From ISS to Mars: Understanding the NASA TA6 Human Health, Life Support, and Habitation Systems Technology Roadmap

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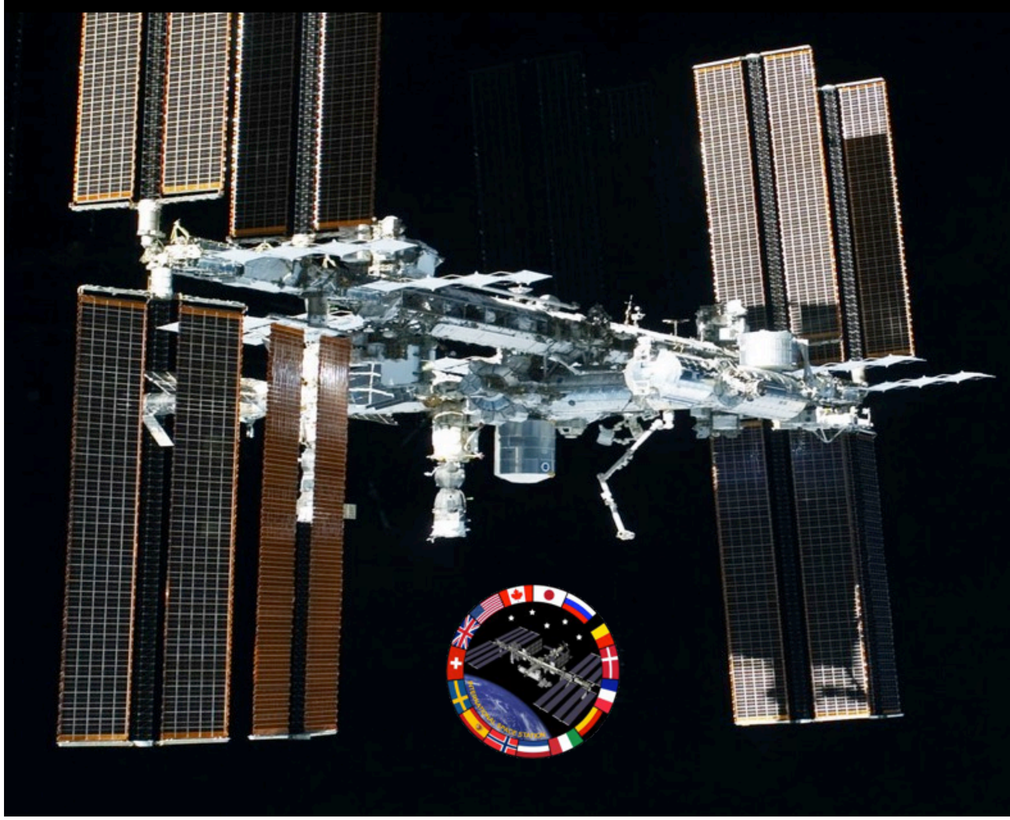

Why Do We Need A Roadmap?

◆ "Few of the technological challenges of a crewed Mars mission are insurmountable, but they represent a huge gap relative to our current capabilities, and our currently available resources."

- **John** Sommerer, Chair, Technical Panel, Pathways to Exploration Report, National Academy of Sciences. Feb 3, 2016 https://science.house.gov/legislation/hearings/space-subcommittee-hearing-charting-course-expert-perspectives-nasa-s-human

◆ "US investment in advanced research and technology for space exploration and development has been reduced to historically low levels, and concurrently has been focused more narrowly than ever before on immediate system designs and development projects."

- **John** Mankins, May 18, 2009. http://thespacereview.com/article/1377/1

◆ "The United States is now living on the innovation funded in the past and has an obligation to replenish this foundational element."

- **NRC (National Research Council), "America's Future in Space: Aligning the Civil Space Program with** National Needs," The National Academies Press, Washington D.C., 2009.

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What are they used for?
How Roadmaps Influence NASA's Technology Development Process

Space Technology Draft Roadmaps

- Congress directed NASA to strengthen advanced technology base
- NASA Strategic Plan – future goals
- OCT developed 14 draft roadmaps
  - 20-year horizon
  - 320 main technologies

National Research Council (NRC) Study

Technology Prioritization:

- Used QFD or decision matrix: benefit, technical risk, alignment
- 83 high-priority technologies (all TA6 areas included)
- 16 highest of high technologies (all ECLSS, all Radiation, & Crew Health)
- Recommended Improvements
- Requested every 4 years

Strategic Space Technology Investment Plan Development

SSTIP/STIP:

- Incorporated Roadmap content
- Guiding principles for technology development
- Strategy to develop essential advanced technologies
- Revised every 2 years

NASA Technology Executive Council (NTEC)

- Senior decision-making body
- NTEC Uses SSTIP to Make Budget Decisions
  - Mission Needs
  - Technical Progress/Gaps
  - Affordability
- Budgeted Annually

