Strategic Space Technology Investment Plan (SSTIP) Overview

NAC Technology and Innovation Committee Meeting
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NASA Goddard Space Flight Center

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Technology definition: a solution that arises from applying the disciplines of engineering science to synthesize a device, process, or subsystem, to enable a specific capability.
• NASA has requested that the NASA Advisory Council (NAC) – Technology and Innovation (T&I) Committee review the Strategic Space Technology Investment Plan (SSTIP) and provide their recommendation to NASA Administrator Bolden that the Agency adopt or not adopt the SSTIP.

• Additionally, the NAC T&I has been asked to provide top-level general comments, as appropriate.

Strategic Space Technology Investment Plan (SSTIP)
(Includes by reference Space Technology Roadmaps and NRC recommendations)

Audience
- Internal Stakeholders (mission directorates and offices)
- External Stakeholders (other Govt. Agencies, international partners, academia and commercial space sector)

Purpose
- Document and communicate strategic framework, investment approach, and principles for NASA’s Space Technology investments
- Strengthen internal Agency technology coordination through NTEC governance of strategic plan
- Maximizing the potential for collaboration on shared goals and objectives

SSTIP Is Not:
- An operational or execution plan.

Each Mission Directorate has program plans and/or project plans that document how they will execute technology development activities. These have schedules with milestones, reviews, and test dates, a appropriate. Similarly, these have budget and risk information.
“Half or more of the growth in the nation’s gross domestic product in recent decades has been attributable to progress in technological innovation”
- NRC, Rising Above the Gathering Storm, Revisited

**•** NASA must, through the development of technology
  - Provide capabilities fundamental to the Agency’s direction and U.S. space enterprise
  - Transform the path for space science and exploration
  - Enhance national innovation and economic growth

**•** NASA technology development addresses National priorities
  - Recognizes NASA’s role in advancing space science, exploration and discovery
  - Directs NASA to work with industry, academia and international partners to implement new space technology development
  - Encourages growth of U.S. commercial space sector
  - Maintain a space technology base that aligns mission directorate investments, increases capability, lowers mission cost and supports long term needs
  - Directs aggressive and prioritized technology investments to supports robotic and human exploration missions
National Science and Technology Priorities for FY 2014

Scientific discovery, technological breakthroughs, and innovation are the primary engines for expanding the frontiers of human knowledge and are vital for responding to the challenges and opportunities of the 21st century.

Administration’s Multi-Agency Priorities (OSTP):

• Resource sharing and cooperation among multiple Federal Agencies for success
• Identify and pursue “Grand Challenges” that require advances in science, technology and innovation to achieve goals beyond single Agency scope
• Support the research tools and infrastructure needed to ensure the U.S. remains at the leading edge
• Strategic prioritization of resources to key science and technology activities
• Promote Innovation and Commercialization from Federal R&D investments
• Promote Science, Technology, Engineering, and Mathematics (STEM) Education where Federal government can have maximum impact

Key Focus Areas
  - Advanced Manufacturing
  - Clean Energy
  - Global Climate Change
  - Information Technology Research and Development
  - Nanotechnology
  - Biological Innovation

NASA’s Office of the Chief Technologist (OCT) is responsible for direct management of NASA’s Space Technology programs and for coordination and tracking of all technology investments across the Agency. The responsibility is shared across the Agency.

Across NASA's Space Technology Programs
  - Basic Research (Feeds Concept Development)
  - Pioneering and Crosscutting Technologies
  - Mission-Specific Technologies

Across NASA's Mission Directorates and Offices
  - Aeronautics Research
  - Human Exploration and Operations
  - Science
  - Office of the Chief Scientist
  - Office of the Chief Engineer

Partnerships with other government agencies, U.S. industry, and internationals

NASA Technology is Aligned with the Nation’s Priorities
NASA’s Technology Portfolio

National Science and Technology Priorities

Top Down Driven Strategic Guidance

External Technology Portfolios & Partnerships
- DoD
- NRO
- Space Command
- FAA
- AFRL
- DARPA
- DoE

Mission Directorate Requirements
- ARMD
- HEOMD
- SMD

Bottom Up Driven Requirements

Technology Portfolio
- SMD
- HEOMD
- Space Technology
- ARMD
# Strategic Goal 3

Create the innovative new space technologies for our exploration, science and economic future.

