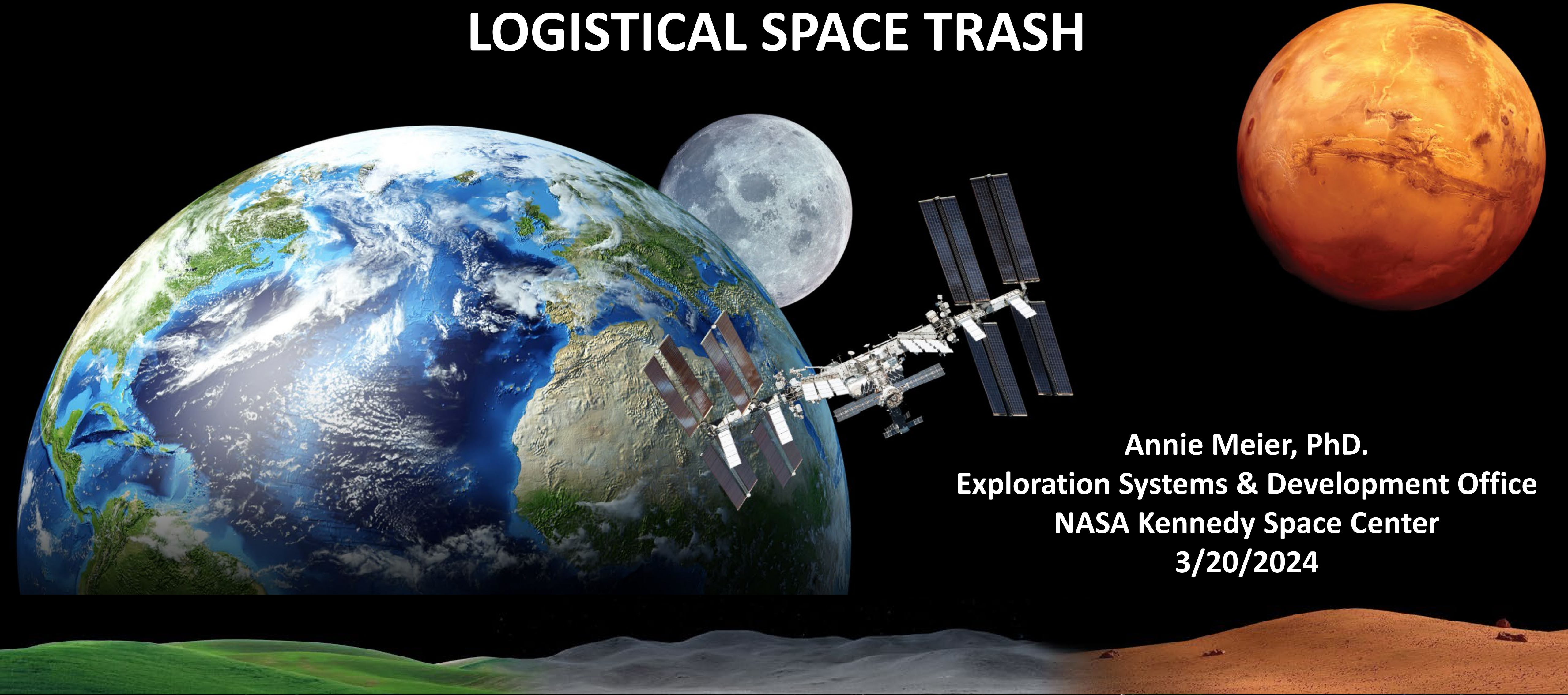
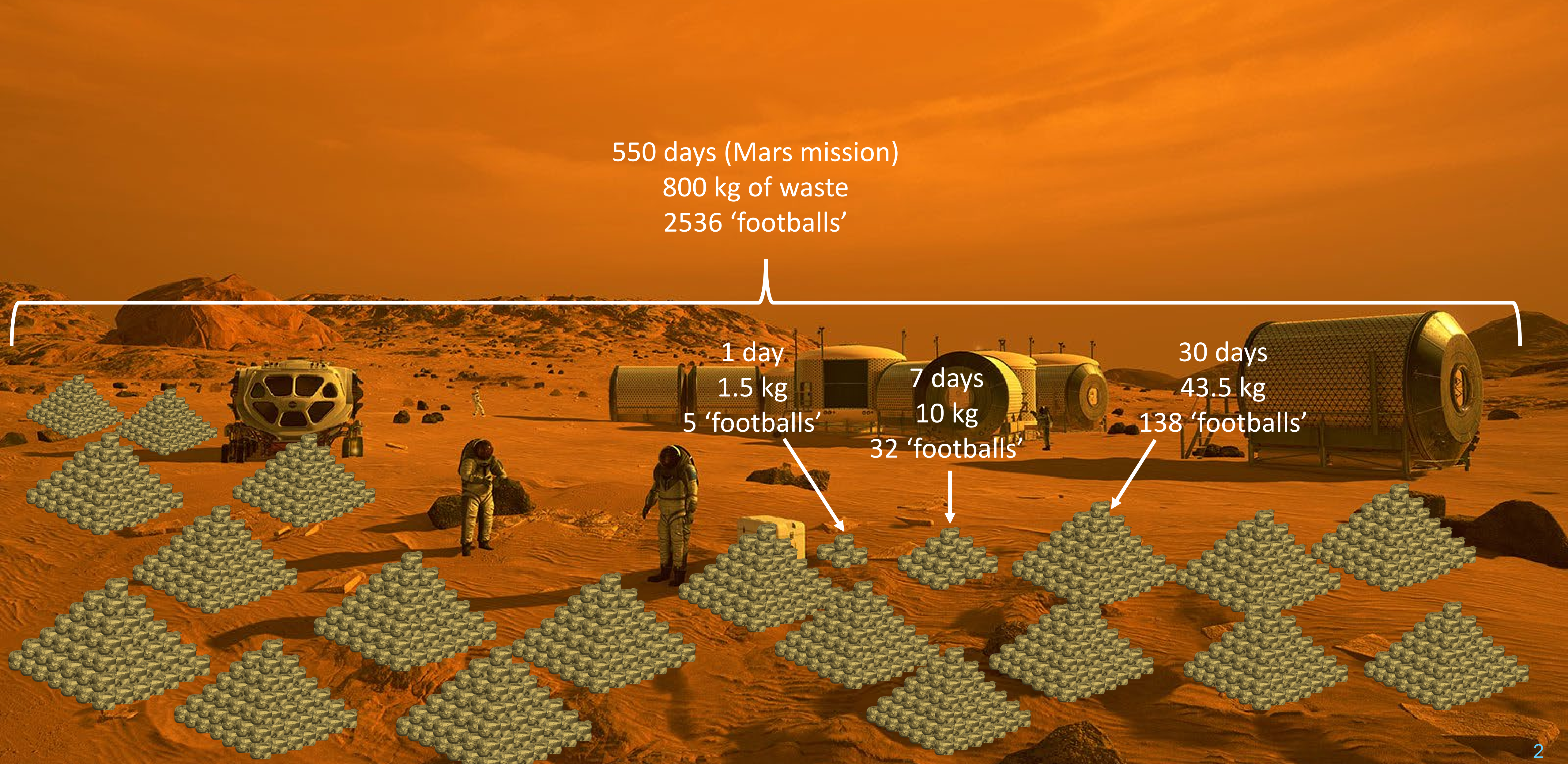
RESOURCE RECOVERY
from
LOGISTICAL SPACE TRASH



Annie Meier, PhD.
Exploration Systems & Development Office
NASA Kennedy Space Center

