

National Aeronautics and  
Space Administration



# Civil Space Shortfall Ranking

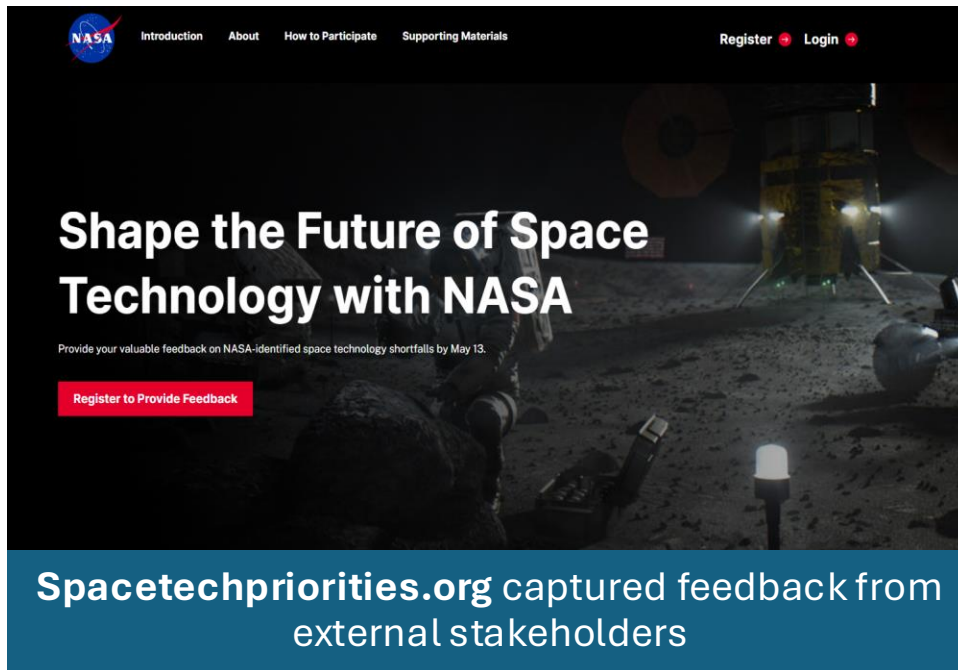
2024 Feedback Results for the STIGUR

NASA's Space Technology Mission Directorate

October 2024

# Spring 2024 Feedback Opportunity Background

In mid-April, STMD released an internal and external feedback opportunity to solicit feedback on 187 shortfalls to better understand civil space's most pressing and pervasive problems. STMD defines shortfalls as identified technology areas requiring further development to meet future exploration, science, and other mission needs.



Submissions scored the shortfalls with either:

- 0, 1, 3, 5, 7, 9, N/A (blanks were treated as N/A)

## Idea Generation

OGAs

## Industry

## Academia

EOP

Hill



## Mission Directorates



## Centers

## Investments/Projects

[illegible]

# National Tech Base Priorities

Publicly-transparent, rigorously-developed process by which we establish our priorities based on comprehensive prioritized needs of our stakeholders



## Projects

Project 2	1525
Project 1	1219
Project 21	1213
Project 13	1135
Project 9	1101
Project 18	1050
Project 20	974
Project 11	535
Project 4	905
Project 24	836
Project 8	393
Project 23	757
Project 17	658
Project 16	601
Project 10	570
Project 15	568
Project 6	829
Project 5	523
Project 19	507
Project 14	490
Project 22	393
Project 3	340
Project 12	329
Project 7	225

