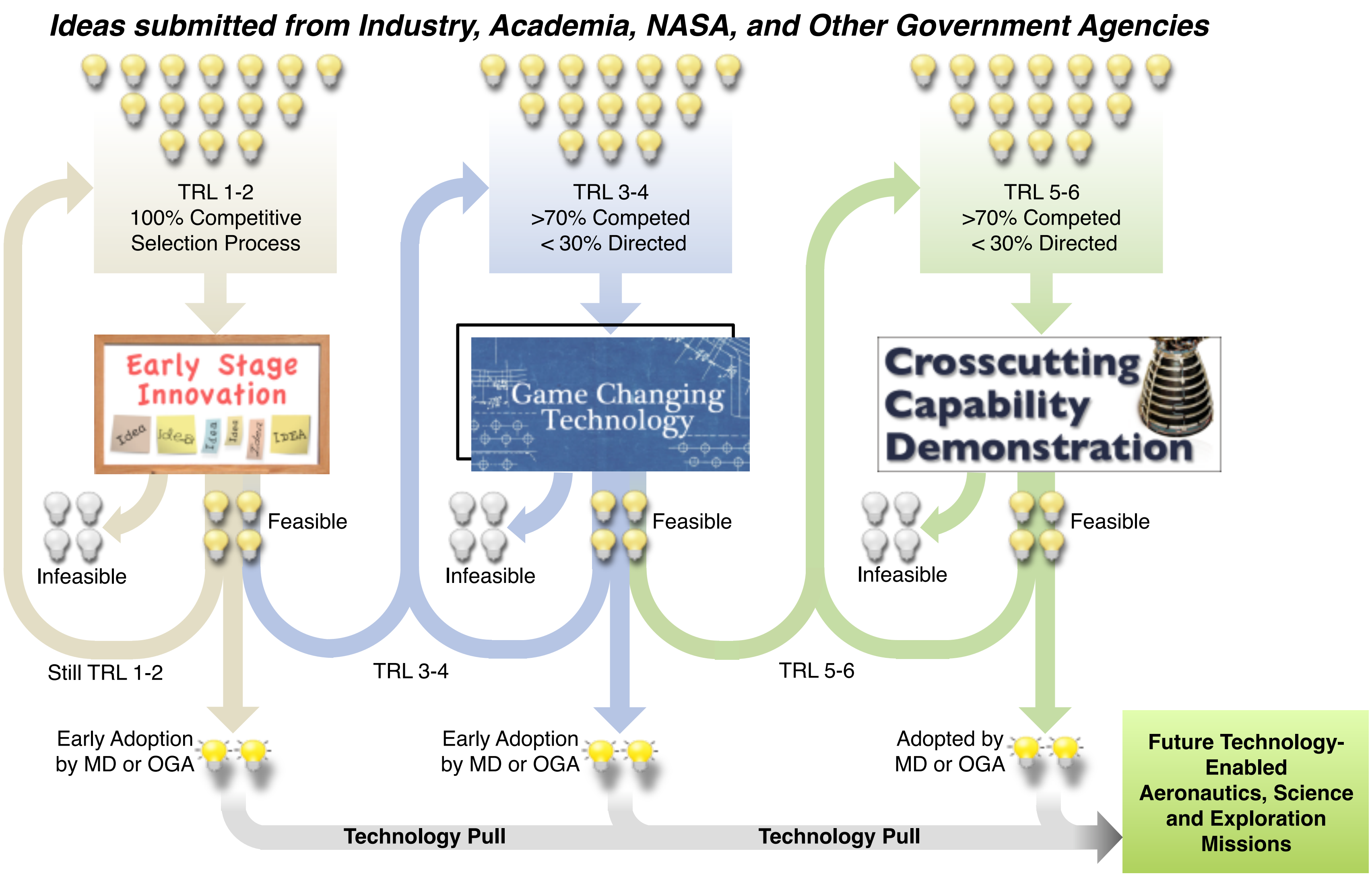
Space Technology: A Different Approach

- **Strategic Guidance**
  - Agency Strategic Plan
  - Grand challenges
  - Technology roadmaps
- **Full spectrum of technology programs that provide an infusion path to advance innovative ideas from concept to flight**
- **Competitive peer-review and selection**
  - Competition of ideas building an open community of innovators for the Nation
- **Projectized approach to technology development**
  - Defined start and end dates
  - Project Managers with full authority and responsibility
  - Project focus in selected set of strategically defined capability areas
- **Overarching goal is to reposition NASA on the cutting-edge**
  - Technical rigor
  - Pushing the boundaries
  - Take informed risk and when we fail, fail fast and learn in the process
  - Seek disruptive innovation such that with success the future will no longer be a straight line
  - Foster an emerging commercial space industry

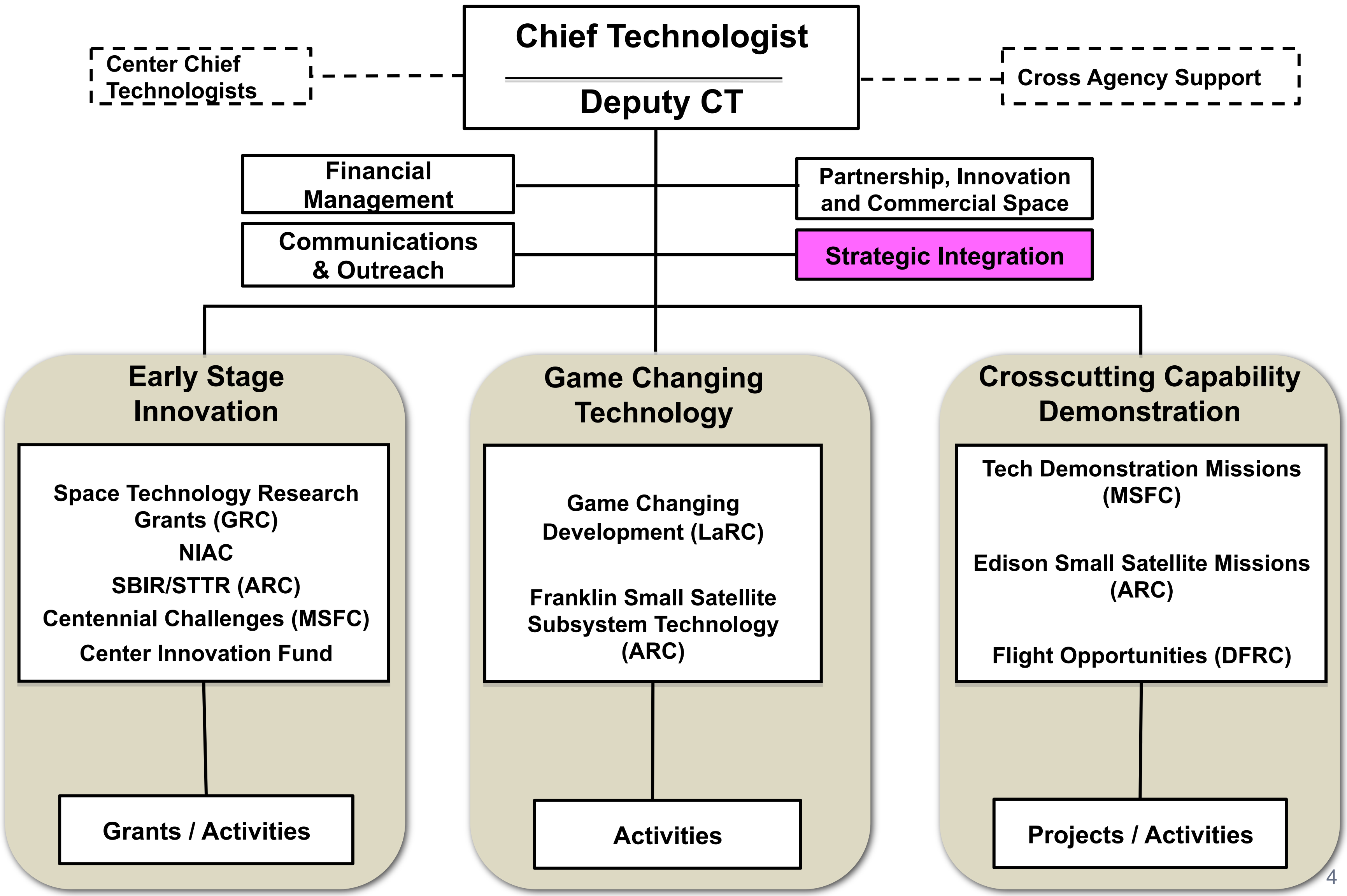
Space Technology Allows for a Range of Technology Development Pathways



Management of Space Technology Programs

- **The NASA Chief Technologist is the final authority of the Space Technology Programs.**
- **Management of the Space Technology Programs will report through the equivalent of Directorate Program Management Council (DPMC) within the Office of the Chief Technologist.**
- **Agency Reporting and Management:**
  - All Space Technology Programs will be subject to tailored versions of 7120.8 at the Program Level
  - As flight projects, the Technology Demonstration Missions will report through the Baseline Performance Reporting (BPR) and the Agency level PMC. These flight projects will be subject to tailored versions of 7120.5
- **The Space Technology Programs (with exception of NIAC and Center Innovation Fund) have Level 2 Center Program Offices.**
  - The Center Program Offices report to Level 1 Program Executives at HQ who report through the OCT Division Directors to the NASA Chief Technologist.

