



State of Trash Conversion and Resource Recovery Technologies for Space Exploration Missions

Presenter:

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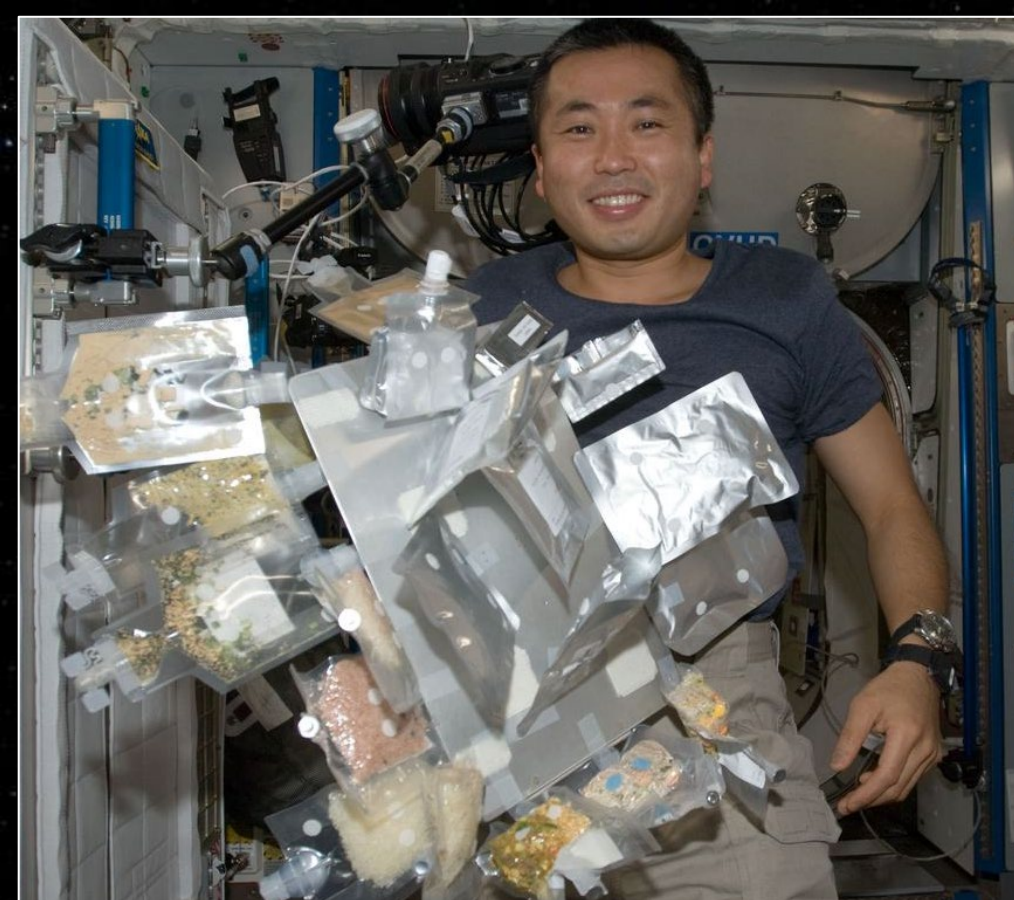
Current Status of Trash Management on ISS



NASA astronaut and Expedition 63 Commander Chris Cassidy collects trash for disposal during weekend housekeeping activities aboard the International Space Station.



NASA astronaut Scott Kelly, Expedition 25 flight engineer, is pictured near three stowage bags floating freely in the Unity node of the International Space Station.



Food and Food Packaging




Cady Coleman, Expedition 26 with a stowage container and its contents in the Harmony node of the ISS.