## Roadmaps



## Initial Tech Status

## Capability Goals

## Prioritized Shortfalls (Gaps)



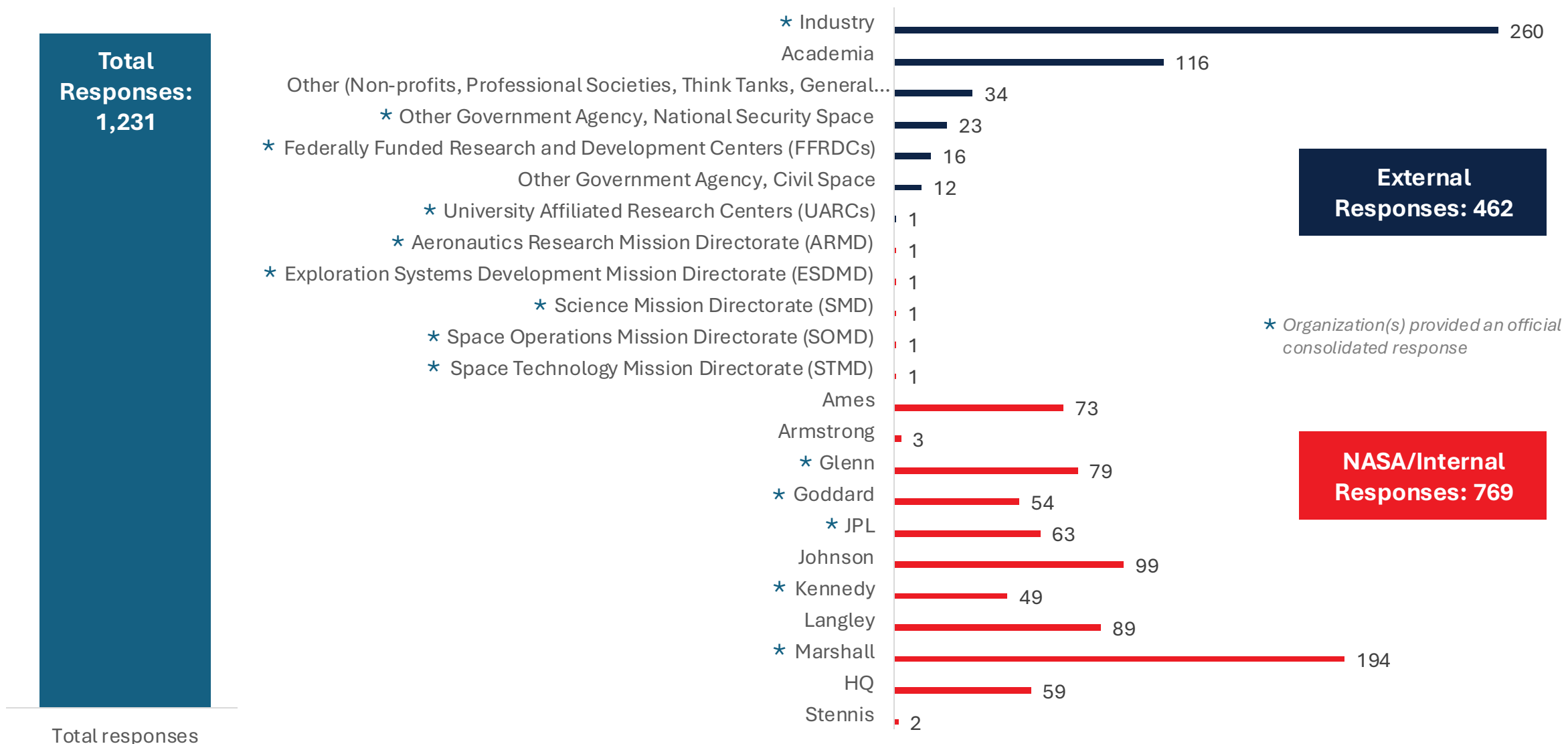
# July 2024 Ranked Results

## Background

- **The inputs received are igniting meaningful conversations to help us and our stakeholders make smarter decisions**
  - STMD plans to use the integrated ranked list and annual updates as one of several factors to guide its technology development projects and investments, beginning with the fiscal year 2026 Planning, Programming, Budgeting, and Execution (PPBE) process
  - To obtain the full ranking results, visit: [www.nasa.gov/civilspaceshortfalls](https://www.nasa.gov/civilspaceshortfalls)
  - These results will inform the development of technology roadmaps
  - Can be a useful tool for organizations across NASA and outside the agency
- **All stakeholder inputs were included and are valued**
  - NASA needs the whole tech base's energy and innovation to deliver on new capabilities we can't even imagine today
- **The ranked results are based on the numerical shortfall scores received and not responses to the open-ended questions**
  - The open-ended responses are still being processed
  - We expect them to provide context to the results, uncover additional shortfalls, and more
- When available, more information about the next feedback opportunity will be posted to [www.nasa.gov/civilspaceshortfalls](https://www.nasa.gov/civilspaceshortfalls)
- If you have questions or concerns, please contact [hq-techport@mail.nasa.gov](mailto:hq-techport@mail.nasa.gov)

# Spring 2024 Feedback Opportunity

## Responses Received

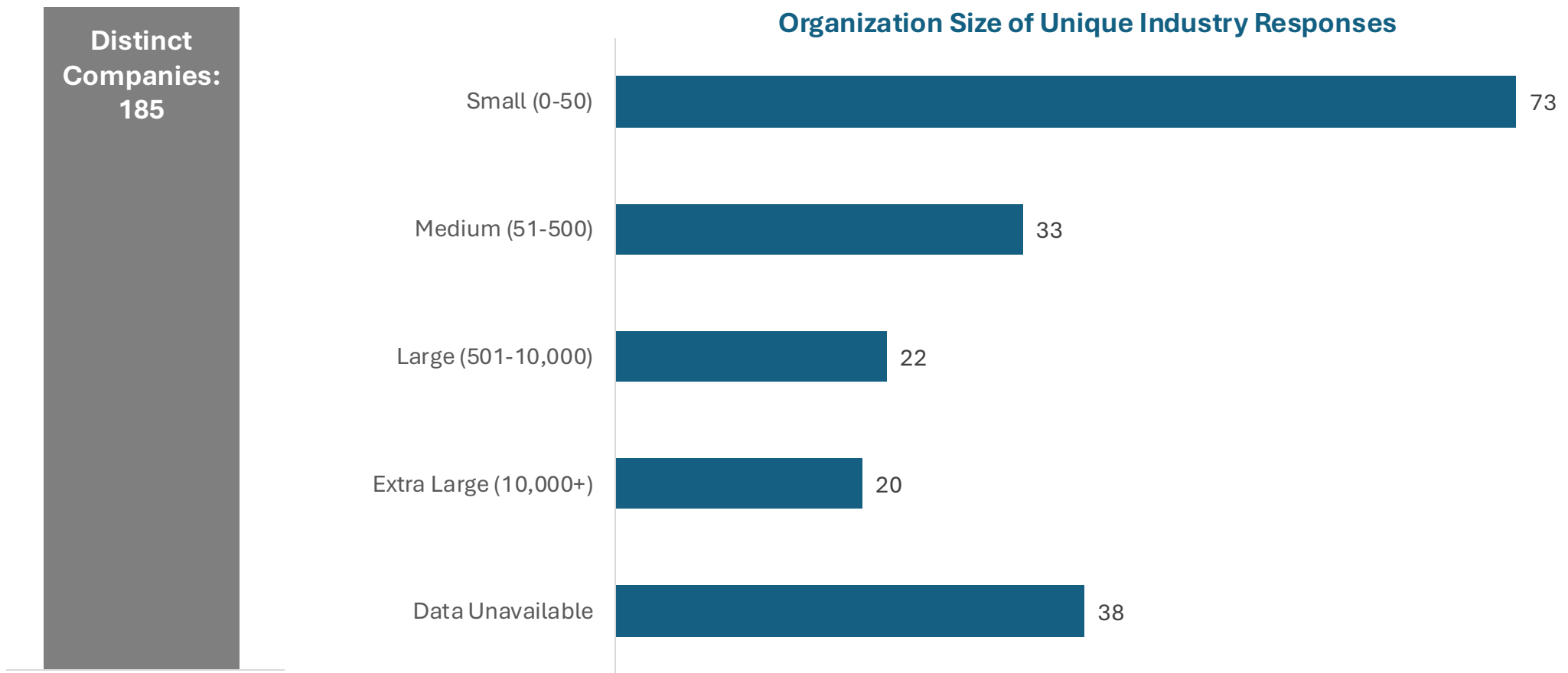


Total responses

# Spring 2024 Feedback Opportunity

## Industry Responses Received

185 unique industry organizations provided feedback. The graph shows size of the companies represented. The top five represented sectors were Defense & Space Manufacturing (29), Aviation & Aerospace Component Manufacturing (21), Space Research and Technology (11), Software Development (8), and Research Services (6).



# Stakeholder Groups

STMD grouped, totaled, and averaged scores for nine stakeholder groups and applied pre-determined weights to determine the integrated shortfall ranking. The bullets further define and/or denote additional feedback included within each stakeholder group.