Office of the Chief Technologist Organization



Internal Technology Coordination Overview

- **OCT established in February 2010**

- **OCT has six main goals and responsibilities:**
  1) Principal NASA advisor and advocate on matters concerning Agency-wide technology policy and programs.
  2) Up and out advocacy for NASA research and technology programs. Communication and integration with other Agency technology efforts.
  3) Direct management of Space Technology Programs.
  4) Coordination of technology investments across the Agency, including the mission-focused investments made by the NASA mission directorates. Perform strategic technology integration.
  5) Change culture towards creativity and innovation at NASA Centers, particularly in regard to workforce development.
  6) Document/demonstrate/communicate societal impact of NASA technology investments. Lead technology transfer and commercialization opportunities across Agency.

- Mission Directorates manage the mission-focused technology programs for directorate missions and future needs
- Beginning in FY 2011, activities associated with the Innovative Partnerships Program are integrated into the Office of the Chief Technologist

NASA Technology Integration Governance

NASA Technology Executive Council

- The NASA Technology Executive Council (NTEC) is organized and chaired by the NASA Office of the Chief Technologist.
- Council membership includes the Mission Directorate AAs (or their designees), and the NASA Chief Engineer (or designee).
- The function of NTEC is to perform Agency-level technology integration, coordination and strategic planning
- 3 Meetings completed: June 10th, July 28th, and Sep 8th

Center Technology Council

- The Center Technology Council (CTC) is organized and chaired by the NASA Office of the Chief Technologist.
- Council membership includes the Center Chief Technologist (CCT) from each NASA Center, and a representative from OCE.
- The CTC will focus upon institutionally funded activities and development of OCT programs.
- 3 Meetings completed: June 22nd, July 29th, and Sep 14th
- Center CTs:
  - **John Hines (ARC)**
  - **David Voracek (DFRC)**
  - **George Schmidt (GRC)**
  - **Peter Hughes (GSFC)**
  - **Thomas Twik (JPL)**
  - **John Saiz (JSC)**
  - **Karen Thompson (KSC)**
  - **Rich Antcliff (LaRC)**
  - **Andrew Keys (MSFC)**
  - **Ramona Travis (SSC)**

Governance model approved in May 2010

Center Chief Technologists

- **A Center Chief Technologist has been appointed at each NASA Center by the Center Director**
- **Center Chief Technologists responsibilities**:
  - Report to Center management. Serve as the principal advisor to Center leadership on matters concerning Center-wide technology development and leverage.
  - Communicate Center technology capabilities through representation on Center Technology Council.
  - Serve as Center POC for the NASA Center Innovation Fund. Responsible for reporting and programmatic management of the Center Innovation Fund at the Center level.
  - Serve as Center focal point for Space Technology Research Fellowships.
  - Lead technology transfer, SBIR/STTR and commercialization opportunities across the center, including activities of solicitation, evaluation, and selection.
  - Serve as Center change agent, particularly regarding the workforce's capacity to innovate.
  - Document, demonstrate and communicate societal impact of Center technology accomplishments.
  - Serve to encourage partnerships and inter-Center collaborations
- **Center Chief Technologists have significant technical experience within the core competencies of their Center and also technical experience at other NASA Centers, within industry or academia.**
- **Center Chief Technologists not only have significant technical depth, but also the ability to think at a system-level and apply technical knowledge to significant societal challenges.**

Space Technology Grand Challenges

Space Technology Grand Challenges

Expand Human Presence in Space

Economical Space Access

Provide economical, reliable and safe access to space, opening the door for robust and frequent space research, exploration and commercialization.

Space Health and Medicine

Eliminate or mitigate the negative effects of the space environments on human physical and behavioral health, optimize human performance in space and expand the scope of space based medical care to match terrestrial care.

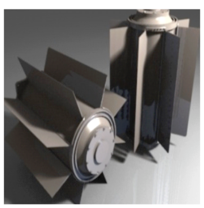
Telepresence in Space

Create seamless user-friendly virtual telepresence environments allowing people to have real-time, remote interactive participation in space research and exploration.

Space Colonization

Create self-sustaining and reliable human environments and habitats that enable the permanent colonization of space and other planetary surfaces.

Manage In-Space Resources

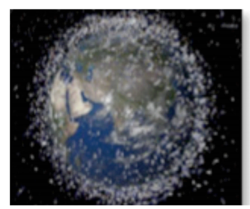


Affordable Abundant Power

Provide abundant, reliable and affordable energy generation, storage and distribution for space exploration and scientific discovery.

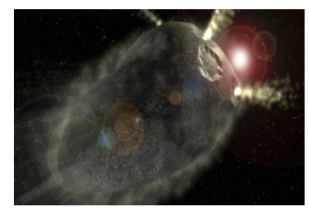
Space Way Station

Develop pre-stationed and in-situ resource capabilities, along with in-space manufacturing, storage and repair to replenish the resources for sustaining life and mobility in space.



Space Debris Hazard Mitigation

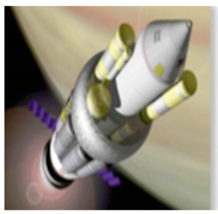
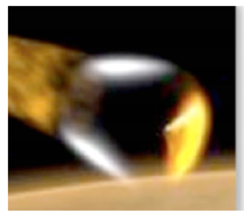
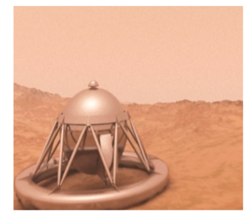
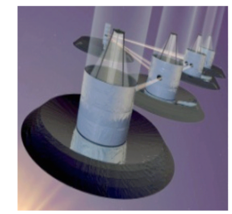
Significantly reduce the threat to spacecraft from natural and human-made space debris.



Near-Earth Object Detection and Mitigation

Develop capabilities to detect and mitigate the risk of space objects that pose a catastrophic threat to Earth.

Space Technology Grand Challenges

Enable Transformational Space Exploration and Scientific Discovery				
				
Efficient In-Space	**High-Mass Planetary Surface Access**	**All Access Mobility**	**Surviving Extreme Space Environments**	
Develop systems that provide rapid, efficient and affordable transportation to, from and around space destinations.	Develop entry, descent and landing systems with the ability to deliver large-mass, human and robotic systems, to planetary surfaces.	Create mobility systems that allow humans and robots to travel and explore on, over or under any destination surface.	Enable robotic operations and survival, to conduct science research and exploration in the most extreme environments of our solar system.	Develop novel technologies to investigate the origin, phenomena, structures and processes of all elements of the solar system and of the universe.

The Broad Challenge of Space

The challenges of flying in space are such that a truly radical improvement in nearly any system used to design, build, launch, or operate a spacecraft has the potential to be transformative. In our search for technologies that will radically improve ourexisting capabilities or deliver altogether new space capabilities, it is likely that any great leap in capability will be the result of several, integrated advances. The Space Technology development portfolio extends across all systems critical to space missions and is not limited to the specific Space Technology Grand Challenges listed above. To meet the broad challenge of maintaining a robust and vibrant space program, investments will be considered in any space technology that has the potential to be transformative.

The future demands active curiosity, open minds, and a determination to resolve challenges as they present themselves. If you have a technology that you believe can answer these challenges, we want to hear about it.

