NASA’s LunaRecycle Challenge
Phase 1 Challenge Rules
September 30, 2024

Table of Contents

Definition of Terms **4**

Challenge Problem Statement **5**

Challenge Goals **5**

Challenge Background **5**

Waste in Space *5*

The Promise of Digital Twins *6*

Potential Intersection of Space and Terrestrial Applications *7*

Challenge Overview **8**

Competition Structure *8*

Phase 1 Overview *9*

Prize Purses (U.S. Winners) *9*

Recognition of International Teams *10*

Competition Timeline *10*

Mission Scenario **11**

Overview *11*

Mission Conditions and Activities *11*

Waste Categories and Items *12*

Waste Item Commercial Equivalents *15*

Available Resources *18*

Additional Considerations *19*

Desirable End Products *19*

Phase 1 Registration and Submissions **21**

Registration (Both Tracks) *21*

Phase 1 Submission (Digital Twin Track) *21*

Phase 1 Submissions (Prototype Build Track) *21*

Judging Criteria **22**

Legal Requirements **25**

In General *25*

Eligibility to Compete *25*

Eligibility to Compete and Win Prizes from NASA *26*

Team Roles and Responsibilities *27*

Intellectual Property Rights *28*
Insurance and Indemnification *28*
Use of Names, Trademarks, and Insights *29*
Delay, Cancellation or Termination *29*
Appendix A: Phase 1 Submission Instructions (Digital Twin Track) **30**
Instructions *30*
Required Sections and Topics *31*
Appendix B: Phase 1 Submission Template (Prototype Build Track) **37**
Instructions *37*
Required Sections and Topics *38*
Appendix C: Expectations for Phase 2 ..... **44**

Definition of Terms

Concept of Operations: A description of the operations of a system from a user's perspective, through a complete production cycle, including cleanup and any activities required to prepare for the following production cycle.

Digital Twin: A digital twin is a set of virtual information constructs that mimics the structure, context, and behavior of a natural, engineered, or social system (or system-of-systems); is dynamically updated with data from its physical twin; has a predictive capability; and informs decisions that realize value.[1] In this challenge, a physical system for recycling on the lunar surface does not yet exist; therefore, teams will design a digital twin that mimics an intended future physical system and includes data for the intended system and the expected bidirectional interaction between the digital twin and the intended system.

Judging Panel: A panel of professionals and subject matter experts from government, academia, and industry who will evaluate and score all submissions.

Manufacturing of End Products: In this challenge, manufacturing of end products is a process that may be separate from the recycling process and results in a finished end product similar to a commercially available product.

Mission Scenario: A hypothetical scenario based on a real-world lunar mission. In this challenge, the Mission Scenario imagines a holistic set of waste management needs and conditions on the lunar surface.

Phase: A stage of the challenge representing a key step in the development of the technologies. This challenge will have up to two phases.

Recycling: In this challenge, recycling includes the processes to convert waste items into feedstocks that can be used to manufacture end products for science, future exploration, and commercial use.

Resource Inputs: In this challenge, resource inputs are defined as the electricity, water, chemicals, minerals, and any other inputs, including crew time, required to operate and maintain the recycling system and manufacturing of end products.

Solid Waste: Waste that will be addressed in this challenge. Solid waste does not include biological waste, hazardous waste, gaseous waste, or metabolic waste. Solid waste categories and items that have accumulated in the hypothetical Mission Scenario are defined in Table 4.

[1] "Foundational Research Gaps and Future Directions for Digital Twins," National Academies, accessed June 23, 2024, https://www.nationalacademies.org/our-work/foundational-research-gaps-and-future-directions-for-digital-twins.

Team: An individual, group of individuals, or a group of individuals represented by an entity that have officially registered and are approved to compete in the challenge.

Unusable Outputs: In this challenge, unusable outputs include any materials or substances extracted from waste items that are not processed into a feedstock or end product, as well as wastewater, excess chemicals, hazardous materials, or any other substance that is left over from and unusable in the recycling process.

Waste Items Not Recycled: In this challenge, teams may choose to ignore one or more waste items in the waste category or categories they choose. If an entire waste item is ignored and not processed in any way, it will be characterized as a Waste Item Not Recycled instead of an Unusable Output.

Challenge Problem Statement

In this Challenge, NASA seeks to incentivize the design and development of innovative, sustainable recycling solutions that can address the types of solid waste expected to accumulate during longer-term missions on the lunar surface.

Challenge Goals

In this Challenge, NASA seeks recycling solutions for the lunar surface that maximize the percentage of waste that can be recycled from a list of waste categories and items that are relevant to a hypothetical 365-day lunar mission. NASA is seeking designs that minimize resource inputs; unusable outputs; and the mass and/or volume of hardware components and systems needed for recycling. For the Digital Twin track, NASA is also seeking highly innovative and imaginative solutions that harness the full potential of a digital twin.

Challenge Background

Waste in Space

NASA is committed to sustainable space exploration.[2] As NASA prepares for future human space missions, there will be a need to consider how various waste streams, including solid waste, can be minimized as well as how waste can be stored, processed, and recycled in a space environment so that little or no waste will need to be returned to Earth.

[2] "NASA's Space Sustainability Strategy," National Aeronautics and Space Administration, accessed June 23, 2024, https://www.nasa.gov/spacesustainability/.

Recent NASA directives have specifically addressed the need for sustainability in these areas. NASA's Moon to Mars Strategy identifies Maintainability and Reuse (RT-5) and Responsible Use (RT-6) as critical strategies fundamental to achieving long-term sustainability of space operations, as well as independence from Earth.[3] More specifically, the strategy includes explicit operational goals to "demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth" (OP-11) and "minimize the disturbance to the local environment, maximize the resources available to future explorers, and allow for reuse/recycling of material transported from Earth (and from the lunar surface in the case of Mars) to be used during exploration" (OP-12).[4]

In addition, NASA's Space Technology Mission Directorate (STMD), which leads the development and demonstration of transformational technologies, has identified a number of research areas requiring further investment to meet future exploration, science, and other mission needs. These include topics such as trash management for habitation, in-space and on-surface manufacturing from recycled materials, and digital transformation technologies for terrestrial, in-Space, on-Surface manufacturing and operations—all of which may be addressed through this challenge.

By utilizing open innovation strategies in this area, NASA has the opportunity to incentivize novel solutions to the challenges of waste in space and ensure the sustainability of future space exploration, industrial activities, and habitats.

The Promise of Digital Twins

According to a 2024 National Academies report, digital twin technologies hold "immense promise" in accelerating scientific discovery and revolutionizing a wide variety of industries. Digital twins typically include bi-directional interaction between a physical system and its virtual twin, creating a dynamic decision-making tool "that goes beyond what has been traditionally possible with modeling and simulation."[5] Specifically, by enabling predictive insights and effective optimizations and simulating dynamic system behavior, digital twins have the potential to "enhance operational efficiency, optimize production strategies, reduce time-to-market, and unlock new avenues for scientific and industrial growth and innovation."[6]

The concept of a digital twin was born at NASA and increasingly represents a critical tool for designing and building physical systems and components that must operate in

---

[3] National Aeronautics and Space Administration, *NASA's Moon to Mars Strategy and Objectives Development* (Washington, DC: National Aeronautics and Space Administration, 2023), https://www.nasa.gov/wp-content/uploads/2023/04/m2m_strategy_and_objectives_development.pdf?emrc=c21aff.