MAG, Fecal Matter, Urine



Washcloth, Sweat, Clothing

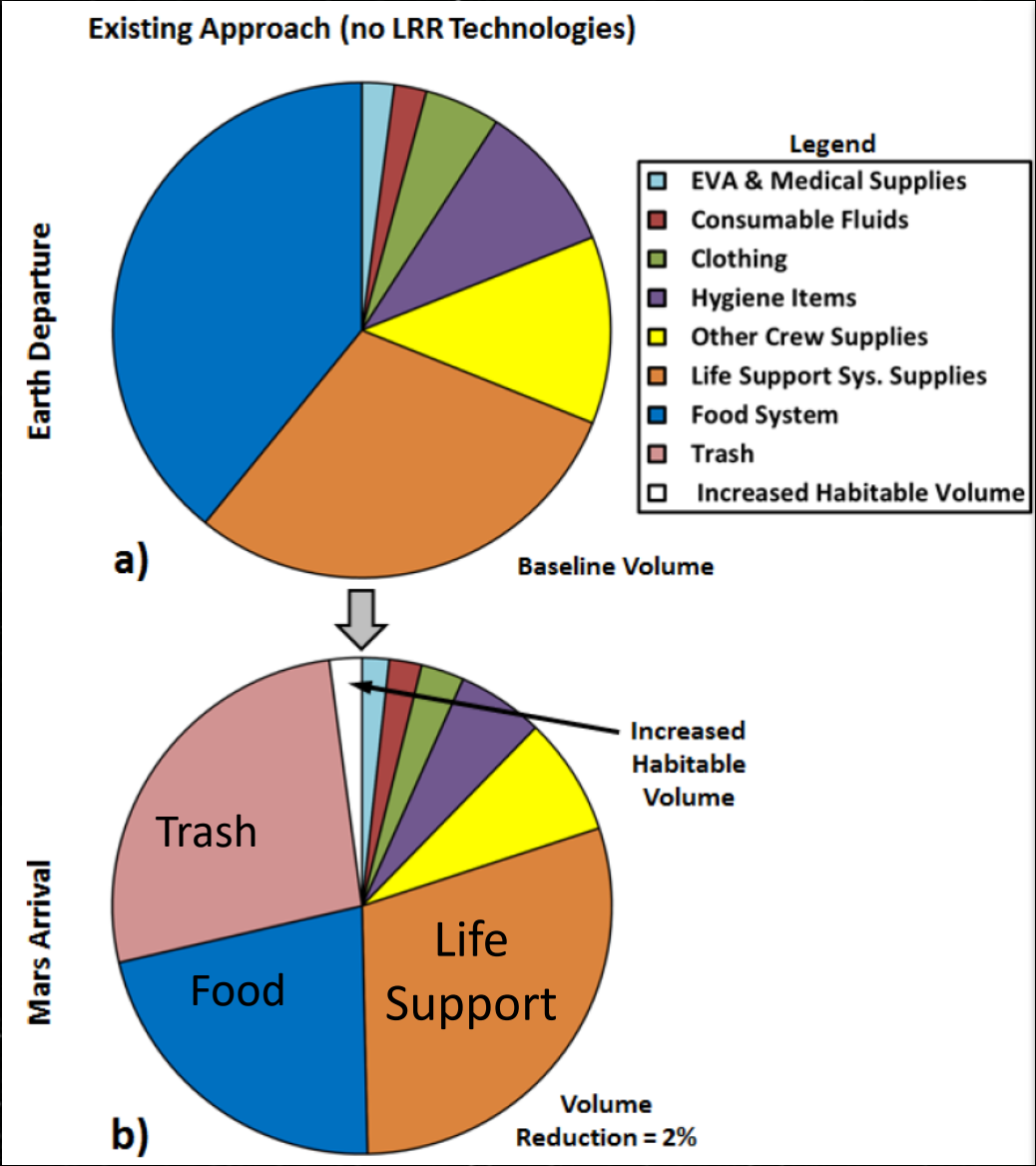


Trash Taxonomy and the Logistics Reduction Project

Consumables and Waste Products for Human Support

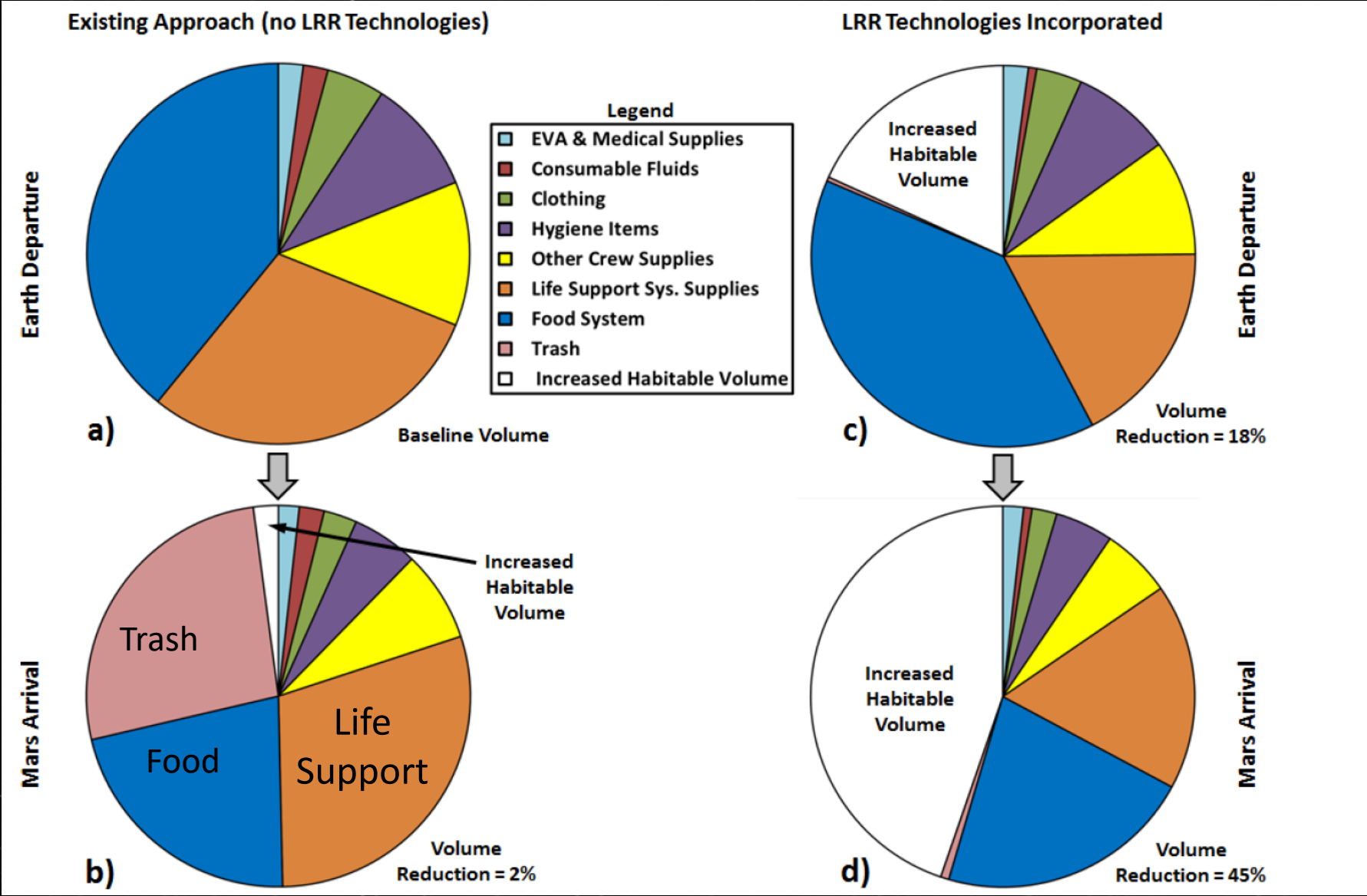
Item	Rate (kg/person/day)
Food	1.86
Wipes and Gloves	0.20
Operational Supplies	2.5/5/20/25
Recreation & Personal Stowage	5/10/25/50
Health Care Consumables	0.09
Trash Bags	0.03
Hygiene Kits	f (Mass * CM * Duration * Fixed Unit #)
Towels	f (Mass * CM * Duration * Fixed Unit #)
Clothing	f (Mass * CM * Duration * Fixed Unit #)
O ₂ Metabolic	0.86
H ₂ O Drink	2.0
H ₂ O Food Rehydration	0.5
H ₂ O Hygiene	0.4
H ₂ O WCS Flush	0.3

