EXPLORESPACE TECH

TECHNOLOGY DRIVES EXPLORATION

Strategic Technology Plan
Midterm Review
Advanced Materials, Structures, and Manufacturing (AMSM)

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STMD Strategic Framework

LEAD

Ensuring American global leadership in Space Technology

- **Lunar Exploration building to Mars and new discoveries at extreme locations**
- **Robust national space technology engine to meet national needs**
- **U.S. economic growth for space industry**
- **Expanded commercial enterprise in space**

Note: Multiple Capabilities are cross cutting and support multiple Thrusts. Primary emphasis is shown

THRUSTS	CAPABILITIES
Go ***Rapid, Safe, & Efficient Space Transportation***	• Advanced Propulsion • Cryogenic Fluid Management
Land ***Expanded Access to Diverse Surface Destinations***	• Human & Robotic Entry, Descent and Landing • Precision Landing
Live ***Sustainable Living and Working Farther from Earth***	• Advanced life support and human performance • Advanced Materials, Structures and Manufacturing • Advanced Power Systems • In-situ Propellant and Consumable Production • Autonomous Systems and Robotics
Explore ***Transformative Missions and Discoveries***	• On-Orbit Servicing, Assembly and Manufacturing • Small Spacecraft Technologies • Advanced Avionics • Advanced Communications and Navigation

Revision date: May 26, 2020

STMD Strategic Outcomes

LEAD

Ensuring American global leadership in Space Technology

- **Lunar Exploration building to Mars and new discoveries at extreme locations**
- **Robust national space technology engine to meet national needs**
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THRUSTS	*OUTCOMES*
Go ***Rapid, Safe, & Efficient Space Transportation***	• Enable Human Earth-to-Mars Round Trip mission durations less than 750 days. • Enable rapid, low cost delivery of robotic payloads to Moon, Mars and beyond. • Enable reusable, safe launch and in-space propulsion systems that reduce launch and operational costs/complexity and leverage potential destination based ISRU for propellants.
Land ***Expanded Access to Diverse Surface Destinations***	• Enable Lunar and Mars Global Access with ~20t payloads to support human missions. • Land Payloads within 50 meters accuracy while also avoiding local landing hazards.
Live ***Sustainable Living and Working Farther from Earth***	• Conduct Human/Robotic Lunar Surface Missions in excess of 28 days without resupply. • Conduct Human Mars Missions in excess of 800 days including transit without resupply. • Provide greater than 75% of propellant and water/air consumables from local resources for Lunar and Mars missions. • Enable Surface habitats that utilize local construction resources. • Enable Intelligent robotic systems augmenting operations during crewed and un-crewed mission segments.
Explore ***Transformative Missions and Discoveries***	• Enable new discoveries at the Moon, Mars and other extreme locations. • Enable new architectures that are more rapid, affordable, or capable than previously achievable. • Enable new approaches for in-space servicing, assembly and manufacturing. • Enable next generation space data processing with higher performance computing, communications and navigation in harsh deep space environments.

Note: Multiple Capabilities are cross cutting and support multiple Thrusts. Primary emphasis is shown

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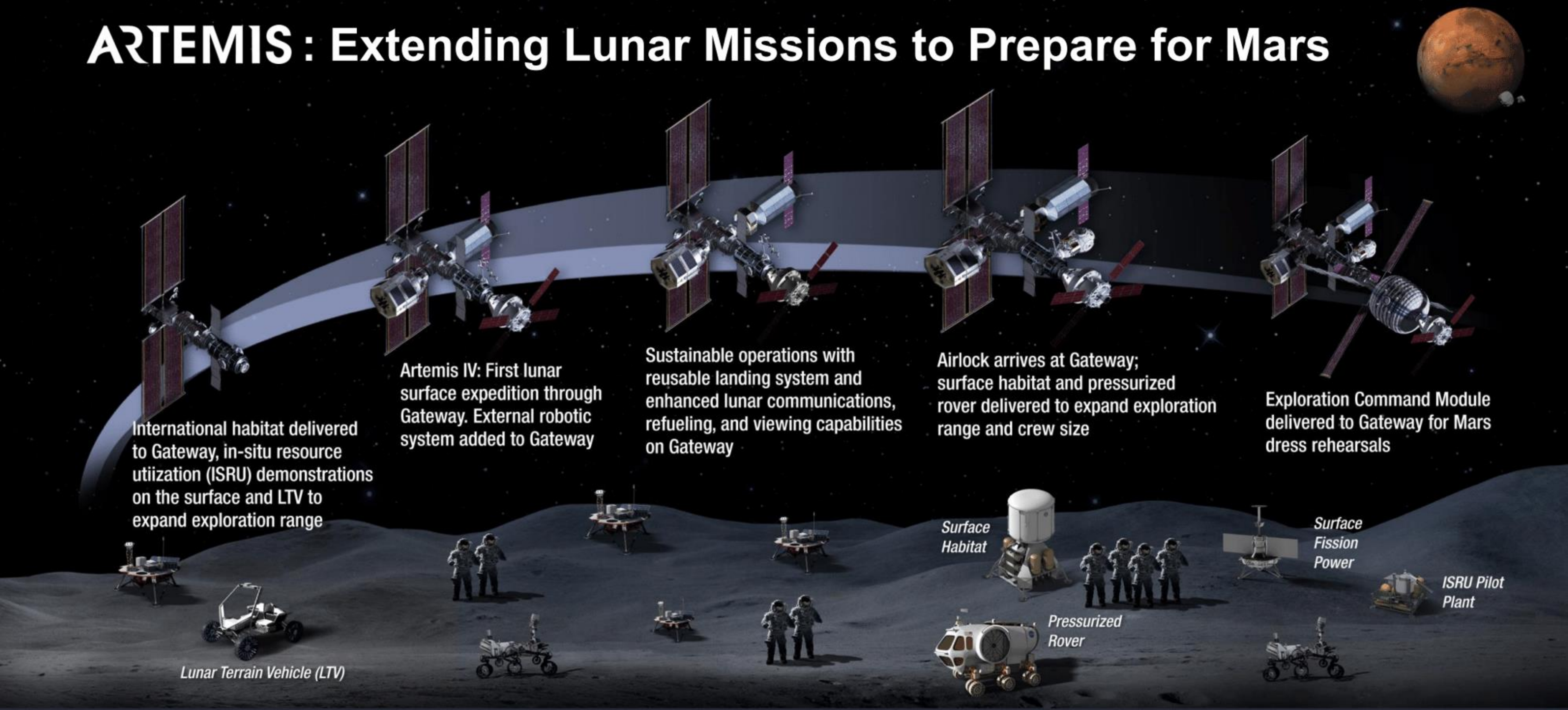
ARTEMIS : Extending Lunar Missions to Prepare for Mars



