

COE CST Eleventh Annual Technical Meeting

Task 396: Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications (2/5/20-12/31/21)

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Center of Excellence for
Commercial Space Transportation



Team Members

- **Principal Investigator:** David Klaus, PhD
- **Students:** Kaitlyn Hauber, MS 2022 and Hunter Hatchell, MS 2022 (prior contributions in fall 2020)
- **Organization:** Aerospace Engineering Sciences, University of Colorado, Boulder



Task Description

- This study was intended to augment the *FAA Environmental Control and Life Support Systems for Flight Crew and Space Flight Participants in Suborbital Space Flight* document (Version 1.0, April 2010)
- Current Effort (Task 396) builds on a sequence of prior related COE CST Tasks...

Schedule

- *Prior Related COE CST Projects*
 - *Task 184: Human-Rating of Commercial Spacecraft (6/1/11-12/31/14)*
 - *Task 320: Commercial Spaceflight Risk Assessment and Communication (6/1/15-5/31/17)*
 - *Task 353: Design and Operational Considerations for Human Space Flight Occupant Safety (6/1/17-5/31/18, NCE 12/31/18)*
- **Current Effort**
 - **Task 396: Mapping Life Support Functions and Technologies to Commercial Spaceflight Applications (2/5/20-12/31/21)**

Relevance to Commercial Space Industry

- *Prior Related COE CST Project Contributions to:*
 - *Task 184: FAA Human-Rating Ground Rules and Assumptions Document (Predecisional, 2013)*
 - *Task 320: FAA Guidance on Informing Crew and Space Flight Participants of Risk (Draft, February 17, 2016)*
 - *Task 353: FAA Recommended Practices for Human Space Flight Occupant Safety (Version 1.0, Aug 2014)*
- **Current Effort**
 - **Task 396: FAA Environmental Control and Life Support Systems for Flight Crew and Space Flight Participants in Suborbital Space Flight (Version 1.0, Apr 2010)**

Specific Goals of Task 396

- Define basic **human physiological needs** across a variety of industry standards (FAA, NASA, OSHA, FDA, etc.)
- Characterize **functional ECLSS requirements** intended to meet those needs
- Construct representative **ECLSS models** for a range of spaceflight profiles (from suborbital to planetary surfaces)
- Identify and characterize **candidate ECLSS technologies** (including vendors) to inform future trade studies
- Provide considerations for **design validation and compliance verification** acceptance testing

Results – ECLSS Functional Requirements

Satisfy human physiological needs

- **Atmospheric Maintenance:** *gas pressure, composition and temperature*
- **Metabolic Inputs:** *oxygen, potable water and food*
- **Primary Outputs/Waste:** *CO₂, heat, water vapor (respiration/perspiration), particulates, volatile trace contaminants, fecal and urine waste streams*
- NASA uses normative design values for the astronaut population
 - Life Support Baseline Values and Assumptions Document (NASA/TP-2015–218570/REV2) 2022
- When looking forward to commercial space flights with more diverse participation, broader ranges may need to be considered
 - NASA standards as a baseline, related values from FAA, OSHA, USDA, FDA, NIH, etc.

Results – ECLSS Functional Requirements

Examples from Different Agencies

Oxygen Provision

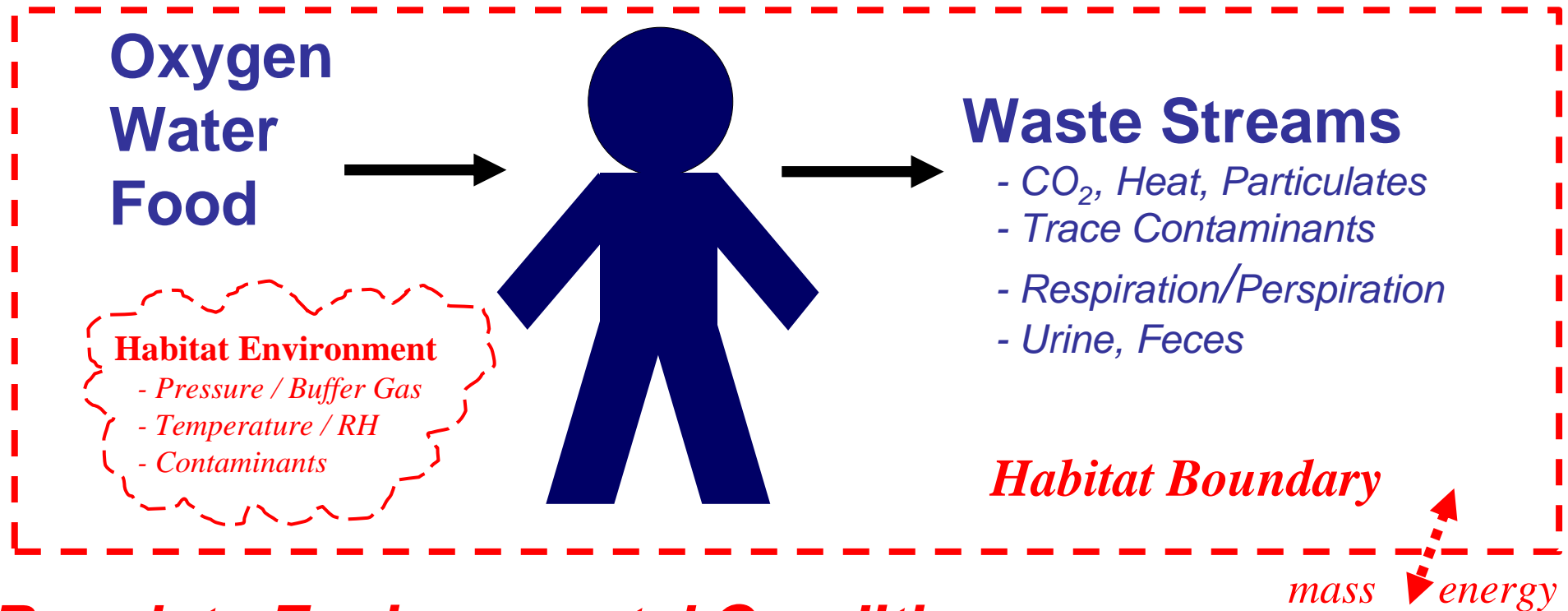
- NASA [BVAD]
 - 0.518-5.67 kg/CM-day
- FAA [Supplemental O2]
 - 15-30 L/min
- OSHA [Indoor Air]
 - 19.5-23.5%
- FDA
 - < 43.8 psia at 20 °C

