National Research Council Dialogue to Assess Progress on

NASA's #13 In Situ Resource Utilization (ISRU) Capability Roadmap Development

General Background and Introduction

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NASA Advanced Planning & Integration Office (APIO)
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Agenda

- General Background and Introduction of Capability Roadmap
  - Agency Objective
  - Strategic Planning Transformation
  - Advanced Planning Organizational Roles
  - Public Involvement in Strategic Planning
  - Strategic Roadmaps and Schedule
  - Capability Roadmaps and Schedule
  - Purpose of NRC Review
- Capability Roadmap Development (Progress to Date)

Agency Goals and Objectives

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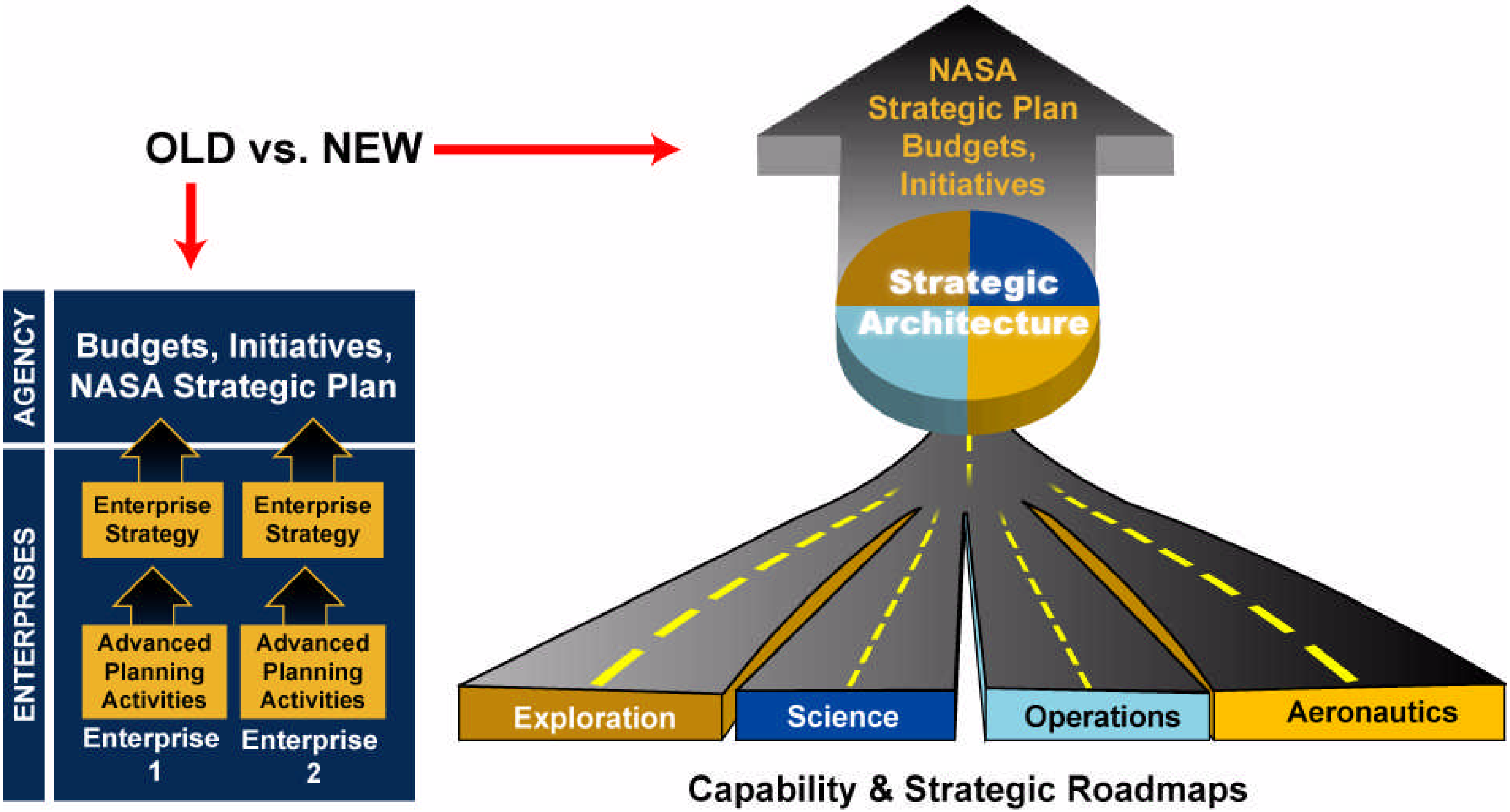
National Goal	**Advance U.S. scientific, security and economic interests through a robust space exploration program.**	
National Objectives	**Implement a sustained and affordable human and robotic program to explore the solar system and beyond.**	**Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations.**
NASA Objectives	**Undertake robotic and human lunar exploration to further science, and to develop and test new approaches, technologies, and systems to enable and support sustained human and robotic exploration of Mars and more distant destinations. First robotic mission no later than 2008. (SRM 1)**	**Return the Space Shuttle to flight and focus its use on completion of the ISS, complete assembly of the ISS, and retire the Space Shuttle as soon as assembly of the ISS is completed, planned for the end of this decade. Conduct ISS activities consistent with U.S. obligations to ISS partners. (SRM 6, 7)**
	Conduct 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. (SRM 2)	**Develop a new crew exploration vehicle to provide crew transportation for missions beyond low Earth orbit. First test flight to be by the end of this decade with operational capability for human exploration NLT 2014. (SRM 5)**
	Conduct robotic exploration across the solar system for scientific purposes and to support human exploration. In particular, explore Jupiter's moons, asteroids and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources. (SRM 3)	**Focus research and use of the ISS on supporting space exploration goals, with emphasis on understanding how the space environment affects human health and capabilities, and developing countermeasures. (SRM 6)**
	Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars. (SRM 4)	**Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than the year 2020. (SRM 1)**
	Explore the universe to understand its origin, structure, evolution, and destiny. (SRM 8)	**Conduct human expeditions to Mars after acquiring adequate knowledge about the planet using robotic missions and after successfully demonstrating sustained human exploration missions to the Moon. (SRM 2)**