3/20/2024

NASA's Trash Strategy…

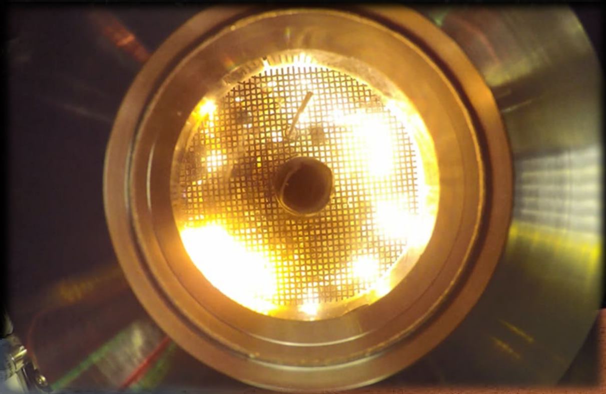


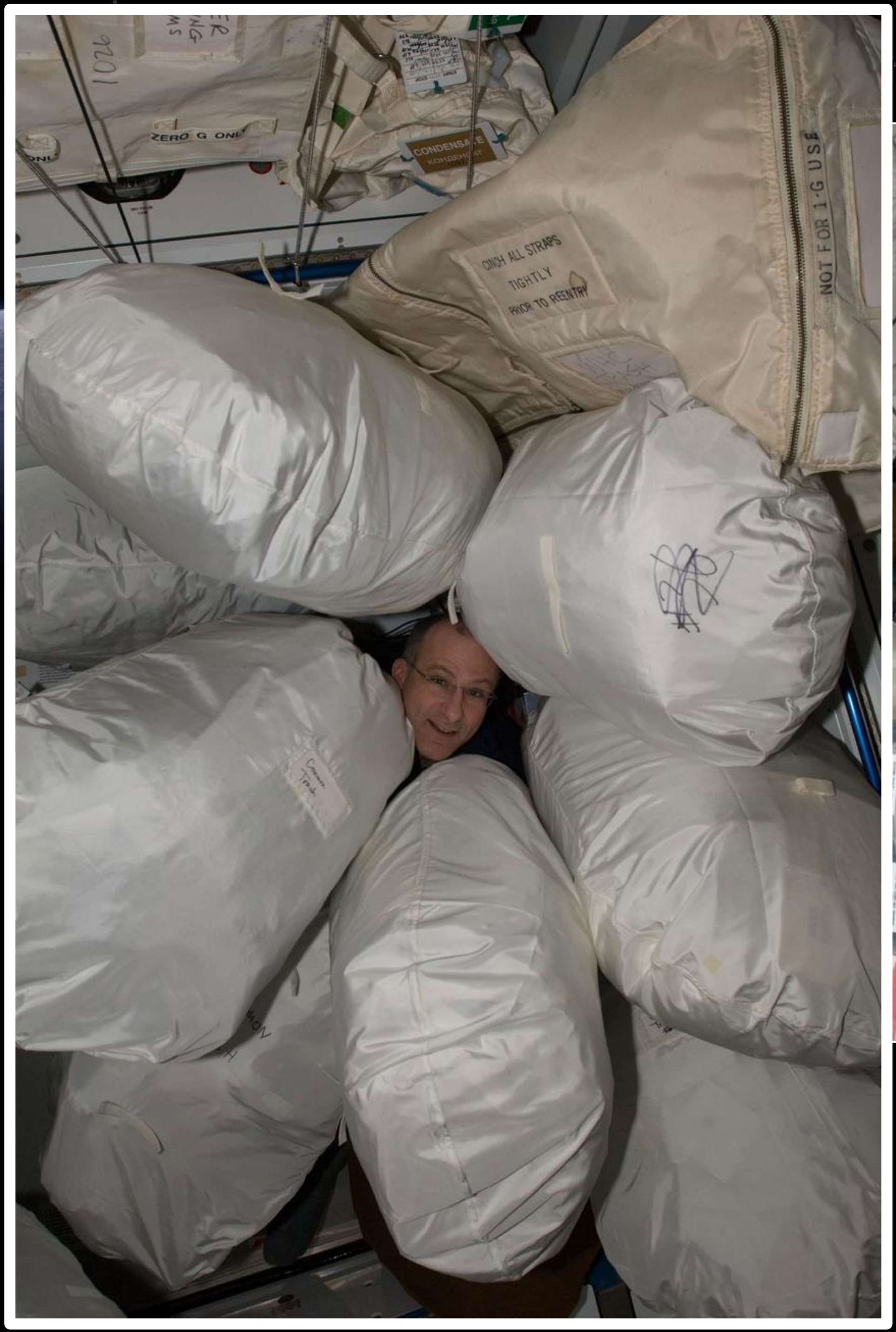
Background image: NASA; Credits: Joel Olson, KSC

Keep

Throw out
(Mass Jettison)

Throw out
(Mass Venting)




CINCH ALL STRAPS
TIGHTLY
PRIOR TO REENTRY
NOT FOR 1-G USE
CONDENSATE


ZIPLOCK, USOS CLOTHING BAG 1
528-21059-436

6.4 kg/day of trash
Crew of 4
Toothpaste
Nitrile Gloves
Shampoo
Clothing
Toilet Paper
Absolutely No Rinsing Necessary
NoRinse
Shampoo
Fecal Stimulant
Food Stimulant
Tech Wipes
Wet Wipes
Food Packaging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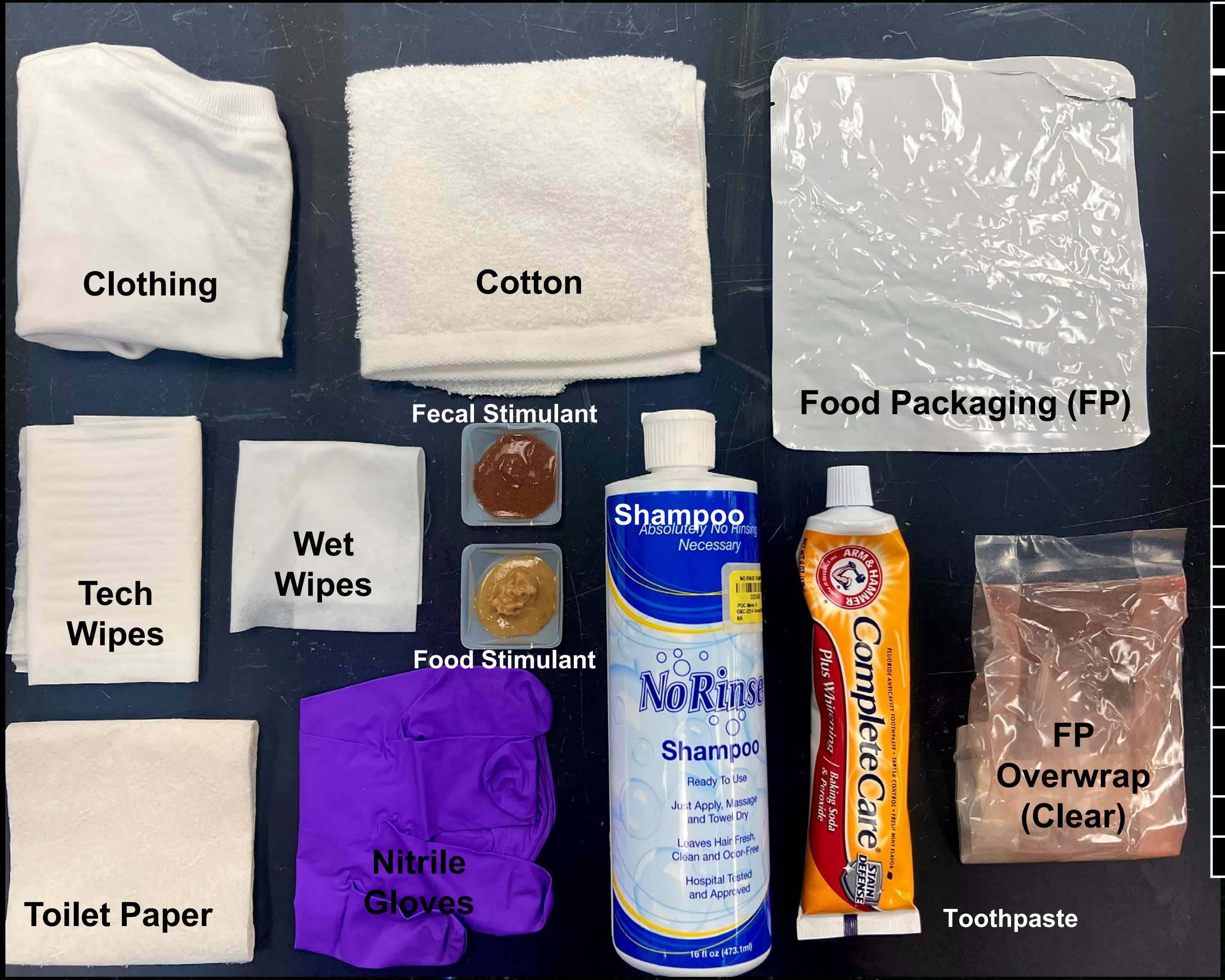
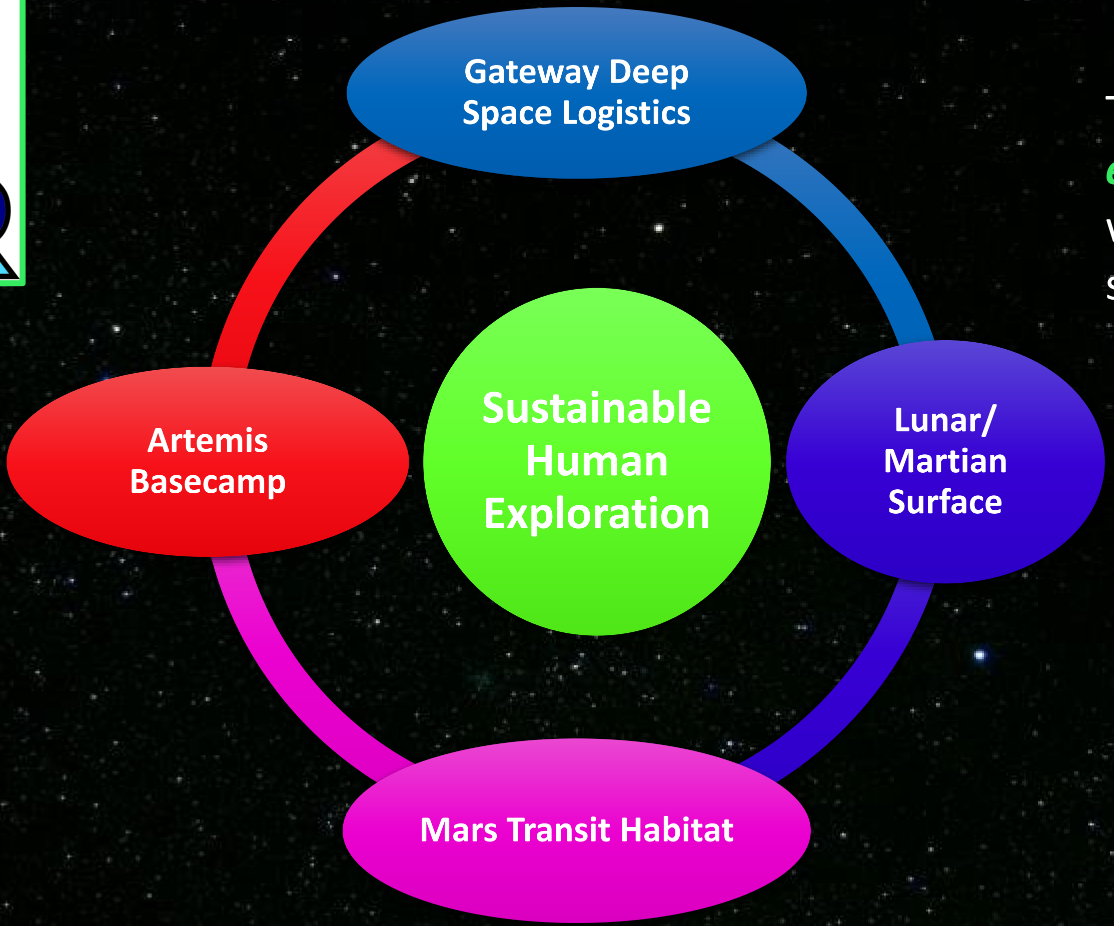
Food Packaging