Logistics Reduction Mission Impacts - Volume

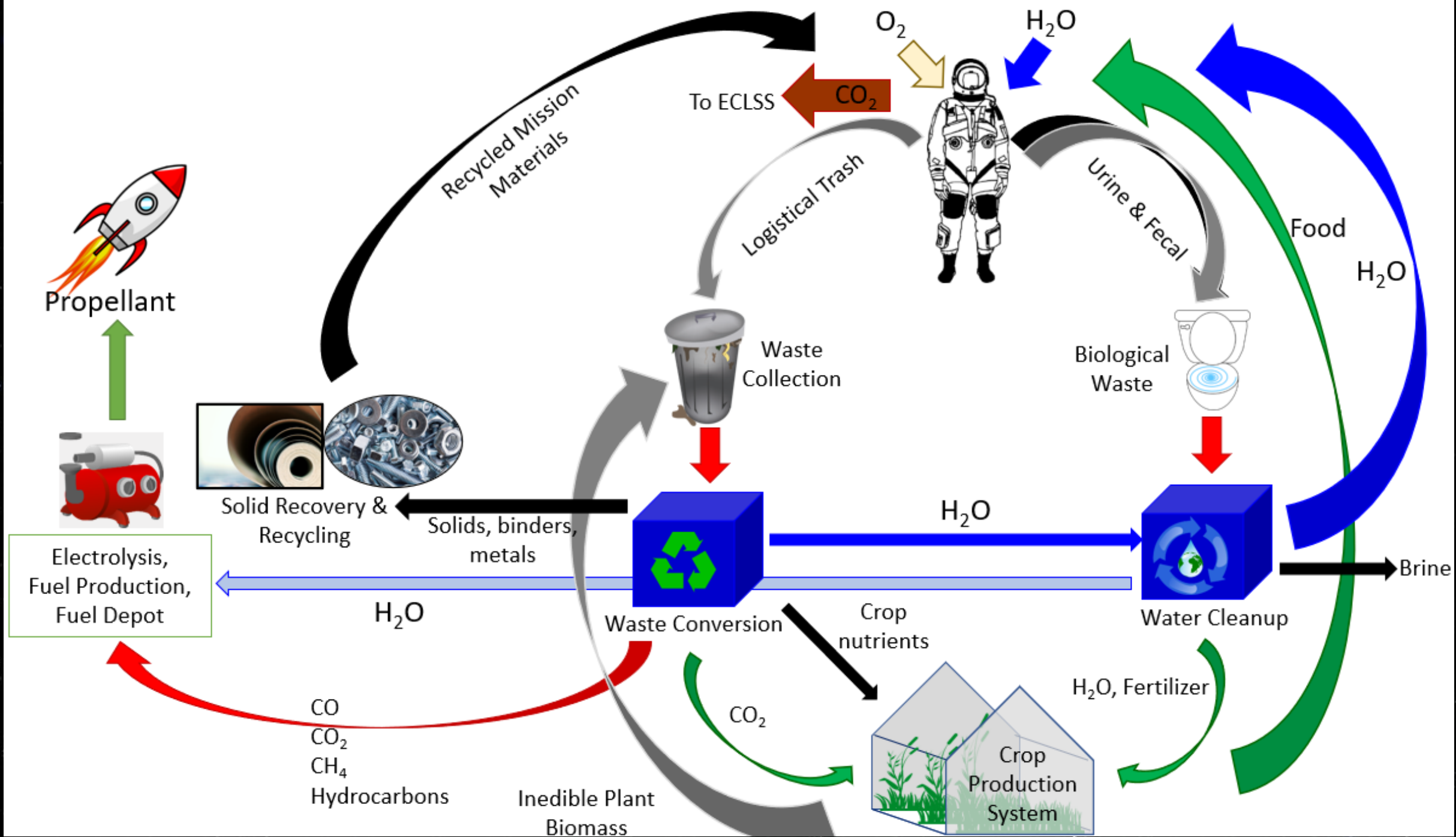


J. L. Broyan, et. Al, "Logistics reduction technologies for exploration missions," presented at the AIAA SPACE 2014.

Logistics Reduction Mission Impacts - Volume



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Logistics Reduction

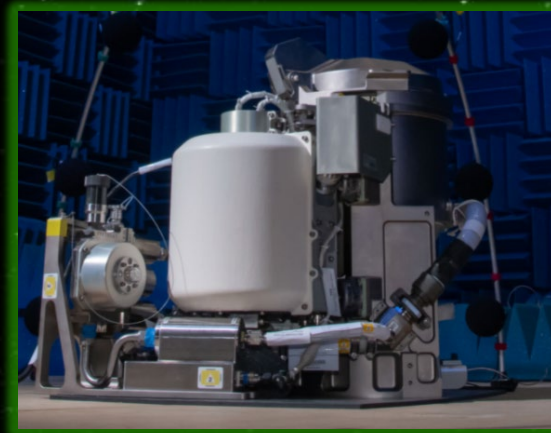
Advanced Clothing System



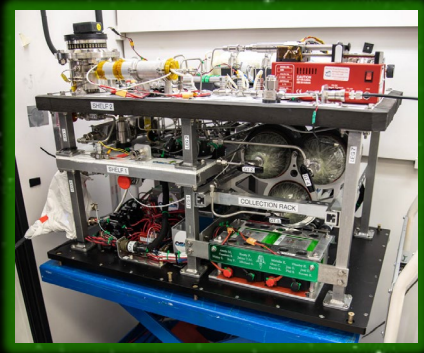
Logistics to Living



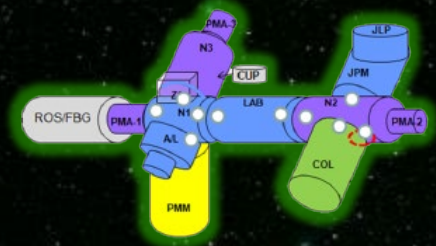
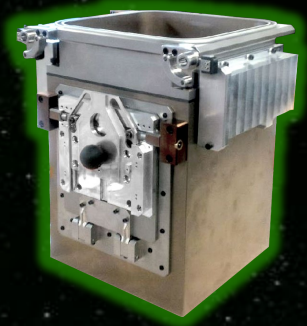
Universal Waste Management System



Trash to Gas



Heat Melt Compactor



Autonomous Logistics Management

Trash Processing Technology Developments



- Air Lock Ejection
- Mass jettison



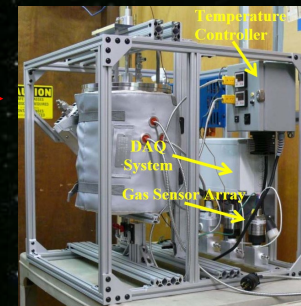
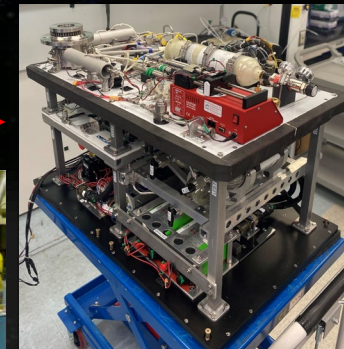
- Heat Melt Compaction (HMC) ^ image*
- Trash Compaction & Processing System (TCPS)
- Volume reduction & radiation protection



- Incineration/gasification
- Advanced Organic Waste Gasifier
- Combustion (OSCAR)
- Steam Reforming
- Plasma (microwave, torch, gasification, pyrolysis)
- Pyrolysis (microwave)

Evaluated TtG Systems

- 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).

