An Independent Assessment of the Technical Feasibility of the Mars One Mission Plan

Updated Analysis

Sydney Do, Koki Ho, Samuel Schreiner, Andrew Owens, Olivier de Weck
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

Original Paper: http://bit.ly/mitM1

FISO Telecon 02-11-15

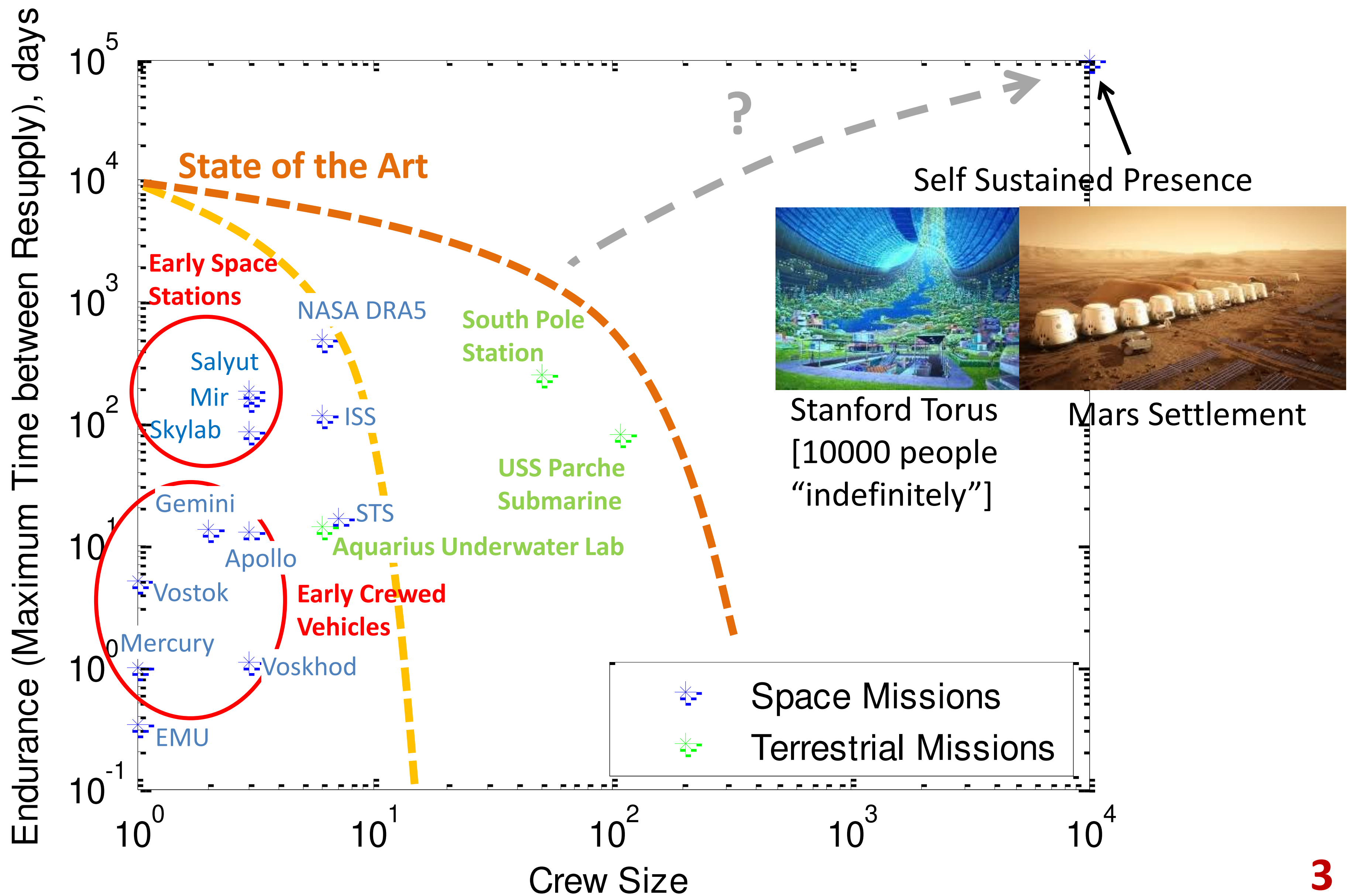
Massachusetts Institute of Technology

Topics of Today's Discussion

- Research Motivation
- Case Study: Mars One Mission Plan
- Analysis Approach and Assumptions
- Analysis Findings
- Summary and Conclusions

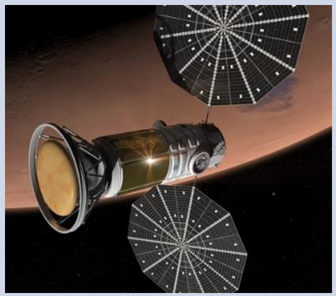
Massachusetts Institute of Technology

Objective Space: Mission Endurance vs Crew Size



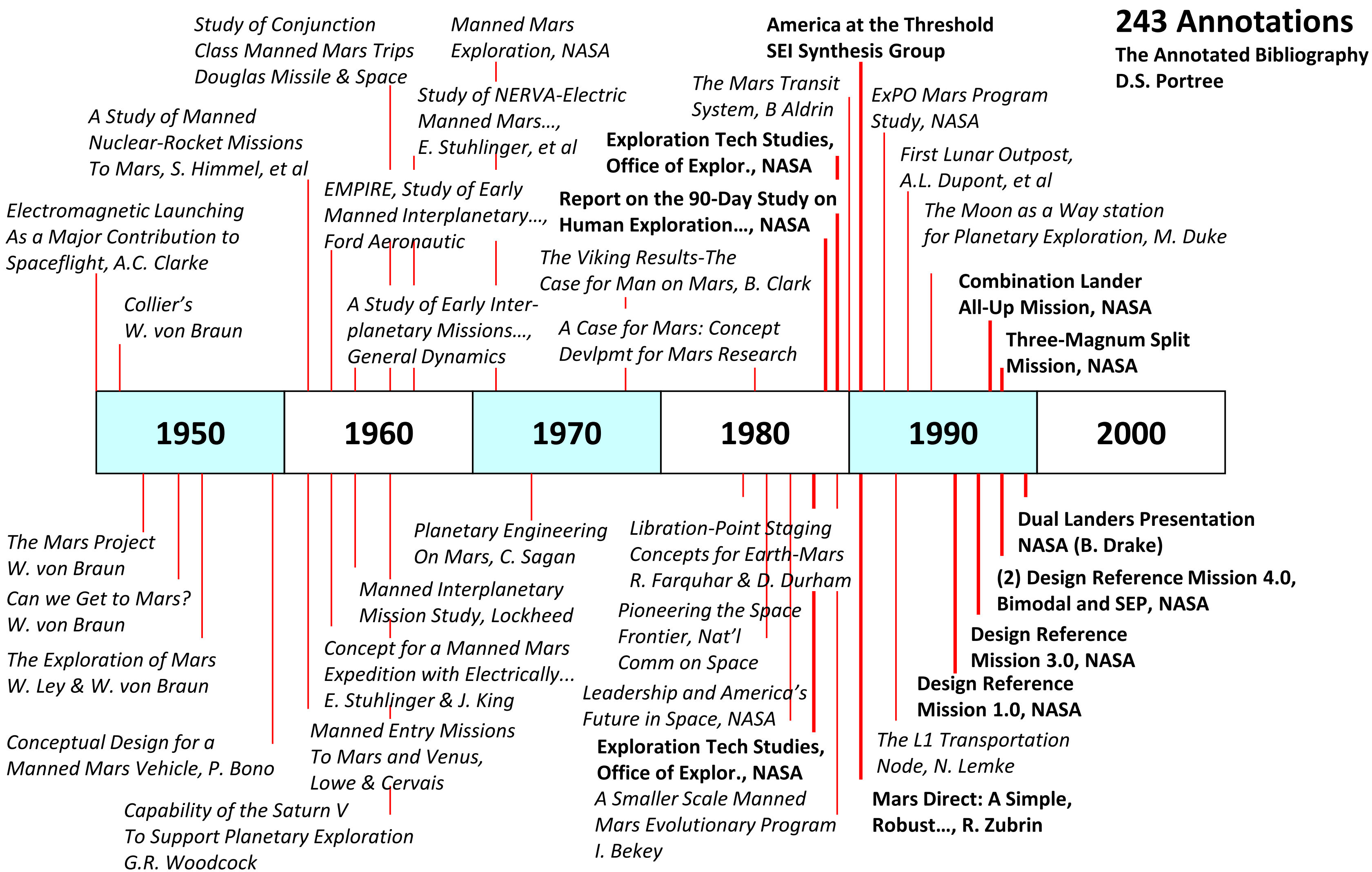
Massachusetts Institute of Technology

Classes of Space Habitation Mission Modes

	Fixed Crew	Increasing Crew
No EVA	**Crew in a Can**  (Inspiration Mars)	**Terrarium Mode**  (Stanford Torus ie. Space Hotel)
With EVA	**Exploration Mode**  (Mars DRA 5.0, CxP Lunar Outpost)	**Colonization Mode**  (Mars One)