<table>
<thead>
<tr>
<th>Strategic Outcomes</th>
<th>Strategic Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Sponsor early-stage innovation in space technologies in order to improve the future capabilities of NASA, other Government agencies, and the aerospace industry.</td>
<td>3.1.1 Create a pipeline of new low Technology Readiness Levels (TRL) innovative concepts and technologies for future NASA missions and national needs.</td>
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<tr>
<td>3.2 Infuse game-changing and crosscutting technologies throughout the Nation’s space enterprise to transform the Nation’s space mission capabilities.</td>
<td>3.2.1 Prove the technical feasibility of potentially disruptive new space technologies for future missions.</td>
</tr>
<tr>
<td>3.2.2 Spur the development of routine, low-cost access to space through small payloads and satellites.</td>
<td>3.2.3 Demonstrate new space technologies and infuse them into future science and exploration small satellite missions and/or commercial use.</td>
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<tr>
<td>3.2.3 Demonstrate new space technologies and infuse them into missions.</td>
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<td>3.2.4 Provide flight opportunities and relevant environments to demonstrate new space technologies.</td>
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</tr>
<tr>
<td>3.3 Develop and demonstrate the critical technologies that will make NASA’s exploration, science, and discovery missions more affordable and more capable.</td>
<td>3.3.1 Demonstrate in-space operations of robotic assistants working with crew.</td>
</tr>
<tr>
<td>3.3.2 Develop and demonstrate critical technologies for safe and affordable cargo and human space exploration missions beyond low Earth orbit.</td>
<td>3.4 Facilitate the transfer of NASA technology and engage in partnerships with other Government agencies, industry, and international entities to generate U.S. commercial activity and other public benefits.</td>
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<tr>
<td>3.4.1 Promote and develop innovative technology partnerships among NASA, U.S. industry, and other sectors for the benefit of Agency programs and national interests.</td>
<td></td>
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</table>
Technology Development as a Priority

- Government-wide emphasis on advancing technology to spur innovation in 2010
  - Agency-level Chief Technologist role established
  - Provide NASA a principle advisor on technology policy

- NASA focus on technology is evident through
  - Establishment of Space Technology Program (STP)
  - Establishment of NASA Technology Executive Council (NTEC)
  - Establishment of a database to consolidate NASA’s technology investment data from across the Agency (TechPort)
  - Establishment of SSTIP process
  - Continued technology investment through Mission Directorates
NASA’s Space Technology Portfolio

2010
Space Technology Roadmaps
- 140 challenges (10 per roadmap)
- 320 technologies
- 20-year horizon

2011
National Research Council (NRC) Study
Prioritization:
- 100 top technical challenges
- 83 high-priority technologies (roadmap-specific)
- 16 highest of high technologies (looking across all roadmaps)

- Requested every 4 years

2012
SSTIP
Updated ST Roadmaps:
- Incorporate NRC Study Results
Developing a Strategic Space Technology Investment Plan:
- current investments
- current MD/Office priorities
- opportunities for partnership
- gaps vs. current budget and capabilities
- 20-Year horizon with 4-year implementation cadence

- Revised every 2 years

Execution
Investment Portfolio
- Technology Developments (across full Technology Readiness Level (TRL) spectrum)
- Flight Demonstrations
- Must accommodate:
  - Mission Needs
  - Push Opportunities
  - Affordability
  - Technical Progress
  - Programmatic Performance
  - Commitments

- Budgeted annually
Types of Agency Technology Investments

- Pioneering and crosscutting technology investments
  - Coordinated through Space Technology Program within OCT
  - Technologies that enable multiple missions
  - Span technology readiness levels from 1 to 7

- Mission-specific
  - Coordinated within mission directorates
  - Develop and mature technologies that provide capabilities for planned and future missions
  - Focus on higher technology readiness levels
The SSTIP is a comprehensive actionable plan that will produce technologies essential to the pursuit of NASA’s mission and achievement of National goals.