CO2 Control

- NASA [BVAD]
 - ppCO2 below 0.53 kPa
- FAA [CFR]
 - 0.5% by volume
- OSHA [Indoor Air]
 - 0.5% by volume
- NIH
 - 22-29 mmol/L (blood)

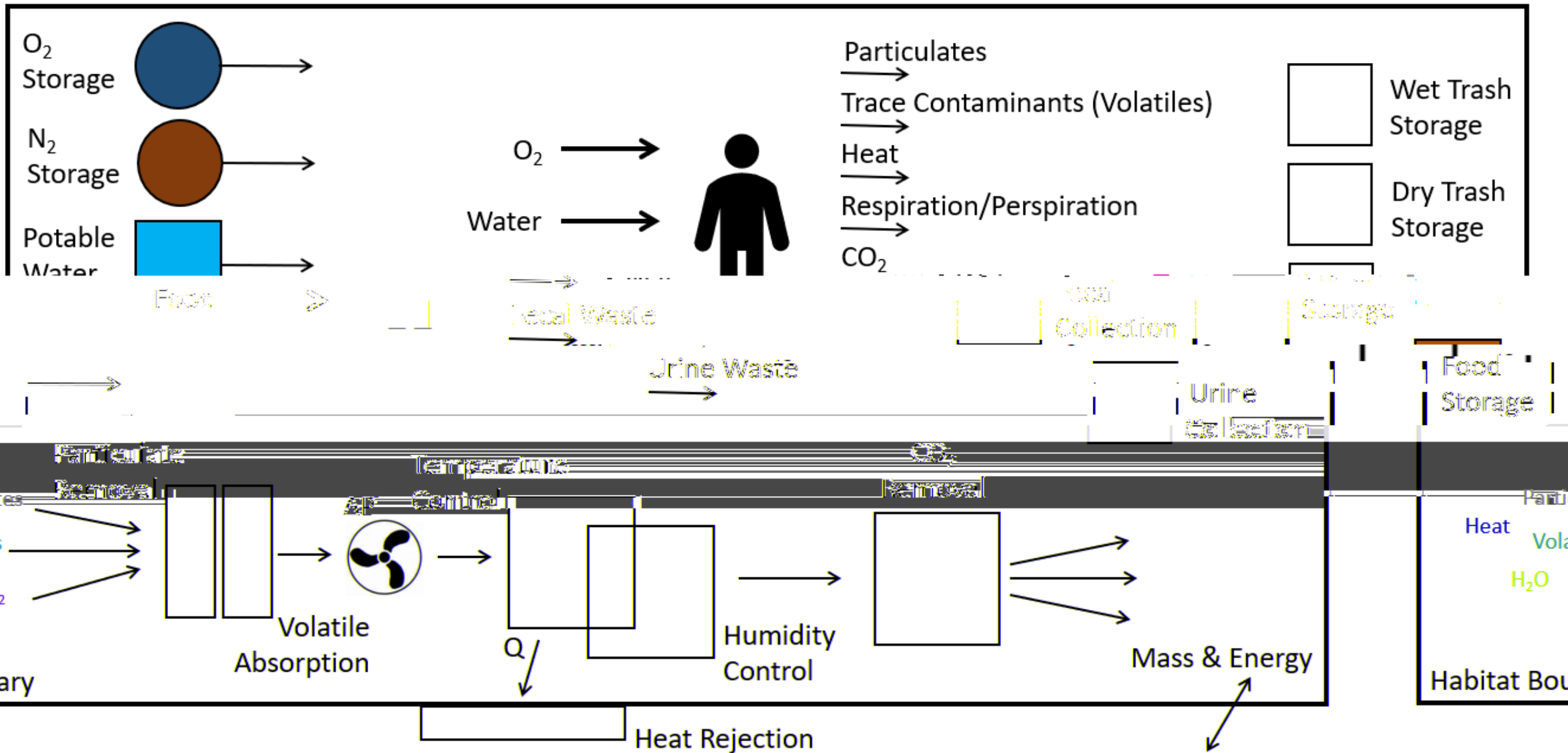
