National Aeronautics and
Space Administration

Water Processing for Space Exploration

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The Artemis Program

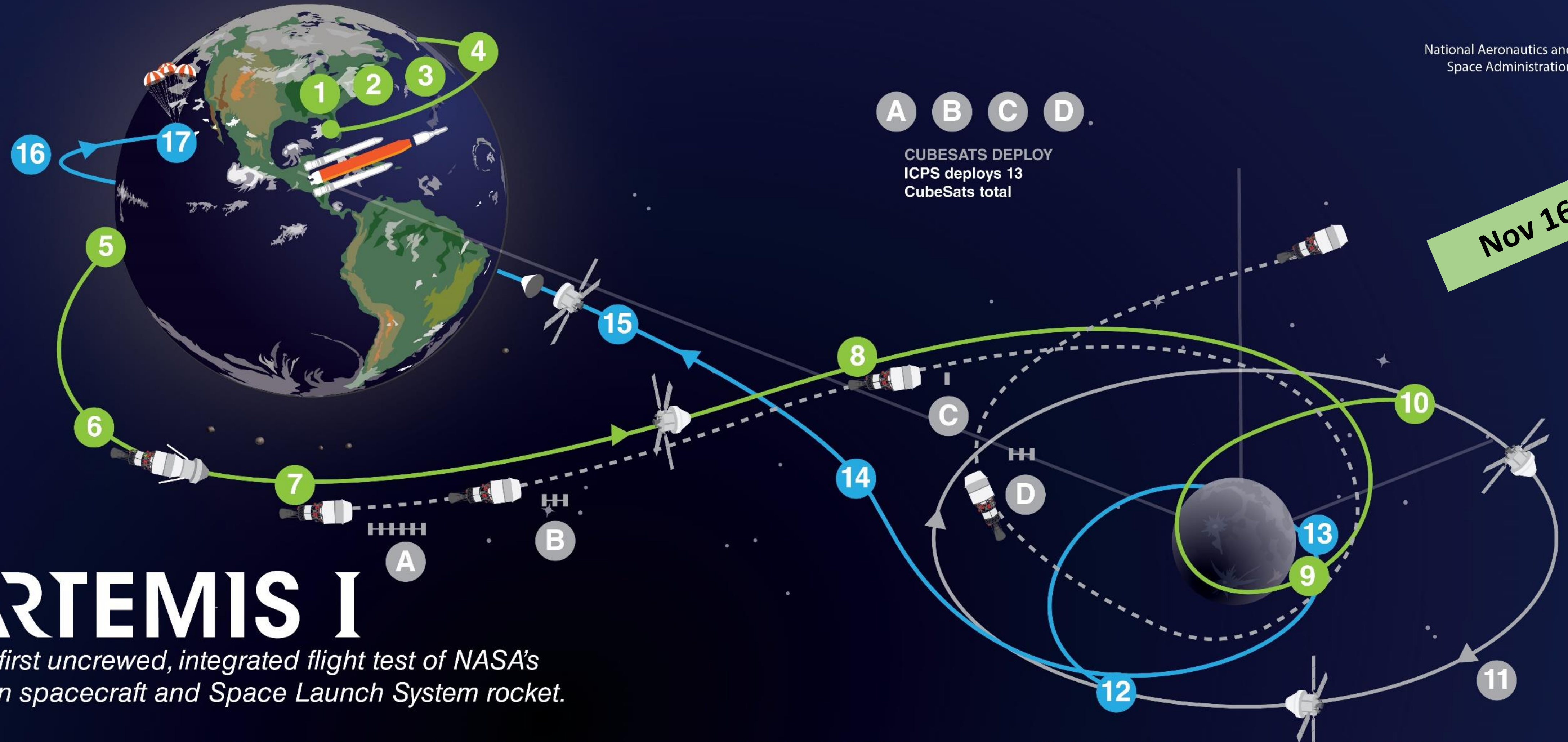
Artemis is the twin sister of Apollo and goddess of the Moon in Greek mythology. Now, she personifies our path to the Moon as the name of NASA’s program to return astronauts to the lunar surface.

When they land, Artemis astronauts will step foot where no human has ever been before: the Moon’s South Pole.

With the horizon goal of sending humans to Mars, Artemis begins the next era of exploration.

ARTEMIS

National Aeronautics and Space Administration



ARTEMIS I

The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket.

1. **LAUNCH**
SLS and Orion lift off from pad 39B at Kennedy Space Center.

2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**

3. **CORE STAGE MAIN ENGINE CUT OFF**
With separation.

4. **PERIGEE RAISE MANEUVER**

5. **EARTH ORBIT**
Systems check with solar panel adjustments.

6. **TRANS LUNAR INJECTION (TLI) BURN**
Maneuver lasts for approximately 20 minutes.

7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL**
The ICPS has committed Orion to TLI.

8. **OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS**
As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).

9. **OUTBOUND POWERED FLYBY (OPF)**
60 nmi from the Moon; targets DRO insertion.

10. **LUNAR ORBIT INSERTION**
Enter Distant Retrograde Orbit for next 6-23 days.

11. **DISTANT RETROGRADE ORBIT**
Perform half or one and a half revolutions in the 12 day orbit period 38,000 nmi from the surface of the Moon.

12. **DRO DEPARTURE**
Leave DRO and start return to Earth.

13. **RETURN POWER FLY-BY (RPF)**
RPF burn prep and return coast to Earth initiated.

14. **RETURN TRANSIT**
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time 5-11 days.

15. **CREW MODULE SEPARATION FROM SERVICE MODULE**

16. **ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.

17. **SPLASHDOWN**
Pacific Ocean landing within view of the U.S. Navy recovery ship.

National Aeronautics and Space Administration

April 2026

ARTEMIS II

Crewed Hybrid Free Return Trajectory, demonstrating astronaut flight and spacecraft systems performance beyond Low Earth Orbit.

1. **LAUNCH**
   Astronauts lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **APOGEE RAISE BURN TO HIGH EARTH ORBIT**
   Begin 42 hour checkout of spacecraft.
6. **PROX OPS DEMONSTRATION**
   Orion proximity operations demonstration and manual handling qualities assessment for up to 2 hours.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) DISPOSAL BURN**
8. **HIGH EARTH ORBIT CHECKOUT**
   Life support, exercise, and habitation equipment evaluations.
9. **TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE**
10. **OUTBOUND TRANSIT TO MOON**
    4 days outbound transit along free return trajectory.
11. **LUNAR FLYBY**
    4,000 nmi (mean) lunar farside altitude.
12. **TRANS-EARTH RETURN**
    Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.
13. **CREW MODULE SEPARATION FROM SERVICE MODULE**
14. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
15. **SPLASHDOWN**
    Astronaut and capsule recovery by U.S. Navy ship.

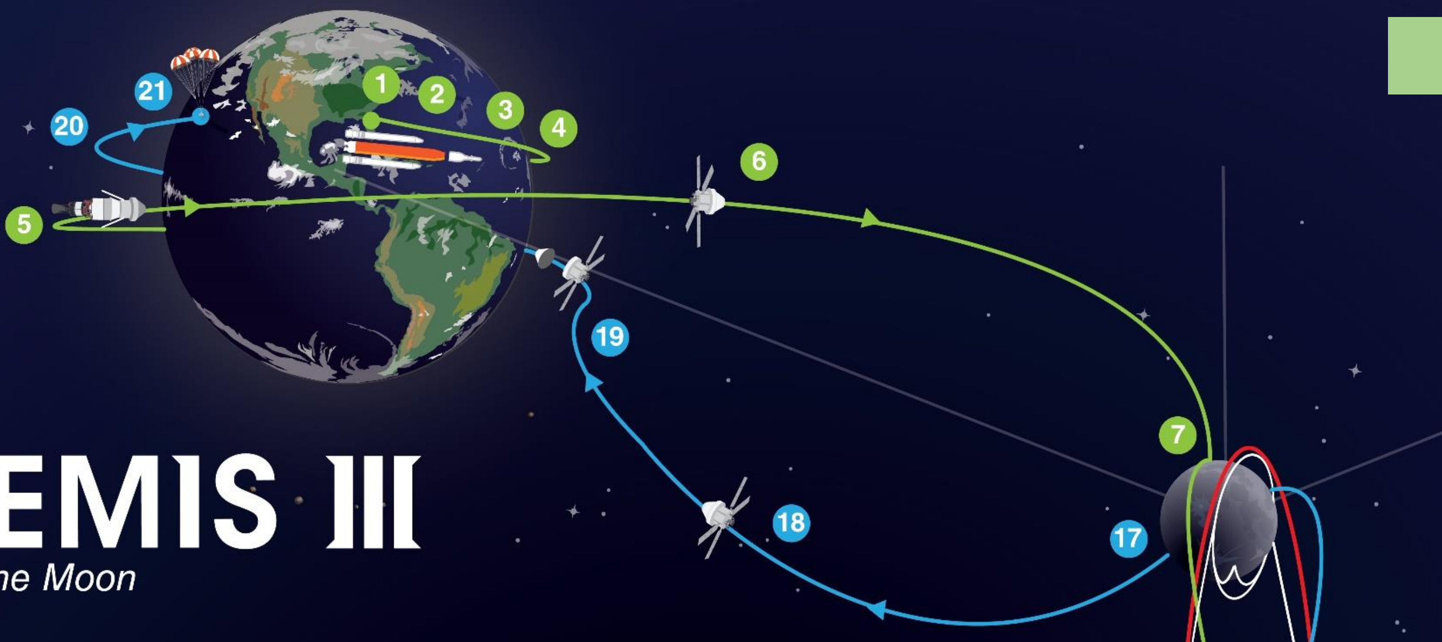
PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE

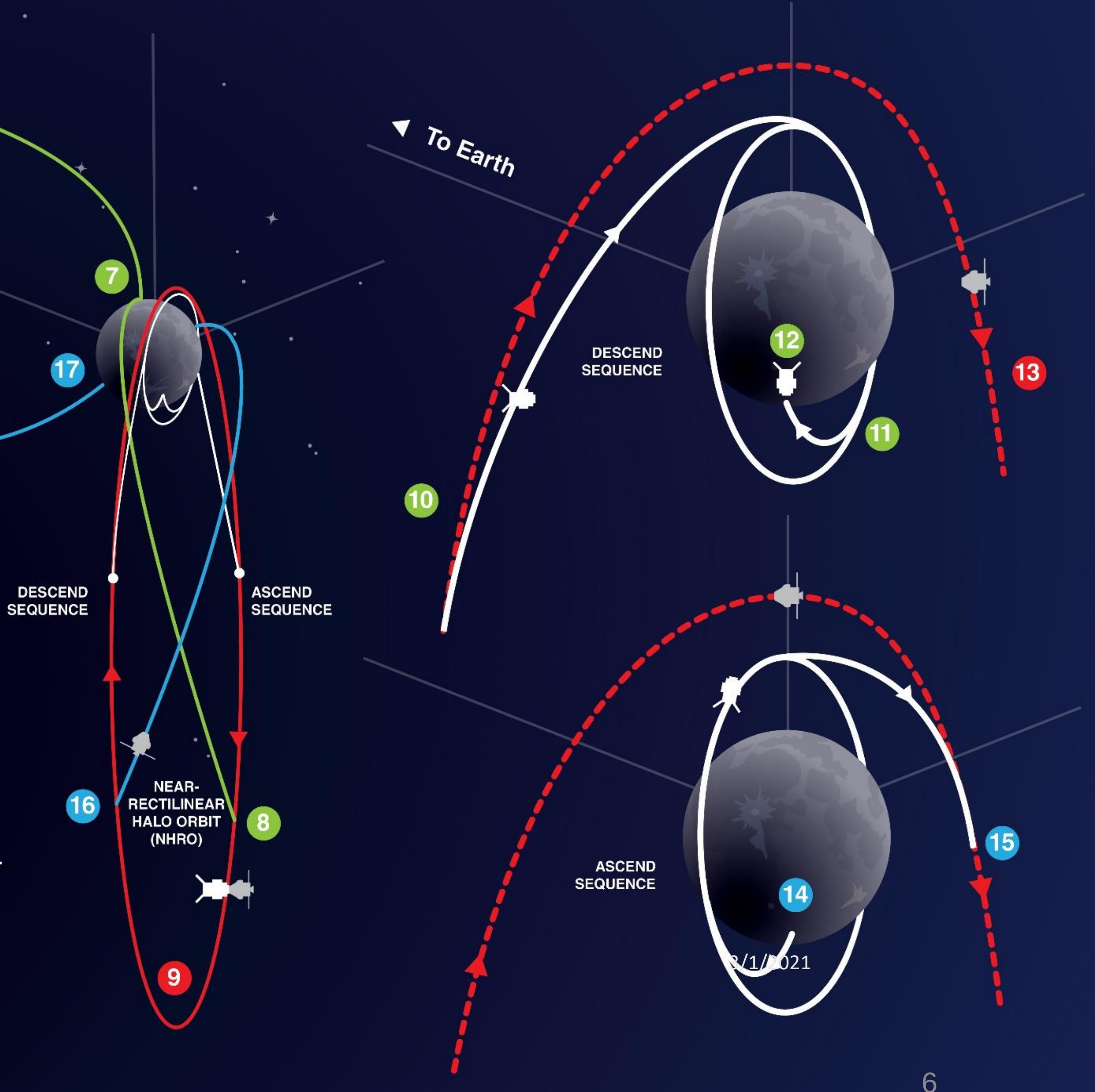
3/1/2021

Mid 2027

National Aeronautics and
Space Administration

ARTEMIS III
Landing on the Moon

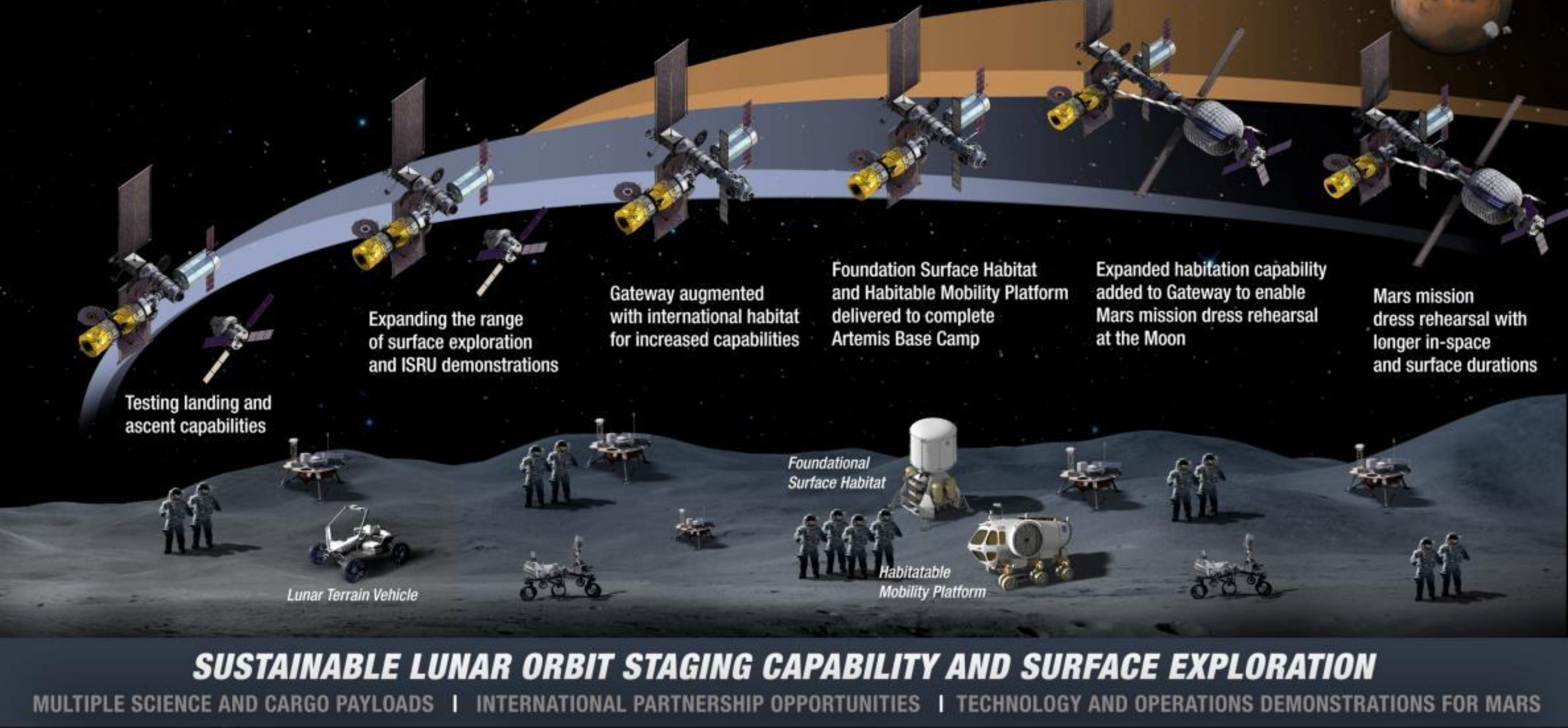




1. **LAUNCH**
SLS and Orion lift off from Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
With separation.
4. **ENTER EARTH ORBIT**
Perform the perigee raise maneuver. Systems check and solar panel adjustments.
5. **TRANS LUNAR INJECTION BURN**
Astronauts committed to lunar trajectory, followed by ICPS separation and disposal.
6. **ORION OUTBOUND TRANSIT TO MOON**
Requires several outbound trajectory burns.
7. **ORION OUTBOUND POWERED FLYBY**
60 nmi from the Moon.
8. **NHRO ORBIT INSERTION BURN**
Orion performs burn to establish rendezvous point and executes rendezvous and docking.
9. **LUNAR LANDING PREPARATION**
Crew activates lander and prepares for departure.
10. **LANDER UNDOCKING AND SEPARATION**
11. **LANDER ENTERS LOW LUNAR ORBIT**
Descends to lunar touchdown.
12. **LUNAR SURFACE EXPLORATION**
Astronauts conduct week long surface mission and extra-vehicular activities.
13. **ORION REMAINS IN NHRO ORBIT**
During lunar surface mission.
14. **LANDER ASCENDS LOW LUNAR ORBIT**
15. **LANDER PERFORMS RENDEZVOUS AND DOCKING**
16. **CREW RETURNS IN ORION**
Orion undocks, performs orbit departure burn.
17. **ORION PERFORMS RETURN POWERED FLYBY**
60 nmi from the Moon.
18. **FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN**
Precision targeting for Earth entry.
19. **CREW MODULE SEPARATION FROM SERVICE MODULE**
20. **ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.
21. **SPLASHDOWN**
Astronaut and capsule recovery by U.S. Navy ship.

