelle Viotti, Jet Propulsion Laboratory, liaison with the Education Strategic Roadmap Committee Liaison
Joseph Wood, NASA Advanced Planning and Systems Integration Office

*December 23, 2004*
*Updated February 4, 2005*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# SOLAR SYSTEM EXPLORATION
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Solar System Exploration Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on conducting robotic exploration across the solar system to search for evidence of life, to understand the history of the solar system, to search for resources, and to support human exploration. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________

Administrator Date

MEMBERSHIP ROSTER

# Solar System Exploration
# Strategic Roadmap Committee

Committee Members
**Orlando Figueroa, NASA Science Mission Directorate, *co-chair***
**G. Scott Hubbard, NASA Ames Research Center, *co-chair***
**Jonathan Lunine, University of Arizona Lunar and Planetary Laboratory, *co-chair***
Andrew B. Christensen, Northrop Grumman
Jerry Chodil, Ball Aerospace (retired)
Ben Clark, Lockheed Martin Astronautics
Greg Davidson, Northrop Grumman
David DesMarais, NASA Ames Research Center
Douglas Erwin, National Museum of Natural History
Wes Huntress, Carnegie Institution of Washington
Torrence V. Johnson, Jet Propulsion Laboratory
Thomas D. Jones, Consultant
Melissa McGrath, NASA Marshall Space Flight Center
Karen Meech, University of Hawaii
John Niehoff, Science Applications International Corporation
Robert Pappalardo, University of Colorado
Ellen Stofan, Proxemy Research, Inc.
Meenakshi Wadhwa, The Field Museum

**Carl Pilcher, Directorate Coordinator, *Designated Federal Official***
Judith Robey, Advanced Planning and Integration Office Coordinator

Ex Officio and Liaison
Andrew Dantzler, NASA Science Mission Directorate
Heidi Hammell, Space Science Institute, Education Roadmap Committee Liaison
Chris Jones, Jet Propulsion Laboratory
Jason Jenkins, NASA Exploration Systems Mission Directorate

*Final 12/22/04*
*Updated 3/4/05*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# SEARCH FOR EARTH-LIKE PLANETS
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Search for Earth-like Planets Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on searching for Earth-like planets and habitable environments around other stars using advanced telescopes. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________
Administrator Date

MEMBERSHIP ROSTER

# Search for Earth-like Planets
# Strategic Roadmap Committee

<u>Committee Members</u>

**Ghassem Asrar, NASA Science Mission Directorate,** ***co-chair***
**Adam Burrows, University of Arizona,** ***co-chair***
**David Spergel, Princeton University,** ***co-chair***
Jerry Chodil, Ball Aerospace (retired)
Tom Greene, NASA Ames Research Center
Maureen Heath, Northrop Grumman Space Technology
John Mather, NASA Goddard Space Flight Center
Victoria Meadows, Jet Propulsion Laboratory
Geoff Marcy, University of California
Frank Martin, Lockheed Martin (retired)
Neil Tyson, American Museum of Natural History
Alycia Weinberger, Observatories of the Carnegie Institution of Washington

**Eric P. Smith, Directorate Coordinator,** ***Designated Federal Official***
Rich Capps, Advanced Planning and Integration Office Coordinator (JPL)

<u>Ex Officio and Liaison</u>

Charles Beichman, Jet Propulsion Laboratory
Mike Devirian, Jet Propulsion Laboratory
Edna Devore, SETI, liaison with the Education Strategic Roadmap Committee
Anne Kinney, NASA Science Mission Directorate
Col Steve Petersen, National Reconnaissance Office, National Security Space liaison

*Final 12/6/04*
*Updated 3/29/05*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# UNIVERSE EXPLORATION
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Universe Exploration Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on exploring our Universe to understand its origin, structure, evolution, and destiny. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________

Administrator Date

MEMBERSHIP ROSTER

# Universe Exploration Strategic Roadmap Committee

Committee Members
**Anne Kinney, NASA Science Mission Directorate, *co-chair***
**Nick White, NASA Goddard Space Flight Center, *co-chair***
**Kathy Flanagan, Massachusetts Institute of Technology, *co-chair***
Chuck Bennett, NASA Goddard Space Flight Center
Craig Hogan, University of Washington
Steve Kahn, Stanford University, Stanford Linear Accelerator Center
Rene Ong, University of California, Los Angeles
Sterl Phinney, California Institute of Technology
Ron Polidan, Northrop Grumman Space Technology
Michael Shull, University of Colorado
Bob Stern, Lockheed Martin
Michael Turner, National Science Foundation
Jakob van Zyl, Jet Propulsion Laboratory