International habitat delivered to Gateway, in-situ resource utiization (ISRU) demonstrations on the surface and LTV to expand exploration range

Artemis IV: First lunar surface expedition through Gateway. External robotic system added to Gateway

Sustainable operations with reusable landing system and enhanced lunar communications, refueling, and viewing capabilities on Gateway

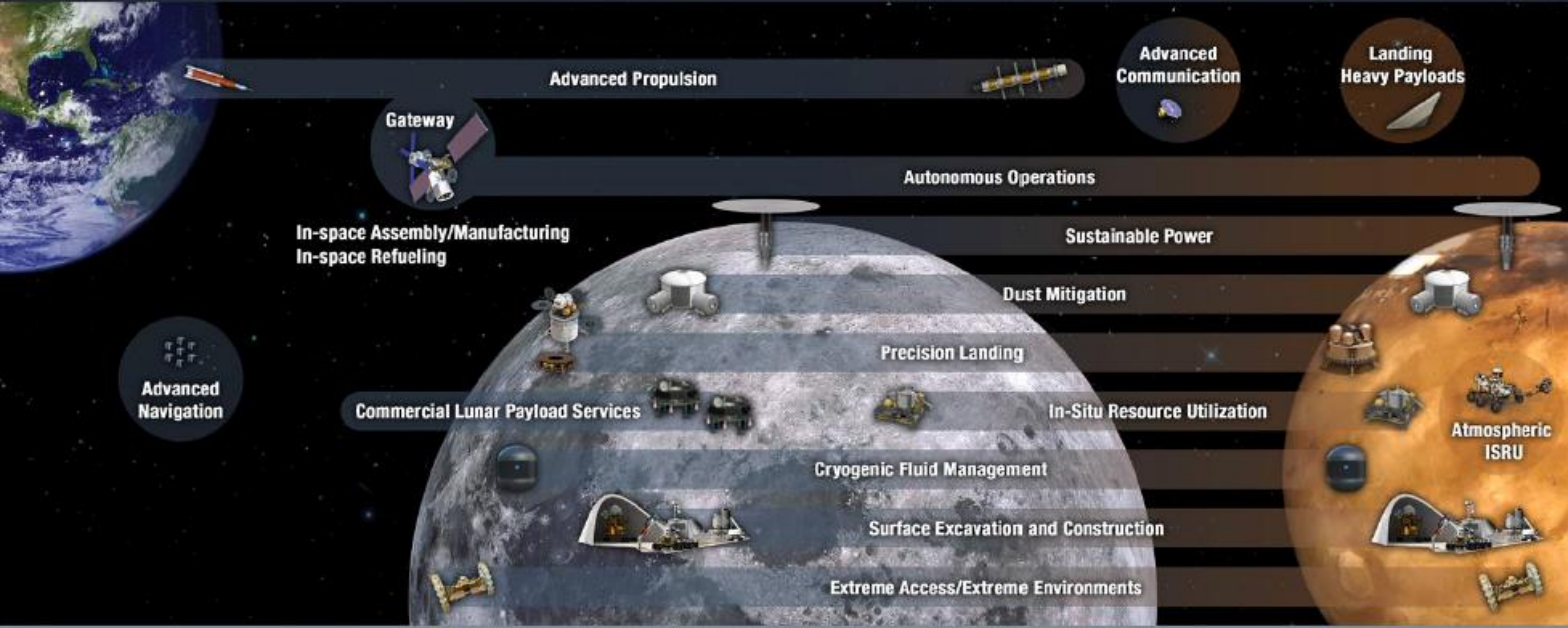
Airlock arrives at Gateway; surface habitat and pressurized rover delivered to expand exploration range and crew size

Exploration Command Module delivered to Gateway for Mars dress rehearsals

SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

GO	LAND	LIVE	EXPLORE
Rapid, Safe, and Efficient Space Transportation	Expanded Access to Diverse Surface Destinations	Sustainable Living and Working Farther from Earth	Transformative Missions and Discoveries