3/1/2021

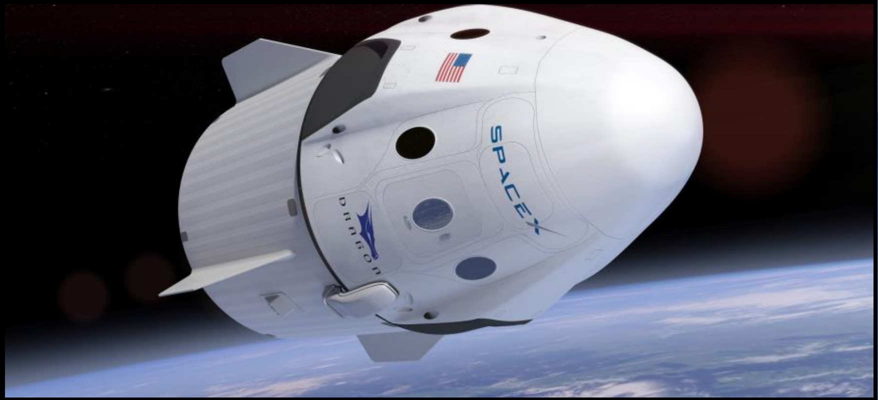
ARTEMIS PREPARES FOR MARS

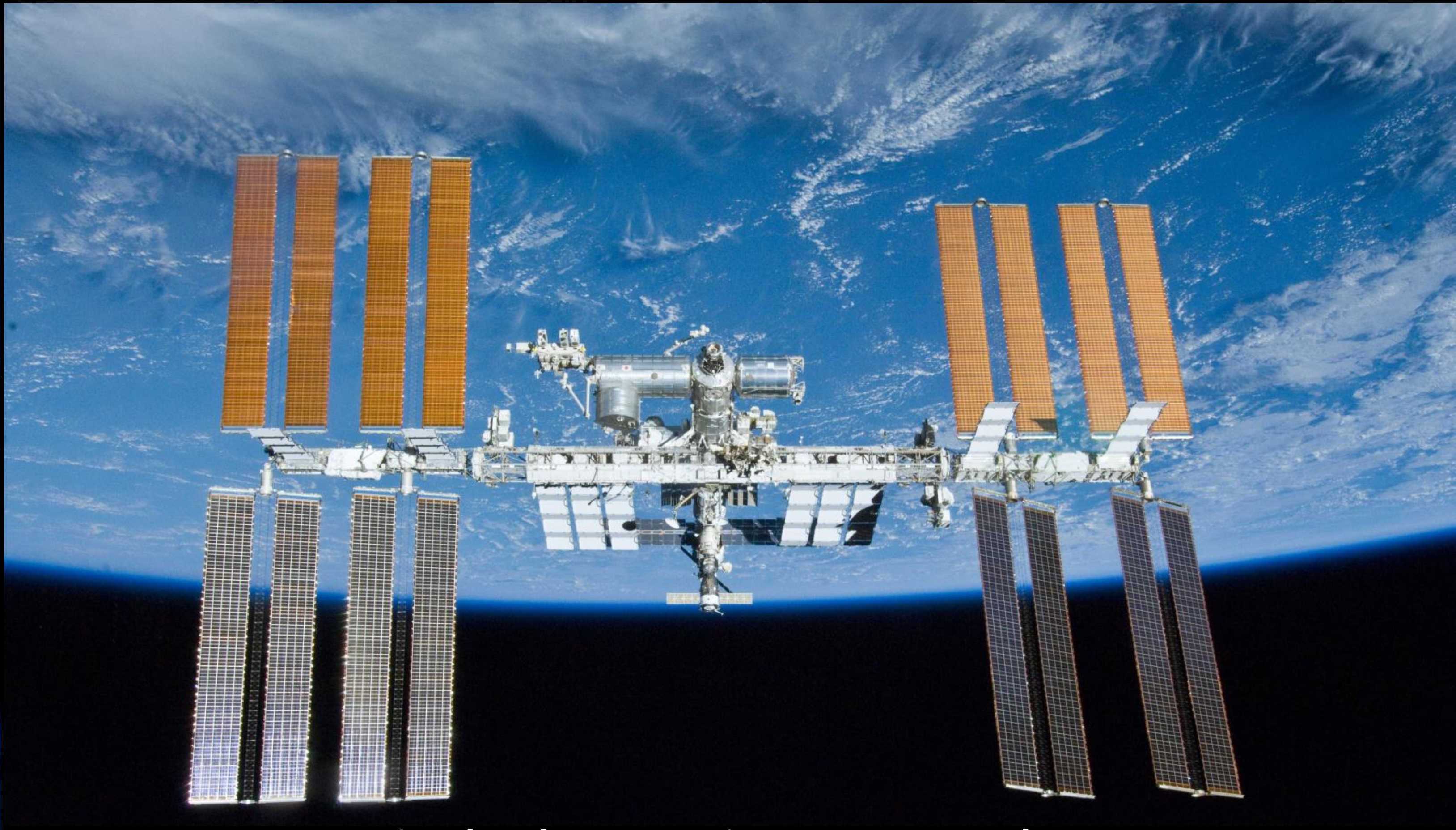


Mission Needs Drive Design

TECHNOLOGY DRIVES EXPLORATION

Physical/Chemical Water Processing for ISS and Crew



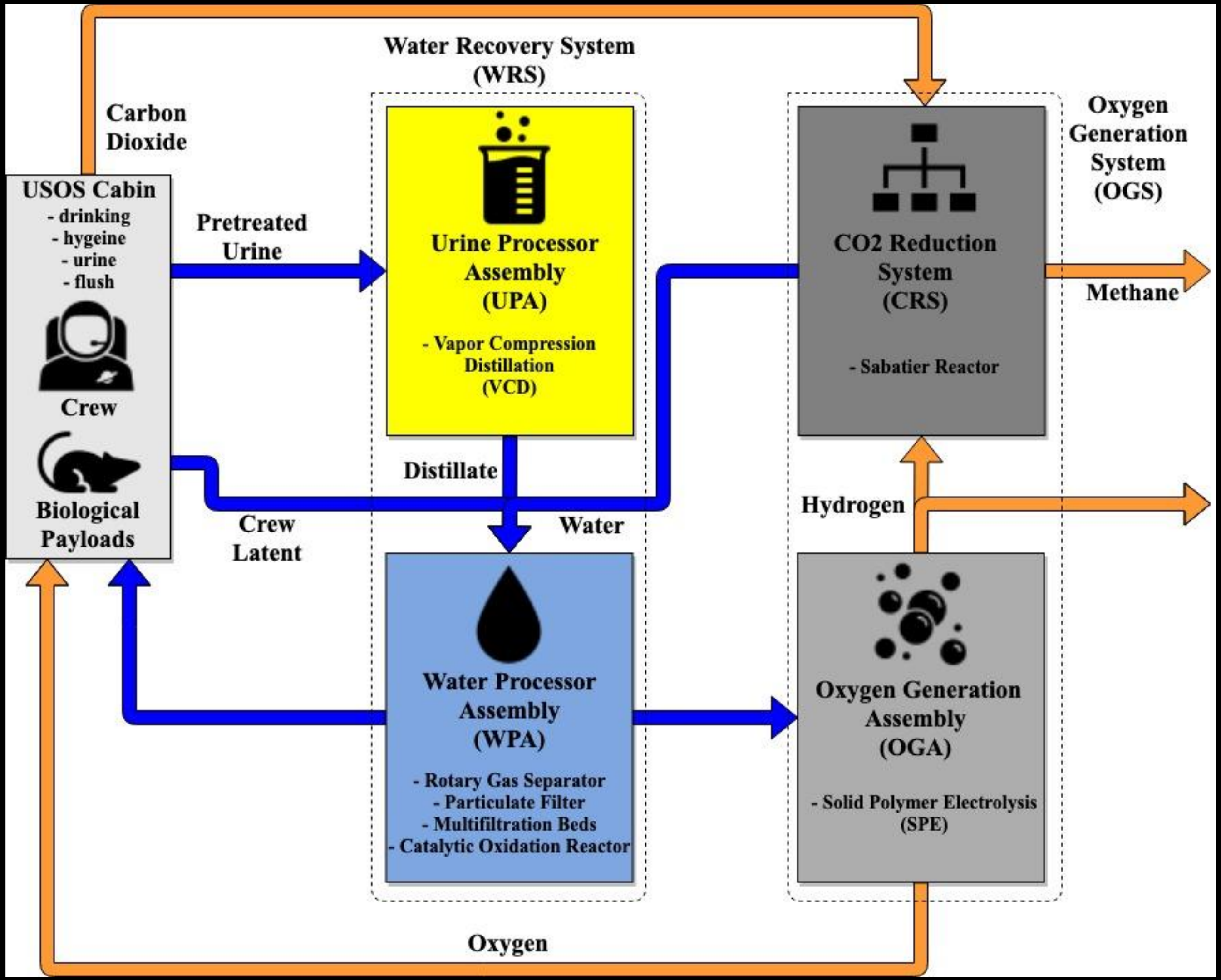


Simple. Short Duration. Easy Resupply.
Focus: Water recovery

ISS Water Processing

Water Recovery System (WRS)

- Urine Processor Assembly (UPA)
- Brine Processor Assembly (BPA)
- Water Processor Assembly (WPA)

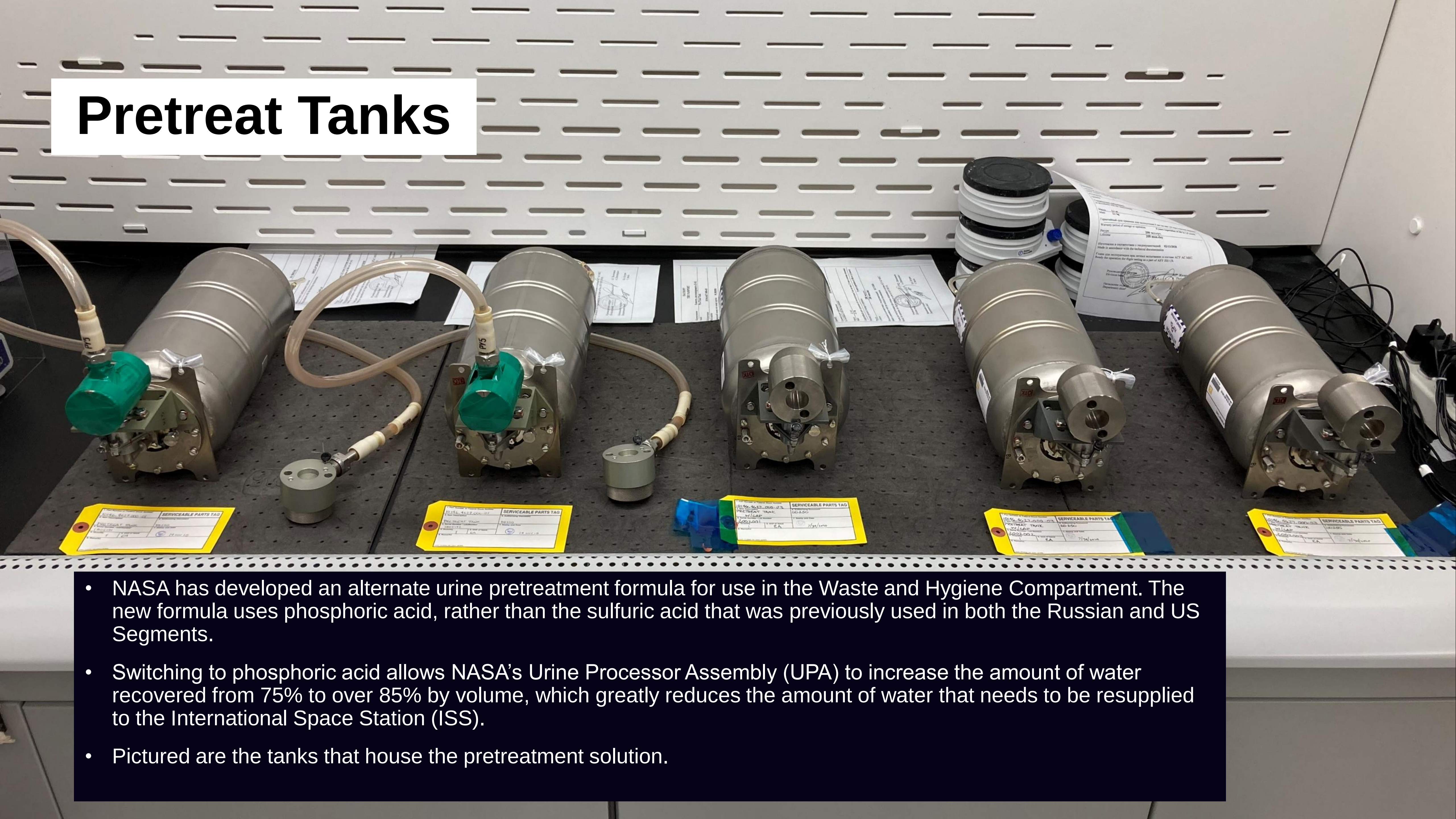


2019, Cater, ICES, 2021, Muirhead, ICES

ISS Water

- 2-3 missions per year resupply the ISS with the pretreat solution
- All flight hardware is sterilized with a silver water biocidal solution prior to pretreat tank/hose filling
- Additional flight hardware is filled with a higher concentration silver water solution to maintain sterility until hardware is utilized on orbit

Pretreat Tanks



- NASA has developed an alternate urine pretreatment formula for use in the Waste and Hygiene Compartment. The new formula uses phosphoric acid, rather than the sulfuric acid that was previously used in both the Russian and US Segments.
- Switching to phosphoric acid allows NASA’s Urine Processor Assembly (UPA) to increase the amount of water recovered from 75% to over 85% by volume, which greatly reduces the amount of water that needs to be resupplied to the International Space Station (ISS).
- Pictured are the tanks that house the pretreatment solution.

ISS Solid Waste Processing

Solid waste is collected using **single-use bags,** stored, followed by jettison offboard to burn up on reentry or returned to Earth for testing.

To store the fecal waste of a crew of 4 for a 1000-day mission (30 months) it will require 400 fecal canisters

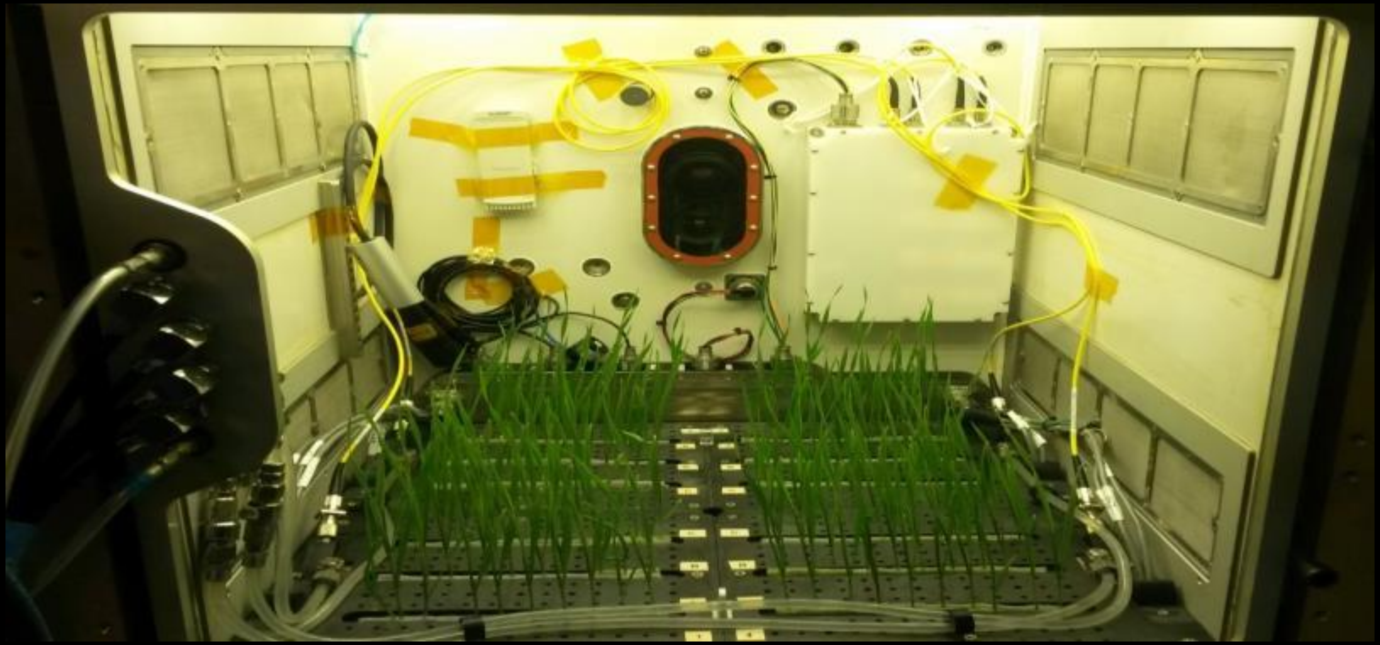
For long duration missions to the Moon and Mars:

- Can't abandon trash
- Can't ship back to Earth
- Storing and processing hazardous waste is risky
- Or…Continuously process and treat

Food Production

Sustainable technologies: Veggie/APH at TRL 9 aboard ISS; OHALO TRL 2-3

Cultivation resources (fertilizer, water, seeds) currently depend on resupply



Issues: Systems designed for food studies, not food production.
Size/Volume constraints limit types of food. Only crops.

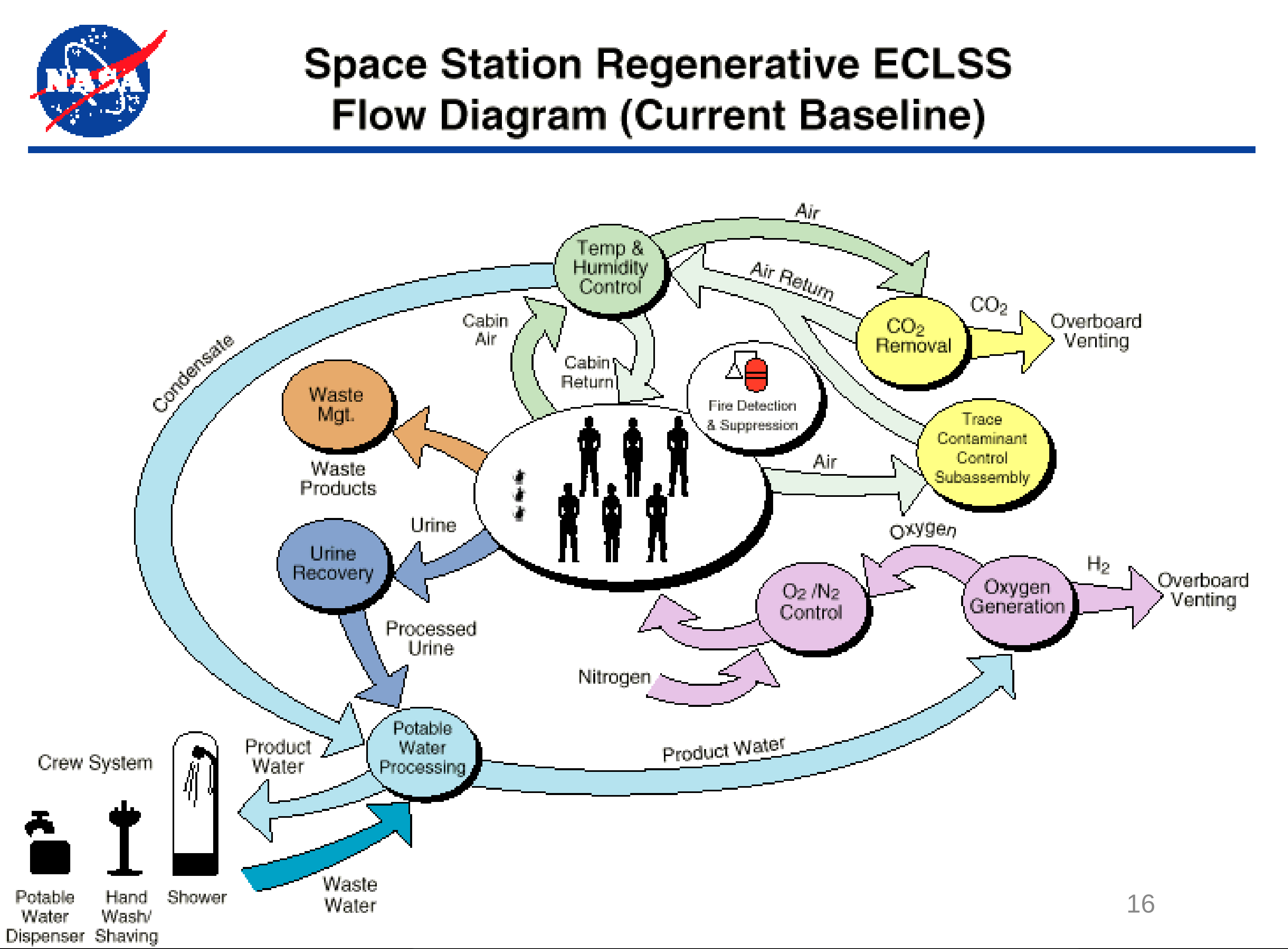
Current Physical/Chemical Architecture for ISS

NASA's current "ECLSS Flow" doesn't include half of the operations and inputs/outputs of the real system!

There are NO human inputs into the system that are regenerative aside from O2. Meaning the system ISN'T regenerative.

ALL food, water, air (nitrogen) MUST be brought or resupplied.

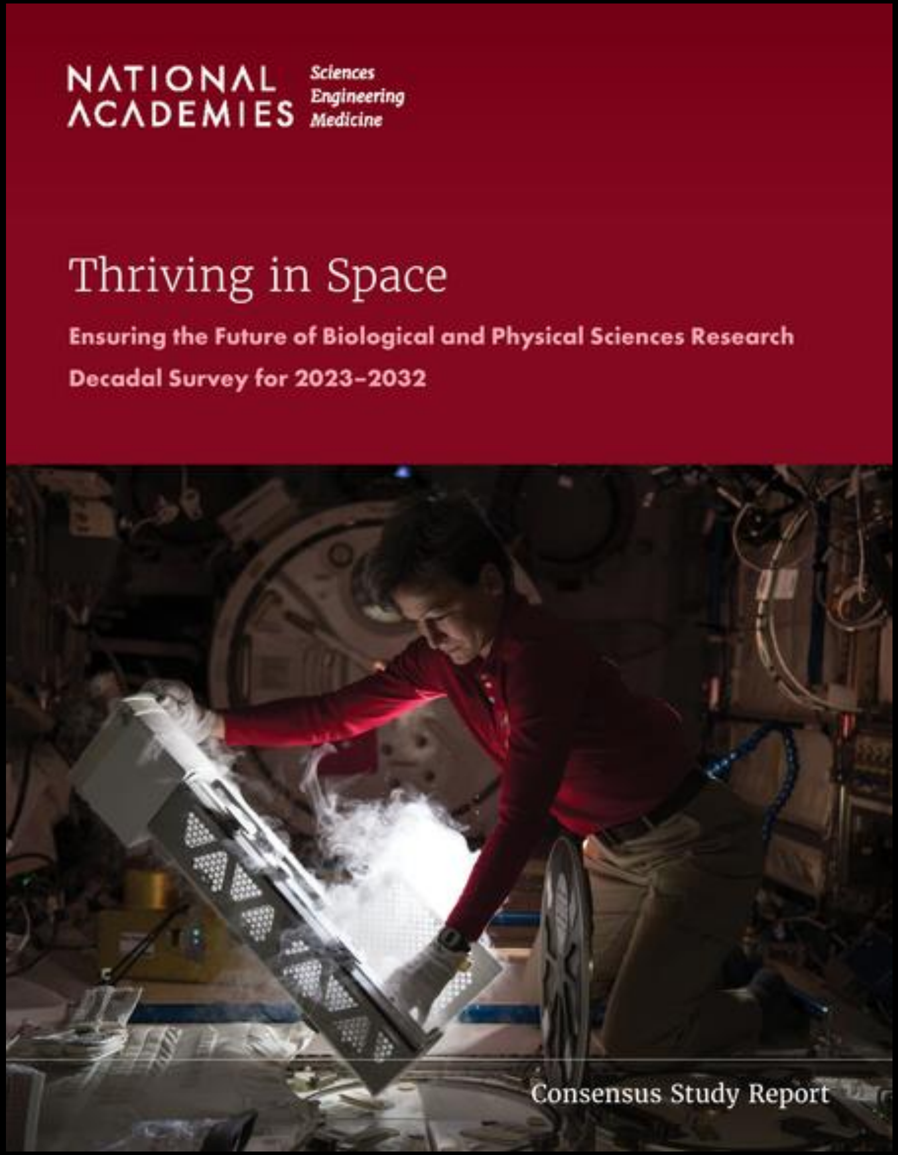
Waste is use as a VERY generic catch-all to include metal, plastic, fecal, menstrual/blood, hazmat. Where does that really go? Overboard ISS isn't possible on the Moon or Mars…



2023 NASA DECADAL SURVEY

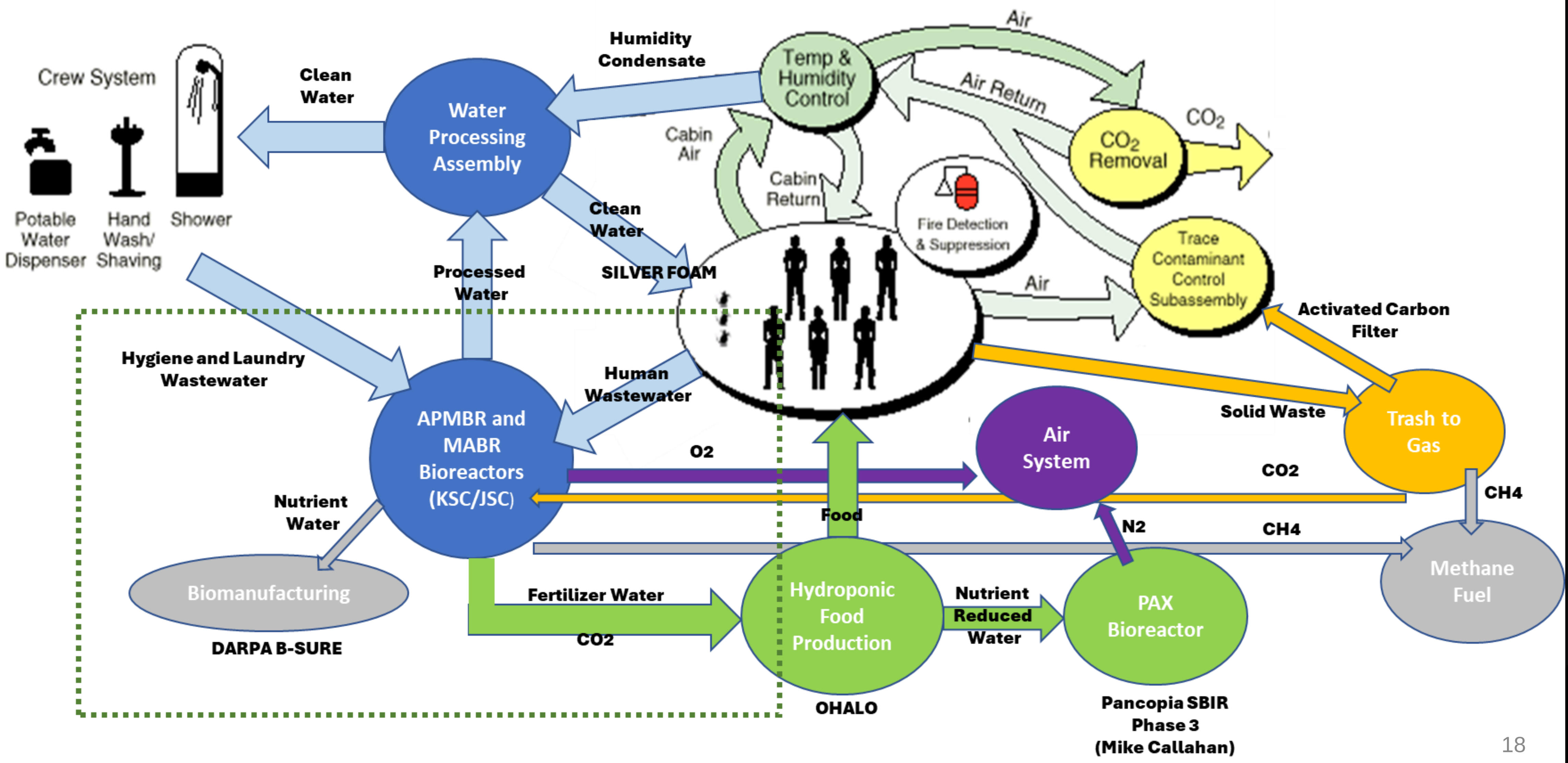
This report identifies key scientific questions, priorities, and ambitious research campaigns that will enable human space exploration and transform our understanding of how the universe works.