**Michael Salamon, Mission Directorate Coordinator, *Designated Federal Official***
Rich Capps, Advanced Planning and Integration Office Coordinator (JPL)

Ex Officio and Liaison
Louis Barbier, NASA Goddard Space Flight Center
Roy Gould, Harvard Center for Astrophysics, liaison with the Education Roadmap Committee
Steve Maran, American Astronomical Society
Colonel Steve Petersen, National Reconnaissance Office, National Security Space liaison

*Final 12/17/04*
*Updated 2/3/05*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# SPACE SHUTTLE
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Space Shuttle Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on returning the Space Shuttle to flight, completing assembly of the International Space Station, and safely transitioning from the Space Shuttle to a new exploration transportation system. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

_________________________ ____________________

Administrator Date

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# INTERNATIONAL SPACE STATION
# STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA International Space Station Strategic Roadmap Committee (the "Committee"), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on completing assembly of the International Space Station and focusing research on supporting space exploration goals, with emphasis on understanding how the space environment affects human health and capabilities, and developing countermeasures. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation's space policy.
2. Members will be appointed for a 15-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 15-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 15 months are estimated to be $400,000 including 0.7 work years of staff support.

DURATION

The Committee shall terminate 15 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

__________________________ ____________________

Administrator Date

MEMBERSHIP ROSTER

# International Space Station
# Strategic Roadmap Committee

<u>Committee Members</u>
**Mark Uhran, NASA Space Operations Mission Directorate, *co-chair***
**Robert Cabana, NASA Johnson Space Center, *co-chair***
**Thomas C. Betterton, Admiral USN (Ret), Naval Postgraduate School, *co-chair***
John-David Bartoe, NASA Johnson Space Center
William Bastedo, Booz Allen Hamilton
Jon Bryson, Aerospace Corporation (retired)
Nick Kanas, University of California at San Francisco
Terri Lomax, NASA Exploration Systems Mission Directorate
Ronald Merrell, Virginia Commonwealth University
Charles Oman, Massachusetts Institute of Technology
Jeffrey Sutton, National Space Biomedical Research Institute
Charles Walker, Boeing Aerospace Corporation

**Michele Gates, Directorate Coordinator**
Stacey Edgington, Advanced Planning and Integration Office Coordinator, *Designated Federal Official*

<u>Ex Officio and Liaison</u>
Michael Lembeck, NASA Exploration Systems Mission Directorate
Edward Lu, NASA Johnson Space Center
Marlene MacLeish, Morehouse School of Medicine, liaison with Education Strategic Roadmap Committee
Richard Williams, NASA Chief Medical Officer

*Final January 24, 2005*
*Updated February17, 2005*

# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
# CHARTER OF THE
# EDUCATION STRATEGIC ROADMAP COMMITTEE

## ESTABLISHMENT AND AUTHORITY

The NASA Administrator hereby establishes the NASA Education Strategic Roadmap Committee (the “Committee”), having determined that it is in the public interest in connection with the performance of Agency duties under the law, and with the concurrence of the General Services Administration, pursuant to the Federal Advisory Committee Act (FACA), 5 U.S.C. App. §§ 1 et seq.

## PURPOSE AND DUTIES

1. The Committee will draw on the expertise of its members and other sources to provide advice and recommendations to NASA on using NASA missions and other activities to inspire and motivate the nation’s students and teachers, to engage and educate the public, and to advance the nation’s scientific and technological capabilities. Recommendations to be provided by the Committee will help guide Agency program prioritization, budget formulation, facilities and human capital planning, and technology investment.
2. The Committee shall function solely as an advisory body and will comply fully with the provisions of the FACA.
3. The Committee reports to the Associate Deputy Administrator for Systems Integration (ADA-SI) and to the Administrator.

## MEMBERSHIP

1. The Committee co-chair(s) will be appointed by the Administrator. The remaining Committee members will be appointed by the ADA-SI. Membership will be selected to assure a balanced representation of expertise and points of view within the government, academia, and private industry in scientific and technological areas relevant to the Nation’s space policy.
2. Members will be appointed for a 21-month term, renewable at the discretion of the ADA-SI. However, members serve at the discretion of the ADA-SI.

## SUBCOMMITTEES AND TASK FORCES

Subcommittees and/or task forces may be established to conduct special studies requiring an effort of limited duration. Such subcommittees and/or task forces will report their findings and recommendations to the Committee. However, if the committee is terminated, all subcommittees and/or task forces will terminate.