[4] Ibid.

[5] "Foundational Research Gaps and Future Directions for Digital Twins," National Academies.

[6] Ibid.

extreme environments like those found on the Moon. Digital twin technologies can significantly improve the development process by enabling development of breakthrough innovations, numerous virtual design iterations and configurations, and eliminating the need for makeshift physical prototypes, saving substantial time and costs.

Potential Intersection of Space and Terrestrial Applications

As of 2018, solid waste streams (similar to those that will be addressed in this challenge) made up just over 50 percent of municipal solid waste in the U.S. This waste includes paper and cardboard (23%); plastics (12%); metals (9%); textiles (6%); and glass (4%).[7] However, among these waste streams, only about 40% of waste is recycled. Moreover, that percentage is made up mostly of paper and cardboard; approximately 70% of paper and cardboard is recycled, while for textiles (18%), plastics (8%), and metals (3%) the percentages are much smaller.[8]

The U.S. Environmental Protection Agency has identified several issues[9] that impede successful recycling in the U.S. These include:

- **Technology and Innovation**: Recycling infrastructure is not always designed to handle the latest materials, packaging, and products, and communication between manufacturers and recyclers is lacking.[10]

- **Economics**: Historically, a significant portion of recycled materials have been exported internationally, but in 2018, China and other countries limited or stopped accepting U.S. recyclables. As a result, large recyclers have higher volumes of waste and fewer buyers for it, leading to the companies charging exponentially increased prices to U.S. municipalities.[11]

- **Marketing and Consumer Education**: Recycling rules vary by state and local jurisdictions, and it can be confusing and time consuming for consumers to properly recycle even simple items. Many consumers engage in “wishcycling” (disposal of waste in a recycling bin with the hope that it will be recycled, when it

[7] “National Overview: Facts and Figures on Materials, Wastes and Recycling,” U.S. Environmental Protection Agency, accessed June 23, 2024, https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#NationalPicture.
[8] Ibid.
[9] “The U.S. Recycling System,” U.S. Environmental Protection Agency, accessed June 23, 2024, https://www.epa.gov/circulareconomy/us-recycling-system.
[10] Ibid.
[11] Michael Corkery, “As Costs Skyrocket, More U.S. Cities Stop Recycling,” *The New York Times*, March 16, 2019, https://www.nytimes.com/2019/03/16/business/local-recycling-costs.html.

cannot or is unlikely to be recycled),[12] which results in contamination of the recycling stream.

- **Policy and Regulation**: Standards vary by state and locality regarding misleading or deceptive recycling symbols, and the U.S. government has been slow to update rules and guidelines.[13]

- **Measurement and Data**: More consistent, standardized measurement methodologies are needed to measure recycling system performance, create realistic goals, and track progress.[14]

This challenge will focus on recycling approaches for materials on the lunar surface that are very similar to materials that are difficult to recycle terrestrially. The challenge has the potential to highlight entirely novel approaches to recycling; processes that improve energy efficiency and water efficiency; processes that reduce unusable outputs and toxic emissions; and smaller-scale solutions that could be deployed in communities in a more distributed way than recycling facilities today. Each of these has the potential to influence and inspire better approaches and outcomes for terrestrial recycling in the future.

Challenge Overview

The LunaRecycle Challenge is a $3 million, two track, two-phase competition focused on the design and development of recycling solutions that can reduce solid waste and improve the sustainability of longer-term lunar missions. In this document, NASA has provided a Mission Scenario with technical requirements that teams must address in their solutions.

Competition Structure

The LunaRecycle Challenge will have two competition tracks:

- **Digital Twin track**, focused on designing a digital twin of a complete system for recycling one or more solid waste categories on the lunar surface **and** manufacturing one or more end products. Teams in this track **must** include the manufacturing of one or more finished end products in their design.

---

[12] "Wishcycling," Wikipedia, accessed June 23, 2024, https://en.wikipedia.org/wiki/Wishcycling.

[13] Ellie Borst, "EPA Looks to Toss 'Deceptive' Plastics Recycling Symbol," *E&E News*, May 15, 2023, https://www.eenews.net/articles/epa-looks-to-toss-deceptive-plastics-recycling-symbol/.

[14] "The U.S. Recycling System," U.S. Environmental Protection Agency.

- **Prototype Build track**, focused on designing and developing hardware components and systems for recycling one or more solid waste categories on the lunar surface. Teams in this track **may—but are not required to**—include the manufacturing of one or more end products in their design. Teams in this track may end their process with the production of one or more commodities, fuels, or feedstocks instead of one or more finished end products.

Teams may compete in either or both competition tracks. Each track is expected to have two phases.

Phase 1 Overview

This document details the challenge rules for Phase 1 of each track. The initiation of Phase 2 is contingent on the emergence of promising submissions in Phase 1 that demonstrate viable approaches to addressing the challenge. Additional details and rules for Phase 2 will be released if and when NASA launches Phase 2 for either or both tracks. General expectations for Phase 2 (both tracks) can be found in Appendix C.

In Phase 1, teams in the Digital Twin track will design a preliminary (low fidelity) digital twin and visualization of their solution. Teams will use a template (see Appendix A) to provide explanations, analyses, and data (as applicable) for their solution.

In Phase 1, teams in the Prototype Build track will develop a detailed design of their solution. Teams are not required to build or submit any hardware in Phase 1. Teams will use a template (see Appendix B) to provide explanations, analyses, and data (as applicable) for their solution.

A judging panel will review the submissions and determine the Phase 1 winners for each track according to the judging criteria described below.

Prize Purses (U.S. Winners)

The LunaRecycle challenge will have a total prize purse of up to $3 million, including a total of up to $1 million available during Phase 1. Prizes are expected to be distributed as summarized in Table 1 and Table 2. Teams must meet the eligibility requirements in order to receive a prize from NASA.

Table 1. LunaRecycle Challenge Total Available Prizes Across Phases

	Digital Twin Track	Prototype Build Track	TOTAL
Phase 1	$400K	$600K	$1.00M
Phase 2	$600K	$1.40M	$2.00M
TOTAL	$1.00M	$2.00M	$3.00M

Table 2. Phase 1 Planned Prize Purse Distribution

	Digital Twin Track	Prototype Build Track
Number of U.S. Winners	Up to 8	Up to 8
Prize Per U.S. Winner	$50K	$75K
Total Phase 1 Prizes	Up to $400K	Up to $600K

Recognition of International Teams

Up to three (3) top scoring International Teams in each track will be recognized as winners. International Teams must meet the eligibility requirements to participate in the challenge and to be recognized as winners. International Teams are not eligible to be awarded prize money.

Competition Timeline

For both tracks, Phase 1 is expected to last eight (8) months, including six (6) months for registration and submission. An expected competition calendar for Phase 1 is summarized in Table 3.