Trash Feedstock Simulant Recipes



Component of OWS	OWS (Mass %)	Component of HFWS	HFWS (Mass %)
Clothing/Cotton	17.9	Urine Brine	21.3
Food Packaging (FP)	13.4	Polyethylene sheet	16.2
FP Overwrap	13.4	Clothing/Cotton	12.6
Hygiene towels	9.5	Fecal Simulant	11.2
Tech Wipes	3.6	Food Simulant	8.9
Toilet Paper	3.6	Hand/face wipes	5.5
Nitrile Gloves	1.6	Tissues	4.9
Fecal Simulant	13.4	Hygiene towels	4.8
Hand/face Wipes	10.8	Nylon sheet	4.6
Toothpaste	1.2	Shampoo	2.4
Shampoo	1.2	Aluminum foil	2.3
Food Simulant	10.6	Nitrile gloves	2.1
Fecal Simulant	11.2	Toothpaste	1.2
		Paper	0.6
		Maximum absorbency garments (MAG)	0.5
		Disinfecting wipes	0.4
		Duct tape	0.4

NASA Sustainable Trash Processing

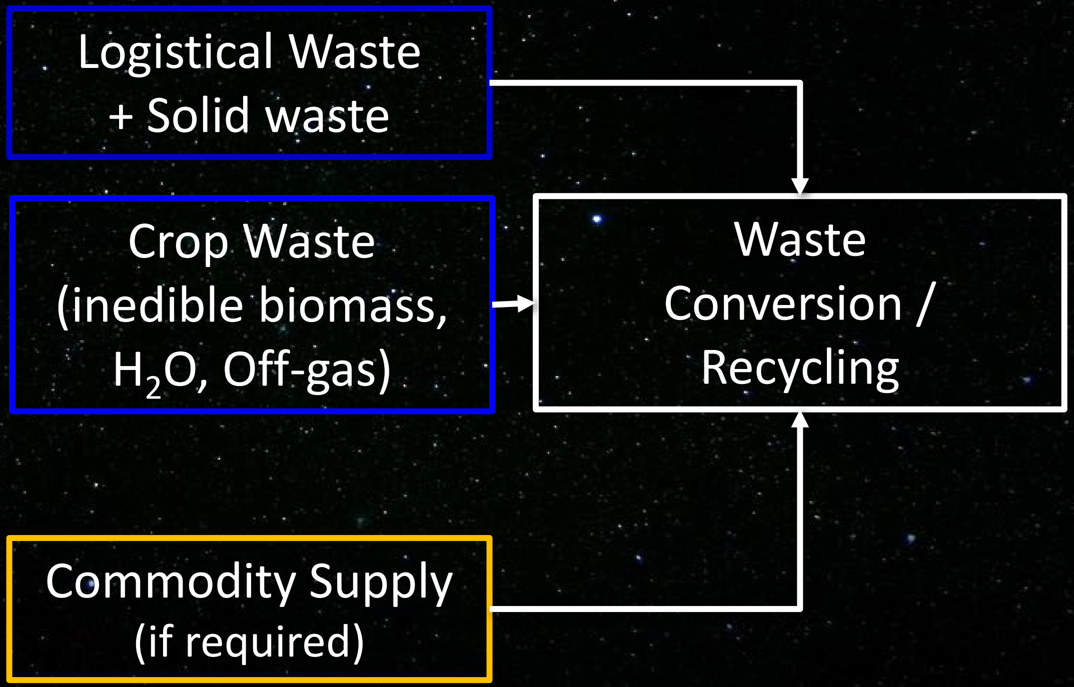


This work lays the framework for ***earnest spaceflight sustainability*** within next generation of human spaceflight & exploration.

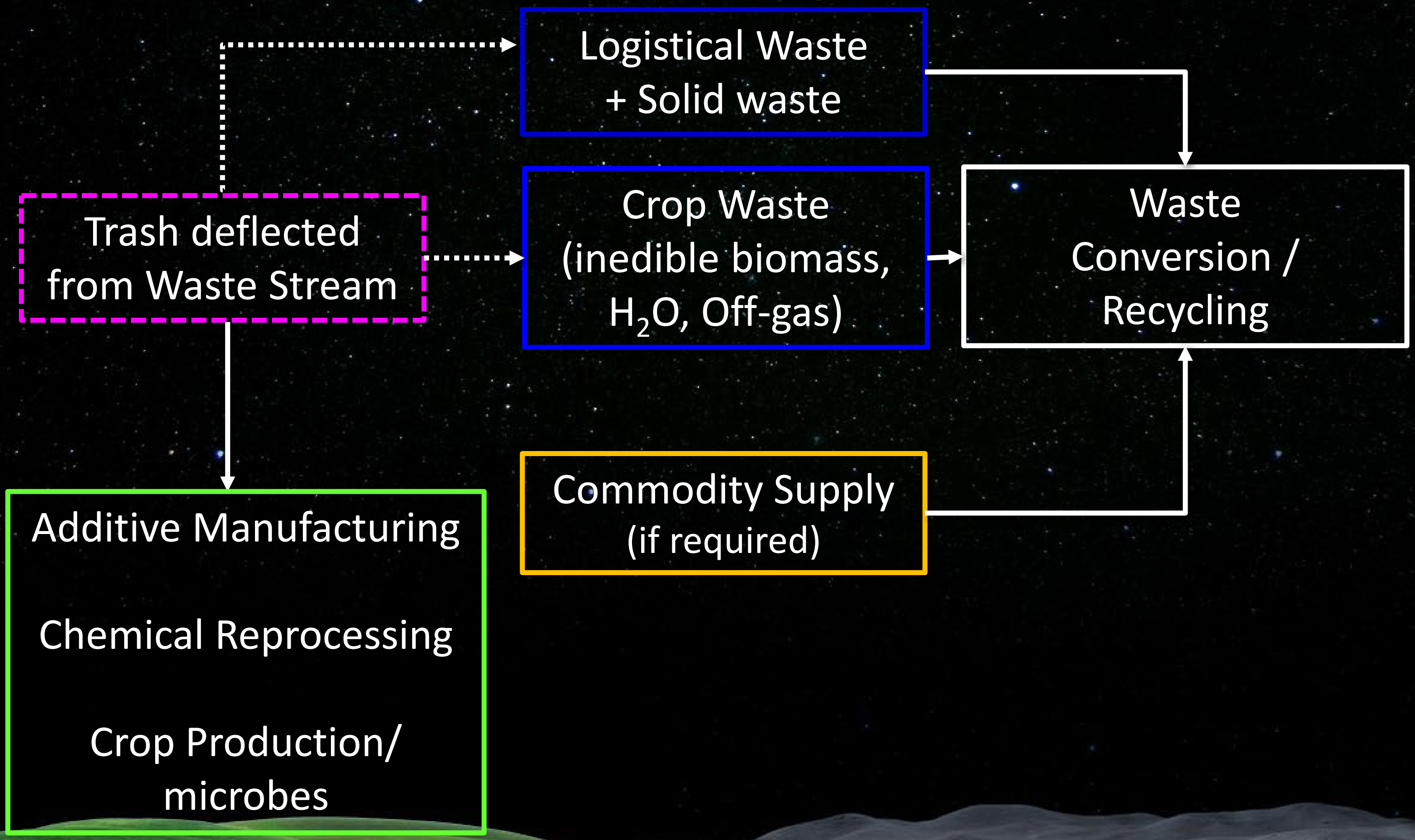
Moon 2 Mars Objectives

- **Trash Conversion/ Trash-to-Gas considers NASA's sustainable architecture for recycling/reuse of on-orbit M2M Objectives:**
  - **OP-12:** Establish procedures and systems that will 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.
  - **RT-5:** Maintainability and Reuse: when practical, design systems for maintainability, reuse, and/or recycling to support the long-term sustainability of operations and increase Earth independence.
  - **RT-6:** Responsible Use: Conduct all activities for the exploration and use of outer space for peaceful purposes consistent with international obligations, and principles for responsible behavior in space.