Massachusetts Institute of Technology

Timeline for Mars Studies*



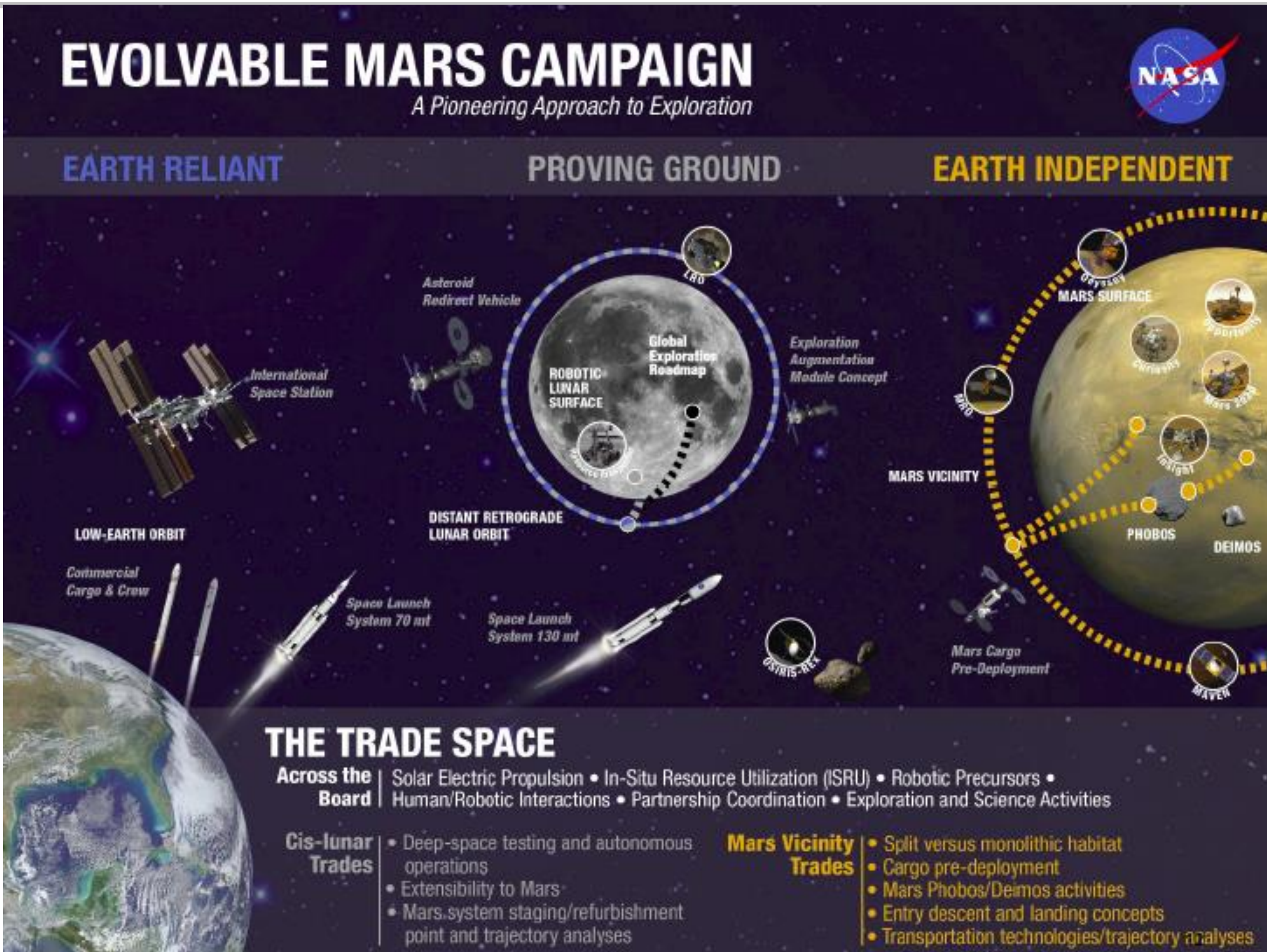
*A Comparison of Transportation Systems for Human Missions to Mars, AIAA 2004-3834

Bold type represents selected studies

Slide adapted from Toups, L., 2012, *Mission Architecture for Mars and Habitation Capability for Deep Space*, Presentation at ICED2012

Massachusetts Institute of Technology

Evolvable Mars Campaign

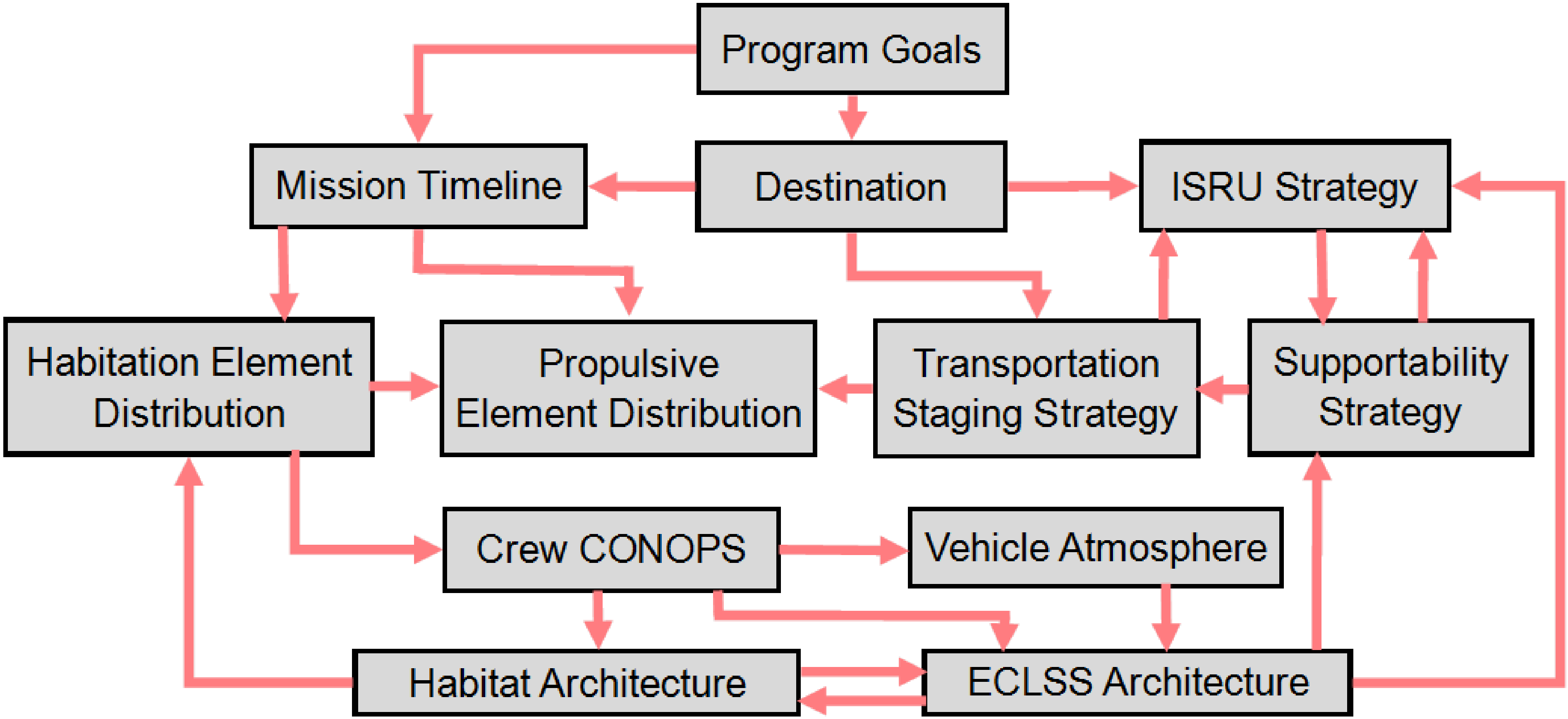


House Committee on Science, Space and Technology Hearing (2/27/2014)

"As we discuss what going to Mars means, we have to be aware of once we get to Mars – what are we going to do there? …
One of the problems with the Lunar program… we went to the Moon, and then it was: 'Okay, we've been to the Moon, now what?' And now it's: 'We've been there done that and we shouldn't go back again'; so we need to have a big picture plan.
What are we going to do? We're going to go to Mars, and we're going to do X, so we just don't go to Mars and then we stop going to Mars cause we've now been to Mars." *Sandy Magnus*, Executive Director, AIAA