Agency Goals and Objectives

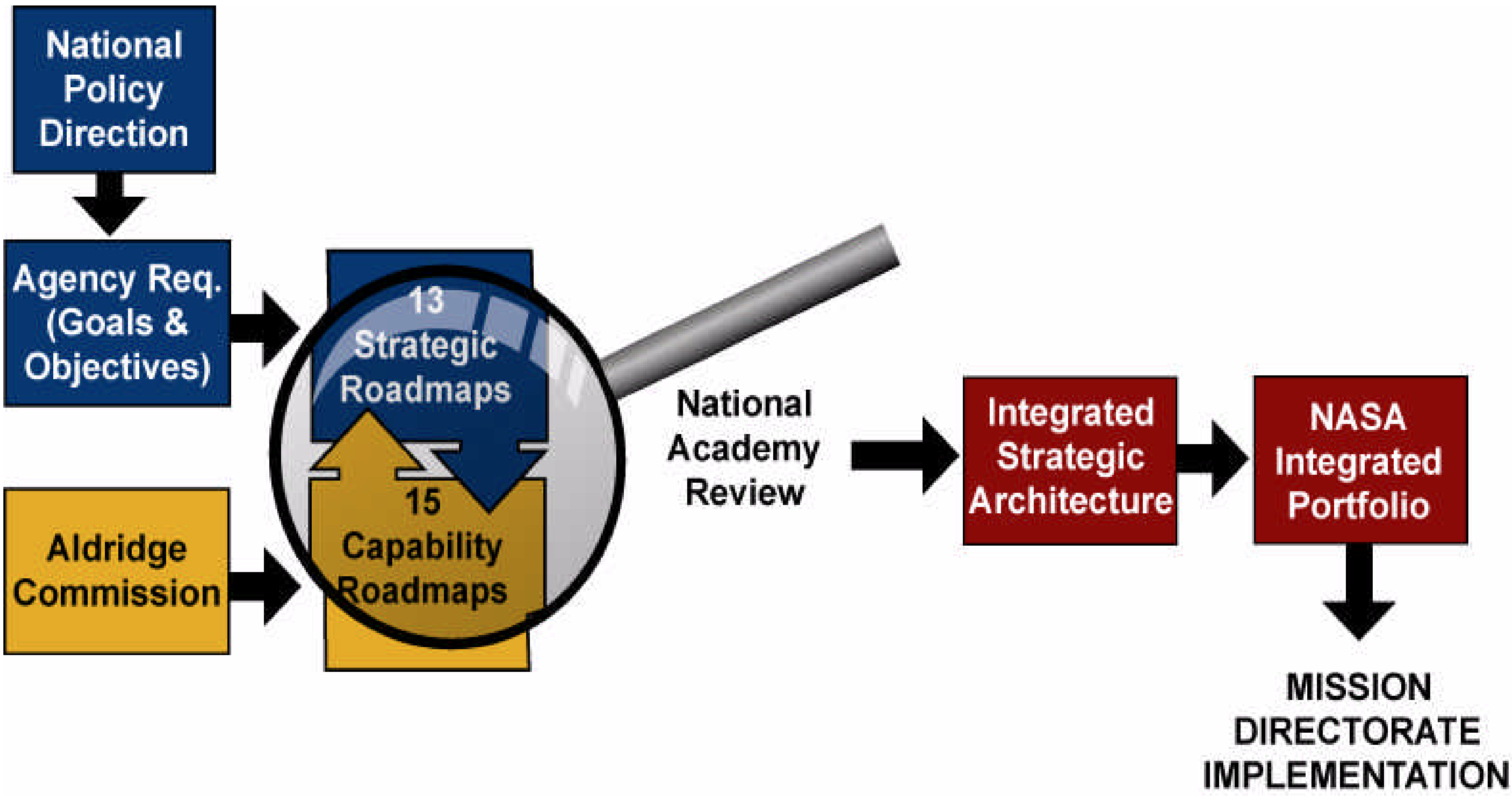
Advanced Planning & Integration Office

National Goal	**Advance U.S. scientific, security and economic interests through a robust space exploration program.**		
National Objectives	Develop innovative technologies, knowledge, and infrastructures both 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 Objectives	Develop and demonstrate power generation, propulsion, life support and other key capabilities required to support more distant, more capable, and/or longer duration human and robotic exploration of Mars and other destinations. (SRM 13 and Capability Roadmaps)	Pursue opportunities for international participation to support U.S. space exploration goals. (All SRMs)	Conduct a program of research and technology development to advance Earth observation from space, improve scientific understanding, and demonstrate new technologies with the potential to improve future operational systems. (SRM 9)
	Provide 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. (SRM 11)	Pursue commercial opportunities for providing transportation and other services supporting International Space Station and exploration missions beyond Earth orbit. Separate to the maximum extent practical crew from cargo. (SRM 5, 6, 7)	Explore 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, and demonstrate technologies that can improve future operational Earth observation systems. (SRM 10)
	Use 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 scientific and technological capabilities of the nation. (SRM 12)	Use U.S. commercial space capabilities and services to fulfill NASA requirements to the maximum extent practical and continue to involve, or increase the involvement of, the U.S. private sector in design and development of space systems. (SRM 5,6,7)	

ACHIEVING THE VISION



Strategic Planning Transformation - continued



Advanced Planning Organizational Roles

- **NASA Strategic Planning Council (Chair, NASA Administrator)**
  - Agency-level strategic decisions & NASA Strategic Plan
- **NASA Operations Council (Chair, NASA Deputy Administrator)**
  - Implementation of strategies through integrated Agency tactical & operational activities
- **Director for Advanced Planning (TBD)**
  - Develops input, options, & assessments for Strategic Planning Council
- **Associate Deputy Administrator for Systems Integration (Mary Kicza)**
  - Tracks & assesses integrated schedules, progress towards goals, Agency needs, strategic investments