Advanced Propulsion

Advanced Communication

Landing Heavy Payloads

Gateway

Autonomous Operations

In-space Assembly/Manufacturing
In-space Refueling

Sustainable Power

Dust Mitigation

Precision Landing

Advanced Navigation

Commercial Lunar Payload Services

In-Situ Resource Utilization

Atmospheric ISRU

Cryogenic Fluid Management

Surface Excavation and Construction

Extreme Access/Extreme Environments

2020

Space Technology Strategy

203X

SPACE TECHNOLOGY PORTFOLIO

AMSM Across the Technology Pipeline

EARLY STAGE INNOVATION

- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/ Early Career Initiative

PARTNERSHIPS AND TECHNOLOGY TRANSFER

- Technology Transfer
- Prizes and Challenges
- iTech

SBIR/STTR PROGRAMS

- Small Business Innovation Research
- Small Business Technology Transfer

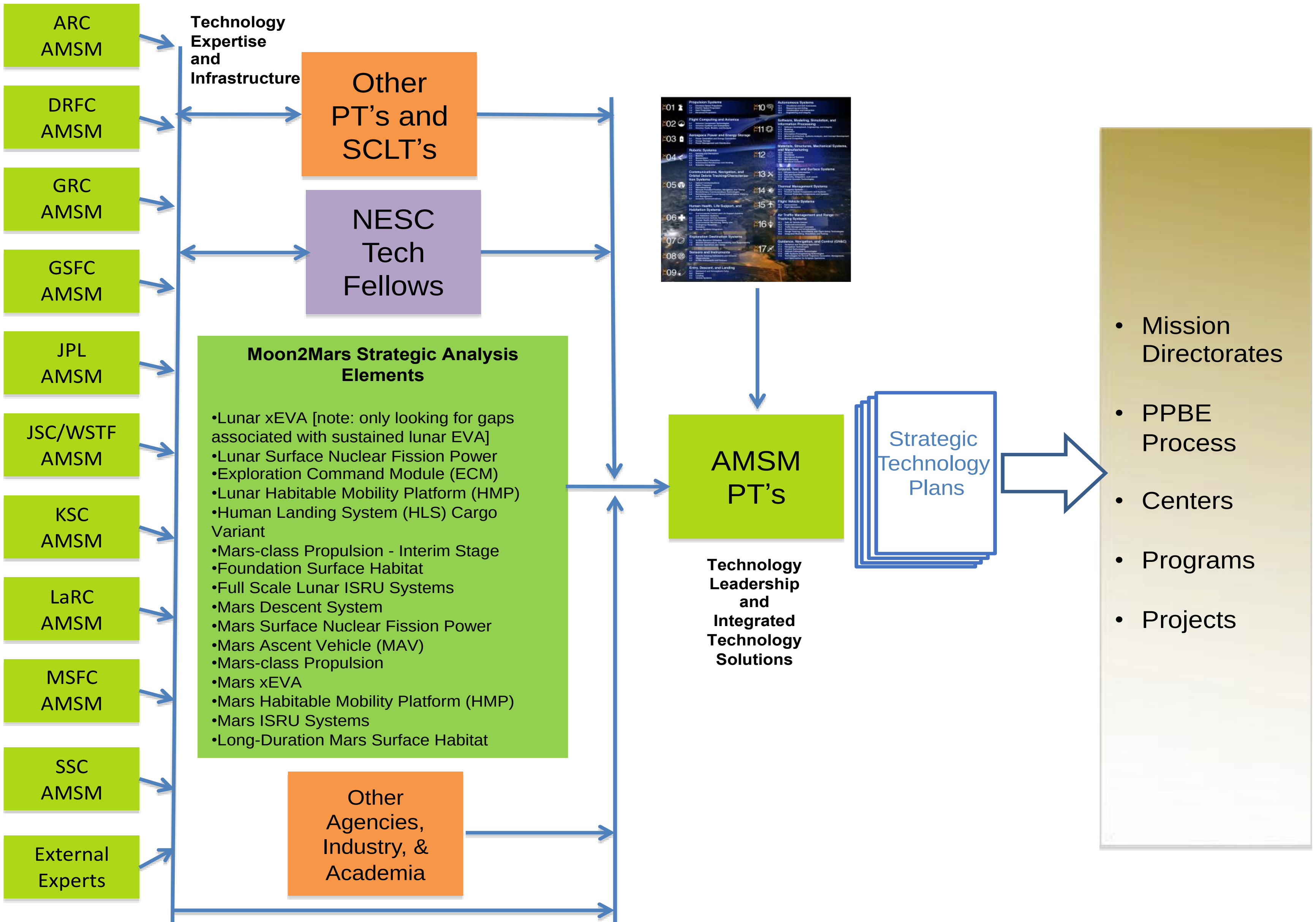
TECHNOLOGY MATURATION

- Game Changing Development
- Lunar Surface Innovation Initiative

TECHNOLOGY DEMONSTRATIONS

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

Integrated AMSM Strategy



ARC AMSM

DRFC AMSM

GRC AMSM

GSFC AMSM

JPL AMSM

JSC/WSTF AMSM

KSC AMSM

LaRC AMSM

MSFC AMSM

SSC AMSM

External Experts

Technology Expertise and Infrastructure

Other PT's and SCLT's

NESC Tech Fellows

Moon2Mars Strategic Analysis Elements

- Lunar xEVA [note: only looking for gaps associated with sustained lunar EVA]
- Lunar Surface Nuclear Fission Power
- Exploration Command Module (ECM)
- Lunar Habitable Mobility Platform (HMP)
- Human Landing System (HLS) Cargo Variant
- Mars-class Propulsion - Interim Stage
- Foundation Surface Habitat
- Full Scale Lunar ISRU Systems
- Mars Descent System
- Mars Surface Nuclear Fission Power
- Mars Ascent Vehicle (MAV)
- Mars-class Propulsion
- Mars xEVA
- Mars Habitable Mobility Platform (HMP)
- Mars ISRU Systems
- Long-Duration Mars Surface Habitat

Other Agencies, Industry, & Academia

TX01 Propulsion Systems
TX02 Flight Computing and Avionics
TX03 Aerospace Power and Energy Storage
TX04 Robotic Systems
TX05 Communications, Navigation, and Orbital Debris Tracking/Characterization Systems
TX06 Human Health, Life Support, and Habitation Systems
TX07 Exploration Destination Systems
TX08 Sensors and Instruments
TX09 Entry, Descent, and Landing
TX10 Autonomous Systems
TX11 Software, Modeling, Simulation, and Information Processing
TX12 Materials, Structures, Mechanical Systems, and Manufacturing
TX13 Ground, Test, and Surface Systems
TX14 Thermal Management Systems
TX15 Flight Vehicle Systems
TX16 Air Traffic Management and Range Tracking Systems
TX17 Guidance, Navigation, and Control (GN&C)

AMSM PT's

Technology Leadership and Integrated Technology Solutions

Strategic Technology Plans

- Mission Directorates
- PPBE Process
- Centers
- Programs
- Projects

Advanced Materials, Structures, and Manufacturing Strategic Technology Plan (AMSM STP)

Table of Contents

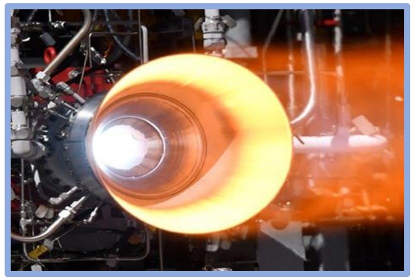
- **Preface** : Boilerplate Common to all plans
- **Section 1: Capability Area**
    - **1.1 Description and Scope**
    - **1.2 Architecture Applicability & Capability Specific Outcomes**
- **Section 2: Architecture Technology & High Risk Development Gaps**
    - **2.1 Overview**
    - **2.2 Technology & High-Risk Development Gaps Index** *(Repeat Section 2.2.x. for each Gap)*
        - **2.2.x Gap Title*** * ECDT raw data input for M2M architectures
        - **2.2.x.1 Gap Definition***
        - **2.2.x.2 Gap Closure Plan**
        - **2.2.x.3 Gap Technical Challenge Assumptions and Dependencies**
- **Section 3: Push Technology and Transformative Approaches**
    - **3.1 Strategy**
    - **3.2 Push Technology and Transformative Approach Concepts**
        - **3.1.1 Low TRL "Pulse" Discussion**
        - **3.1.2 NASA Investments**
- **Section 4: Forward Plans:** Boilerplate Common to all plans
    - **4.1 NASA Internal Usage**
    - **4.2 Industry and Public Engagement**
    - **4.3 International Engagement**