Results – ECLSS Functional Requirements

Provide Metabolic Inputs & Collect Byproducts

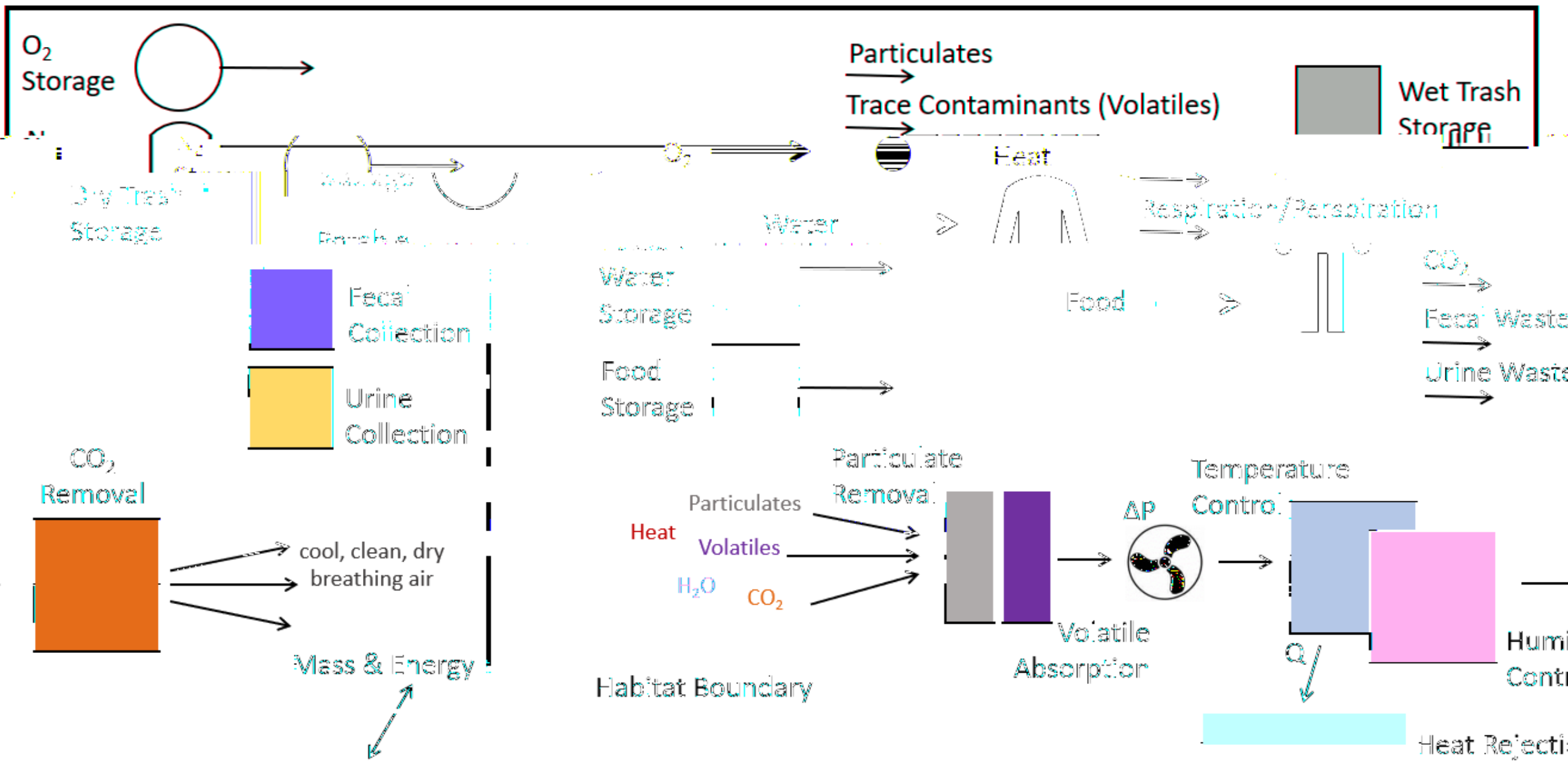


Regulate Environmental Conditions