Technology Roadmapping

Technology Roadmapping Background

- OCT documented and received Agency-level concurrence on the "Process to Create and Maintain NASA's Space Technology Roadmap (STR)" – *released version posted with OCT policy documents at www.nasa.gov/OCT*

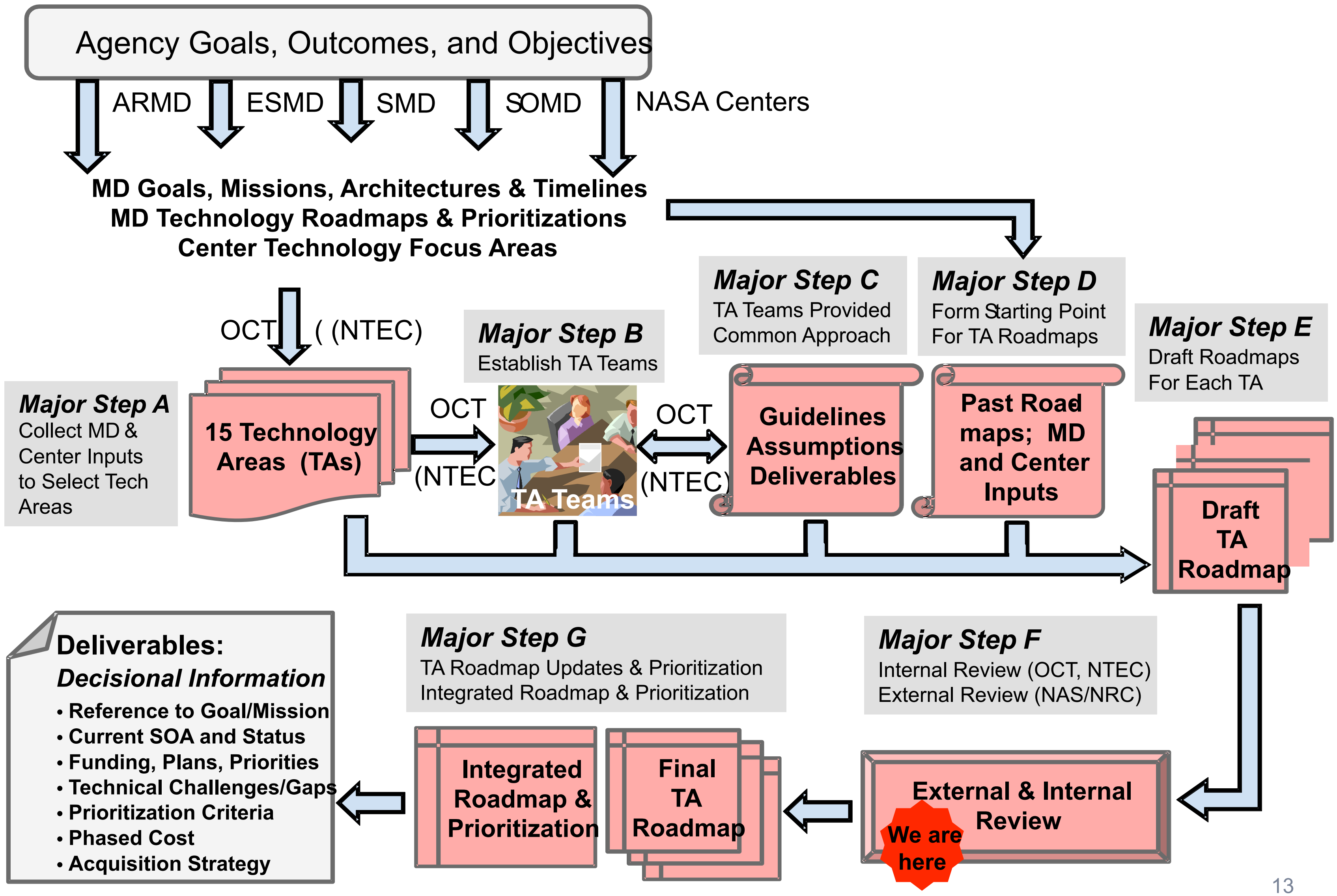
- STR performs a 'decadal' survey that:
  - Creates a set of 14 cross-cutting Technology Area (TA) roadmaps and links them to an integrated strategic roadmap
  - Calls for internal and external stakeholder participation in roadmap development and review

- OCT's Office of Strategic Integration (OCT/SI) was charged with developing, vetting, and executing the STR process

Technology Areas (TAs)

	A-STAR TAXONOMY
1	LAUNCH PROPULSION SYSTEMS
2	IN-SPACE PROPULSION SYSTEMS
3	SPACE POWER AND ENERGY STORAGE SYSTEMS
4	ROBOTICS, TELE-ROBOTICS, AND AUTONOMOUS SYSTEMS
5	COMMUNICATION AND NAVIGATION SYSTEMS
6	HUMAN HEALTH, LIFE SUPPORT AND HABITATION SYSTEMS
7	HUMAN EXPLORATION DESTINATION SYSTEMS
8	SCIENTIFIC INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS
9	ENTRY, DESCENT, AND LANDING SYSTEMS
10	NANOTECHNOLOGY
11	MODELING, SIMULATION, INFORMATION TECHNOLOGY AND PROCESSING
12	MATERIALS, STRUCTURAL & MECHANICAL SYSTEMS, AND MANUFACTURING
13	GROUND AND LAUNCH SYSTEMS PROCESSING
14	THERMAL MANAGEMENT SYSTEMS

STR Process



Agency Goals, Outcomes, and Objectives
ARMD
ESMD
SMD
SOMD
NASA Centers
MD Goals, Missions, Architectures & Timelines
MD Technology Roadmaps & Prioritizations
Center Technology Focus Areas
OCT
((NTEC)
Major Step A
Collect MD & Center Inputs to Select Tech Areas
15 Technology Areas (TAs)
OCT
(NTEC
Major Step B
Establish TA Teams
TA Teams
OCT
(NTEC)
Major Step C
TA Teams Provided Common Approach
Guidelines Assumptions Deliverables
Major Step D
Form Starting Point For TA Roadmaps
Past Road maps; MD and Center Inputs
Major Step E
Draft Roadmaps For Each TA
Draft TA Roadmap
Deliverables:
Decisional Information
• Reference to Goal/Mission
• Current SOA and Status
• Funding, Plans, Priorities
• Technical Challenges/Gaps
• Prioritization Criteria
• Phased Cost
• Acquisition Strategy
Major Step G
TA Roadmap Updates & Prioritization
Integrated Roadmap & Prioritization
Integrated Roadmap & Prioritization
Final TA Roadmap
Major Step F
Internal Review (OCT, NTEC)
External Review (NAS/NRC)
External & Internal Review
We are here

External Review Process (NRC)

Using NASA-provided, draft TA roadmaps, the National Research Council (NRC) will:

- Form technology area panels to review the draft technology area roadmaps
- Hold focused workshops – primarily to ask externals to comment on drafts and to identify new and alternate ideas.
- Develop an interim report that reviews the draft roadmaps along with outputs from the workshops, and provides suggested changes and improvements to the NASA drafts
- Develop a final report that provides findings and recommendations for the NASA technology roadmaps
- This activity is not affected by current Congressional debates (all bills call for NASA to build Agency technology roadmap/decadal survey)
- Current Status: NRC funding secured. Contract signed. Draft roadmaps are delivered to the NRC and available publicly.

STR Schedule

- ✓ Roadmapping Kickoff meeting with TA chairs
  7/28/10
- ✓ First cut, 1-pg TABS and TASRs provided by each TA
  8/13/10
- ✓ Presentation of Rev 1 Draft Roadmaps for NASA Review
  9/15-16/10
- ✓ Draft Roadmap Review comments due to OCT
  9/27/10
- ✓ TA team disposition of comments and report revisions
  10/22/10
- ✓ OCT approval of final "draft" TA roadmap reports
  11/10/10
- ✓ Draft NASA Roadmaps sent to NRC & widely distributed
  12/2/10
- NRC kick-off meeting
  1/25-27/11
- NRC panel meetings and workshops 2-4/11
- NRC Interim Report 8/11
- NRC Final Report 1/12

