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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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**: *CO_2, 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

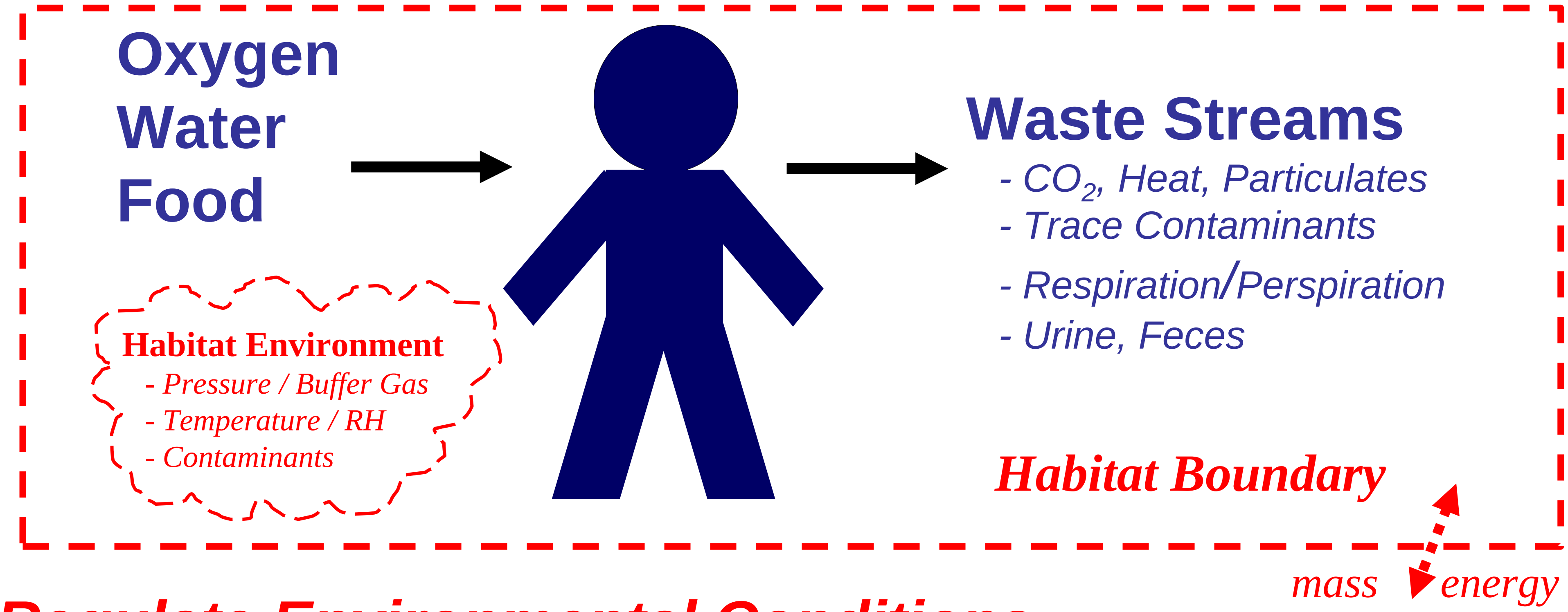
- NASA [BVAD]
  - 0.518-5.67 kg/CM-day
- FAA [Supplemental O2]
  - 15-30 L/min
- OSHA [Indoor Air]
  - 19.5-23.5%
- FDA
  - < 43.8 psia at 20 °C