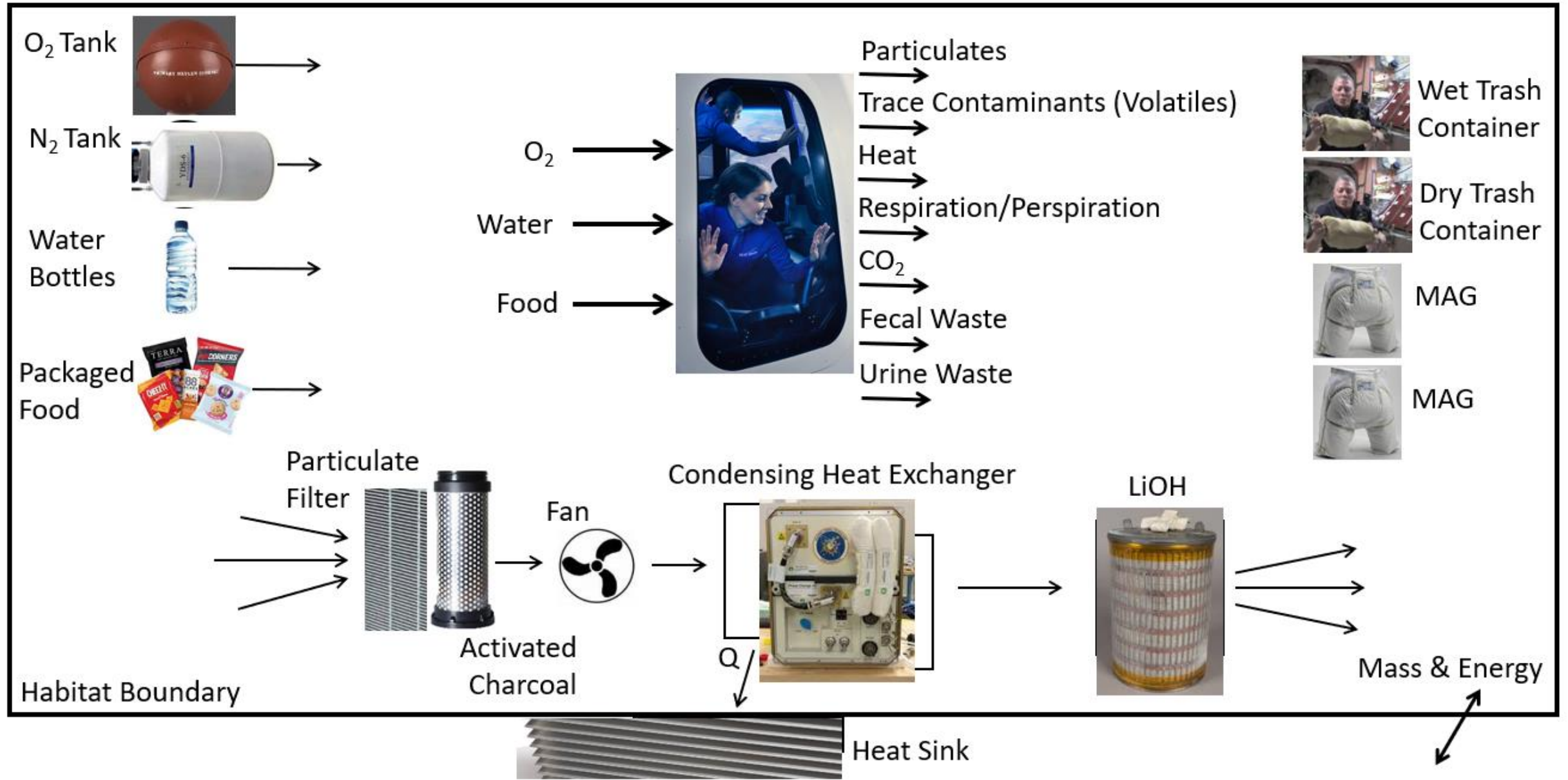
Integrated Functions – Fully Loaded (pre-flight)



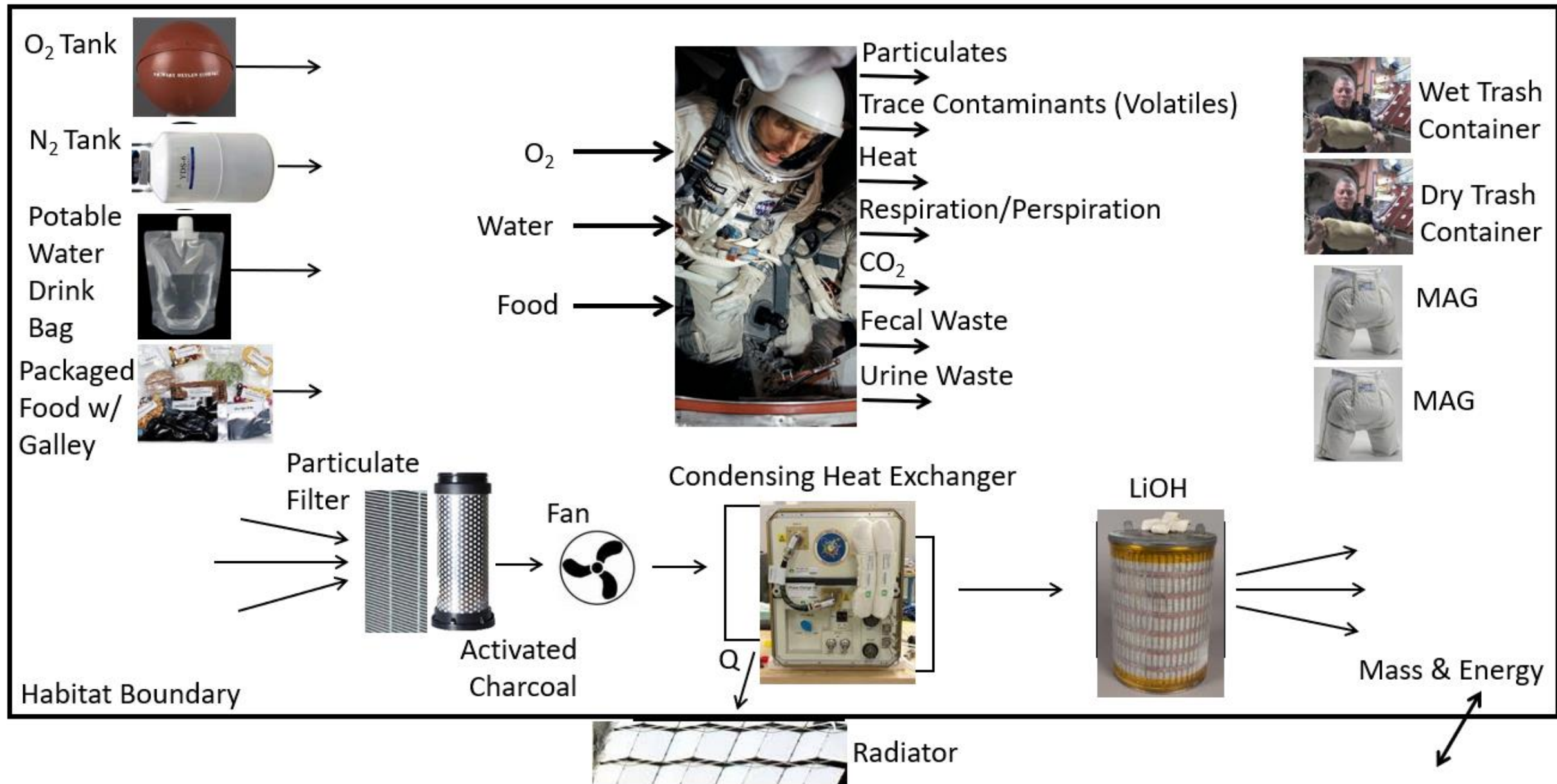
Integrated Functions – 100% depleted (post-flight)