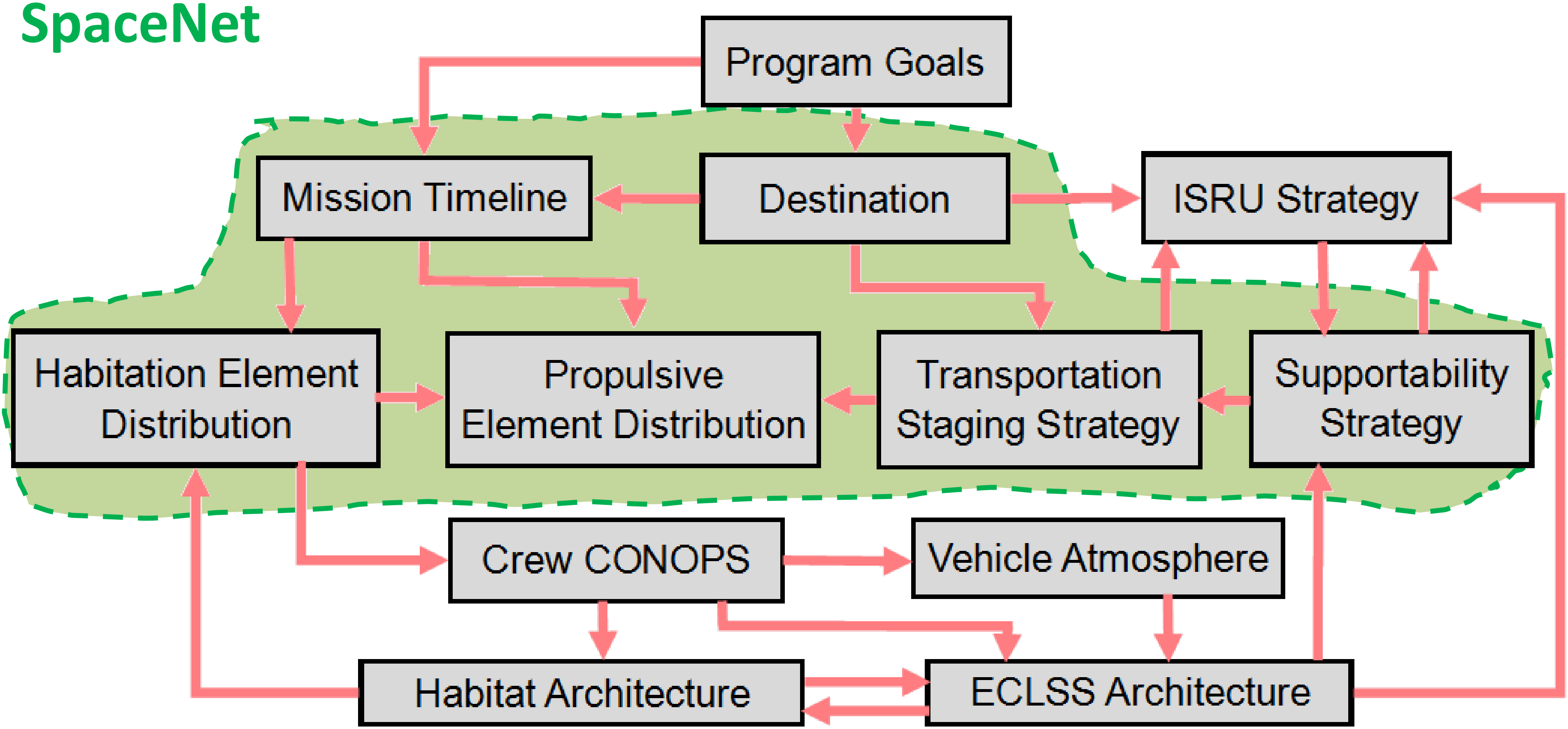
Massachusetts Institute of Technology

Simplified Architecture Decision Graph for Exploration Campaigns

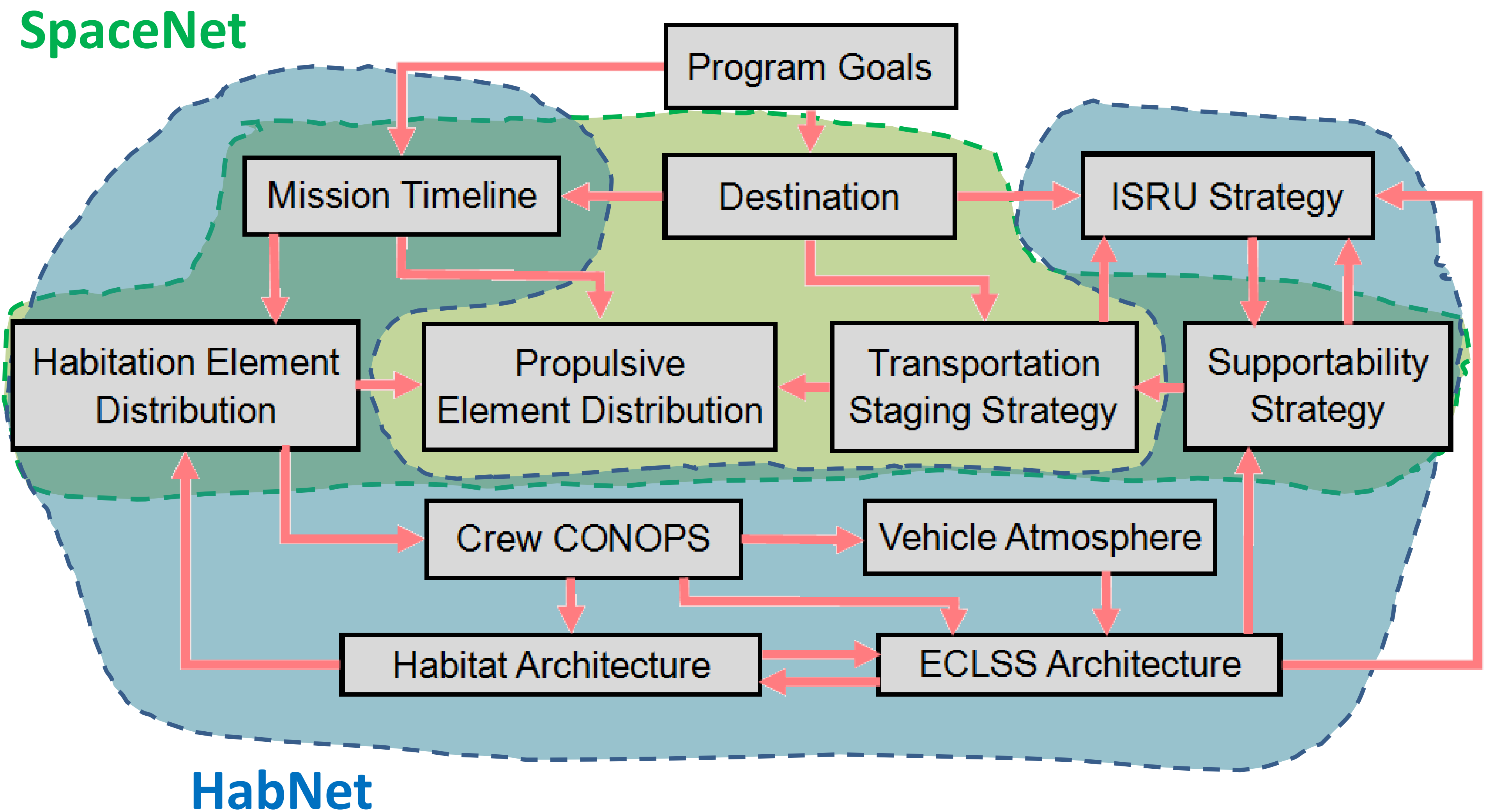


Simplified Architecture Decision Graph for Exploration Campaigns

SpaceNet



Simplified Architecture Decision Graph for Exploration Campaigns



Case Study:
Mars One Mission Plan

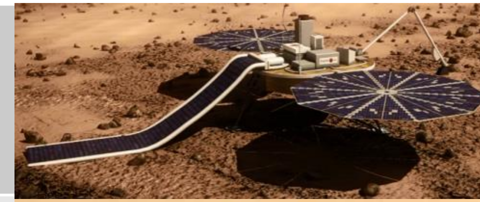
Massachusetts Institute of Technology

Mars One Mission Overview

Summary:
Gradual colonization of Mars via successive four-person, one-way missions to Mars starting in 2024

Mission Design Philosophy:
1. Permanent settlement
2. Maximize ISRU
3. All power from solar
4. Exploit currently available technology
5. International mission

Claim:
"No new major developments or inventions are needed to make the mission plan a reality. Each stage of Mars One mission plan employs existing, validated and available technology."

Phase	Year	Image
Precursor	2018	
Pre-deploy	2020	
Habitat Pre-deploy	2022 to 2023	
1st Crew Transit	2024	
Expansion	2025	

Analysis Focus

Massachusetts Institute of Technology

Integrated Simulation Overview

Habitation Module

- Functional ECLS model based on NASA JSC BioSim
- Captures resource interaction between EVA, ECLS, and Biomass Production
- Plant model based on NASA Modified Energy Cascade Models