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)*

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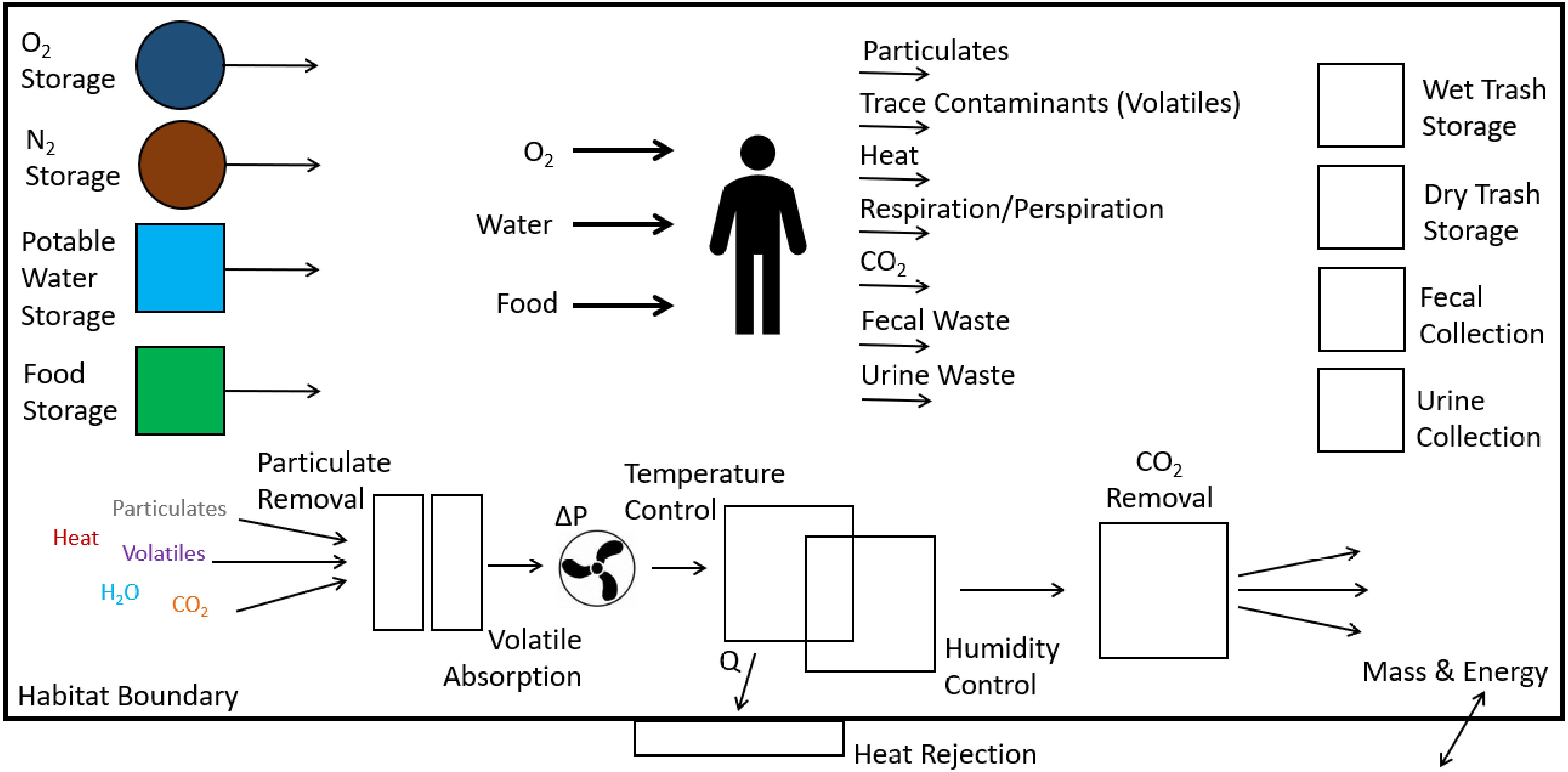
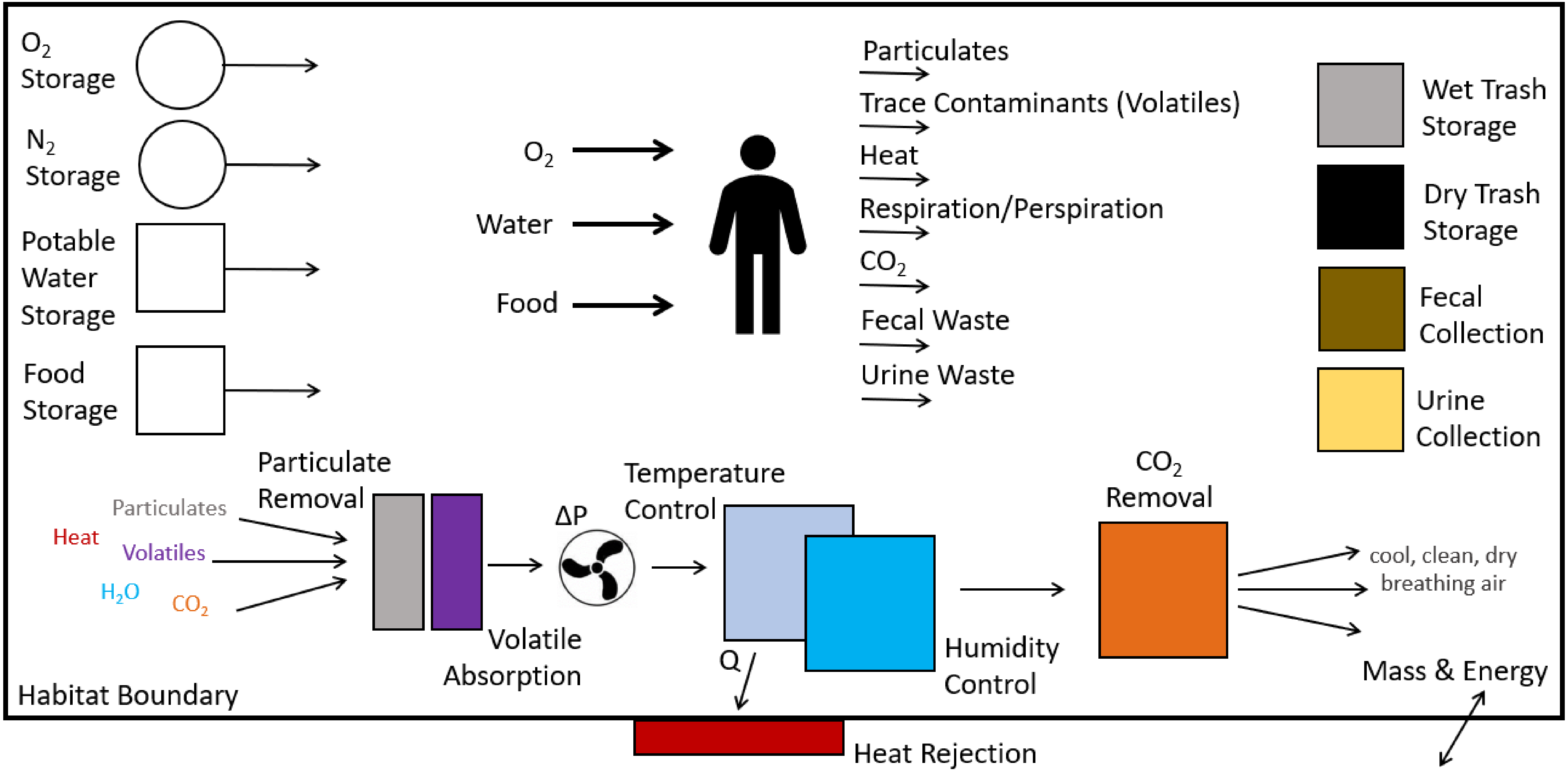
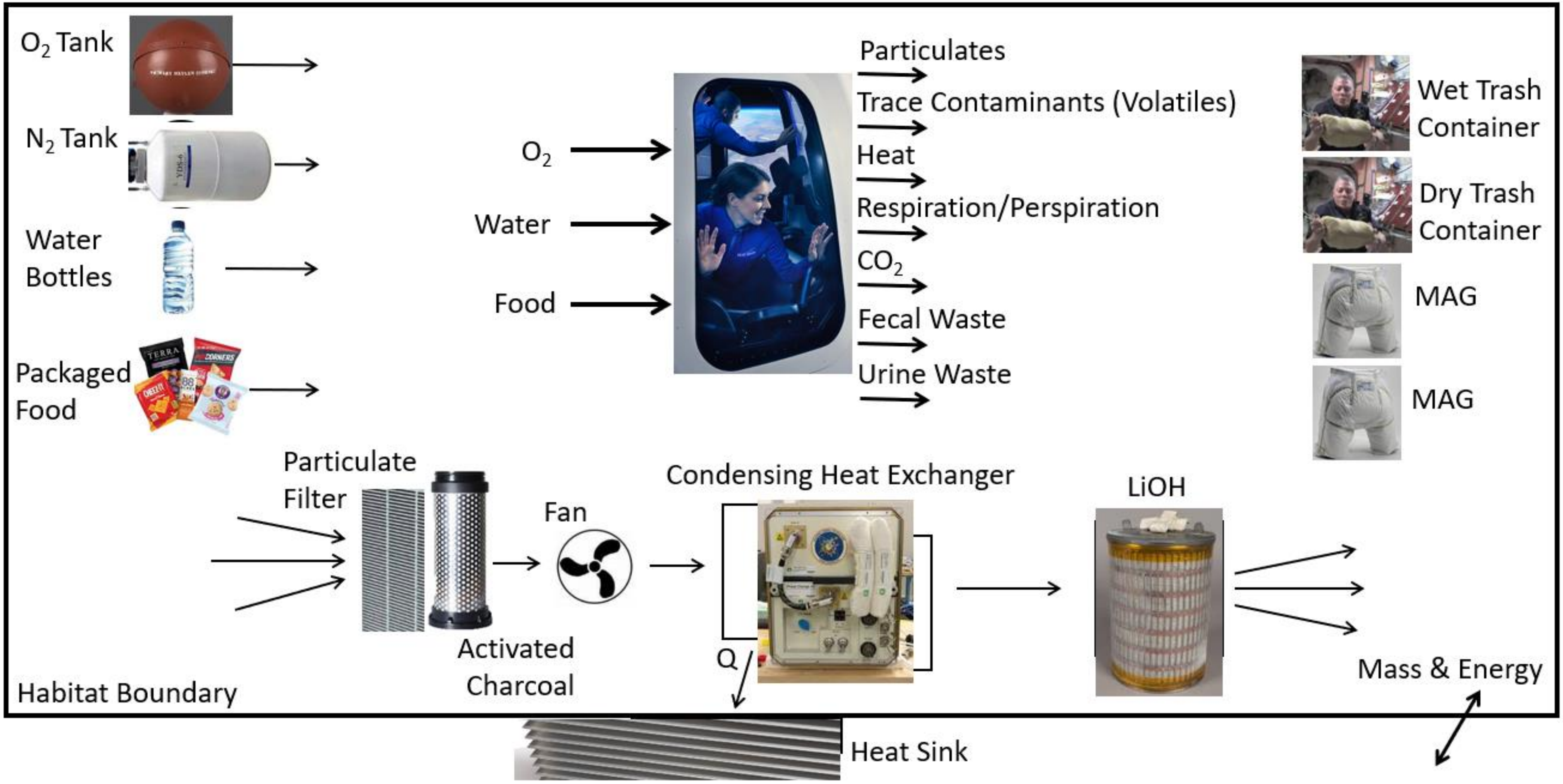