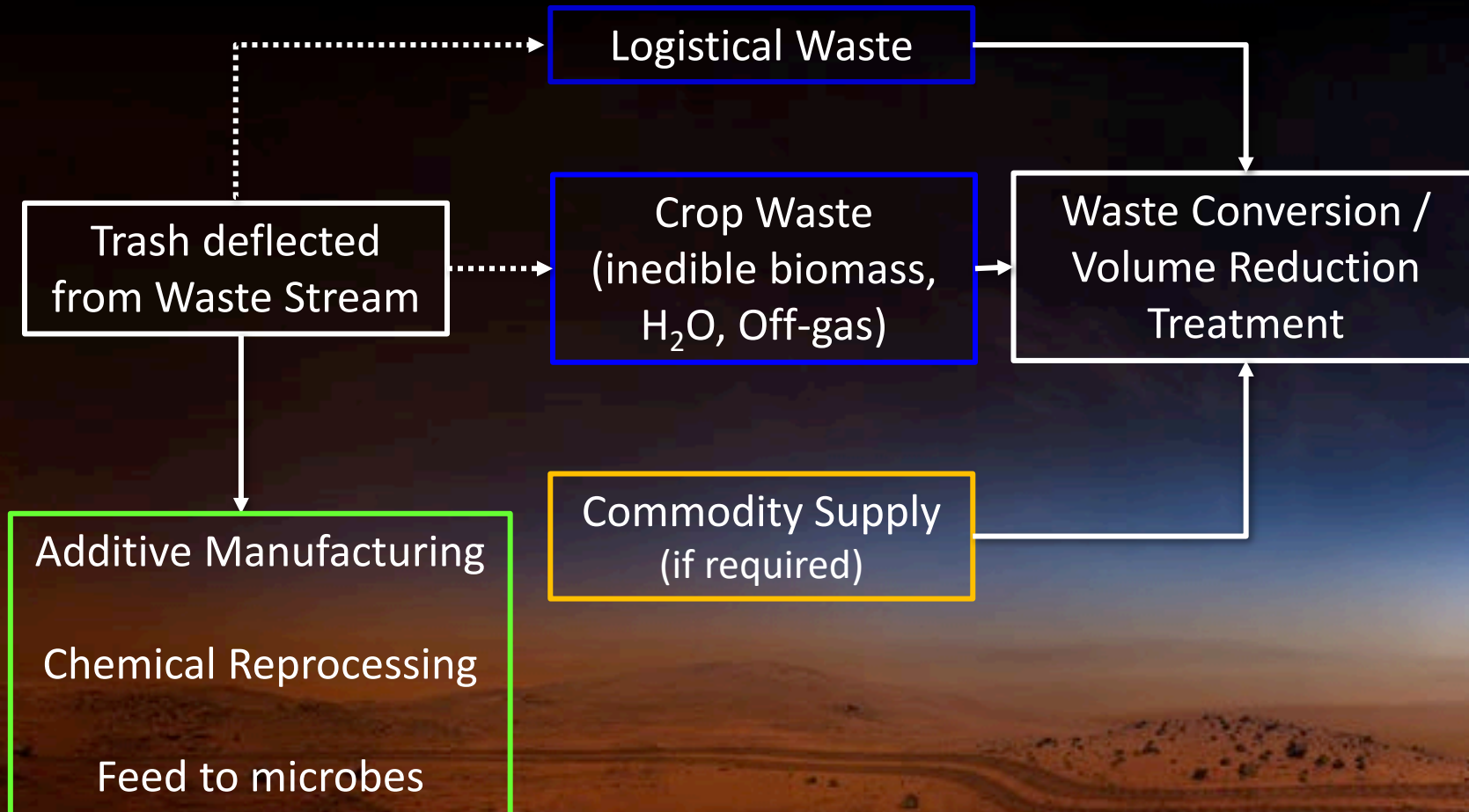


Trash-to-Gas systems evaluated Mars transit propellant requirements

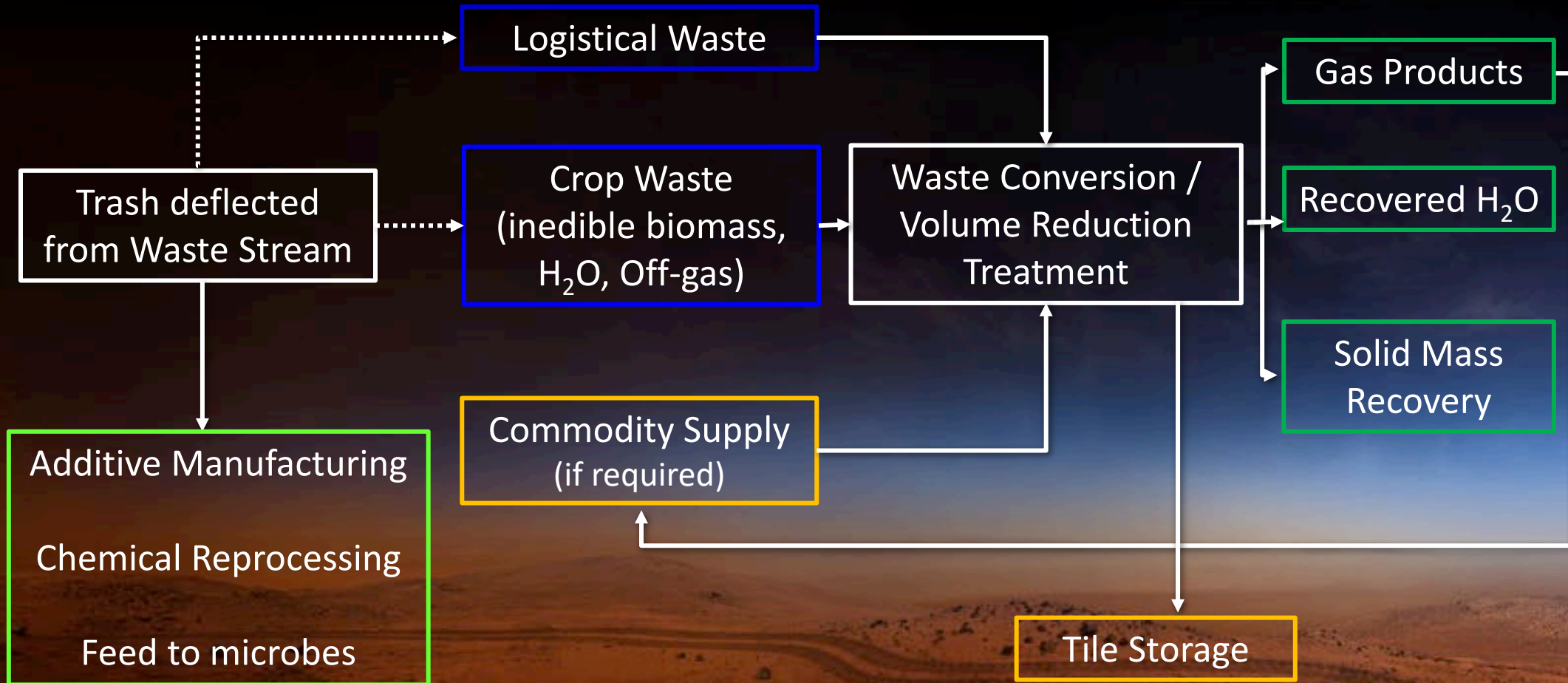
TtG System Name, Year of Operational Report	Thermal Process Technology	Total Vehicle Mass	Total Mass Reduction
		(kg)	(kg)
Baseline (Stowage Model)	n.a.	309,296	--
NASA Incinerator/Gasifier (Inc-Gas), 2014 [23]	Incineration and Gasification	303,074	6,222
NASA Plasma Gasification [30] (Plas-Gas), 2019	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.

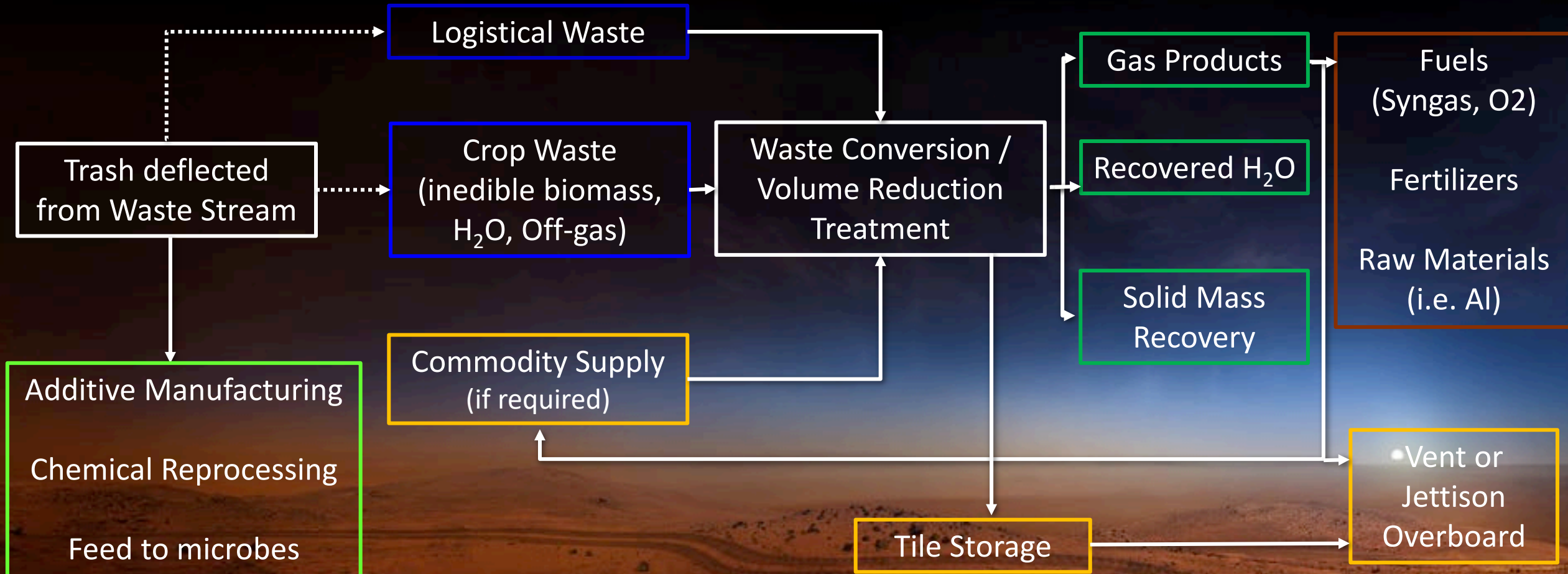
Potential Trash Infusion/Reuse/Recycle Possibilities



Potential Trash Infusion/Reuse/Recycle Possibilities



Potential Trash Infusion/Reuse/Recycle Possibilities



Technology Improvements

- Physical space (mass, volume, area)
- Power
- Automation, crew time, consumables
- Crew Health and Safety
- Complex materials

Benefits/Opportunities:

- Decrease waste volume (i.e., increase habitable volume)
- Resource recovery of commodities: i.e. H_2O , O_2 , CH_4 .
- Reduce launch mass, save \$\$
- Implementation = spaceflight sustainability, extracting resources from waste streams
- Minimization of orbital debris and planetary protection waste material concerns
- New industry, new players: new technology infusion, new architecture implementation

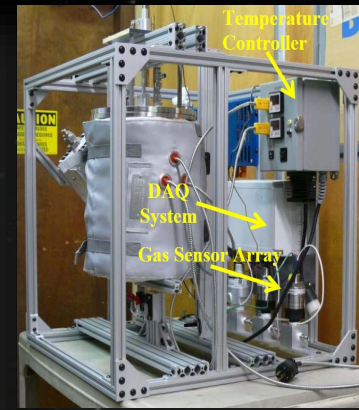
Plasma Pyrolysis



Plasma Gasification



Torrefaction Processing Unit (TPU)



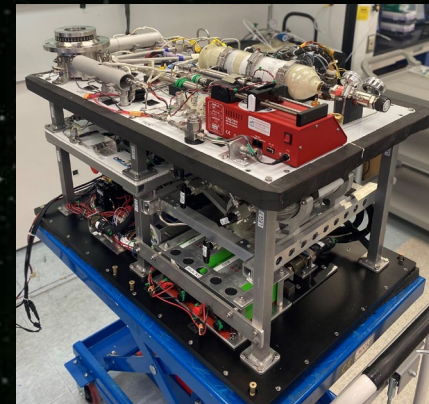
Microwave Assisted Pyrolysis (MAP)



Incinerator/Gasifier



Orbital Syngas Commodity Augmentation Reactor (OSCAR)



Advanced Organic Waste Gasifier (AOWG)



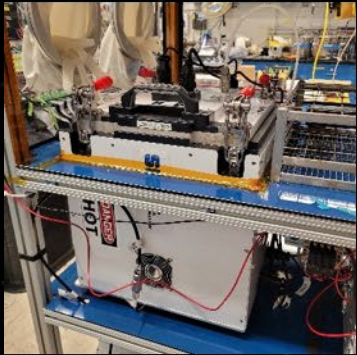
Thank you!