- **Advanced Planning & Integration Office (Dir. APIO, Bernie Seery)**
  - Provides staff to the Director for Advanced Planning and the Associate Deputy Administrator for Systems Integration
- **Mission Directorates (Craig Steidle, Al Diaz, Victor Lebacqz, William Readdy)**
  - Technical knowledge & expertise to implement overall Agency architecture(s)

Public Involvement in Strategic Planning

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- NASA wants:
  - A broad community perspective when doing its strategic planning
  - Best strategies and most creative and innovative ideas from across the nation to implement the Vision
  - To provide opportunities for community input
    - RFI for Capability and Strategic Roadmap Input
      - Public workshop held in Washington DC on November 30th for Capability Roadmaps (509 people attended, 514 white papers submitted)
      - White Papers submitted for Strategic Roadmaps
    - Roadmap team members drawn from NASA, other Government Agencies, Academia, and Industry
    - Review by the National Research Council (NRC)
    - Presentations to professional societies, workshops, and conferences

Strategic Roadmaps

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- Strategic Roadmap
  - One of thirteen elements of the NASA Strategy that will explore options and establish pathways for implementing the Vision for Exploration.

Roadmaps will include:

- Broad human and robotic science and exploration goals, priorities, anticipated discoveries
- High-level milestones, options, and decision points
- Implementation approaches, suggested missions

Strategic Roadmaps - continued

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Roadmap	Chairs (HQ Directorate, Center)	External chair
Robotic and Human Lunar Exploration	Adm. (Ret.) Craig Steidle (HQ/ESMD) and William Readdy (HQ/SOMD) Gen. (Ret.) Jefferson Howell (JSC)	Gen. (Ret.) Tom Stafford
Robotic and Human Exploration of Mars	Al Diaz (HQ/SMD) Dr. Charles Elachi (JPL)	Tom Young (Lockheed Martin, Ret.)
◤ Solar System Exploration	Orlando Figueroa (HQ/SMD) Scott Hubbard (ARC)	Dr. Jonathan Lunine (Uni. of Arizona)
◤ Search for Earth-Like Planets	Dr. Ghassem Asrar (HQ/SMD) Dr. Charles Beichman (JPL)	Dr. Adam Burrows (Uni. of Arizona)
Exploration Transportation System	Adm. (Ret.) Craig Steidle (HQ/ESMD) Jim Kennedy (KSC)	Gen. (Ret.) Charles Bolden
International Space Station	Mark Uhran (HQ/SOMD) Bob Cabana (JSC)	Adm. (Ret.) Tom Betterton
Space Shuttle	*Deferred*	*Deferred*