ADMINISTRATIVE PROVISIONS

1. The Committee will meet approximately three to four times during a 21-month period. Meetings will be open to the public unless it is determined that the meeting, or a portion of the meeting, will be closed in accordance with the Government in the Sunshine Act, or that the meeting is not covered by FACA.
2. The Executive Secretary of the Committee will be appointed by the ADA-SI and will serve as the Designated Federal Official.
3. The Advanced Planning and Integration Office will provide staff support and operating funds for the Committee and is responsible for reporting requirements of section 6(b) of the FACA.
4. The operating costs for its expected duration of 21 months are estimated to be $500,000 including 1.0 work years of staff support.

DURATION

The Committee shall terminate 21 months from the date of this charter unless terminated before that date or subsequently renewed by the NASA Administrator.

___________________________ ____________________
Administrator Date

MEMBERSHIP ROSTER

# Education Roadmap Committee

Committee

**Adena Williams Loston, NASA Chief Education Officer, *co-chair***
**Julian Earls, NASA Glenn Research Center, *co-chair***
**France A. Córdova, University of California, Riverside, *co-chair***
Edna DeVore, SETI Institute
Roy Gould, Harvard Center for Astrophysics
Susan Hackwood, California Council on Science and Technology
Heidi Hammel, Space Science Institute
Roberta Johnson, University Corporation for Atmospheric Research
Wayne C. Johnson, Hewlett-Packard
Douglas R. King, St. Louis Science Center
Rosamond Kinzler, American Museum of History
Lt. Col. Timothy Lea, National Security Space
Marlene MacLeish, Morehouse University
Jeff Rosendhal, NASA (retired)
Cassandra Runyon, College of Charleston
Mary Anne Thompson, Aerospace Education Foundation
Michelle Viotti, Jet Propulsion Laboratory

**Shelley Canright, Directorate Coordinator, *Designated Federal Official***
Ashley Stockinger, Advanced Planning and Integration Office Coordinator

Ex Officio and Liaison

Bill Anderson, NASA Education Division
Larry Bilbrough, NASA Education Division
Katie Blanding, NASA Education Division
Larry Cooper, NASA Education Division
Jason Freeman, NASA Education Division
Angie Johnson, NASA Education Division
Mayra Montrose, NASA Exploration Systems Division
Nitin Naik, NASA Assistant Chief Technology Officer
Melissa Riesco, NASA Office of Human Capital Management
Carla Rosenberg, NASA Education Division
James Stofan, NASA Education Division
Ming-Ying Wei, NASA Education Division

Staff

*(as identified)*

Acronym List

| | |
|---|---|
| AAMP | Auroral Acceleration Multi-Probe |
| AIM | Aeronomy of Ice in the Mesosphere |
| AOA | Analysis of Alternative |
| APIO | Advanced Planning and Integration Office |
| ATM | Air Traffic Management |
| ATS | Application Technology Satellite |
| BBO | Big Bang Observer |
| Bio | Biological |
| BHFP | Black Hole Finder Probe |
| BHI | Black Hole Imager |
| CENR | Committee on Environment and Natural Resources |
| CEV | Crew Exploration Vehicle |
| CFD | Computational Fluid Dynamics |
| CNS | Communication, Navigation, and Surveillance |
| CCSP | Climate Change Science Program |
| CCTP | Climate Change Technology Program |
| Con-X | Constellation X |
| COROT | Convection, Rotation and Planetary Transits |
| CRM | Capability Roadmap |
| DBC | Dayside Boundary Constellation |
| DFO | Designated Federal Official |
| DOE | U.S. Department of Energy |
| DP | Deep Probe |
| ECLSS | Environmental Control and Life Support Systems |
| EDL | Entry, Descent, and Landing |
| EELV | Evolved Expendable Launch Vehicle |
| ELV | Expendable Launch Vehicle |
| EME | Electromagnetic Effects |
| EPO | Education and Public Outreach |
| ESA | European Space Agency |
| ESMD | Exploration Systems Mission Directorate |
| E-STOL | Extreme Short Takeoff and Landing |
| EVA | Extra-Vehicular Activity |
| FAA | Federal Aviation Administration |
| FACA | Federal Advisory Committee Act |
| FB | Flyby |
| FEP | Frequency of Earth-Like Planets |
| FGDC | Federal Geographic Data Committee |
| FIRSI | Far-Infrared Space Interferometer |
| FS | Far-Side Sentinels |
| G | Gravity |
| GEC | Geospace Electrodynamics Cluster |
| GEMINI | GEospace Magnetosphere-Ionosphere Neutral Imagers |
| GEO | Group on Earth Observations |