Concept: Trash Processing & Reuse Systems / Trash-to-Gas+



Concept: Trash Processing & Reuse Systems / Trash-to-Gas+



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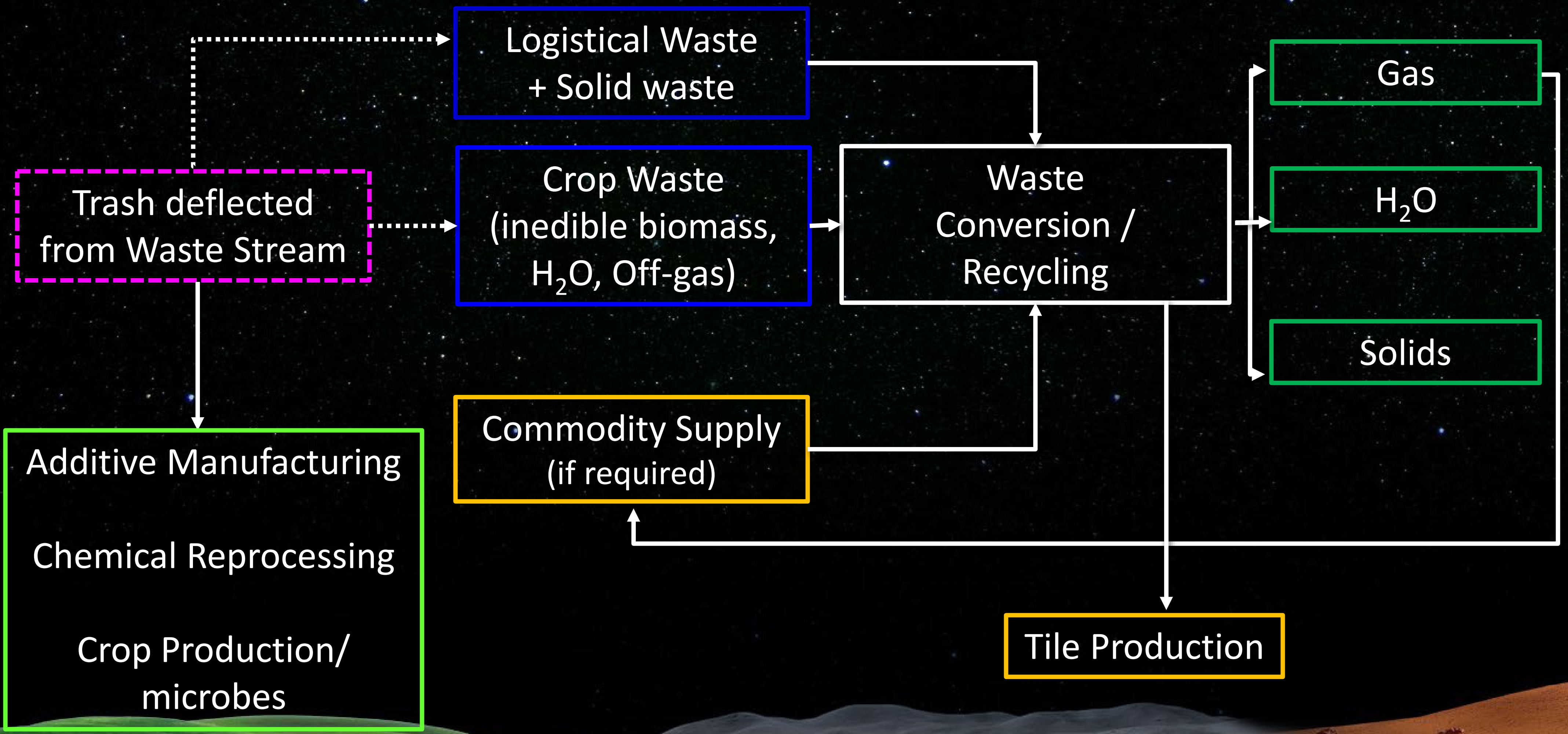
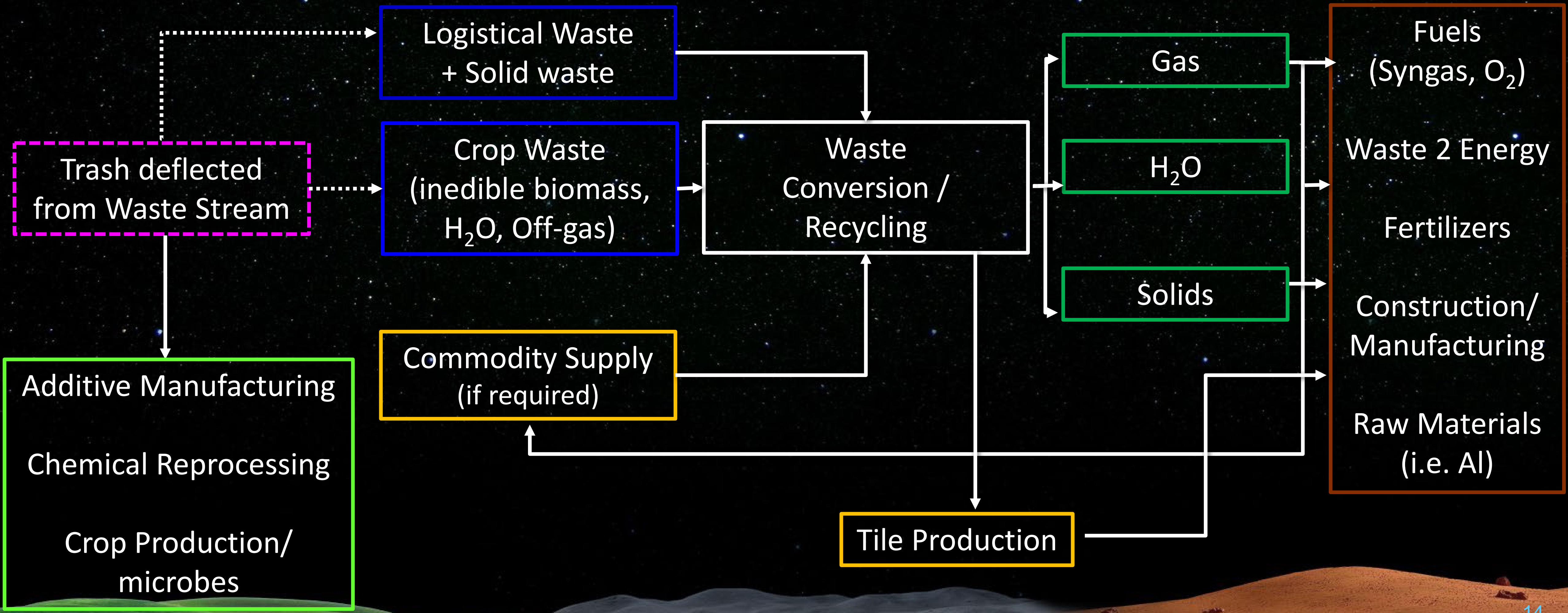
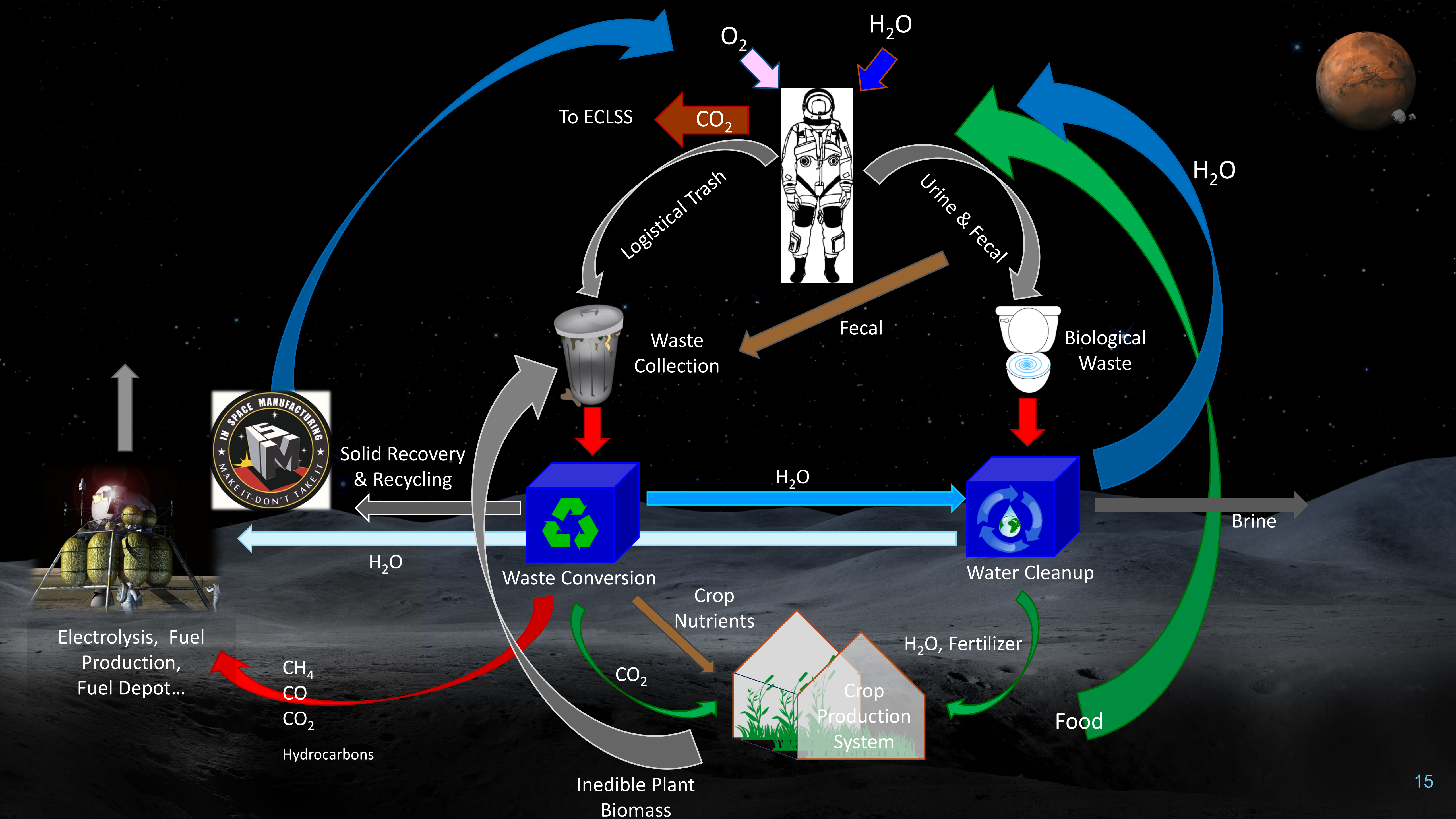
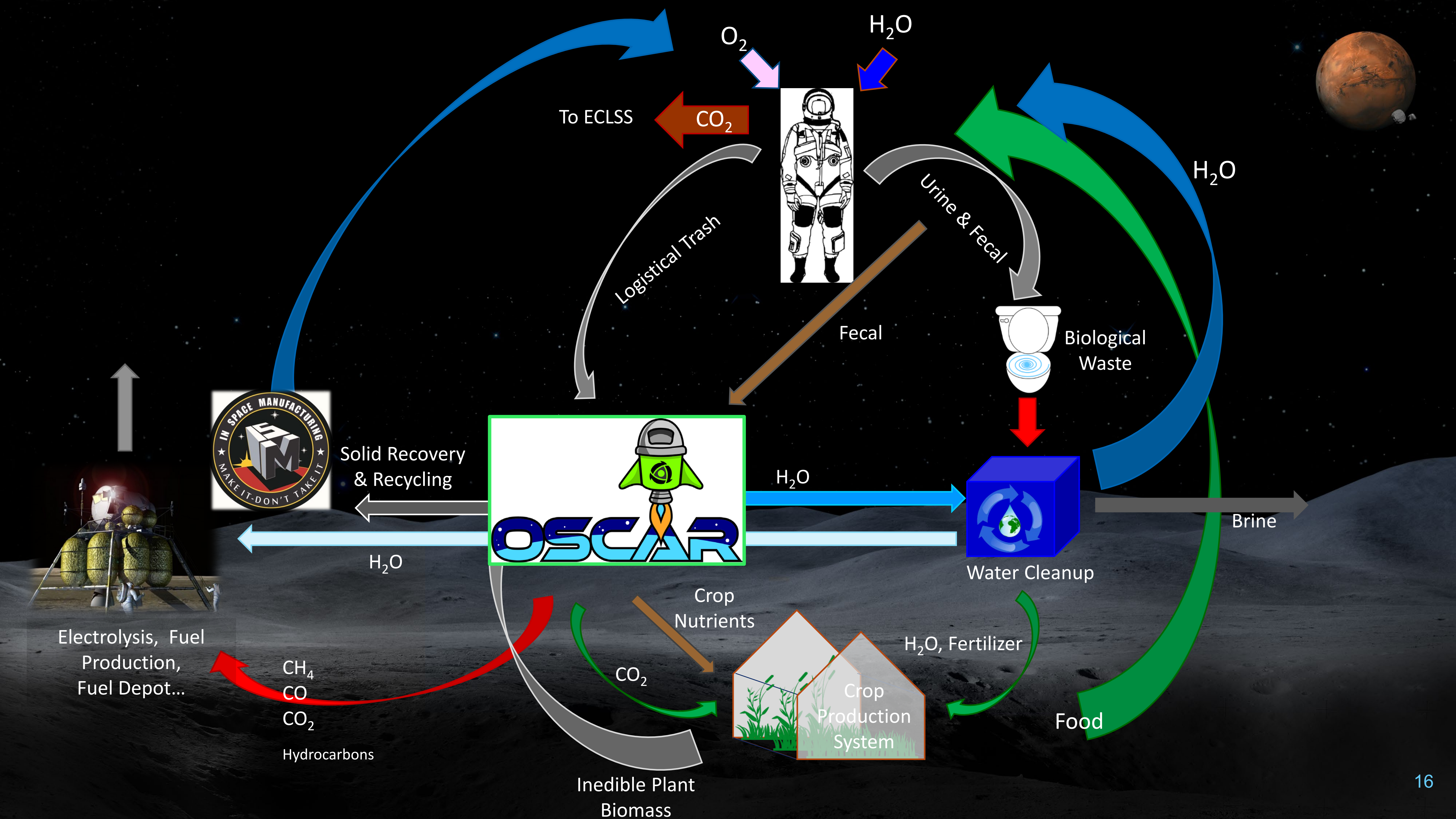