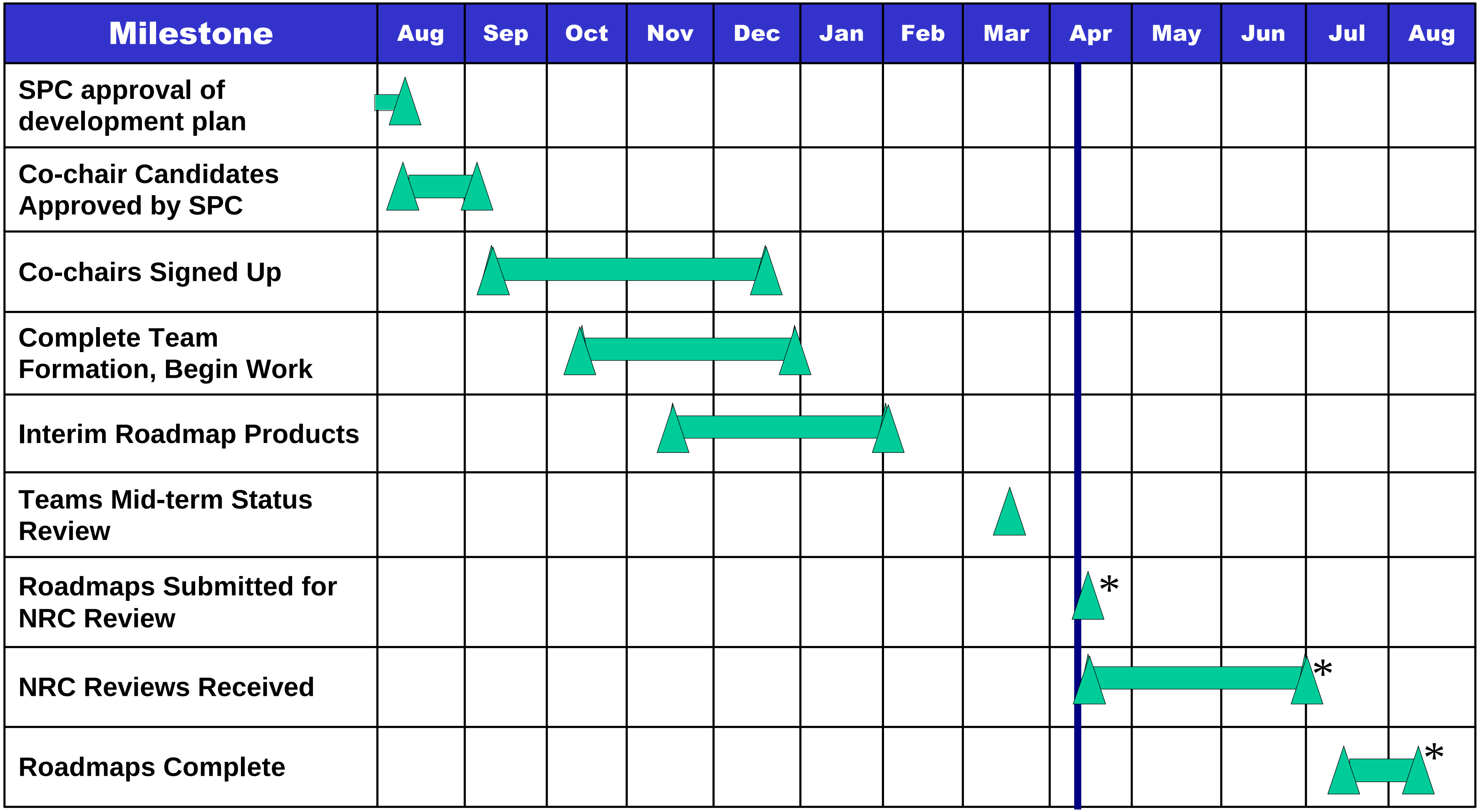
Directorate and APIO Coordinators Also with Each Team

◤ = DoD Participation

Strategic Roadmaps - continued

Roadmap	Chairs (HQ Directorate, Center)	External Chair
Universe Exploration	Dr. Anne Kinney (HQ/SMD) Dr. Nick White (GSFC)	Dr. Kathy Flanagan (MIT)
Earth Science and Applications from Space	Orlando Figueroa (HQ/SMD) Dr. Diane Evans (JPL)	Dr. Charles Kennel (UCSD/Scripps)
Sun-Solar System Connection	Al Diaz (HQ/SMD) Dr. Franco Einaudi (GSFC)	Dr. Timothy Killeen (NCAR)
Aeronautical Technologies	Terry Hertz (HQ/ARMD) None (Center)	James Jamieson (Boeing)
Education	Dr. Adena Loston (HQ/Office of Education) Dr. Julian Earls (GRC)	Dr. France Cordova (Uni. of Cal., Riverside)
Nuclear Systems	Adm. (Ret.) Craig Steidle (HQ/ESMD) Chris Scolese (GSFC)	Dr. John Ahearne (Duke Uni.)