- **Identifies:**
  - Technology investment framework
  - Focused investment approach
  - Strategic decision making and governance
  - Six principles for execution of plan
- **Guides investment over next 4 years, building to a 20-year horizon**
  - Updated every two years, roadmap revisions every four years
- **Optimizes benefits to stakeholders**
  - NASA Mission Directorates, other U.S. Government agencies, the private sector, and the Nation
- **Does not include aeronautics**
SSTIP Development Process
Four pillars of Agency Space Technology Investment

Each pillar comprises:
- Strategic investment goal
- Capability objectives
- Technical challenges

Built upon:
- NASA Space Technology Roadmaps
- NRC recommendations
- NASA technology portfolio assessments
- Survey of stakeholder needs
- U.S. National Space Policy
- Office of Management and Budget (OMB) Science and Technology Priorities for the FY 2014 Budget
Investment Approach

• Three levels of investment
  1. Core
  2. Adjacent
  3. Complementary

• Together these investments:
  – Span the four pillars
  – Include pioneering, crosscutting and mission specific technology development
  – Guide future technology expenditures
  – Rapidly produce critical capabilities
  – Seed future innovation

Core:
• 70% investment
• Represent the majority of the NRC’s top priority recommendations
• Focus on mission specific technologies and 8 critical pioneering and crosscutting areas
• Near-term investments necessary to accomplish demanding science and exploration missions

Adjacent:
• 20% investment
• Not part of the Core technologies, but part of NRC’s 83 high priorities
• Development may take more time

Complementary:
• 10% investment
• Does not include core or adjacent
• Does include the remaining technology capabilities in the pillars and corresponding Space Technology Roadmaps
• Seeds innovation providing some early development in technologies that are not needed immediately
• Provide technologies relevant within the 20-year horizon of this strategic plan
Strategic Decision Making and Governance

- NASA Technology Executive Council (NTEC) will be the governing body for the SSTIP

- NTEC will:
  - Evaluate the content and progress of the space technology program
  - Evaluate the Agency technology portfolio, balance the portfolio, or concur on a variation from the 70% - 20% - 10% approach
  - Make decisions on technology gaps, overlaps, and synergies

The Deep Space Atomic Clock
Source: NASA

Hypersonic Inflatable Aerodynamic Decelerator
Source: NASA

Computer simulations derived from data from years of Hubble observations indicate the Andromeda and Milky Way galaxies will collide in 4 billion years, depicted in this artist’s rendering.

Source: NASA
Guiding Principles

Six principles optimize investments, maintain a balanced portfolio, use developed technologies, and provide transparency to the American public.

1. Balance investment across all 14 Space Technology Areas in the Roadmaps
2. Balance investment across all levels of technology readiness (TRL)
3. Ensure developed technologies are infused into Agency missions
4. Pursue partnerships to help achieve NASA's technology goals
5. Use a systems engineering approach when planning technology investments
6. Reach out to the public and share information about its technology investments
## Pillars of Agency Space Technology Investment

<table>
<thead>
<tr>
<th>PILLAR 1</th>
<th>PILLAR 2</th>
<th>PILLAR 3</th>
<th>PILLAR 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GOAL:</strong> Extend and sustain human presence and activities in space</td>
<td><strong>GOAL:</strong> Explore the structure, origin, and evolution of the Solar System, and search for life past and present</td>
<td><strong>GOAL:</strong> Expand understanding of the Earth and the Universe (remote measurements)</td>
<td><strong>GOAL:</strong> Energize domestic space enterprise and extend benefits of space for the nation</td>
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### CAPABILITY OBJECTIVES

<table>
<thead>
<tr>
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<th>PILLAR 2</th>
<th>PILLAR 3</th>
<th>PILLAR 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Achieve improved spacecraft system reliability and performance</td>
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<td>1. Achieve improved spacecraft system reliability and performance</td>
</tr>
<tr>
<td>2. Enable transportation to, from, and on planetary bodies</td>
<td>2. Enable transportation to, from, and on planetary bodies</td>
<td>2. Enable transportation to space</td>
<td>2. Enable transportation to and from space</td>
</tr>
<tr>
<td>4. Enable payload delivery and human exploration of destinations and planetary bodies</td>
<td></td>
<td>4. Enable large-volume, efficient flight and ground computing and data management</td>
<td>4. Meet the robotic and autonomous navigation needs of space missions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5. Enable large-volume, efficient flight and ground computing and data management</td>
</tr>
</tbody>
</table>

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**Note:** The content is a representation of the image and may not include all details or formatting of the original document.
Goal 1: Extend and Sustain Human Presence and Activities in Space

Autonomous systems such as satellite servicing will advance technologies to achieve improved spacecraft system reliability and performance.