Concept: Trash Processing & Reuse Systems / Trash-to-Gas+



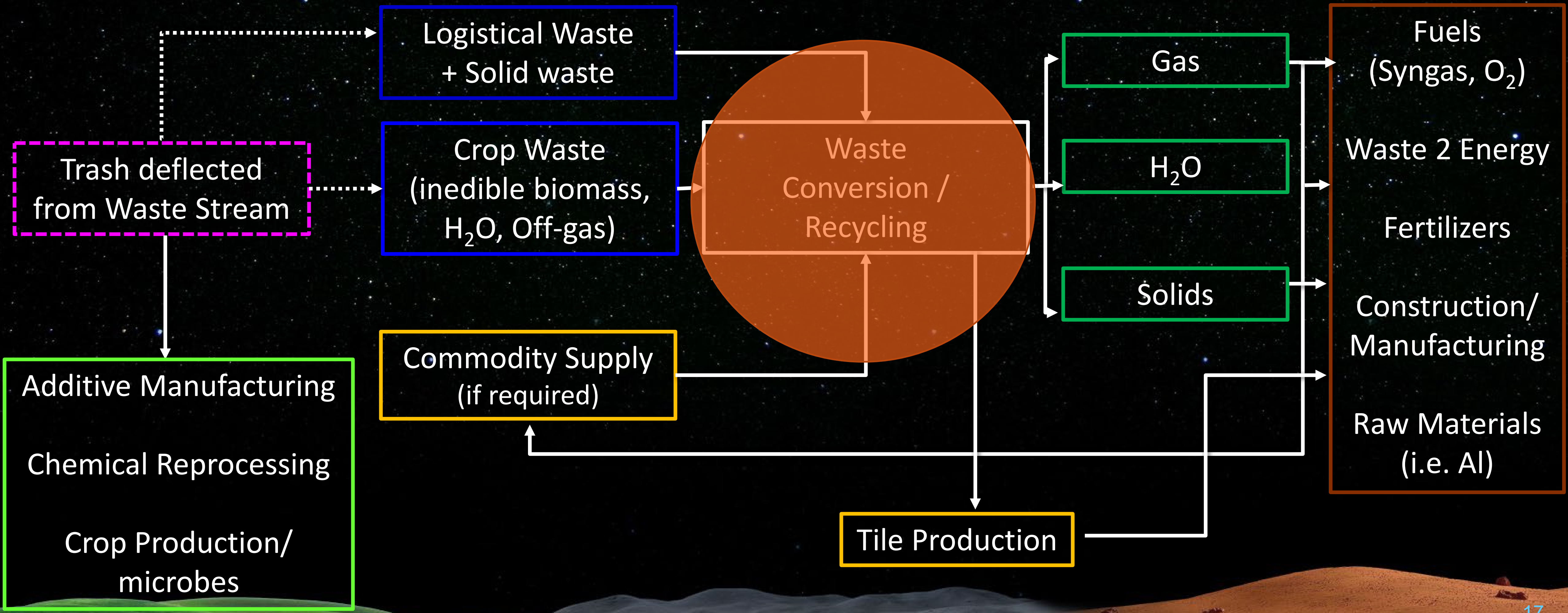

O_2
H_2O
To ECLSS
CO_2
Logistical Trash
Urine & Fecal
H_2O
Fecal
Waste
Collection
Biological
Waste
IN SPACE MANUFACTURING
MAKE IT-DON'T TAKE IT
Solid Recovery
& Recycling
H_2O
Brine
H_2O
Waste Conversion
Water Cleanup
Crop
Nutrients
H_2O, Fertilizer
Electrolysis, Fuel
Production,
Fuel Depot…
CH_4
CO
CO_2
Hydrocarbons
CO_2
Crop
Production
System
Food
Inedible Plant
Biomass



O_2
H_2O
To ECLSS
CO_2
Logistical Trash
Urine & Fecal
Fecal
H_2O
Biological Waste
Solid Recovery & Recycling
IN SPACE MANUFACTURING
MAKE IT-DON'T TAKE IT
OSCAR
H_2O
H_2O
Water Cleanup
Brine
Electrolysis, Fuel Production, Fuel Depot…
CH_4
CO
CO_2
Hydrocarbons
CO_2
Crop Nutrients
H_2O, Fertilizer
Crop Production System
Food
Inedible Plant Biomass

Concept: Trash Processing & Reuse Systems / Trash-to-Gas+

Have flown sub-scale trash conversion unit. Other units need fundamental research for advancing the circular process.



Resources Available for Future Mission Scenarios in Trash

850-Day Mars Mission

- Mission duration: 850 days
- Mission location: Mars
- Crew size: 4
- Trash production rate: 1.607 kg/CM-d
- Trash composition: OSCAR-FS

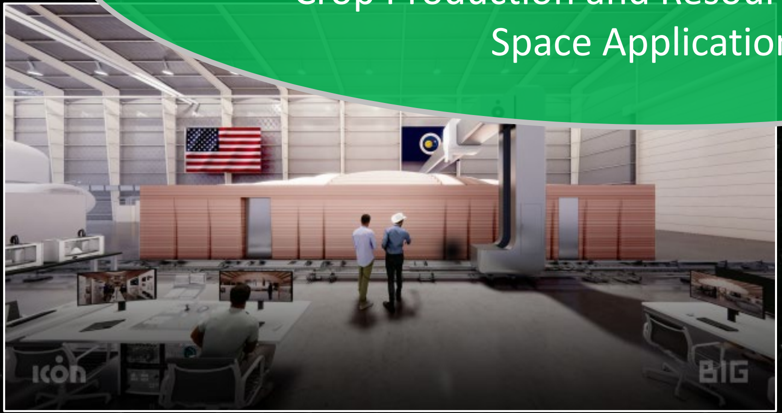
30-Day Lunar Mission

- Mission duration: 30 days
- Mission location: Moon
- Crew size: 4
- Trash production rate: 1.607 kg/CM-d
- Trash composition: OSCAR-FS

Resources Available in (Crew Consumable) Waste Stream (kg)								
Mission Type	**Trash Total**	**Oxygen**	**Water**	**Polyethylene**	**Polyester**	**Polypropylene**	**Nylon**	**Aluminum**
850-Day Mars	**5463.8**	**1148.9**	**628.3**	**968.7**	**535.4**	**299.6**	**916.6**	**173.6**
30-Day Moon	**192.8**	**40.6**	**22.2**	**34.2**	**18.9**	**10.6**	**32.4**	**6.1**