Strategic Roadmaps Schedule



*Schedule under review.

Capability Roadmaps

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- Capability is defined as a set of systems (or system of systems) with associated technologies & knowledge that enable NASA to perform a function (e.g. scientific measurements) required to accomplish the NASA mission.

- Capability Roadmap is a description of the developments (including alternate paths and options) required to achieve the capability.

Capability Charter

- NASA, in response to the Presidential Commission recommendations, will prepare roadmaps and related implementation plans that define national capabilities needed to meet the Agency's strategic roadmaps. The roadmap titles are based on the Presidential Commission's recommendation of seventeen technologies, updated by the NASA Strategic Council.
- The capability roadmap development process will be accomplished in two phases.
  - Phase 1 will be the development of capability roadmaps and associated technical products.
    - During this phase, technical experts both internal and external to NASA will provide the technical knowledge and expertise in the development of roadmaps which identify the capabilities that are needed to meet the missions of the Agency.   The capability roadmap team will identify and analyze each of the associated technologies and assess the capability performance afforded by the current state of the art, the performance level needed by the strategic mission and trace the development required.
  - Phase 2 will be the development of Investment Plans.
    - During this phase, a NASA team will develop investment plans for the capability roadmaps.   This team will be working to determine the critical capabilities that are identified on the roadmaps and to develop an investment plan for each individual roadmap area to include schedules and yearly budgets. The activity of the Investment Plan Teams consists of using the perspectives and values described by the Capability Roadmaps and selecting and then formulating an optimized development plan suitable for consideration by the Agency in its budget submissions.

Process for Team Selection

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- Guidelines for Team Member Selection
  - Small teams of 12 -15 members with participation from:
    - 1/3 Industry
    - 1/3 NASA & other Government Agencies
    - 1/3 Academia
- Strategic Planning Council assigned roadmaps to Mission Directorate
- Mission Directorates assigned a NASA Chair with roadmap expertise
- NASA Chairs chose team members from industry, academia, other Government & within NASA who are recognized experts

Capability Roadmaps - continued

Capability	NASA chair	External chair
◤ High-Energy Power and Propulsion	Joe Nainiger (GRC)	Dr. Tom Hughes (Penn State Uni.)
◤ In-Space Transportation	Paul McConnaughey (MSFC)	Col. Joe Boyles (US Air Force SMC)
◤ Advanced Telescopes and Observatories	Lee Feinberg (GSFC)	Dr. Howard MacEwen (SRS Technologies)
◤ Communication and Navigation	Bob Spearing (HQ/SOMD)	Michael Regan (DoD)
Robotic Access to Planetary Surfaces	Mark Adler (JPL)	Dr. Robert Braun (Georgia Tech)
Human Planetary Landing Systems	Robert Manning (JPL)	Dr. Harrison Schmitt
Human Health and Support Systems	Dennis Grounds (JSC)	Al Boehm (Ret, Hamilton-Sundstrand)
◤ Human Exploration Systems and Mobility	Chris Culbert (JSC)	Dr. Jeff Taylor (Uni. of Hawaii)

Directorate and APIO Coordinators Also with Each Team

◤ = DoD Participation

Capability Roadmaps - continued

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Capability	NASA chair	External chair
Autonomous Systems and Robotics	Dr. Steve Zornetzer (ARC)	Doug Gage (Ret. DARPA)
Transformational Spaceport/Range	Karen Poniatowski (HQ/SOMD)	Gen. (Ret.) Jimmy Morrell Col. Dennis Hilley (OSD)
Scientific Instruments/Sensors	Rich Barney (GSFC)	Dr. Maria Zuber (MIT)
In Situ Resource Utilization (ISRU)	Jerry Sanders (JSC)	Dr. Mike Duke (Colorado School of Mines)
Advanced Modeling, Simulation, Analysis	Dr. Erik Antonsson (JPL)	Dr. Tamas Gombosi (Uni. Of Michigan)
Systems Engineering Cost/Risk Analysis	Steve Cavanaugh (LaRC)	Dr. Alan Wilhite (Georgia Institute of Technology)
Nanotechnology	Dr. Murray Hirschbein (HQ/ARMD) and Dr. Minoo Dastoor (HQ/ESMD)	Dr. Dimitris Lagoudas (Texas A&M)