Report recommends NASA focus more on Bioregenerative Life Support Systems (BLiSS) and Manufacturing in space – specifically biomanufacturing.

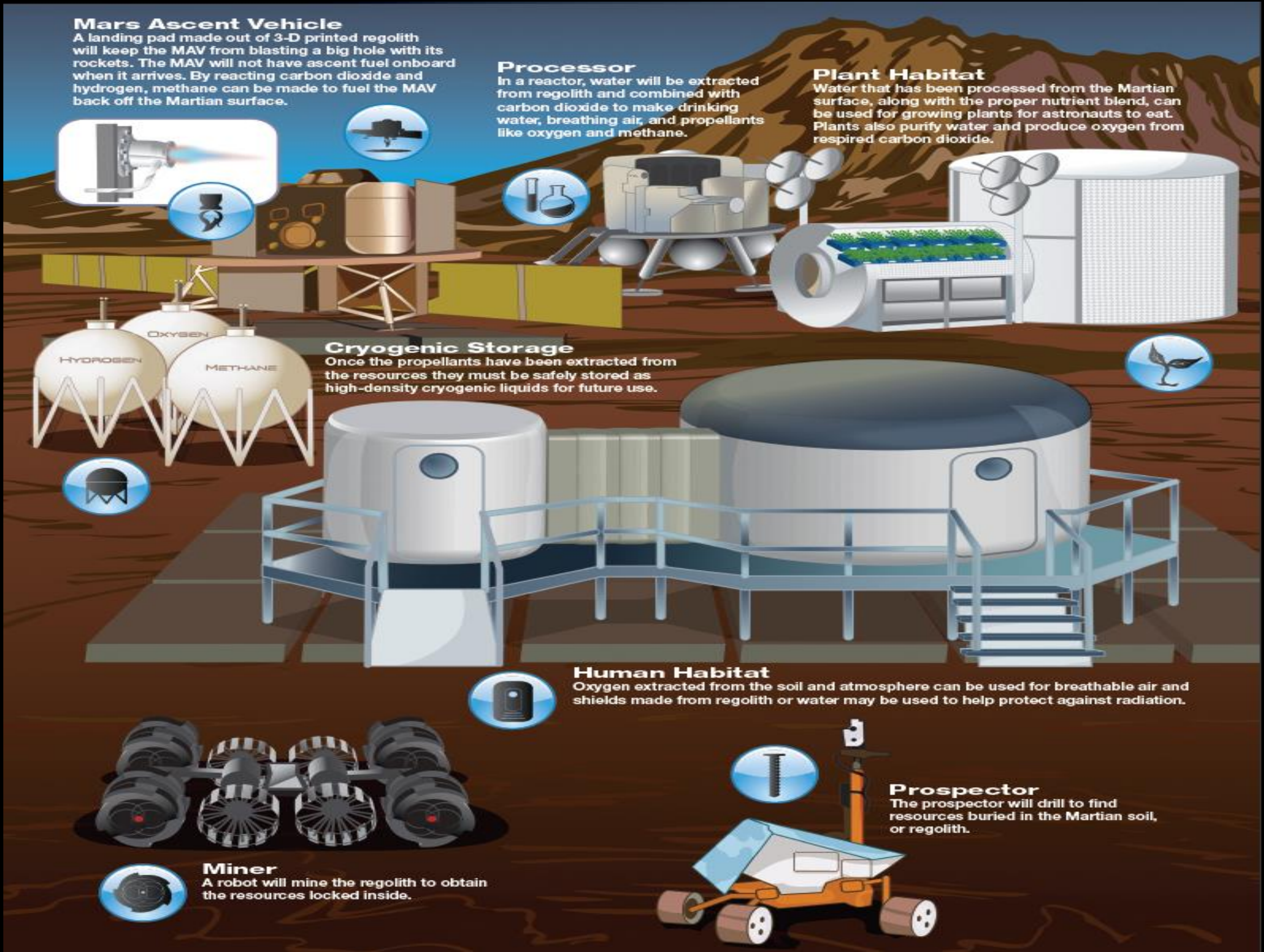


https://nap.nationalacademies.org/catalog/26750/thriving-in-space-ensuring-the-future-of-biological-and-physical

Proposed BLiSS Architecture for Partial Gravity Habitats



NASA Surface Systems



2024 NASA Technology Taxonomy (TX)

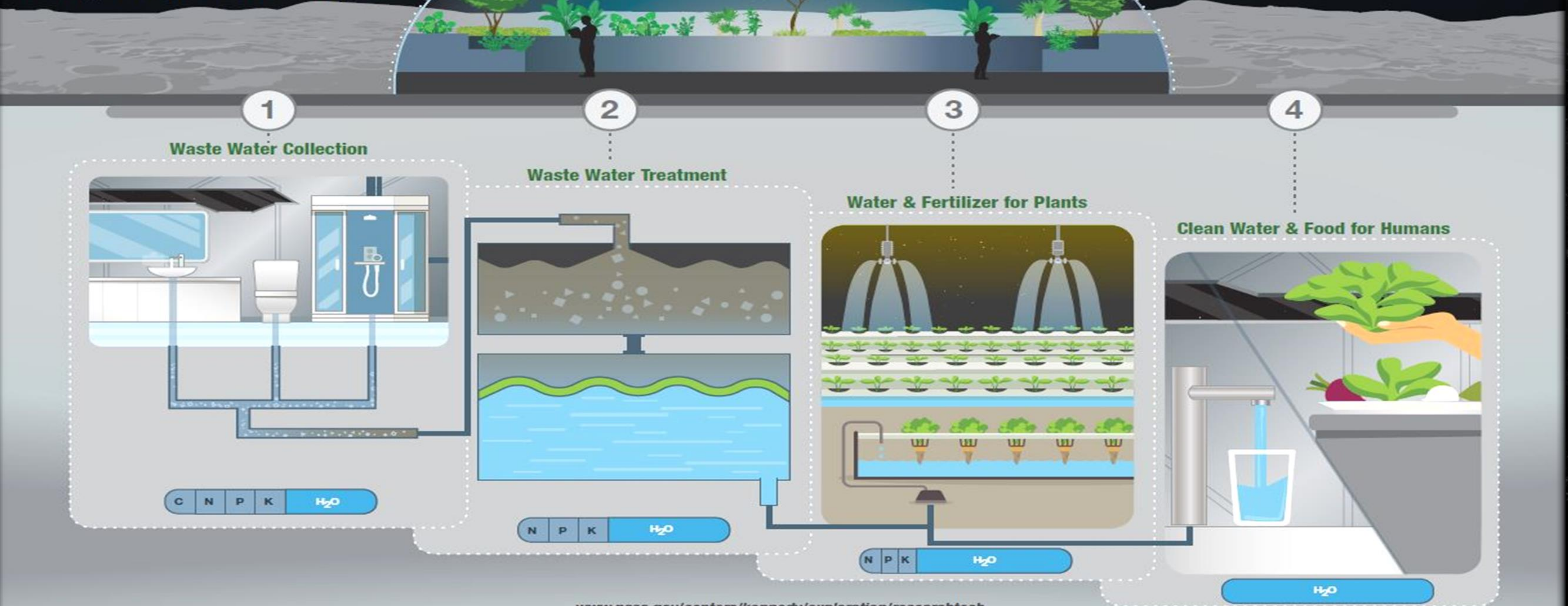
BLiSS Driven Challenges

	Goals	Challenges
TX 6.1.2 Water Recovery and Management	Increase re-useable water recovered from sources	Production of water with minimal expendables and maintenance Tolerance to dormancy Recovery of water from complex mixture of inorganic and organic sources
TX 6.1.3 Waste Management	Enable the utilization of solid and liquid metabolic wastes and trash	Effective separation and treatment of metabolic liquid and solid waste
TX 6.3.5 Food Production, Processing, and Preservation	Reduce food resupply requirement	Sustainable food growth, processing, and preparation

National Aeronautics and Space Administration

WATER: SUSTAINING LIFE ON THE MOON

Sustainably exploring the Moon will require a safe habitat for the crew. To stay on the Moon, new technology is needed to simulate Earth's environment that will reliably regenerate water, air, and food. Smart water recycling within the habitat will treat wastewater, provide necessary fertilizers and water for food crops, and create safe drinking water for our explorers. Proving these technologies will then take us to Mars and beyond.



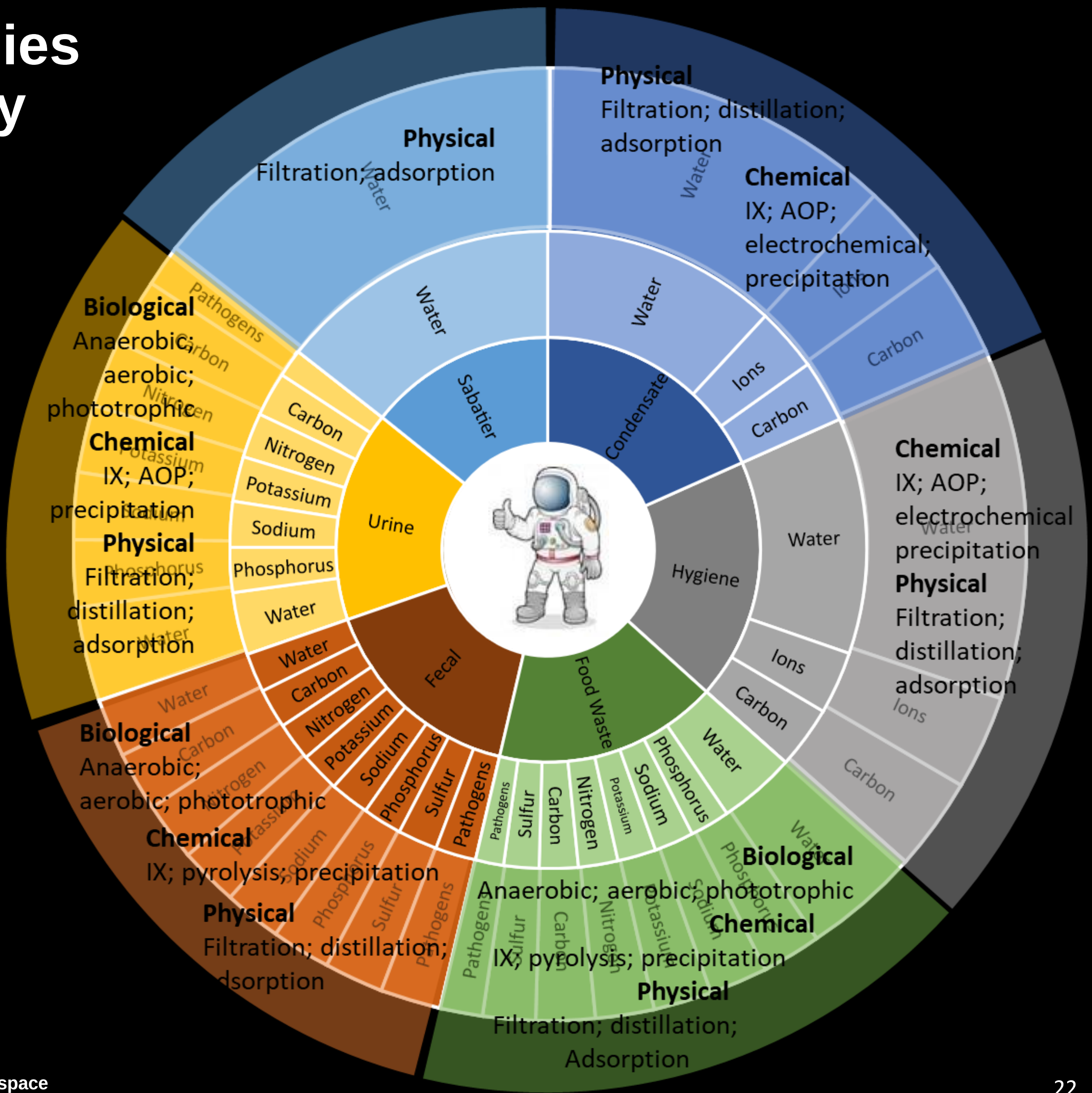
www.nasa.gov/centers/kennedy/exploration/researchtech

www.nasa.gov

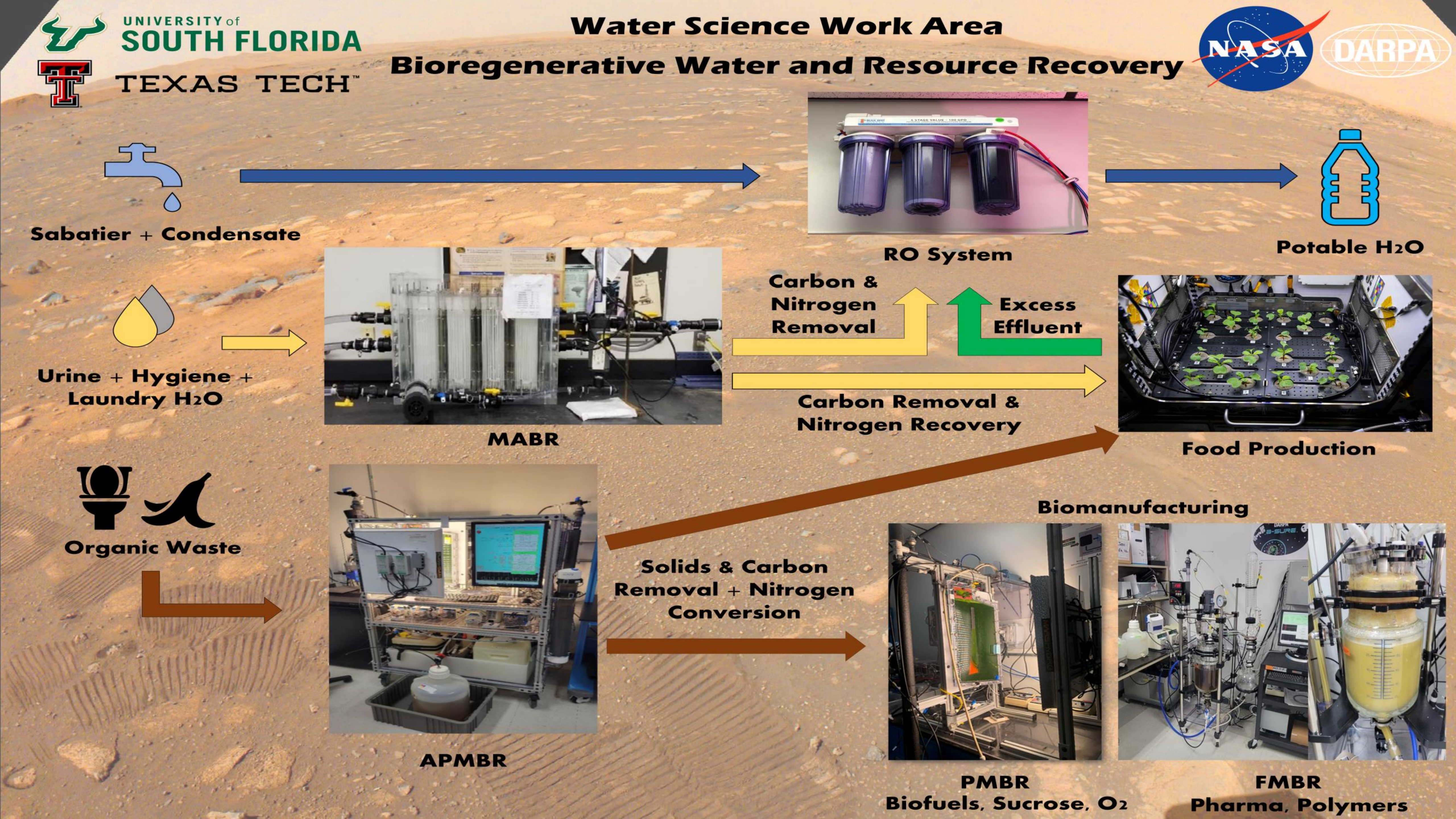
Primary Wastewater Streams: Constituents and potential technologies for treatment and resource recovery

		Constituents by type										Constituents by size		
Process Stream	**Description**	**C**	**N**	**P**	**K**	**S**	**Na**	**Ca**	**Mg**	**Other ions**	**Pathogens**	**Particulate**	**Colloidal**	**Dissolved**
Food Waste	High content of complex particulate OM, fibers, COD	4	3	3	2	3	2	2	2	2	2	4	4	3
Fecal	High content of complex particulate OM, fibers, COD, pathogens	4	3	3	2	3	2	2	2	2	4	4	4	3
Urine	Mod COD, organic N, urea, ammonium, phosphate, other salts	3	4	4	4	2	3	2	2	3	2	0	2	4
Hygiene	Low COD, constituents from skin and body secretions, environmental contaminants	2	2	1	1	1	2	1	1	2	2	2	2	3
Humidity	Mostly pure condensate, with contaminants from air and surfaces	1	1	0	1	0	1	0	0	1	1	0	0	2
Sabatier	Pure, potentially aggressive, can use for dilution, regeneration, backwash	0	0	0	0	0	0	0	0	1	1	0	0	0

Notes: First two rows denote streams currently not addressed by technologies on ISS
Relative concentration: Very High (4) High (3), Medium (2), Low (1), Trace (0)
COD = chemical oxygen demand

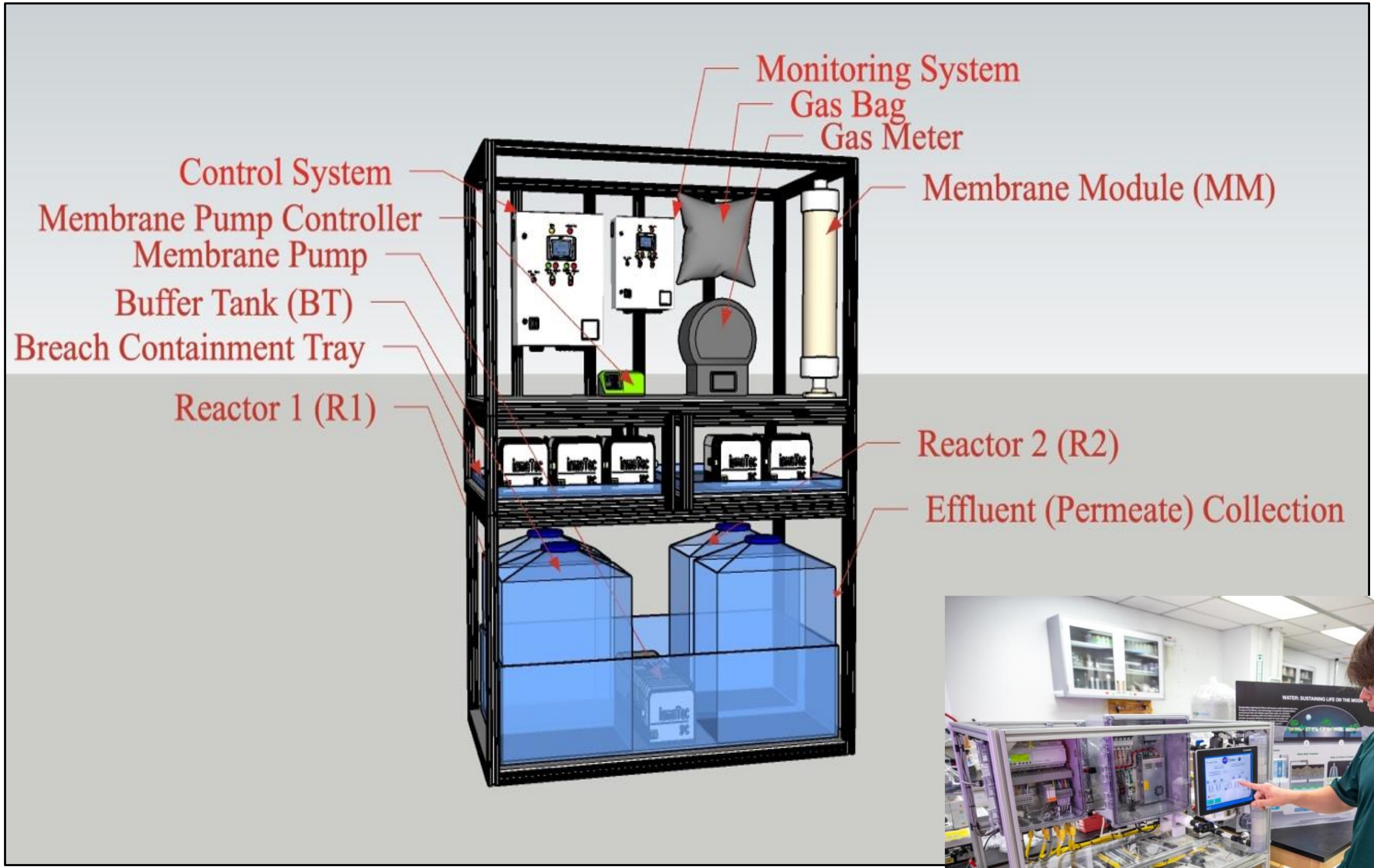


Source: Pickett, M., L. Roberson, J. Calabria, T. Bullard, G. Turner, D. Yeh. 2020. Regenerative water purification for space applications: Needs, challenges, and technologies towards 'closing the loop'. *Life Science in Space Research, 24: 64-82.*



UNIVERSITY of SOUTH FLORIDA
TEXAS TECH
Water Science Work Area
Bioregenerative Water and Resource Recovery
NASA
DARPA
Sabatier + Condensate
RO System
Potable H_2O
Urine + Hygiene + Laundry H_2O
MABR
Carbon & Nitrogen Removal
Excess Effluent
Carbon Removal & Nitrogen Recovery
Food Production
Organic Waste
APMBR
Solids & Carbon Removal + Nitrogen Conversion
Biomanufacturing
PMBR
Biofuels, Sucrose, O_2
FMBR
Pharma, Polymers

THE ANAEROBIC MEMBRANE BIOREACTOR



Bullard, Roberson, Yeh, et. al. "A Prototype Early Planetary Organic Processor Assembly (OPA) Based on Dual-Stage Anaerobic Membrane Bioreactor (AnMBR) for Fecal and Food Waste Treatment and Resource Recovery."2020. ICES-2020-323.