Transportation to planetary bodies will be enabled through entry, descent, and landing (EDL) technologies, such as low density supersonic decelerators.

Surface systems, including lightweight reliable habitats, will enable human exploration of destinations.
Exploring the solar system will require high-bandwidth communications to improve spacecraft performance. The Mars Science Laboratory will use high-bandwidth communication technologies as it searches for life past and present.

Deep space atomic clock technologies are necessary for efficient and accurate navigation and enable transportation to and from planetary bodies.

Autonomous robotic technologies allow for maneuvering and manipulation of samples on planetary surfaces, enabling in-situ measurement and exploration.
Goal 3: Expand Understanding of the Earth and the Universe (Remote Measurements)

Technologies such as those being advanced for solar electric in-space propulsion will help enable space transportation.

New techniques for using scientific instruments and sensors, like telescopes with a starshade, will enable future space-based observations.

Efficient computing and data management will be enabled by technologies for improving flight computers, such as low-power flight computers for cubesats.
Technologies for hazard detection and avoidance enable descent and landing on Earth and other planetary bodies.

Advancements in robotic and autonomous technologies will support future on-orbit assembly activities.

Autonomous mission operations require high data rates. Technologies to improve computing will extend benefits to domestic space enterprises.
Percent of FY 2012 Investment Dollars in Core, Adjacent, and Complementary Technologies

- Over the next 4 years, NASA will invest:
  - 70% in mission-specific and Core technologies
  - 20% in Adjacent technologies
  - 10% in Complementary technologies

- FY 2012 dollars align with these targeted investment percentages
  - 68% in Core technologies
  - 21% in Adjacent technologies
  - 11% in Complementary technologies
The Core technologies represent 8 focus areas of technology investment that are indispensable for NASA’s present and planned future missions.

- Core technologies are the central focus of technology investment and will comprise approximately 70% of the Agency’s technology investment of the next 4 years.

Launch and In-space Propulsion

High Data-Rate Communications

Lightweight Space Structures and Materials

Robotics and Autonomous Systems

Environmental Control and Life Support Systems

Space Radiation

Scientific Instruments and Sensors

Entry, Descent, and Landing
Adjacent technologies are a significant focus of technology investment and will comprise 20% of the Agency’s technology investment over the next 4 years.

Though not part of the Core, these technologies are still high-priority and integral to supporting the 4 pillars of investment.

The following is a sample of the Adjacent technologies:

<table>
<thead>
<tr>
<th>Technology Investment Classification</th>
<th>Associated SSTIP Technical Challenge Area</th>
<th>TABS</th>
<th>Associated NRC High Priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjacent</td>
<td>Advanced Power Generation, Storage and Transmission; Increased Available Power</td>
<td>3.2</td>
<td>Batteries</td>
</tr>
<tr>
<td>Adjacent</td>
<td>Efficient Accurate Navigation, Positioning and Timing</td>
<td>5.4</td>
<td>Timekeeping and Time Distribution</td>
</tr>
<tr>
<td>Adjacent</td>
<td>Long Duration Health Effects</td>
<td>6.3</td>
<td>Long Duration Crew Health</td>
</tr>
<tr>
<td>Adjacent</td>
<td>Surface Systems</td>
<td>7.4</td>
<td>Smart Habitats; Habitation Evolution</td>
</tr>
<tr>
<td>Adjacent</td>
<td>Improved Flight Computers</td>
<td>11.1</td>
<td>Flight Computing; Ground Computing</td>
</tr>
</tbody>
</table>
Complementary Technology Investments

- Opportunities to invest in future technologies beyond nearer term needs
- Will comprise 10% of the Agency’s technology investment over the next 4 years
- Investments might include:
  - Concepts for mitigating orbital debris
  - Innovative propulsion concepts
  - Ground processing technologies
  - New information technologies
NASA can transform the path for space science and exploration:

- Providing capabilities fundamental to the Agency’s direction and the U.S. space enterprise
- Supporting scientific, robotic, and human exploration missions through aggressive and prioritized technology investments
- Seeking transformative opportunities through technology innovations from other parts of the economy
- Maintaining an Agency space technology base to enable future missions
Strategic Space Technology Investment Plan (SSTIP) Summary

- 20-year horizon, investment guidance for next 4 years
- 4 pillars of Agency technology investment, each pillar has:
  - A Goal
  - Capability Objectives
  - Technical Challenges
- 4-year investment approach (focus on subset of pillar content)
  - 70% - 8 Core technologies - Represent 12 of 16 NRC top priority recommendations across 4 pillars
  - 20% - Adjacent Technologies - Not part of the Core but are part of the NRC’s 83 high priorities
  - 10% - Seeding Innovation - Smaller Investments in remaining technologies described in the pillars that were not part of the NRC’s 83 high priorities.
- Governance – NTEC
- 6 Principles of Investment

CORE TECHNOLOGIES

1. Launch and In-Space Propulsion
2. High Data Rate Communications
3. Lightweight Space Structures
4. Robotics and Autonomous Systems
5. Environmental Control and Life Support Systems (ECLSS)
6. Space Radiation
7. Science Instruments and Sensors
8. Entry, Descent, and Landing
Flying, Building, Testing Technologies For Tomorrow
Alignment of SSTIP Technology Investments with NRC Recommended Technologies

The NRC Top 16 includes a total of 31 technologies derived from the TA Roadmaps:

Relative Guidance Algorithms, 4.6.2
Onboard Autonomous Navigation and Maneuvering, 5.4.2
GN&C Sensors and Systems (EDL), 9.4.6
Rigid Thermal Protection Systems, 9.1.1
Flexible Thermal Protection Systems, 9.1.2
Ascent/Entry Thermal Protection Systems, 14.3.1
ECLSS Water Recovery and Management, 6.1.2
Air Revitalization, 6.1.1
ECLSS Waste Management, 6.1.3
Habitation, 6.1.4
Radiation Monitoring Technology, 6.5.5
Radiation Prediction, 6.5.4
Radiation Risk Assessment Modeling, 6.5.1
Radiation Mitigation, 6.5.2
Radiation Protection Systems, 6.5.3
(Nano) Lightweight Materials and Structures, 10.1.1
Structures: Innovative, Multifunctional Concepts, 12.2.5
Structures: Lightweight Concepts, 12.2.1
Materials: Lightweight Structures, 12.1.1
Structures: Design and Certification Methods, 12.2.2

NRC Top 16

- Electric Propulsion, 2.2.1
- (Nuclear) Thermal Propulsion, 2.2.3
- Extreme Terrain Mobility, 4.2.1
- GN&C, 4.6, 5.4, 9.4
- EDL TPS, 9.1, 14.3
- ECLSS, 6.1
- Radiation Mitigation for Human Spaceflight, 6.5
- Focal Planes, 8.1.1
- Optical Systems (Instruments and Sensors), 8.1.3
- High Contrast Imaging and Spectroscopy Technologies, 8.2
- In-Situ Instruments and Sensors, 8.3.3
- Lightweight and Multifunctional Materials and Structures, 10.1, 12.1, 12.2
- Active Thermal Control of Cryogenic Systems, 14.1.2
- Solar Power Generation (Photovoltaic and Thermal), 3.1.3
- Fission Power Generation, 3.1.5
- Long-Duration Crew Health, 6.3.2

SSTIP Core Investments

- Launch and In-Space Propulsion, 1.1-1.4, 2.1, 2.2, 2.4
- Robotics and Autonomous Systems, 4.1-4.6, 5.4
- Entry, Descent, and Landing, 9.1-9.4, 14.3
- Environmental Control and Life Support Systems, 6.1
- Space Radiation, 6.5
- Scientific Instruments and Sensors, 8.1-8.3
- Lightweight Space Structures and Materials, 12.1-12.3
- High Data Rate Communications, 5.1, 5.2, 5.5