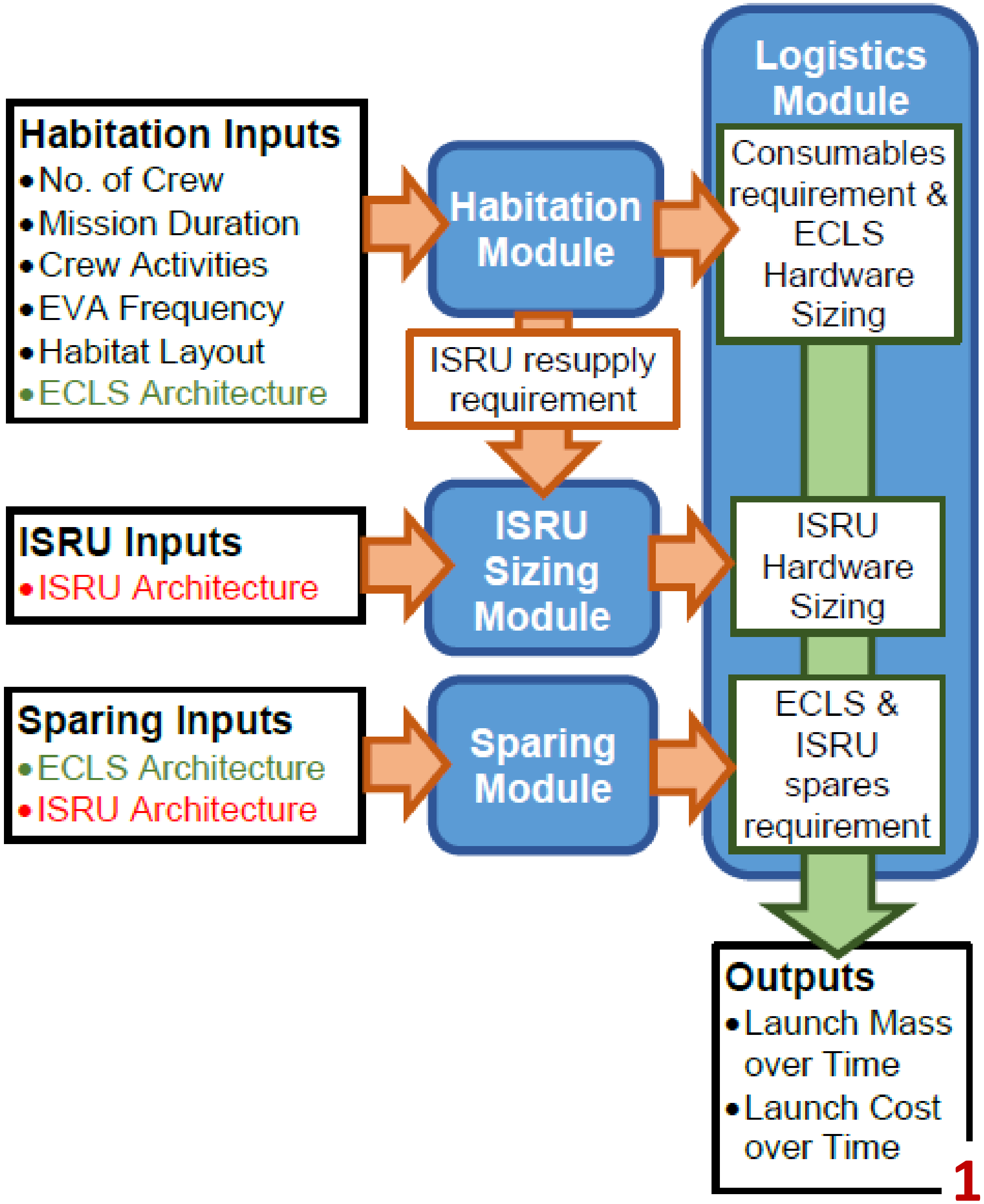
ISRU Module

- Sizing models for:
  - Soil processor oven (H_2O extraction)
  - Atmosphere processor (N_2 extraction)

  based on conceptual ISRU designs

Sparing Module

- Models systems as a Semi-Markov Process (SMP) to determine no. of spares to ensure >99% probability of having enough spares to repair all failures over the mission lifetime
- Random failure modeled by exponential distributions based on part MTBF and LL



Life Support Unit - The Te

www.mars-one.com/technology/life-support-unit

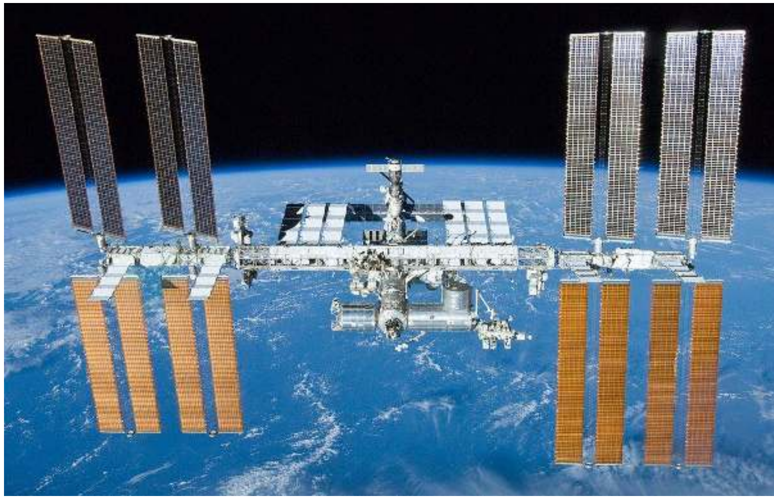
what we breathe on Earth is the element nitrogen.

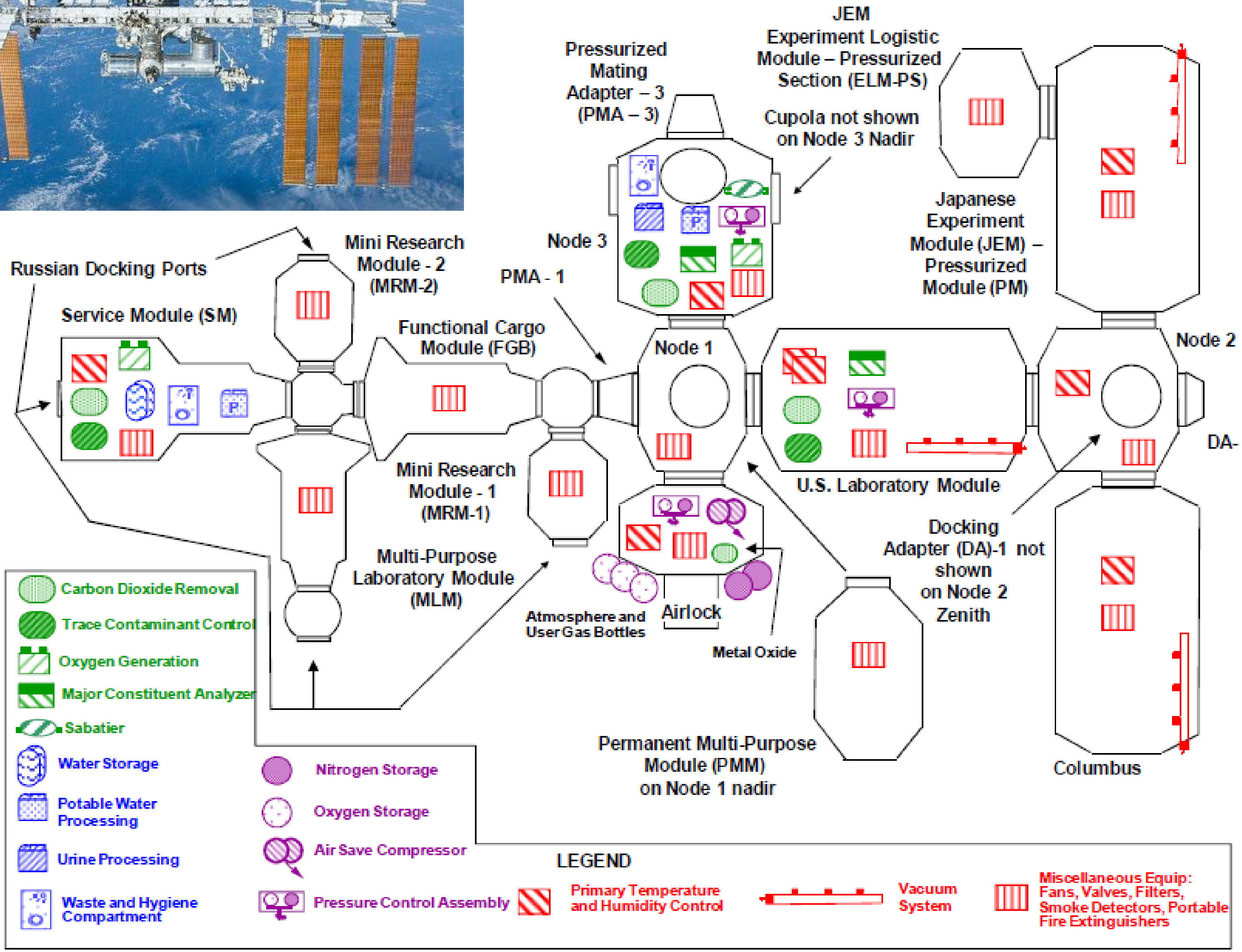
The Life Support Unit is connected to the Living Unit by a tube which feeds the oxygen, nitrogen, and argon to create a habitable atmosphere. Once the astronauts have landed, it will also be in charge of the water purification and removal of waste gas (carbon dioxide) from the Living Unit atmosphere.

The Life Support Unit is hosted inside a Lander. This system will be very similar to those units which are fully functional on-board the International Space Station.