THE ANAEROBIC MEMBRANE BIOREACTOR

Anaerobic Microbiome

"Wet combustion"

Passive breakdown of particulate organic matter and liberating nutrients

\+

Ultrafiltration Membrane

Solids /liquid separation (0.03 um)

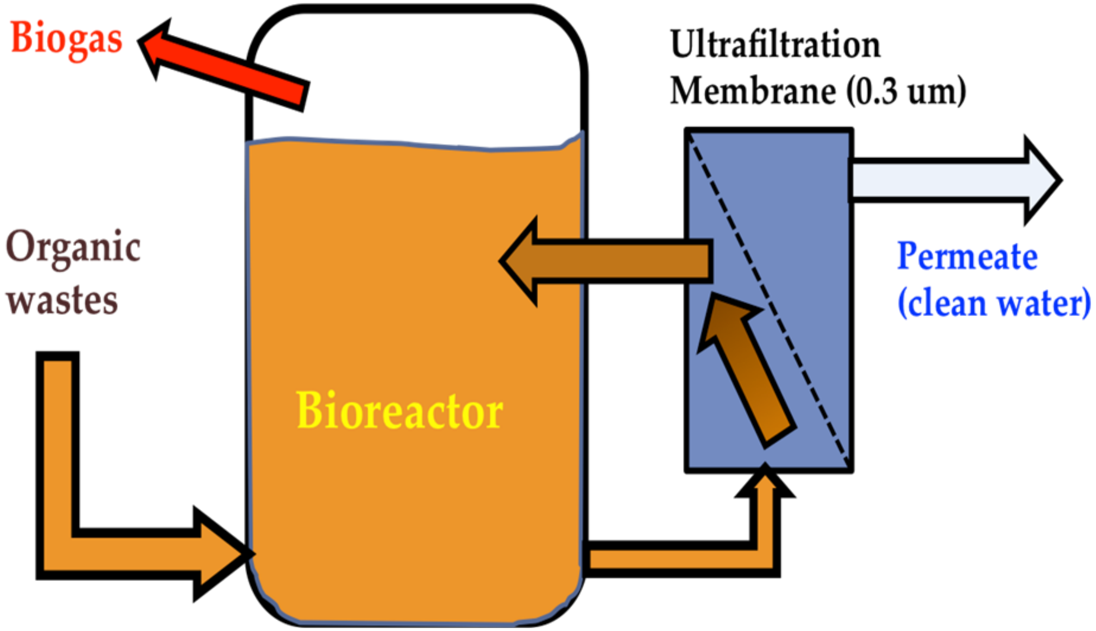
Consists of multiple tubular (5.2 mm diameter), ultrafiltration, PVDF membranes, with an average pore size of 0.03 µm.

=

AnMBR

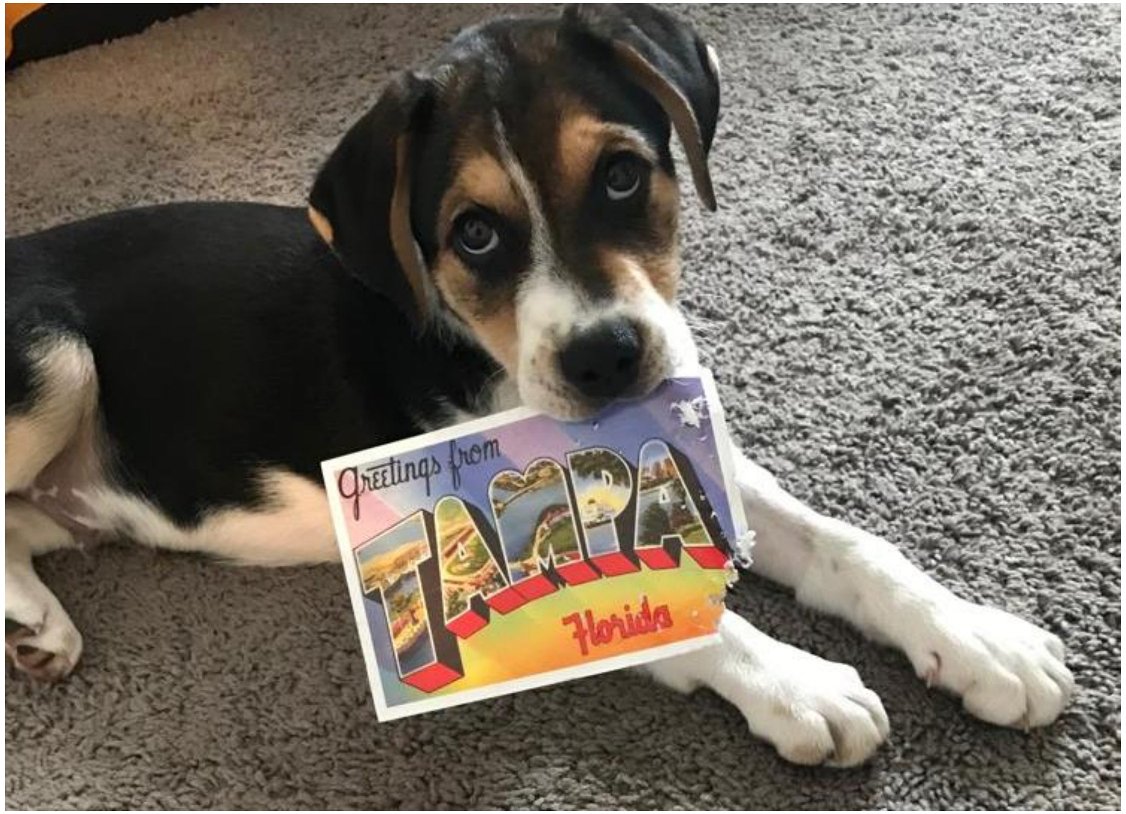
Removes solids and organic carbon

Recover nutrients already in a liquid form



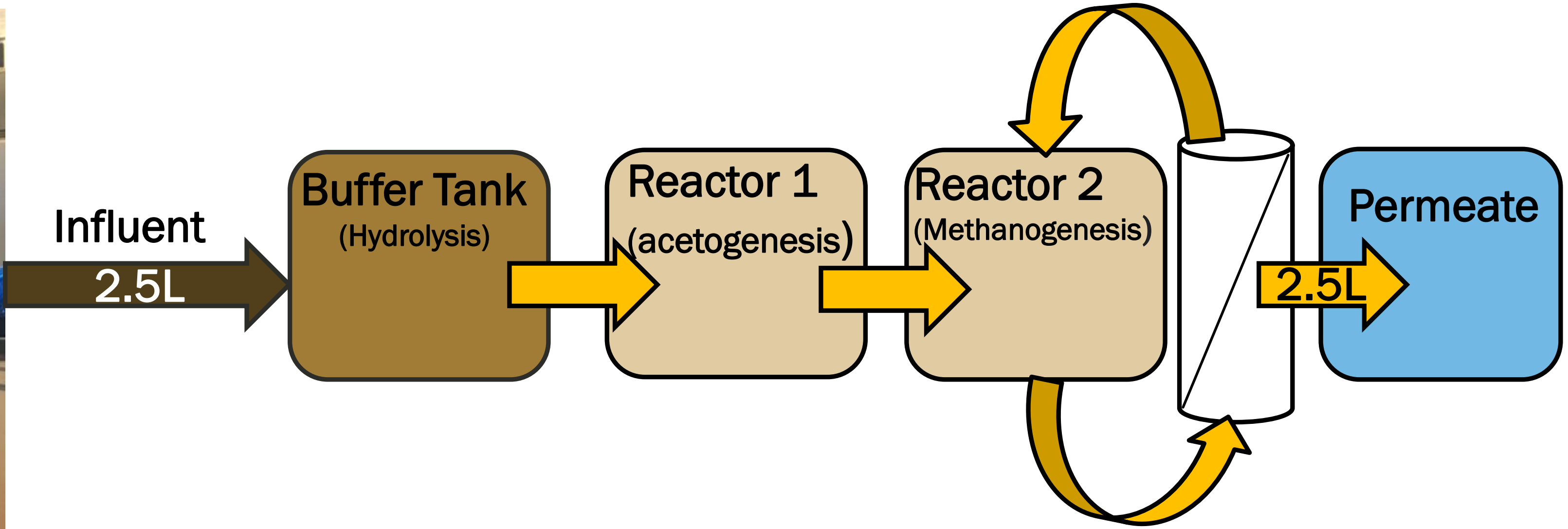
ANMBR TREATMENT RATE

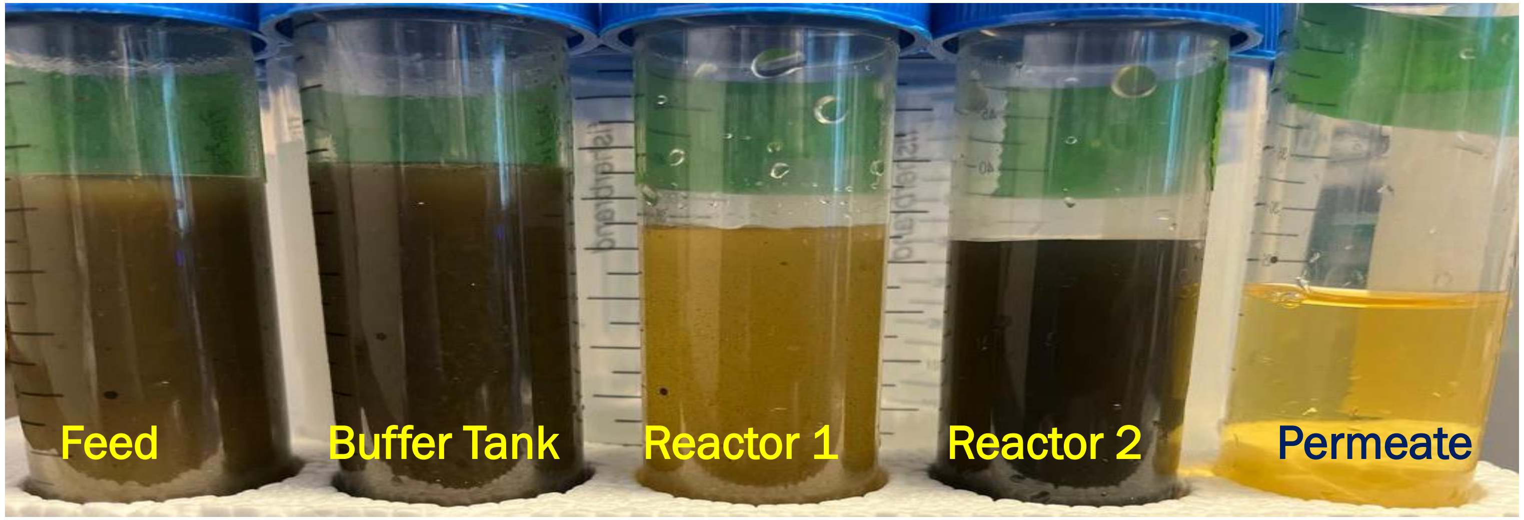
- 2.5 L/day is the estimated volume produced by 4 crew members (waste + flush)*
  - 0.132 kg/CM-day (0.032 kg/CM-day dry weight) and accounting for 0.5 kg/CM day of flush water*
- Input volume = output volume. 2.5 L/day of product water.
- Product water (permeate) a nutrient-rich liquid byproduct that can be used downstream
  - Algae photobioreactor
  - Hydroponics
  - Further polishing



*Pickett, M.; Roberson, L.; Calabria, J.; Bullard, T.; Turner, G.; Yeh, D., Regenerative Water Purification for Space Applications: Needs, Challenges, and Technologies to 'Close the Loop'. Life Sciences in Space Research 2019.
NASA Artemis. https://www.nasa.gov/specials/artemis/

ANMBR PROCESS FLOW



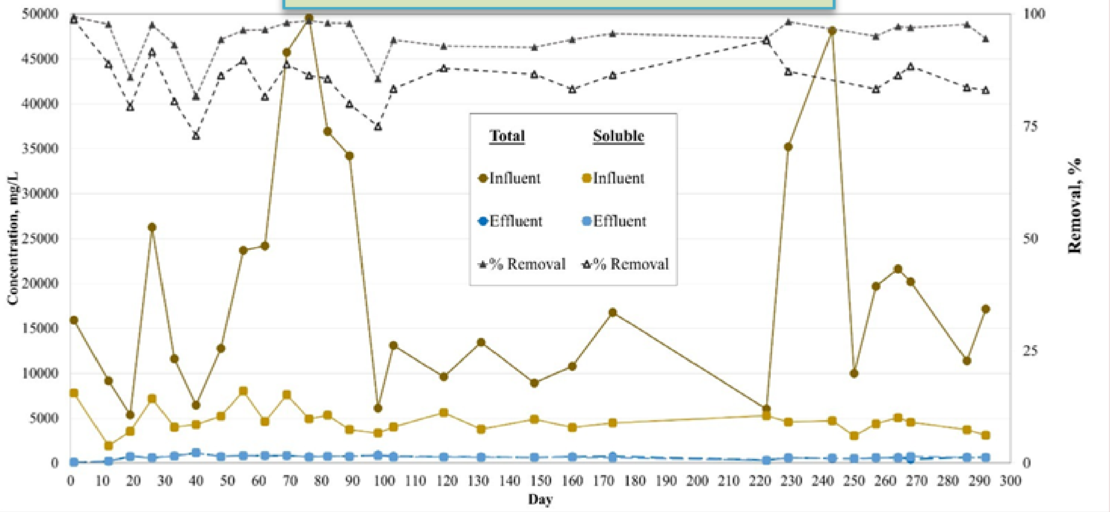


ANMBR DATA SETS

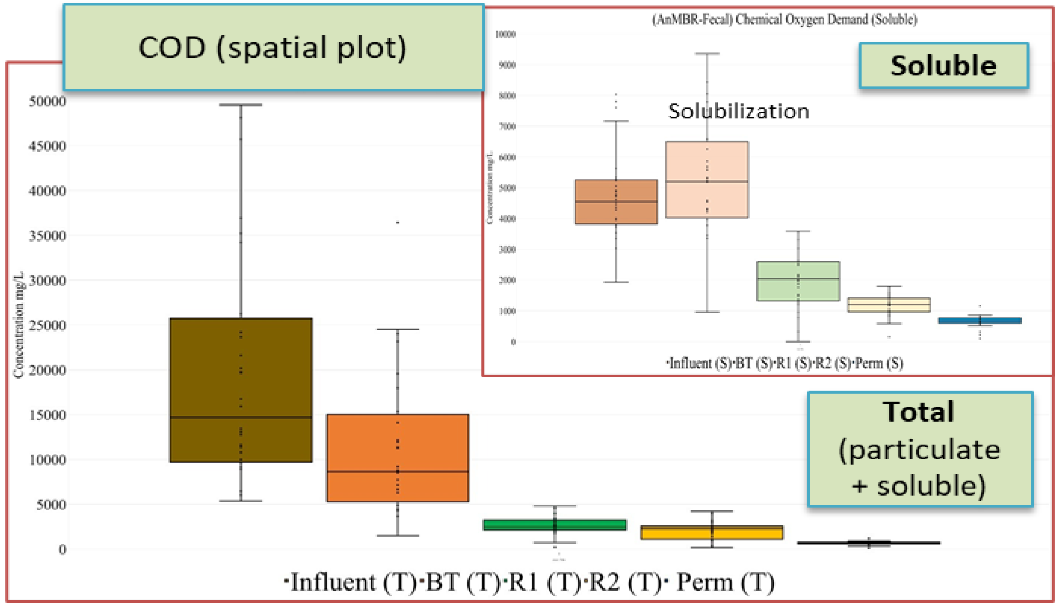
AnMBR 1 (influent: canine fecal waste, 5%)

Smith, Roberson, Yeh, et. al. "Management of fecal and food waste utilizing a hybrid anaerobic membrane bioreactor. International Conference on Environmental Systems." ICES-2022-272

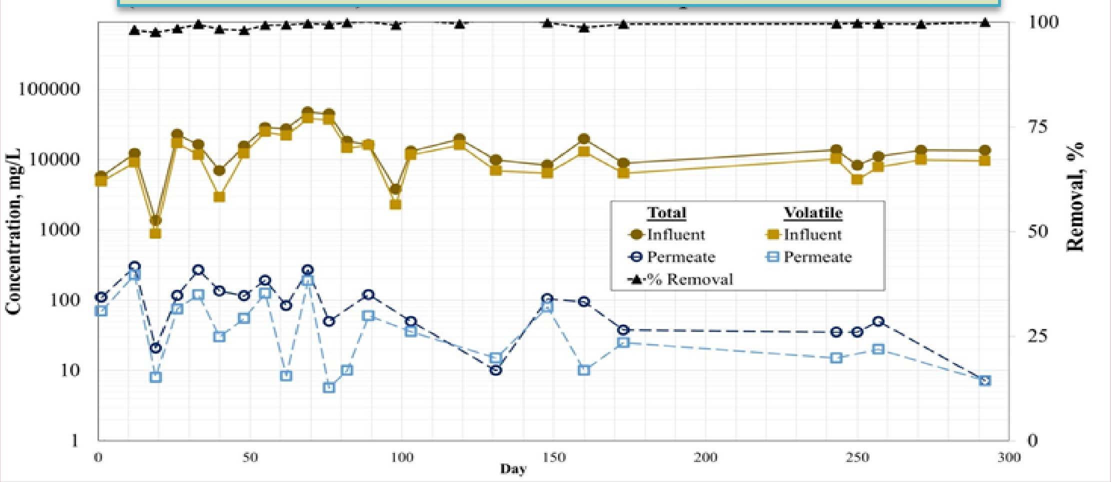
COD (time series)



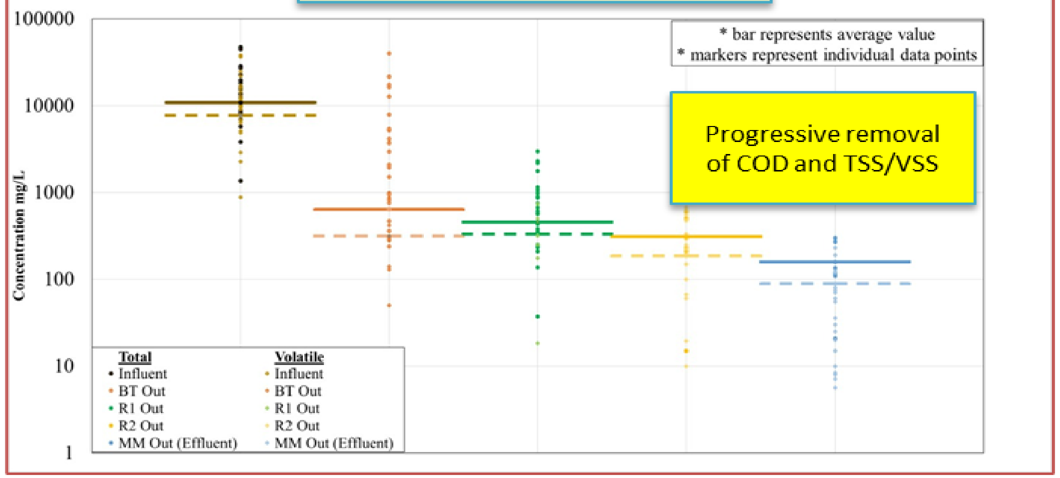
COD (spatial plot)



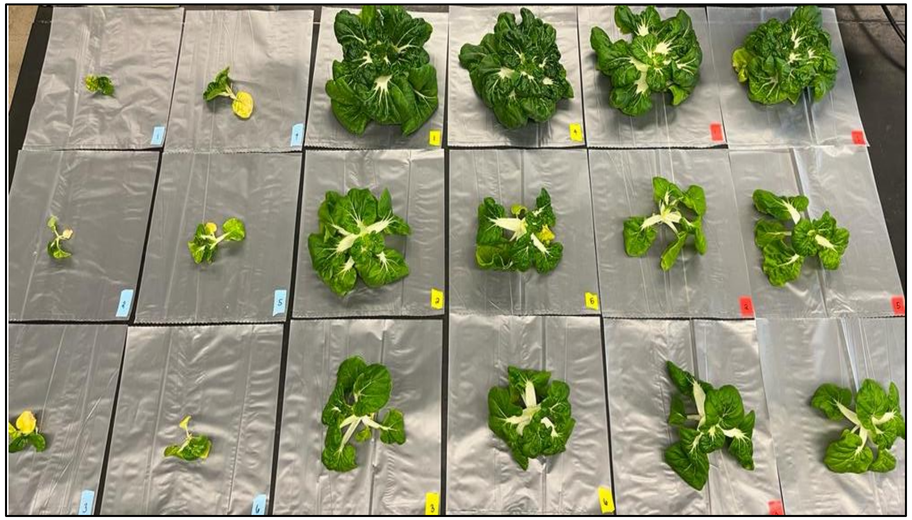
TSS/VSS (time series)

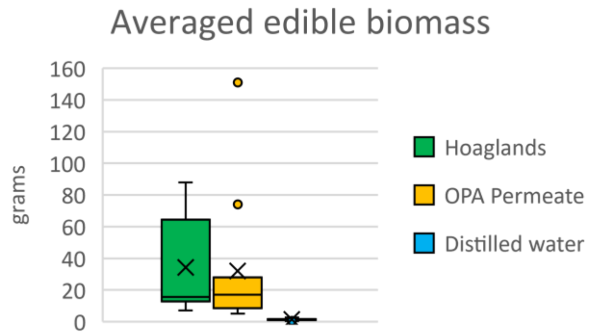


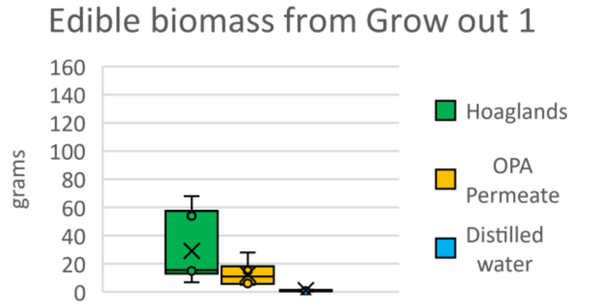
TSS/VSS (spatial plot)