Integrated Functions – 100% depleted *(post-flight)*



ECLSS Suborbital Model System *(~hours)*



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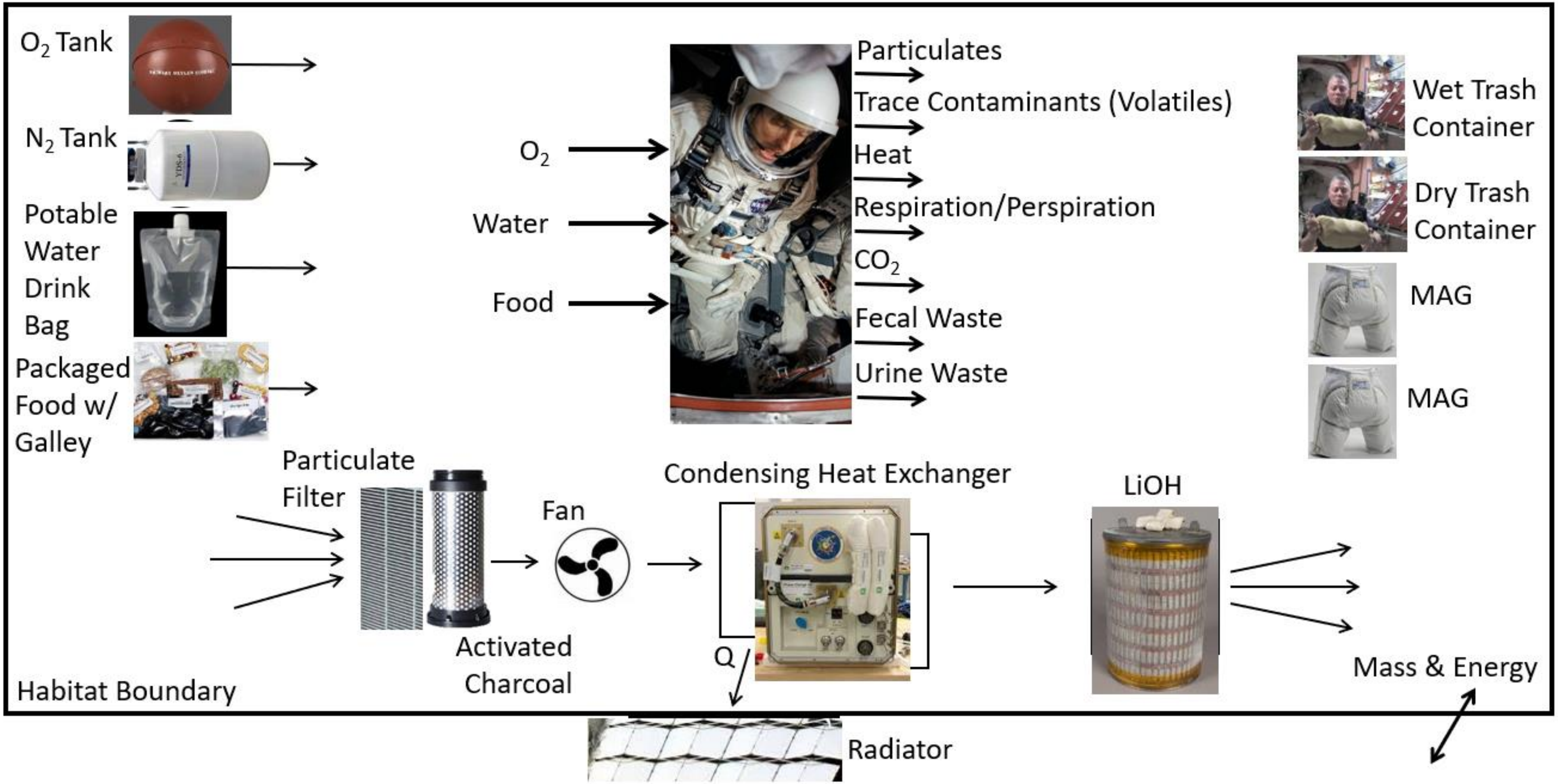
ECLSS Orbital Model System (*~days*)