SSTIP Adjacent Investments

(Adjacent Investments incorporate all 83 NRC high priority technologies not included in Core Investments)
SSTIP Appendices

- Detailed mapping of investment categories to the space technology area breakdown structure and NRC 83 high priorities
- Summary of Agency FY 2012 pioneering and crosscutting investments
- Detailed SSTIP development process and overview of data collected for development
- Updated space technology roadmap technology area breakdown structure
- List of SSTIP contributors
At the end of 2010, NASA drafted roadmaps to guide Agency-wide technology investment. The National Research Council (NRC) led a yearlong study to assess these roadmaps, prioritizing prospective technology-investment opportunities in terms of their value to NASA’s future and the Nation as a whole.
Space Technology Roadmap Development Process

**NASA Process**

1. **START & Input from MDs & Center**
   - Identified MD Goals, Missions, Architectures & Timelines;
   - MD Technology Roadmaps & Prioritizations;
   - Center Technology Focus Areas

2. **Identify Technology Areas**
   - Identified Technology Areas (TAs)

3. **Establish TA Teams**
   - OCT established NASA internal 6-member subject expert teams for each TA, with one or two chairs

4. **Common Approach for TA Teams**
   - Guidelines, assumptions, deliverables

5. **Form Starting Point for TA Roadmaps**
   - Assessed past roadmaps; MD & Center inputs

6. **Roadmapping Process**
   - Preliminary roadmaps for TA areas

7. **Internal Reviews**
   - Each TA Roadmap reviewed by OCT & extended teams of subject experts

8. **DRAFT NASA STRs**
   - OCT released draft Space Technology Roadmaps to the NRC & to the Public

**NRC Process**

A: **Establish NRC Teams**
   - NRC appointed steering committee and 6 panels

B: **Identify Common Assessment Approach**
   - NRC established a set of criteria to enable prioritization within and among all TAs

C: **Initial Community Feedback**
   - NRC solicited external input from industry & academia

D: **Additional Community Feedback**
   - NRC conducted public workshops

E: **Deliberations by NRC Panels**
   - NRC panels met individually to prioritize technologies and suggested improvements to roadmaps

F: **Documentation by NRC Panels**
   - NRC Panels provided written summary to Steering Committee

G: **NRC Interim Findings**
   - NRC released a brief interim report that addressed high-level issues associated with the roadmaps, such as the advisability of modifying the number or technical focus of the draft NASA roadmaps

H: **FINAL NRC REPORT**
   - With decisional information, including: summary of findings and recommendations for each of the roadmaps; integrated outputs from the workshops and panels; identified key common threads and issues; priorities, by group (e.g., high, medium, low), of the highest priority technologies from the TAs
### NRC Recommendations – 3 Technology Objectives and 10 Associated Technical Challenges

<table>
<thead>
<tr>
<th>Technology Objective A</th>
<th>Technology Objective B</th>
<th>Technology Objective C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extend and sustain human activities beyond LEO</td>
<td>Explore the evolution of the solar system and the potential for life elsewhere (in-situ measurements)</td>
<td>Expand understanding of the Earth and the universe (remote measurements)</td>
</tr>
<tr>
<td>A1. Improved Access to Space</td>
<td>B1. Improved Access to Space</td>
<td>C1. Improved Access to Space</td>
</tr>
</tbody>
</table>
Three technology objectives were defined by the NRC study steering committee:

- **Technology Objective A**: Extend and sustain **human activities beyond low Earth orbit**. Technologies to enable humans to survive long voyages throughout the solar system, get to their chosen destination, work effectively, and return safely.

- **Technology Objective B**: Explore the evolution of the solar system and the potential for life elsewhere. Technologies that enable **humans and robots to perform in-situ measurements** on Earth (astrobiology) and on other planetary bodies.

- **Technology Objective C**: Expand our understanding of Earth and the universe in which we live. Technologies for **remote measurements** from platforms that orbit or fly by Earth and other planetary bodies, and from other in-space and ground-based observatories.