R.Pitts et.al. “Development of a Predictive Model for In-Situ Resource Utilization of Space Exploration Waste”, ASCEND 2023

Pending Publication ICES-2024-288
“Thermal Degradation and Rapid Composting of Inedible Biomass and Logistical Waste for Crop Production and Resource Recovery in Space Applications”



Innovations/Future Focus:

- Large scale demonstrations
- Integration into crop/LSS
- Full Scale OSCAR/ Trash-to-Gas Demonstration
  - OSCAR-Full Scale
  - crew of 4 on 1 year mission
  - ~6.5 kg/day for 30 days demo
  - Large reactor to accept 1 kg / batch of trash.
- Crop infusion with solids/ash nutrient tuning
- Water, ash and gas recovery
- Plasma VOC mitigation
- High throughput plasma gasification system.
- CHAPEA Mars Analog Habitat trash and data collection
- Alternative material selection for logistics packaging
- Additive manufacturing with polymers or recovered metals from logistics materials/packaging


Hood 3

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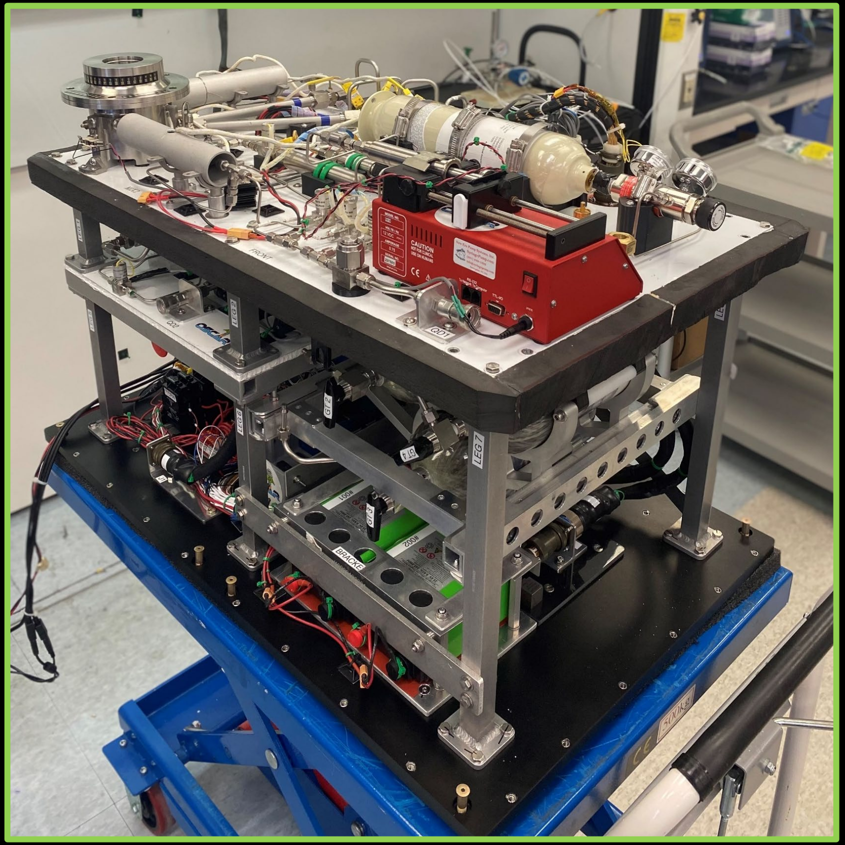
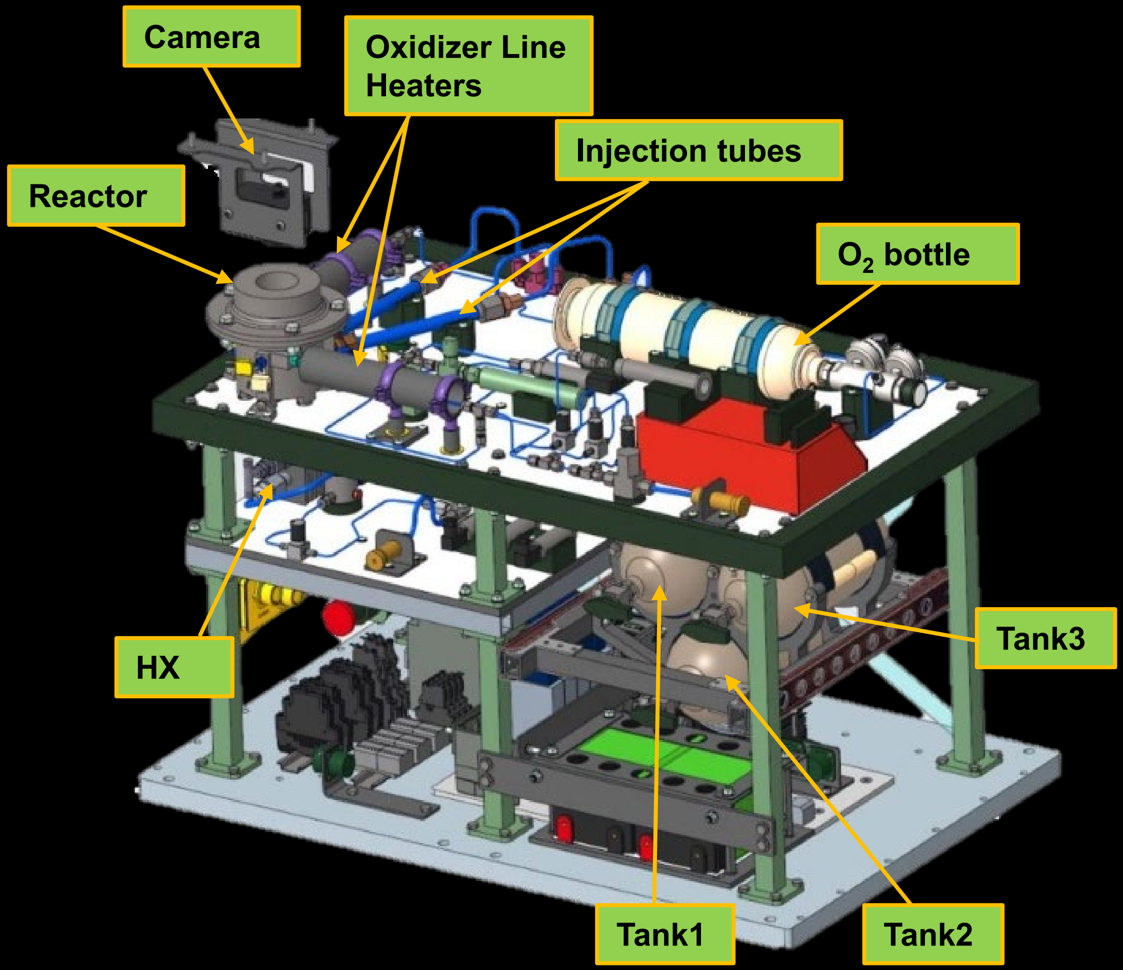
BACKUP SLIDES

Trash Processing & Reuse Systems / Trash-to-Gas / OSCAR



- “OSCAR” (Orbital Syngas Commodity Augmentation reactor) was for suborbital flight subscale demonstration only.
  - (15 min flight time with 3 minutes microgravity).
- Sub-scale: 10g processed in 3 minutes.
- 0.5 L reactor w/trash injection tubes
- 100% O2 feed gas at 1 SLPM
- 308 kPa / 45 PSIG



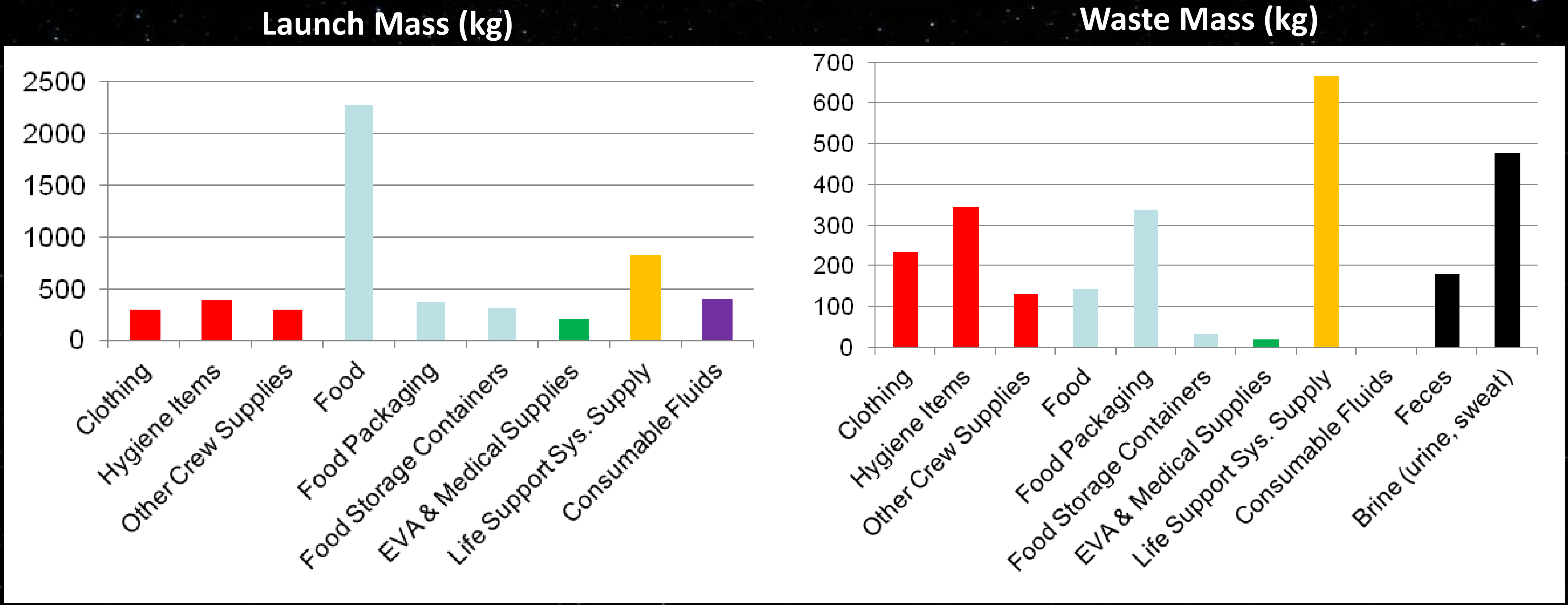
OSCAR Sub-scale System for Suborbital Flight