ECLSS Orbital Model System (*<1 month*)

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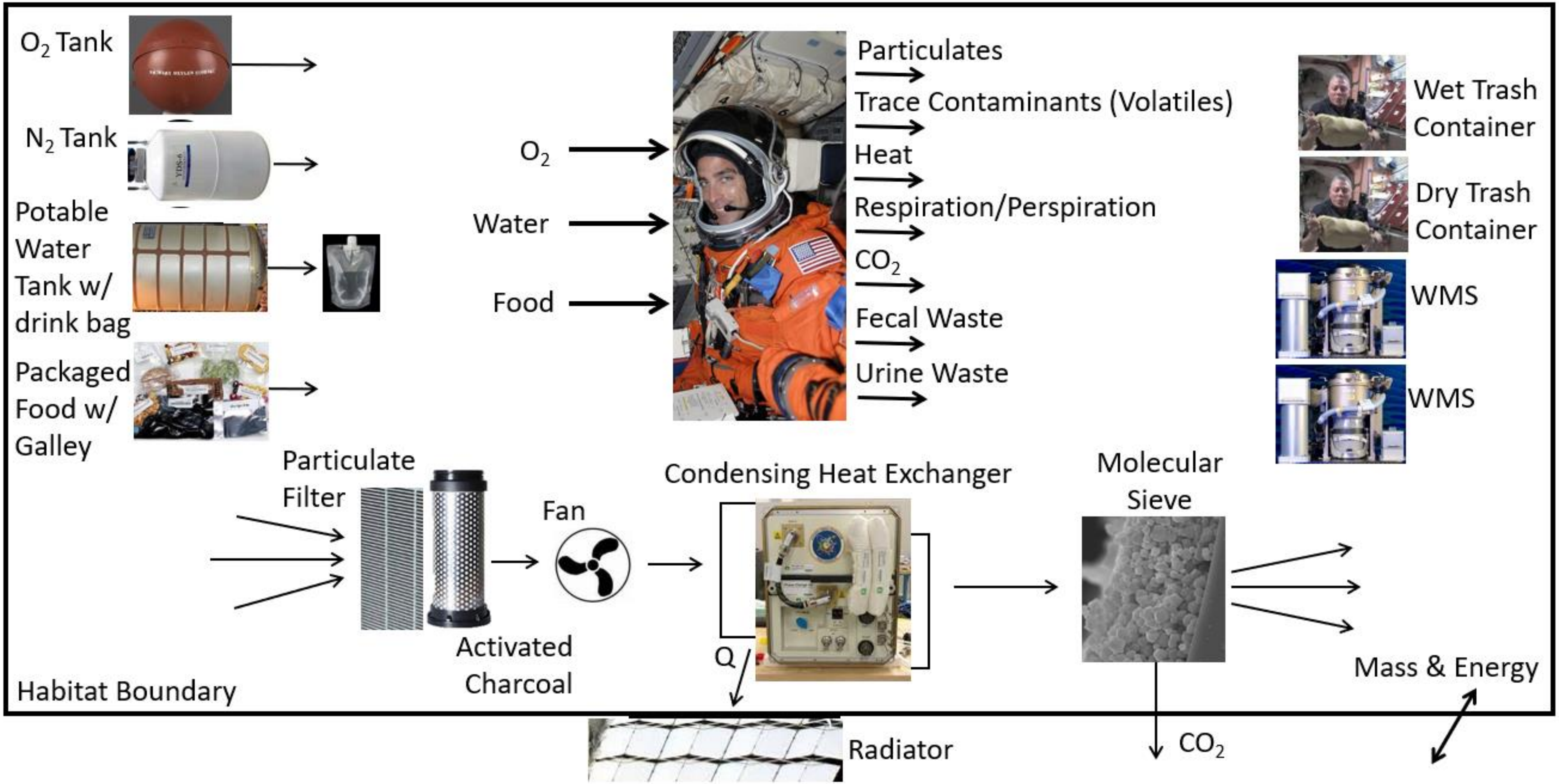