| | |
|---|---|
| GLAST | Gamma-ray Large Area Space Telescope |
| GOS | Geospatial One-Stop |
| GPM | Global Precipitation Measurement |
| GRC | Glenn Research Center |
| HEO | High-Earth Orbit |
| HIGO | Heliospheric Imager and Galactic Observer |
| HST | Hubble Space Telescope |
| IFR | Instrument Flight Rules |
| IGM | Intergalactic Medium |
| IHS | Inner Heliospheric Sentinels |
| IOC | Initial Operational Capability |
| IP | Inflation Probe |
| IP | Interstellar Probe |
| IPCC | Intergovernmental Panel on Climate Change |
| IR | Infrared |
| ITSP | Ionosphere-Thermosphere Storm Probes |
| ISRU | In Situ Resource Utilization |
| ISS | International Space Station |
| ITAR | International Traffic in Arms Regulations |
| ITImager | Ionosphere-Thermosphere Imager |
| ITMC | Ionosphere-Thermosphere-Mesosphere Coupler |
| ITMW | Ionosphere-Thermosphere-Mesosphere Waves |
| IWGEO | Interagency Working Group on Earth Observations |
| JDEM | Joint Dark Energy Mission |
| JIMO | Jupiter Icy Moons Orbiter |
| JPO | Jupiter Polar Orbiter |
| JWST | James Webb Space Telescope |
| KBO | Kuiper Belt Object |
| KSC | Kennedy Space Center |
| LCDM | Landsat Continuity Data Mission |
| LEAG | Lunar Exploration Analysis Group |
| LEO | Low Earth Orbit |
| LF | Life Finder |
| LISA | Laser Interferometer Space Antenna |
| LRO | Lunar Reconnaissance Orbiter |
| LUVO | Large Ultraviolet Visible Observatory |
| LV | Launch Vehicle |
| ManPADS | Man Portable Air Defense System |
| MC | Magnetospheric Constellation |
| MMS | Magnetospheric Multi-Scale |
| MSFC | Marshall Space Flight Center |
| MSL | Mars Science Laboratory |
| MSR | Mars Sample Return |
| MT | Metric Ton |
| MTRAP | Magnetic Transition Region Probe |
| Nano | Nanotechnology |

| | |
|---|---|
| NAS | National Airspace System |
| NavCom | Navigation and Communications |
| NEO | Near-Earth Object |
| NEP | Nuclear Electric Propulsion |
| NEPA | National Environmental Policy Act |
| NO | Neptune Orbiter |
| NPOESS | National Polar-Orbiting Environmental Satellite System |
| NSF | National Science Foundation |
| NSTC | National Science and Technology Council |
| NTP | Nuclear Thermal Propulsion |
| OCO | Orbiting Carbon Observatory |
| OEP | Operational Evolution Plan |
| OLI | Operational Land Imager |
| OSTM | Ocean Surface Topography Mission |
| OSTP | White House Office of Science and Technology Policy |
| R&A | Research and Analysis |
| RAM | Reconnection and Micro-Scale |
| RBSP | Radiation Belt Storm Probes |
| R&D | Research and Development |
| RIA | Runway Independent Aircraft |
| RPS | Radioisotope Power Source |
| RTG | Radioisotope Thermoelectric Generator |
| SAFIR | Single Aperture Far Infrared |
| SAR | Synthetic Aperture Radar |
| SCOPE | Solar Connection Observatory for Planetary Environments |
| SEP | Solar-Electric Propulsion |
| SCOPE | Solar Connection Observatory for Planetary Environments |
| SDO | Solar Dynamics Observatory |
| SHIELDS | Solar Heliospheric and Interplanetary Environment Lookout for Deep Space |
| SI | Stellar Imager |
| SIM | Space Interferometry Mission |
| SNDR | Subcommittee on Natural Disaster Reduction |
| SOFIA | Stratospheric Observatory for Infrared Astronomy |
| SP | Solar Probe |
| SPAB | South Pole Aitken Basin |
| SECIP | Sun-Earth Coupling by Energetic Particles |
| SPI | Solar Polar Imager |
| SR | Sample Return |
| SRM | Strategic Roadmap |
| SRTM | Shuttle Radar Topography Mission |
| SRC | Strategic Roadmap Committee |
| SSSC | Sun-Solar System Connection |
| SSE | Solar System Exploration |
| SST | Super Sonic Transport |
| STERO | Solar-Terrestrial Relations Observatory |