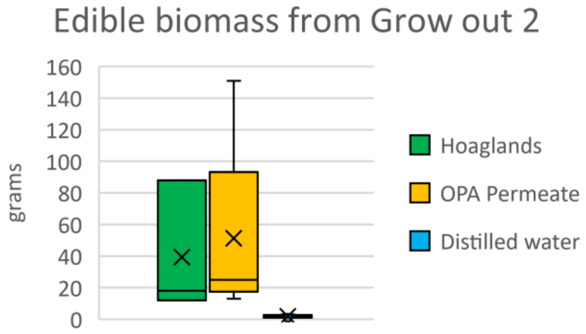


ANMBR HYDROPONIC TEST

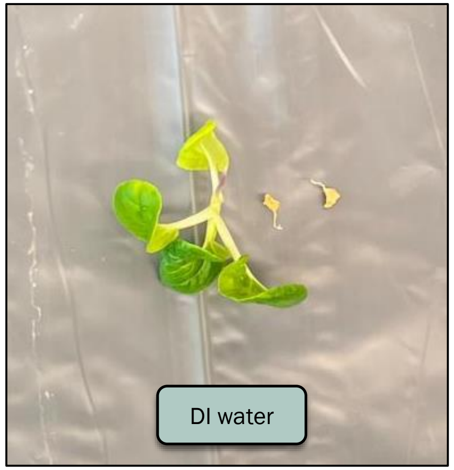






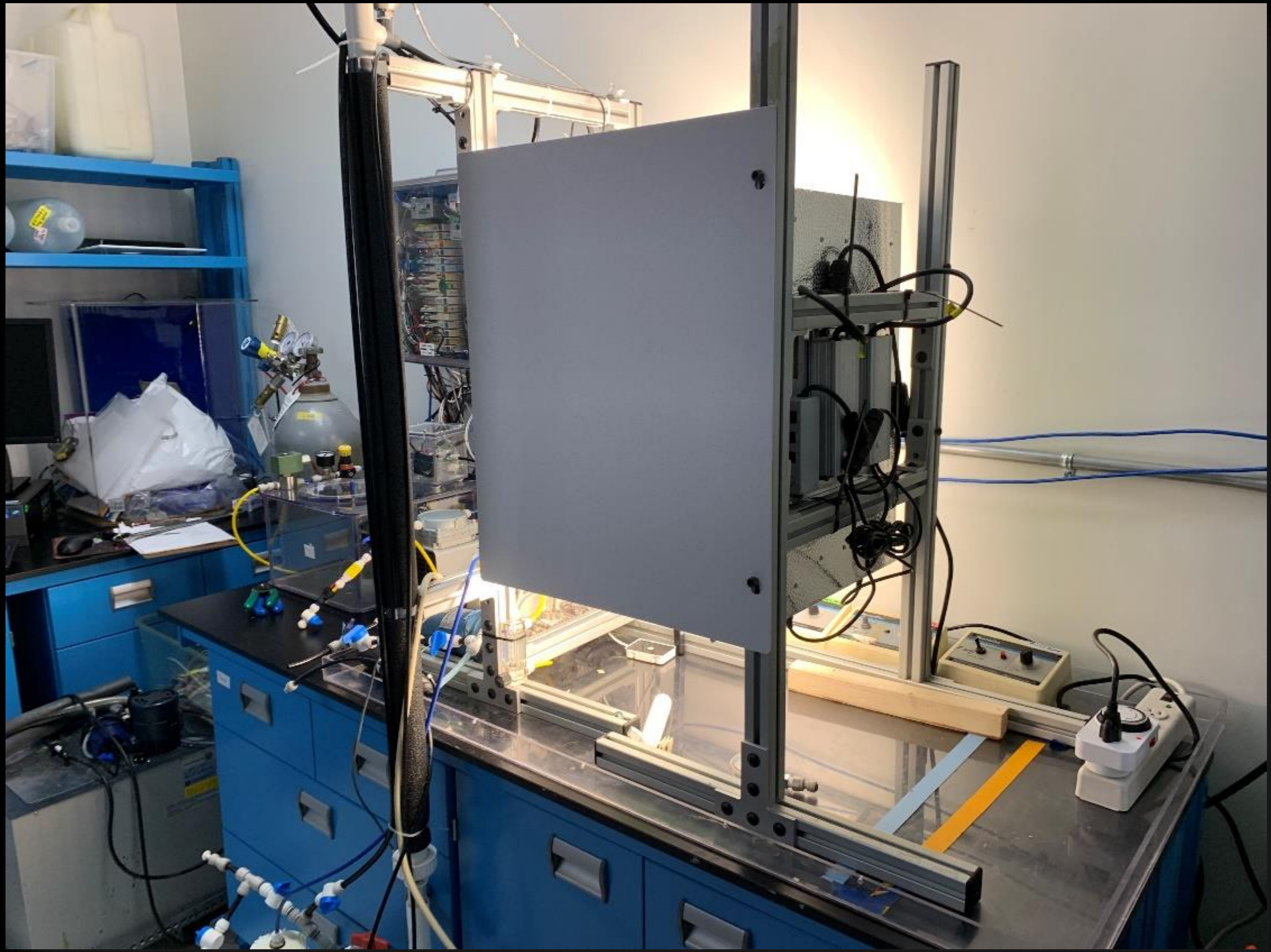


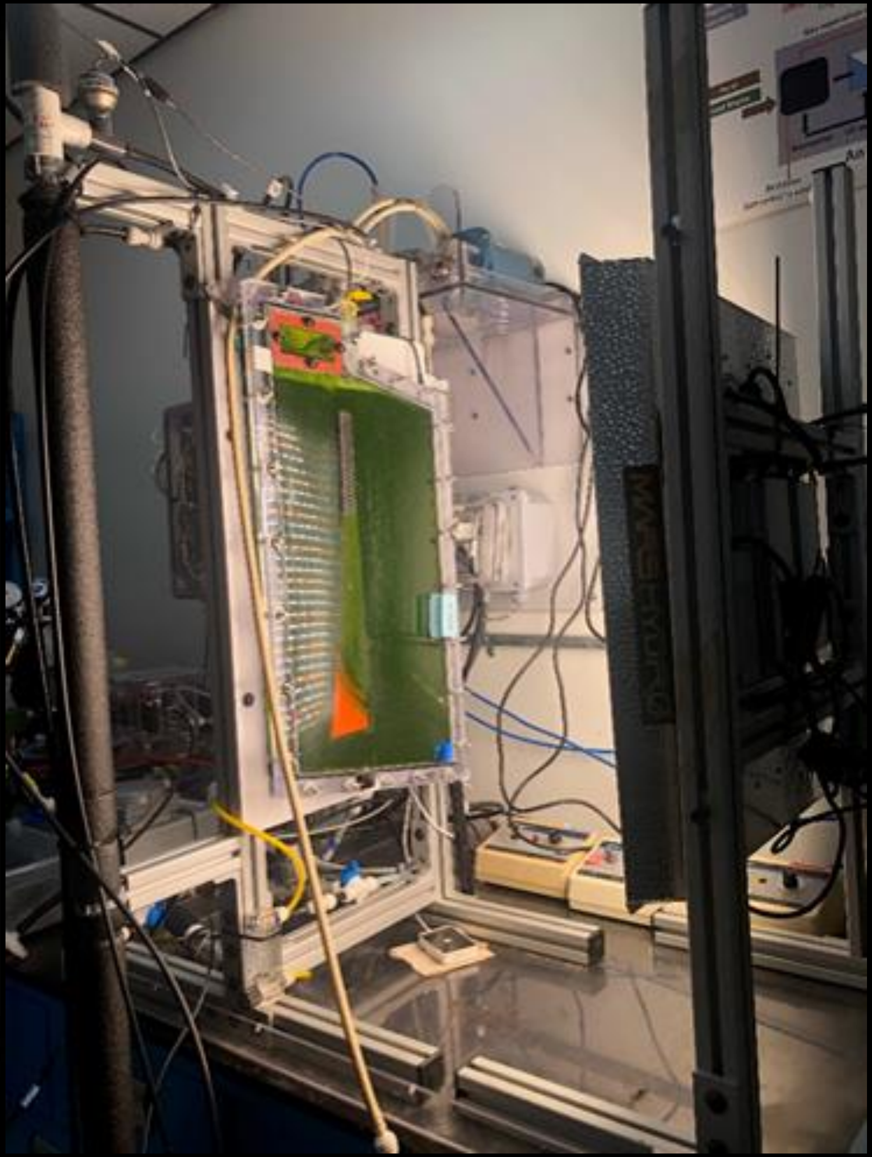
Recap:
AnMBR1 permeate was used in comparison to ½ concentration Hoagland's nutrient solution and distilled water in hydroponic Nutrient Film towers using dwarf Pak Choi, both grow outs spanning 40 days from germination to harvest.



Smith, Bullard, Saetta, Yeh, Fischer, Roberson, et. al. "Using Effluent from a Hybrid Anaerobic Membrane Bioreactor Treating Fecal Waste for Fertigation of Pak Choi". ICES-2023-263.
Smith, Roberson, Yeh, et. al. "Management of fecal and food waste utilizing a hybrid anaerobic membrane bioreactor. International Conference on Environmental Systems." ICES-2022-272

Photo Membrane Bioreactors for Nitrogen Balance

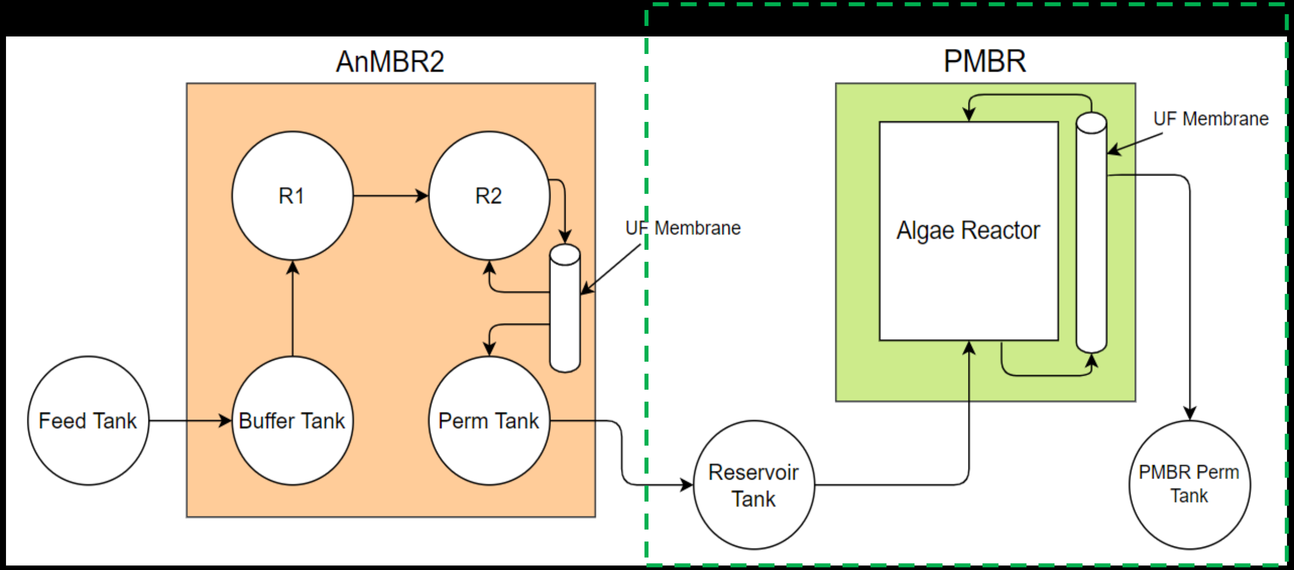


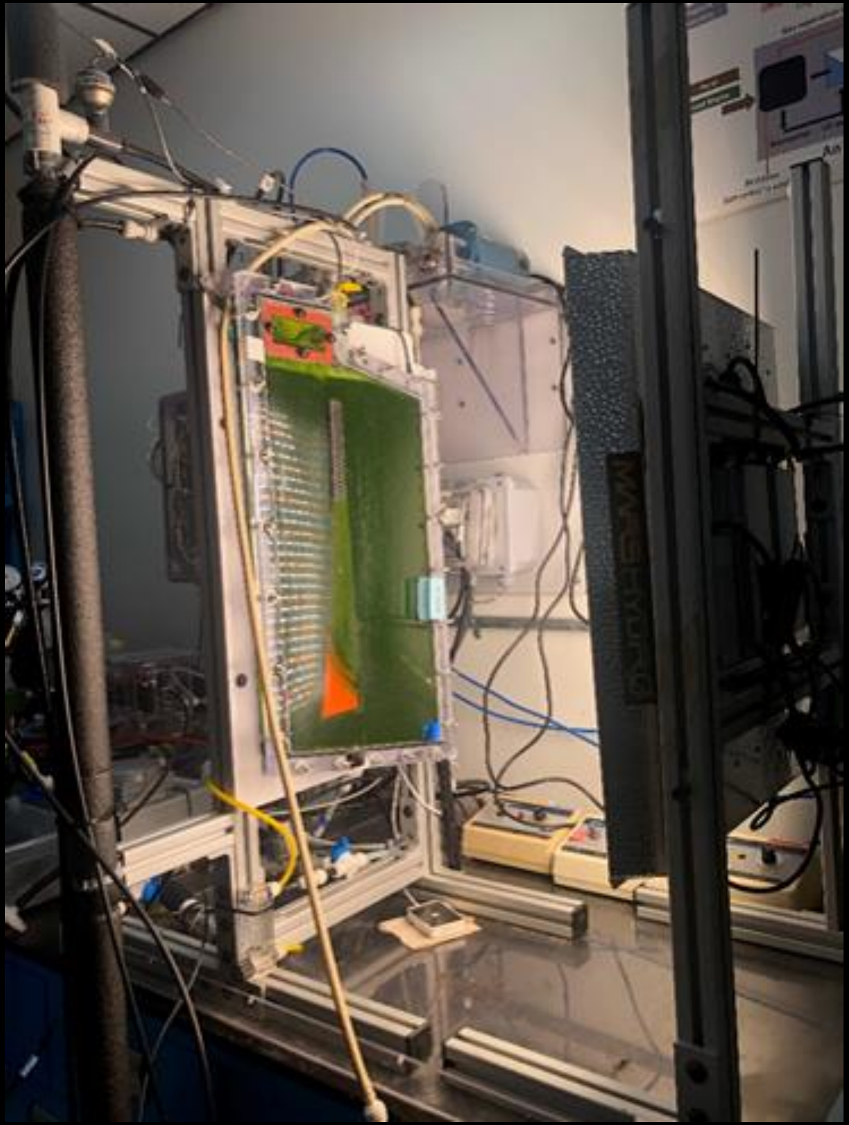


Saetta, Roberson, Yeh, et. al. “Design and operation of Photomembrane Bioreactor (PMBR) to balance nitrogen in high-ammonia wastewater treatment effluents. International Conference on Environmental Systems.” ICES-2022-202.

Photo Membrane Bioreactors for Nitrogen Balance

- **GOAL: Use the algae/bacteria community to balance the nitrogen cycle in the AnMBR effluent.**
- **The PMBR nitrifies the ammonia in the AnMBR effluent into nitrate, a more suitable form of plant fertilizer.**



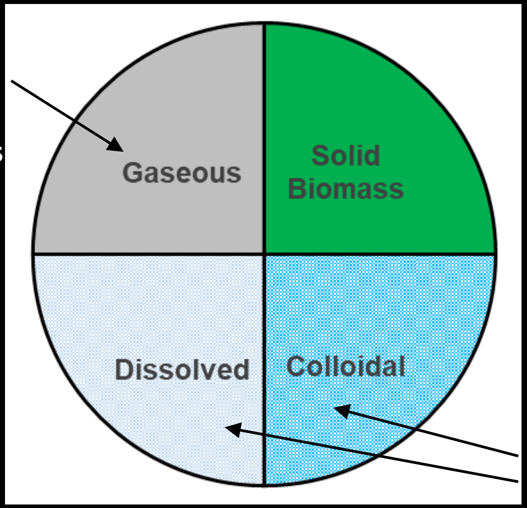


Sampling Locations
Influent (Reservoir Tank, RT)
PMBR Contents
PMBR Permeate

Measured Parameters	
Optical Density	Total Organic Carbon
Ammonia	Total Suspended Solids
Nitrate	Reservoir tank pH
Nitrite	pH/CO_2/DO on-line sensors
Total Nitrogen	

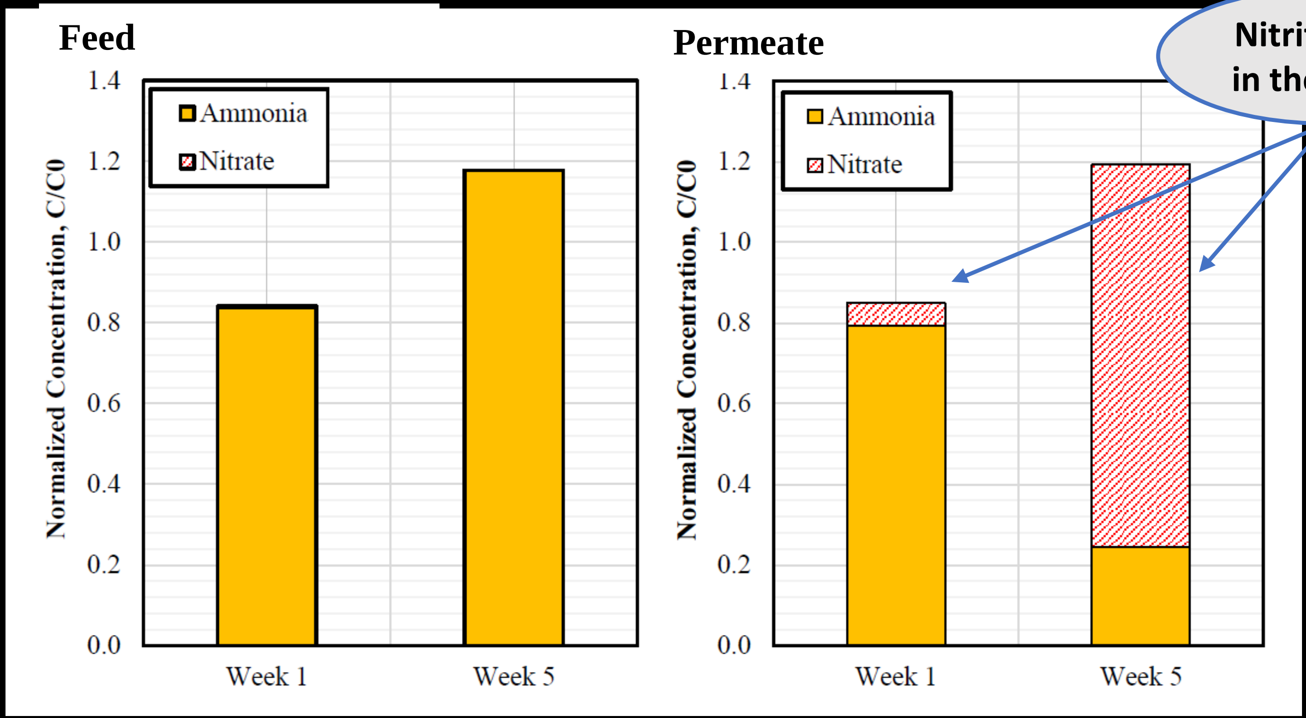
PMBR for Nitrogen Balance

At pH < 8, gaseous nitrogen is assumed negligible



Liquid phase in PMBR, can be ammonia, nitrate, nitrite, or organic nitrogen

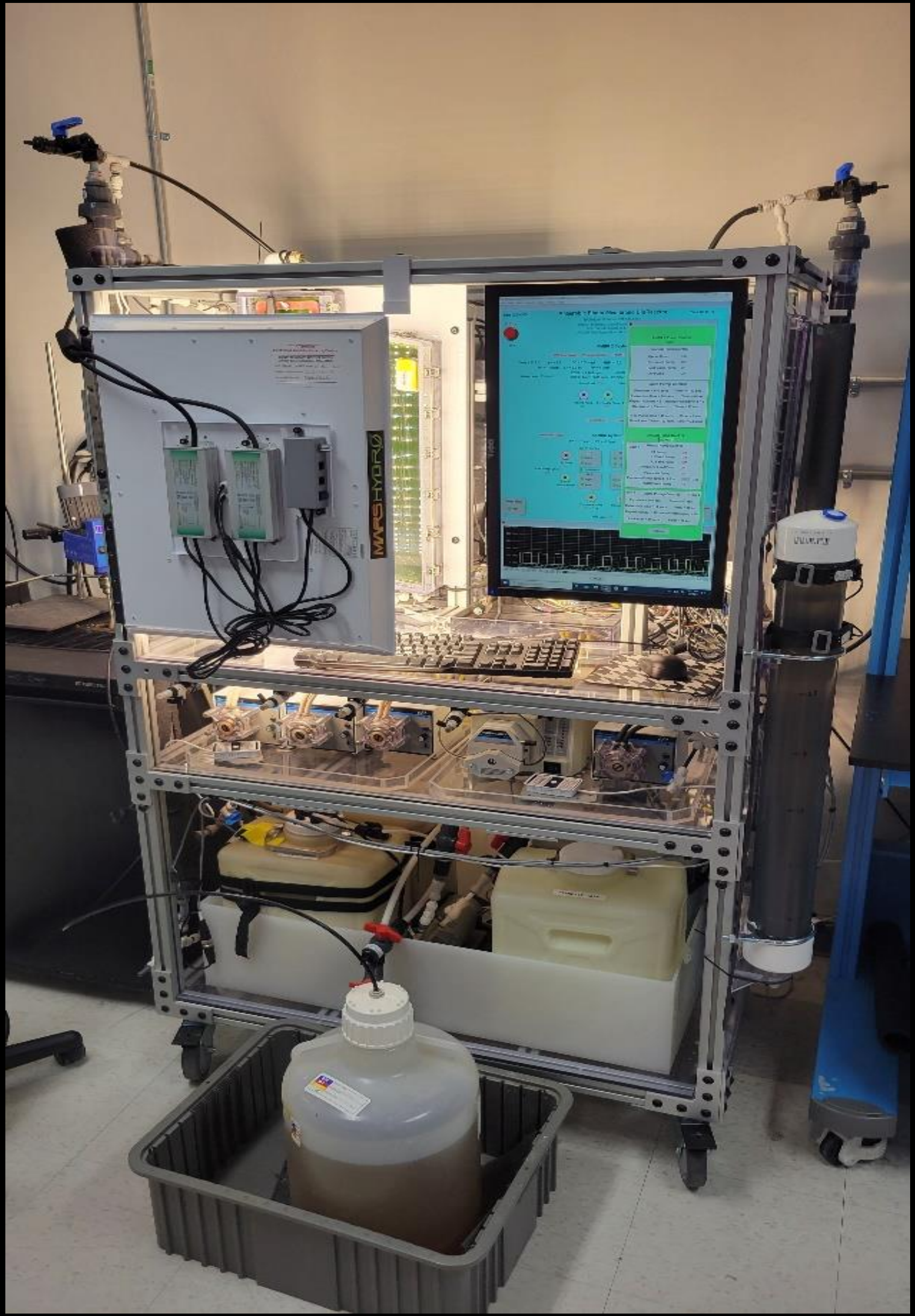
Daniella, Riley, and Jason in front of PMBR



Nitrification in the PMBR

Saetta, Roberson, Yeh, et. al. "Design and operation of Photomembrane Bioreactor (PMBR) to balance nitrogen in high-ammonia wastewater treatment effluents. International Conference on Environmental Systems." ICES-2022-202.