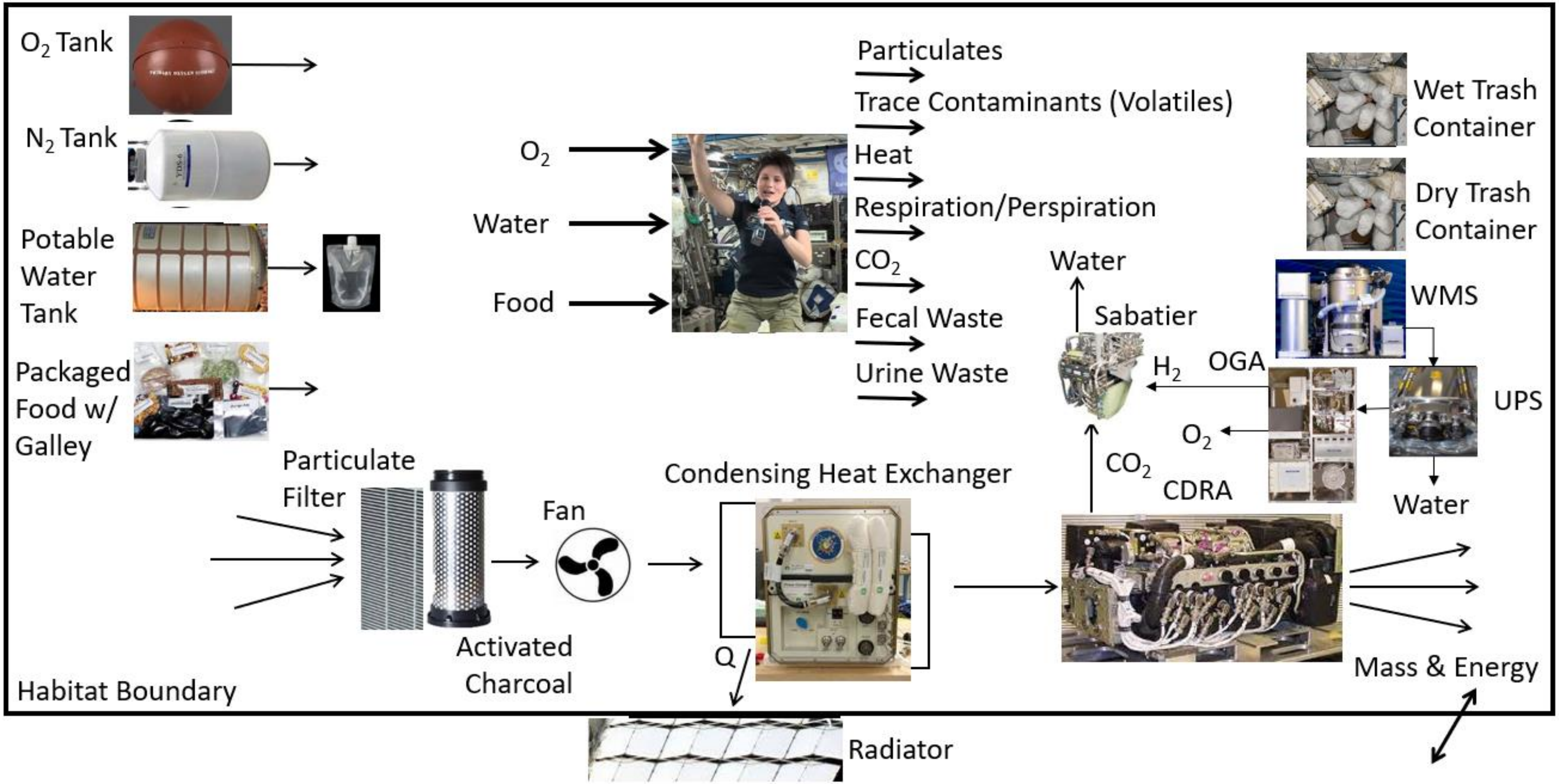
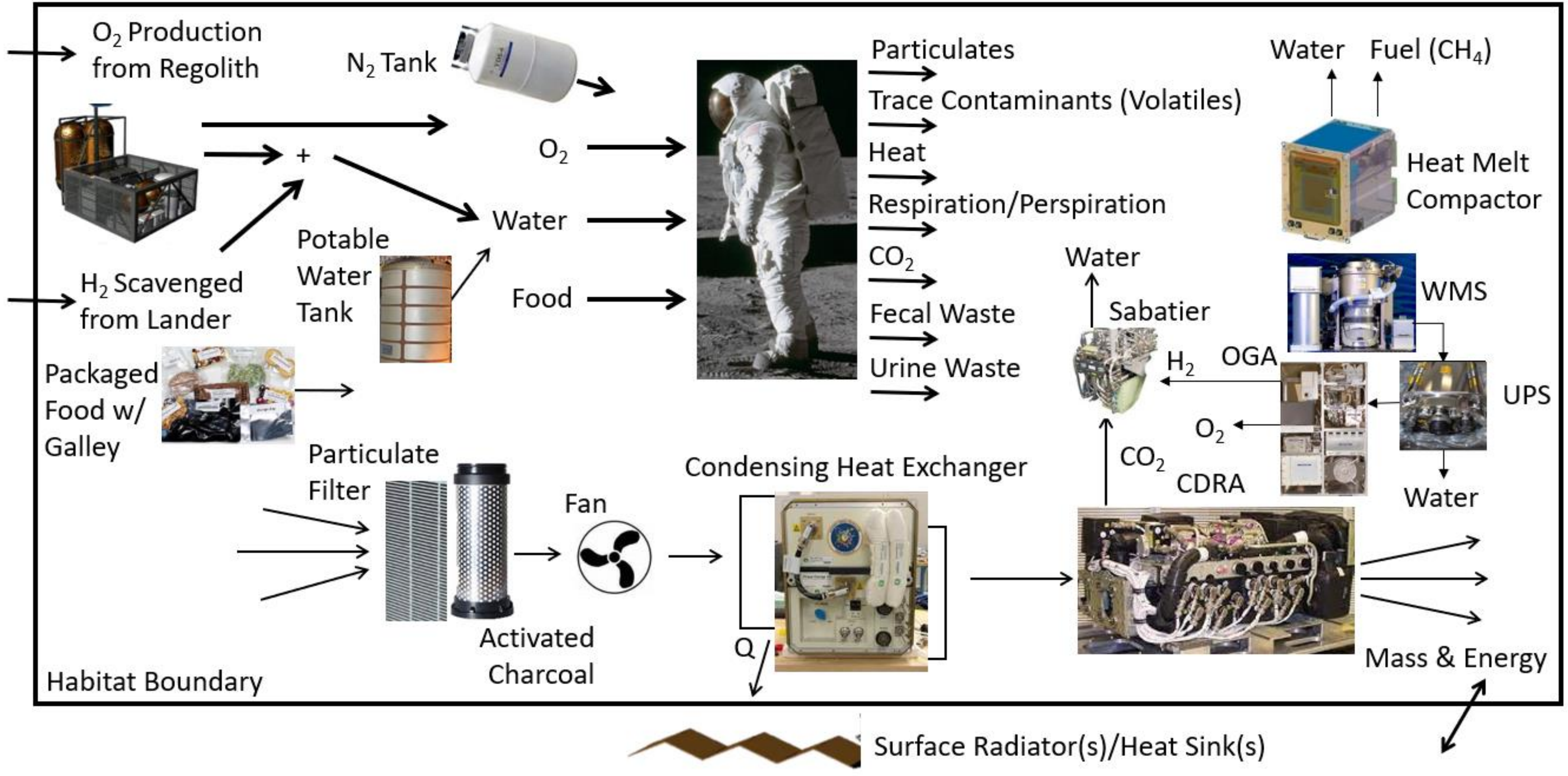