Table 3. Phase 1 Competition Calendar

Expected Date	Activity
September 30, 2024	Phase 1 registration begins
October 2024 - March 2025	Webinars and team recruitment activities Judges webinar/training
March 31, 2025	Deadline for registration (both tracks)
March 31, 2025	Deadline for Phase 1 submission (both tracks)
May 2025	Phase 1 winners announced (both tracks)
TBD	Phase 2 rules announced
Note: All deadlines are at 4:00 PM Eastern on the specified date.	

Mission Scenario

Overview

This Mission Scenario is a hypothetical example of the potential waste management needs of future NASA missions. This Mission Scenario contains information that is relevant for both competition tracks. Please see the specific questions for each track in the submission templates (Appendix A and Appendix B, respectively).

Mission Conditions and Activities

In this Mission Scenario, a crew of eight (8) people has been living on the lunar surface for 365 Earth days. During this time, they have accumulated 4,200 kg (42 m^3) of solid waste across six categories and including 17 different waste items (see Table 4). NASA is seeking recycling systems that can recycle this waste into commodities, fuels, and feedstocks and/or finished end products that are similar to commercially available products.

Recycling systems to address this waste may be located **outside on the lunar surface and/or inside a pressurized habitat**. If a system is designed for outside operation, it must be designed to take into account the *outside* gravity, atmospheric pressure, and temperature range described below. If a system is designed for inside operation, it must

be designed for the *inside* gravity, atmospheric pressure, temperature range, air composition, and volume constraints described below.

- Outside, on the lunar surface:
    - Gravity is 1.625 m/s^2
    - Atmospheric pressure is 0.3 nanopascal (nPa)
    - Temperatures range from 50 K to 250 K

- Inside a pressurized habitat:
    - Gravity is 1.625 m/s^2
    - Atmospheric pressure is 57.2 kilopascals (kPa)
    - Temperatures range from approximately 18°C to 27°C
    - Air composition is approximately 34% oxygen and 66% nitrogen and water vapor
    - Volume: The solution must fit within the space used by four (4) EXPRESS (EXpedite the PRocessing of Experiments to the Space Station) Rack double lockers; each EXPRESS Rack double locker is 48.26 cm height by 41.91 cm width by 24.13 cm depth.

Waste Categories and Items

Table 4 describes six waste categories and 17 waste items. In both tracks, teams must choose one or more waste categories to recycle. Teams are not required to recycle all items in the category or categories that they choose. If a team chooses to ignore an item, it will be considered a Waste Item Not Recycled, per the definition above. Teams are also not required to recycle 100% of any item that they choose to recycle. The leftover amount of material not recycled will be considered an Unusable Output, per the definition above. Teams will be judged (among several other criteria) on the Net Waste Recycled in each category they choose, as described below in the Judging Criteria section.

Table 4. Solid Waste Categories and Items

Difficulty Factor	Waste Category	Total Mass (kg)	Total Volume (m3)	Waste Item	Key Materials	Approx. Moisture Content (%)	% of Item by Mass	% of Item by Volume
3	Foam packaging	1000	10	Zotek F30	Zotek F30 100%	~0%	100%	100%
2	EVA Waste	100	1	Cargo Transfer Bags (CTBs)	Nomex 92% Nylon 3% Polyester 2%	~0%	100%	100%
2	Fabrics	1000	10	Clothing	Cotton/cellulose 56% Nylon 6% Polyester 38%	4%	77%	59%
				Wash cloths	Cotton/cellulose 100%	5%	21%	39%
				Disinfectant Wipes	Cotton/cellulose 100%	69%	2%	2%
2	Food Packaging	1000	10	Overwrap	Polyester 13% Polyethylene 15% Aluminum 30%	~0%	29%	29%
				Rehydratable Pouch	Nylon 41% Polyethylene 33% Ethylene vinyl alcohol (EVOH) 11%	4%	39%	40%
				Drink Pouch	Aluminum 24% Polyethylene 65% Polyethylene Terephthalate 11%	3%	8%	8%

				Thermal pouch	Nylon 13% Polyester 13% Polypropylene 56% Aluminum 18%	1%	24%	24%
2	Structural Elements	1000	10	Aluminum structure/struts	Aluminum >90%	~0%	90%	90%
				Polymer matrix composites	Thermoset or thermoplastic plastic resin 40% Carbon fiber 60%	~0%	10%	10%
1	Other Packaging and Gloves	100	1	Air Cushion	Polyethylene 100%	~0%	4%	2%
				Bubble Wrap Filler	Polyethylene 100%	~0%	1%	2%
				Reclosable bags	Polyethylene 100%	~0%	9%	2%
				Anti-Static Bubble Wrap Bags	Polyethylene 100%	~0%	9%	2%
				Plastazote LD45R	Polyethylene 100%	~0%	36%	68%
				Nitrile Gloves	Nitrile 100%	2%	41%	22%

Waste Item Commercial Equivalents

Table 5 provides examples of a commercial equivalent, manufacturer, and image for each of the waste items described in Table 4 above.

This information is being provided so that teams may understand the typical form factors of each waste item and procure commercially equivalent items to aid in design and testing, if they choose. None of the references in Table 5 should be construed as a NASA endorsement of the item or manufacturer, nor do they imply that NASA plans to use any item or manufacturer for any actual mission or activity.

If the item listed here includes a container or packaging, teams do not need to address the container or packaging in their recycling system.

Table 5. Waste Item Commercial Equivalents

Waste Item	Example Commercial Equivalent	Link to Example Manufacturer	Example Image
Zotek F30	Zotek F30	https://www.zotefoams.com/product/zotek/zotek-f-lightweight-pvdf-foam/	
Cargo Transfer Bags (CTB)	Magid NOM10 Nomex White Hood[15]	https://www.magidglove.com/magid-nom10-nomex-white-hood-nom10	

[15] Although this example commercial equivalent is a different shape than a cargo transfer bag (CTB), it approximates the material most used in CTBs.

Clothing	Hanes Men's Undershirt	https://www.hanes.com/hanes-men-s-undershirt-pack-v-neck-moisture-wicking-100-cotton-with-odor-control-6-pack.html	
Towels/Wash Cloths	R&R Textile Wash Cloth	https://www.grainger.com/product/R-R-TEXTILE-Wash-Cloth-White-38X621	
Disinfectant Wipes	Virox PreEmpt Wipes	https://info.virox.com/hubfs/PREempt_Product_Pages/PREempt_Wipes_US_Sell_Sheet.pdf	
Overwrap	Glenroy White Ready Seal 225	https://www.glenroy.com/flexible-packaging/narrow-web-packaging-films/	
Drink Pouch	Kraft Heinz Capri Sun[16]	https://www.kraftheinz.com/capri-sun/adults	

[16] Teams should disregard the straw included in this example commercial equivalent; the straw is not included as part of the item to be recycled.