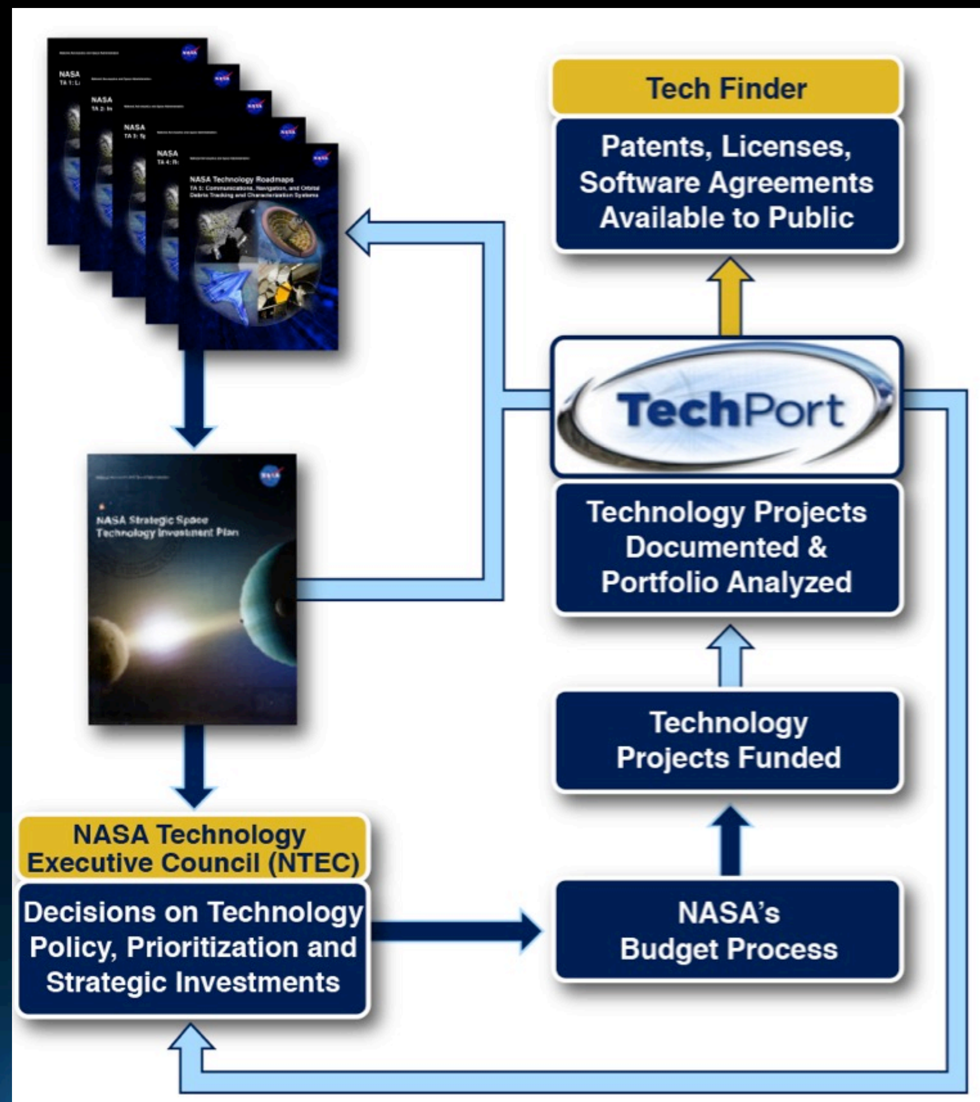
Process Summary: Roadmaps identify the technical foundation upon which to achieve strategic goals and deep space capabilities

Roadmaps
What We Could Do

NRC and STIP (Priorities)
What We Should Do

NTEC and Budget Process
What We Will Do

Technology Projects Funded
What We Are Doing



NASA Roadmap Teams Used a Capability Driven Framework to Identify Future Needed Technologies

