Space Crop Production as a Component of BLiSS

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Bioregenerative Life Support Systems (BLiSS) Research Campaign 2024

Human Life Support Requirements

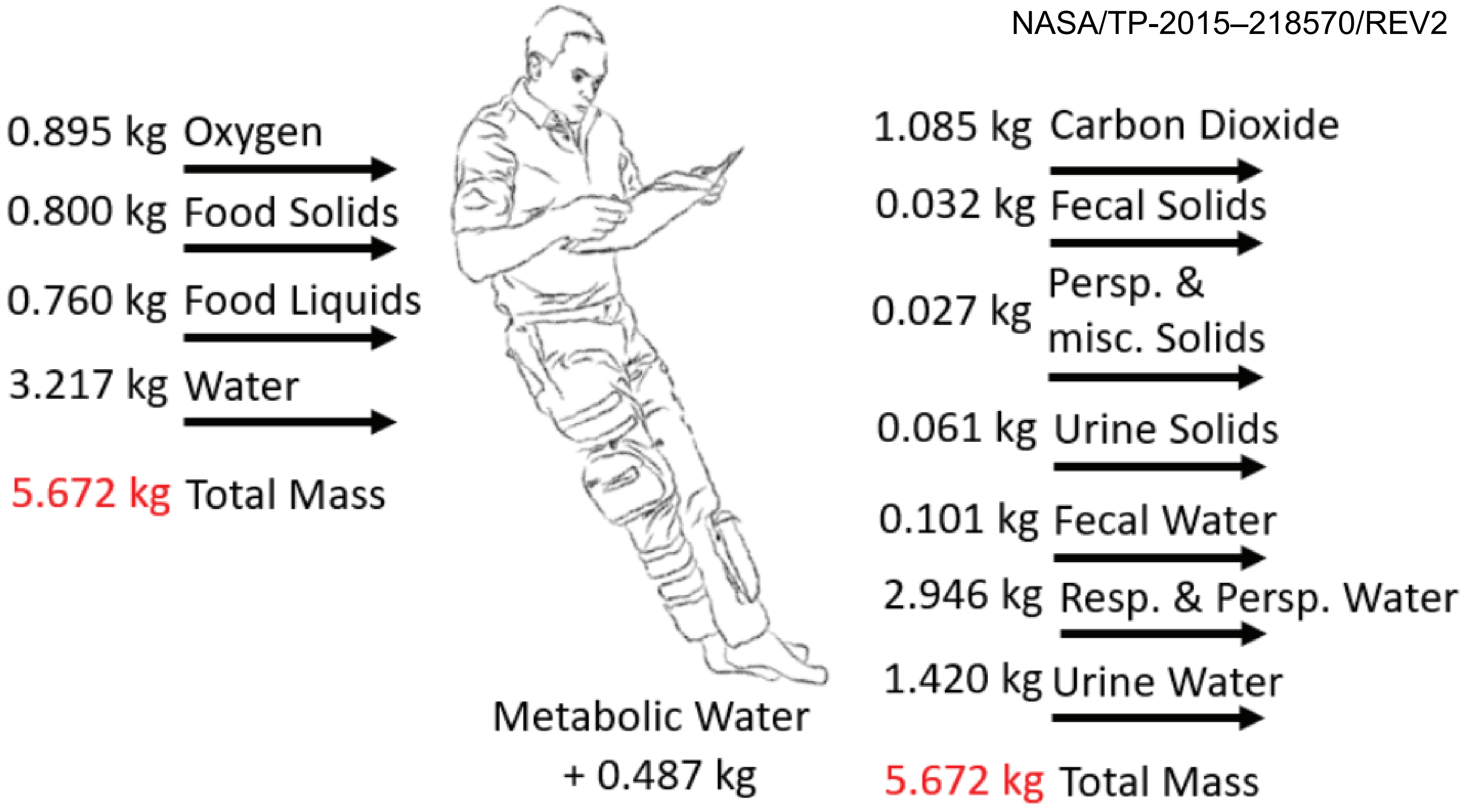
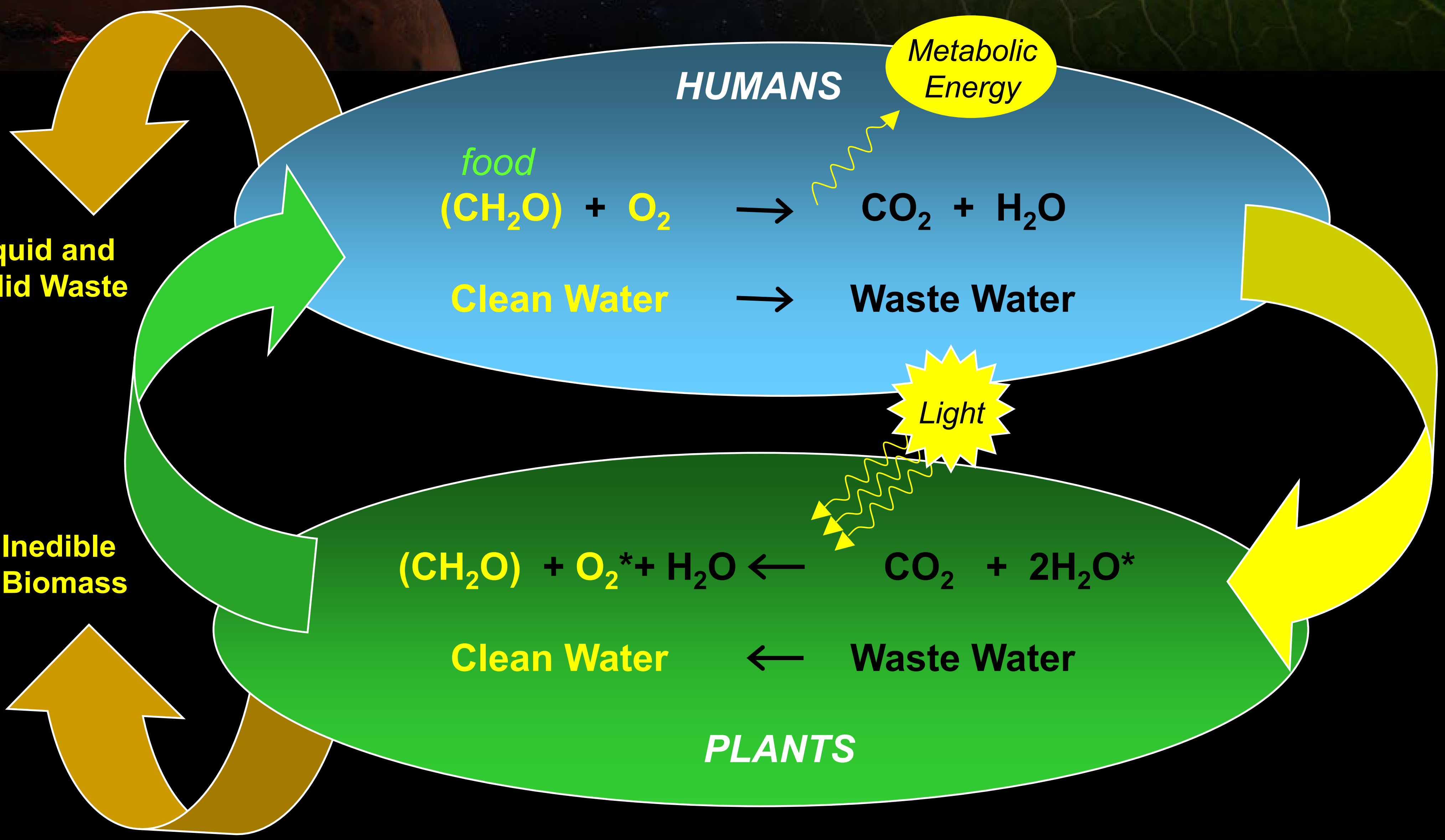