Rehydratable Pouch	Winpak Multi-Purpose Forming Film (MB225PL)	https://www.imperialade.com/catalog/product-detail/multi-purpose-forming-film-25-2554-in-plastic-clear-1-roll-winpak-MB%20225PL?id=39108	
Aluminum Structure/Struts	Uline Aluminum Steam Table Pan	https://www.uline.com/Product/Detail/S-22409/Take-Out-Containers/Aluminum-Steam-Table-Pans-Full-Size	
Polymer matrix composites	True Composites Carbon Fiber and Resin Kit	https://truecomposites.com/products/true-composites-carbon-fiber-sheet-epoxy-resin-kit-36-x-6-8oz-of-epoxy-2x2-twill-3k-5-7-oz-carbon-fiber-fabric-carbon-fiber-repair-kit-kit-de-lamina-de-fibra-de-carbono-y-resina-epoxi	
Air cushion	Uline Air Pillow Film	https://www.uline.com/Product/Detail/S-22467/Air-Pillows/Air-Pillow-Film-for-Uline-Air-Cushion-Machine-8-x-4	
Bubble wrap filler	Office Depot Brand Small Bubble Cushioning	https://www.officedepot.com/a/products/653338/Office-Depot-Brand-Small-Bubble-Cushioning/	

Reclosable bags	CEL Scientific Kynar gas sampling bags (any size)	https://www.celscientific.com/KynarBag.html	
Anti-Static Bubble Wrap Bags	Uline Anti-Static Bubble Bags (any size)	https://www.uline.com/BL_7651/Anti-Static-Bubble-Bags	
Plastazote LD45 FR	Zotefoams Plastazote LD45 FR (Flame-Retarded Low Density Polyethylene Foam)	https://www.zotefoams.com/wp-content/uploads/2016/03/LD45FR-December-2017.pdf	
Nitrile gloves	Med Pride Medical Examination Nitrile Gloves	https://www.medpride.com/product/nitrile-gloves/	

Available Resources

In this Mission Scenario, teams may assume the following with regard to resources:

- **Electricity** is available continuously for the recycling process. Teams should not propose any solutions for their own electricity generation, transmission, or energy storage separate from the recycling process; for example, teams should not propose a separate standalone solar system with battery storage as a way to power their system.
- **Water** is available for use in the recycling process. However, teams should seek to minimize their use of water in the recycling process.
- **Outputs from the Recycling Process**, such as waste heat, wastewater, or other outputs may be converted and/or re-used as inputs to the recycling process to increase process efficiency.

- **Crew** are available to operate, monitor, and maintain the recycling system, if necessary. However, teams are encouraged to minimize crew time needed for the recycling process.
- **Lunar regolith** is available for use in the recycling process. Lunar regolith in this Mission Scenario is defined as LHS-1 Lunar Highlands Simulant, the specifications for which can be found at: https://sciences.ucf.edu/class/wp-content/uploads/sites/23/2019/02/Spec_LHS-1.pdf. This document will also be made available on the challenge website. Teams may assume that any amount of regolith with these characteristics is available at the site of the recycling process. Teams do not need to address how the regolith is excavated or transported to the site of the recycling process; they must only address how it would be used in the recycling process (if they choose to use it).

Additional Considerations

Teams should also consider the following:

- Waste cannot be burned or incinerated.
- Teams should avoid the release of any toxic emissions or other harmful/toxic byproducts. If the recycling or manufacturing process will result in any hazardous emissions or materials, the team must disclose them in their submission.
- Teams should avoid the release of any per- and polyfluoroalkyl substances (PFAS). If the recycling or manufacturing process will result in any PFAS, the team must disclose them in their submission.
- Teams should avoid the creation of any microplastics, including in any wastewater from the recycling or manufacturing process. If the recycling or manufacturing process will result in any microplastics, the team must disclose them in their submission.

Desirable End Products

NASA will have a need for a variety of end products that may wholly or partially utilize materials created from the recycling process. Table 6 highlights a number of examples of end products that would be desirable in a lunar settlement. Teams are also encouraged to imagine other useful end products that might be created through their proposed processes and solutions.

Table 6. Examples of End Products Made from Recycled Materials that are Desirable in a Lunar Settlement

Product	Key Characteristics
Utensils	-Safe and non-toxic (able to be used to prepare and consume food) -Durable (will not break easily) -Recyclable
Towels	-Safe and non-toxic (able to be used without irritation to the skin) -Durable (can be used repeatedly/over a specific period of time) -Recyclable
Small storage containers for food	-Safe and non-toxic (able to be used for food storage) -Recyclable
Large storage containers for water, chemicals, or gasses	-Safe (to operate) -Avoids leaks or contamination of contents -Durable (can safely store a commodity for a significant period of time)
Nitrile gloves	-Safe and non-toxic (able to be worn without irritation to the skin) -Protective (protect the skin) -Recyclable
Tools (for example cable ties, straps, strap holders, harness hardware, wrench, driver replacements, screws)	-Safe (for a crew member to use) -Durable (can be used repeatedly/over a specific period of time)
“Simple Luxury Item” that would improve crew quality of life but not otherwise be transported to the Moon	Defined by the team/specific to the item
Other Items imagined by the team…	Defined by the team/specific to the item

Phase 1 Registration and Submissions

Registration (Both Tracks)

All interested teams must register for the challenge by March 31, 2025, 4:00PM Eastern Daylight Time (EDT) and meet the Legal Requirements explained below.

NASA has partnered with the University of Alabama as the Allied Organization to help execute the LunaRecyle Challenge. The registration process will be administered by the University of Alabama. Registration will take place through challenge website: lunarecyclechallenge.ua.edu.

As part of registration, teams must submit the following:

- Team Information; and
- Team Agreement and other legal documentation, as described in the Legal Requirements section below.

Additional details regarding the process for registration will be available on the challenge website.

Phase 1 Submission (Digital Twin Track)

For the Digital Twin Track, teams must submit the following three (3) items:

1. A presentation file saved as a PDF using the template provided in Appendix A;
2. A recorded presentation/explanation of the presentation file; and
3. A stand-alone animation, visualization, and/or simulation that mimics the behavior of a real-world system.

For the Digital Twin Track, each team may only have one (1) entry. Teams must submit their materials on the challenge website lunarecyclechallenge.ua.edu by March 31, 2025, 4:00PM Eastern Daylight Time (EDT).

Phase 1 Submissions (Prototype Build Track)

For the Prototype Build Track, teams must submit the following two (2) items:

1. A document file saved as a PDF using the template in Appendix B; and
2. A short pitch video (no more than 2 minutes) describing their team and solution.

For the Prototype Build Track, each team may have multiple entries. Teams must submit their materials on the challenge website lunarecyclechallenge.ua.edu by March 31, 2025, 4:00PM Eastern Daylight Time (EDT).

Judging Criteria

The following is a summary of the Phase 1 judging criteria for both tracks. Teams in both tracks will be judged on **Completeness**; **Net Waste Recycled**; and **Additional Criteria**, as described below. To be eligible for a Phase 1 award, teams must receive the following minimum scores:

- A “Pass” score on COMPLETENESS
- A minimum score of 2 points on NET WASTE RECYCLED
- A minimum score of 60 points (out of 100 points) on the ADDITIONAL CRITERIA

COMPLETENESS will be judged on a Pass/Fail basis. All teams will be judged on Completeness. In order to receive a “Pass” score for completeness, teams must address all of the sections of the submission template for their respective track. PLEASE NOTE: Submissions that receive a “Fail” score for completeness will not be judged and will not be eligible for a prize.