## Internal Stakeholder Groups

### Exploration Systems Development Mission Directorate (ESDMD)

### Science Mission Directorate (SMD)

#### NASA Centers

- Ames Research Center
- Armstrong Flight Research Center
- Glenn Research Center
- Goddard Space Flight Center
- Headquarters
- Jet Propulsion Laboratory
- Johnson Space Center
- Kennedy Space Center
- Langley Research Center
- Marshall Space Flight Center
- Stennis Space Center

#### Other Mission Directorates

- Aeronautics Research Mission Directorate (ARMD)
- Space Operations Mission Directorate (SOMD)
- Space Technology Mission Directorate (STMD)

## External Stakeholder Groups

### Large Industry (> 500 employees), including:

- Federally Funded Research and Development Centers (FFRDCs)
- University Affiliated Research Centers (UARC)s

### Small Industry ( $\leq$ 500 employees)

### Other Government Agencies

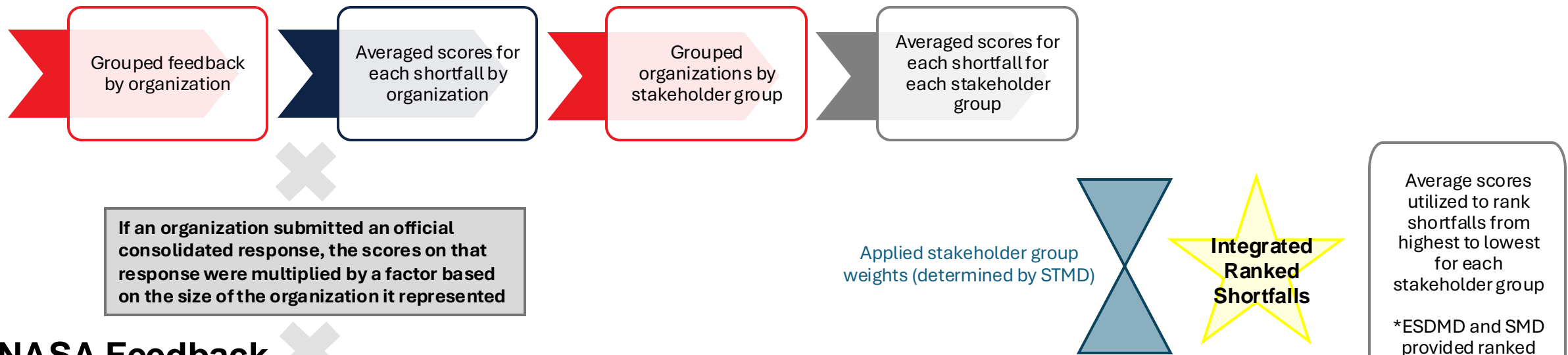
### Academia

### Other, including:

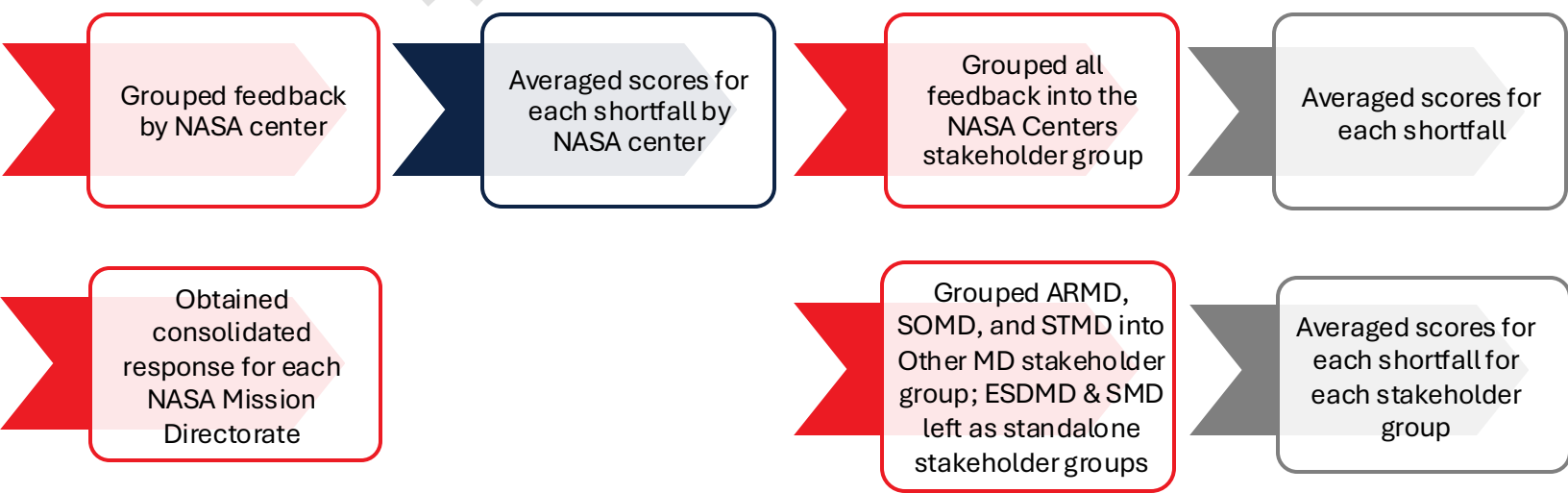
- Non-profits
- Professional Societies
- Think Tanks
- General Public

# 2024 Ranking Methodology

## External Feedback



## NASA Feedback







# Weighting Approach

- The integrated list utilized weights that reflect STMD's primary customers and their demand for future capabilities as well as other stakeholders' roles in partnering to provide solutions for such capabilities
- NASA inputs received  $\frac{2}{3}$  of the overall weight and external scores received the remaining  $\frac{1}{3}$
- STMD considered the following tenets of its investment strategy, in priority order, and developed the percentage weight for each stakeholder group
  1. Align with the Administration and the NASA Administrator's priorities that address the Blueprint Objectives (Artemis)
  2. Focus on investments that support science priorities identified in the Decadal Surveys
  3. Foster creation and growth of the space economy through partnering with industry and supporting small business innovation
  4. Engage NASA's workforce to deliver innovative solutions to the nation's toughest technology challenges
  5. Encourage transformative, cross-cutting technologies that benefit NASA as well as other government agencies
  6. Empower a broad community of innovators and academia through emphasis on early-stage investments