Back to the technology overview

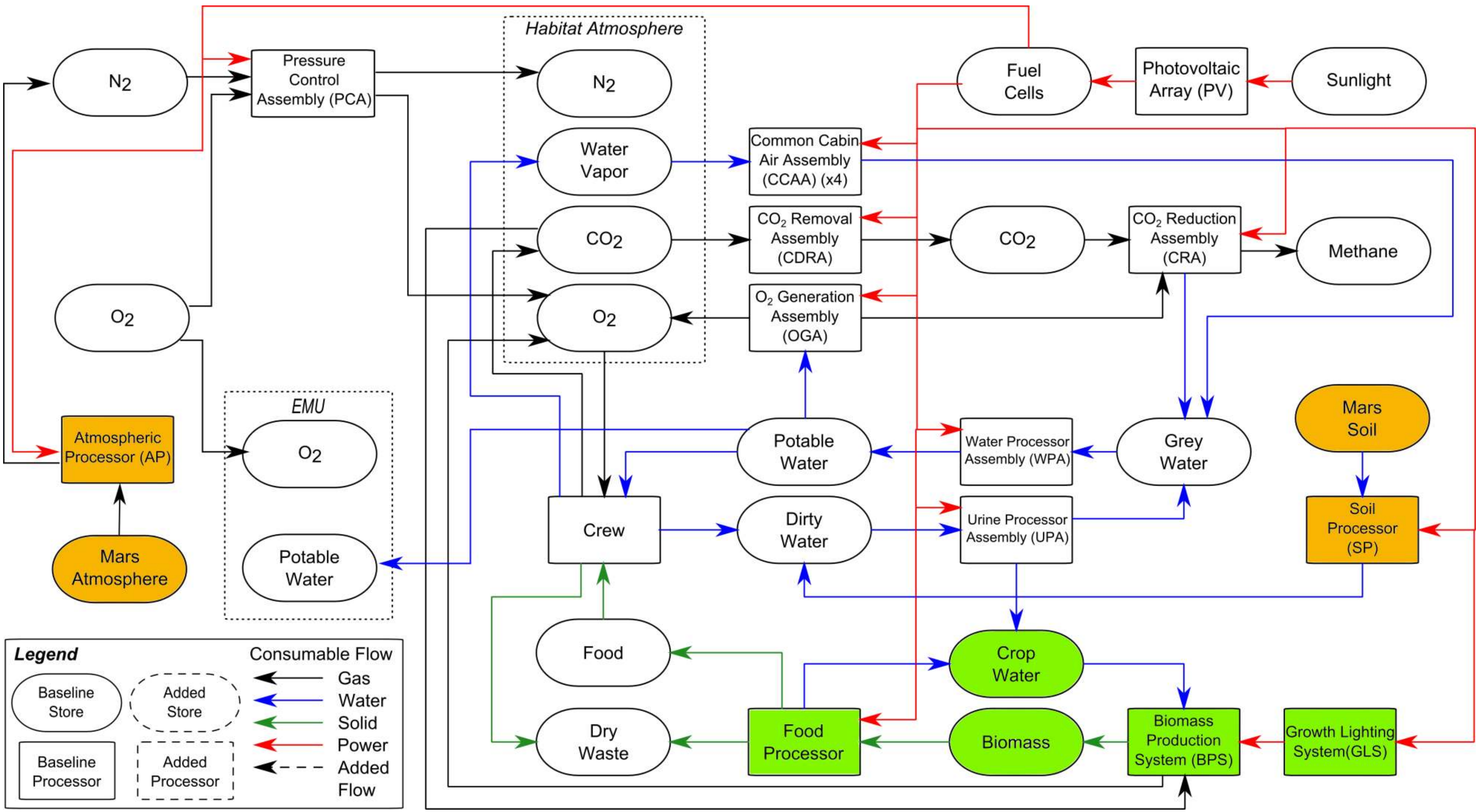
ISS Life Support Technologies





Massachusetts Institute of Technology

Baseline Mars One ECLS and ISRU Architecture



Will the astronauts have e…

www.mars-one.com/faq/health-and-ethics/will-the-astronauts-have-e

requirements.

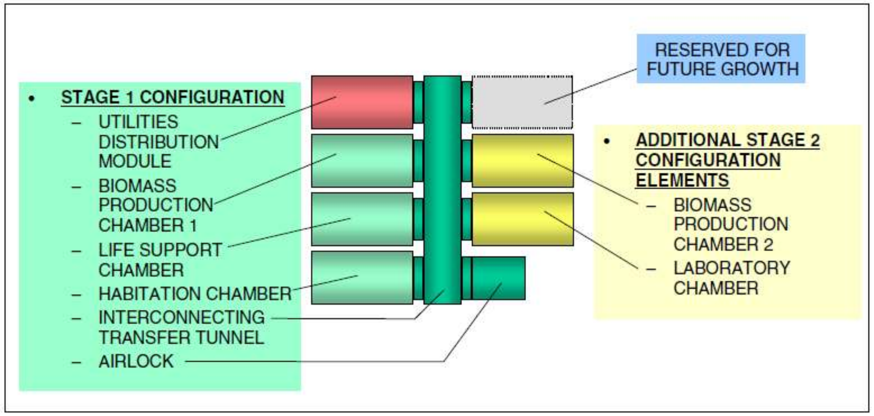
In total there will be about 50 m^2 available for plant growth. A thick layer of Martian soil on top of the inflatable habitat will protect the plants (and the astronauts) from radiation. CO_2 for the plants is available from the Mars atmosphere and water is available through recycling and from the soil of Mars.

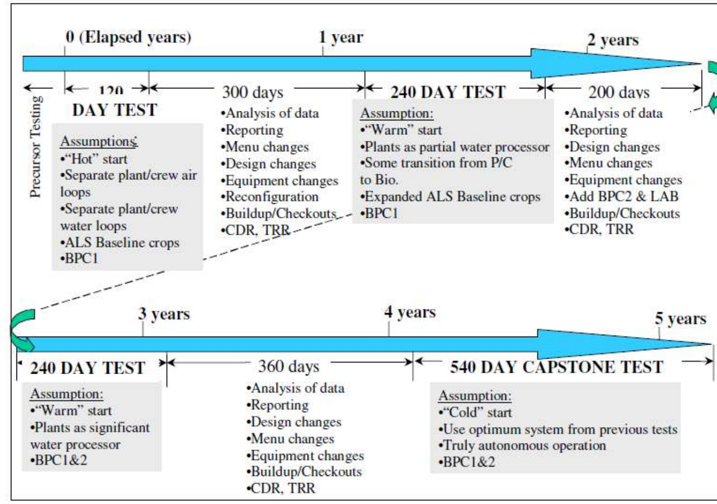
There will be sufficient plant production capacity to feed about three crews of four. Any plant production surplus will be stored as emergency rations for the second crew, and for other emergencies. Non-edible parts of the plants will be recycled, or will be stored until more advanced recycling equipment is shipped from Earth.

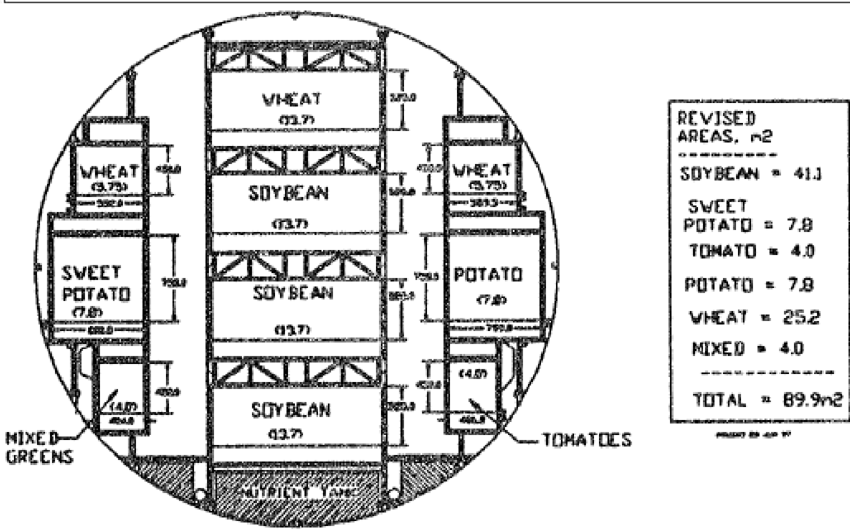
Back to the FAQ overview

NASA Bio-PLEX Program

- NASA program initiated ~1988 to develop an integrated biological life support system / habitation testbed
- Three test phases planned: 425 day, 120 day, and 240 day tests
- Program funding cancelled in 2002







For more info, see: SAE 972342,SAE 1999-01-2186

Massachusetts Institute of Technology

Preliminary Analysis Findings: Diet Planning and Crop Selection

Mars One Baseline:
Food is 100% locally grown

Diet Planning:

- Caloric budget: 3040.1Calories/CM/day
- Target diet: 68% carbs, 12% protein, 20% fat
- Determine growth area via optimization:

$$\min w_1 \sum_{i=1}^{i=9} x_i + w_2 \sigma(\mathbf{x})$$

Total area (min. system mass)

Standard Deviation (max. variety)

$$\text{s.t.} \quad \sum_{i=1}^{i=9} c_i r_i x_i \geq 2067.2$$

Meet minimum carb req.

$$\sum_{i=1}^{i=9} p_i r_i x_i \geq 364.8$$

Meet minimum protein req.

$$\sum_{i=1}^{i=9} f_i r_i x_i \geq 270.2$$

Meet minimum fat req.

$$x_i \geq 0 \quad \text{for } i = 1,\ldots,9$$

All areas are positive

Selected Crop Growth Areas:

Crop	Growth Area (m^2)
Dry Bean	-
Lettuce	-
Peanut	72.7
Rice	-
Soybean	39.7
Sweet Potato	9.81
Tomato	-
Wheat	72.5
White Potato	4.99
Total Growth Area (m^2)	**199.7**

Mars One claim: $50m^2$ for 12 crew

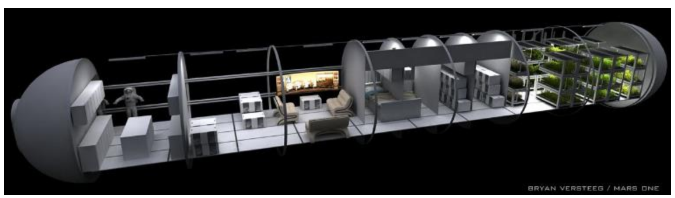
Calculated requirements:

- ~$200m^2$ of plant shelf area for 4 crew
- 875 LED lighting systems
- 22000L of nutrient solution