Capability Roadmap Development Schedule Overview

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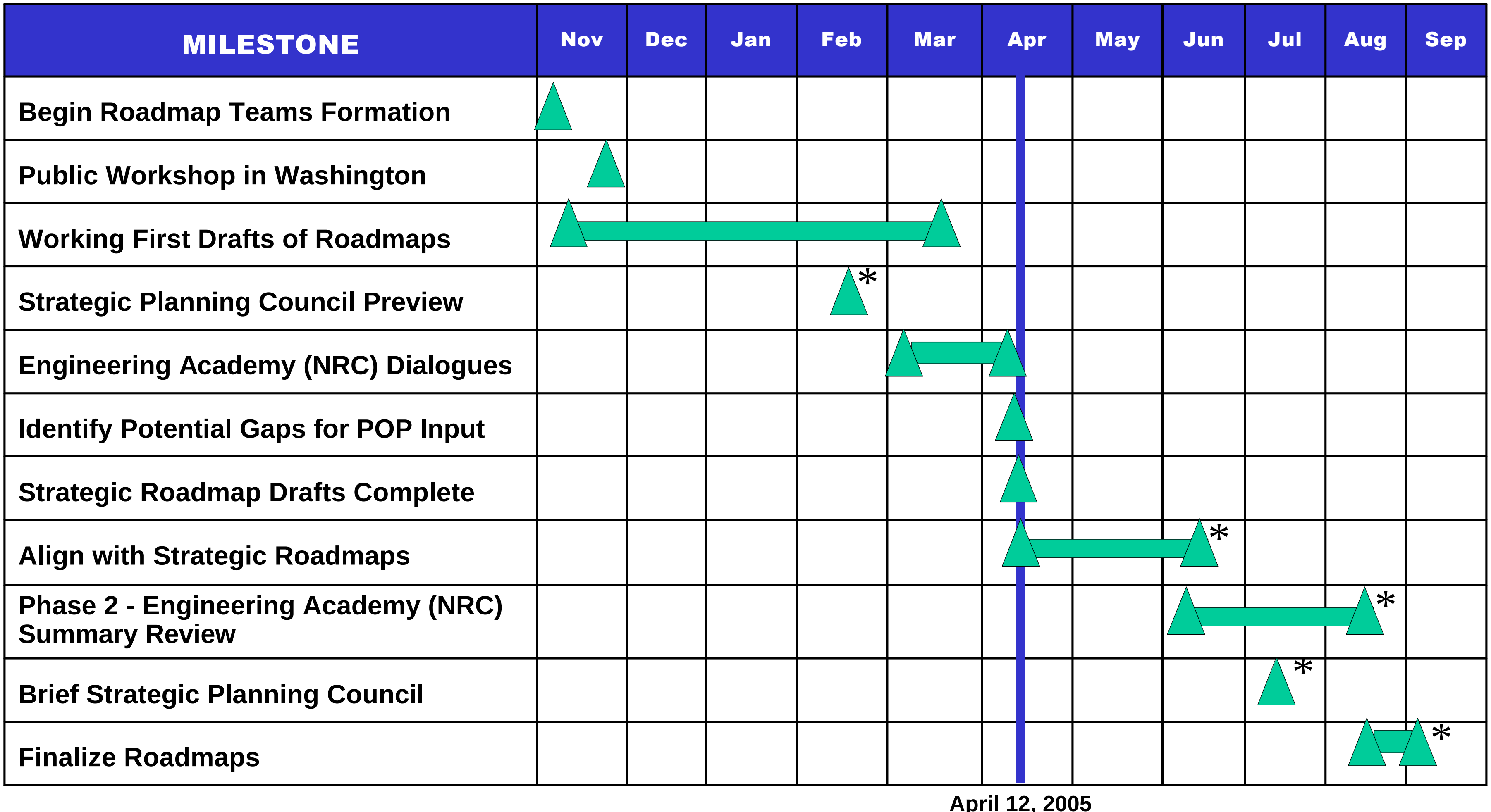

*Schedule under review.

Purpose of NRC Review

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- NASA wants the National Research Council (NRC) to review Capability Roadmap products and assess progress in four areas:

Four NRC Questions:

Do the Capability Roadmaps provide a clear pathway to (or process for) technology and capability development?

Are technology maturity levels accurately conveyed and used? (Note: Maturity levels will be evaluated using Technology Readiness Levels (TRLs) and Capability Readiness Levels (CRLs) or other appropriate methodologies)

Are proper metric for measuring advancement of technical maturity included?

- Do the Capability Roadmaps have connection points to each other when appropriate

Technology Readiness Levels

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9	Actual System Proven in Operation
8	Actual System Qualified by Demonstration
7	System Prototype Demonstration in an Operational Environment
6	System/Subsystem Model or Prototype Demonstration in a Relevant Environment
5	Component and/or Breadboard Validation in a Relevant Environment
4	Component and/or Breadboard Validation in a Laboratory Environment
3	Analytical and Experimental Critical Functions Characteristic Proof-of-Concept
2	Technology Concept and/or Application Formulated
1	Basic Principles Observed and Reported

Capability Readiness Levels

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7	Capability Operational Readiness
6	Integrated Capability Demonstrated in an Operational Environment
5	Integrated Capability Demonstrated in a Relevant Environment
4	Integrated Capability Demonstrated in a Laboratory Environment
3	Sub-Capabilities* Demonstrated in a Relevant Environment
2	Sub-Capabilities* Demonstrated in a Laboratory Environment
1	Concept of Use Defined, Capability, Constituent Sub-capabilities* and Requirements Specified