# July 2024 Integrated Ranked Shortfalls

## Overall Observations

- **#1 ranked shortfall in integrated list: Thermal-1618, survive and operate through the lunar night**
  - Was in the top 10 across all stakeholder groups
- **Agreement across stakeholder groups that the top 5 shortfalls are very important**
- **Relatively broad consensus and support for the top 30 shortfalls**
- **Diverse representation of capability areas in the top 20**
  - Advanced Habitation Systems (4 entries)
  - Autonomous Systems and Robotics (4)
  - Communication and Navigation (3)
  - Power (2)
  - Avionics (2)
  - Nuclear Propulsion (2)
  - Cryogenic Fluid Management (1)
  - Thermal Management Systems (1)
  - Sensors and Instruments (1)
- **Bottom 20 were dominated by Advanced Manufacturing and Non-Nuclear Propulsion capabilities**
- **Majority of Human Exploration and Science top priority shortfalls fall in the aggregate top quartile**
  - NASA center rankings were mixed in the aggregate top quartile compared to ESDMD and SMD rankings
- **Beyond the top quartile, the stakeholder priorities are largely mixed and likely align to their interests**
  - Shortfall rankings within many of the capability areas spanned a large range

# Integrated Shortfall Ranking (1-30)

Top 3 in Capability Category

Integrated Rank	Average Integrated Score	Shortfall ID	Category
1	8.1035	<b>1618: Survive and operate through the lunar night</b>	Thermal Management Systems
2	7.6118	<b>1596: High Power Energy Generation on Moon and Mars Surfaces</b>	Power
3	7.4345	<b>1554: High Performance Onboard Computing to Enable Increasingly Complex Operations</b>	Avionics
4	7.3831	<b>1557: Position, Navigation, and Timing (PNT) for In-Orbit and Surface Applications</b>	Communication and Navigation
5	7.2473	<b>1545: Robotic Actuation, Subsystem Components, and System Architectures for Long-Duration and Extreme Environment Operation</b>	Autonomous Systems and Robotics
6	7.2076	<b>1552: Extreme Environment Avionics</b>	Avionics
7	7.1961	<b>1519: Environmental Monitoring for Habitation</b>	Advanced Habitation Systems
8	7.1679	<b>709: Nuclear Electric Propulsion for Human Exploration</b>	Propulsion: Nuclear
9	7.1145	<b>1304: Robust, High-Progress-Rate, and Long-Distance Autonomous Surface Mobility</b>	Autonomous Systems and Robotics
10	7.0946	<b>1520: Fire Safety for Habitation</b>	Advanced Habitation Systems
11	7.0517	<b>1531: Autonomous Guidance and Navigation for Deep Space Missions</b>	Autonomous Systems and Robotics
12	7.0449	<b>1591: Power Management Systems for Long Duration Lunar and Martian Missions</b>	Power
13	7.0341	<b>702: Nuclear Thermal Propulsion for Human Exploration</b>	Propulsion: Nuclear
14	7.0315	<b>1559: Deep Space Autonomous Navigation</b>	Communication and Navigation
15	6.9684	<b>1527: Radiation Countermeasures (Crew and Habitat)</b>	Advanced Habitation Systems
16	6.9478	1526: Radiation Monitoring and Modeling (Crew and Habitat)	Advanced Habitation Systems
17	6.9465	<b>879: In-space and On-surface, Long-duration Storage of Cryogenic Propellant</b>	Cryogenic Fluid Management
18	6.8425	1548: Sensing for Autonomous Robotic Operations in Challenging Environmental Conditions	Autonomous Systems and Robotics
19	6.8039	<b>1558: High-Rate Communications Across The Lunar Surface</b>	Communication and Navigation
20	6.7919	<b>1626: Advanced Sensor Components: Imaging</b>	Sensors and Instruments
21	6.7837	<b>792: In-space and On-surface Transfer of Cryogenic Fluids</b>	Cryogenic Fluid Management
22	6.7199	<b>1569: High-Mass Mars Entry and Descent Systems</b>	Entry Descent and Landing
23	6.7110	1525: Food and Nutrition for Mars and Sustained Lunar	Advanced Habitation Systems
24	6.6953	<b>1571: Navigation Sensors for Precision Landing</b>	Entry Descent and Landing
25	6.6892	<b>1573: Terrain Mapping Capabilities for Precision Landing and Hazard Avoidance</b>	Entry Descent and Landing
26	6.6618	1562: Advanced Algorithms and Computing for Precision Landing	Entry Descent and Landing
27	6.5927	<b>1597: Power for Non-Solar-Illuminated Small Systems</b>	Power
28	6.5922	1568: Entry Modeling and Simulation for EDL Missions	Entry Descent and Landing
29	6.5842	1516: Water and Dormancy Management for Habitation	Advanced Habitation Systems
30	6.5694	1524: Crew Medical Care for Mars and Sustained Lunar	Advanced Habitation Systems

# Integrated Shortfall Ranking (31-60)

Top 3 in Capability Category

Integrated Rank	Average Integrated Score	Shortfall ID	Category
31	6.5659	1546: Robotic Mobile Manipulation for Autonomous Large-Scale Logistics, Payload Handling, and Surface Transport	Autonomous Systems and Robotics
32	6.4985	1592: High Power, Long Distance Energy Transmission Across Distributed Surface Assets	Power
33	6.4521	1542: Metrics and Processes for Establishing Trust and Certifying the Trustworthiness of Autonomous Systems	Autonomous Systems and Robotics
34	6.4434	1390: Power and Data Transfer in Dusty Environments	Power
35	6.4170	1532: Autonomous Planning, Scheduling, and Decision-Support to Enable Sustained Earth-Independent Missions	Autonomous Systems and Robotics
36	6.4155	<b>610: Solar Electric Propulsion - High Specific Impulse</b>	Propulsion: Non Nuclear
37	6.3832	1563: Aerocapture for Spacecraft Deceleration and Orbit Insertion	Entry Descent and Landing
38	6.3135	1560: High-Rate Deep Space Communications	Communication and Navigation
39	6.3088	<b>1194: Prediction Modeling of Cryogenic Fluid Dynamics and Operations</b>	Cryogenic Fluid Management
40	6.2932	<b>498: Broad and dependable supply chain for space-qualified robotic hardware, electronics, and associated software</b>	ISAM and RPOC
41	6.2747	<b>1430: Small Spacecraft Propulsion</b>	Small Spacecraft
42	6.2668	<b>1588: Protect Earth from Destructive Natural Impacts (Planetary Defense)</b>	Miscellaneous
43	6.2439	1565: Assessment and Validation Capabilities for Integrated Precision Landing Systems	Entry Descent and Landing
44	6.2410	<b>1608: Surface-based lunar logistics management for near/mid-term missions</b>	Surface Systems
45	6.2297	<b>1610: Surface-based food management for sustained lunar evolution</b>	Surface Systems
46	6.2273	<b>361: Surface Mating Mechanisms</b>	ISAM and RPOC
47	6.2202	<b>844: Passive Dust Mitigation Technologies for Diverse Applications</b>	Dust Mitigation
48	6.2096	<b>1438: Autonomy, Edge Computation, and Interoperable Networking for Small Spacecraft</b>	Small Spacecraft
49	6.2061	<b>1553: Foundational Technologies for Future Avionics Devices and Systems</b>	Avionics
50	6.2023	<b>1138: In-Space Transfer of Electric Propulsion Propellant</b>	ISAM and RPOC
51	6.1992	1529: EVA and IVA Suit System Capabilities for Mars Missions	Advanced Habitation Systems
52	6.1786	1523: Earth Independent Human Operations within Habitat Elements	Advanced Habitation Systems
53	6.1779	<b>1578: Extraction and separation of water from extraterrestrial surface material</b>	ISRU
54	6.1514	<b>1613: Surface-based fluid management for sustained lunar evolution</b>	Surface Systems
55	6.1509	<b>1586: Enhanced Access to Orbital and Suborbital Space for Flight Demonstration and Test</b>	Miscellaneous
56	6.1362	<b>1047: Active Dust Mitigation Technologies for Diverse Applications</b>	Dust Mitigation
57	6.1356	1595: Energy Storage to Enable Robust and Long Duration Operations on Moon and Mars	Power
58	6.1308	<b>1221: Mars Ascent Vehicle Propulsion</b>	Propulsion: Non Nuclear
59	6.1197	<b>1603: Situational Awareness Sensors and Tools for Astronauts</b>	Sensors and Instruments
60	6.1171	1612: Surface-based fluid management for near/mid-term missions	Surface Systems