Assumed Baseline Mars One Habitat Layout

Massachusetts Institute of Technology

Mars One Baseline



Mars One Baseline with Resized Plant Growth System

Legend

- Technologies
- Stores / Tanks
- **Grey** Zones

Atmosphere Control and Supply

PCA: Pressure Control Assembly
PPRV: Positive Pressure Relief Valve
IMV: Intermodule Ventilation Fan
OGA: Oxygen Generation Assembly

Temperature and Humidity Control

CCAA: Common Cabin Air Assembly (contains Condensing Heat Exchanger and Intramodule Ventilation Fan)

Air Revitalization

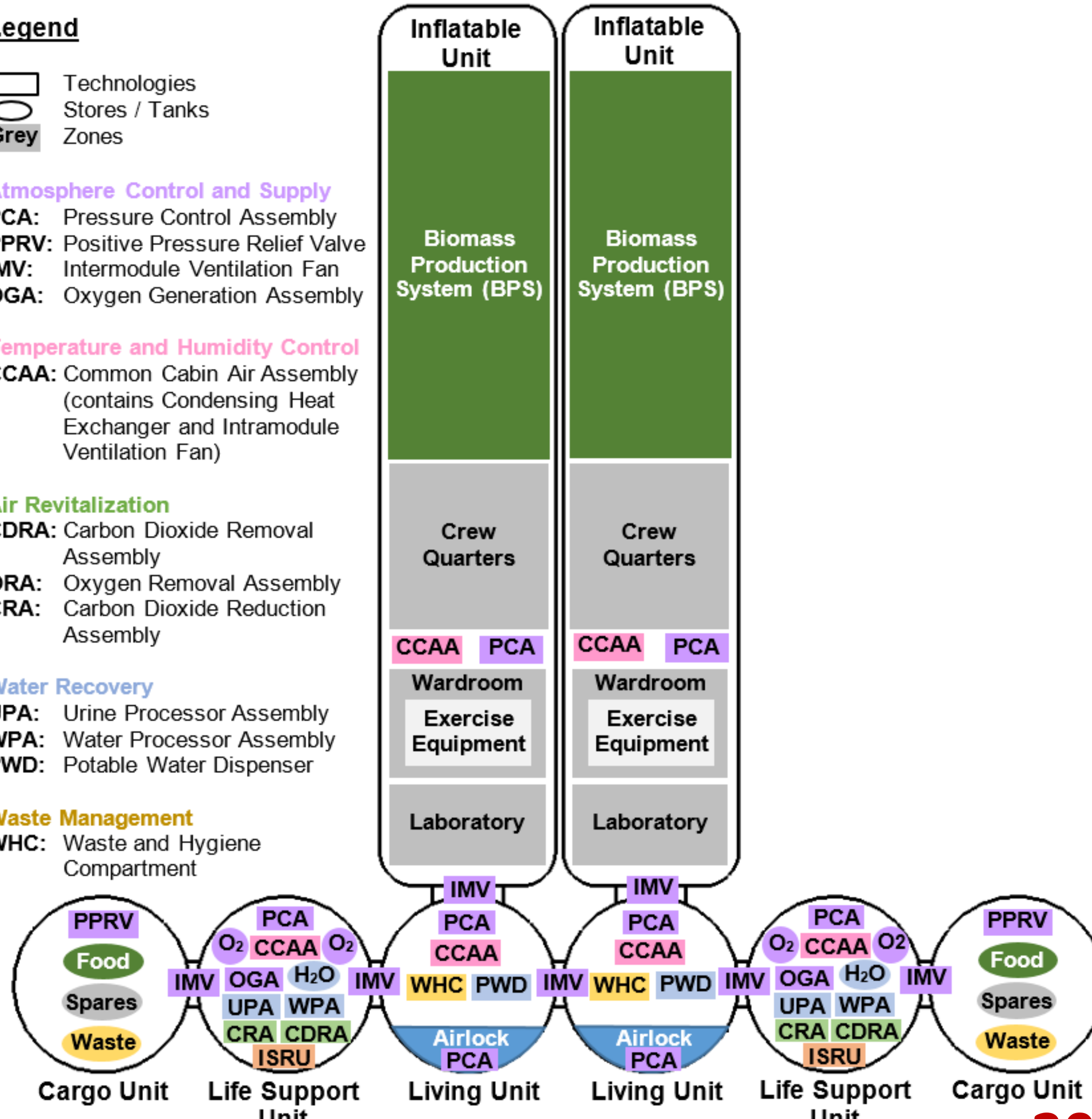
CDRA: Carbon Dioxide Removal Assembly
ORA: Oxygen Removal Assembly
CRA: Carbon Dioxide Reduction Assembly

Water Recovery

UPA: Urine Processor Assembly
WPA: Water Processor Assembly
PWD: Potable Water Dispenser

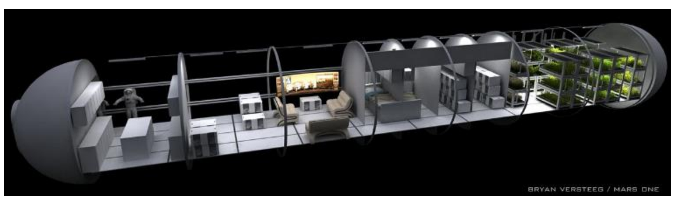
Waste Management

WHC: Waste and Hygiene Compartment

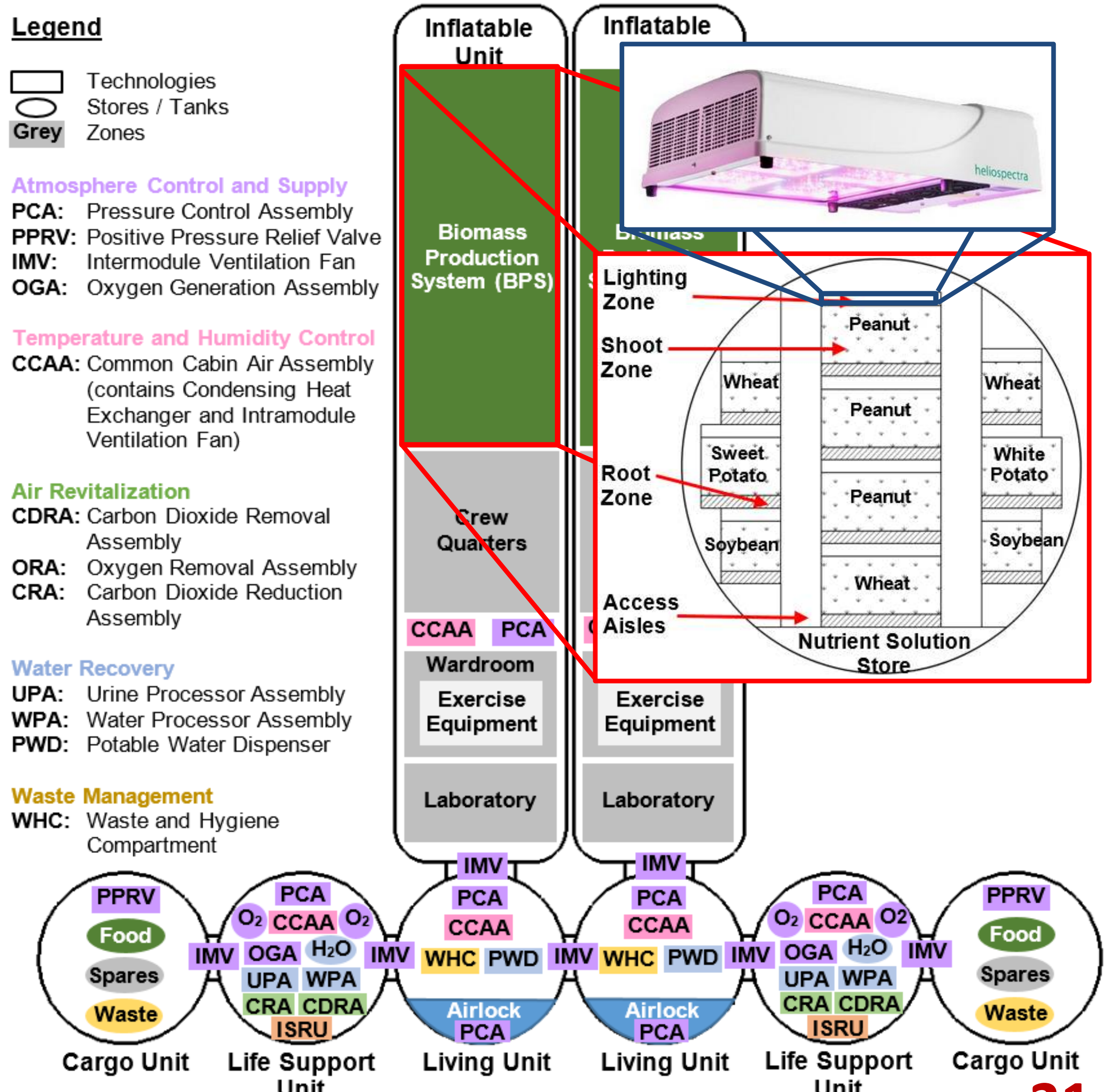


Assumed Baseline Mars One Habitat Layout

Mars One Baseline



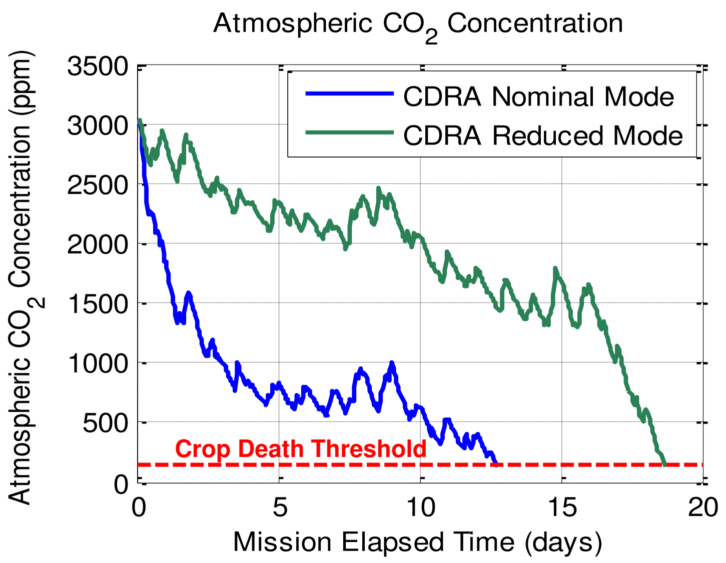
Mars One Baseline with Resized Plant Growth System