Description and Scope – Executive Summary

- **This Strategic Technology Plan (STP) describes the *Advanced Materials, Structures, and Manufacturing* (AMSM) technologies used in the design, development, manufacture, construction, and certification of spaceflight and exploration system hardware elements for NASA missions.**
- **AMSM technologies have a wide range of potential applications including crewed and uncrewed - launch vehicles, in-space transportation, landers, surface infrastructure and construction, satellites, science platforms, and commercial space systems.**
- **AMSM applications to subsystems within these larger systems cross over into many different disciplines such as, advanced propulsion; cryogenic fluid management; entry, decent and landing; in situ resource utilization; life support and habitat systems; and power generation.**
- **Strategic planning across Centers, MD's, OGA's, industry, academia, and international.**
- **Commercial impact - A 2018 NIST-commissioned report estimates the potential economic benefit of an improved materials innovation infrastructure for the United States to be between $123 billion and $270 billion per year.**
- **AMSM technology advancement is never finished, it is a work in progress and requires support across the technology pipeline to fully leverage current research and development investments and sustain the innovation ecosystem.**

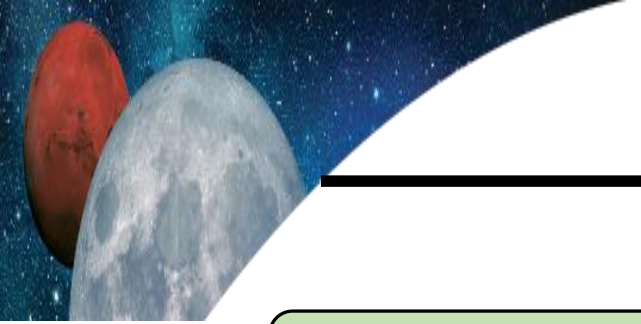
Description and Scope – Executive Summary

- The scope of AMSM technologies is significant and includes sixteen different technology categories and 63 sub-categories across the AMSM domain
- AMSM applications and technology areas are diverse, several overarching themes are present and include:
  - Lightweight Materials and Structures
  - Materials and Structures for Extreme Environments
  - Multifunctional and Specialized Materials and Structures
  - Advanced Manufacturing Processes
  - Model-based Technologies for Materials, Structures, and Manufacturing
  - Lunar Surface Excavation, Manufacturing and Construction
  - Materials and Manufacturing Research and Technology for the Commercialization of Space

Materials Technology Taxonomy

- Lightweight Structural Materials
  - Advanced Alloys
  - Advanced Composites
  - Engineered Materials
  - Nanomaterials
- Computational Materials
  - Multiscale Modeling
  - Multiphysics Modeling
  - Materials Design and Tailoring
  - Durability, Damage Tolerance & Life Prediction
  - Test Methods & Instruments
- Flexible Materials
  - Flexible Structural Materials
  - Fabrics
  - Materials for Soft Robotics
  - Materials for Flexible Sensors and Electronics
- Materials for Extreme Environments
  - High-Temperature
  - Low-Temperature
  - Dust and Wear Resistant
  - Radiation Protection and Resistance
  - Coatings
- Materials with Specialized Functions
  - Multifunctional Materials
  - Adhesives
  - Self-Sensing and Self-Repair
  - Smart Materials
  - Power Generation & Energy Storage
- Materials for Advanced Manufacturing and Construction
  - Materials for Additive Manufacturing
  - Materials for ISRU-Based Construction
  - Repurposable & Recyclable Materials