Figure 3-4 Daily mass balance of an 82 kg astronaut

From: Life Support Baseline Values and Assumptions Document, https://ntrs.nasa.gov/api/citations/20210024855/downloads/BVAD_2.15.22-final.pdf

Plants for Bioregenerative Life Support



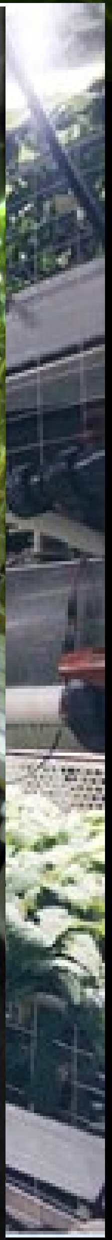
Wheeler et al., 2001. In: Tako et al. (Eds.) Proc. IES CEEF.

Key Considerations for Plants in BLiSS

- Assuming moderate to high light intensity (> ¼ sunlight) provided to plants:
  - ≈20 m^2 plants can provide O_2 and remove CO_2 for one human[(1)]
  - ≈5 m^2 plants can provide enough water (condensed transpiration) for 1 human[(1)]
  - ≈50 m^2 of plants (crops) can provide dietary energy (2500 kcal/day) for one human[(1)]
- Growing area needed for plants to provide exploration crews with required micronutrients/vitamins[(2)] is unknown
- There are a few elemental mismatches between crops and humans – e.g. Na^+
- Other types of regenerative foods could be integrated (algae, fungi, insects, fish, etc.) but acceptability and ease of processing need to be addressed, as would competition for O_2
- BLiSS crop growth configuration will vary with mission architecture/scenario
- Plants are robust, resilient, and plastic in their growth; control systems are not
- Solving these challenges requires a deeply interdisciplinary approach

1. Based on studies at Russian Bios-3 Facility (1970-1980s), NASA Biomass Production Chamber and University Research (1980s-1990s), Chinese Lunar Palace 1 (2010s to present).
2. Smith, Scott M.; Zwart Sara, R, "Nutritional Requirements for Exploration Missions up to 365 days", NASA, JSC-67378 Rev1, 2020. https://ntrs.nasa.gov/citations/20205008306

NASA’s Biomass Production Chamber



NASA’s Space Crop Production Vision

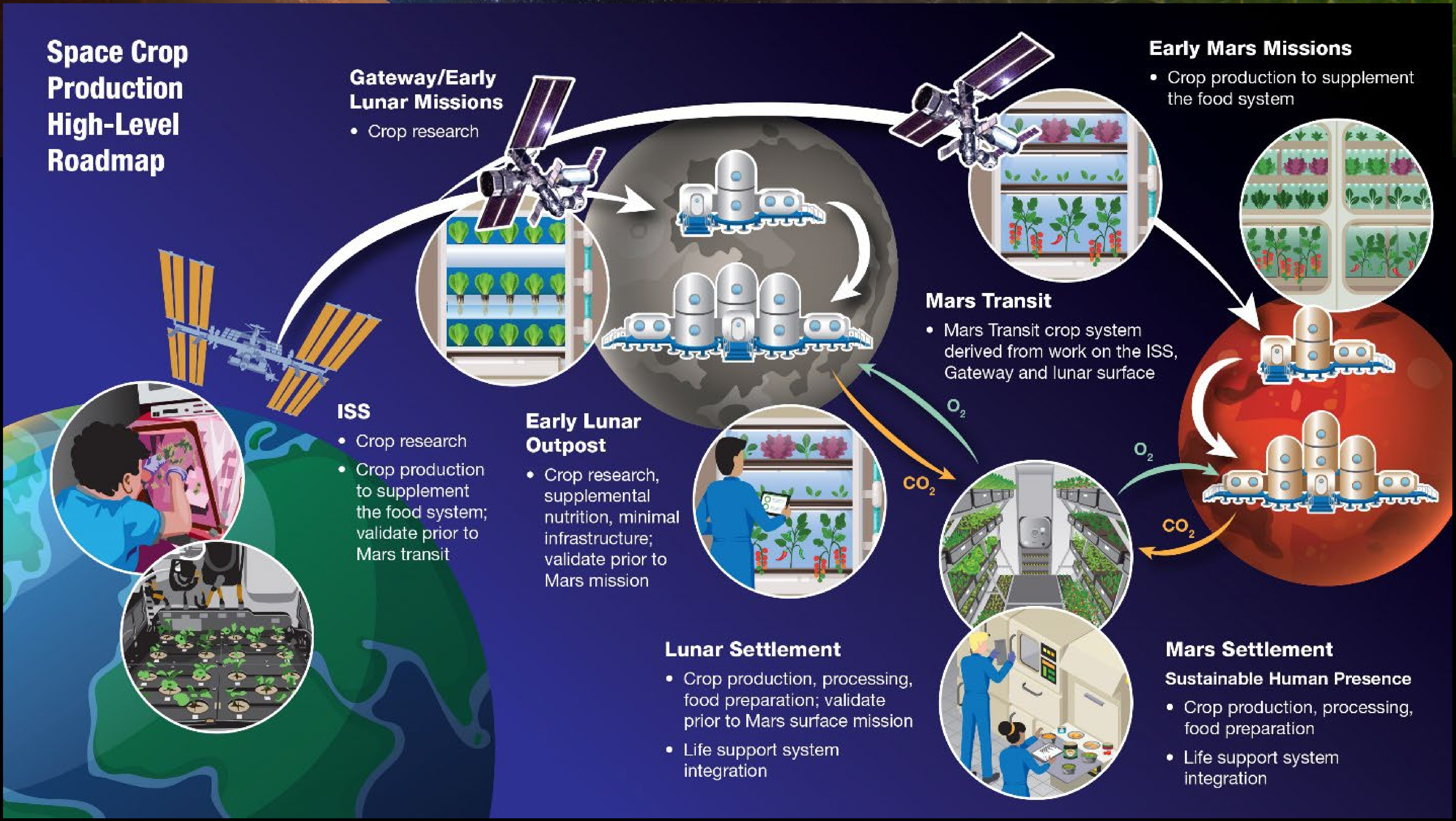
Ensure Food System Security on Long Duration Missions Beyond LEO