# Integrated Shortfall Ranking (61-90)

Top 3 in Capability Category

Integrated Rank	Average Integrated Score	Shortfall ID	Category
61	6.0245	1609: Surface-based lunar logistics management for sustained lunar evolution	Surface Systems
62	5.9940	<b>1589: Space Situational Awareness</b>	Miscellaneous
63	5.9911	<b>1561: Advanced Modeling and Test Capabilities to Characterize Dust Effects on Hardware</b>	Dust Mitigation
64	5.9908	<b>1577: Perform resource reconnaissance to locate and characterize resources and estimate reserves</b>	ISRU
65	5.9710	1538: General-Purpose Robotic Manipulation to Perform Human-Scale Logistics, Maintenance, Outfitting, and Utilization	Autonomous Systems and Robotics
66	5.9451	<b>1620: Conditioned stowage to maintain science and/or nutritional integrity</b>	Thermal Management Systems
67	5.9391	<b>1599: Quantum Sensors That Use Atoms, Ions, and Spins</b>	Sensors and Instruments
68	5.9363	<b>1580: Extraction and separation of oxygen from extraterrestrial minerals</b>	ISRU
69	5.9320	<b>1431: Access Beyond LEO for Small Spacecraft</b>	Small Spacecraft
70	5.9286	1590: Planetary Protection	Miscellaneous
71	5.9220	<b>611: Sub-kW and kW Class Electric Propulsion Systems</b>	Propulsion: Non Nuclear
72	5.9065	1535: Autonomous Vehicle, System, Habitat, and Infrastructure Health Monitoring and Management	Autonomous Systems and Robotics
73	5.8983	1598: Quantum Sensors That Use Photons	Sensors and Instruments
74	5.8717	1566: Characterization of Plume Surface Interaction	Entry Descent and Landing
75	5.8643	1336: Robotic Mobility for Robust, Repeatable Access To and Through Extreme Terrain, Surface Topography, and Harsh Environmental Conditions	Autonomous Systems and Robotics
76	5.8302	1226: Cryogenic Liquefaction	Cryogenic Fluid Management
77	5.8287	<b>1621: Cryogenic cooling for science instrumentation</b>	Thermal Management Systems
78	5.8267	1483: Enable commercially-provided Rendezvous, Proximity Operations, and Capture (RPOC) products and services	ISAM and RPOC
79	5.8252	1583: Produce propellants and mission consumables from extracted in-situ resources	ISRU
80	5.7795	1625: Intelligent Multi-Agent Constellations for Cooperative Operations	Autonomous Systems and Robotics
81	5.7580	<b>1576: Micrometeoroid-Robust Protection of In-space Observatories</b>	Advanced Materials and Structures
82	5.7484	1619: High temperature heat rejection for nuclear applications	Thermal Management Systems
83	5.7072	1541: Intuitive and Efficient Human-Robot Interaction for Safe Teaming and Remote Supervisory Control	Autonomous Systems and Robotics
84	5.6803	1617: Autonomous on-surface maintenance and repair for sustained lunar evolution	Surface Systems
85	5.6619	680: Robust Robotic Intelligence for High-Tempo Autonomous Operations in Dynamic Mission Conditions	Autonomous Systems and Robotics
86	5.6023	1615: Common tools for on-surface maintenance and repair for reduced crew interaction	Surface Systems
87	5.6017	1518: Logistics Tracking, Clothing, and Trash Management for Habitation	Advanced Habitation Systems
88	5.5988	<b>1575: Thermal and Vibrational Isolation for Ultra-stable Science Payloads</b>	Advanced Materials and Structures
89	5.5786	1611: Surface-based end-of-life equipment management	Surface Systems
90	5.5381	1616: Dissipation of electrical charge on surface assets	Surface Systems