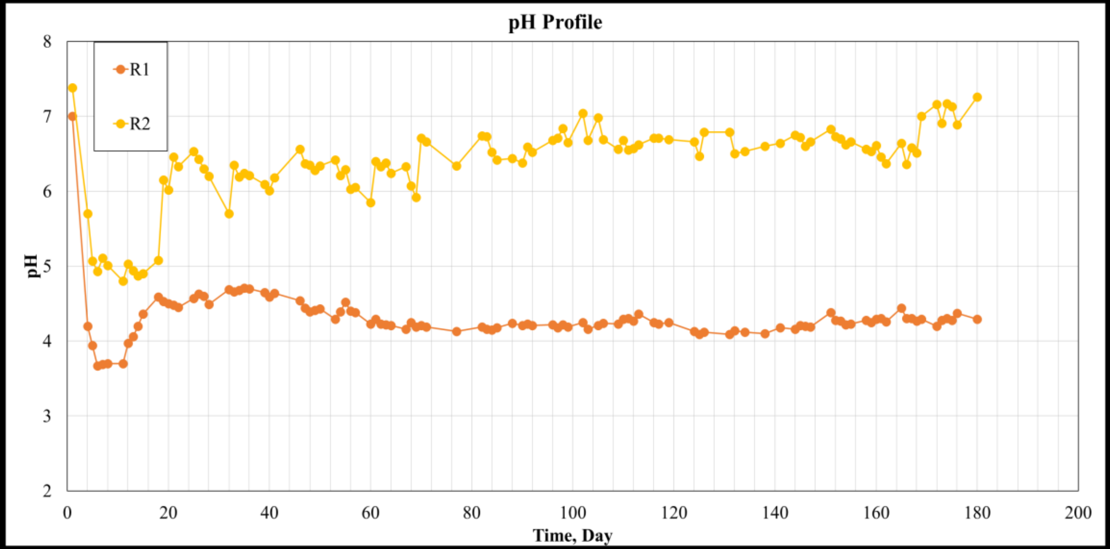
APMBR Treatment Process

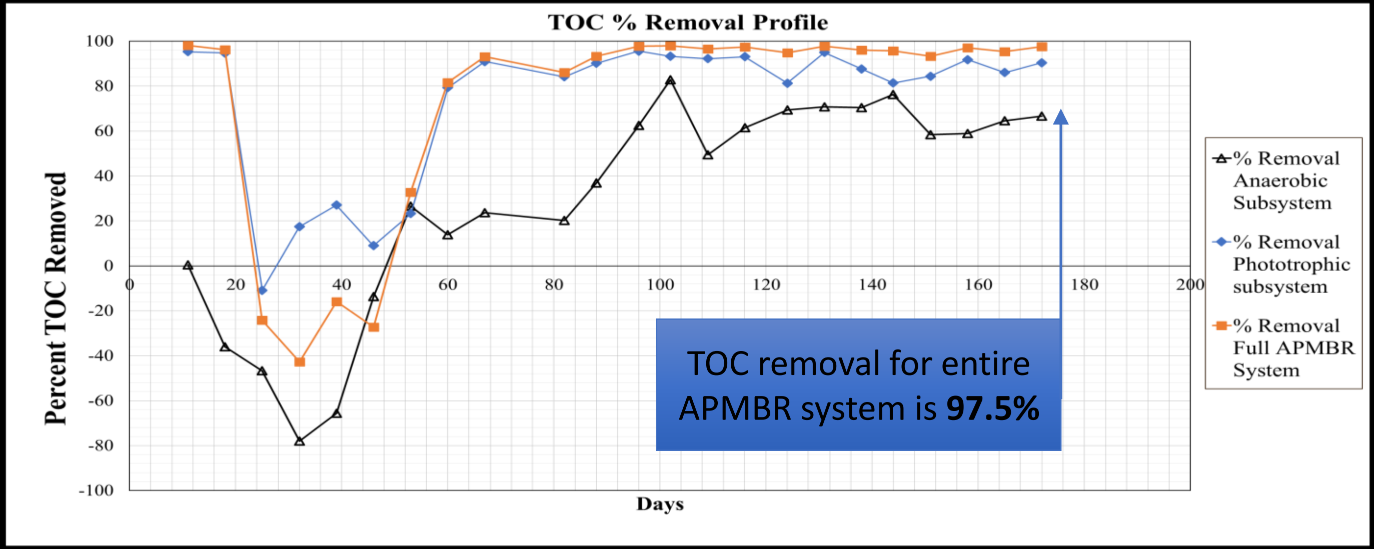


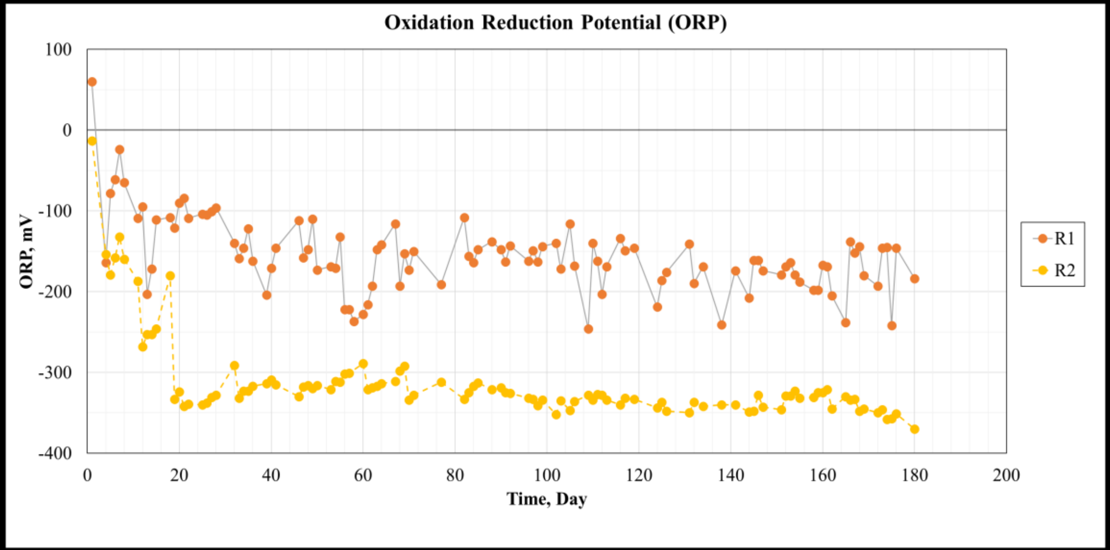
- APMBR has operated over a year using simulant feedstock.
- C/N Ratio of AnMBR perm remains close to 1 indicating proper microbial processing.

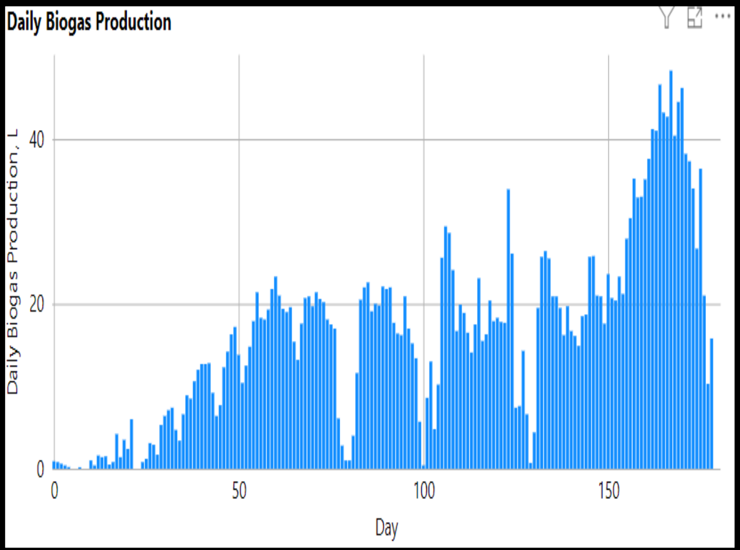
FIscher, Yeh, Roberson, et. al. “Unleashing the Power of Anaerobic–phototrophic Membrane Bioreactors for Sustainable Bioregenerative Life Support .” ICES-2024-347

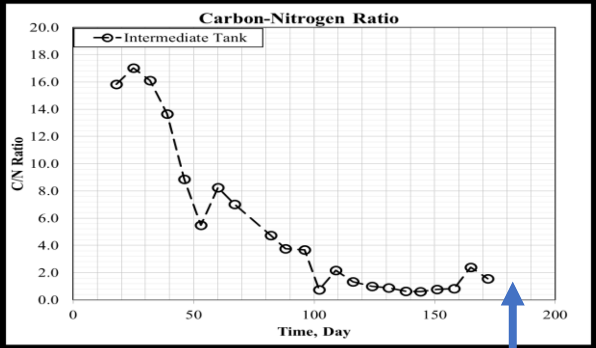
APMBR Treatment Data







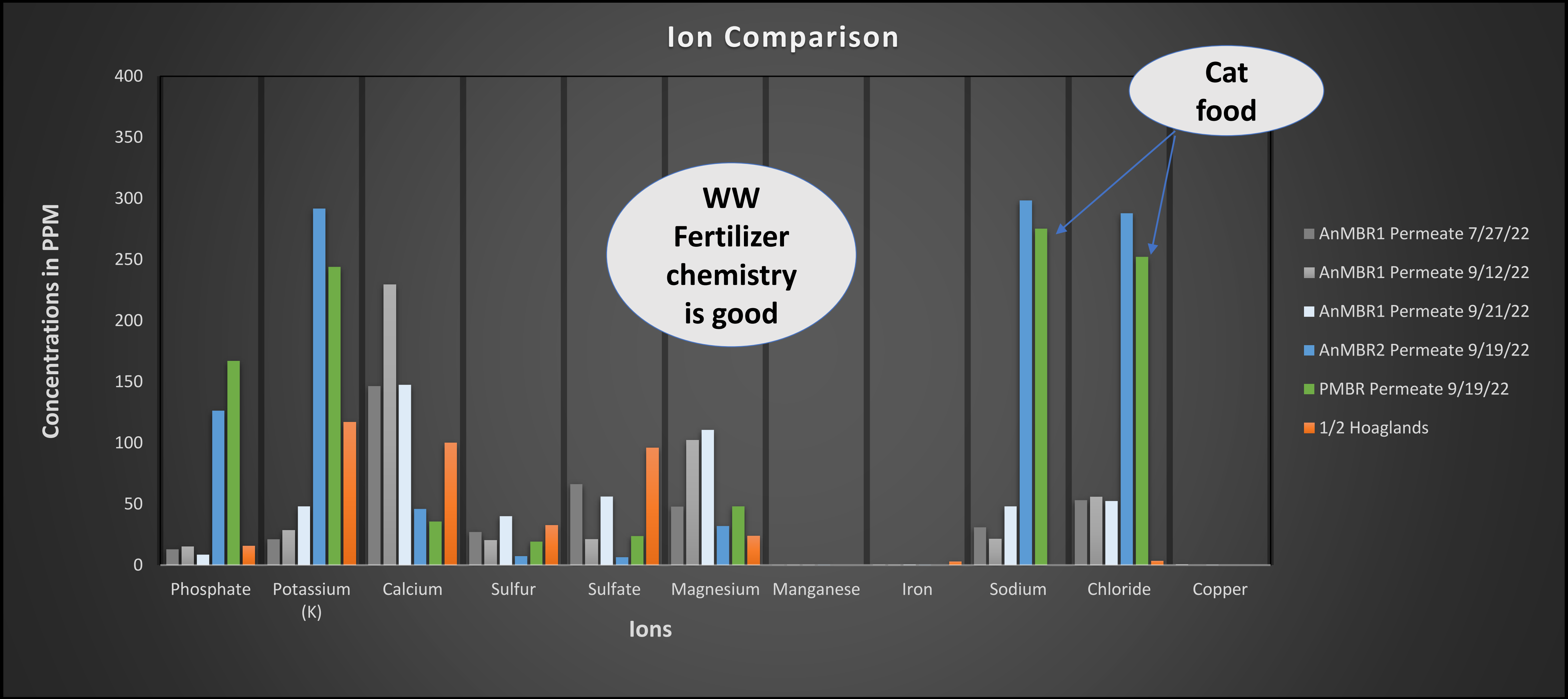




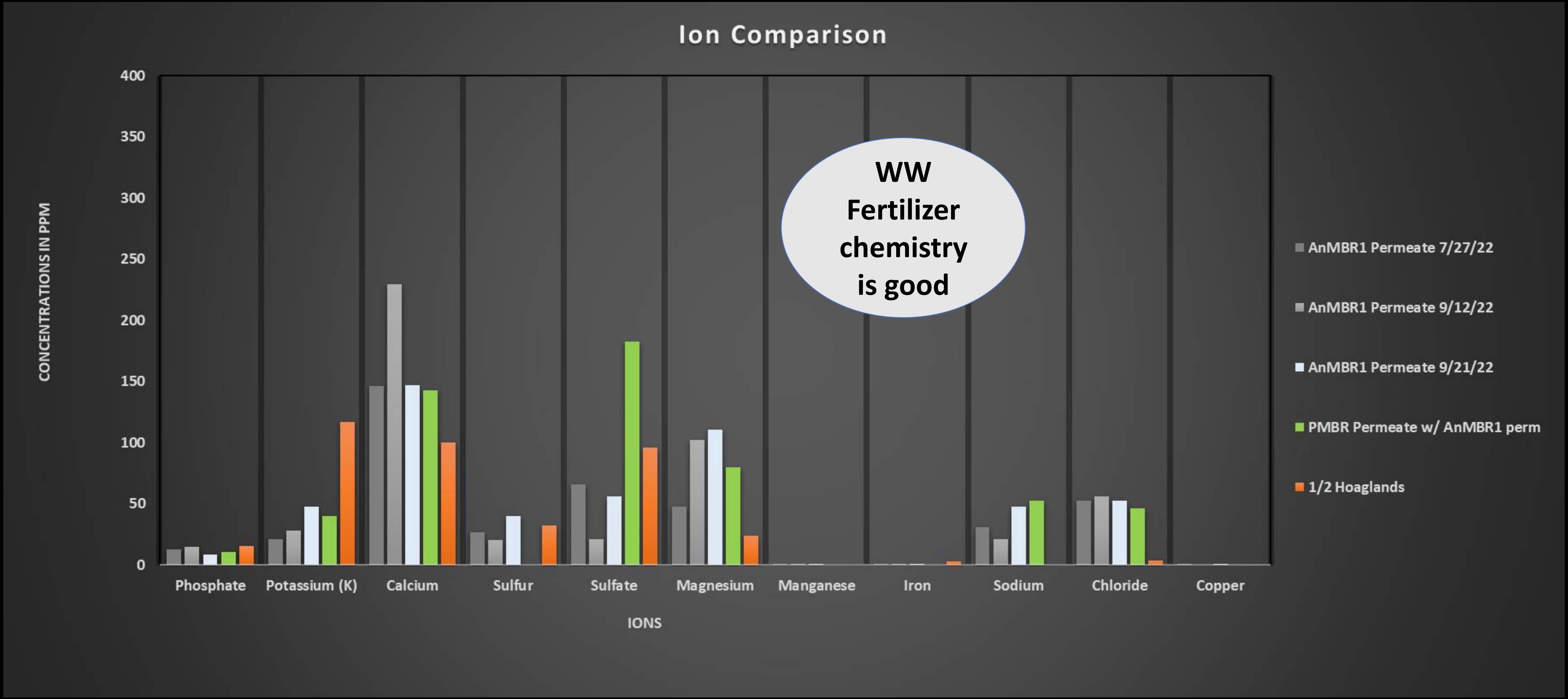
C/N Ratio of permeate leaving the anaerobic subsystem is **1.57**

Fischer, Yeh, Roberson, et. al. "Unleashing the Power of Anaerobic–phototrophic Membrane Bioreactors for Sustainable Bioregenerative Life Support ." ICES-2024-347

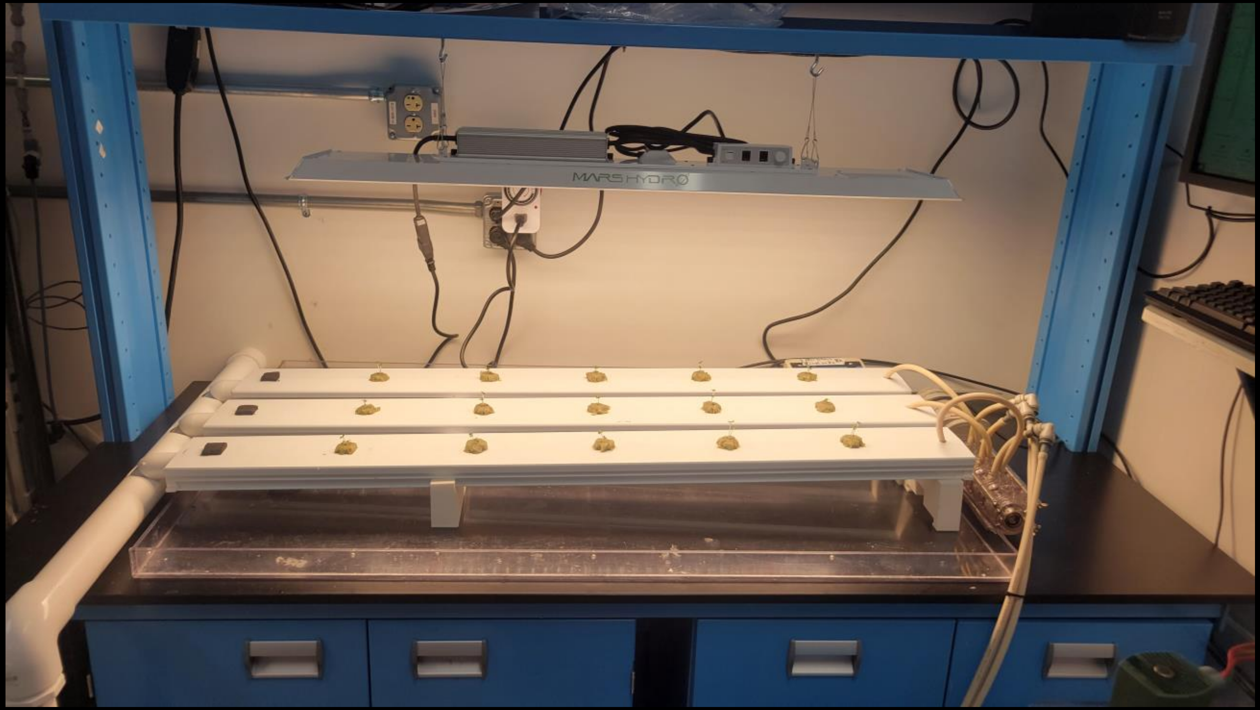
Biomanufacturing Wastewater into Fertilizer – AnMBR2