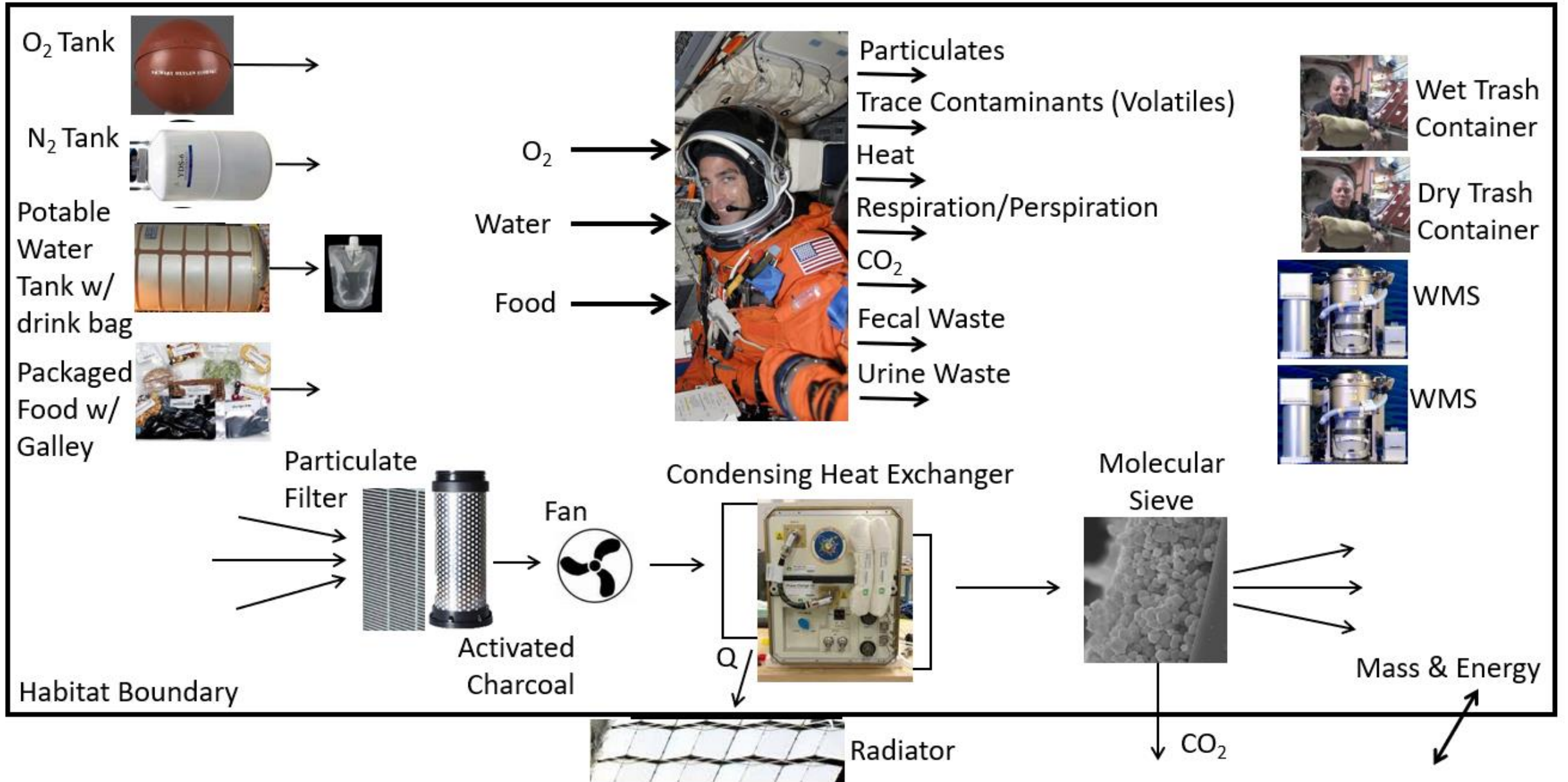
ECLSS Suborbital Model System (~hours)