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Backup



Particulate Monitoring Instruments

Dewpoint sensors, CO2 sensors

HMC Gen 3



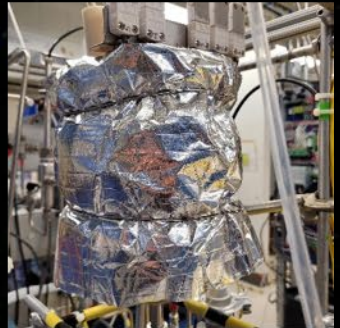
CatOx

HMC Gen 3 Computer

Heater Control Box

CatOx Computer

Water Collection

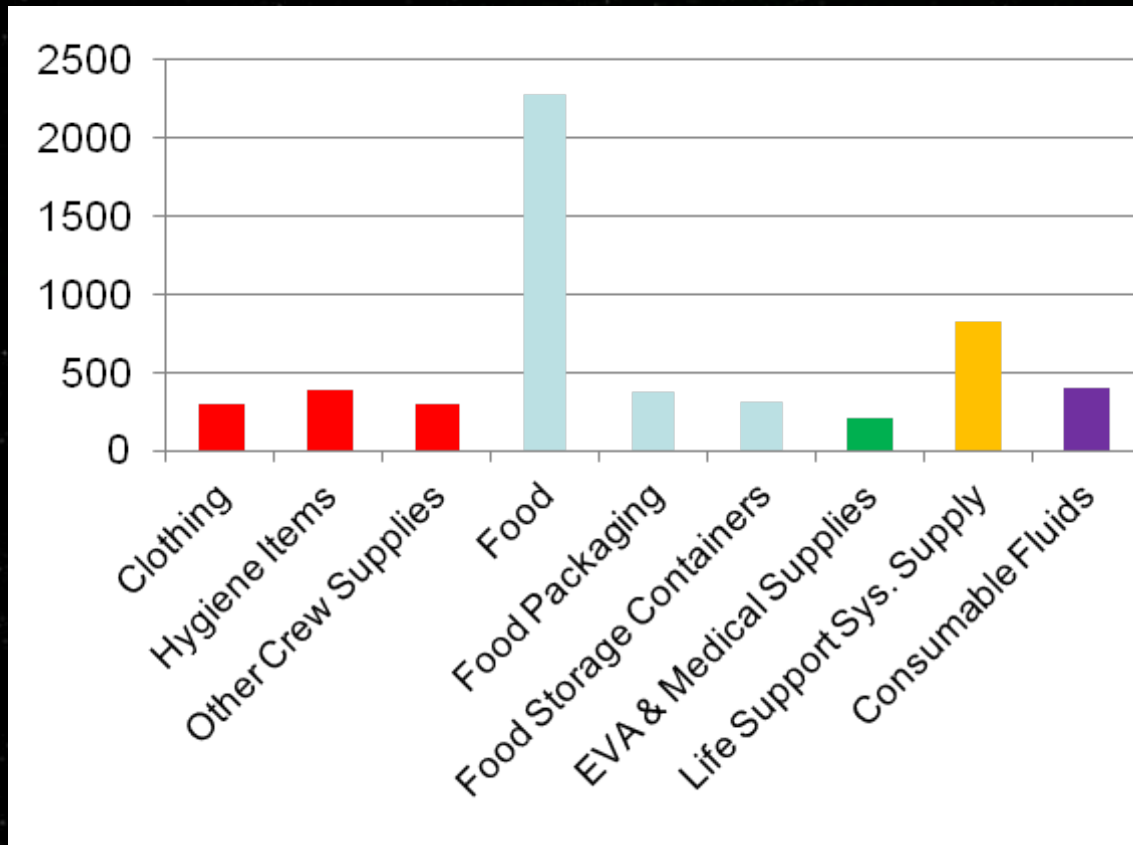


HMC Gen 3 (Heat Melt Compactor Unit)

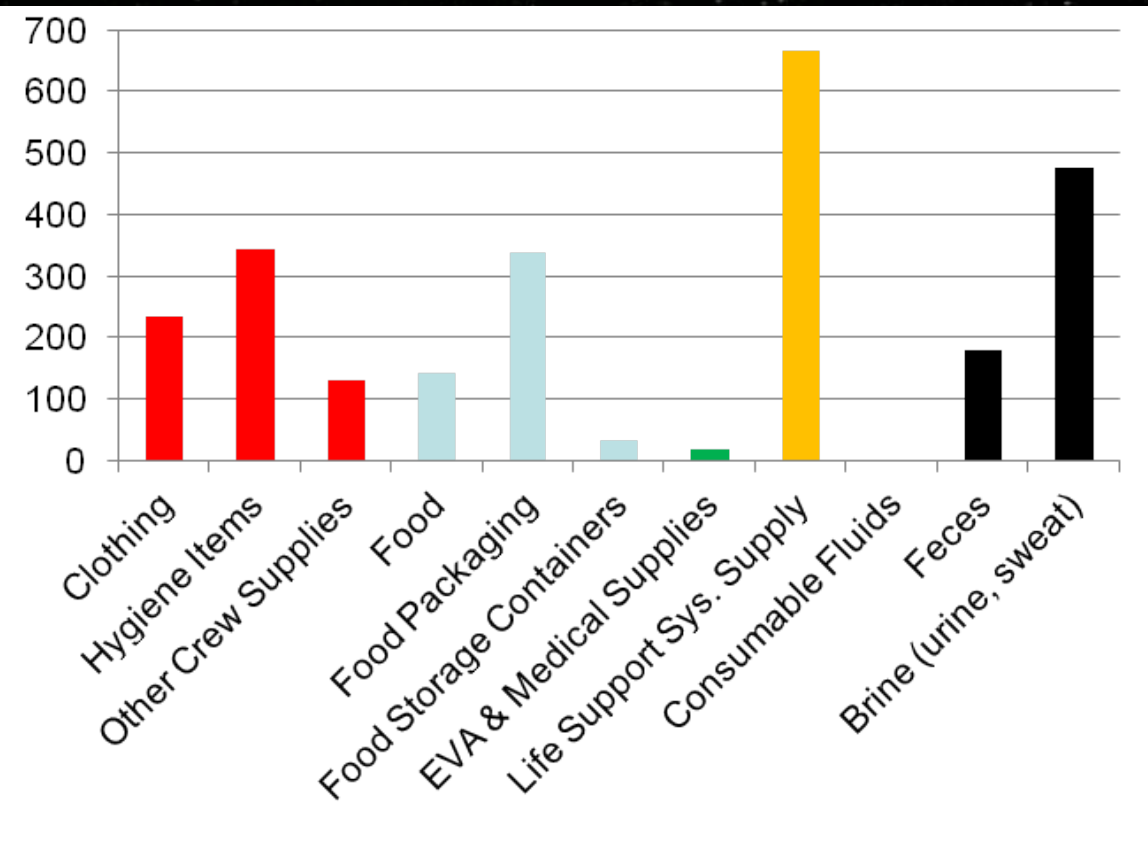
Source Contaminant Control System (Including the Catalytic Oxidizer, CatOx)

Logistics Waste Model – 1 year, 4 people

Launch Mass (kg)



Waste Mass (kg)



Key Performance Parameters

- Equivalent dry mass of test waste (g)
- Mass of residual solid (g)
- Percent solid reduction (%)
- Mass fraction CO₂ produced by reactor (w/w)
- Mass fraction CO produced by reactor (w/w)
- Mass fraction CH₄ produced by reactor (w/w)
- Mass fraction H₂ produced by reactor (w/w)

- Reactor operating temperature (°C)
- System mass (kg)
- System volume (m³)
- System power consumption (kW)
- Estimated TRL (--)

1. Development of Key Performance Parameters (KPPs).
2. System-level mass balance calculations.
3. Equivalent System Mass (ESM) and differential mass (ΔM).
4. Mission approach.

KPP Results – TtG Comparison Study

KPP	units	Inc-Gas	Plas-Gas	AOWG	OSCAR	MAP	Plas-Pyro	TPU
Equivalent dry mass of test waste	g	64.6	1.00	550	7.52	56.0	1.57	24,949* (2,083)
Mass of residual solid	g	5.7	0.131	64	0.849	10	0.257	23,430* (1,269)
Percent solid reduction	%	91	87	88	89	82	74	6.1
Mass fraction CO ₂ produced by reactor	w/w	0.9309	0.6947	0.5096	0.9664	0.2731	0.3818	0.9650
Mass fraction CO Produced by reactor	w/w	0.0627	0.2779	0.1872	0.0303	0.3121	0.3152	0.0350
Mass fraction CH ₄ produced by reactor	w/w	0.0064	0.0206	0.0096	0.0033	0.4149	0.2627	0.0000
Mass fraction H ₂ produced by reactor	w/w	0.0000	0.0067	0.2936	0.0000	0.0000	0.0403	0.0000
Reactor operating temperature	°C	600	400	800	600	700	300	225
System mass (reported/projected)	kg	80/66**	13.6/43**	90/90**	75/66**	92/76**	13.6/31**	22/22**
System volume (reported/projected)	m ³	0.47/1.35**	--/0.70**	2.0/2.0**	0.28/1.35**	0.16/1.67**	--/0.38**	0.136/0.136**
System power consumption	kW	1.63	0.20	0.58	1.18	4.6	0.30	0.10
Estimated TRL	--	3-4	3	5	4	4	3	5-6

*Projected total waste. Measured waste (fecal only) is given in parentheses (see Section II above for details).