# Integrated Shortfall Ranking (91-120)

Top 3 in Capability Category

Integrated Rank	Average Integrated Score	Shortfall ID	Category
91	5.5326	1522: Crew Health Countermeasures – Non-Exercise	Advanced Habitation Systems
92	5.5088	<b>1485: In-Space and On-Surface Manufacturing of Parts/Products from Surface and Terrestrial Feedstocks</b>	Advanced Manufacturing
93	5.4992	1432: Rendezvous, Proximity Operations, and Debris Remediation using Small Spacecraft	Small Spacecraft
94	5.4897	1528: Spacesuit Physiology	Advanced Habitation Systems
95	5.4553	<b>1477: Mitigation of New Orbital Debris Generation</b>	Orbital Debris
96	5.4513	1521: Crew Exercise and Sensorimotor Countermeasures	Advanced Habitation Systems
97	5.4441	672: Long-life thermal control for surface suits capable of extreme access	Thermal Management Systems
98	5.3922	1623: Advanced thermal modeling capabilities	Thermal Management Systems
99	5.3787	1555: Next Generation Avionics Architectures	Avionics
100	5.3439	1506: In-Space & Surface Transfer of High-Pressure Gases	ISAM and RPOC
101	5.3355	512: Cooperative interfaces, aids, and standards	ISAM and RPOC
102	5.3268	<b>662: Robotic regolith manipulation and site preparation</b>	Excavation Construction and Outfitting
103	5.3171	1585: Extraterrestrial surface environmental simulators, test facilities, and test sites	ISRU
104	5.2725	<b>384: Excavation of hard/compacted/icy material</b>	Excavation Construction and Outfitting
105	5.2711	1533: Autonomous Robotic Sample Identification, Classification, Collection, Manipulation, Verification, and Transport	Autonomous Systems and Robotics
106	5.2485	1574: Validated Performance Models for Planetary Parachutes	Entry Descent and Landing
107	5.2409	1581: Extraction and separation of extraterrestrial atmospheric resources and gaseous products/reactants	ISRU
108	5.2217	<b>369: Excavation of granular (surface) regolith for ISRU commodities production</b>	Excavation Construction and Outfitting
109	5.2127	376: Modular design for in-space installation	ISAM and RPOC
110	5.2125	1582: Extraction and separation of metals/metalloids from extraterrestrial minerals	ISRU
111	5.2061	1224: In-Space & Surface Transfer of Earth Storable Propellants	Propulsion: Non Nuclear
112	5.1952	1514: Atmospheric Metabolic Constituent Management for Habitation	Advanced Habitation Systems
113	5.1824	700: Solar Sails for Propellant-less Propulsion	Propulsion: Non Nuclear
114	5.1598	1624: Advanced thermal management technologies for diverse applications	Thermal Management Systems
115	5.1554	1627: Advanced Sensor Components for Heliophysics and Lunar-Based Astronomy	Sensors and Instruments
116	5.1497	<b>1486: In-Space and On-Surface NDE and Qualification of Components for Manufacturing, Assembly, and Construction</b>	Advanced Manufacturing
117	5.1095	581: ISRU System Modeling	ISRU
118	5.1006	385: Regolith and resource delivery system	Excavation Construction and Outfitting
119	5.0870	1434: Communication Technology and Capabilities for Small Spacecraft	Small Spacecraft
120	5.0865	1600: Enable Paradigm for System Science to Include Interactions Between Subsystems	Sensors and Instruments

# Integrated Shortfall Ranking (121-150)

Top 3 in Capability Category

Integrated Rank	Average Integrated Score	Shortfall ID	Category
121	5.0666	1515: Atmospheric Non-Metabolic Constituent Management for Habitation	Advanced Habitation Systems
122	5.0443	<b>705: Low Power Nuclear Electric Propulsion</b>	Propulsion: Nuclear
123	5.0280	<b>1262: Remediation of Small Debris</b>	Orbital Debris
124	5.0274	707: Transformational Advanced Energetic Propulsion (AEP)	Propulsion: Non Nuclear
125	5.0194	379: Upgrade or Install Instruments on Large Space Observatories	ISAM and RPOC
126	5.0163	544: Solar Electric Propulsion to Support Orbital Platforms	Propulsion: Non Nuclear
127	4.9967	1614: Surface-based planning and scheduling technologies for sustained lunar evolution	Surface Systems
128	4.9962	1530: Aerial Robotic Mobility and Onboard Intelligence for Expanded Capabilities on Mars, Venus, and Titan	Autonomous Systems and Robotics
129	4.9858	1587: Wildfire Integrated Effect Chain	Miscellaneous
130	4.9389	1547: Robotic Systems for Sub-Surface Access	Autonomous Systems and Robotics
131	4.9270	1564: Aeroshell In-Situ Flight Performance Data During EDL	Entry Descent and Landing
132	4.9158	<b>767: Advanced designs for lightweight inflatable surface elements</b>	Advanced Materials and Structures
133	4.9120	1540: Intelligent Robots for the Servicing, Assembly, and Outfitting of In-Space Assets and Industrial-Scale Surface Infrastructure	Autonomous Systems and Robotics
134	4.9063	1539: Intelligent Robotic Systems for Crew Health and Performance During Long-Duration Missions	Autonomous Systems and Robotics
135	4.9054	<b>1476: Remediation of Large Debris</b>	Orbital Debris
136	4.8606	1550: Crew Audio/Visual Interfaces for Long Duration Missions Beyond LEO	Avionics
137	4.8445	1602: 3D/3D+ Imaging and Tomography of Complex Features and Dynamical Processes	Sensors and Instruments
138	4.8017	1480: On-surface Outfitting of Lunar Structures	Excavation Construction and Outfitting
139	4.7856	1543: Multi-Agent Robotic Coordination and Interoperability for Cooperative Task Planning and Performance	Autonomous Systems and Robotics
140	4.7840	1551: Distributed Avionics to Enable Improved Performance and SWaP Efficiency	Avionics
141	4.7776	1604: Find, Study Habitable Zone Earth-like Exoplanets and Search for Biosignatures	Sensors and Instruments
142	4.7660	1584: Produce manufacturing and construction feedstock from extracted in-situ resources	ISRU
143	4.7572	1570: Lander Capabilities for Soft Touchdown	Entry Descent and Landing
144	4.7544	1517: Metabolic Waste Management for Habitation	Advanced Habitation Systems
145	4.6999	425: On-Surface In-situ Construction of Vertical Structures	Excavation Construction and Outfitting
146	4.6761	1567: Entry Capabilities for Small-Scale and Commercial Spacecraft	Entry Descent and Landing
147	4.6694	1433: Position, Navigation, and Timing for Small Spacecraft	Small Spacecraft
148	4.6511	617: On-surface robotic assembly of vertical structures	Excavation Construction and Outfitting
149	4.6454	<b>1490: Additive Manufacturing for New and High-Performance Materials</b>	Advanced Manufacturing
150	4.6350	1408: Advanced deployable load-bearing structures	Advanced Materials and Structures