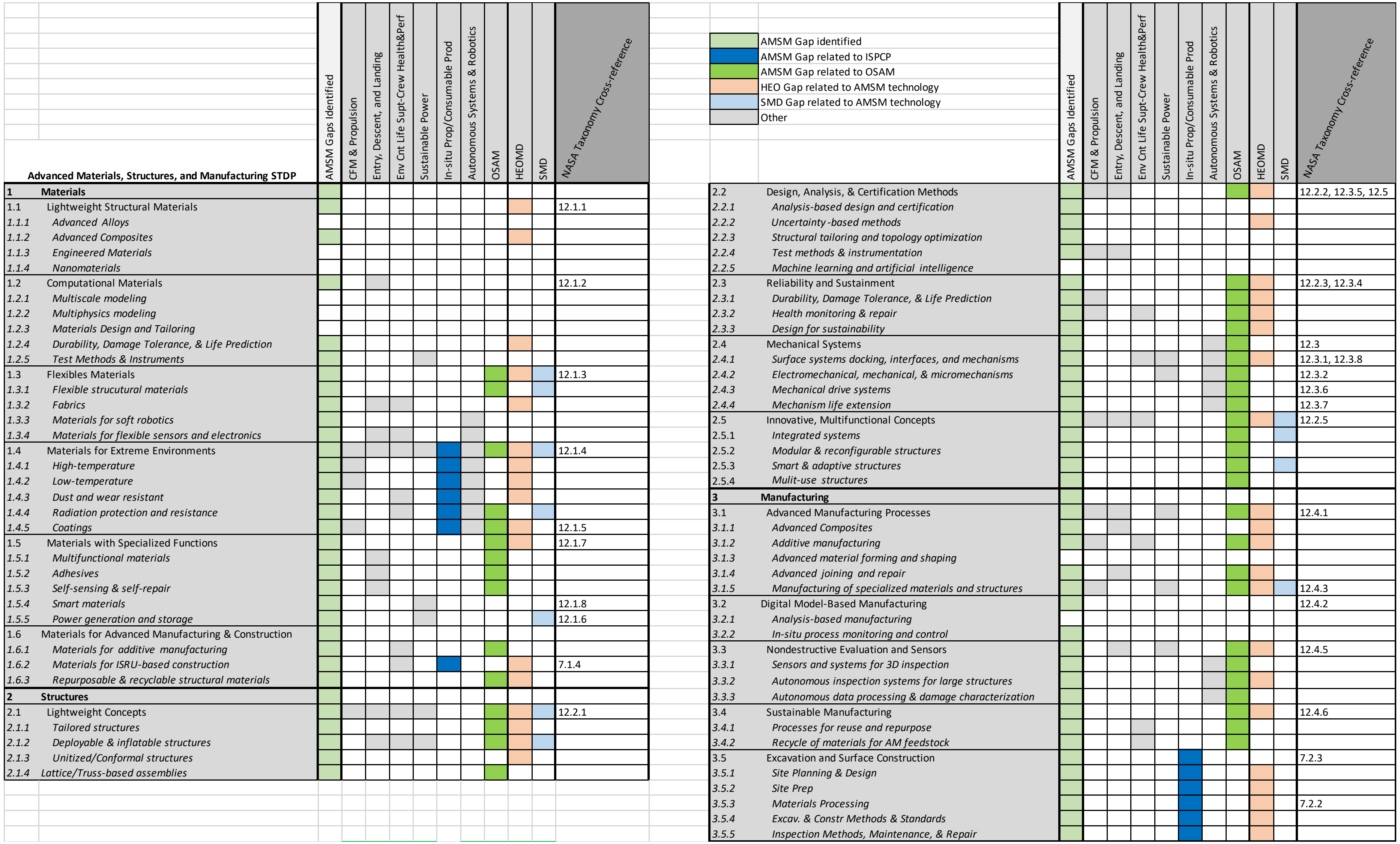
Structures Technology Taxonomy

- Lightweight Concepts
  - Tailored Structures
  - Deployable & Inflatable Struc.
  - Unitized/Conformal Structures
  - Lattice/Truss-Based Assemblies
- Design, Analysis, and Certification Methods
  - Analysis-Based Design & Cert.
  - Uncertainty-Based Methods
  - Structural Tailoring & Topology Optimization
  - Test Methods and Instrumentation
  - Machine Learning and Artificial Intelligence
- Reliability and Sustainment
  - Durability, Damage Tolerance, & Life Assessment
  - Health Monitoring & Repair
  - Design for Sustainability
- Innovative, Multifunctional Concepts
  - Integrated Systems
  - Modular & Reconfigurable Structures
  - Smart and Adaptive Structures
  - Multi-Use Structures
- Mechanical Systems
  - Surface System Docking and Interfaces
  - Elec-mech, Mech, Micromech.
  - Mechanical Drive Systems
  - Mechanism Life Extension

Manufacturing Technology Taxonomy

- Advanced Manufacturing Processes
  - Advanced Composites
  - Additive Manufacturing
  - Advanced Material Forming & Shaping
  - Advanced Joining & Repair
  - Specialized Materials and Structures
- Digital Model-Based Manufacturing
  - Analysis-Based Manufacturing
  - In-Situ Process Monitoring and Control
- Nondestructive Evaluation
  - Sensors and Systems for 3D Inspection
  - Autonomous Inspection Systems for Large Structures
  - Autonomous Data Processing & Damage Characterization
- Sustainable Manufacturing
  - Design for Reuse
  - Recycle of Metals and Composites for AM Feedstock
- Excavation and Surface Construction
  - Site Planning & Design
  - Site Prep
  - Materials Processing
  - Excav. & Constr. Methods and Standards
  - Inspection Methods Maintenance & Repair

Cross-Cutting AMSM Applications

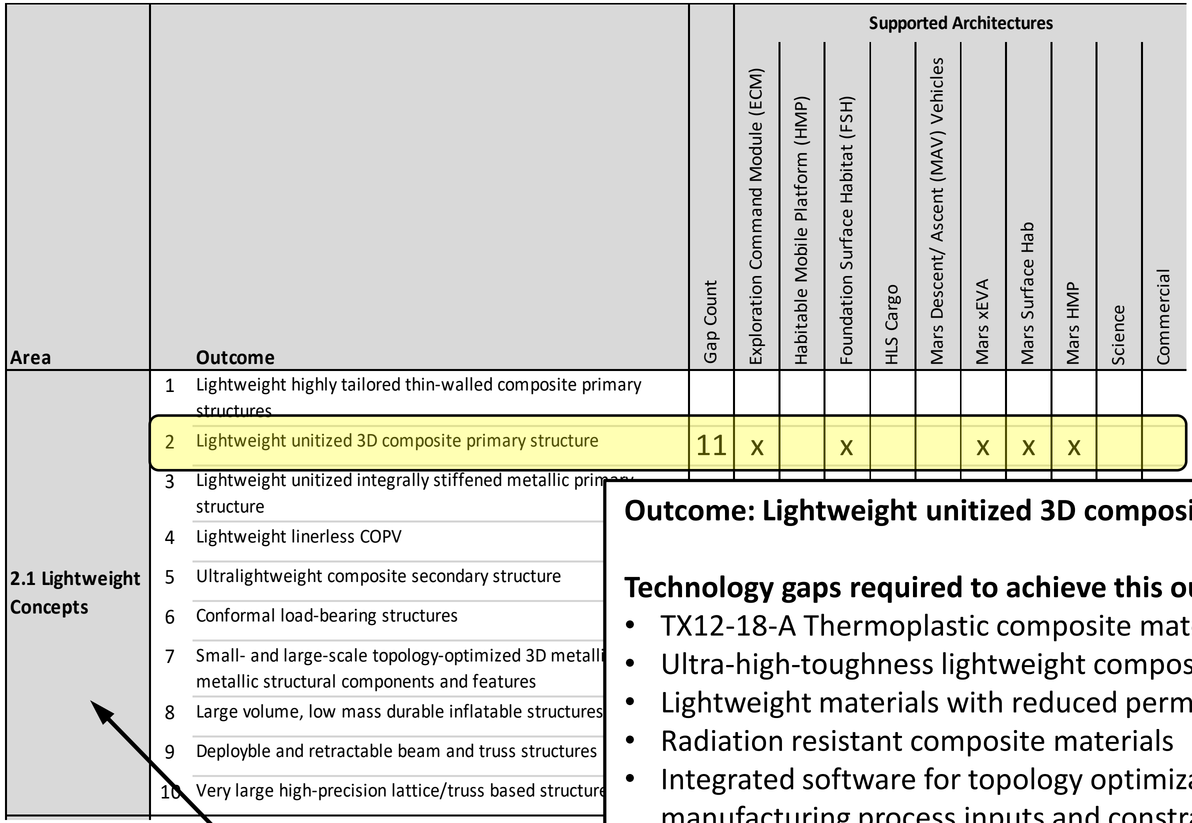


🟩	AMSM Gap identified
🟦	AMSM Gap related to ISPCP
🟢	AMSM Gap related to OSAM
🟧	HEO Gap related to AMSM technology
🔹	SMD Gap related to AMSM technology
▨	Other