Trash-to-Gas systems evaluated Mars transit propellant requirements

TtG System Name, Year of Operational Report	Thermal Process Technology	Total Vehicle Mass (kg)	Total Mass Reduction (kg)
Baseline (Stowage Model)	n.a.	309,296	--
NASA Incinerator/Gasifier (Inc-Gas), 2014 [23]	Incineration and Gasification	303,074	6,222
NASA Plasma Gasification [30] (Plas-Gas), 2019	Plasma-Induced Incineration and Gasification	303,145	6,151
Advanced Organic Waste Gasifier (AOWG), Pioneer Astronautics, Inc. (developed under NASA SBIR.) 2020 [23]	Oxygen-Enhanced Steam Reforming	303,391	5,905
Orbital Syngas Commodity Augmentation Reactor (OSCAR), 2021 [28], [48]	Oxygen-Enriched Combustion	303,141	6,155
Microwave Assisted Pyrolysis (MAP), (Advanced Fuel Research (AFR) Corporation (developed under NASA SBIR)) 2014 [23]	Microwave-Induced Pyrolysis	303,430	5,866
(Plas-Pyro), 2020 [45]	Plasma-Induced Pyrolysis	303,511	5,785
Torrefaction Processing Unit, (TPU), AFR Corporation (NASA SBIR), 2019 [40]	Torrefaction	305,597	3,699

J. A. Olson, P. Chai, D. Rinderknecht, and A. J. Meier, "A Comparison of Propellant Requirements for Crewed Mars Missions Incorporating Different Waste Processing Technologies," presented at the ASCEND, Las Vegas, Nevada & Virtual, 2021. doi: 10.2514/6.2021-4080.

Logistics Waste Model – 1 year, 4 people



M. K. Ewert and J. L. Broyan, "Mission Benefits Analysis of Logistics Reduction Technologies," in 43rd International Conference on Environmental Systems, 2013.

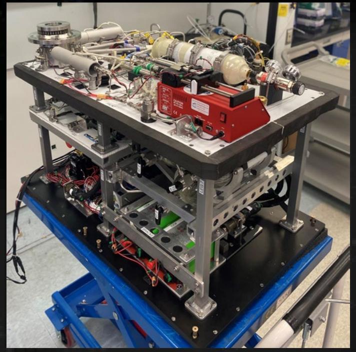
Evaluated Trash-to-Gas Systems evaluated in trade studies from 2020+ (does not include all from 2011-2019)

- Incineration/gasification (**Inc-Gas**; NASA/KSC; Anthony and Hintze, *44th ICES*, 2014, 016).

- Plasma gasification (**Plas-Gas**; NASA/KSC).

- Advanced Organic Waste Gasifier (**AOWG**); Pioneer Astronautics, Inc.).

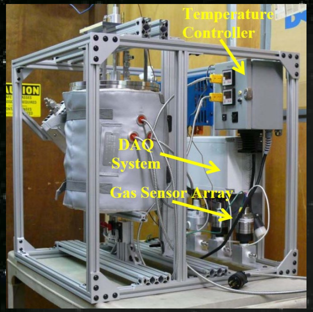
- Orbital Syngas Commodity Augmentation Reactor (**OSCAR**; NASA/KSC).



- Microwave Assisted Pyrolysis (**MAP**; Advanced Fuel Research Corporation).

- Plasma Pyrolysis (**Plas-Pyro**; NASA/KSC).

- Torrefaction Processing Unit (**TPU**; Advanced Fuel Research Corporation).



Olson, J.; Rinderknecht, D.; Essumang, D.; Kruger, M.; Golman, C.; Norvell, A.; Meier, A. A Comparison of Potential Trash-to-Gas Waste Processing Systems for Long-Term Crewed Spaceflight. **2021**.

Trash to Supply Gas – General Sys. Analysis

Waste Volume Reduction: 19 m^3

Equivalent to pressurized volume of one Orion Spacecraft.

Enough delta-V for yearly station keeping at Earth-Moon Lagrange point.

Production:

~800 kg of O_2 , ~900 kg of H_2O, 1,100 kg of CO_2

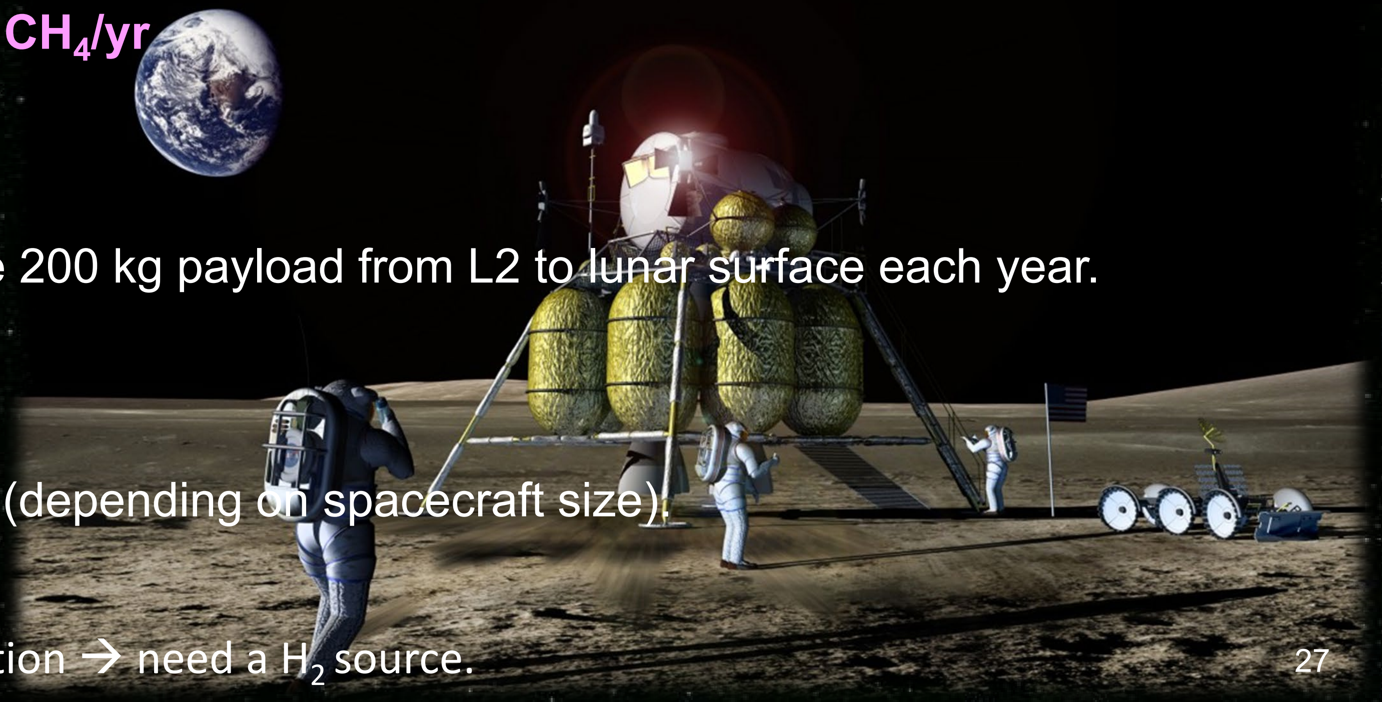
~800 to 1500 kg of CH_4/yr

Lunar:

Enough to send one 200 kg payload from L2 to lunar surface each year.