Setting Expectations

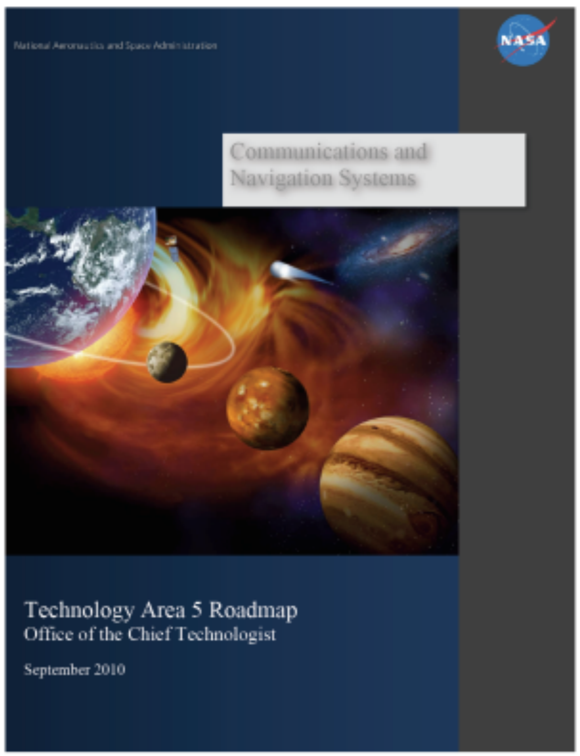
- **The 14 TA Roadmaps were generated by the TA teams in 6 weeks**
- **The intent was to capture a comprehensive set of the phased technology needs to support future NASA missions & national needs**
  - **Mission Pull:** Mission Directorate strategic plans were used to identify specific future missions requiring technology development
  - **Mission Push:** TA teams were also asked to identify specific emerging innovations and technologies within their domains that would enable missions to meet NASA strategic goals in ways currently not considered within the Mission Directorate plans
- **However, view these DRAFT products in the proper context:**
  - The desire was to develop DRAFT products as a starting point for the NRC as quickly as practical
  - Focus was NOT placed on formatting or final narrative quality
  - Focus was placed on capturing known technical content by the Agency's technology subject matter experts
  - NRC would significantly augment the technical content by performing external reviews and soliciting external inputs through focused workshops
  - No attempt occurred to develop cost estimates or comprehensive prioritizations
- **The Bottom Line: These are DRAFT products that serve as a starting point for the NRC, and NOT final NASA positions regarding technology roadmaps**

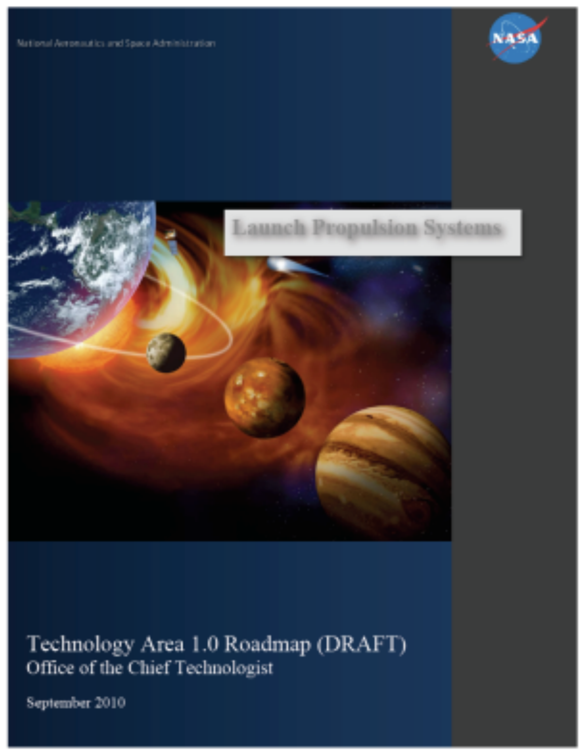
Initial Draft Roadmaps Received, Internal Review Completed, & Publicly Available

We now have draft 25 page reports in for each of the 14 roadmaps on the OCT website (reviewed by):

- MD POCs and whomever in NASA they ask to help
- Center Chief Technologists and up to 15 others they can ask
- OCT Division Leads and up to 3 others
- OCT SI members, especially the POCs to each roadmap team

http://www.nasa.gov/offices/oct/home/roadmaps/index.html





EXAMPLE TA01:
Benefits—Launch Propulsion System Goals

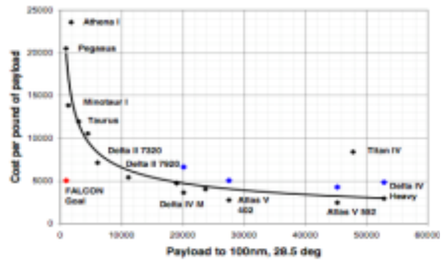


Figure 2. Launch Costs of Common Space Launch Systems

BASELINE
Shuttle, EELVs, Small Launchers

Near Term

- 25% recurring cost reduction
- 5Ξ increase in reliability

Mid-term

- 50% recurring cost reduction
- 10Ξ increase in reliability
- Enable new capabilities

Long Term

- Greater than 50% (game changing) recurring cost reductions
- Greater than 50Ξ increase in reliability
- Enable new capabilities

2010 2015 2020 2025 2030 2035

EXAMPLE - TA01:
Proposed Launch Propulsion Systems TABS

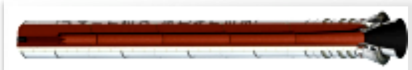
1.0 Launch Propulsion Systems

- 1.1 Solid Rocket Propulsion Systems
  - 1.1.1 Propellants
  - 1.1.2 Case Materials
  - 1.1.3 Nozzle Systems
  - 1.1.4 Hybrid Rocket Propulsion Systems
  - 1.1.5 Fundamental Solid Propulsion Technologies
- 1.2 Liquid Rocket Propulsion Systems
  - 1.2.1 LH2/LOX Based
  - 1.2.2 RP/LOX Based
  - 1.2.3 CH4/LOX Based
  - 1.2.4 Detonation Wave Engines (Closed Cycle)
  - 1.2.5 Propellants
  - 1.2.6 Fundamental Liquid Propulsion Technologies
- 1.3 Air Breathing Propulsion Sys
  - 1.3.1 TBCC
  - 1.3.2 RBCC
  - 1.3.3 Detonation Wave Engines (Open Cycle)
  - 1.3.4 Turbine Based Jet Engines (flyback boosters)
  - 1.3.5 Ramjet/Scramjet Engines (accelerators)
  - 1.3.6 Deeply-cooled Air Cycles
  - 1.3.7 Air Collection & Enrichment System
  - 1.3.8 Fundamental Air Breathing Propulsion Technologies
- 1.4 Ancillary Propulsion Systems
  - 1.4.1 Auxiliary Control Systems
  - 1.4.2 Main Propulsion Systems (Excluding Engines)
  - 1.4.3 Launch Abort Systems
  - 1.4.4 Thrust Vector Control Systems
  - 1.4.5 Health Management and Sensors
  - 1.4.6 Pyro and Separation Systems
  - 1.4.7 Fundamental Ancillary Propulsion Technologies
- 1.5 Unconventional/ Other Propulsion Systems
  - 1.5.1 Ground Launch Assist
  - 1.5.2 Air Launch/Drop Systems
  - 1.5.3 Space Tether Assist
  - 1.5.4 Beamed Energy / Energy Addition
  - 1.5.5 Nuclear
  - 1.5.6 High Energy Density Materials/ Propellants

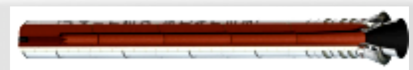
EXAMPLE - TA01: 1.1 Solid Propulsion Systems - Challenges (1 of 2)

Current | **Near to Midterm** | **Far Term**

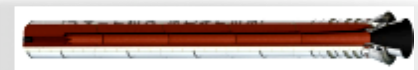
Solid Propulsion Systems



RSRMV – PBAN with Steel Case



HTPB with Composite Case
~10% boost in payload



Adv. Green Prop. SRM with Composite Case

Propellants

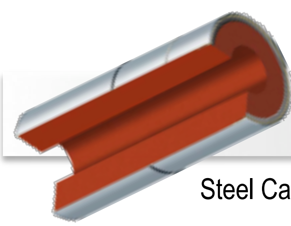
Double mix
& pour batch sizes

Continuous mix
& pour

Many bad combustion products such as Hydrochloric acid (HCl), Carbon monoxide (CO), Carbon dioxide (CO_2), Chlorine (Cl_2), Nitric oxide (NO), Nitrogen dioxide (NO_2)

Green Propellant

Case Materials



Steel Case

Composite Case

Damage tolerance limits and detection methods; Large composite cases handling and operations processing

EXAMPLE - TA01:
1.1 Solid Propulsion Systems - Challenges (2 of 2)

	Current	Near to Midterm	Far Term

Nozzle Systems

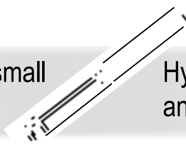
Domestic source for nozzle composite wrap materials