Near-Term Goal
Nutrient Supplementation of Prepackaged Food

Near term missions will rely on Physico-Chemical Regenerative ECLSS and Stowed Food with Supplemental Fresh Food

Long-Term Goal
Staple Crops to Move towards Earth Independence

For future, longer duration habitation on the Moon or Mars, Bioregenerative Life Support including Plants can be expanded to increase Mission Autonomy and Earth Independence



Douglas et al., 2021, Sustaining Astronauts: Resource Limitations, Technology Needs, and Parallels between Spaceflight Food Systems and those on Earth, Sustainability

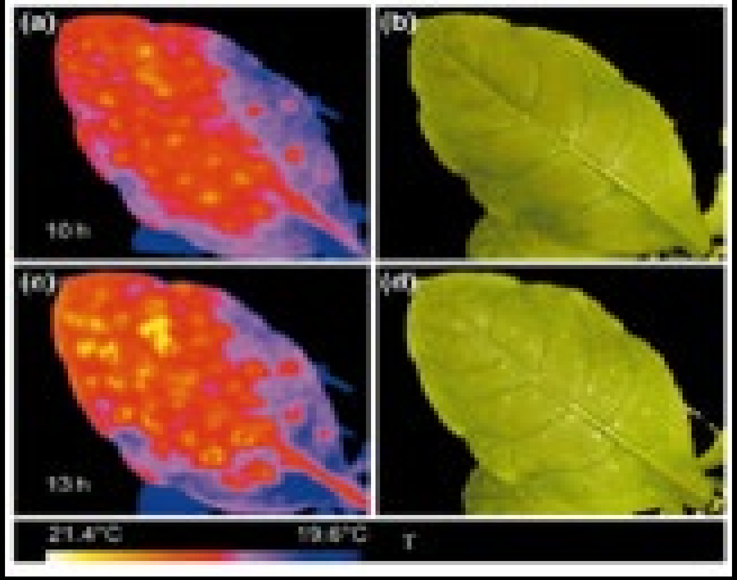
Space Crop Production Gaps

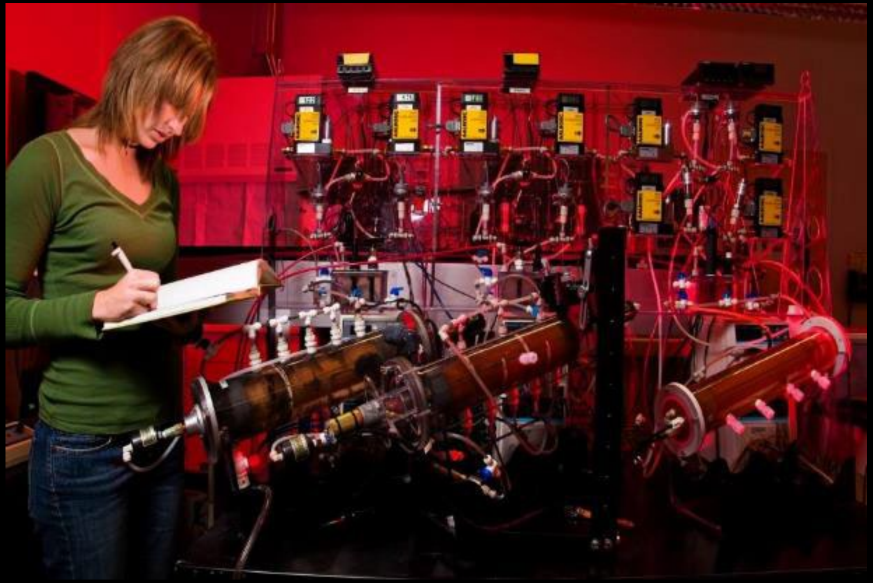
- ~65 different Knowledge and Technology Gaps identified
- Gaps fall into 13 areas related to crops, ecosystems, and hardware
- Highest priority gaps are in the areas of:
    - Crop Performance
    - Environmental Control and Monitoring
    - Microbiome and Food Safety
    - Plant Environmental Response
    - Horticultural Practices
    - Sustainability
    - Systems Architecture
    - Human-Plant Interaction