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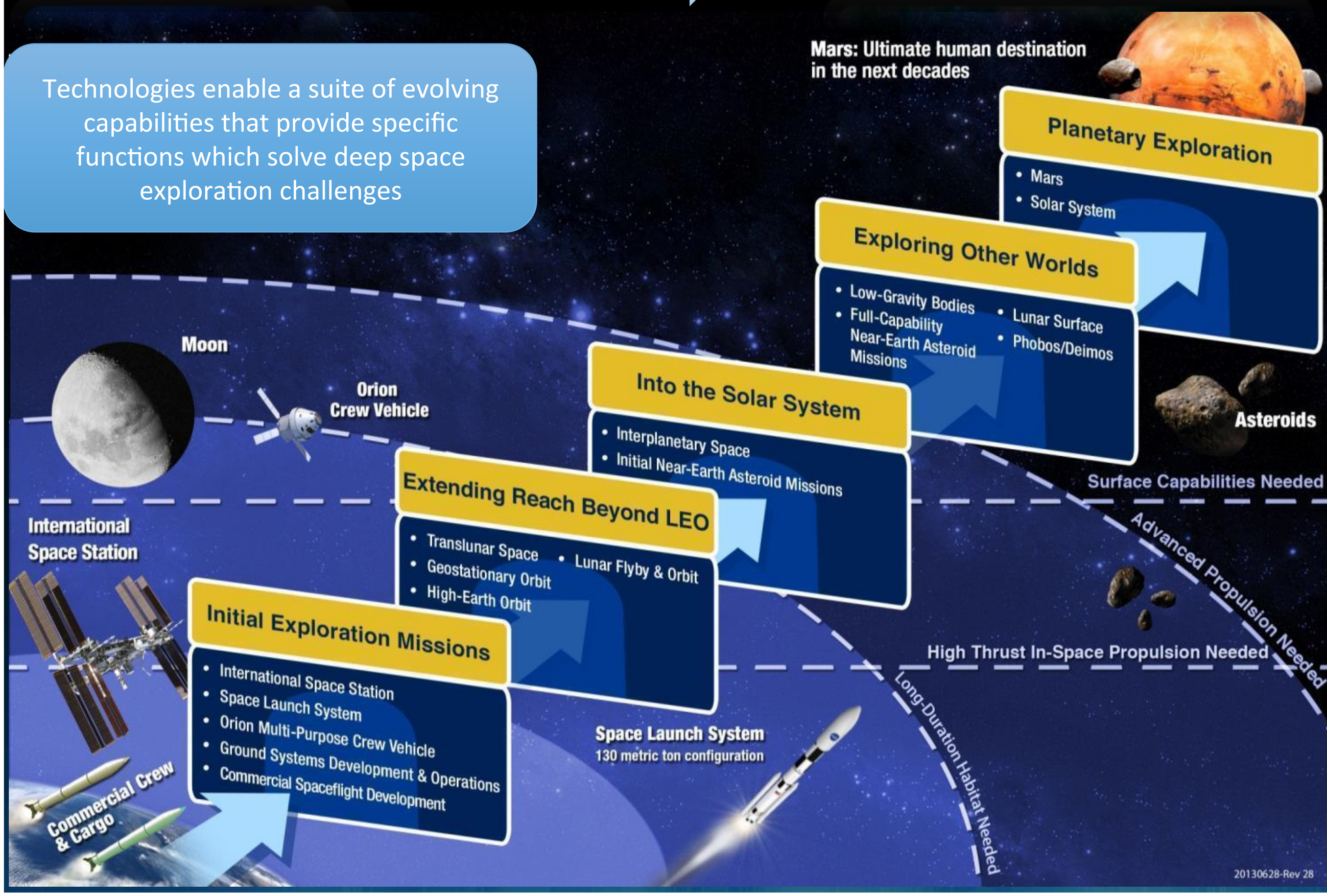
State of the Art Technology → 20 Years (2015 -2035) → **Capability Performance Goals**

Technologies enable a suite of evolving capabilities that provide specific functions which solve deep space exploration challenges



Example Capabilities

- ISS/Earth Reliant
  - Research on human health
  - Test deep space technologies
- Cislunar Space/Proving Ground
  - SLS, Orion
  - Deep space habitation
  - In-space propulsion
- Earth Independent/Mars Ready
  - Entry, Descent and Landing
  - Surface capabilities