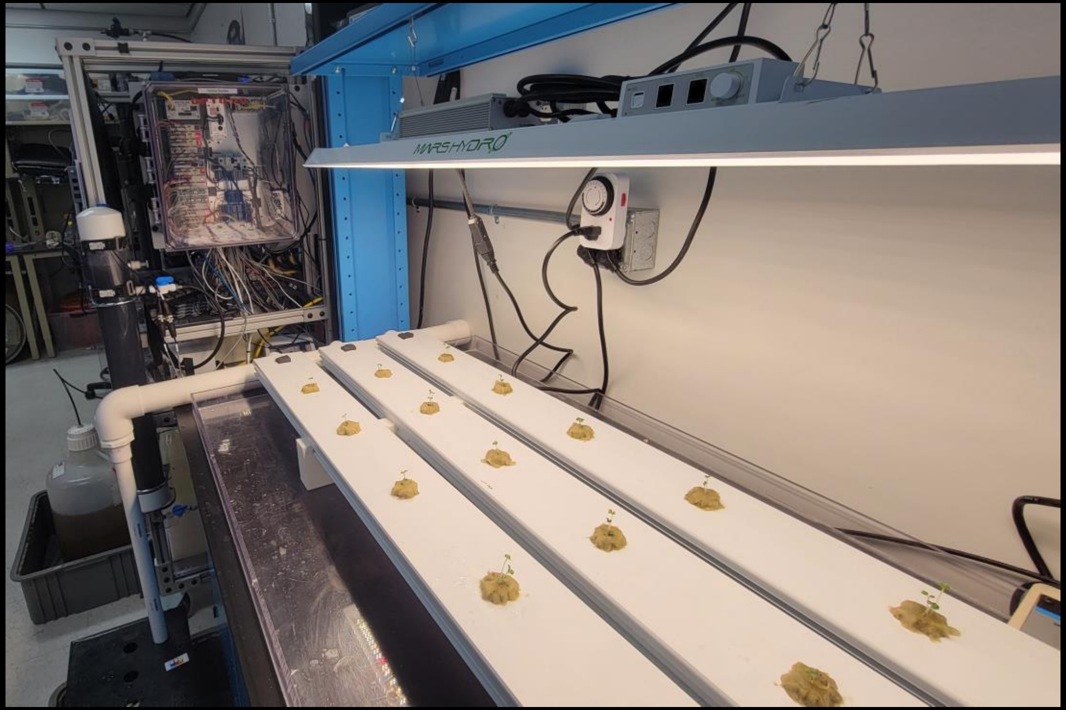


Biomanufacturing Wastewater into Fertilizer – AnMBR1



APMBR + Hydroponics



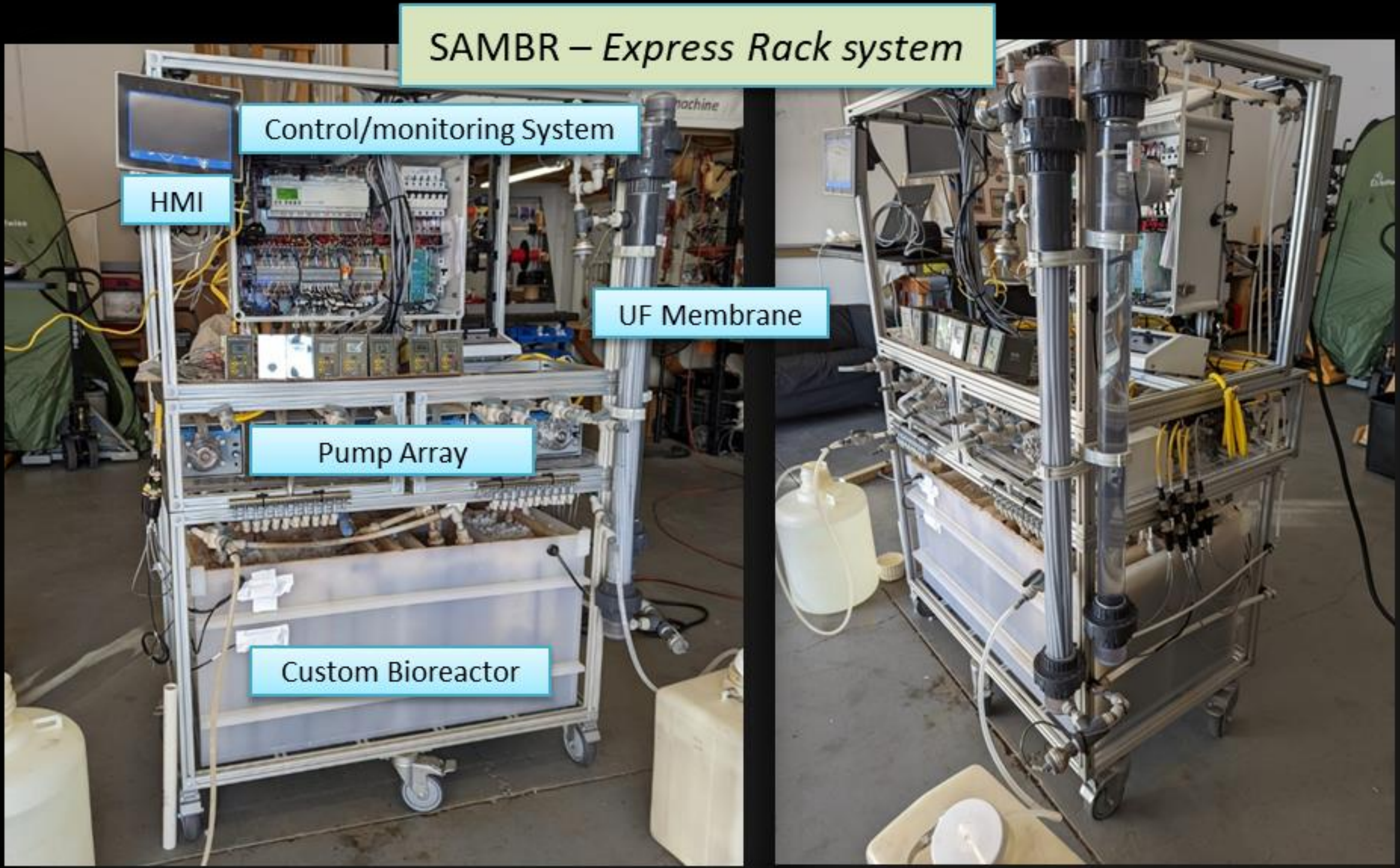


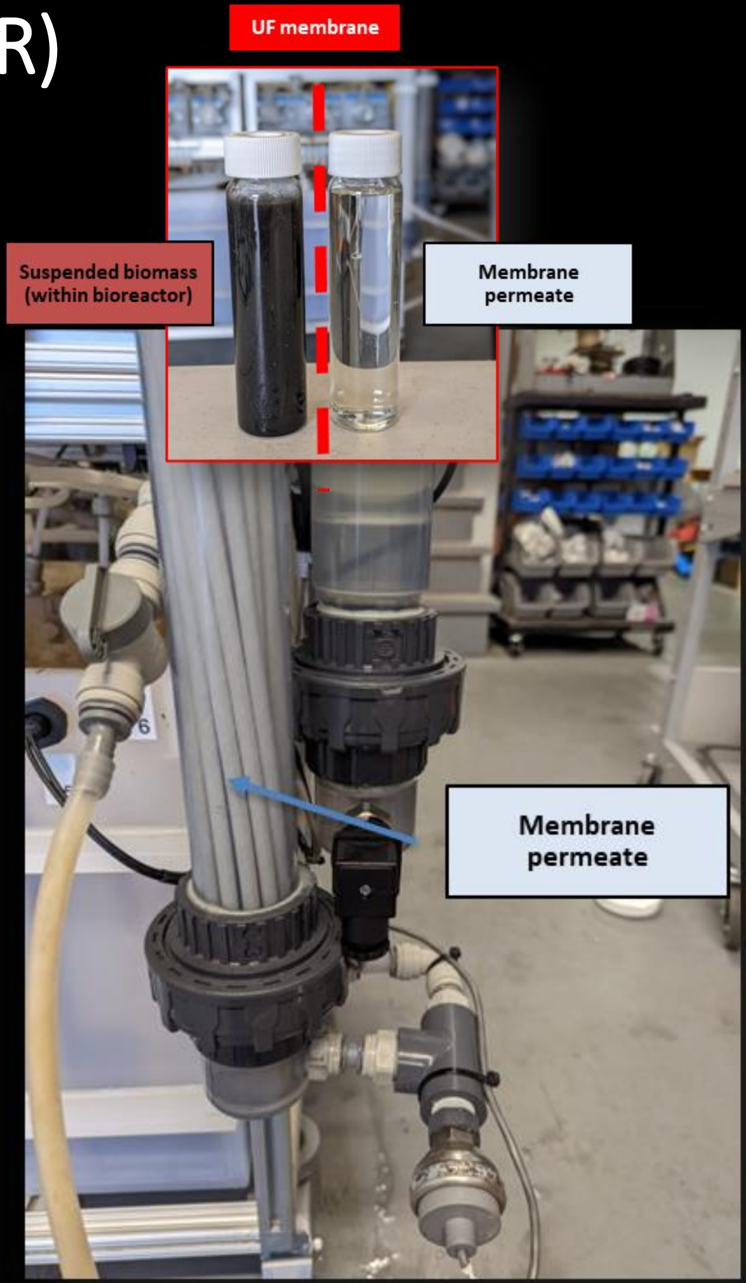
Hydroponics control grow out of Extra Dwarf Pok Choi on 1/2x Hoaglands nutrient solution started. The plants will reach maturity at 28 days at which point they will be harvested and analyzed. The nutrient solution is also being sampled and analyzed throughout the grow out to determine plants effects on water chemistry. After the control grow out, we will test the same batch of plant seeds using APMBR permeate as the nutrient solution in recirculating flow.

FIscher, Yeh, Roberson, et. al. “Unleashing the Power of Anaerobic–phototrophic Membrane Bioreactors for Sustainable Bioregenerative Life Support .” ICES-2024-347

Suspended Aerobic Membrane Bioreactor (SAMBR)

<u>Function:</u> to process **urine** and **hygiene water** for a crew of 4
** alternative to the urine processor assembly (UPA) **

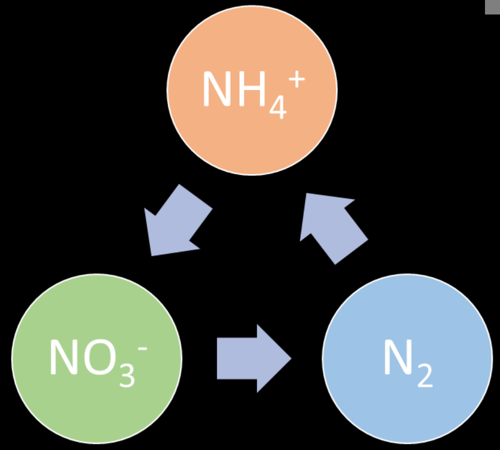




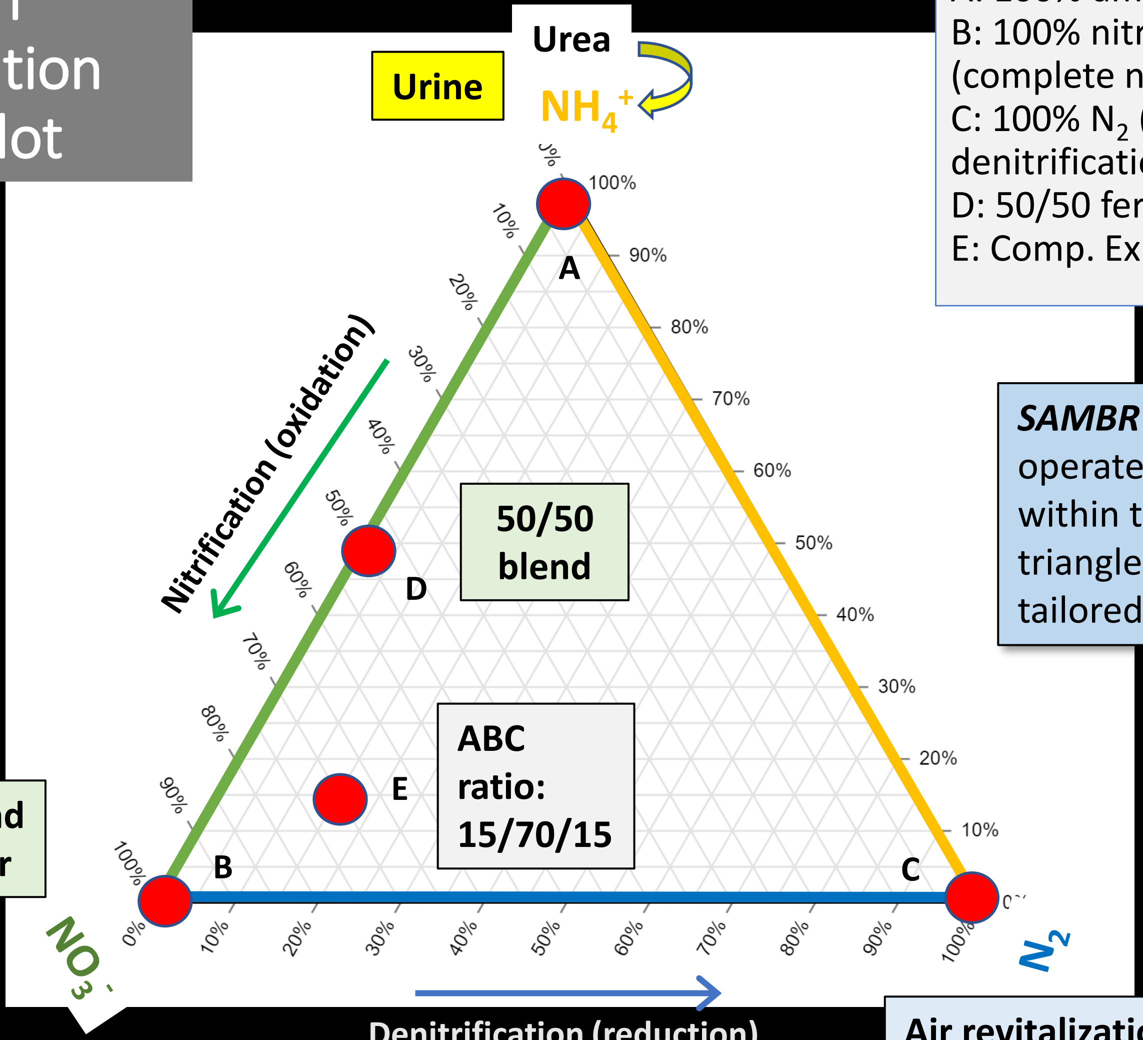
Bullard, Roberson, Yeh, et al. *Alternative Treatment and Resource Recovery of Crew Urine and Gray Water Using a Hybrid Membrane Technology*. ICES-2022-353.

Suspended Aerobic Membrane Bioreactor (SAMBR)

Nitrogen Transformation Ternary Plot



12



Hoagland Fertilizer

(incl. NO_2^-)

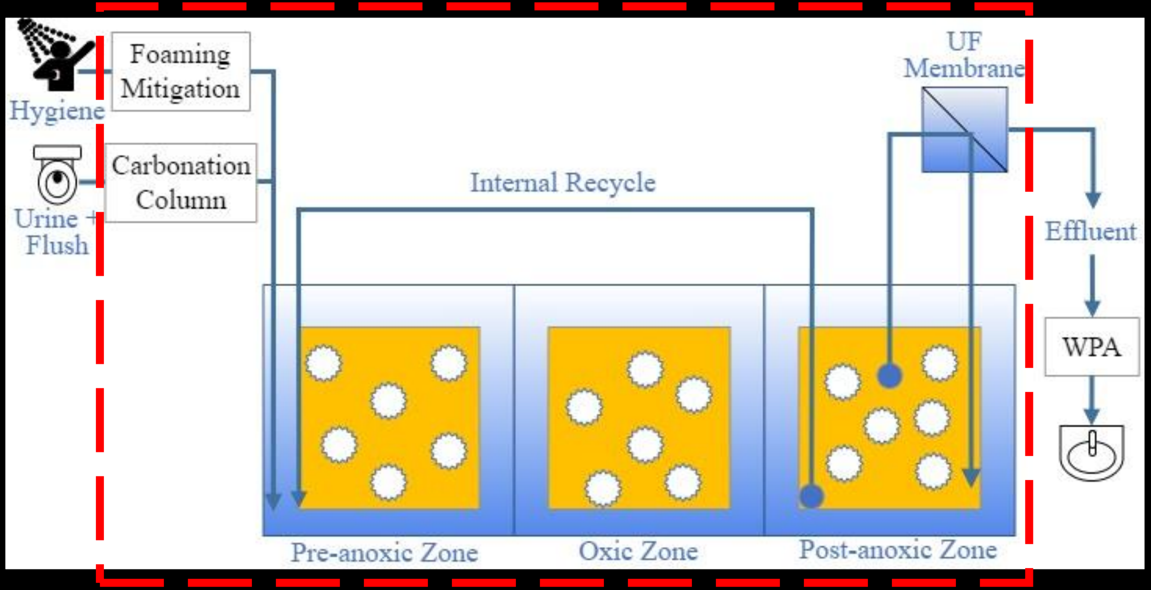
Air revitalization

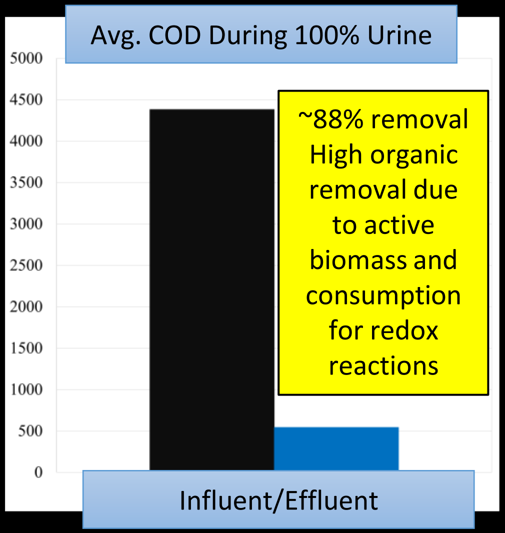
A: 100% ammonium
B: 100% nitrate (complete nitrification
C: 100% N_2 (complete denitrification)
D: 50/50 fertilizer blend
E: Comp. Ex. (MABR?)

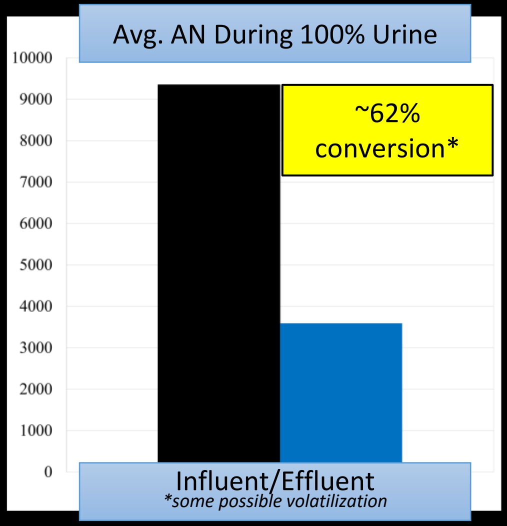
SAMBR aims to operate anywhere within this triangle for tailored output

<u>Target:</u> nitrogen transformation for removal or reuse

Suspended Aerobic Membrane Bioreactor (SAMBR) DATA

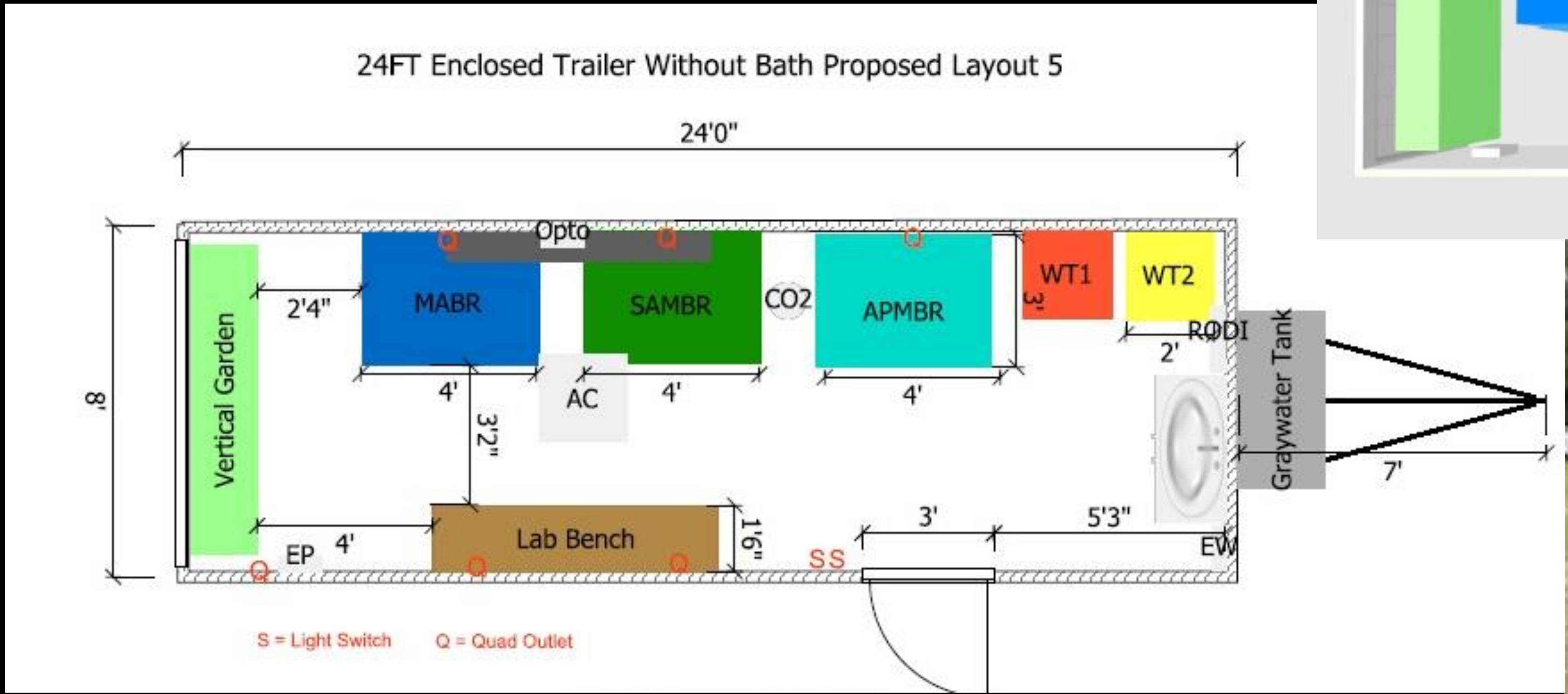


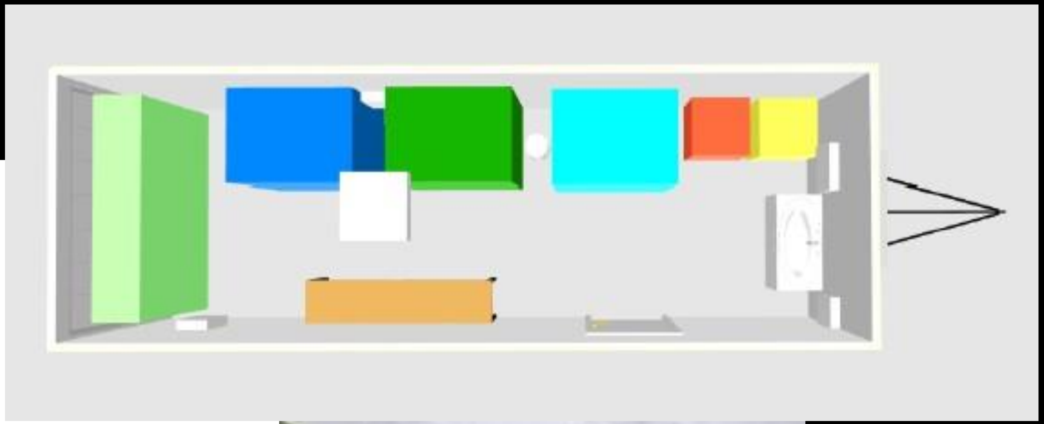




Phase	Preliminary	Evaluation		Phase I Experimental							Phase II Experimental
Stage	A-1	A-2	B	C	D	E	F	G	H	I	J
Base Feed Type	Synthetic: Ammonium bicarbonate	Synthetic: Ammonium bicarbonate + carbon source		Urine (actual) and Flush						Urine (actual), Flush, and Hygiene (Ersatz)	
Objective	Assess and validate oxic zone performance/operation (nitrification only)		Couple anoxic/oxic zones and validate operation w/Internal Recirculation (IR) (nitrification + denitrification)	Assess performance, and acclimate consortia with increasing concetrations of urine to reach full strength (nitrification + denitrification)						Expand treatment to include simulated hygiene water (N + D)	Incorporate Algal Photo-Bioreactor (APBR) (N + D)
Influent nitrogen (mg-N/L)	46	46	46	46	450	1700	3500	5000	7061	1701	1701
Influent COD (mg/L)	0	70	70	70	693	2617	5388	7697	10870	2618	2618
Influent carbon (mg/L)	0	44	44	44	431	1630	3355	4793	6769	1630	1630
Vol (urine + flush) as % of total influent	1%	1%	1%	1%	6%	24%	50%	71%	100%	24%	24%
Q (L/d)	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	38.2	38.2
HRT (d)	12	12	12	12	12	12	12	12	12	2.9	2.9
Internal recirculation (IR)	OFF	OFF	ON	ON	ON	ON	ON	ON	ON	ON	ON

Deployable WWTF





Integration of wastewater processes for a deployable wastewater treatment facility (DWWTF)

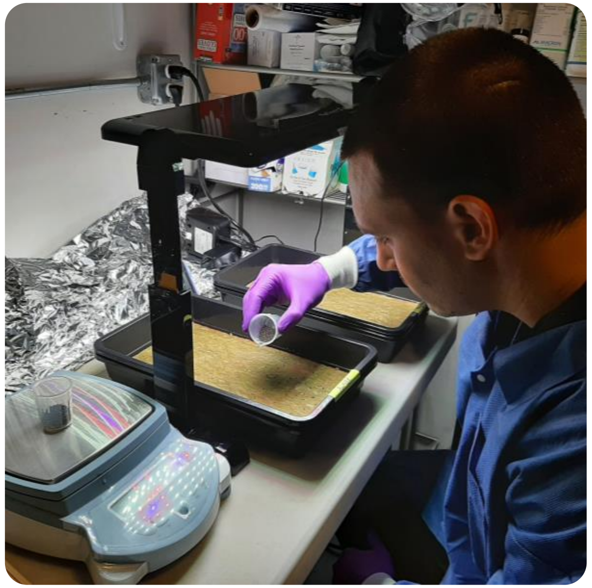
Treats divergent wastewater streams into nutrient solutions and potable water

Easily transferred to low fidelity analog mission

FIscher, Yeh, Roberson, et. al. "Unleashing the Power of Anaerobic–phototrophic Membrane Bioreactors for Sustainable Bioregenerative Life Support ." ICES-2024-347

HI-SEAS

- **H**awaii **S**pace **E**xploration **A**nalog and **S**imulation is an analog habitat and environment purposed to simulate manned Mars/Lunar surface missions.
- Missions take place in a dome structure that is 36 feet in diameter and has about **1150 square feet** of living space. Power and heat are supplied via the solar panel farm, as well water is housed in a storage unit outside the habitat structure.
- Provides a great environment to perform feasibility studies for a variety of projects. NASA hardware such as VEGGIE has been tested at HISEAS!
- Future longer-term feasibility studies with bioregenerative purification systems at HISEAS would garner a better understanding of how these systems work in a simulated high-fidelity early planetary base-like habitat.