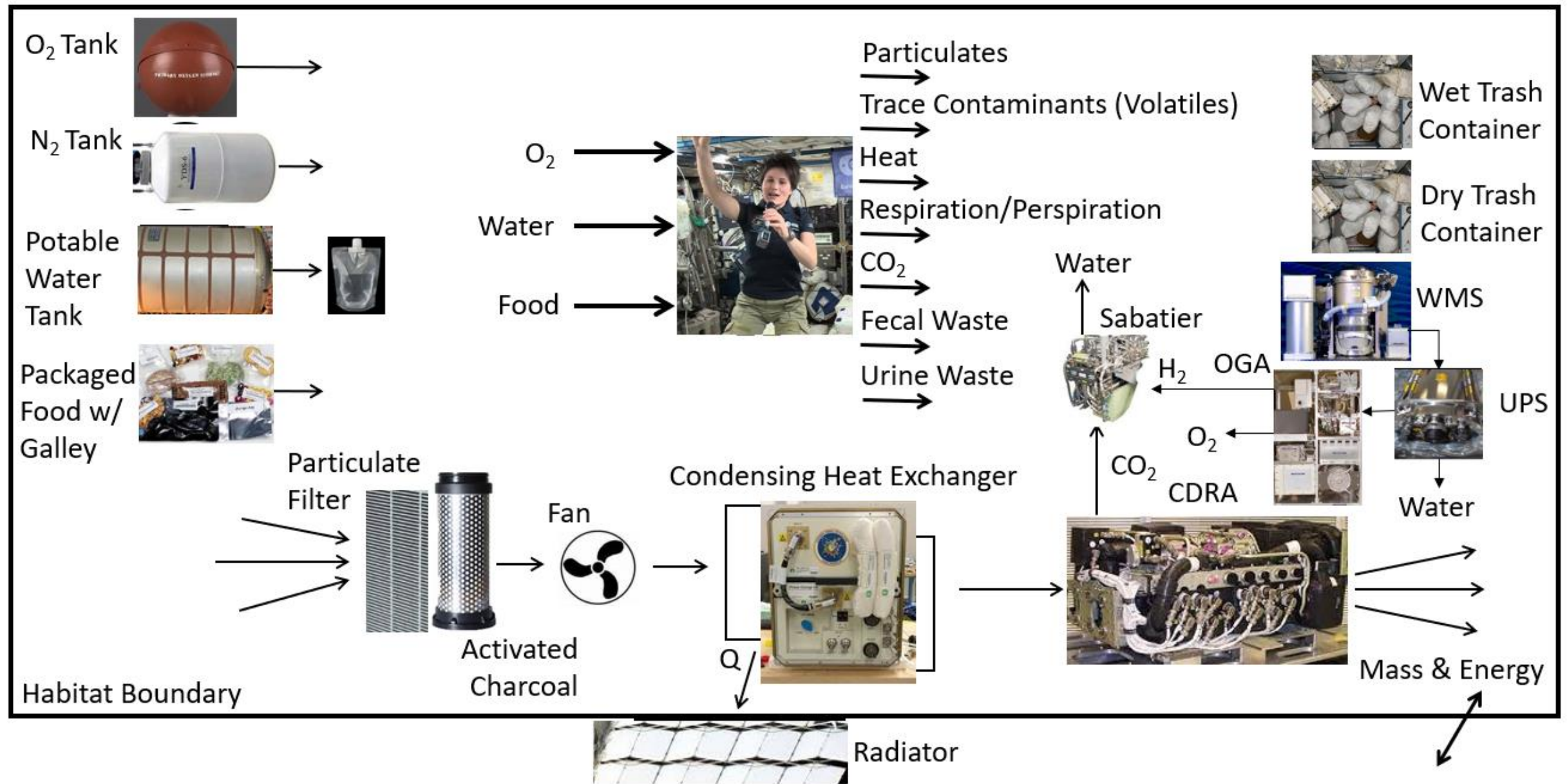
ECLSS Orbital Model System (~days)