Hybrid Rocket Propulsion Systems

LM Hybrid Sounding Rocket

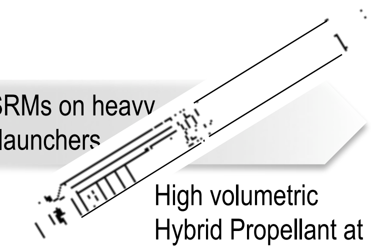
Spaceship One Hybrid Rocket Motor

Hybrids replace SRMs on small and medium launchers



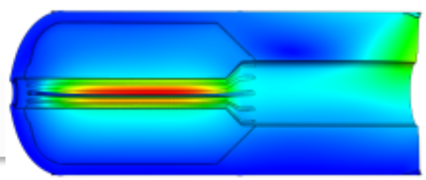
High volumetric Hybrid Propellant at 250Klbf thrust class

Hybrids replace SRMs on heavy and super heavy launchers

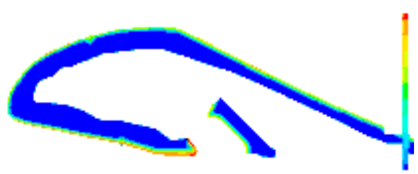


High volumetric Hybrid Propellant at 1Mlbf thrust class

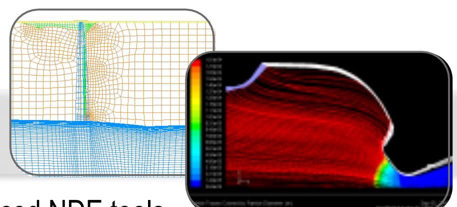
Fundamental Solid Propulsion Technologies



Finite Element Analysis (FEA)

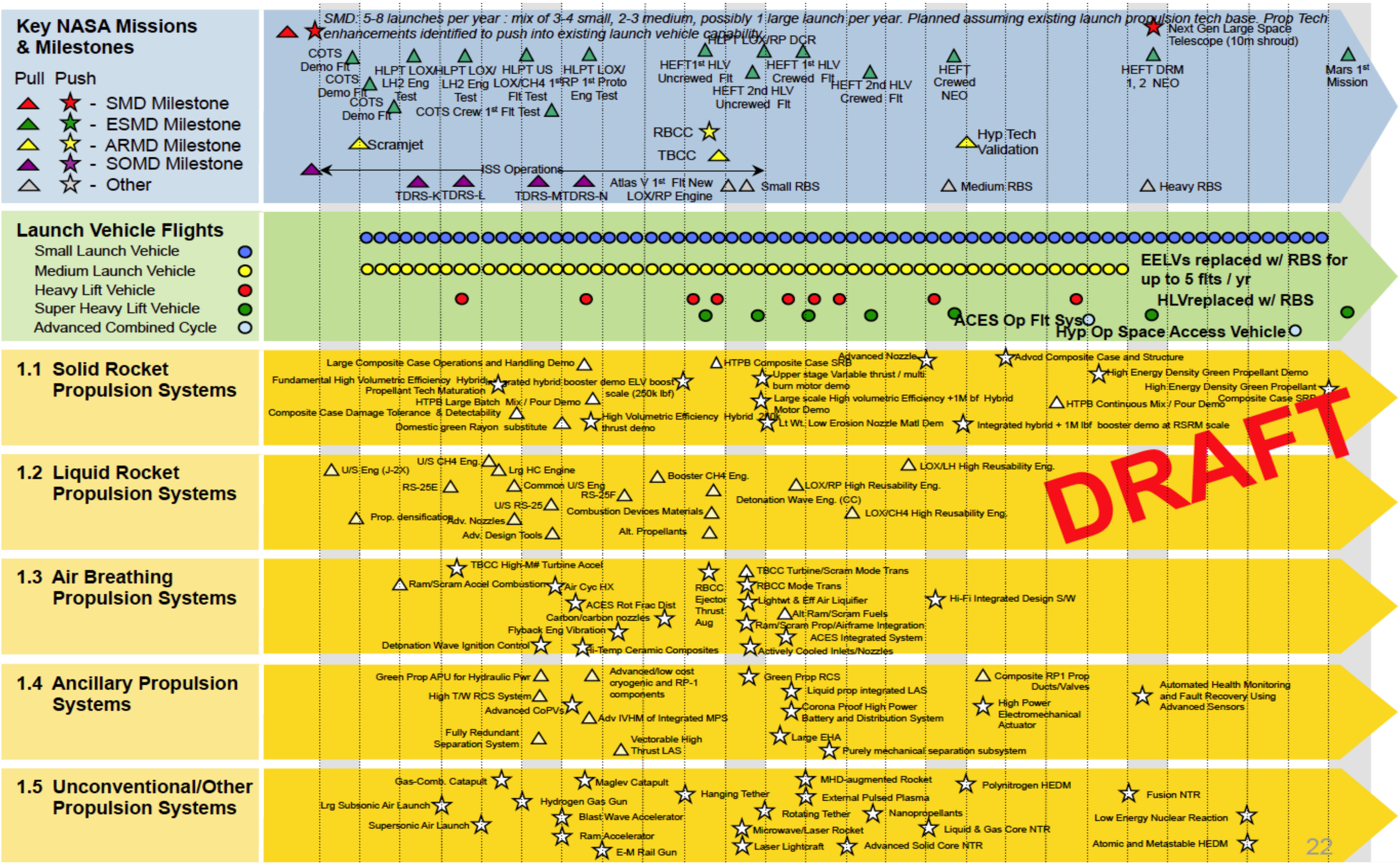


Nozzle Thermal/Ablative Analysis



- Advanced NDE tools
  - 50 x faster than SOA
- Flaw data insertion FEM tools
  - 20 x faster than SOA
- Structural/ballistic tools
  - 125 x faster than SOA methodology

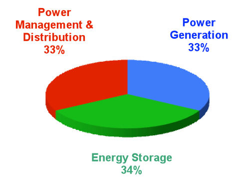
EXAMPLE - TA01:
Launch Propulsion Systems Technology Roadmap



EXAMPLE - TA03: Space Power and Energy Storage

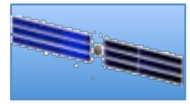
Description

- **Major power subsystems**
  - Power Generation/Conversion
  - Energy Storage
  - Power Management and Distribution



- **Advances in Power and Energy Storage Technology:**
- Enable high power robotic and crewed electric propulsion missions
- Enable solar and nuclear powered outer planetary science missions
- Enable green aviation
- Enable nano-satellite, and small planetary probes
- Enable missions with high radiation and extreme temperature environments (Venus, Europa, Mars polar, Lunar polar science missions)
- Enable in-situ resource utilization missions (ISRU)
- Enhance the capabilities of crewed exploration vehicles (for LEO, HEO, NEO & Mars missions)
- Enhance the capability of crewed surface habitats

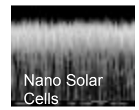
Graphic

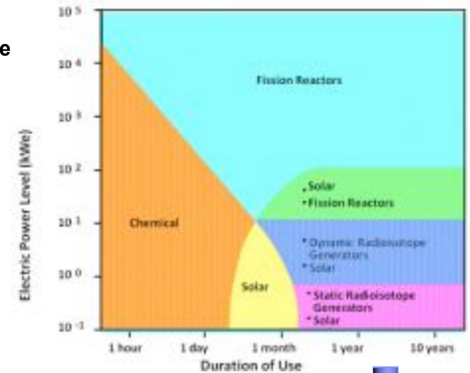


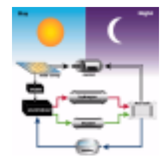
High Specific Powe Solar Array

Power for UAVs

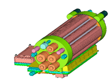
Power Beaming



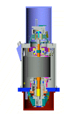




Advanced Storage

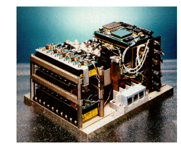


PEM Fuel Cell

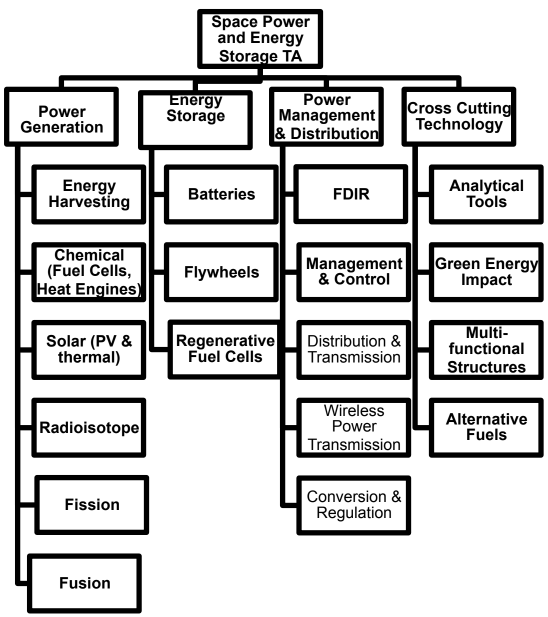


Advance Flywheel

ASRG: 8 W/kg, 30%



Power Management & Distribution



Top Technical Challenges

Power system is typically 20-30% of spacecraft mass and costs 20% of the spacecraft budget. The overall challenge is to lessen these amounts and increase capability, specifically by creating:

Power systems that provide significant mass and volume savings (3-4 x SOP)

- High specific power solar arrays (> 500 W/kg, < 2 kg/kW)
- Low specific mass nuclear power systems (< 5 kg/kW)
- High specific energy batteries (500 Wh/kg)
- High specific power fuel cells (400 W/kg)

Power systems with high voltage (100-1000 V), high power (100 kW- 5 MW) capabilities.