# Integrated Shortfall Ranking (151-180)

Integrated Rank	Average Integrated Score	Shortfall ID	Category
151	4.5955	1549: Advanced Data Acquisition Systems for Diverse Applications	Avionics
152	4.5733	1601: Enable Observation of Whole Top-to-Bottom Dynamic Ecosystems	Sensors and Instruments
153	4.5437	513: Robotic Assembly and Construction of Modular Systems for Sustained In-Space Infrastructure	ISAM and RPOC
154	4.5432	1491: Additive Manufacturing of Large-Scale Components	Advanced Manufacturing
155	4.5333	1537: Free-Flying Systems for Robotic Inspection, Data Collection, and Servicing of In-Space Assets	Autonomous Systems and Robotics
156	4.5246	1437: Dynamic and Capable Thermal Control for Small Spacecraft	Small Spacecraft
157	4.5128	1511: Advanced Computational Fluid Dynamics Tools / Capabilities	Propulsion: Non Nuclear
158	4.4926	696: Enable Storable Propulsion Systems in Low Temperature Environments	Propulsion: Non Nuclear
159	4.4918	1400: On-surface robotic assembly of horizontal structures	Excavation Construction and Outfitting
160	4.4363	666: On-Surface In-situ Construction of Horizontal Structures	Excavation Construction and Outfitting
161	4.4023	1605: Peer Back Farther in Time to the Early Universe	Sensors and Instruments
162	4.3772	1607: Detect New Astronomical Messenger - Gravitational Waves	Sensors and Instruments
163	4.3541	1488: Additive Manufacturing for Propulsion	Advanced Manufacturing
164	4.3352	755: Cross-Discipline Cryogenic Fluid Management Technologies	Cryogenic Fluid Management
165	4.3234	1436: Efficient and Safe Higher Power Systems for Small Spacecraft	Small Spacecraft
166	4.3084	1534: Autonomous Robotics for Sustained In-Space Manufacturing Operations	Autonomous Systems and Robotics
167	4.2945	703: Rotating Detonation Rocket Engine (RDRE)	Propulsion: Non Nuclear
168	4.2749	1606: Observe Some of the Most Energetic Phenomena in the Universe	Sensors and Instruments
169	4.2665	1579: Extraction and separation of non-water volatile resources from Lunar regolith	ISRU
170	4.1533	1492: Materials and Process Modeling for In-Space and On-Surface Manufacturing	Advanced Manufacturing
171	4.1513	1495: Advanced Manufacturing for Improved Dimensional Control of Large-Scale Space Structures	Advanced Manufacturing
172	4.1431	1489: In-Space and On-Surface Manufacturing from Recycled and Reused Materials and Components	Advanced Manufacturing
173	4.1423	612: In-Space Diagnostics for Electric Propulsion	Propulsion: Non Nuclear
174	4.1280	1496: In-Space and On-Surface Manufacturing, Assembly, and Repair of Composite Structures	Advanced Manufacturing
175	4.0730	1622: Novel thermal technologies to improve environmental control of habitats	Thermal Management Systems
176	4.0204	1494: Digital Transformation Technologies for Terrestrial, In-Space, On-Surface Manufacturing, and Operations	Advanced Manufacturing
177	3.9682	1544: Resilient Agency: Adaptable Intelligence and Robust Online Learning for Long-Duration and Dynamic Missions	Autonomous Systems and Robotics
178	3.9458	1593: Lunar Surface Power Generation from ISRU Derived Resources	Power
179	3.9353	1487: In-Space and On-Surface Welding Technologies for Manufacturing, Assembly, and Construction	Advanced Manufacturing
180	3.8944	1513: Advanced Solid Propulsion Systems	Propulsion: Non Nuclear

# Integrated Shortfall Ranking (181-187)

Integrated Rank	Average Integrated Score	Shortfall ID	Category
181	3.8813	1572: Performance-Optimized Low-Cost Aeroshells for EDL Missions	Entry Descent and Landing
182	3.8091	1052: EVA/IVA Support Propulsion Development	Propulsion: Non Nuclear
183	3.6367	1594: Martian Surface Power Generation from ISRU Derived Resources	Power
184	3.6049	1493: Computational Materials-Informed Qualification and Certification for In-Space and On-Surface Manufacturing	Advanced Manufacturing
185	3.4893	701: Green Propellant Propulsion Systems	Propulsion: Non Nuclear
186	3.4305	1536: Free-Flying Mobility Aids for Crew EVA	Autonomous Systems and Robotics
187	3.0722	1512: Modern Solid Motor Design and Analysis Tools / Capabilities	Propulsion: Non Nuclear

# Integrated Top 30 Shortfalls Compared to Stakeholder Group Rank

Integrated Rank	Shortfall ID	Category
1	1618: Survive and operate through the lunar night	Thermal Management Systems
2	1596: High Power Energy Generation on Moon and Mars Surfaces	Power
3	1554: High Performance Onboard Computing to Enable Increasingly Complex Operations	Avionics
4	1557: Position, Navigation, and Timing (PNT) for In-Orbit and Surface Applications	Communication and Navigation
5	1545: Robotic Actuation, Subsystem Components, and System Architectures for Long-Duration and Extreme Environment Operation	Autonomous Systems and Robotics
6	1552: Extreme Environment Avionics	Avionics
7	1519: Environmental Monitoring for Habitation	Advanced Habitation Systems
8	709: Nuclear Electric Propulsion for Human Exploration	Propulsion: Nuclear
9	1304: Robust, High-Progress-Rate, and Long-Distance Autonomous Surface Mobility	Autonomous Systems & Robotics
10	1520: Fire Safety for Habitation	Advanced Habitation Systems
11	1531: Autonomous Guidance and Navigation for Deep Space Missions	Autonomous Systems & Robotics
12	1591: Power Management Systems for Long Duration Lunar and Martian Missions	Power
13	702: Nuclear Thermal Propulsion for Human Exploration	Propulsion: Nuclear
14	1559: Deep Space Autonomous Navigation	Communication and Navigation
15	1527: Radiation Countermeasures (Crew and Habitat)	Advanced Habitation Systems
16	1526: Radiation Monitoring and Modeling (Crew and Habitat)	Advanced Habitation Systems
17	879: In-space and On-surface, Long-duration Storage of Cryogenic Propellant	Cryogenic Fluid Management
18	1548: Sensing for Autonomous Robotic Operations in Challenging Environmental Conditions	Autonomous Systems & Robotics
19	1558: High-Rate Communications Across The Lunar Surface	Communication and Navigation
20	1626: Advanced Sensor Components: Imaging	Sensors and Instruments
21	792: In-space and On-surface Transfer of Cryogenic Fluids	Cryogenic Fluid Management
22	1569: High-Mass Mars Entry and Descent Systems	Entry Descent and Landing
23	1525: Food and Nutrition for Mars and Sustained Lunar	Advanced Habitation Systems
24	1571: Navigation Sensors for Precision Landing	Entry Descent and Landing
25	1573: Terrain Mapping Capabilities for Precision Landing and Hazard Avoidance	Entry Descent and Landing
26	1562: Advanced Algorithms and Computing for Precision Landing	Entry Descent and Landing
27	1597: Power for Non-Solar-Illuminated Small Systems	Power
28	1568: Entry Modeling and Simulation for EDL Missions	Entry Descent and Landing
29	1516: Water and Dormancy Management for Habitation	Advanced Habitation Systems
30	1524: Crew Medical Care for Mars and Sustained Lunar	Advanced Habitation Systems