	Advanced Materials, Structures, and Manufacturing STDP	AMSM Gaps Identified	CFM & Propulsion	Entry, Descent, and Landing	Env Cnt Life Supt-Crew Health&Perf	Sustainable Power	In-situ Prop/Consumable Prod	Autonomous Systems & Robotics	OSAM	HEOMD	SMD	NASA Taxonomy Cross-reference
1	**Materials**	🟩										
1.1	Lightweight Structural Materials	🟩								🟧		12.1.1
1.1.1	*Advanced Alloys*											
1.1.2	*Advanced Composites*	🟩								🟧		
1.1.3	*Engineered Materials*											
1.1.4	*Nanomaterials*											
1.2	Computational Materials	🟩		▨								12.1.2
1.2.1	*Multiscale modeling*											
1.2.2	*Multiphysics modeling*											
1.2.3	*Materials Design and Tailoring*											
1.2.4	*Durability, Damage Tolerance, & Life Prediction*	🟩								🟧		
1.2.5	*Test Methods & Instruments*	🟩				▨						
1.3	Flexibles Materials	🟩							🟢	🟧	🔹	12.1.3
1.3.1	*Flexible strucutural materials*	🟩							🟢		🔹	
1.3.2	*Fabrics*	🟩		▨	▨					🟧		
1.3.3	*Materials for soft robotics*	🟩						▨				
1.3.4	*Materials for flexible sensors and electronics*	🟩		▨	▨			▨				
1.4	Materials for Extreme Environments	🟩	▨	▨	▨	▨	🟦	▨	🟢	🟧	🔹	12.1.4
1.4.1	*High-temperature*	🟩	▨				🟦	▨		🟧		
1.4.2	*Low-temperature*	🟩	▨				🟦	▨		🟧		
1.4.3	*Dust and wear resistant*	🟩			▨		🟦	▨		🟧		
1.4.4	*Radiation protection and resistance*	🟩			▨		🟦	▨	🟢		🔹	
1.4.5	*Coatings*	🟩	▨				🟦	▨	🟢	🟧		12.1.5
1.5	Materials with Specialized Functions	🟩							🟢	🟧		12.1.7
1.5.1	*Multifunctional materials*	🟩		▨					🟢			
1.5.2	*Adhesives*	🟩		▨					🟢			
1.5.3	*Self-sensing & self-repair*	🟩		▨					🟢			
1.5.4	*Smart materials*	🟩				▨						12.1.8
1.5.5	*Power generation and storage*	🟩				▨					🔹	12.1.6
1.6	Materials for Advanced Manufacturing & Construction	🟩										
1.6.1	*Materials for additive manufacturing*	🟩			▨				🟢			
1.6.2	*Materials for ISRU-based construction*	🟩			▨		🟦			🟧		7.1.4
1.6.3	*Repurposable & recyclable structural materials*	🟩							🟢	🟧		
2	**Structures**	🟩										
2.1	Lightweight Concepts	🟩	▨	▨	▨	▨			🟢	🟧	🔹	12.2.1
2.1.1	*Tailored structures*	🟩							🟢	🟧		
2.1.2	*Deployable & inflatable structures*	🟩		▨	▨	▨			🟢	🟧	🔹	
2.1.3	*Unitized/Conformal structures*	🟩								🟧		
2.1.4	*Lattice/Truss-based assemblies*	🟩							🟢			

		AMSM Gaps Identified	CFM & Propulsion	Entry, Descent, and Landing	Env Cnt Life Supt-Crew Health&Perf	Sustainable Power	In-situ Prop/Consumable Prod	Autonomous Systems & Robotics	OSAM	HEOMD	SMD	NASA Taxonomy Cross-reference
2.2	Design, Analysis, & Certification Methods	🟩	▨	▨					🟢	🟧		12.2.2, 12.3.5, 12.5
2.2.1	*Analysis-based design and certification*	🟩										
2.2.2	*Uncertainty -based methods*	🟩								🟧		
2.2.3	*Structural tailoring and topology optimization*	🟩										
2.2.4	*Test methods & instrumentation*	🟩	▨	▨								
2.2.5	*Machine learning and artificial intelligence*											
2.3	Reliability and Sustainment	🟩							🟢	🟧		12.2.3, 12.3.4
2.3.1	*Durability, Damage Tolerance, & Life Prediction*	🟩	▨						🟢	🟧		
2.3.2	*Health monitoring & repair*	🟩	▨		▨				🟢	🟧		
2.3.3	*Design for sustainability*	🟩							🟢	🟧		
2.4	Mechanical Systems	🟩						▨	🟢			12.3
2.4.1	*Surface systems docking, interfaces, and mechanisms*	🟩			▨	▨		▨	🟢	🟧		12.3.1, 12.3.8
2.4.2	*Electromechanical, mechanical, & micromechanisms*	🟩				▨		▨	🟢			12.3.2
2.4.3	*Mechanical drive systems*	🟩						▨	🟢			12.3.6
2.4.4	*Mechanism life extension*	🟩						▨	🟢			12.3.7
2.5	Innovative, Multifunctional Concepts	🟩	▨	▨	▨				🟢	🟧	🔹	12.2.5
2.5.1	*Integrated systems*	🟩							🟢		🔹	
2.5.2	*Modular & reconfigurable structures*	🟩							🟢			
2.5.3	*Smart & adaptive structures*	🟩							🟢		🔹	
2.5.4	*Mulit-use structures*	🟩							🟢			
3	**Manufacturing**	🟩										
3.1	Advanced Manufacturing Processes	🟩	▨	▨		▨			🟢	🟧		12.4.1
3.1.1	*Advanced Composites*	🟩		▨						🟧		
3.1.2	*Additive manufacturing*	🟩	▨		▨				🟢	🟧		
3.1.3	*Advanced material forming and shaping*											
3.1.4	*Advanced joining and repair*	🟩		▨					🟢	🟧		
3.1.5	*Manufacturing of specialized materials and structures*	🟩	▨			▨			🟢	🟧	🔹	12.4.3
3.2	Digital Model-Based Manufacturing	🟩										12.4.2
3.2.1	*Analysis-based manufacturing*											
3.2.2	*In-situ process monitoring and control*	🟩										
3.3	Nondestructive Evaluation and Sensors	🟩		▨		▨			🟢	🟧		12.4.5
3.3.1	*Sensors and systems for 3D inspection*	🟩						▨	🟢			
3.3.2	*Autonomous inspection systems for large structures*	🟩						▨	🟢	🟧		
3.3.3	*Autonomous data processing & damage characterization*	🟩						▨	🟢			
3.4	Sustainable Manufacturing	🟩							🟢	🟧		12.4.6
3.4.1	*Processes for reuse and repurpose*	🟩			▨				🟢			
3.4.2	*Recycle of materials for AM feedstock*	🟩			▨				🟢			
3.5	Excavation and Surface Construction	🟩					🟦					7.2.3
3.5.1	*Site Planning & Design*	🟩					🟦			🟧		
3.5.2	*Site Prep*	🟩					🟦			🟧		
3.5.3	*Materials Processing*	🟩					🟦			🟧		7.2.2
3.5.4	*Excav. & Constr Methods & Standards*	🟩					🟦			🟧		
3.5.5	*Inspection Methods, Maintenance, & Repair*	🟩					🟦			🟧		