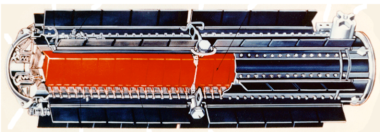
- High Voltage & High Power Solar Arrays (1000 V; >100 kW)
- Nuclear fission (2 kW_e; 40 kW_e; > 1 MW_e Power Systems)
- Aneutronic fusion power system (>50 MW_e)
- High Voltage & High Power PMAD (100-1000 V; 100 kW-1 MW)

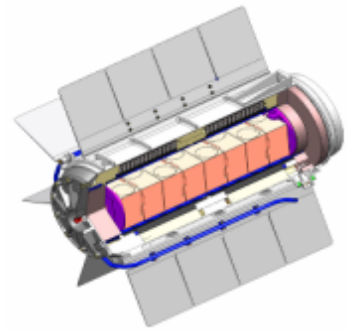
Power systems with operational capability in extreme space environments

- Extreme Temperatures (-100 to 450°C)
- High radiation environments (5 MRAD)
- Dusty environments

Power systems with long life capability (> 30 years), high reliability and safety

EXAMPLE - TA03:
Power Generation: Radioisotope Power Systems





State-of-Practice Systems

- SOP Systems: GPHS RTG, MMRTG
- Performance Capabilities:
  - 6-8% efficiency,
  - Specific Power 3-5 W/kg,
  - Life: > 15 years
- Applications:
  - Outer Planet spacecraft, Mars Rovers
- Limitations: Low efficiency and heavy