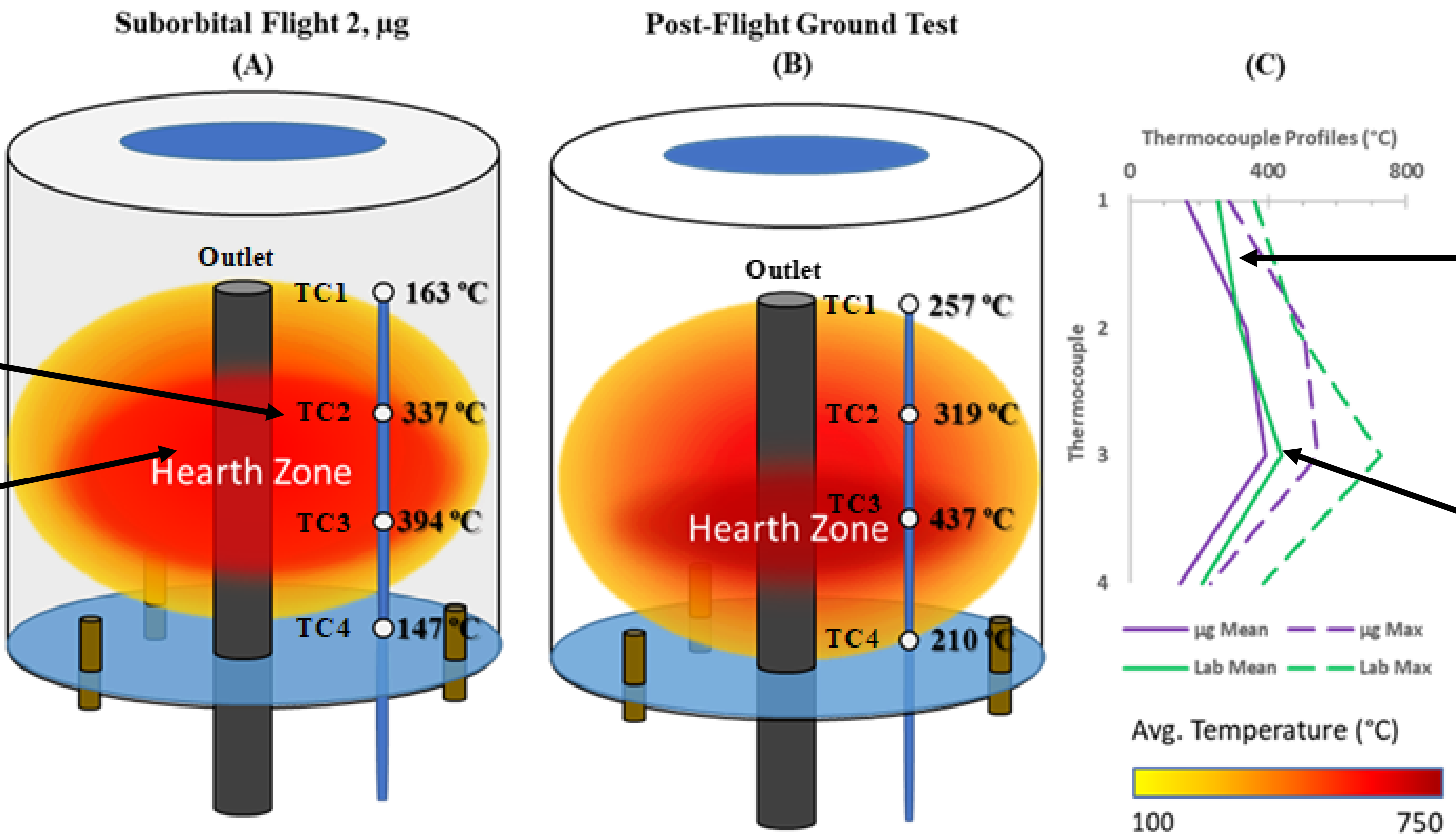
Mars:

Course Corrections (depending on spacecraft size).



C is limiting reagent.

If CO_2 used for CH_4 production → need a H_2 source.



Warmer TC2 due to torch behavior

Trash floating

More efficient heat transfer in lab

Lab temperatures warmer overall

Expected Trash Production Rate for Exploration

6.4 kg/day of trash
Crew of 4

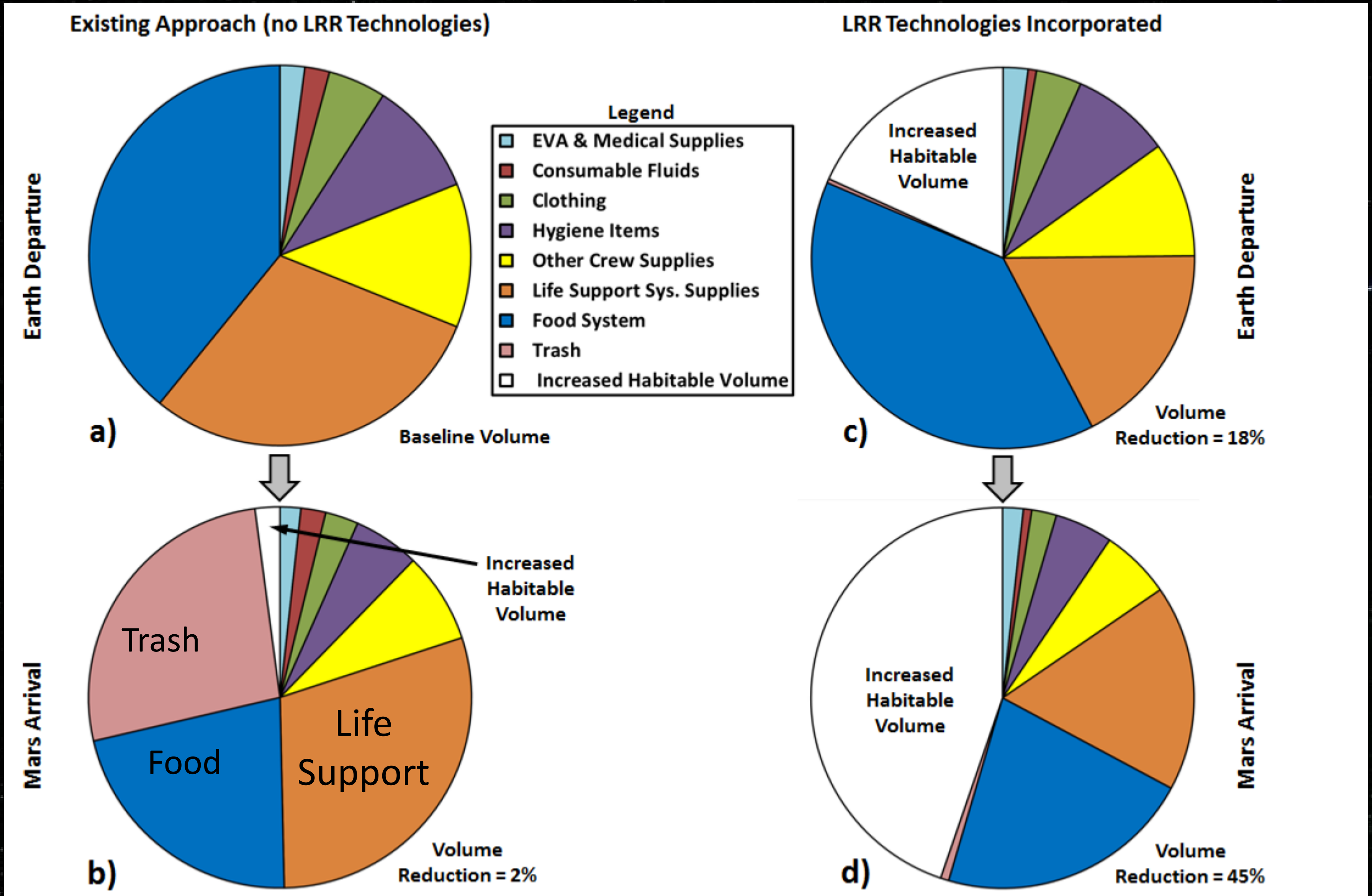
TOP DOWN

Estimate production rates of each high-level waste category (refer to "Logistics Rates and Assumptions for Future Human Spaceflight Beyond LEO" (AIAA Control ID: 3907708)

Waste Category	*Production Rate* ($kg*CM^{-1}*day^{-1}$)
Food Packaging and Adhered Food	0.56
Waste & Hygiene Consumables	0.30
Wipes and Gloves	0.20
Fecal/Urine Collection Bags	0.17
Healthcare Consumables	0.09
Hygiene Kits	f(crew size, duration)*
Used Clothing	f(crew size, duration)*
Used Towels	f(crew size, duration)*

Notes:
* Hygiene kits, clothing, and towel waste productions vary per item and are a function of crew size and mission duration. Refer to the ELPG for discrete production rates for each item type.

Logistics Reduction Mission Impacts - Volume



J. L. Broyan, et. Al, “Logistics reduction technologies for exploration missions,” presented at the AIAA SPACE 2014.

Other papers for data on waste processing for space applications:

1. McKinley, M. K., Ewert, M. K., Borrego, M. A., Orndoff, E., Fink, P., Sepka, S., Richardson, J., and Meier, A. **Advancements in Logistics Reduction for Exploration Missions.** Presented at the 52nd International Conference on Environmental Systems, Calgary, Canada, 2023.
2. Olson, J. A., Chai, P., Rinderknecht, D., and Meier, A. J. A Comparison of Propellant Requirements for Crewed Mars Missions Incorporating Different Waste Processing Technologies. Presented at the ASCEND, Las Vegas, Nevada & Virtual, 2021.
3. Olson, J., Rinderknecht, D., Essumang, D., Kruger, M., Golman, C., Norvell, A., and Meier, A. A Comparison of Potential Trash-to-Gas Waste Processing Systems for Long-Term Crewed Spaceflight. Presented at the 50th International Conference on Environmental Systems, 2021.
4. Chen, T., et al. **Benefits of Trash-to-Gas versus Jettison of Waste via Trash-Lock for Mars Transit.** Presented at the 52nd International Conference on Environmental Systems, Calgary, Canada, 2023.
5. Linne, D. L., Palaszewski, B. A., Gokoglu, S. A., Balasubramaniam, B., Hegde, U. G., and Gallo, C. Waste Management Options for Long-Duration Space Missions: When to Reject, Reuse, or Recycle. Presented at the 7th Symposium on Space Resource Utilization, AIAA SciTech Forum, 2014.
6. Shah, M. G., Pitts, R. P., Benson, M. A., and Gleeson, J. R. **Investigating Waste Preparation Methods for Trash-to-Gas Technologies.** Presented at the 51st International Conference on Environmental Systems, St. Paul, Minnesota, USA, 2022.
7. Meier, A., Rinderknecht, D., Olson, J., Shah, M., Toro Medina, J., Pitts, R., Carro, R., Gleeson, J., Hochstadt, J., Forrester, E., Kruger, M., and Essumang, D. “Pioneering the Approach to Understand a Trash-to-Gas Experiment in a Microgravity Environment.” *Gravitational and Space Research*, Vol. 9, No. 1, 2021, pp. 68–85. https://doi.org/10.2478/gsr-2021-0006.