Gaps Linked to Outcomes and Architectures



Area		Outcome	Gap Count	Supported Architectures Exploration Command Module (ECM)	Habitable Mobile Platform (HMP)	Foundation Surface Habitat (FSH)	HLS Cargo	Mars Descent/ Ascent (MAV) Vehicles	Mars xEVA	Mars Surface Hab	Mars HMP	Science	Commercial
2.1 Lightweight Concepts	1	Lightweight highly tailored thin-walled composite primary structures											
	2	Lightweight unitized 3D composite primary structure	11	X		X			X	X	X		
	3	Lightweight unitized integrally stiffened metallic prim structure											
	4	Lightweight linerless COPV											
	5	Ultralightweight composite secondary structure											
	6	Conformal load-bearing structures											
	7	Small- and large-scale topology-optimized 3D metalli metallic structural components and features											
	8	Large volume, low mass durable inflatable structures											
	9	Deployble and retractable beam and truss structures											
	10	Very large high-precision lattice/truss based structure											

1 of 16 technology areas

Outcome: Lightweight unitized 3D composite primary structure

Technology gaps required to achieve this outcome are as follows:
- TX12-18-A Thermoplastic composite materials for unitized primary structures
- Ultra-high-toughness lightweight composites
- Lightweight materials with reduced permeability and outgassing
- Radiation resistant composite materials
- Integrated software for topology optimization of composite components with manufacturing process inputs and constraints
- High-fidelity physics-based structural simulations for design and certification of composite structures
- Durability, damage tolerance, & life prediction of advanced composite materials and structures
- Uncertainty-based design and analysis methods
- OoA manufacturing of large-scale complex unitized composite structures
- Digital model-based manufacturing
- In-situ inspection and manufacturing process control

Highest Priority AMSM Outcomes

Materials

- **High temperature materials for high performance NTP - Additive manufacturing of refractory alloys; extremely high temperature composites capability, up to 2700°C (4892°F).**
- **Materials for Extreme Environments (e.g. Radiation shielding) - Infuse composites to ensure the safety of space crews exposed to solar particles and galactic cosmic rays that permeate the deep space environment. Degradation of materials.**
- **Ultralightweight composite structures - CNT-based materials; lattice-based/engineered materials for ultrahigh-specific stiffness applications.**
- **Expanding the LEO economy - Utilizing the ISS national lab for materials discovery to develop commercial products. (i.e microgravity materials science program)**
- **Dust tolerant textiles and mechanisms – Technology solutions can be implemented to mitigate the effects of dust on hatches, spacesuits, mechanisms, and mating surfaces. Other environmental parameters (temperature, electrostatic environment) are related to dust adherence.**

Highest Priority AMSM Outcomes

Structures

- **Long duration cryogenic propellant storage - Cryogenic composite tanks propellant storage with little to no boil-off, includes integral thermal insulation limiting heat leak into tanks.**
- **Inflatable structures - Materials, structures and manufacturing technology and certification methods for habitats, airlocks, and crew tunnels.**
- **Lightweight Unitized Composite Structures - Thermoplastic composites that significantly improve processing, joining, reusability, structural tailoring and lightweighting. Habitats and pressurized rovers.**
- **Next Generation D&DT to Support Certification of Flight Hardware - Addresses the imminent proliferation of parts produced by additive manufacturing (AM) and advanced composites.**
- **High-fidelity physics-based materials, structures and manufacturing simulations - Enables accelerated design, certification, production and operations. (i.e. Digital Twin)**
- **Uncertainty Quantification for Structures and Dynamics - Reduce unnecessary conservatism by developing configuration-specific design factors of safety.**
- **Integrated structural heath monitoring - Damage characterization, inspection and repair. High fidelity computational NDE tools to enable the rapid development of optimal inspection methods with established inspection confidences.**

Highest Priority AMSM Outcomes

Manufacturing

- **Lunar surface excavation and construction - Technology for building roads, launch/landing pads, dust free zones, foundations, blast protection, radiation shielding, shade structures, unpressurized shelters, and pressurized habitats.**
- **<u>Excavation of frozen volatiles - Extract resources from the icy regolith in permanently shadowed regions and surrounding areas.</u>**
- **Lunar surface manufacturing and repair capabilities - Manufacturing, servicing, and repair for ISRU systems, power systems, mobility platforms, EVA, and robotics. (3D Printing, etc.)**
- **<u>Reusable, refuellable Lunar descent/ascent propulsion system - Additive manufacturing of liquid propulsion system components.</u>**
- **Very large-scale additive manufacturing - Metallic additive for engine nozzles, common berthing mechanism (CBM) hardware, etc. Composite additive for lunar infrastructure.**
- **Large ultra-light precision optics- Additive manufacturing or autonomous assembly of lattice structure beryllium mirror substrate; Improve affordability, mass and thermal/dimensional stability of telescope composite backplane structures.**
- **Space Based Verification and Validation (V&V) - Autonomous inspection systems for lunar structures manufacturing and high fidelity computational NDE tools.**

Gap Format

Gap UID: TX12-XX
Gap Title:
Gap Description:
Outcome:
Current State of the Art (SoA) Performance Metrics:
Minimum Acceptable Performance Metrics for Exploration Missions:
Impacts if Not Closed:
Is Intermediate Capability Beneficial?:
Currently Funded Gap Closing Activities:
TRL of Currently Funded Gap Closing Activities:
Projected Gap Closure:
Testing and Demonstration Platform:
Platforms/Elements Enhanced or Enabled:
Associated Gaps:

Example Gap

Gap number: TX1 01-03 NTP

Gap Title: **Hot structure technology applicable to Nuclear Thermal Propulsion (NTP).**

Gap Description: Additive manufacturing of refractory alloys. Advancements are needed for additive manufactured (AM) refractory alloys TRL's by developing methods/materials to generate propulsion components with an integrated computational materials engineering approach and test under prototypic sustained high temperature operating environments. AM of refractory alloys enables higher temperature performance with reduction in cost over traditional methods.