ASRG
8 W/kg, 30%

ARTG
8 W/kg,
10-15%

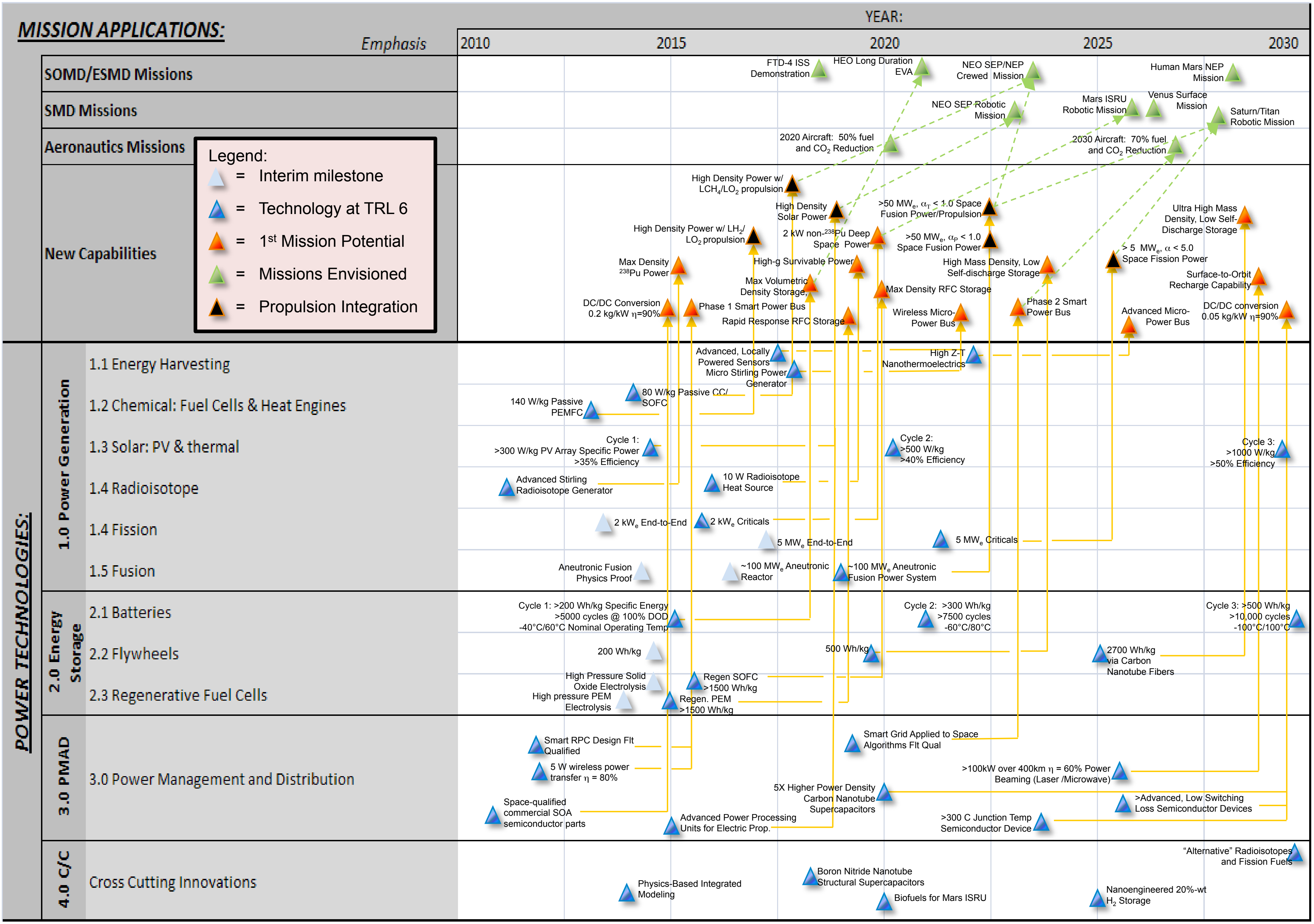
TPV 8 W/kg,
15%

Advanced Radioisotope Power Systems

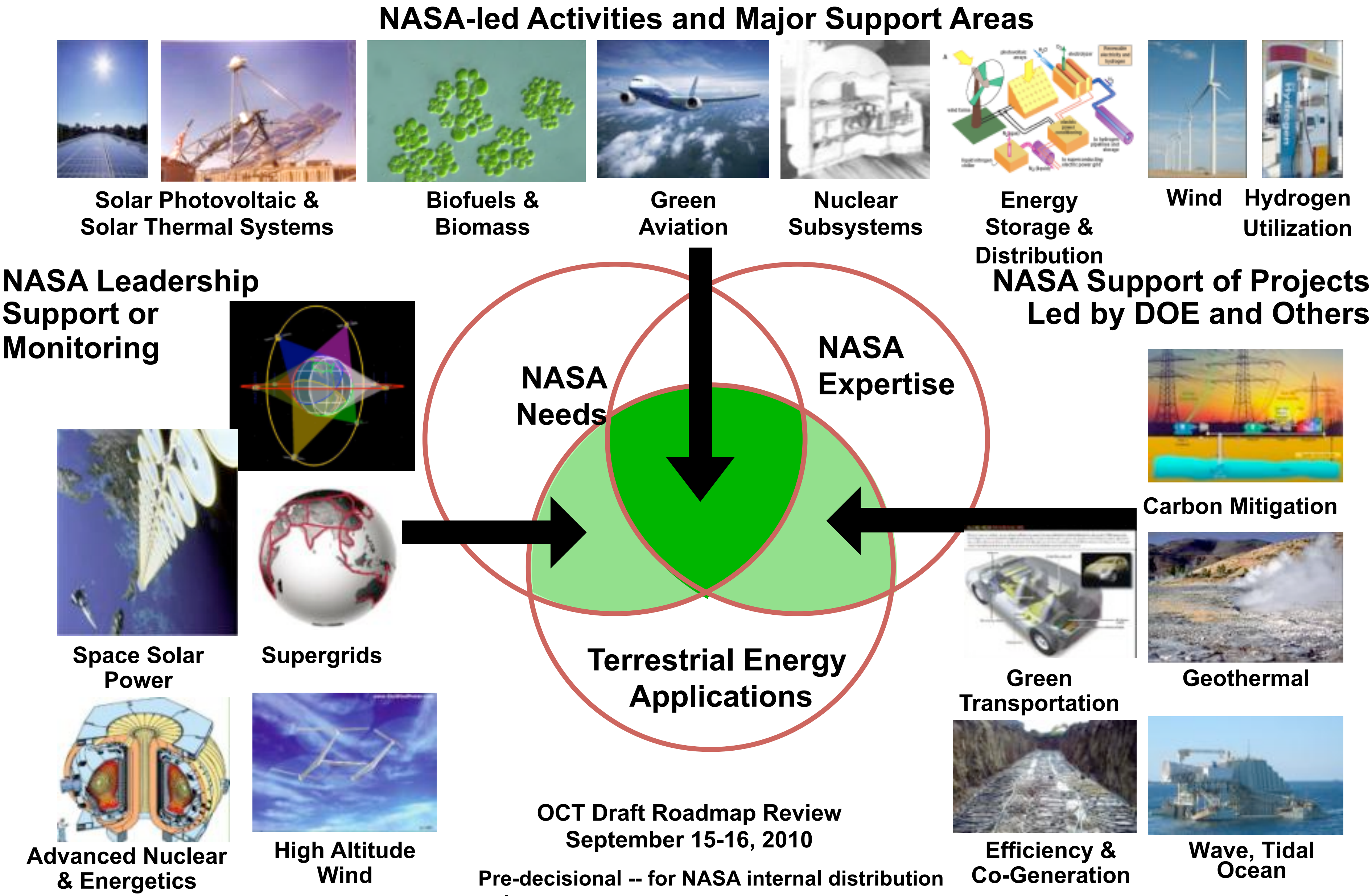
- Capabilities: High Efficiency: > 28% Specific Power: > 8 We/Kg; Life > 14 years
- Challenges: High efficiency power conversion systems with very long life capability.
- Status: SMD is developing advanced RPSs for future space science missions.
- Potential Space Applications: Outer Planet Flagship missions (Up to 1 kWe) & Rovers, (1 - 2 kWe)

Enables nuclear powered outer planetary science and Mars rover

EXAMPLE - TA03: Power and Energy Storage Roadmap

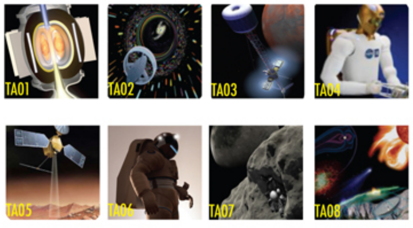


EXAMPLE - TA03:
Where NASA Can Make a Difference In Green Energy



Technology Area Breakdown Structure

National Aeronautics and Space Administration



TA01 • LAUNCH PROPULSION SYSTEMS

Solid Rocket Propulsion Systems
- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies

Liquid Rocket Propulsion Systems
- LH_2/LOX Based
- RP/LOX Based
- CH_4/LOX Based
- Detonation Wave Engines (Closed Cycle)
- Propellants
- Fundamental Liquid Propulsion Technologies

Air Breathing Propulsion Systems
- TBCC
- RBCC
- Detonation Wave Engines (Open Cycle)
- Turbine Based Jet Engines (Flyback Boosters)
- Ramjet/Scramjet Engines (Accelerators)
- Deeply-cooled Air Cycles
- Air Collection & Enrichment System
- Fundamental Air Breathing Propulsion Technologies

Ancillary Propulsion Systems
- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management & Sensors
- Pyro & Separation Systems
- Fundamental Ancillary Propulsion Technologies

Unconventional / Other Propulsion Systems
- Ground Launch Assist
- Air Launch / Drop Systems
- Space Tether Assist
- Beamed Energy / Energy Addition
- Nuclear
- High Energy Density Materials/Propellants

TA02 • IN-SPACE PROPULSION TECHNOLOGIES

Chemical Propulsion
- Liquid Storable
- Liquid Cryogenic
- Gels
- Solid
- Hybrid
- Cold Gas/Warm Gas
- Micro-propulsion

Non-Chemical Propulsion
- Electric Propulsion
- Solar Sail Propulsion
- Thermal Propulsion
- Tether Propulsion

Advanced (TRL <3) Propulsion Technologies
- Beamed Energy Propulsion
- Electric Sail Propulsion
- Fusion Propulsion
- High Energy Density Materials
- Antimatter Propulsion
- Advanced Fission
- Breakthrough Propulsion

Supporting Technologies
- Engine Health Monitoring & Safety
- Propellant Storage & Transfer
- Materials & Manufacturing Technologies
- Heat Rejection
- Power

TA03 • SPACE POWER & ENERGY STORAGE

Power Generation
- Energy Harvesting
- Chemical (Fuel Cells, Heat Engines)
- Solar (Photo-Voltaic & Thermal)
- Radioisotope
- Fission
- Fusion

Energy Storage
- Batteries
- Flywheels
- Regenerative Fuel Cells

Power Management & Distribution
- FDIR
- Management & Control
- Distribution & Transmission
- Wireless Power Transmission
- Conversion & Regulation

Cross Cutting Technology
- Analytical Tools
- Green Energy Impact
- Multi-functional Structures
- Alternative Fuels

TA04 • ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

Sensing & Perception
- Stereo Vision
- LIDAR
- Proximity Sensing
- Sensing Non-Geometric Terrain Properties
- Estimating Terrain Mechanical Properties
- Tactile Sensing Arrays
- Gravity Sensors & Celestial Nav.
- Terrain Relative Navigation
- Real-time Self-calibrating of Hand-eye Systems

Mobility
- Simultaneous Localiz. & Mapping
- Hazard Detection Algorithms
- Active Illumination
- 3-D Path Planning w/ Uncertainty
- Long-life Extr. Enviro. Mechanisms
- Robotic Jet Backpacks
- Smart Tethers
- Robot Swarms
- Walking in Micro-g

Manipulation
- Motion Planning Alg., High DOF Sensing & Control
- Robot Arms (light, high strength)
- Dexterous Manipul., Robot Hands
- Sensor Fusion for Grasping
- Grasp Planning Algorithms
- Robotic Drilling Mechanisms
- Multi-arm / Finger Manipulation
- Planning with Uncertainty

Human-Systems Integration
- Crew Decision Support Systems
- Immersive Visualization
- Distributed Collaboration
- Multi Agent Coordination
- Haptic Displays
- Displaying Range Data to Humans

Autonomy
- Spacecraft Control Systems
- Vehicle Health, Prog/Diag Systems
- Human Life Support Systems
- Planning/Scheduling Resources Operations
- Integrated Systems Health Management
- FDIR & Diagnosis
- System Monitoring & Prognosis
- V&V of Complex Adaptive Sys's
- Automated Software Generation
- Software Reliability
- Semi Automatic Systems

Auton. Rendezvous & Docking
- Rendezvous and Capture
- Low impact & Androgenous Docking Systems & Interfaces
- Relative Navigation Sensors
- Robust AR&D GN&C Algorithms & FSW
- Onboard Mission Manager
- AR&D Integration & Standardiz.n

RTA Systems Engineering
- Human safety
- Refueling Interfaces & Assoc. Tools
- Modular / Serviceable Interfaces
- High Perf., Low Power Onboard Computers
- Environment Tolerance
- Thermal Control
- Robot-to-Suit Interfaces
- Common Human-Robot Interfaces
- Crew Self Sufficiency

TA05 • COMMUNICATION & NAVIGATION

Optical Comm. & Navigation
- Detector Development
- Large Apertures
- Lasers
- Acquisition & Tracking
- Atmospheric Mitigation

Radio Frequency Communications
- Spectrum Efficient Technologies
- Power Efficient Technologies
- Propagation
- Flight & Ground Systems
- Earth Launch & Reentry Comm.
- Antennas

Internetworking
- Disruptive Tolerant Networking
- Adaptive Network Topology
- Information Assurance
- Integrated Network Management

Position, Navigation, and Timing
- Timekeeping
- Time Distribution
- Onboard Auto Navigation & Maneuver
- Sensors & Vision Processing Systems
- Relative & Proximity Navigation
- Auto Precision Formation Flying
- Auto Approach & Landing

Integrated Technologies
- Radio Systems
- Ultra Wideband
- Cognitive Networks
- Science from the Comm. System
- Hybrid Optical Comm. & Nav. Sensors
- RF/Optical Hybrid Technology