### Top 16 Technology Priorities and Relative Rankings by Objective

<table>
<thead>
<tr>
<th>Objective</th>
<th>Technology Priority</th>
<th>Technology Objective A</th>
<th>Technology Objective B</th>
<th>Technology Objective C</th>
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<tbody>
<tr>
<td>2.2.1</td>
<td>Electric Propulsion</td>
<td>#3</td>
<td>#6</td>
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<tr>
<td>2.2.3</td>
<td>(Nuclear) Thermal Propulsion</td>
<td>#5</td>
<td></td>
<td></td>
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<tr>
<td>3.1.3</td>
<td>Solar Power Generation (Photovoltaic and Thermal)</td>
<td>#7</td>
<td>#2</td>
<td>#7</td>
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<tr>
<td>3.1.5</td>
<td>Fission (Power)</td>
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<td></td>
<td>#4</td>
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<td>4.2.1</td>
<td>Extreme Terrain Mobility</td>
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<td></td>
<td>#8</td>
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<td>6.3.2</td>
<td>Long-Duration (Crew) Health</td>
<td>#2</td>
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<td>8.1.1</td>
<td>Detectors &amp; Focal Planes</td>
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<td></td>
<td>#3</td>
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<tr>
<td>8.1.3</td>
<td>(Instrument and Sensor) Optical Systems</td>
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<td></td>
<td>#1</td>
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<tr>
<td>8.2.4</td>
<td>High-Contrast Imaging and Spectroscopy Technologies</td>
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<td></td>
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<tr>
<td>8.3.3</td>
<td>In Situ (Instruments and Sensor)</td>
<td>#6</td>
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<tr>
<td>14.1.2</td>
<td>Active Thermal Control of Cryogenic Systems</td>
<td>#5</td>
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<tr>
<td>X.1</td>
<td>Radiation Mitigation for Human Spaceflight</td>
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<tr>
<td>X.2</td>
<td>Lightweight and Multifunctional Materials and Structures</td>
<td>#6</td>
<td>#7</td>
<td>#4</td>
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<tr>
<td>X.3</td>
<td>Environmental Control and Life Support System</td>
<td>#3</td>
<td></td>
<td></td>
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<tr>
<td>X.4</td>
<td>Guidance, Navigation, and Control</td>
<td>#4</td>
<td>#1</td>
<td></td>
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<tr>
<td>X.5</td>
<td>Entry, Descent, and Landing Thermal Protection Systems</td>
<td>#8</td>
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## How the “Big 9” Map to Technology Investments

<table>
<thead>
<tr>
<th>Technology Investments</th>
<th>“Big 9”</th>
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<tbody>
<tr>
<td>Core</td>
<td>Launch and In-space Propulsion</td>
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<tr>
<td></td>
<td>Composite Cryotank Tech and Demo</td>
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<td></td>
<td>Cryogenic Propellant: Storage and Transfer</td>
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<td>Mission Capable Solar Sail</td>
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<tr>
<td>Core</td>
<td>High Data-Rate Communications</td>
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<td>Core</td>
<td>Lightweight Space Structures and Materials</td>
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<td>Robotiq and Autonomous Systems</td>
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<td>Human Robotic Systems</td>
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<td>Robotiq Satellite Servicing</td>
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<td>Environmental Control and Life Support Systems</td>
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<tr>
<td>Core</td>
<td>Space Radiation</td>
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<td>Core</td>
<td>Scientific Instruments and Sensors</td>
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<td>Core</td>
<td>Entry, Descent, and Landing</td>
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<td></td>
<td>Hypersonic Inflatable Aerodynamic Decelerators</td>
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<td>Low Density Supersonic Decelerators</td>
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<tr>
<td>Adjacent</td>
<td>Deep Space Atomic Clock</td>
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</table>
Acronyms

- ECLSS  Environmental Control and Life Support Systems
- EDL     Entry, Descent, and Landing
- NAC     NASA Advisory Council
- NRC     National Research Council
- NTEC    NASA Technology Executive Council
- OCT     Office of the Chief Technologist
- OMB     Office of Management and Budget
- SSTIP   Strategic Space Technology and Investment Plan
- STEM    Science, Technology, Engineering, and Mathematics
- STP     Space Technology Program
- T&I     Technology and Innovation
- TRL     Technology Readiness Level