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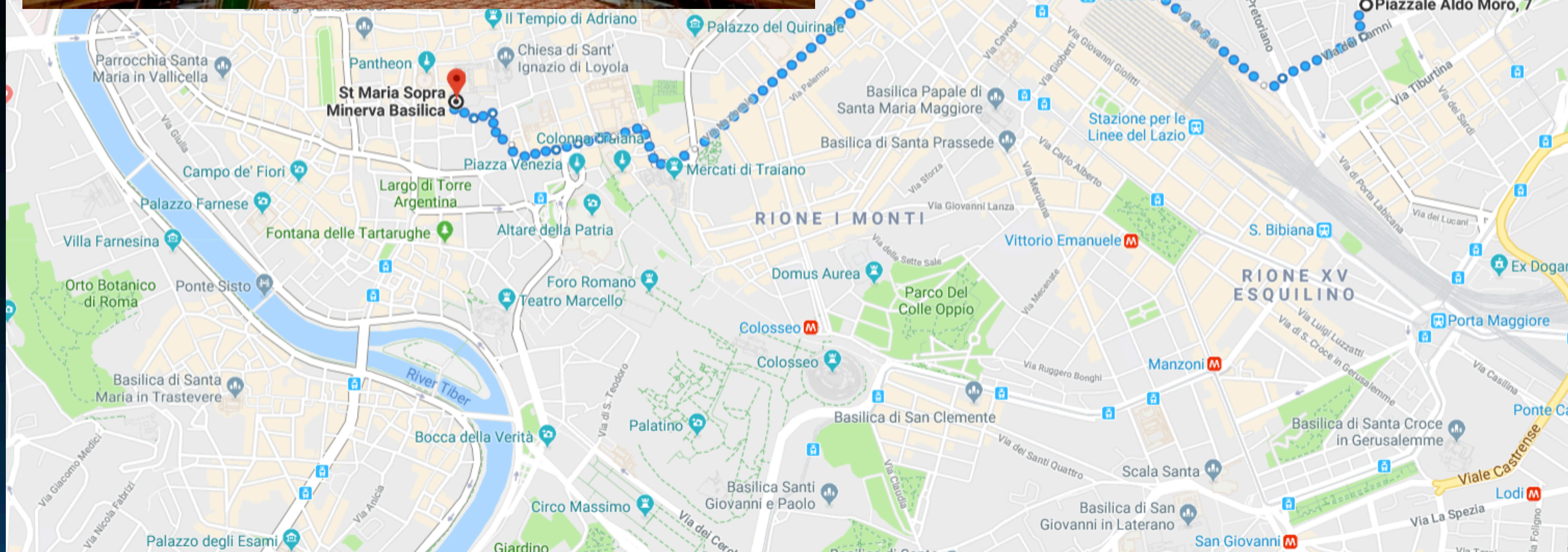
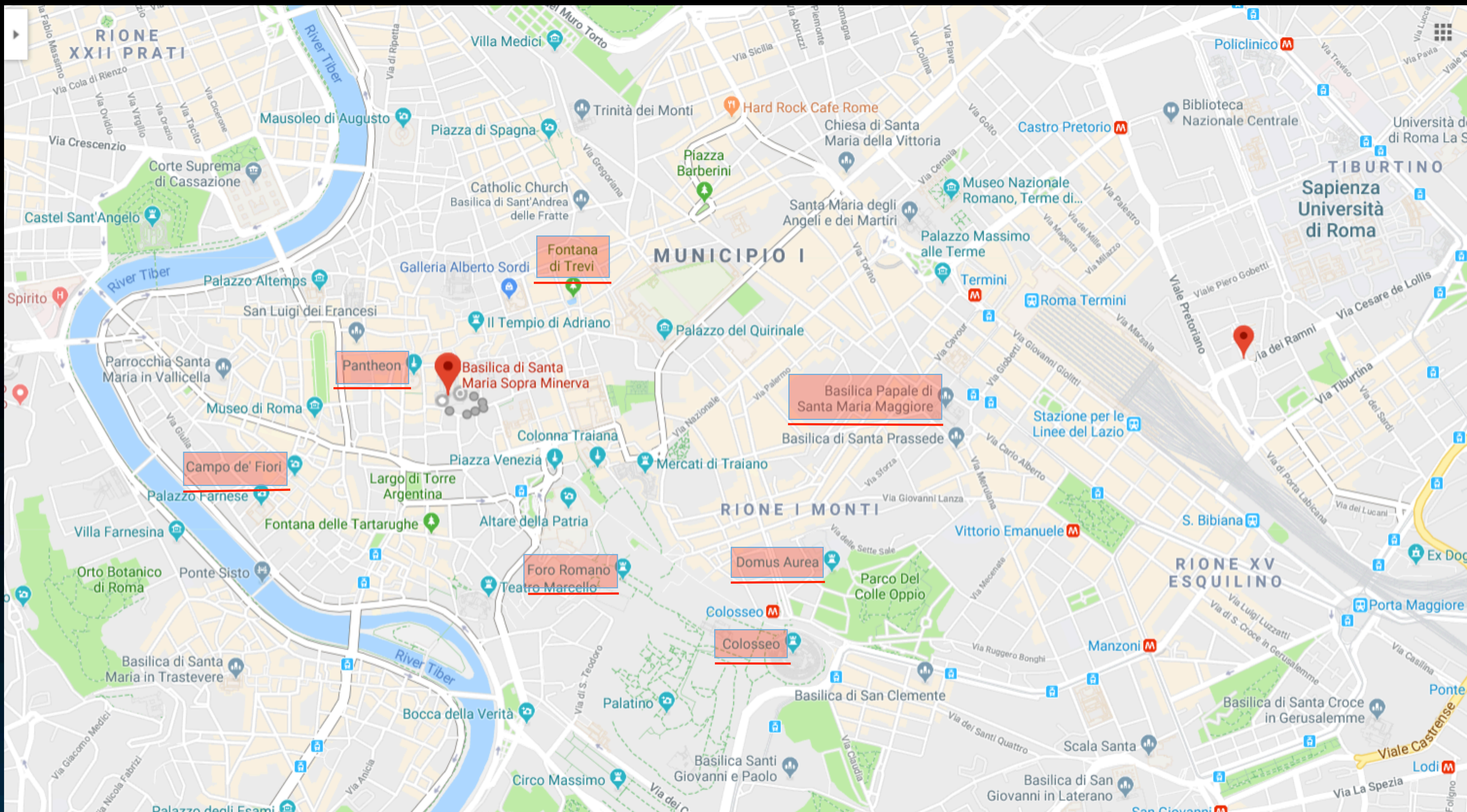
So Not This Kind of Roadmap…



But More Like This Kind of a Roadmap



2015 Roadmap Technology Areas and Breakdown Structure

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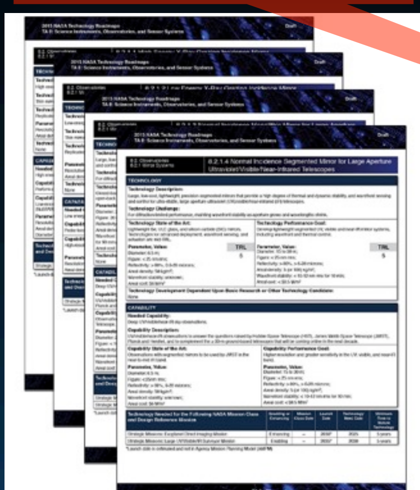
Technology Candidate Snapshots