Revolutionary Concepts
- X-Ray Navigation
- X-Ray Communications
- Neutrino-Based Navigation & Tracking
- Quantum Key Distribution
- Quantum Communications
- SQIF Microwave Amplifier
- Reconfigurable Large Apertures

TA06 • HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

Environmental Control & Life Support Systems & Habitation Sys.
- Air Revitalization
- Water Recovery & Management
- Waste Management
- Habitation

Extravehicular Activity Systems
- Pressure Garment
- Portable Life Support System
- Power, Avionics and Software

Human Health & Performance
- Medical Diagnosis / Prognosis
- Long-Duration Health
- Behavioral Health & Performance
- Human Factors & Performance

Environmental Monitoring, Safety & Emergency Response
- Sensors: Air, Water, Microbial, etc.
- Fire: Detection, Suppression
- Protective Clothing / Breathing
- Remediation

Radiation
- Risk Assessment Modeling
- Radiation Mitigation
- Protection Systems
- Space Weather Prediction
- Monitoring Technology

TA07 • HUMAN EXPLORATION DESTINATION SYSTEMS

In-Situ Resource Utilization
- Destination Reconnaissance, Prospecting, & Mapping
- Resource Acquisition
- Consumables Production
- Manufacturing & Infrastructure Emplacement

Sustainability & Supportability
- Logistics Systems
- Maintenance Systems
- Repair Systems

"Advanced" Human Mobility Systems
- EVA Mobility
- Surface Mobility
- Off-Surface Mobility

"Advanced" Habitat Systems
- Integrated Habitat Systems
- Habitat Evolution

Mission Operations & Safety
- Crew Training
- Environmental Protection
- Remote Mission Operations
- Planetary Safety

Cross-Cutting Systems
- Modeling, Simulations & Destination Characterization
- Construction & Assembly
- Dust Prevention & Mitigation

TA08 • SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

Remote Sensing Instruments / Sensors
- Detectors & Focal Planes
- Electronics
- Optical Components
- Microwave / Radio
- Lasers
- Cryogenic / Thermal

Observatories
- Mirror Systems
- Structures & Antennas
- Distributed Aperture

In-Situ Instruments / Sensor
- Particles: Charged & Neutral
- Fields & Waves
- In-Situ

TA09 • ENTRY, DESCENT & LANDING SYSTEMS

Aeroassist & Atmospheric Entry
- Rigid Thermal Protection Systems
- Flexible Thermal Protection Systems
- Rigid Hypersonic Decelerators
- Deployable Hypersonic Decelerators
- Instrumentation & Health Monitoring
- Entry Modeling & Simulation

Descent
- Attached Deployable Decelerators
- Trailing Deployable Decelerators
- Supersonic Retropropulsion
- GN&C Sensors
- Descent Modeling & Simulation

Landing
- Touchdown Systems
- Egress & Deployment Systems
- Propulsion Systems
- Large Body GN&C
- Small Body Systems
- Landing Modeling & Simulation

Vehicle Systems Technology
- Architecture Analyses
- Separation Systems
- System Integration & Analyses
- Atmosphere & Surface Characterization

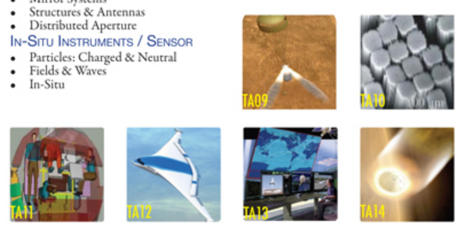
TA10 • NANOTECHNOLOGY

Engineered Materials & Structures
- Lightweight Structures
- Damage Tolerant Systems
- Coatings
- Adhesives
- Thermal Protection & Control

Energy Generation & Storage
- Energy Storage
- Energy Generation

Propulsion
- Propellants
- Propulsion Components
- In-Space Propulsion

Sensors, Electronics & Devices
- Sensors & Actuators
- Nanoelectronics
- Miniature Instruments



TA11 • MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

Computing
- Flight Computing
- Ground Computing

Modeling
- Software Modeling & Model-Checking
- Integrated Hardware & Software Modeling
- Human-System Performance Modeling
- Science & Engineering Modeling
- Frameworks, Languages, Tools & Standards

Simulation
- Distributed Simulation
- Integrated System Lifecycle Simulation
- Simulation-Based Systems Engineering
- Simulation-Based Training & Decision Support Systems

Information Processing
- Science, Engineering & Mission Data Lifecycle
- Intelligent Data Understanding
- Semantic Technologies
- Collaborative Science & Engineering
- Advanced Mission Systems

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

Materials
- Lightweight Structure
- Computational Design
- Flexible Material Systems
- Environment
- Special Materials

Structures
- Lightweight Concepts
- Design & Certification Methods
- Reliability & Sustainment
- Test Tools & Methods
- Innovative, Multifunctional Concepts

Mechanical Systems
- Deployables, Docking and Interfaces
- Mechanism Life Extension Systems
- Electro-mechanical, Mechanical & Micromechanisms
- Design & Analysis Tools and Methods
- Reliability / Life Assessment / Health Monitoring
- Certification Methods

Manufacturing
- Manufacturing Processes
- Intelligent Integrated Manufacturing and Cyber Physical Systems
- Electronics & Optics Manufacturing Process
- Sustainable Manufacturing

Cross-Cutting
- Nondestructive Evaluation & Sensors
- Model-Based Certification & Sustainment Methods
- Loads and Environments

TA13 • GROUND & LAUNCH SYSTEMS PROCESSING

Technologies to Optimize the Operational Life-Cycle
- Storage, Distribution & Conservation of Fluids
- Automated Alignment, Coupling, & Assembly Systems
- Autonomous Command & Control for Ground and Integrated Vehicle/Ground Systems

Environmental and Green Technologies
- Corrosion Prevention, Detection, & Mitigation
- Environmental Remediation & Site Restoration
- Preservation of Natural Ecosystems
- Alternate Energy Prototypes

Technologies to Increase Reliability and Mission Availability
- Advanced Launch Technologies
- Environment-Hardened Materials and Structures
- Inspection, Anomaly Detection & Identification
- Fault Isolation and Diagnostics
- Prognostics Technologies
- Repair, Mitigation, and Recovery Technologies
- Communications, Networking, Timing & Telemetry

Technologies to Improve Mission Safety/Mission Risk
- Range Tracking, Surveillance & Flight Safety Technologies
- Landing & Recovery Systems & Components
- Weather Prediction and Mitigation
- Robotics / Telerobotics
- Safety Systems

TA14 • THERMAL MANAGEMENT SYSTEMS

Cryogenic Systems
- Passive Thermal Control
- Active Thermal Control
- Integration & Modeling

Thermal Control Systems
- Heat Acquisition
- Heat Transfer
- Heat Rejection & Energy Storage

Thermal Protection Systems
- Entry / Ascent TPS
- Plume Shielding (Convective & Radiative)
- Sensor Systems & Measurement Technologies

Space Technology Roadmaps **STR • TABS**

TECHNOLOGY AREA BREAKDOWN STRUCTURE

Future Work

- It is recognized that these draft reports are 'need-driven' as opposed to 'budget-driven or budget-constrained'.
- Moving forward, cost estimates and prioritization will occur for individual technologies the proposed demonstrations – within and across TAs.
- These reports also need evaluation with better knowledge of ongoing investments by other government agencies, academia and industry.
- Further work is also needed to see how the TASRs can be integrated into a common overall roadmap.
- Updates will be necessary as individual Mission Directorates' plans (technology development as well as mission sets) change.
- **Nonetheless, the set of reports provides a critical snapshot of specific capabilities and challenges and how they can support NASA's missions and strategic goals.**

Next Phase

- The next phase of this activity will be led by the NRC through the ASEB.
- In this phase, we will be seeking inputs from across the community.
  - This will involve NASA personnel and additional coordination efforts across the existing TA teams, and now will also involve personnel in other government agencies, academia and industry, as well as the public
- **Key Point: the "c.g." in this next phase is at the NRC.**
- http://www.nasa.gov/offices/oct/home/roadmaps/index.html
  - 14 Draft technology area roadmaps
  - STR Overview document, including the TABS
  - Technology forecast document – NASA strategic plan, technology roadmaps, space technology grand challenges, and Mission Directorate technology plans
- http://sites.nationalacademies.org/DEPS/ASEB/DEPS_059552
  - NRC technology roadmapping information
  - Ability to comment on the draft technology roadmaps