NET WASTE RECYCLED will be calculated according to the methods described below. All teams will be judged on Net Waste Recycled. Teams will score higher or lower based on the percentage of waste they can recycle; the difficulty level of the waste category or categories they choose; and the number of waste categories they choose. The judging panel will also assess the credibility of the percentages that teams submit, based on the explanations and data included in the submission. If the judging panel deems the percentages not credible, they may reduce the total net waste recycled score.

First, for each waste category that a team recycles, they will receive a number of points based on the percentage of net waste recycled, as follows:

Percentage of Net Waste Recycled	Points
0% to 9% recycled	0 points
10% to 25% recycled	1 point
26% to 50% recycled	2 points
51% to 75% recycled	4 points
76% to 99% recycled	8 points
100% recycled	10 points

Then, for each waste category that a team chooses to recycle, their point total will be multiplied by a difficulty factor, as follows:

Difficulty Factor (as noted in Table 4)	Bonus
1	0%
2	50%
3	100%

The total NET WASTE RECYCLED score will be the sum of the points assigned for the percentage of each waste category recycled plus any bonus.

For example:

- Team A recycles 60% of the Fabrics category (Difficulty 2). They receive 4 points for the percentage recycled plus 2 points bonus for a total net waste recycled score of 6.

- Team B recycles 55% of the Fabrics category (Difficulty 2) and 70% of Other Packaging (Difficulty 1). They receive 4 points for the percentage recycled of the first category and 4 points for the percentage recycled of the second category plus 2 points bonus for a total net waste recycled score of 10.

- Team C recycles 80% of the Zotek category (Difficulty 3). They receive 8 points for the percentage recycled plus 8 points bonus for a total net waste recycled score of 16

ADDITIONAL CRITERIA will be assessed and scored by the judging panel. Each judge will assign points based on an evaluation of the team's submission. A total of 100 points for ADDITIONAL CRITERIA are available in each track. The available points for each criterion in each track are described in Table 7.

Some Additional Criteria apply to **both** tracks (Innovation, Estimated Mass and Volume, and Efficiency of the Recycling Process). Some Additional Criteria apply **only** to the Digital Twin Track (Digital Twin Architecture, Digital Twin Characteristics, and Quality of Digital Twin Visualization), and some Additional Criteria apply **only** to the Prototype Build Track (Feasibility of the Solution and Development Plan for System Fabrication and Testing).

Table 7. Summary of Phase 1 Judging Criteria

Criteria	Description	Digital Twin	Prototype Build
COMPLETENESS	Did the team address all requirements and provide detailed descriptions and robust supporting data/analysis?	Pass/ Fail	Pass/ Fail
NET WASTE RECYCLED	What is the percentage of net waste recycled? What is the difficulty level of the waste category or categories that will be recycled?	Calculated	Calculated
ADDITIONAL CRITERIA - BOTH TRACKS			
Innovation	How innovative is the approach and proposed systems? How does it compare to recycling solutions already used terrestrially? How does it leverage advanced technologies?	Up to 20 points	Up to 15 points
Estimated Mass and Volume of System	What is the estimated mass and volume of the system? Have both mass and volume been optimized to enable transport to and operation on the lunar surface?	Up to 20 points	Up to 20 points
Efficiency of Recycling Process	What is the expected energy efficiency and water efficiency of the proposed process? How well does it minimize additional resource inputs and unusable outputs? How well does it minimize crew time?	Up to 20 points	Up to 20 points
ADDITIONAL CRITERIA - DIGITAL TWIN TRACK			
Digital Twin Architecture	Is the design approach technically sound? Does it address all the necessary elements of a Digital Twin? Does it include all of the necessary engineering data and information?	Up to 20 points	

Digital Twin Characteristics	Does the design address each of the required Digital Twin characteristics? How well does it address these characteristics?	Up to 10 points	
Quality of Digital Twin Visualization	How well does the visualization represent the overall Digital Twin?	Up to 10 points	
ADDITIONAL CRITERIA - PROTOTYPE BUILD TRACK			
Feasibility of the Solution	How feasible will the design be to build and implement—both during the challenge and in a future NASA mission? How well does the team understand and articulate potential technical risks and how they may be mitigated?		Up to 25 points
Development Plan for System Fabrication and Testing	How well has the team planned for actually developing, building, and testing hardware if they move onto Phase 2 of the challenge? How well have they planned for the necessary personnel, budget, and other development needs?		Up to 20 points
TOTAL		**Up to 100 points**	**Up to 100 points**

Legal Requirements

In General

Teams are responsible for understanding and complying with these Requirements.

Eligibility to Compete

NASA welcomes applications from individuals, groups of individuals, and/or organizations or entities that meet the eligibility requirements provided below.

In order to participate in the Challenge, each individual, whether acting alone or as part of a Competitor Team must identify their nationality.

No Team member shall be a citizen of a country on the NASA Export Control Program list of Designated Countries List Category II: Countries determined by the Department of State to support terrorism. The current list of designated countries can be found at http://oiir.hq.nasa.gov/nasaecp. Please check the link for the latest updates. This includes individuals with dual citizenship unless they are a U.S. citizen or a lawful permanent U.S. resident (green card holder).

While China is not a Category II designated country, pursuant to Public Law 116-6, Section 530, NASA is prohibited from participating, collaborating, or coordinating bilaterally in any way with China or any Chinese-owned entity. Team members who are citizens of China but not affiliated with a Chinese entity may be permitted to participate on a Team.

Subject to the conditions set forth herein, foreign nationals and foreign national teams can participate in the Challenge. However, they are not eligible for a cash prize and must acknowledge acceptance of this by signing and submitting a Foreign Participant Acknowledgement Form.

Eligibility to Compete and Win Prizes from NASA

In order to be eligible to win a prize from NASA:

- Individuals must be U.S. citizens OR permanent residents of the United States, AND over the age of 18.
- Organizations must be an entity incorporated in AND maintaining a primary place of business in the United States.
- Teams must be comprised of otherwise eligible individuals or organizations AND led by an otherwise eligible individual or organization.
- Team Leader must be a U.S. citizen or permanent resident.

A Team may include foreign nationals and be eligible to win prize money as long as the foreign national signs and delivers a disclosure wherein they disclose his/her citizenship and acknowledge that he/she is not eligible to win a prize from NASA, AND the foreign national is:

- An employee of an otherwise eligible U.S. entity participating in the Challenge,
- An owner of such entity, so long as foreign citizens own less than 50% of the interests in the entity,
- A contractor under written contract to such entity, OR
- A full-time student who, during the time of the Challenge, (1) is enrolled in an accredited institution of higher learning, (2) has a valid student visa and (3) is otherwise in compliance with all local, state, and U.S. Government laws and regulations regarding the sale and export of technology.

Team Members must furnish proof of eligibility (including proof of citizenship or permanent resident status, for individuals, and proof of incorporation and primary place of business, for entities) which proof must be satisfactory to NASA in its sole discretion. A Team's failure to comply with any aspect of the eligibility requirements will result in the Team being disqualified from winning a Prize from NASA.

U.S. government employees may enter the competition, or be members of prize-eligible teams, so long as they are not acting within the scope of their Federal employment, and they rely on no facilities, personnel, hardware, access, knowledge, information previously developed, or other resources that are available to them as a result of their employment except for those resources available to all other Teams on an equal basis.