| | |
|---|---|
| SWB | Solar Wind Buoys |
| SWIM | System Wide Integrity Management |
| TAF | Terminal Area Forecast |
| TE | Titan Explorer |
| THEMIS | Time History of Events and Macroscale Interactions during Substorms |
| TPF | Terrestrial Planet Finder |
| TPF-C | Terrestrial Planet Finder-Coronagraph |
| TPF-I | Terrestrial Planet Finder-Interferometer |
| TRL | Technology Readiness Levels |
| TPS | Thermal Protection System |
| UAV | Unmanned Aerial Vehicle |
| USWRP | U.S. Weather Research Program |
| UV | Ultraviolet |
| VAP | Venus Aeronomy Probe |
| VIIRS | Visible/Infrared Imager/Radiometer Suite |
| WMAP | Wilkinson Microwave Anisotropy Probe |
| WMO | World Meteorological Organization |
| WSSD | World Summit on Sustainable Development |
| Wx | Weather |
| XMM | X-Ray Multi-Mirror |

**Contact List**

Please contact the following individuals for more information:

**Strategic Roadmap Committees**

Dr. Marc Allen, Team Lead
(202) 358-0733
marc.allen@nasa.gov

| Committee | Designated Federal Official | Phone | Email |
|---|---|---|---|
| Robotic and Human Lunar Exploration | Scott Wilson | (202) 358-3924 | Scott.wilson-1@nasa.gov |
| Robotic and Human Exploration of Mars | Dr. Michael Meyer | (202) 358-0307 | Michael.a.meyer@nasa.gov |
| Solar System Exploration | Dr. Carl Pilcher | (202) 358-0291 | Carl.b.pilcher@nasa.gov |
| Search for Earth-like Planets | Dr. Eric P. Smith | (202) 358-2439 | Eric.p.smith@nasa.gov |
| Exploration Transportation | Dana Gould | (757) 864-7747 | Dana.c.gould@nasa.gov |
| Universe Exploration | Dr. Michael Salamon | (202) 358-0441 | Michael.h.salamon@nasa.gov |
| Earth Science and Applications from Space | Dr. Gordon Johnston | (202) 358-4685 | Gordon.johnston@nasa.gov |
| Sun-Solar System Connection | Dr. Barbara Giles | (202) 358-1762 | Barbara.giles@nasa.gov |
| Aeronautical Technologies | Yuri Gawdiak | (202) 358-1853 | Yuri.o.gawdiak@nasa.gov |
| Nuclear Systems | Victoria Friedensen | (202) 358-1916 | Victoria.p.friedensen@nasa.gov |

**Capabilities Roadmap Teams**

Rita Willcoxon, Team Lead
(321) 867-7771
rita.g.willcoxon@nasa.gov

| Roadmap | Expert | Phone | Email |
|---|---|---|---|
| High Energy Power and Propulsion | Joe Naniger | 216-977-7103 | joseph.j.nainiger@nasa.gov |
| In-Space Transportation | Paul McConnaughey | 256-544-1599 | paul.k.mcconnaughey@nasa.gov |
| Advanced Telescopes and Observatories | Lee Feinberg | 301-286-5923 | lee.d.feinberg@nasa.gov |
| Communication and Navigation | Bob Spearing | 202-358-4780 | bob.spearing@nasa.gov |
| Robotic Access to Planetary Surface | Mark Adler | 818-354-6277 | mark.adler@quest.jpl.nasa.gov |
| Human Planetary Landing Systems | Rob Manning | 818-393-7815 | robert.m.manning@jpl.nasa.gov |
| Human Health & Support Systems | Dennis Grounds | 281-483-6338 | dennis.j.grounds@nasa.gov |
| Human Exploration Systems and Mobility | Christopher Culbert | 281-483-8080 | christopher.j.culbert@nasa.gov |
| Autonomous Systems Robotics and Computing | James Crawford | 650-604-1139 | jcrawford@arc.nasa.gov |
| Transformational Spaceport and Range | Karen Poniatowski | 202-358-2469 | karen.s.poniatowski@nasa.gov |
| Scientific Instruments and Sensors | Richard Barney | 301-286-9588 | richard.d.barney@nasa.gov |
| In-situ Resource Utilization | Gerry Sanders | 281-483-9066 | |
| Advanced Modeling and Simulation | Erik Antonsson | 818-393-7600 | ekantons@mail.jpl.nasa.gov |
| Systems Engineering Cost Risk analysis | Steve Cavanaugh | 757-864-7019 | stephen.cavanaugh-1@nasa.gov |
| Nanotechnology | Murray Hirschbein<br>Minoo Dastoor | 202-358-4662<br>202-358-4518 | murray.s.hirschbein@nasa.gov<br>minoo.n.dastoor@nasa.gov |