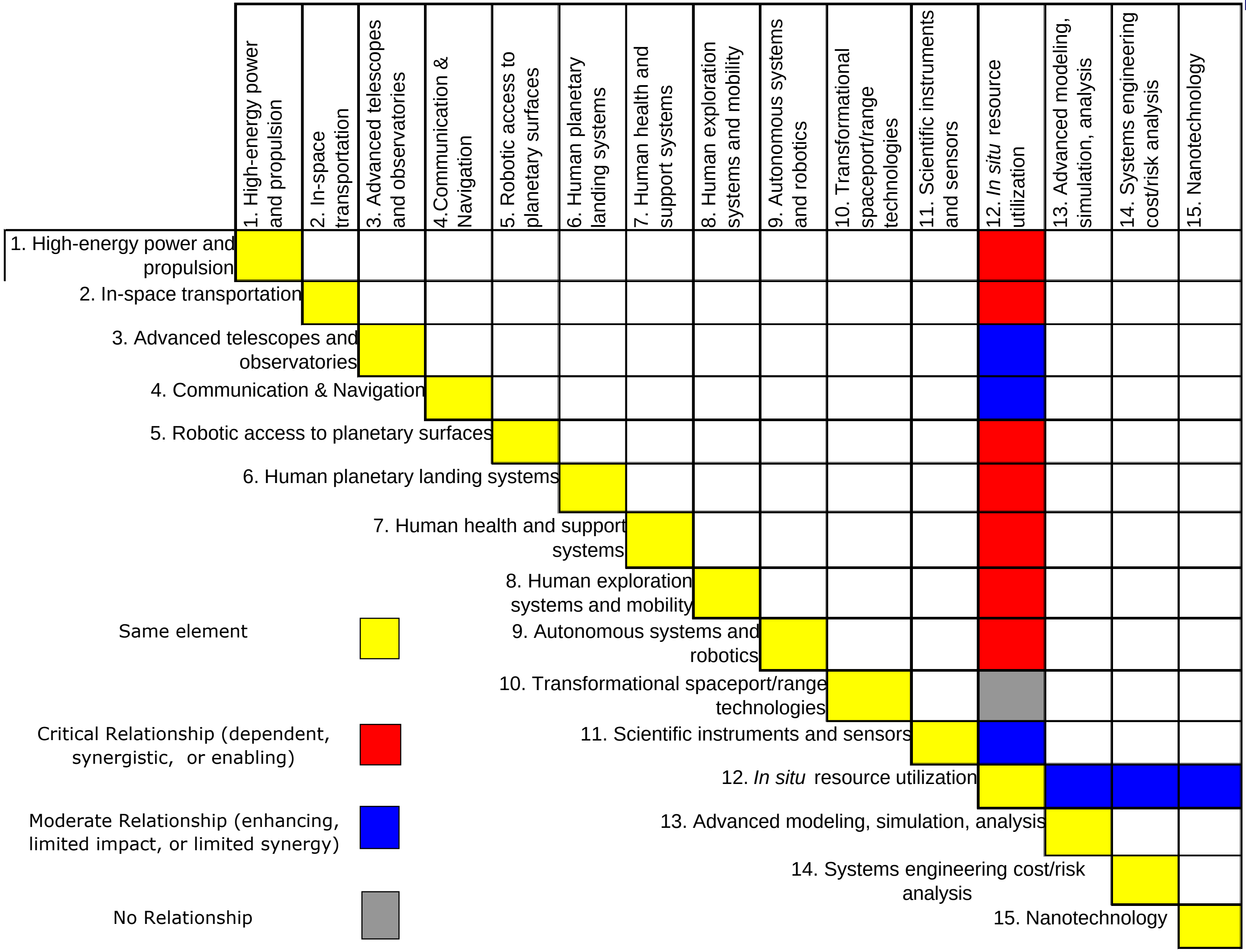
A Capability is defined as a set of systems (or system of systems) with associated technologies & knowledge that enable NASA to perform a function (e.g. scientific measurements) required to accomplish the NASA mission.