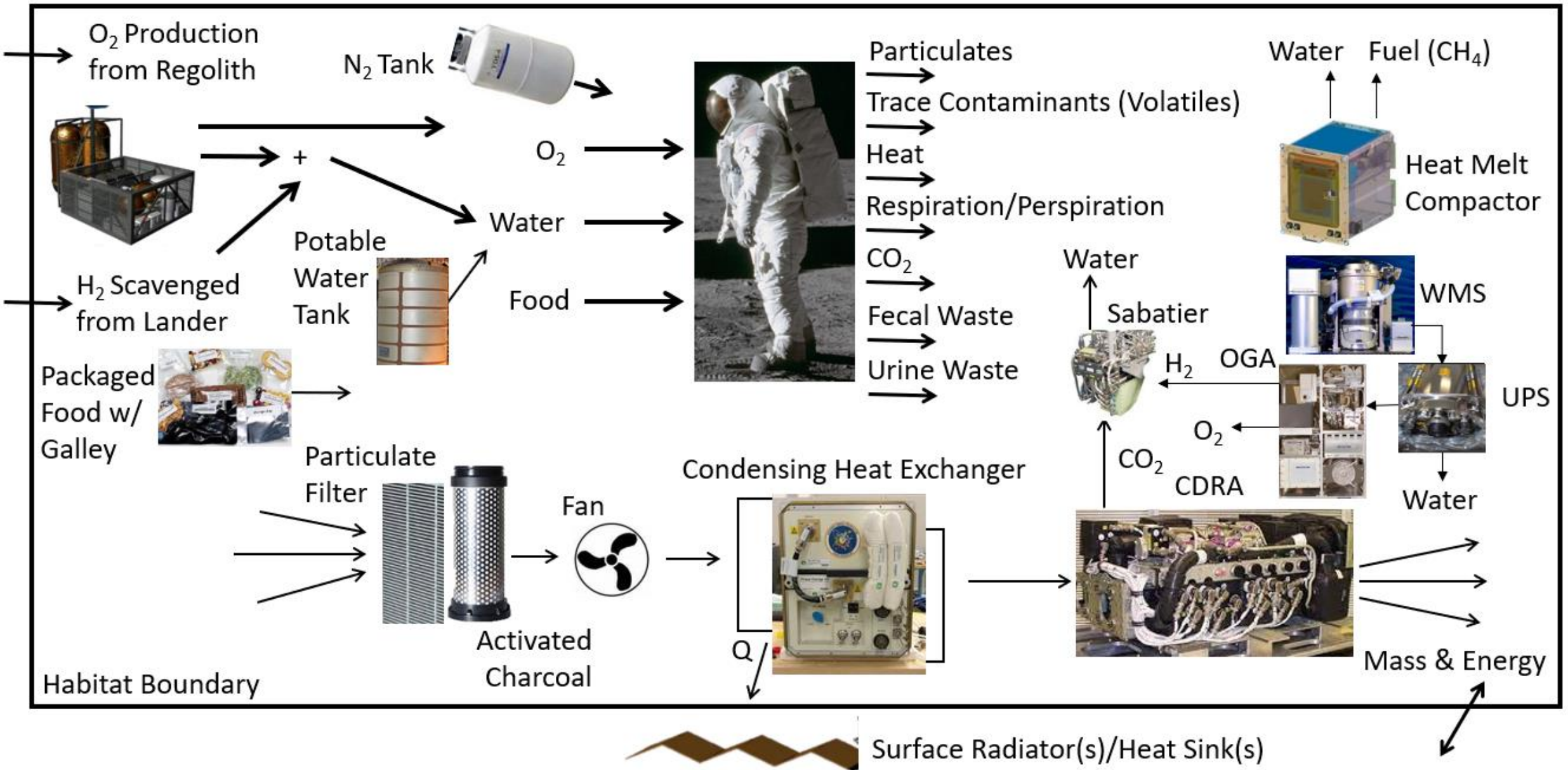
ECLSS Orbital Model System (<1 month)



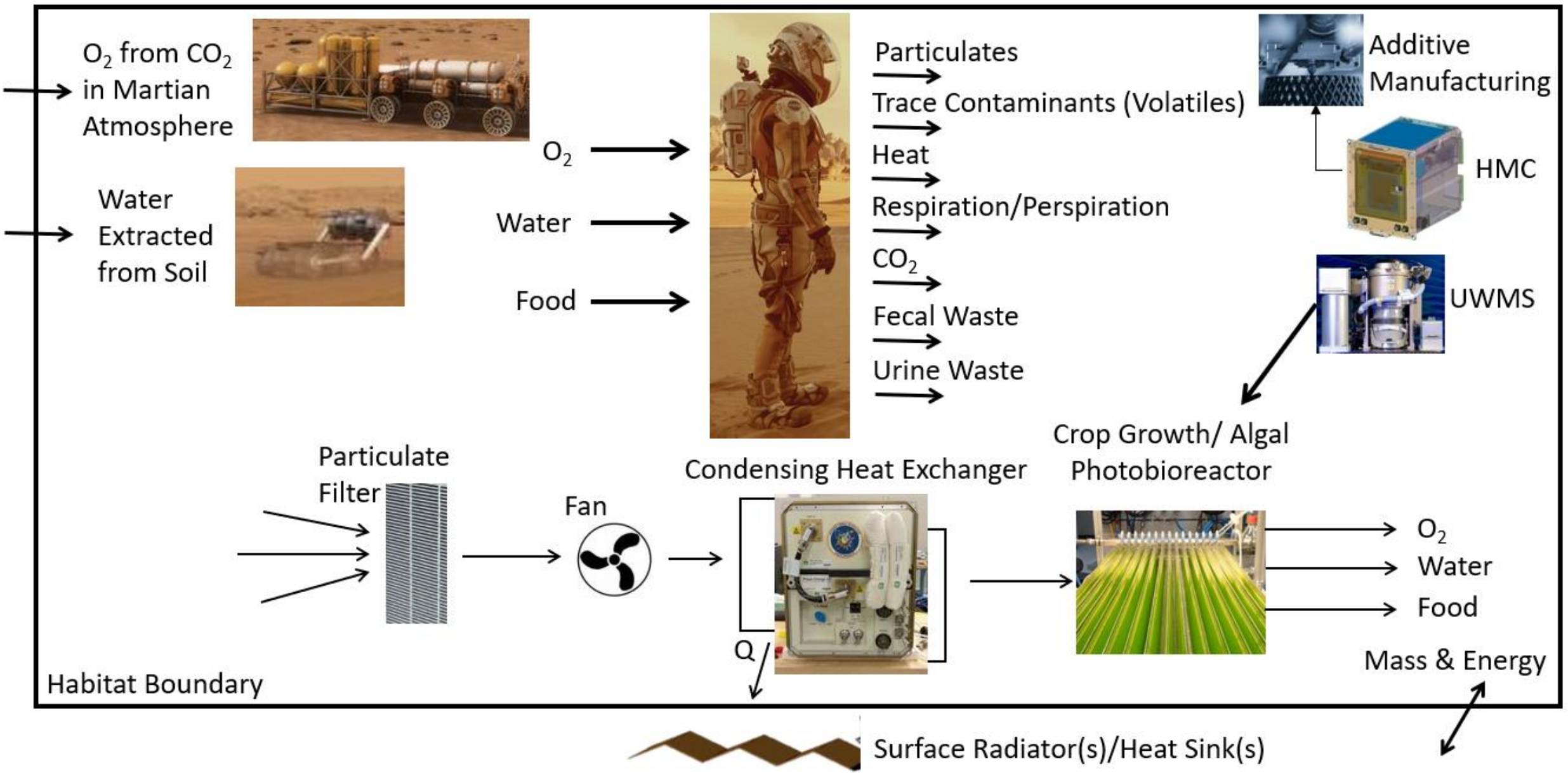
ECLSS Orbital Model System (>1 month)