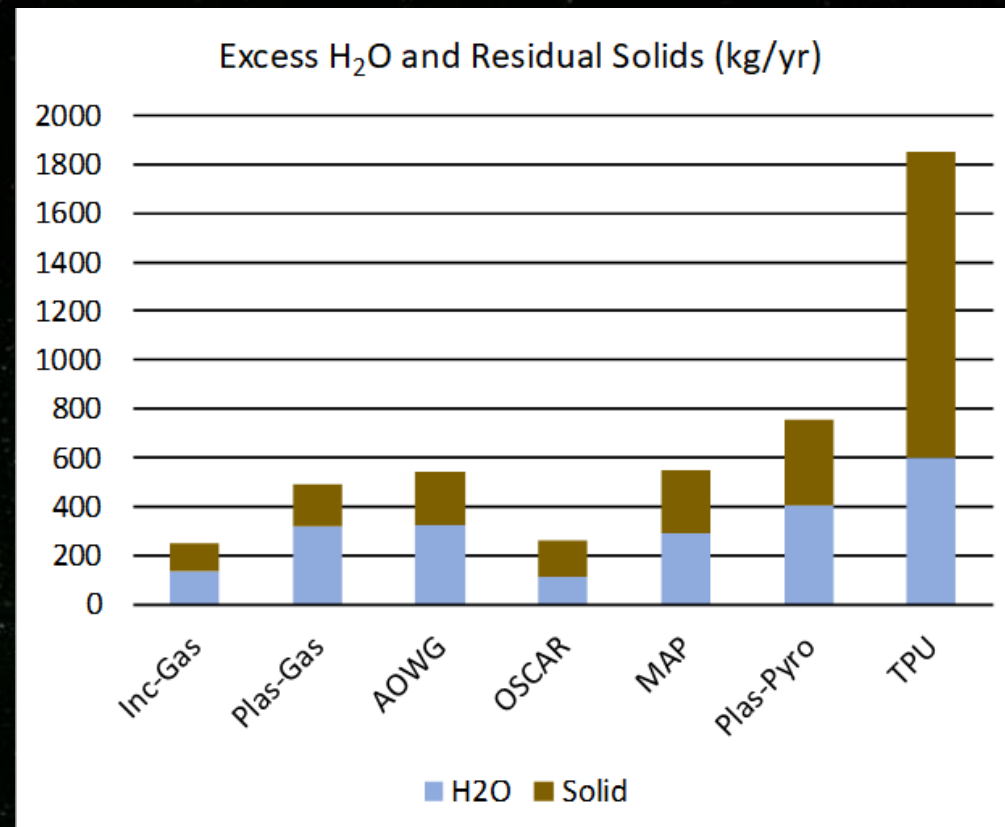
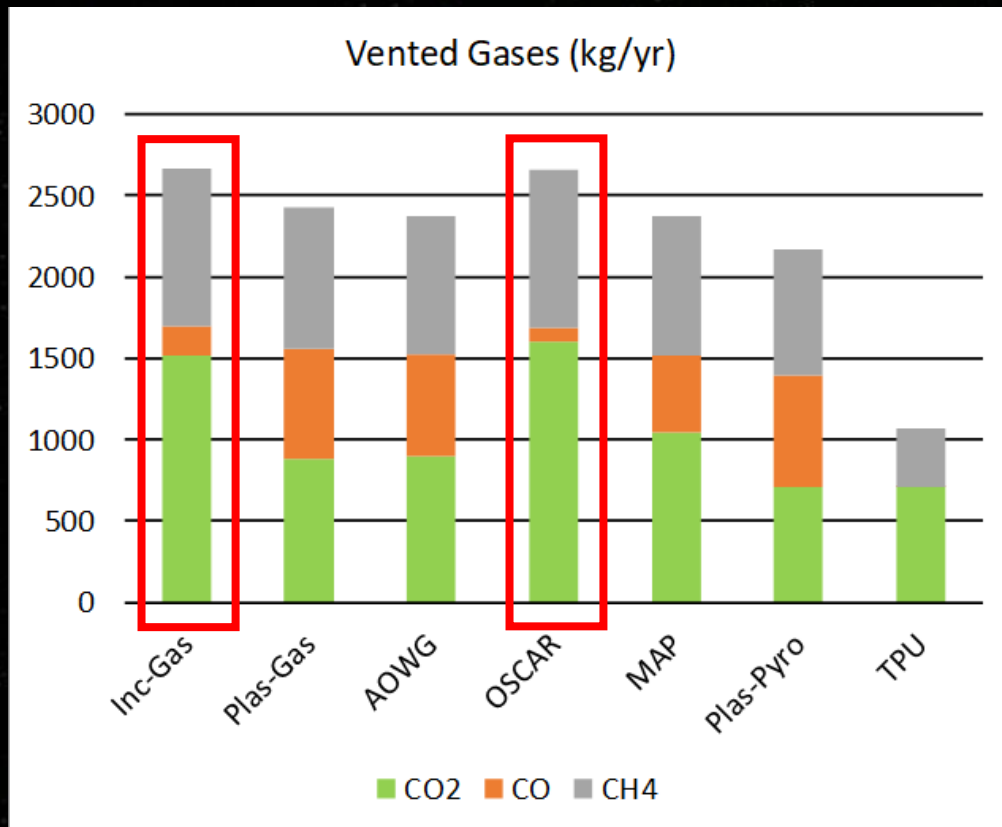
**Reported/scaled (see Section II above for details). Measured values are provided when available. The scaled values (after the slash) were used for calculations herein.