Higher Ranking Shortfalls > Lower Ranking Shortfalls						
1	30	60	90	120	150	180

Not Ranked (NR)
-----------------

Stakeholder Group Rank								
Academia	Small Industry	Large Industry	OGA	Other	NASA Centers	ESDMD	SMD	Other MDs
4	2	2	2	9	6	4	9	1
13	1	1	40	20	4	21	NR	16
80	28	21	27	13	3	34	1	56
9	11	15	29	67	10	28	NR	3
34	27	28	63	10	40	13	9	49
176	49	6	38	23	54	6	9	62
20	101	72	75	61	49	17	19	13
43	131	23	4	52	32	7	NR	7
27	42	30	121	91	34	25	25	66
23	24	78	12	12	12	29	55	14
47	67	24	3	89	42	64	23	15
40	12	10	52	24	68	35	NR	27
36	114	36	14	78	62	7	NR	11
62	129	27	5	120	38	64	23	10
5	23	22	6	2	5	63	NR	6
6	53	41	81	1	13	27	38	35
21	37	3	95	22	1	59	NR	2
42	17	26	90	16	44	14	26	57
25	73	29	77	162	20	5	NR	51
18	75	12	45	160	22	NR	18	68
17	29	4	51	26	2	62	NR	29
152	156	48	117	5	33	16	NR	12
8	32	116	41	45	30	11	NR	58
14	62	37	23	4	31	45	28	9
30	31	9	12	8	11	45	28	53
54	65	45	23	3	25	45	28	8
85	26	5	39	125	47	93	12	20
101	115	76	60	15	50	45	5	45
49	98	127	158	53	69	26	51	22
12	64	94	1	11	21	58	NR	17

ESDMD and SMD provided ranked lists (numbers shown above) in addition to shortfall scores (used for integrated list).  
ESDMD and SMD did not score all shortfalls. Unscored shortfalls were also not ranked.



## Summary & Next Steps

- Hearing from 1,200 stakeholders in the same format is extremely valuable and we continue to utilize this data to drive our planning and strategy across the organization
- We will use what we learned this year and evolve the process next year and beyond
- Information from the text responses will inform the next iteration of the shortfall description document
- STMD will use the integrated ranked shortfall list as a tool
  - It is one of several factors that will help inform and guide STMD's investments
  - It remains important for STMD to maintain balanced technology development portfolio across all capabilities and readiness levels
- STMD remains committed to soliciting feedback on a regular basis
  - As a result, the ranked shortfalls may change

**BACK UP**

# Civil Space Shortfalls

- NASA compiled an initial list of **187 shortfalls** organized into **20 capability areas**
- The shortfall description document and feedback form were organized accordingly

ID	Shortfall Title
1514	Atmospheric Metabolic Constituent Management for Habitation
<p><b>Description</b></p> <p>All habitat elements need carbon dioxide (CO<sub>2</sub>) removal and oxygen (O<sub>2</sub>) generation. The current ISS SOA systems provide basic functionality for adsorption of CO<sub>2</sub> and partial oxygen recovery (~47%). Issues with long-term reliability are being addressed but need validation with long-term integrated testing for extended endurance missions. Trace gas contamination can decrease system performance in integrated vehicle. Upgraded and new technologies are needed to reduce mass/power/volume/maintenance and improve oxygen recovery for long duration exploration missions. (Dependency: Launched food water content must be reduced to ~30% for the mass savings of increased oxygen recovery to be beneficial.) Technologies for high-pressure/purity oxygen generation for EVA recharge are needed for high frequency surface EVA missions. Technologies for providing high flow rate oxygen for days to treat potential medical conditions without exceeding cabin material oxygen flammability limits are needed for long duration missions. Monitoring of atmospheric metabolic constituents is addressed in the "Environmental Monitoring for Habitation" shortfall. Improved system performance, improved reliability, and system enhancements to allow lower-level maintenance are beneficial to a reduction of departure mass and improved crew safety on long endurance missions where resupply is not feasible. System improvements and diagnostics assistance that reduces crew time are also beneficial.</p>	
<p><b>Related Shortfalls</b></p> <p>AHS-353: Recovering &amp; Recycling O<sub>2</sub> from Metabolic CO<sub>2</sub>  AHS-760: Oxygen Generation System improved reliability and decreased complexity  AHS-787: Oxygen Generation for low pressure cabin environments  AHS-878: High Pressure Oxygen for EVA tank resupply  AHS-1059: Highly reliable, closed-loop-forward CO<sub>2</sub> removal systems  AHS-1222: Medical O<sub>2</sub> Generation &amp; Supply</p>	
<p><b>Metrics</b></p> <ul style="list-style-type: none"> <li>• CO<sub>2</sub> removal at &lt;2.5 mmHg-enabling, &lt;2.0 mmHg-enhancing demonstrated at 14.7 psia and at future surface habitat pressure</li> <li>• Reduction in mass/kg O<sub>2</sub> produced</li> <li>• &gt;75% oxygen recovery from CO<sub>2</sub></li> <li>• Capability to recharge EVA O<sub>2</sub> bottle</li> <li>• Enriched medical oxygen (50-90% vol)</li> </ul>	

**Shortfall:** *Identified technology area requiring further developments to meet future exploration, science, and other mission needs*

Capability Area	# of Shortfalls
Advanced Habitation Systems	16
Advanced Manufacturing	12
Advanced Materials & Structures	4
Autonomous Systems & Robotics	23
Avionics	7
Communication & Navigation	4
Cryogenic Fluid Management	5
Dust Mitigation	3
Entry, Descent & Landing	13
Excavation, Construction & Outfitting	9
In-Situ Resource Utilization	10
In-Space Servicing, Assembly & Manufacturing	9
Orbital Debris	3
Power	8
Propulsion	18
Sensors & Instruments	12
Small Spacecraft	8
Surface Systems	10
Thermal Management Systems	8
Miscellaneous	5