U.S. government employees participating as individuals, or who submit applications on behalf of an otherwise eligible organization, will be responsible for ensuring that their participation in the Challenge is permitted by the rules and regulations relevant to their position and that they have obtained any authorization that may be required by virtue of their government position. Failure to do so may result in the disqualification of them individually or of the entity which they represent or in which they are involved.
Teams will be ineligible to win the Prize if any Team Member is a U.S. Government entity or employee acting within the scope of their employment. This includes any U.S. Government organization or organization principally or substantially funded by the U.S. Government, including Federally Funded Research and Development Centers, Government-owned, contractor operated (GOCO) facilities, and University Affiliated Research Centers. Any such entity or individual will obtain prior written approval from their cognizant ethics officer that such participation does not violate federal personnel laws or applicable agency policy. A copy of this approval to participate in the Challenge will promptly be provided to the University of Alabama.

Participants may not use Federal funds from a grant award, cooperative agreement, or other transaction award to develop their challenge submissions or to fund efforts in support of their challenge submissions.

Current employees, consultants, and students of the University of Alabama may only participate as Team Members on a Team when that Team is not competing for the Prize from NASA. Participation of such parties as Team Members on a Team will make a Team ineligible for any Prize award from NASA.

Team Roles and Responsibilities

Each Team will designate a Team Leader. The Team Leader will be responsible for compliance with the rules, including prize eligibility rules, by all members of their Team. Prize funding will be released only to the Team Leader.

Intellectual Property Rights

Notwithstanding anything to the contrary in these rules, NASA and the University of Alabama claim no intellectual property (IP) rights from the Team. All trade secrets, copyrights, patent rights, and software rights will remain with each respective Team.

To the extent the Team owns IP resulting from its participation in the Challenge, the Team agrees to negotiate in good faith with NASA for a grant of a nonexclusive, nontransferable, irrevocable license to practice or have practiced for or on behalf of the United States, the intellectual property throughout the world, at reasonable compensation, if NASA chooses to pursue such a license.

Insurance and Indemnification

Each Team Member agrees to assume any and all risks and waives claims against the University of Alabama and the U.S. Government and its related entities, except in the case of willful misconduct, for any injury, death, damage, or loss of property, revenue, or profits, whether direct, indirect, or consequential, arising from each Team Member's participation in the Challenge, whether such injury, death, damage, or loss arises through negligence or otherwise. For the purposes of this section, the term "related entity" means a contractor or subcontractor at any tier, and a supplier, user, customer, cooperating party, grantee, investigator, or detailee.

Team agrees to obtain any and all insurance policies and coverage as stated in the Team Agreement and required by its local, state, or Federal governments to conduct any and all activities related to or required by participation of Team and the Team Members in the Challenge. In addition, Teams are required to obtain liability insurance in the amount of $5,000 USD minimum that covers each Team Member or otherwise demonstrate financial responsibility for that amount. The Team's liability insurance will provide coverage for all claims by (A) a third party for death, bodily injury, or property damage, or loss resulting from an activity carried out in connection with participation in the Challenge, with the U.S. Government and the University of Alabama named as an additional insured under the Team's insurance policies; and (B) the U.S. Government, the University of Alabama, and its contractors for damage or loss to Government or the University of Alabama property resulting from or related to Challenge activities. The Team and all Team Members jointly and severally agree to indemnify the U.S. Government and the University of Alabama against third-party claims for damages arising from or related to Challenge activities. Should an onsite activity be held all the University of Alabama insurance requirements must be met.

Proof of insurance in such form as reasonably required by University of Alabama shall be provided to University of Alabama by the Submission Deadline as outlined in Exhibit C of the Team Agreement. Alternatively, if Team intends to fulfill this requirement by demonstrating financial responsibility in the requisite amount, Team shall submit to University of Alabama in writing such information as demonstrates to University of

Alabama, in University of Alabama's reasonable discretion, that Team has sufficient financial responsibility to cover the potential claims cited in the requisite minimum amount as outlined in Exhibit C of the Team Agreement.

Use of Names, Trademarks, and Insights

Team may not use the name, trademark or insignia of University of Alabama, its contractors, collaborators, or NASA on its printed materials related to the participation of Team in the Challenge without University of Alabama's or its contractor's, collaborator's, or NASA's prior written consent, whichever Party is applicable.

Team agrees that unauthorized use of such names, trademarks, and insignias shall result in elimination from participation in the Challenge if Team continues unauthorized use after being notified to cease and desist by University of Alabama or NASA, as applicable.

Delay, Cancellation or Termination

The Competitor Team acknowledges that circumstances may arise that require the Challenge to be delayed indefinitely or canceled. Such delay or cancellation, and/or the termination of the Challenge, shall be within the full discretion of NASA, and the Team accepts any risk of damage or loss due to such delay, cancellation, and/or termination.

Appendix A: Phase 1 Submission Instructions (Digital Twin Track)

Instructions

In General:

- The submission must address each required section and topic described below. Teams should maintain all numbered section headings in their submission. PLEASE NOTE: Any submission that does not address all of the requirements will receive a “Fail” score for completeness, will not be judged, and will not be eligible for a prize.

Presentation:

- The presentation must be a PDF file and may include no more than 30 slides. Judges will not review any materials beyond 30 slides. This instruction section does not count toward the page limit and may be deleted prior to submission.
- The text on slides must be no smaller than 16-point font (Arial or Times New Roman recommended). Teams should use a standard size slide with 4:3 aspect ratio.
- Each section includes a recommended length for the answer. These recommendations are intended to provide guidance on NASA’s expectations for the length and quality of the answer, but teams are not required to adhere to these recommendations. Teams may allocate space to different sections as they see fit.
- The recorded presentation may be no longer than 30 minutes. Judges will not review the presentation beyond 30 minutes.

Visualization File:

- The animated visualization must be submitted as a separate file and may not be longer than 10 minutes. Judges will not review the visualization beyond 10 minutes.

Required Sections and Topics

1. Team Information (*1 slide suggested*)

    1.1 Team Name: (Teams are encouraged to use a creative team name. This name may be used in promotional materials related to the challenge.)

    1.2 Team Lead:

    1.3 Team Affiliations/Organizations (if applicable):

    1.4 Relevant Past Work (if applicable):

    1.5 Geographic Location (City and State/Territory):

    1.6 One Sentence Description: (Provide a one-sentence description of your solution that may be used in promotional materials related to the challenge. Do not reference any confidential elements of your solution in this description.)

2. Vision and Innovation *(3-4 slides suggested)*

    2.1 What specifically is innovative about your approach?

    2.2 How is it different from and/or better than recycling approaches currently used terrestrially?

    2.3 How is it different from and/or better than recycling approaches currently contemplated for space applications?

    2.4 How does your approach leverage advanced technologies or advanced manufacturing methods?

    2.5 How does it address the conditions and activities of the hypothetical lunar settlement described in the Mission Scenario? Please specifically address: a) whether your system will be located outside on the lunar surface and/or inside a pressurized habitat; and b) how your system will be designed for the lunar conditions relevant to its location (as described in the Mission Scenario).

    2.6 Teams are not required to design solutions to operate in lunar dust conditions. However, please describe how your solution might be adapted to operate in lunar dust conditions in the future and/or whether/how it might be inherently dust resistant.