TA 6 Human Health, Life Support, and Habitation Systems

6.1 Environmental Control and Life Support Systems and Habitation Systems
- 6.1.1 Air Revitalization
- 6.1.2 Water Recovery and Management
- 6.1.3 Waste Management
- 6.1.4 Habitation

6.2 Extravehicular Activity Systems
- 6.2.1 Pressure Garment
- 6.2.2 Portable Life Support System
- 6.2.3 Power, Avionics, and Software

6.3 Human Health and Performance
- 6.3.1 Medical Diagnosis and Prognosis
- 6.3.2 Long-Duration Health
- 6.3.3 Behavioral Health
- 6.3.4 Human Factors

6.4 Environmental Monitoring, Safety, and Emergency Response
- 6.4.1 Sensors: Air, Water, Microbial, and Acoustic
- 6.4.2 Fire: Detection, Suppression, and Recovery
- 6.4.3 Protective Clothing and Breathing
- 6.4.4 Remediation

6.5 Radiation
- 6.5.1 Risk Assessment Modeling
- 6.5.2 Radiation Mitigation and Biological Countermeasures
- 6.5.3 Protection Systems
- 6.5.4 Space Weather Prediction
- 6.5.5 Monitoring Technology

Summary of TA6 Top Level SOA vs. Deep Space Capabilities

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State of the Art (SOA)	Future Needed Capabilities
6.1 Environmental Control & Life Support Systems (ECLSS)	
- Earth-supplied consumables, expendables and replacement equipment	- Increased self-sufficiency
- Partially closed air and water loops	- Increased loop closure
- Some maintenance & reliability issues (<6 mo MTBF)	- High reliability (>2 yr MTBF)
6.2 Extravehicular Activity (EVA)	
- Short duration infrequent EVAs	- Increased frequency and duration EVAs (surface) (less mass, better mobility, enhanced life support)
- “Clean” environment of Earth-orbital missions	- Increased dust tolerance
6.3 Human Health & Performance (HHP)	
- Near real-time communication with Earth	- Increased autonomy due to communication time lags
- Exercise countermeasures for short u-g missions	- Countermeasures for long missions, variable-g
- Samples returned to Earth for analysis	- On-board diagnostic data
- Medical care evacuation strategy within hours	- On-board medical care and imaging
6.4 Environmental Monitoring, Safety, Emergency Response	
- Limited crew-intensive on-board capabilty	- On-board monitoring
- Sample return (water quality & microbial monitoring)	- On-board analysis; quantify organisms in air & water
- Smoke particle detector/single use CO_2 tanks	- Approach that works across lg. & sm. architecture elements (eliminate false positives, rechargeable)
6.5 Radiation	
- Earth’s magnetic field - Passive shielding on vehicle (polyethylene in CQ’s) - Relatively short mission durations	- Combination of improved SPE forecasting/storm shelter, shielding, biological countermeasures, and sensors/monitoring devices (low power, distributed)

Understanding the NASA TA6: Human Health, Life Support, and Habitation Systems Technology Roadmap, *with emphasis on Life Support*

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Technology Candidate Snapshots

TA 6 Human Health, Life Support, and Habitation Systems

6.1 Environmental Control and Life Support Systems and Habitation Systems	6.2 Extravehicular Activity Systems	6.3 Human Health and Performance	6.4 Environmental Monitoring, Safety, and Emergency Response	6.5 Radiation
6.1.1 Air Revitalization	6.2.1 Pressure Garment	6.3.1 Medical Diagnosis and Prognosis	6.4.1 Sensors: Air, Water, Microbial, and Acoustic	6.5.1 Risk Assessment Modeling
6.1.2 Water Recovery and Management	6.2.2 Portable Life Support System	6.3.2 Long-Duration Health	6.4.2 Fire: Detection, Suppression, and Recovery	6.5.2 Radiation Mitigation and Biological Countermeasures
6.1.3 Waste Management	6.2.3 Power, Avionics, and Software	6.3.3 Behavioral Health	6.4.3 Protective Clothing and Breathing	6.5.3 Protection Systems
6.1.4 Habitation		6.3.4 Human Factors	6.4.4 Remediation	6.5.4 Space Weather Prediction
				6.5.5 Monitoring Technology