Integrated Simulation
(Without ISRU to size ISRU systems)

Simulation Result:

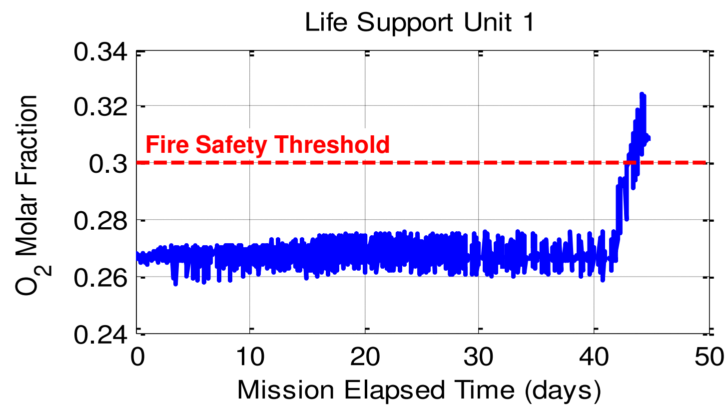
- Crop death occurs at Day 12-19 due to insufficient CO_2

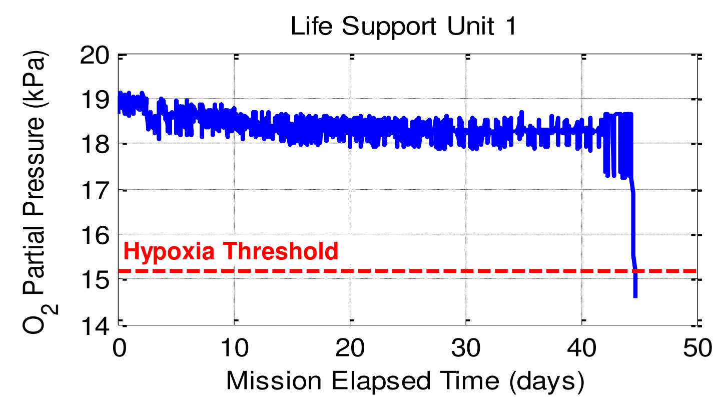


Integrated Simulation (Without ISRU to size ISRU systems)

Simulation Result:

- Crop death occurs at Day 12-19 due to insufficient CO_2
- With CO_2 injection system incorporated, fire safety threshold exceeded at Day 43, and first crew fatality at Day 45 due to suffocation from too low ppO_2





Integrated Simulation (Without ISRU to size ISRU systems)

Massachusetts Institute of Technology

Simulation Result:

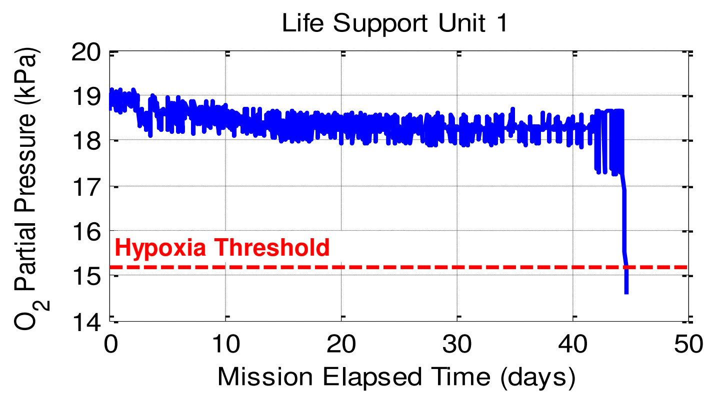
- Crop death occurs at Day 12-19 due to insufficient CO_2
- With CO_2 injection system incorporated, fire safety threshold exceeded at Day 43, and first crew fatality at Day 45 due to suffocation from too low ppO_2

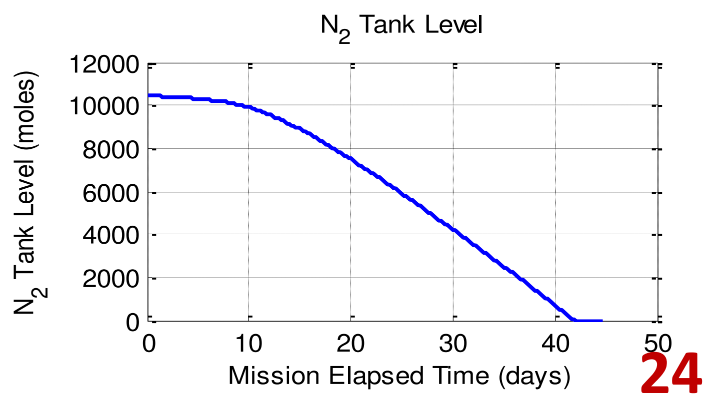
Cause:

- Crops produce too much O_2 (rises as crops reach maturity)
- PCA vents gases and introduces N_2 to maintain atmospheric composition
- This continues until N_2 store is depleted on Day 42
- Plants continue to produce O_2, raising O_2 molar fraction above fire safety threshold
- Lack of N_2 causes module leakage to dominate, reducing total pressure, and ppO_2 below hypoxic threshold

Finding:

- Peak N2 depletion of 360moles/day, requires an ISRU system that is 1.1mT and 5m^3 (>45% and >20% of lander capacity, respectively) → prohibitively large system

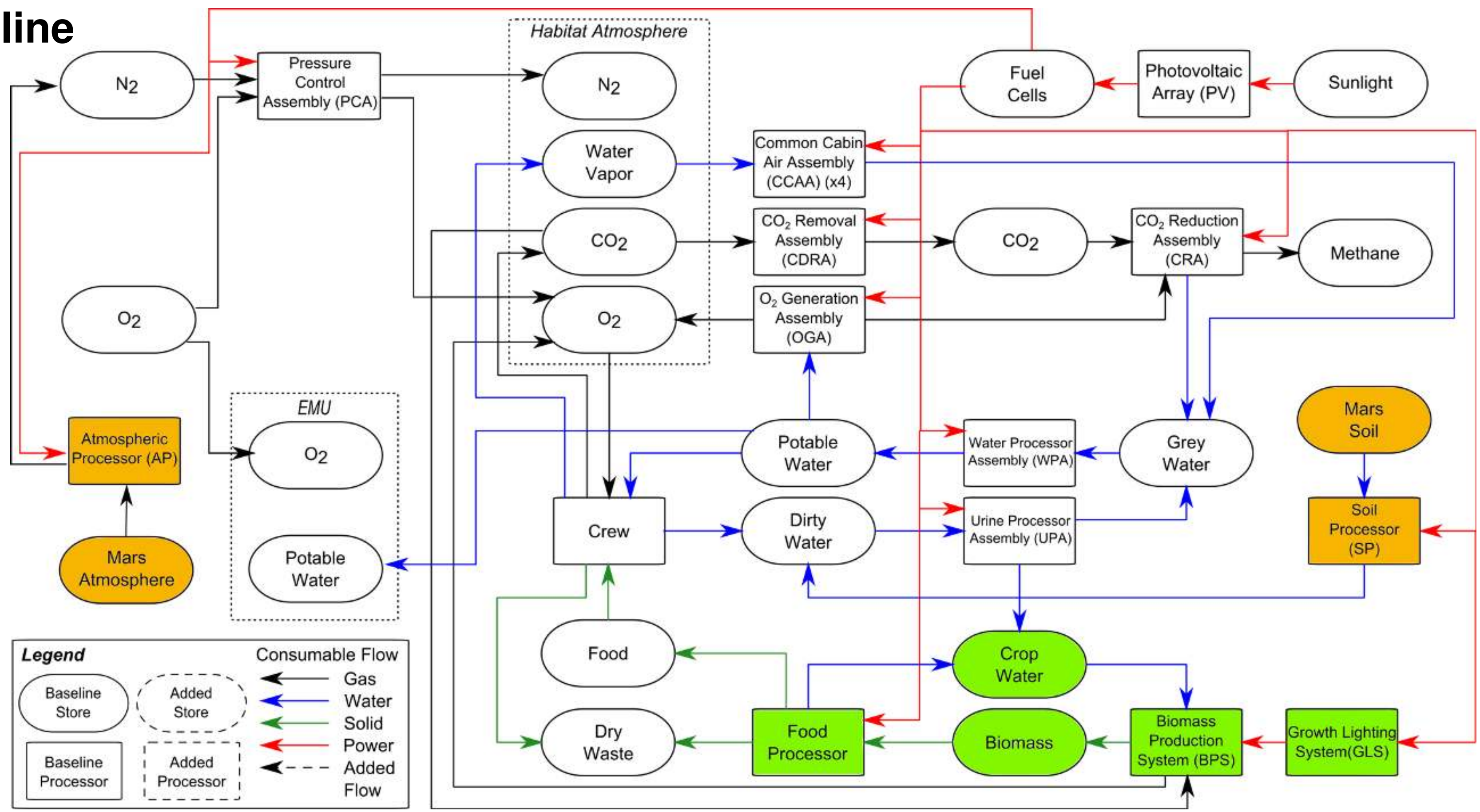




Simulation Case 1 – BPS Case: Oxygen Removal Assembly with BPS

- Place crops in their own plant growth chamber
- Install a "CO_2 Injector" to sustain crops
- Install an "Oxygen Removal Assembly" (ORA) → (Contradicts the "validated technology" claim)
  - Selectively removes excess O2 from the atmosphere
  - Sends excess O2 to a high pressure tank via a compressor, for use during EVA