2.7 This challenge is focused on recycling systems for the lunar surface. However, please describe how your solution might have application, or be adapted to have application, to recycling systems on Earth.

3. Recycling and Manufacturing Process (*8-9 slides suggested*)

3.1 What **waste category/categories** will your process address? Within each waste category, what waste items will your process address? Please provide details about the estimated amounts (% by mass and % by volume) and materials that will be recycled.

3.2 Describe the **usable outputs** produced from your process, including the types and amounts (kg) of feedstocks and any finished end products (kg or number).

3.3 What are the **systems and components** that make up your process? Please provide detailed descriptions, schematics, and other relevant data for these systems and components.

3.4 What is your **concept of operations**? Please describe: a) a full production cycle of your process, including the duration; and b) how many full production cycles will be required to recycle the estimated amounts and materials that you described in question 3.1 and produce the usable outputs that you described in question 3.2. In addition, please note whether operation of your system will require crew, and if so, what operational activities they will need to perform.

3.5 What **maintenance** for your system will be needed during your process or after your process has completed one or more full production cycles? Please describe any maintenance activities and whether the activities require crew.

3.6 Describe the **resource inputs** needed for your process (consistent with sections 3.1, 3.2, 3.3, and 3.4 above) including the total electricity, water, chemicals, minerals, and any other inputs, including crew time. Include the following RESOURCE INPUTS TABLE in your presentation for each waste category that you are addressing. If your recycling process addresses more than one waste category simultaneously, you may provide one table for multiple waste categories.

RESOURCE INPUTS TABLE

Waste Category	**Resource Input**	**Total amount required for your process**
(Name of the Waste Category, from Table 4 in the challenge rules)	Electricity	–Peak demand over a specific time period (kW) –Total electricity consumed (kWh) –Net electricity consumed, if any electricity is produced in the recycling process (kWh)
	Water	kg
	Chemicals/ Minerals/Other Resource Inputs	kg
	Crew Time to Operate the System	# of crew and hours per crew member
	Crew Time needed for Maintenance Activities	# of crew and hours per crew member

3.7 Describe the types and amounts (kg) of any **unusable outputs** that will result from your process. Unusable outputs are defined in the Definitions section above.

3.8 Use the following NET WASTE RECYCLED TABLE to show the **net waste recycled**. In Phase 1 of the challenge, net waste recycled for each waste category is equal to the sum of the percentage recycled (by mass) of each waste item in a category.

For example, Team A has chosen the Fabrics category. Their process will recycle (by mass) 70% of the clothing, 80% of the towels, and none of the disinfectant wipes. Team A will multiply the percentage recycled by the total % by mass of each item, as listed in Table 4. Therefore, Team A's net waste recycled is: (70% X 77%) + (80% X 21%) + (0% X 2%) = 71%.

Please use one row for each waste category that your process will address and one column for each waste item in the category. You may add additional rows

and columns to this template as appropriate. Percentages should be rounded to whole numbers.

NET WASTE RECYCLED TABLE

Waste Category	Waste Item 1 (% recycled by mass)	Waste Item 2 (% recycled by mass)	Waste Item 3 (% recycled by mass)	Net Waste Recycled (%)
(Team A example) Fabrics	54%	17%	0%	**71%**

4. Digital Twin Architecture (*8-10 slides suggested*)

4.1 Describe the architecture of your digital twin

4.1.1 What is your design approach? Describe the physics-based models, simulation, and visualization you will use to create a virtual representation of an intended future physical system.

4.1.2 Describe the level of fidelity and resolution that demonstrates how closely the digital representation matches the real-world system.

4.1.3 Describe the sensors and observing systems and the data acquisition and data integration approaches.

4.1.4 Describe any automated control and decision-making capabilities.

4.1.5 Describe any artificial intelligence, machine learning, and empirical modeling capabilities.

4.1.6 Describe your expected approach to virtual prototyping and testing to test performance and functionality in a simulated environment.

4.1.7 Describe your validation approach for computer models (e.g., how accurately the model's predictions or outputs align with real-world intended future systems).

4.1.8 Describe how the digital twin would communicate with physical assets that would be part of the intended future physical system.

5. Digital Twin Key Characteristics (*4 slides suggested*)

5.1 Describe how your Digital Twin Prototype addresses the following key characteristics:

5.1.1 Accuracy, defined as the degree to which the digital representation reflects the real-world physical asset in data fidelity, model fidelity, and predictive capability.

5.1.2 Cohesion, defined as how closely coupled the different parts of the digital representation (e.g., model/simulation) are and how the model/simulation adheres to the laws of physics the same way the physical twin does.

5.1.3 Flexibility, defined as the ability of the digital representation to adapt and change to reflect the real-world physical asset and handle increasing complexity as the technologies or physical asset evolves.

5.1.4 Predictive Capabilities, defined as the ability of the digital model to anticipate the future behavior and performance of the physical asset.

5.1.5 Repeatability, defined as the ability to consistently create and operate digital twins that are reliable, can be replicated, and function as expected across multiple scenarios.

5.1.6 Usability, defined as the ease with which users can interact with, understand, and leverage the digital representation of a physical asset. NASA is seeking a digital twin that is user-friendly and enables efficient decision-making.

5.1.7 Verification and Validation, defined as how the digital twin meets specifications and requirements, including: a) How the various models will be assembled/integrated together; b) What are the analysis, demonstration, and test approaches for verification and validation; and c) What is the process for determining the degree to which a model is an accurate representation of the real world asset.

6. Digital Twin Visualization (*2 slides suggested*)

6.1 Describe what is included or addressed in the visualization provided in your submission

6.1.1 How was the visualization created?
6.1.2 What engineering data does it incorporate?
6.1.3 What does it show?

Appendix B: Phase 1 Submission Template (Prototype Build Track)

Instructions

In General:

- The submission must address each required section and topic described below. Teams should maintain all numbered section headings in their submission. PLEASE NOTE: Any submission that does not address all of the requirements will receive a "Fail" score for completeness, will not be judged, and will not be eligible for a prize.

Submission Document:

- The submission must be a PDF file and may include no more than 20 pages. Teams must adhere to this limit. Judges will not review any materials beyond 20 pages. This instruction section does not count toward the page limit and may be deleted prior to submission.
- A "page" is defined as 8" X 11" size paper with 11-point font (Arial or Times New Roman), 1-inch margins, single spaced. Any text included in tables, figures, or captions may be as small as 10-point font.
- Each section includes a recommended length for the answer. These recommendations are intended to provide guidance on NASA's expectations for the length and quality of the answer, but teams are not required to adhere to these recommendations. Teams may allocate space to different sections as they see fit.

Pitch Video:

- Teams must also submit as a separate file a short pitch video (no more than 2 minutes) describing their team and solution. Judges will not review the video beyond 2 minutes.

Required Sections and Topics

1. Team Information (*1 page suggested*)

    1.1 Team Name: (Teams are encouraged to use a creative team name. This name may be used in promotional materials related to the challenge.)

    1.2 Team Lead:

    1.3 Team Affiliations/Organizations (if applicable):

    1.4 Relevant Past Work (if applicable):

    1.5 Geographic Location (City and State/Territory):

    1.6 One Sentence Description: (Provide a one-sentence description of your solution that may be used in promotional materials related to the challenge. Do not reference any confidential elements of your solution in this description.)