11m^2 of wheat provided Oxygen needed for one human for 15 days (Nigel Packham, NASA JSC, 1995)

Example Knowledge and Technology Gaps for BLiSS

- Water and nutrient delivery approaches at different gravity levels
- Plant health monitoring technologies
- Lack of effective options to recover resources from inedible plant wastes and human waste streams





Space Crop Production -Feeding Exploration-

ISS LEO Research

HARDWARE SYSTEMS

TECHNOLOGY TASKS
- µG Water and Nutrient Delivery
- µG Volume Optimization
- Growth System Concepts
- Subsystem Technologies

CROP SCIENCE TASKS
- Candidate Crop Selection
- Plant Science
- Terrestrial vs. µg Nutrition

ECOSYSTEM TASKS
- µG Plant/Human Microbiomes
- Food Safety
- Long-Duration Radiation Studies

HUMAN FACTORS
- Long-term Isolation
- Psychosocial Plant/Crew Interactions

Gateway Research

HARDWARE SYSTEMS
- Plant Research Habitat
- Suite of Plant Research Tools Adapted from ISS

TECHNOLOGY TASKS
- Seed Storage Systems
- Water and Nutrient Delivery for Gateway Plant Habitat

CROP SCIENCE TASKS
- Candidate Crop Selection
- Long-Duration Seed Storage

ECOSYSTEM TASKS
- Microbiome Studies
- Radiation Studies
- Food Safety Assessments

LEVERAGE GATEWAY CONCEPT OF OPERATIONS
- Logistics Flights

Mars Transit Vehicle Operations

OPERATIONAL SYSTEM
- Supplemental Food Production Capability for Pick-and-Eat Crops
- Plant Care as Meaningful Work
- Preliminary Long-Duration Shakedown

Mars Surface Operations

OPERATIONAL SYSTEM
- Leverage Lunar Surface and µG Experience in Operational Crop Production
  - Systems to Move towards Earth Independence
- Pick-and-Eat and Staple Crops
  - Scale to Habitat, Mission
  - Robotics and Automation
- Bioregenerative Life Support Systems (BLiSS)
- Potential for Incorporation of ISRU

Ground Research

HARDWARE SYSTEMS
- Water Delivery Testing
- Ground Control Hardware

TECHNOLOGY TASKS
- Water and Nutrient Delivery
- Water Loop Closure
- Volume and Resource Optimization
- Lighting
- Plant Health Monitoring and Advanced Plant Imaging
- Automation
- Sensors

CROP SCIENCE TASKS
- Candidate Crop Selection
- Plant Science
- Nutrition
- Sensory Acceptability
- Radiation Studies

ECOSYSTEM TASKS
- Microbiome Characterization and Engineering
- Food safety

HUMAN FACTORS
- Use of Ground Analogs
  - CHAPEA
  - EDEN-ISS
  - DLR Ground Test Demonstrator

Lunar Surface Operations

HARDWARE SYSTEMS
- Develop and Test H/W Systems
- Sustained Operations
- Demonstrate Component Longevity and Crew Operability

TECHNOLOGY TASKS
- Partial G Water and Nutrient Delivery
- 3/8 G Simulation with Centrifuge
- Model Validation for Water and Airflow
- Hybrid Lighting
- Regolith Evaluation
- Automation

CROP SCIENCE TASKS
- Long-Duration and Multigenerational Growth
- Crop Responses to 1/6 G
- Crop Validation

ECOSYSTEM TASKS
- Microbiome Studies
- Ecosystem Succession and Evolution

EARTH INDEPENDENCE

Funding Sources

- Space Biology
- Human Research Program
- Mars Campaign Office
- Other

Partnerships

- USDA
- Australian Centre of Plants for Space (P4S)
- Canadian Space Agency
- German Space Agencyy
- Growing Beyond Earth
- Winston Salem State Univ.
- Florida Inst. of Technology
- Univ. of Florida
- DOD

Thank you!

- Space Crop Production team
- NASA's Biological and Physical Sciences Division, Human Research Program, Mars Campaign Office, SBIR program