System-Level Mass Balance

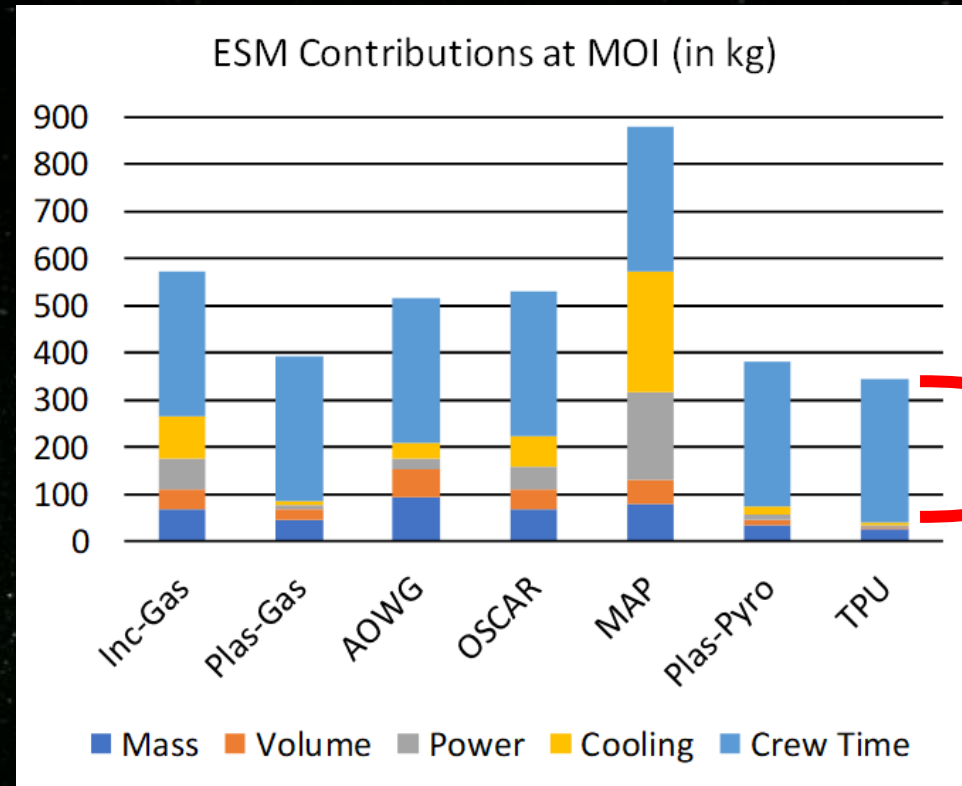
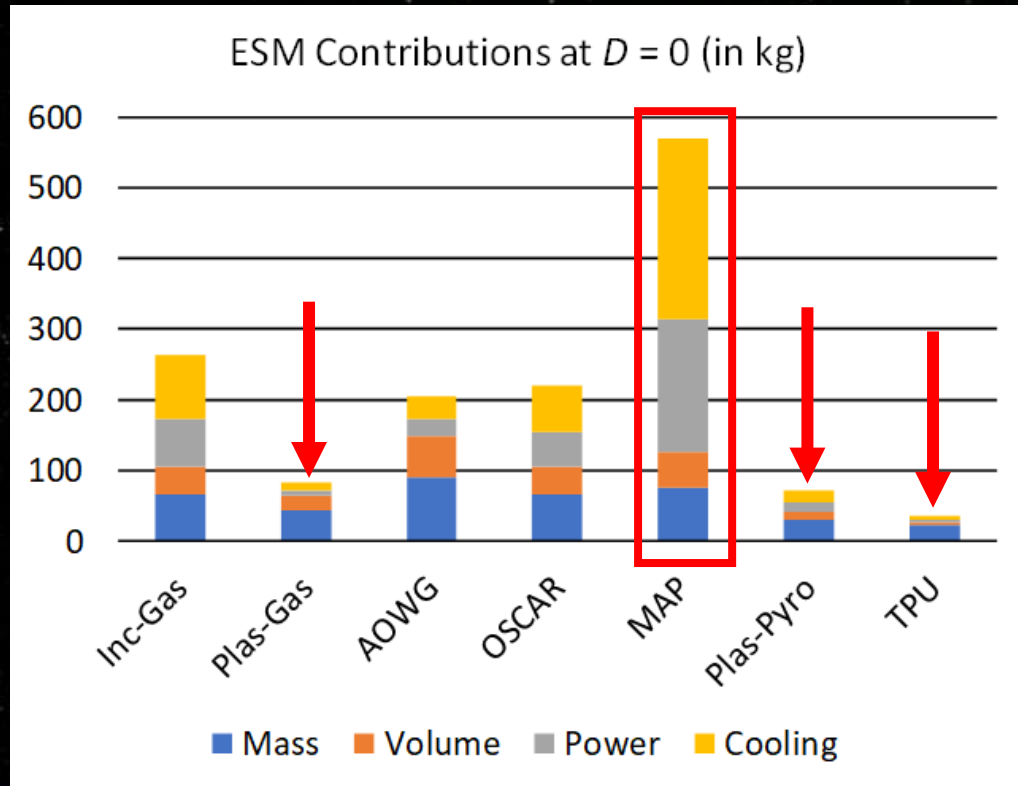
All values in kg for a crew of 4 over 1 year.

Material Product	Inc-Gas	Plas-Gas	AOWG	OSCAR	MAP	Plas-Pyro	TPU
Vented CO ₂	1513	881	898	1599	1040	706	706
Vented CO	181	674	624	88	478	689	3
Vented CH ₄	976	873	854	974	856	771	359
Total Vented Gas	2670	2428	2376	2661	2374	2166	1068
Residual Solids	119	175	221	145	255	350	1251
H ₂ O Produced	133	318	323	115	292	404	602

System-Level Mass Balance



ESM Results



Trash to Supply Gas – General Sys. Analysis

Waste Volume Reduction: 19 m³

Equivalent to pressurized volume of one Orion Spacecraft.

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

Production:

~800 kg of O₂, ~900 kg of H₂O, 1,100 kg of CO₂

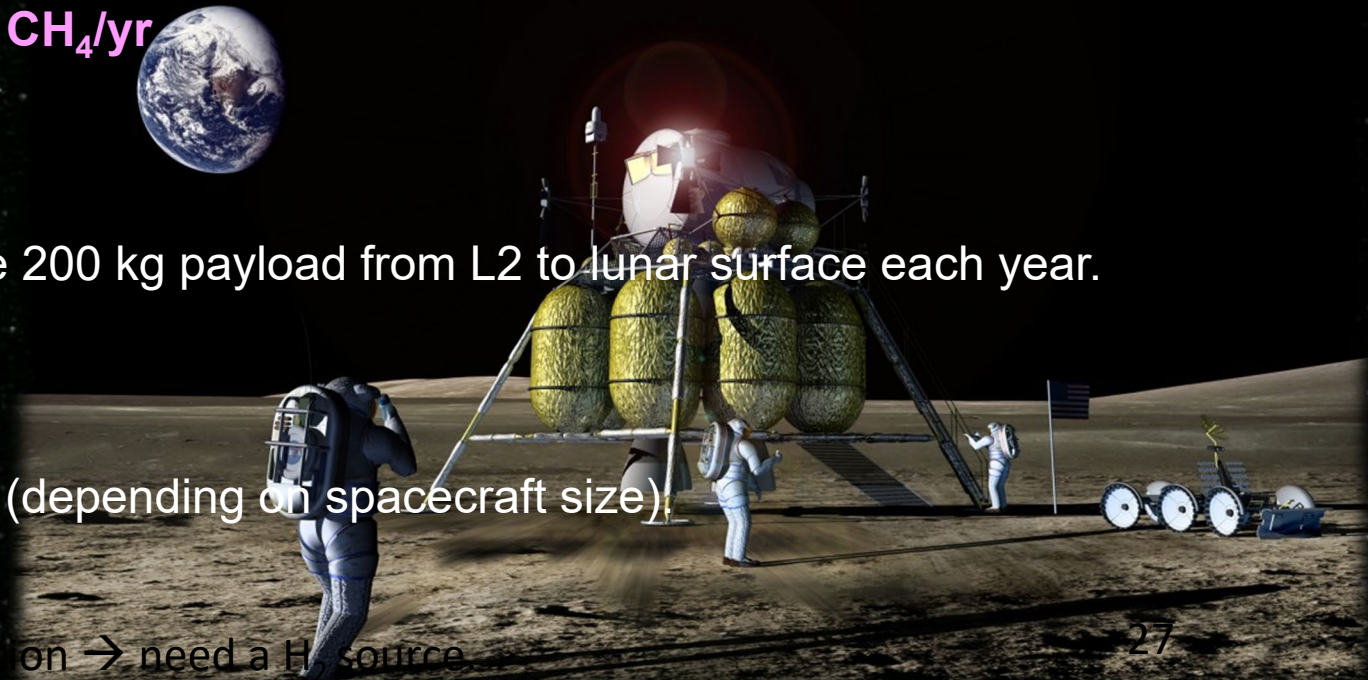
~800 to 1500 kg of CH₄/yr

Lunar:

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

Mars:

Course Corrections (depending on spacecraft size)