2. Vision and Innovation *(2-3 pages suggested)*

    2.1 What specifically is innovative about your approach?

    2.2 How is it different from and/or better than recycling approaches currently used terrestrially?

    2.3 How is it different from and/or better than recycling approaches currently contemplated for space applications?

    2.4 How does your approach leverage advanced technologies or advanced manufacturing methods?

    2.5 How does it address the conditions and activities of the hypothetical lunar settlement described in the Mission Scenario? Please specifically address: a) whether your system will be located outside on the lunar surface and/or inside a pressurized habitat; and b) how your system will be designed for the lunar conditions relevant to its location (as described in the Mission Scenario).

    2.6 Teams are not required to design solutions to operate in lunar dust conditions. However, please describe how your solution might be adapted to operate in lunar dust conditions in the future and/or whether/how it might be inherently dust resistant.

2.7 This challenge is focused on recycling systems for the lunar surface. However, please describe how your solution might have application, or be adapted to have application, to recycling systems on Earth.

3. Recycling and Manufacturing Process (*8-10 pages suggested*)

3.1 What **waste category/categories** will your process address? Within each waste category, what waste items will your process address? Please provide details about the estimated amounts (% by mass and % by volume) and materials that will be recycled.

3.2 Describe the **usable outputs** produced from your process, including the types and amounts (kg) of feedstocks and any finished end products (kg or number), if applicable to your process.

3.3 What are the **systems and components** that make up your process? Please provide detailed descriptions, schematics, and other relevant data for these systems and components.

3.4 What is your **concept of operations**? Please describe: a) a full production cycle of your process, including the duration; and b) how many full production cycles will be required to recycle the estimated amounts and materials that you described in question 3.1 and produce the usable outputs that you described in question 3.2. In addition, please note whether operation of your system will require crew, and if so, what operational activities they will need to perform.

3.5 What **maintenance** for your system will be needed during your process or after your process has completed one or more full production cycles? Please describe any maintenance activities and whether the activities require crew.

3.6 Describe the **resource inputs** needed for your process (consistent with sections 3.1, 3.2, 3.3, and 3.4 above) including the total electricity, water, chemicals, minerals, and any other inputs, including crew time. Include the following RESOURCE INPUTS TABLE in your presentation for each waste category that you are addressing. If your recycling process addresses more than one waste category simultaneously, you may provide one table for multiple waste categories.

RESOURCE INPUTS TABLE

Waste Category	**Resource Input**	**Total amount required for your process**
(Name of the Waste Category, from Table 4 in the challenge rules)	Electricity	–Peak demand over a specific time period (kW) –Total electricity consumed (kWh) –Net electricity consumed, if any electricity is produced in the recycling process (kWh)
	Water	kg
	Chemicals/ Minerals/Other Resource Inputs	kg
	Crew Time to Operate the System	# of crew and hours per crew member
	Crew Time needed for Maintenance Activities	# of crew and hours per crew member

3.7 Describe the types and amounts (kg) of any **unusable outputs** that will result from your process. Unusable outputs are defined in the Definitions section above.

3.8 Use the following NET WASTE RECYCLED TABLE to show the **net waste recycled**. In Phase 1 of the challenge, net waste recycled for each waste category is equal to the sum of the percentage recycled (by mass) of each waste item in a category.

For example, Team A has chosen the Fabrics category. Their process will recycle (by mass) 70% of the clothing, 80% of the towels, and none of the disinfectant wipes. Team A will multiply the percentage recycled by the total % by mass of each item, as listed in Table 4. Therefore, Team A's net waste recycled is: (70% X 77%) + (80% X 21%) + (0% X 2%) = 71%.

Please use one row for each waste category that your process will address and one column for each waste item in the category. You may add additional rows and columns to this template as appropriate. Percentages should be rounded to whole numbers.

NET WASTE RECYCLED TABLE

Waste Category	**Waste Item 1 (% recycled by mass)**	**Waste Item 2 (% recycled by mass)**	**Waste Item 3 (% recycled by mass)**	**Net Waste Recycled (%)**
(Team A example) Fabrics	54%	17%	0%	**71%**

4. Hardware and Components (*2-3 pages suggested*)

4.1 Preliminary Schematics*:* Provide assembly-level CAD models showing envelopes and key dimensions for your solution.

4.2 Equipment List and Mass/Volume Estimates: Use the following EQUIPMENT TABLE to provide a draft master equipment list, including mass and volume estimates for each major component or system. Please add as many rows as necessary to the template.

EQUIPMENT TABLE

Description of Equipment	Estimated Mass (kg)	Estimated Volume (cm^3)	Expected Allowable Ranges for Temperature and Atmospheric Pressure

5. Development Planning (*2-3 pages suggested*)

- Development Plan*:* Describe your plan for further developing your solution into a functional prototype during Phase 2. Teams should address the technical steps necessary for hardware development and testing; success criteria for testing; personnel and other resources; and expected timeline/schedule.

- Risk Assessment*:* Describe the technical and other risks associated with developing your solution in Phase 2. For each risk, include an assessment of the risk (such as high, medium, low) and your proposed risk mitigation strategy.

- Development Budget*:* Use the following BUDGET TABLE to estimate the budget necessary to execute your Development Plan in Phase 2. In this challenge, NASA is not focused on comparing the overall cost of solutions; rather this section is intended to assess how well the team has thought through the budget necessary to build their solution, if they are chosen to move onto Phase 2. In the "Expected funding sources" column, teams should address whether you will already have funds in place to support work during Phase 2, and if not, how you will work to secure the necessary funds. You may assume the Phase 1 prize purse in your budget.

BUDGET TABLE

Type of cost	**Description**	**Estimated budget for developing your solution in Phase 2 ($)**	**Potential funding source(s)**
Materials			
Equipment			
Lab/testing			
Personnel			
Admin			
Other (if applicable)			

Appendix C: Expectations for Phase 2

The initiation of Phase 2 is contingent on the emergence of promising submissions in Phase 1 that demonstrate viable approaches to addressing the challenge. Additional details and rules for Phase 2 will be released if and when NASA launches Phase 2 for either or both tracks.

Generally, in Phase 2, NASA expects that teams will focus on more advanced versions of recycling solutions for the lunar surface. Typically, Phase 2 is open to any eligible team, whether or not they competed in Phase 1. The duration of Phase 2 may be up to 24 months.

In Phase 2 of the Digital Twin track, NASA expects that teams will focus on developing a high-fidelity digital twin that incorporates the data and capabilities necessary to virtually model and demonstrate a recycling system that fully mimics an intended future physical system.

In Phase 2 of the Prototype Build track, NASA expects that teams will develop hardware components and/or systems for recycling. NASA may conduct site visits to see and verify progress and/or hold one or more testing and demonstration events at NASA or other similar facilities during Phase 2.

In either/both tracks, NASA may offer one or more milestone prize purses, in addition to a grand prize purse. Total prize purses across both tracks in Phase 2 are expected to be up to $2 million.

Additional details and the challenge rules for Phase 2 will be released if and when NASA launches Phase 2 for either or both tracks.