Lunar Habitat Model System *(TBD duration)*



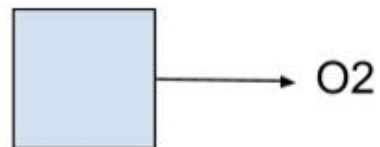
Mars Habitat Model System *(indefinite)*



Results – ECLSS Technology Categories

- Atmosphere Regulation
- Potable Water Provision
- Food Provision
- Waste Management
- *Regenerative Technologies, Consumable Recovery and ISRU*
- ECLSS Technology Specification Sheets
- ECLSS Technology/Component Vendors

1.1.1a Oxygen Tank (High Pressure Gas)



Sample ECLSS Technology Specification Sheet

Function	<i>Atmospheric pressure and composition regulation - provision of gaseous oxygen</i>
Mode	<i>Active - high pressure storage/ release</i>
Description	<i>Oxygen is stored in a tank at a high pressure until it is released for consumption by the spacecraft inhabitants</i>
Performance Requirements	<i>Provide a range of 0.518-5.67 kg/CM-day oxygen (BVAD p. 53), with a daily average of 0.818 kg/CM-day. Design Margin added to account for potential higher metabolic demands, extended flight duration, 'feed the leak' scenarios, etc.</i>
Primary Inputs	<i>Gaseous oxygen (high pressure)</i>
Primary Outputs	<i>Gaseous oxygen (regulated to cabin pressure)</i>
Expendable Inputs	<i>Full tanks</i>
Expendable Outputs	<i>Empty tanks</i>
TRL (1-9)	<i>9, currently in use on the ISS, historically used on various vehicles</i>
Validation/ Initial Acceptance Criteria	<i>Confirm that functional requirements for the specified mission profile are mapped to technologies present in the vehicle</i>
Verification Compliance	<i>Demonstrated by design, inspection, analysis, test, and/or certification **Flight testing on parabolic aircraft, if standardized could be by certification * Gravity-dependent verification .</i>
Reference(s)/ Vendor(s)	<i>Worthington Industries https://worthingtonindustries.com/Products/High-Pressure-Composites/Space</i>
Prepared by	<i>Kaitlyn Hauber 5-16-2021</i>

Results - ECLSS Technology Vendors

- Airbus
- Boeing
- Cobham
- Collins Aerospace
- Dynetics
- Honeywell
- Iron Ring
- Jacobs
- Oceaneering Space Systems
- Paragon Space Development Corp.
- Sierra Nevada Corp (Sierra Space)
- SpaceX

Related IVA/LEA Pressure Garments

- NASA Orion Crew Survival System (OCSS)
- Boeing Suit for Starliner
- Final Frontier Design
- SpaceX for Crew Dragon

Results – V&V Considerations

- Function – ECLSS requirement
- Technology Options – candidate ECLSS components to meet requirement
- Description – processes involved
- Quantitative – nominal ranges
- Relevant System Parameters – capacity, rates, compatibility, etc.
- Design and Contingency Margins – uncertainty analysis
- Risk Mitigation – redundancy, fault tolerance, etc.
- **Validation – initial acceptance criteria (e.g., analysis, He leak check, etc.)**
- **Verification – re-flight (consumable load, flow rate, pressure decay, etc.)**

Conclusions and Future Work

- Guidelines defined for aligning the metabolic needs of onboard humans with ECLSS configurations under differing flight profiles
- Considerations for ensuring the intended performance parameters are achieved via design validation and compliance verification
- ECLSS Technology and Vendor database established
- Task 396 Final Report submitted Dec 2021 (Henry Lampazzi, FAA TM)

- Future Related Opportunities with the Industry-led FAA Commercial Space Innovation Institute (CSII) follow-on

Publications, Presentations, Awards & Recognition

PUBLICATIONS

- Klaus, D. and Hauber, K. (2022) *Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications*. IEEE Aerospace Proceedings (978-1-6654-3760-8/22 paper no. 2531)

PRESENTATIONS

- Klaus, D. FAA AST Senior Management and Staff Briefing, COE CST Research Area 3: Human Spaceflight Tasks, virtual event, December 2020
- Hauber, K. *Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications*. (student poster) 50th Int'l Conference on Environmental Systems (ICES), July 2021
- Klaus, D. *Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications*. IEEE Aerospace Conference, Big Sky, MT, April 2022

AWARDS & RECOGNITION

- Kaitlyn Hauber received 1st place for her poster titled 'Characterizing Non-invasive Biometric Sensors For Use In Task Performance Prediction And Operational Design' at the NASA Human Research Program (HRP) Investigators' Workshop Annual (Virtual) Meeting in Feb. 2022
- Professor Klaus received the CU College of Engineering & Applied Science Dean's Faculty Performance Award and the CU Aerospace Department Distinguished Performance Award in 2021

Acknowledgements

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