Two Key Distinctions between Life Support SOA and Future Needed Capabilities

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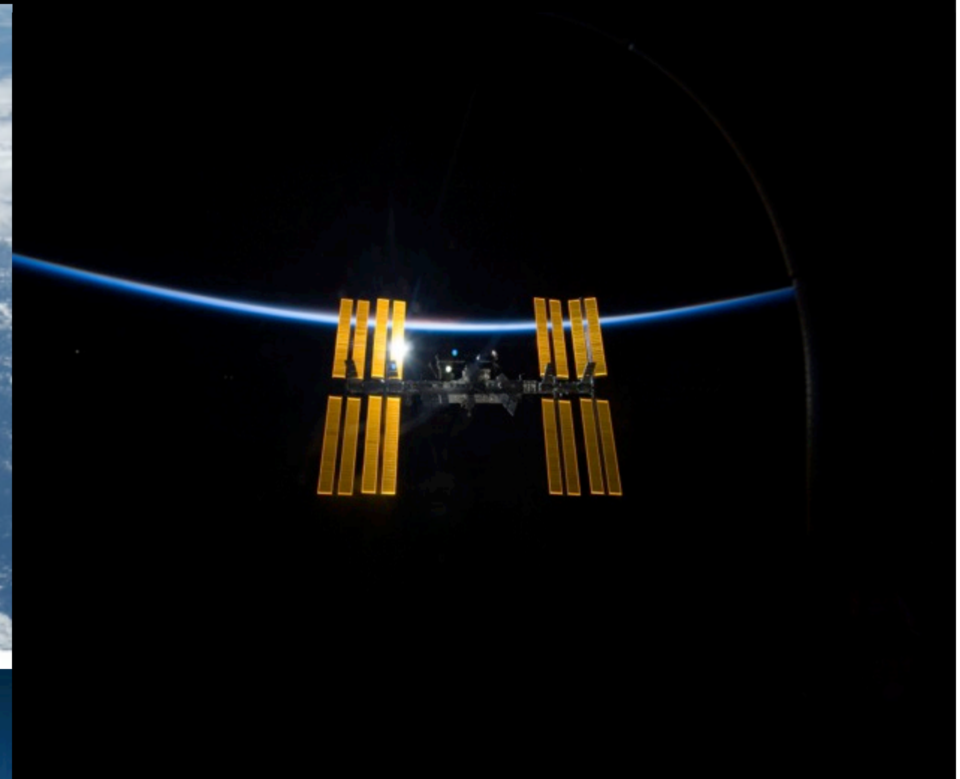
State of the Art Technology

- Near Earth for:
  - Stored consumables (water, oxygen, food)
  - Expendables (filters, sorbent beds),
  - Replacement equipment
- Quick abort/return option

Deep Space Capabilities

- Far from reliable logistics depots
- No quick return option



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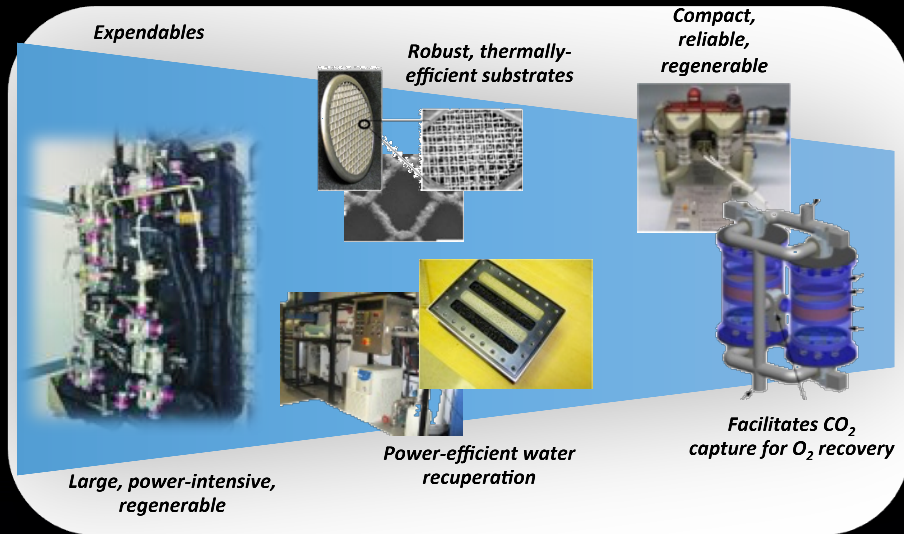
6.1.1 Air Revitalization



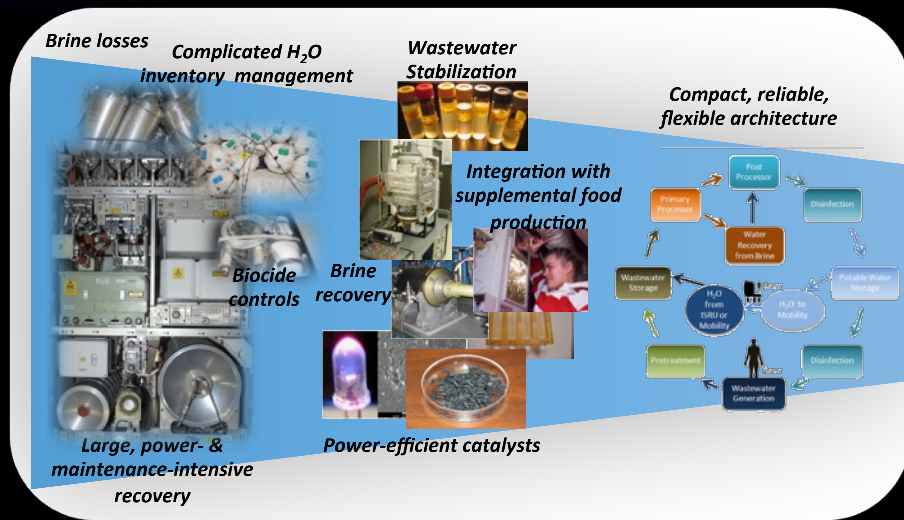
SOA

- CO_2 cabin concentrations >4mmHg (ppCO2) associated with crew health and performance issues
- CDRA – zeolite dust-related valve and air-save pump failures
- CRA - <50% of the CO_2 produced is recovered as O_2