Back-up charts

- **CRL 1: Concept of Use Defined, Capability, Constituent Sub-capabilities* and Requirements Specified**
  - The Capability is defined in written form. The use/application of the Capability is described in a concept paper. The uses are speculative, and no proof or detailed analysis exists to support the concept. The constituent Sub-capabilities and requirements of the Capability are specified.
- **CRL 2: Sub-Capabilities* Demonstrated in a Laboratory Environment:**
  - A Proof-of-Concept analysis of the Capability is performed. Analytical and laboratory studies of the Sub-capabilities are performed to physically validate separate elements of the Capability. Analytical studies are performed to determine how constituent Sub-capabilities will work together.
- **CRL 3: Sub-Capabilities* demonstrated in a Relevant Environment:**
  - Sub-capabilities are demonstrated with realistic supporting elements to simulate an operationally relevant environment (e.g. to the Capability).
    - of appropriate scale
    - functionally equivalent flight articles
    - major system interactions identified
  - Limited analytical modelling of the integrated Capability can be performed.
- **CRL 4: Integrated Capability Demonstration in a Laboratory Environment**
  - A representative model or prototype of the integrated Capability is tested in a laboratory environment. Performance of the constituent Sub-capabilities are observed in addition to the Capability as an integrated system. are specified.
- **CRL 5: Integrated Capability Demonstration in a Relevant Environment**
  - An integrated prototype of the Capability is demonstrated with realistic supporting elements to simulate an operationally relevant environment (e.g. to the Capability).
    - of appropriate scale
    - actual flight articles
    - all system interactions identified
- **CRL 6: Integrated Capability Demonstration in an Operational Environment**
  - The Capability is near or at the completed system stage. This level represents the demonstration of an integrated Capability in an operational environment with representatives of the intended user organization(s).

  -full scale flight articles
  -demonstration in appropriate operational 'envelope'
- **CRL 7: Capability Operational Readiness**
  - The Capability has been proven to work in its final form and under expected operational conditions. This level represents the application of the Capability in its operational configuration and under "mission" conditions.

ISRU Integration Crosswalk



Crosswalk Details Example

	2. In-space transportation	**Capability Flow & Criticality**	**12. In situ resource utilization**	Nature of Relationship
	Ascent /Descent Stages	←	Resource Processing, storage and Distribution	Propellant made on Moon/ Mars may provide significant mass savings
	Earth Departure Stage	←	Resource Processing, storage and Distribution	Propellant made on Moon may be used for Earth (L1) Departure Stage
	Earth Return Stage	←	Resource Processing, storage and Distribution	Propellant made on Mars may be used for Earth Return Stage

	8. Human exploration systems and mobility		**12. In situ resource utilization**	
	Sub-Topic or Subsidiary Capability	**Capability Flow & Criticality**	Sub-Topic or Subsidiary Capability	Nature of Relationship
	Crew Mobility - Surface Mobility Systems	→	Resource Assessment / Extraction	Geologists will require mobility to access resource areas for evaluation
	Refueling and fluids support systems	←	Surface Consumable & Product Storage and Distribution	Automated umbilicals will supply breathing air, propellants and purges
	Fuel Cell	←	Surface Consumable & Product Storage and Distribution	In Situ Produced Propellants can supply fuel cells for surface mobility

SR-#	Short	Full Name	Chartered Objective	In Situ Resource Utilization (ISRU)	Relationship
1	Moon	Robotic and Human Lunar Exploration	Robotic and human exploration of the Moon to further science and to enable sustained human and robotic exploration of Mars and other destinations.		ISRU for propulsion propellant, life support, mobility propellant, in-situ manufacturing, in-situ construction, radiation protection
2	Mars	Robotic and Human Exploration of Mars	Exploration of Mars, including robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future		ISRU for propulsion propellant, life support, mobility propellant, in-situ manufacturing, in-situ construction, radiation protection
3	Solar System	Solar System Exploration	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.		Search for Solar System Resources
4	Earth-like Planets	Search for Earth-Like Planets	Search for Earth-like planets and habitable environments around other stars using advanced telescopes.		Not Applicable
5	CEV / Constellation	Exploration Transportation System	Develop a new launch system and crew exploration vehicle to provide transportation to and beyond low Earth orbit.		ISRU can reduce mass launched from Earth
6	Space station	International Space Station	Complete assembly of the International Space Station and focus research to support space exploration goals, with emphasis on understanding how the space		In Space & In Situ manufacturing / In Situ Logistics and Repair Capability
7	Shuttle	Space Shuttle	Return the space shuttle to flight, complete assembly of the International Space Station, and safely transition from the Space Shuttle to a new exploration		In Space & In Situ manufacturing / In Situ Logistics and Repair Capability
8	Universe	Universe Exploration	Explore the universe to understand its origin, structure, evolution, and destiny.		Not Applicable
9	Earth	Earth Science and Applications from Space	Research and technology development to advance Earth observation from space, improve scientific understanding, and demonstrate new technologies with the potential to improve future operational systems.		Not Applicable
10	Sun-Solar System	Sun-Solar System Connection	Explore the Sun-Earth system to understand the Sun and its effects on the Earth, the solar system, and the space environmental conditions that will be experienced by human explorers.		Not Applicable
11	Aero	Aeronautical Technologies	Advance 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.		ISRU can provide propellants for planetary fliers
12	Education	Education	Use 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.		Use ISRU principles to educate, inspire and motivate
13	Nuclear	Nuclear Systems	Utilize nuclear systems for the advancement of space science and exploration.		Utilize nuclear power for ISRU systems