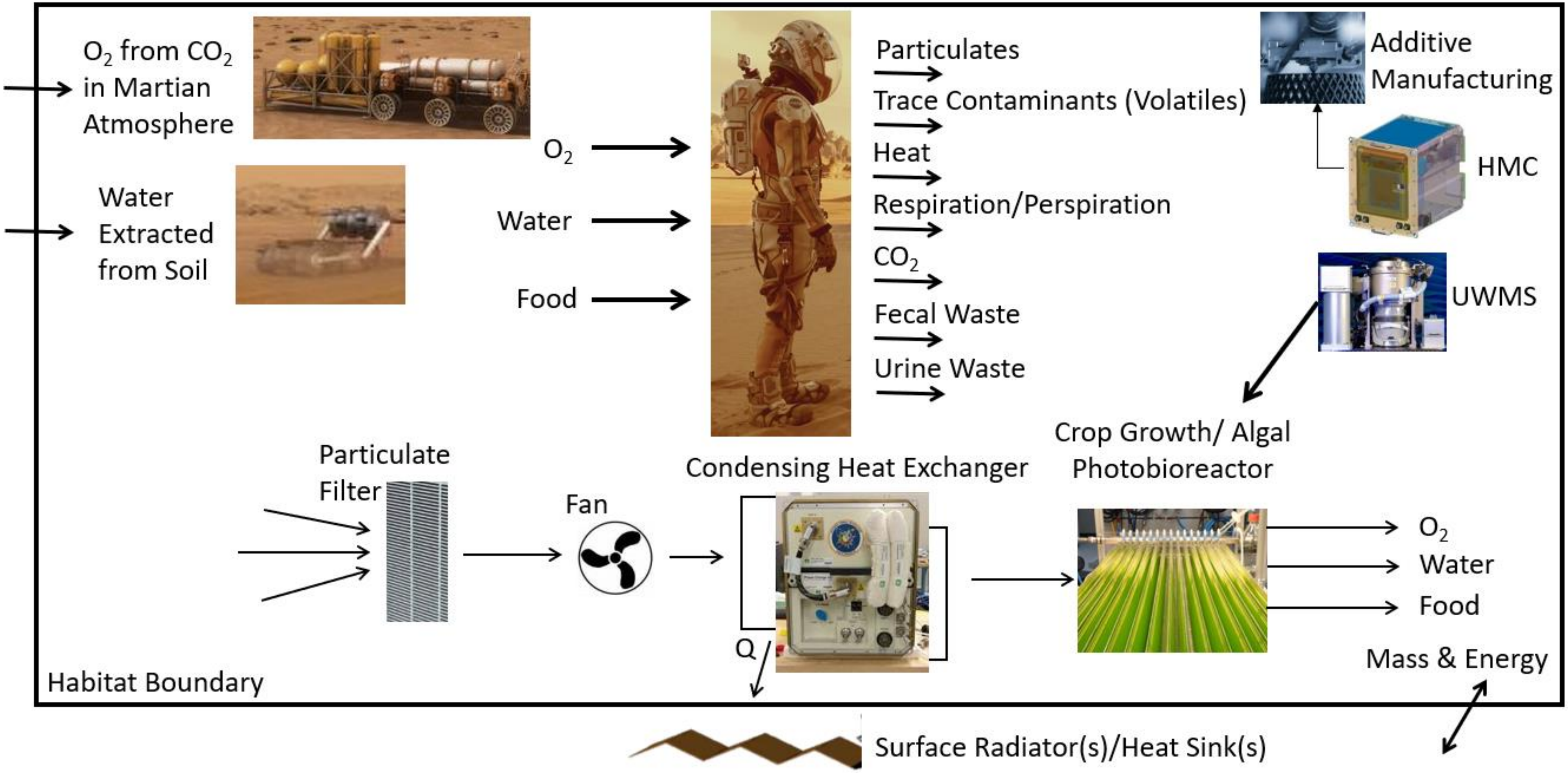
ECLSS Orbital Model System *(>1 month)*



Lunar Habitat Model System (*TBD duration*)



Mars Habitat Model System (*indefinite*)



Results – ECLSS Technology Categories

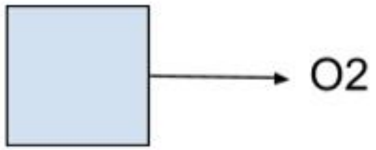
- Atmosphere Regulation
- Potable Water Provision
- Food Provision
- Waste Management

- *Regenerative Technologies, Consumable Recovery and ISRU*

- ECLSS Technology Specification Sheets
- ECLSS Technology/Component Vendors

Sample ECLSS Technology Specification Sheet

1.1.1a Oxygen Tank (High Pressure Gas)



Function	*Atmospheric pressure and composition regulation - provision of gaseous oxygen*
Mode	*Active - high pressure storage/ release*
Description	*Oxygen is stored in a tank at a high pressure until it is released for consumption by the spacecraft inhabitants*
Performance Requirements	*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.*
Primary Inputs	*Gaseous oxygen (high pressure)*
Primary Outputs	*Gaseous oxygen (regulated to cabin pressure)*
Expendable Inputs	*Full tanks*
Expendable Outputs	*Empty tanks*
TRL (1-9)	*9, currently in use on the ISS, historically used on various vehicles*
Validation/ Initial Acceptance Criteria	*Confirm that functional requirements for the specified mission profile are mapped to technologies present in the vehicle*
Verification Compliance	*Demonstrated by design, inspection, analysis, test, and/or certification* ***Flight testing on parabolic aircraft, if standardized could be by certification* ** Gravity-dependent verification .*
Reference(s)/ Vendor(s)	*Worthington Industries* *https://worthingtonindustries.com/Products/High-Pressure-Composites/Space*
Prepared by	*Kaitlyn Hauber* *5-16-2021*

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

Please include publications, presentations, awards, and recognitions you have received for the past year.

Acknowledgements

The FAA has sponsored this project in part through the Center of Excellence for Commercial Space Transportation (Cooperative Agreement 15-C-CST-UC Amendment 25). However, the agency neither endorses nor rejects the findings of this research. The presentation of this information is in the interest of invoking technical community comment on the results and conclusions of the research.