Technology Challenges/Performance Goals

- Recover 75->90% O_2 from CO_2 (increased loop closure)
  - CO2 Removal – techs that maintain CO_2 cabin concentrations <2mmHg, lower maintenance
  - CO2 Reduction – increased O_2 recovery, catalyst life, moisture tolerance, carbon management
- Trace Contaminant Control – increased ability to maintain NH_3, VOCs, CO below SMAC
  - increased ability to recover water vapor (operate HXs below dew point)
- Support increased frequency and duration of EVAs – deliver 99.989% O_2 @ 3600psia

6.1.2 Water Recovery and Management



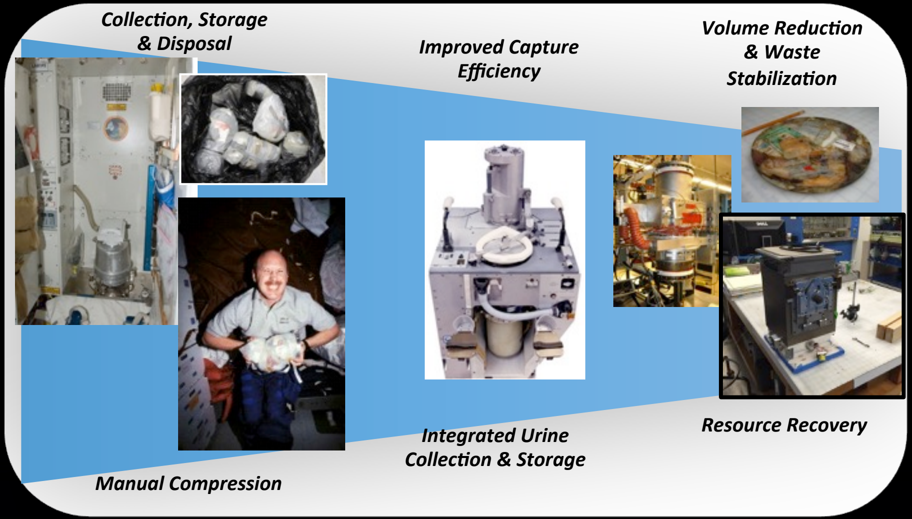
SOA

- ~88% total water recovery rate (from humidity condensate and urine)
- Consumables (0.032 kg/kg H_2O) – multi-filtration beds, ion exchange beds, O_2 (for VOC oxidation)
- Sensitivity to polar organic compounds limits housekeeping/hygiene products
- Recovers ~20% of anticipated deep space mission water volume (containing broader composition)

Technology Challenges/Performance Goals

- Achieve >98% total water recovery rate
  - Brine recovery (tolerance to precipitated solids, feed streams nearly saturated with organic & inorganic compounds)
  - Ability to process wastewater from multiple new sources (hygiene, CO_2 reduction product water, laundry, water from trash, solid wastes) & remain compatible with the water processor
- Provide long duration disinfection and microbial control of potable water
- Dormancy periods of up to 18 months without significant reactivation efforts (some missions)

6.1.3 Waste Management



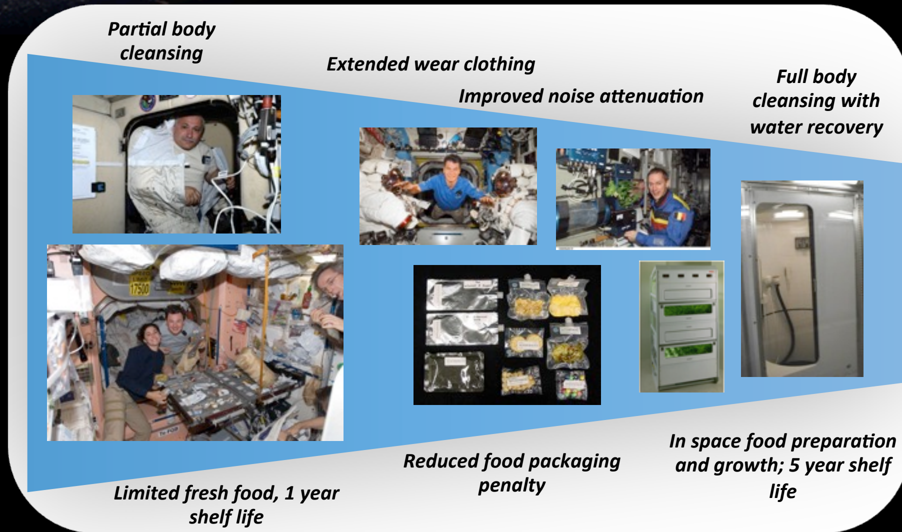
SOA

- Human Solid Waste
  - Collection via airflow entrainment
  - Containment in porous bags
  - Storage in canisters (disposed of in Progress modules/return to Earth)
- Urine
  - Collection through funnel & hose via airflow entrainment (urine and fecal escapes occur)
- Wet and Dry Trash
  - Collection and manual compression only
  - Storage in bags at ambient cabin temperature for up to 120 days (biologically active)

Technology Challenges/Performance Goals

- Commode – hygienically collect & store or process wastes for mixed crews; improved capture efficiency; compatible with water recovery and waste stabilization systems
- Trash – new processing functions to reduce volume (10x), provide biological stability (up to 3 yrs)
- Resource Recovery from trash and metabolic wastes (H_2O, CO_2, etc.)