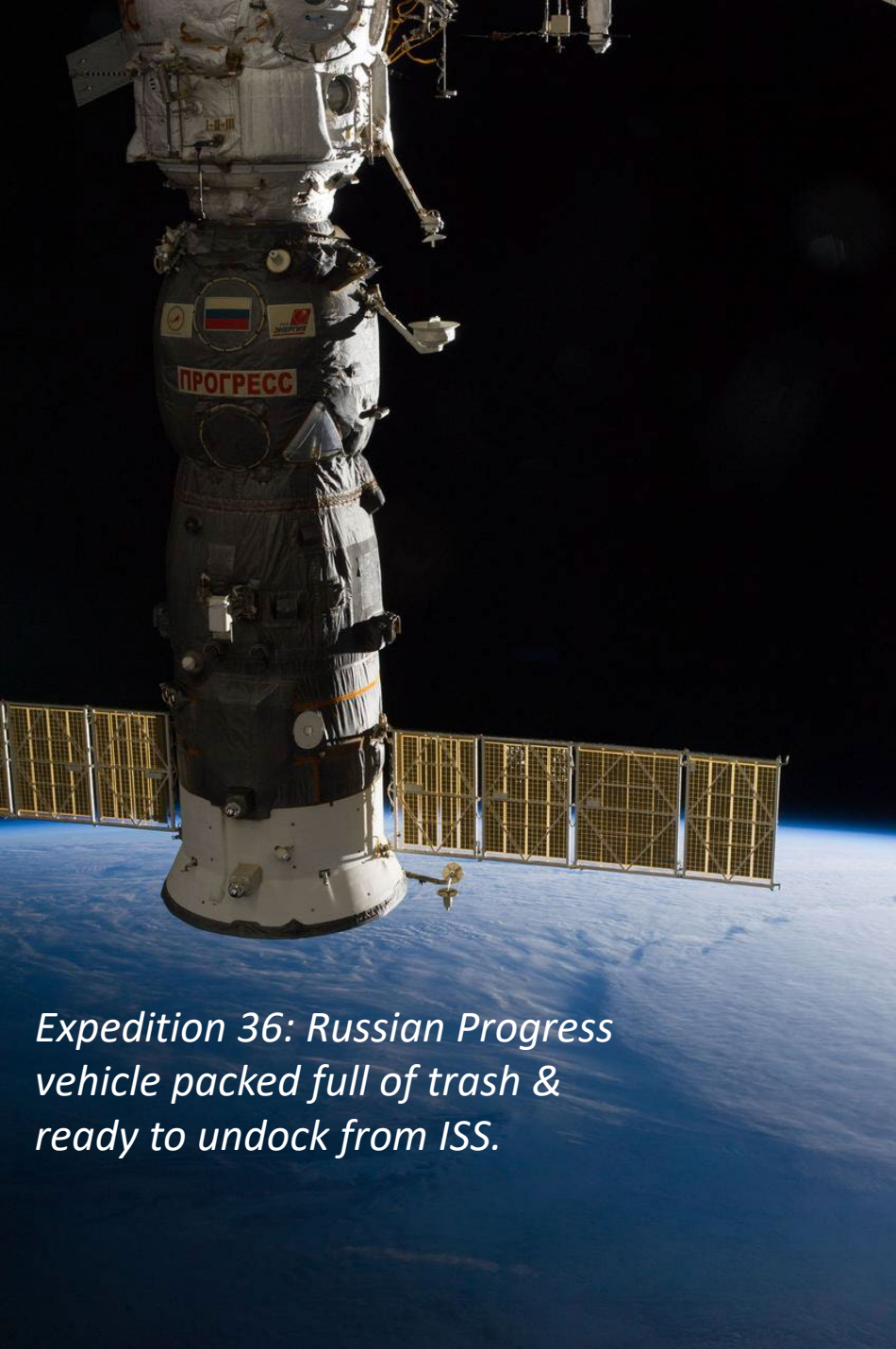




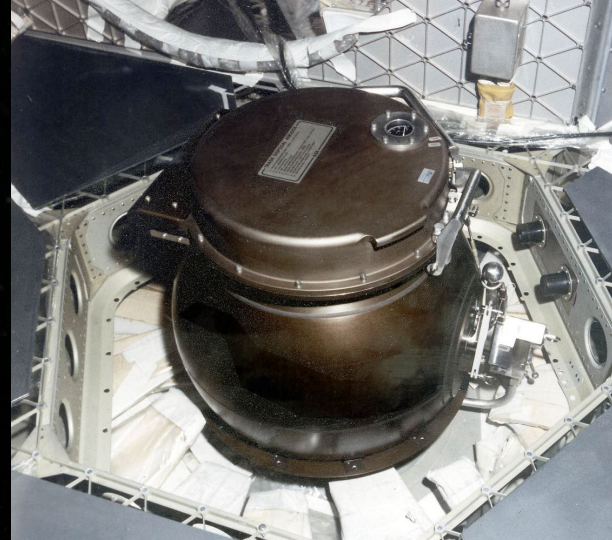
Left: STS073-356-018 -1995) - Kent V. Rominger, pilot, demonstrates an age-old trash-compacting method on the middeck of the Earth-orbiting Space Shuttle Columbia.

Right: ISS030-E-020706 - 2012) - Don Pettit, Expedition 30 flight engineer, is pictured among stowage bags in the Harmony node of the ISS.

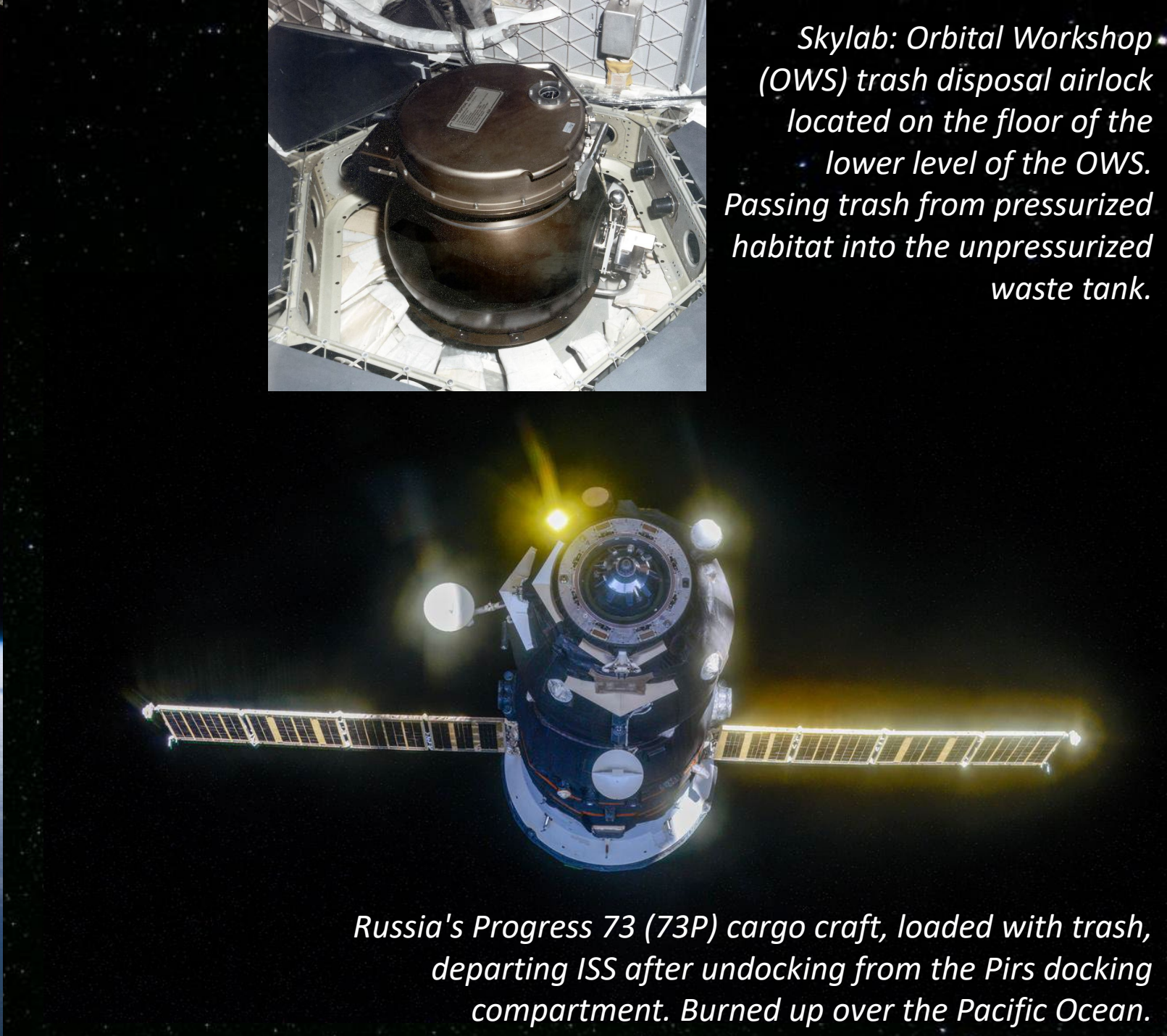




Expedition 36: Russian Progress vehicle packed full of trash & ready to undock from ISS.



Skylab: Orbital Workshop (OWS) trash disposal airlock located on the floor of the lower level of the OWS. Passing trash from pressurized habitat into the unpressurized waste tank.



Russia's Progress 73 (73P) cargo craft, loaded with trash, departing ISS after undocking from the Pirs docking compartment. Burned up over the Pacific Ocean.