Outcome: Enhanced Nuclear Thermal Propulsion Systems

Current State of the Art (SoA) Performance Metrics: TRL 3. AM primarily used for intermediate melt temperatures alloys.

Minimum Acceptable Performance Metrics for Exploration Missions: Significant reductions (> 25%) in the design, fabrication, assembly schedules while cost.

Example Gap

Gap number: TX1 01-03 NTP (continued)

Gap Title: **Hot structure technology applicable to Nuclear Thermal Propulsion (NTP).**

Impacts if Not Closed: Component designs are not optimized for performance, increasing mass, production risk, cost, and lead time.

Is intermediate capability beneficial: Yes, since AM has projected order of magnitude cost reduction with improved properties.

Currently Funded Gap Closing Activities: None

TRL of Currently Funded Gap Closing Activities: None

Projected Gap Closure: New alloys designed for AM printability and weldability are needed. Model/design alloy compositions; Develop AM feedstock; Develop AM parameters & heat treatments; Characterize properties; AM demonstration components; Test components in prototypic environments.

Testing and Demonstration Platform: Ground

Platforms/Elements Enhanced or Enabled: Nuclear thermal propulsion systems, Surface power systems

Associated Gaps: Other AM related propulsion system technology

Example Gap

Gap UID: TX12-18-A

Gap Title: **Thermoplastic composite materials for unitized primary structures**

Gap Description: Spacecraft may exceed mass and volume limits. Thermoplastic composites have numerous distinct advantages over their thermoset counterparts, particularly with respect to processing and joining. Because thermoplastics are processable with heat and pressure alone (i.e. no chemical reaction in play), thermoplastic composites lend themselves to relatively straightforward joining processes. Where thermosets must be chemically bonded, thermoplastics must be simply fused. Where joining techniques with thermoplastics are used, the highly-sensitive processes associated with traditional adhesive bonding with thermosets can be avoided. In this way, complex structures can be effectively unitized yielding significant benefits in structural efficiency. While thermoplastics use in aerospace applications is on the rise, NASA and industry currently suffers from a lack of qualified candidate materials and processes as well as an insufficient understanding of the structural behavior of complex, unitized structures.

Outcome: Lightweight composite primary structures

Current State of the Art (SoA) Performance Metrics: TRL3; Metallic and thermoset composites; Limited application of composite materials in launch vehicles in general;

Minimum Acceptable Performance Metrics for Exploration Missions: Reduce mass by 10% (threshold) to 30% (stretch).

Impacts if Not Closed: Spacecraft may exceed mass and volume limits.

Is intermediate capability beneficial: Mass savings are a 1:1 ratio between savings and payload.

Example Gap

Gap UID: TX12-18-A (continued)

Gap Title: **Thermoplastic composite materials for unitized primary structures**

Currently Funded Gap Closing Activities: None

TRL of Currently Funded Gap Closing Activities: None

Projected Gap Closure: Mature and demonstrate through in-house and public/private partnerships advanced technologies to reduce cost and weight of thermoplastic composite structures. Advance NASA's and industry's position with respect to thermoplastic composites, particularly in the areas of (1) qualified material systems for cost-effective manufacturing, (2) high-rate, high-reliability joining processes, and (3) the structural behavior of unitized thermoplastic composite components. Developing Advance technologies with respect to automated fiber placement (AFP) processing for thermoplastics. Partnering with material supplier(s) to qualify emerging thermoplastic materials for AFP (MSFC, GRC). Working with industry partner(s) to develop and qualify advanced thermoplastic joining technique(s) applicable to lightweight structures used on on-orbit servicing & assembly, lunar surface infrastructure assembly, human lander system, launch vehicles, and science missions. Develop advanced analytical tools for structural systems employing thermoplastics. Develop understanding the structural behavior of unitized thermoplastic composite components.

Testing and Demonstration Platform: Ground

Platforms/Elements Enhanced or Enabled: Spacecraft, ISRU infrastructure, Propellant depots, Habitat, Pressurized Rover.

Associated Gaps: TX12-15 - Lightweight composite primary structures, TX12-18 – Large-scale lightweight composite cryo tanks, TX12-22 - D&DT of advanced materials and structures, TX12-XX - Uncertainty Quantification for Structures and Dynamics

Definitions

Capability Gap: The inability to complete a task or meet an exploration objective. The gap may be the result of no existing capability, lack of proficiency or sufficiency in an existing capability solution, or the need to replace an existing capability solution to prevent a future gap.

Technology Gap: new and/or novel performance or function that has not been demonstrated (solutions to this gap type are generally TRL 1-4); this gap type aligns with the “New” Technology TRL 1-4 definition within the NASA Technology Readiness Assessment Report (2016)

Development Gap: at least one potential solution has been identified, but additional work is required to ensure feasibility of the new and/or novel performance or function in a specific operational application (solutions to this gap type are generally TRL 5-9); this gap type aligns with the “New” Technology TRL 5-9 definition within the NASA Technology Readiness Assessment Report (2016)

Engineering Gap: performance or function is well accepted (not new or novel), but requires engineering development for a specific mission (solutions to this gap type are generally TRL 5-9)

Knowledge Gap: unknown data (e.g., chemical and physical properties) that will ultimately drive hardware requirements; these gaps typically require additional scientific research in order to close

Architecture Gap: unknown mission parameters that will ultimately drive hardware requirements; further refinement of mission plans to clarify capability need

Enabling: System/architecture cannot function or achieve mission success without closing this gap; there may be alternatives such as different operational approaches or accepting more risk but usually at additional cost/resources

Enhancing: Not strictly required to function or achieve mission success, but closing this gap (potentially in combination with other gaps) improves the architecture by adding functionality or resiliency