6.1.4 Habitation



SOA (Crew quarters, hygiene supplies, clothing & linens, galley/food systems, cargo transfer bags)

- Hygiene - open-ended rack-sized compartment for partial body-cleansing with a wetted washcloth; moderate water containment; limited water recovery
- Clothing - ~0.2kg/person-day worn for short duration (days); manual laundering; produce lint; trash
- Noise – passive acoustic blankets with ~12dB attenuation/crew quarters
- Food systems – dehydrated; 1 yr shelf life; limited refrigerated/frozen/fresh; 15% packaging penalty

Technology Challenges/Performance Goals

- Hygiene - full body cleansing with >90% water recovery; compatible with ECLSS (volume, surfactants)
- Clothing - <0.1 kg/person-day extended wear; simple laundry w/ minimal water; minimal lint
- Noise – quiet fans; active noise attenuation >25dB in open cabin environment
- Food systems – 5 yr stability; reduced packaging; in space bulk preparation and fresh food capability

TA 7 Human Exploration Destination Systems

7.1 In-Situ Resource Utilization

7.1.1 Destination Reconnaissance, Prospecting, and Mapping

7.1.2 Resource Acquisition

7.1.3 Processing and Production

7.1.4 Manufacturing Products and Infrastructure Emplacement

7.2 Sustainability and Supportability

7.2.1 Autonomous Logistics Management

7.2.2 Maintenance Systems

7.2.3 Repair Systems

7.2.4 Food Production, Processing, and Preservation

7.3 Human Mobility Systems

7.3.1 EVA Mobility

7.3.2 Surface Mobility

7.3.3 Off-Surface Mobility

7.4 Habitat Systems

7.4.1 Integrated Habitat Systems

7.4.2 Habitat Evolution

7.4.3 "Smart" Habitats

7.4.4 Artificial Gravity

7.5 Mission Operations and Safety

7.5.1 Crew Training

7.5.2 Planetary Protection

7.5.3 Integrated Flight Operations Systems

7.5.4 Integrated Risk Assessment Tools

7.6 Cross-Cutting Systems

7.6.1 Particulate Contamination Prevention and Mitigation

7.6.2 Construction and Assembly

TA 7 – 7.2 Sustainability & Supportability

- 7.2.4 Food Production, Processing and Preservation (including packaging, storage, preparation)
  - Objectives: Reduce the quantity of food being resupplied. Reduce the mass and volume of food packaging.
  - Challenges: Certify ingredient functionality, proper nutrition, sanitation, bulk stowage. Provide in-space food growth, processing, and preparation in gravity and radiation environments of mission destinations.

✓ ***Benefits of Technology***

Current space food is double-packaged to increase shelf life. However, current shelf life will not support missions lasting three or more years.

- 7.2.4.1 Bioregenerative Food System
  - The challenge to the development of this technology is to be able to certify ingredient functionality, proper nutrition, sanitation, bulk stowage, and food growth, processing, and preparation. All of this would need to be demonstrated in the gravity and radiation environments of the Design Reference Missions, with particular shelf life and delivery plans.

Conclusions

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- There has been a recognized need for NASA to replenish and strengthen its advanced technology development base.

- In response to congressional direction, the NASA Technology Roadmaps are a set of documents that identify a wide range of needed technology candidates and development pathways to enable human exploration beyond low-Earth orbit.

- The 2015 roadmap update incorporated NRC recommendations, broad participation from NASA field centers, other government agencies, academia, the commercial space sector and the public, and ensured traceability of all candidate technologies to NASA's Capability Driven Framework.

- NASA is using the roadmaps in their technology development solicitations

  Examples
  NASA Innovative Advanced Concepts (NAIC), Phase I
  NASA Innovative Advanced Concepts (NIAC) Phase II
  Cooperative Agreement Notice (CAN) Experimental Program To Stimulate Competitive Research (EPSCOR)
  Cooperative Agreement Notice (CAN) Technology Advancing Partnerships (Kennedy Space Center)
  Space Technology Research Grants Program, Early Stage Innovations, (NRA)
  Space Technology Research, Development, Demonstration, and Infusion (SpaceTech-REDDI)
  Game Changing Development Program, Advanced Oxygen Recovery For Spacecraft Life Support Systems

- As the roadmaps are updated every four years, they are intended to serve as the basis for technology portfolio assessment and prioritization, and as the foundation upon which to achieve the first ever human missions beyond the Moon into deep space.

Acknowledgements

NASA2015 Technology Roadmaps Available at:

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

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