NDU - ILMAH

- **North Dakota University** (NDU) **I**nflatable **L**unar/**M**ars **A**nalog **H**abitat **(LIMAH)** is a low fidelity analog habitat and environment used to simulate manned Mars/Lunar surface missions.
- Missions combine habitat, exploration rover, and EVA suits for full experience.
- Provides TRL advancement for providing a better understanding of how these systems work in a simulated low-fidelity early planetary base-like habitat.
- Provides testing platform to meet requirements for longer-term, higher-fidelity studies at HERA & CHAPEA.

https://aero.und.edu/space/human-spaceflight-lab/ilmah/index.html

CHAPEA

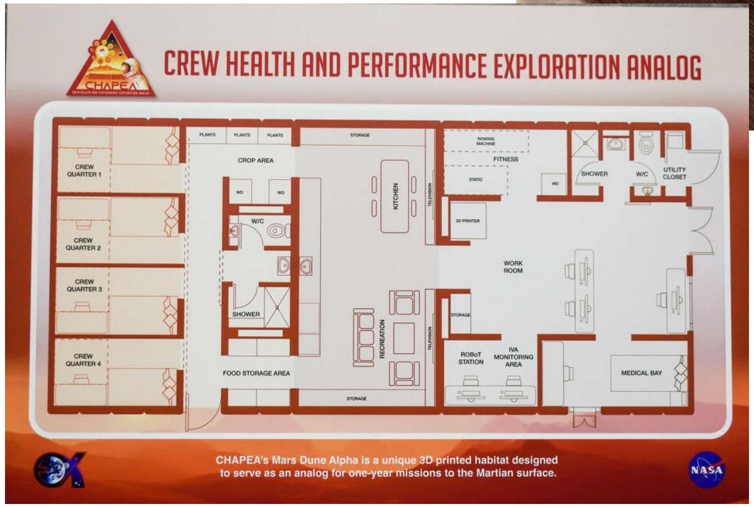
- **C**rew **H**ealth **a**nd **P**erformance **E**xploration **A**nalog is an analog habitat and environment purposed to simulate manned Mars/Lunar surface missions at Johnson Space Center.
- 1-year missions take place in a 3D printed structure that has about **1700 square feet** of living space. Four private crew quarters, dedicated medical and workstations, lounge areas, galley, and food growing areas.

2024-28 Test Plan

Phase 1: Integrate wastewater treatment processes into CHAPEA and test their engineering constraints, performance, and capabilities. (FY25-26)

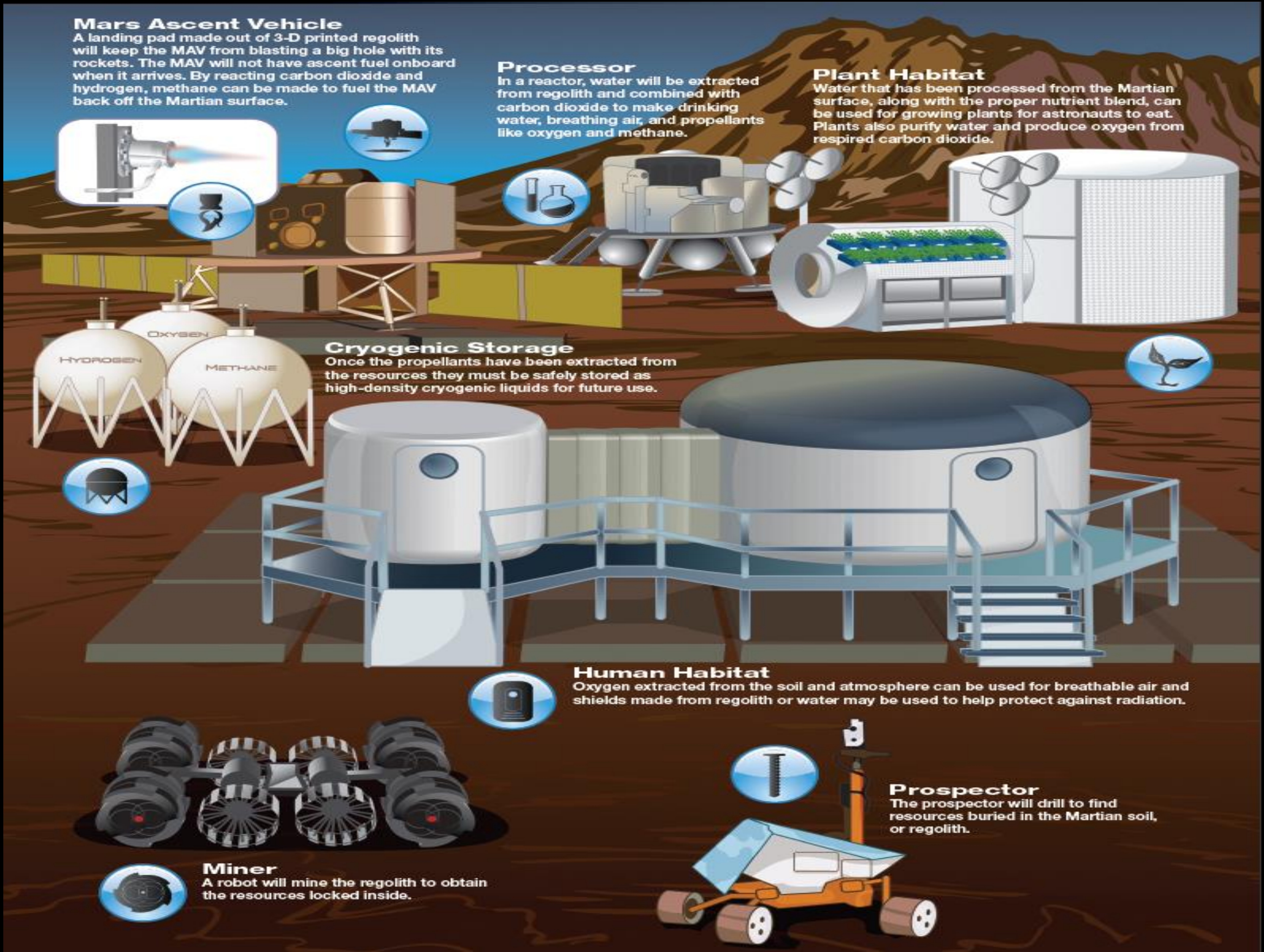
Phase 2: Develop post-processing treatment methods that generate value added products and test for requirement conformance. (FY27)

Phase 3. Develop air and trash integration points for a fully sustainable architecture, integrate those systems, and test full system performance. (FY28)



https://www.nasa.gov/humans-in-space/chapea/

NASA Surface Systems



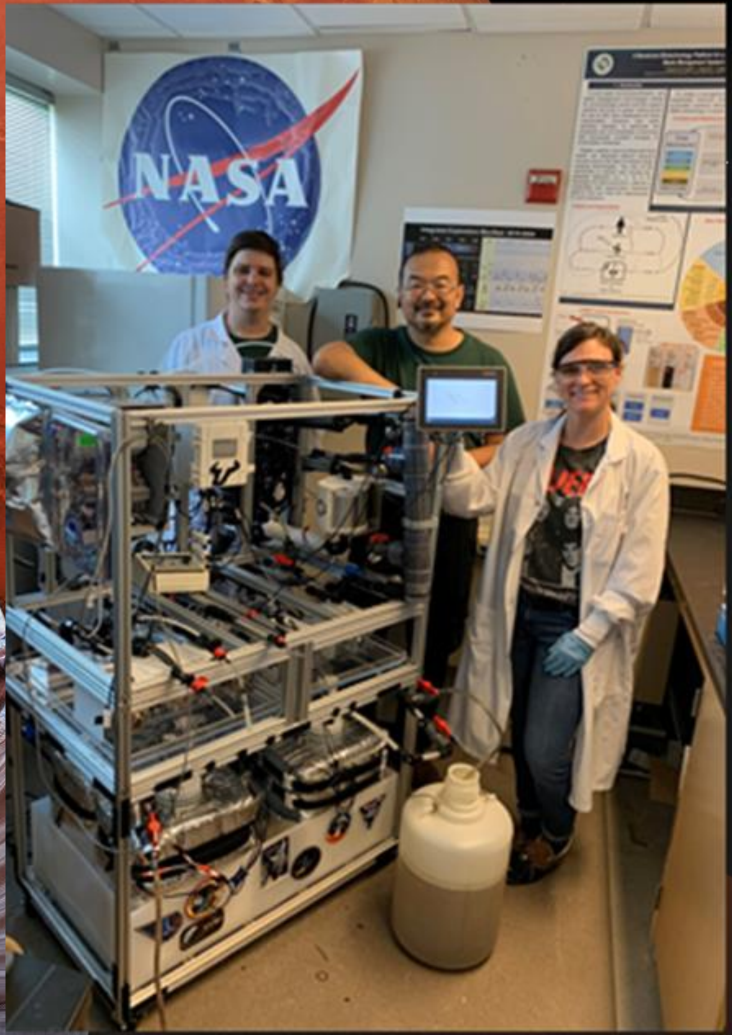
OPPORTUNITIES FOR YOU!!!

www.intern.nasa.gov

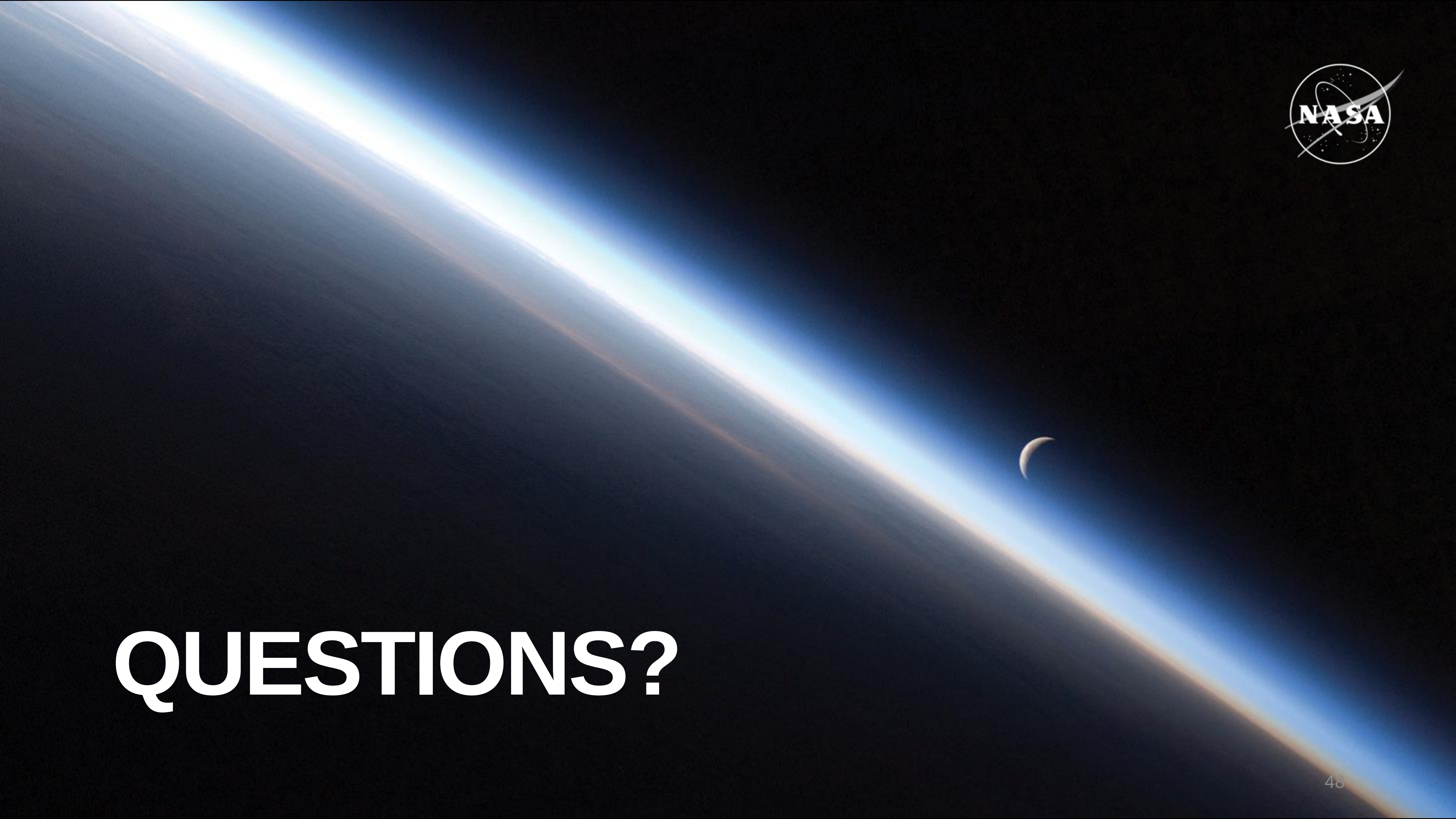
www.usajobs.gov

www.nspires.nasa.gov

www.KSCpartnerships.ksc.nasa.gov



Acknowledgements



QUESTIONS?

Back Up Slides

Humans on Mars

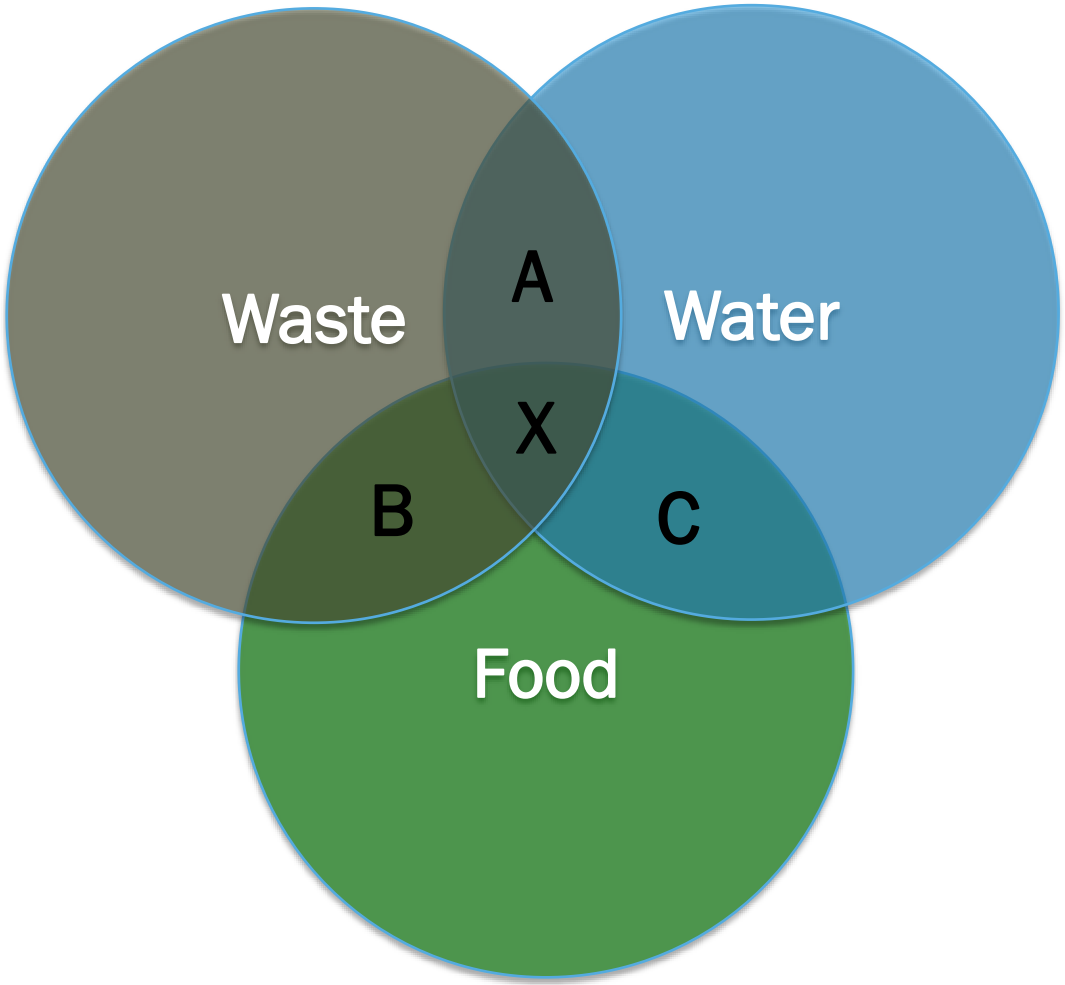
Pushing the Boundaries of Current Possibilities

Go	Land	Live	Explore
Rapid, safe, & efficient space transportation	***Expanded access to diverse surface destinations***	***Sustainable living and working farther from Earth***	***Transformative missions and discoveries***

Lack of Gravity Has a Huge Impact

SUSTAINABLE ECLSS

An integrative approach is needed



Region	Problems	Opportunities
A	Wet metabolic wastes (e.g., fecal)	Wastewater treatment; Water recovery
B	Plant residues; food wastes	Fertilizer recovery
C	Plant irrigation needs	Use plants to remove ions to clean water
X	Efficient & integrative treatment	Resource recovery

X – integrative bioregenerative approach at KSC/USF to simultaneously sustain water recycling, waste management, and food production

ECLSS SUSTAINABILITY

For a 30-month mission, a single Crew Member (CM) will require:

2250 kg water

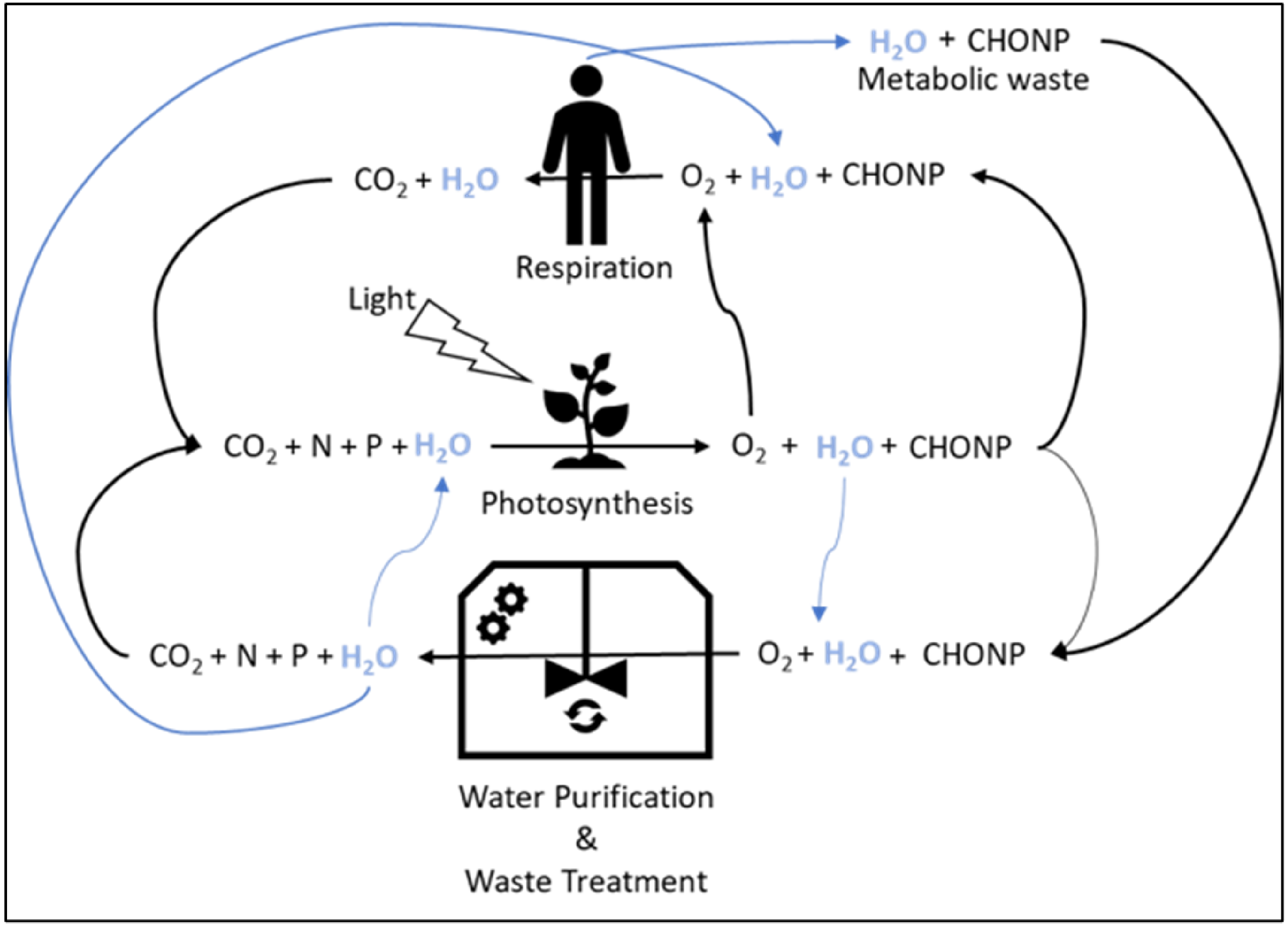
1359 kg food

And generate:

5678 kg total waste

1612 kg metabolic waste

Exceeds $16M/CM at a payload cost of $10,000/lb (~$4,535/kg)



Developing Future ECLSS

- Wastewater Processing enables cross cutting technologies for sustainably managing metabolic waste.
- Trades better than Phys/Chem systems over 120 days.
- Benefits:
  - Significantly decreases requirement for waste storage
  - Addresses wet-waste tech gap
  - Increased water recovery
  - Enables sustainable food production