Baseline

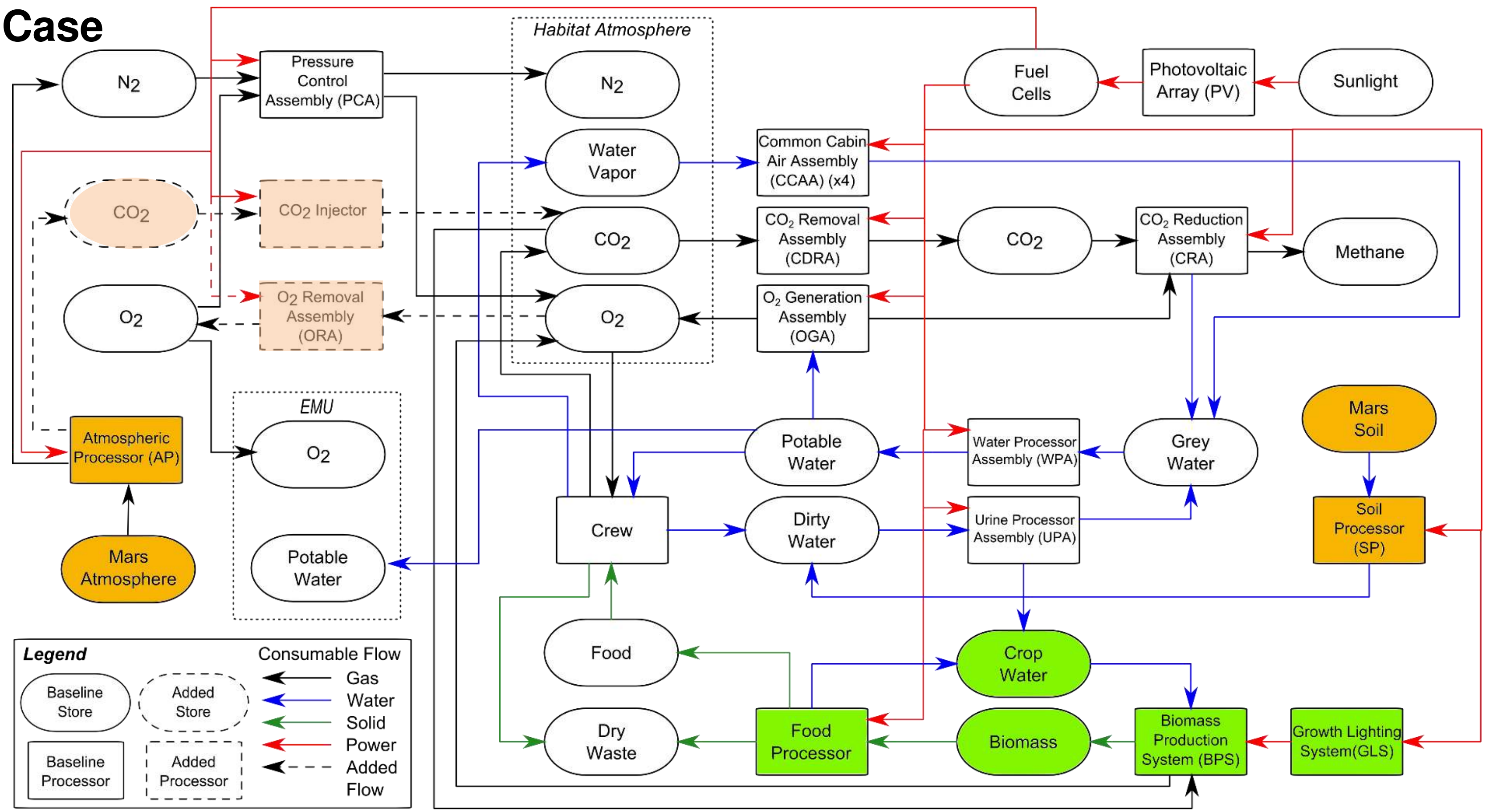


Massachusetts Institute of Technology

Simulation Case 1 – BPS Case: Oxygen Removal Assembly with BPS

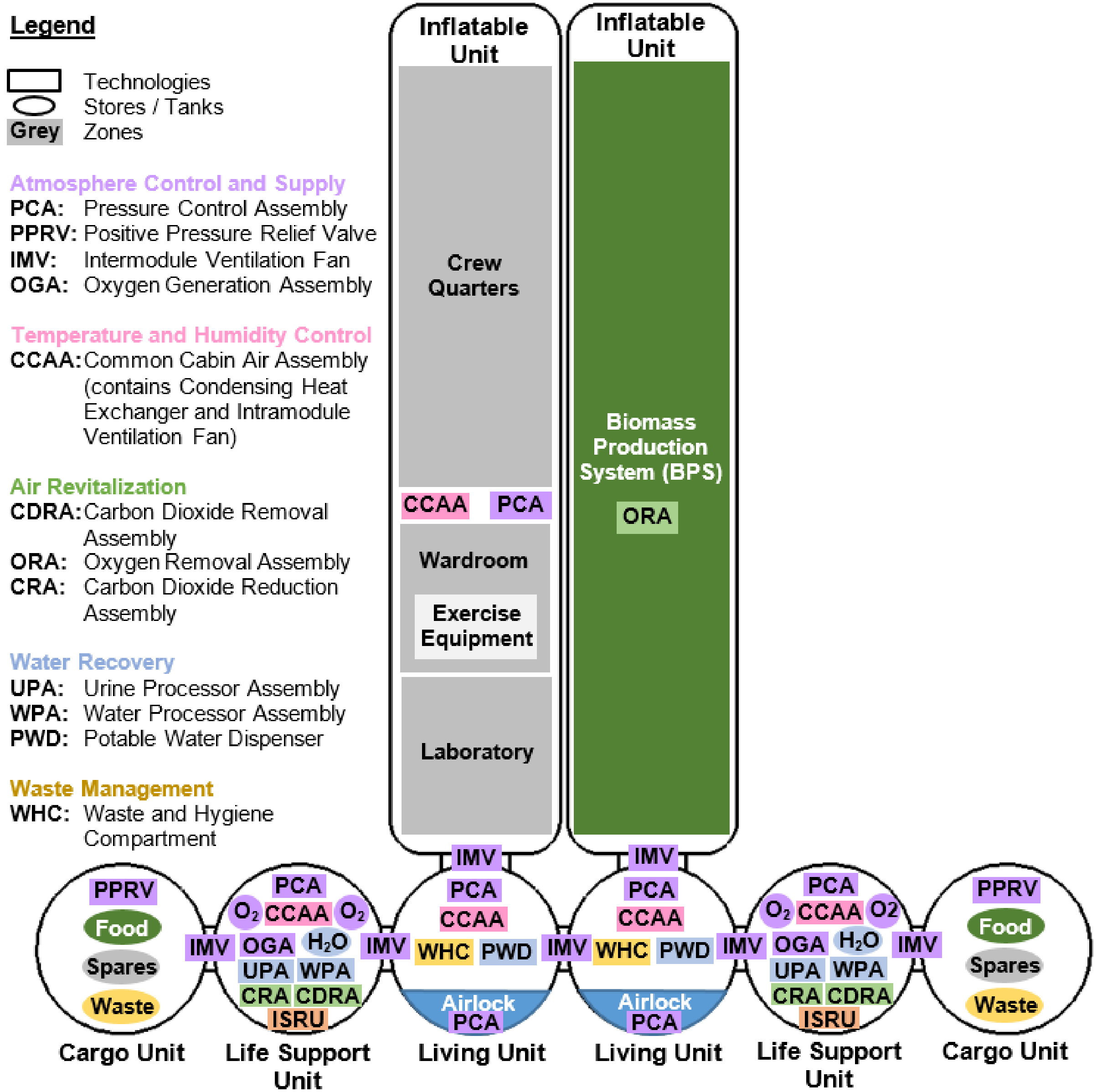
- Place crops in their own plant growth chamber
- Install a "CO_2 Injector" to sustain crops
- Install an "Oxygen Removal Assembly" (ORA) → (Contradicts the "validated technology" claim)
  - Selectively removes excess O2 from the atmosphere
  - Sends excess O2 to a high pressure tank via a compressor, for use during EVA

BPS Case



Massachusetts Institute of Technology

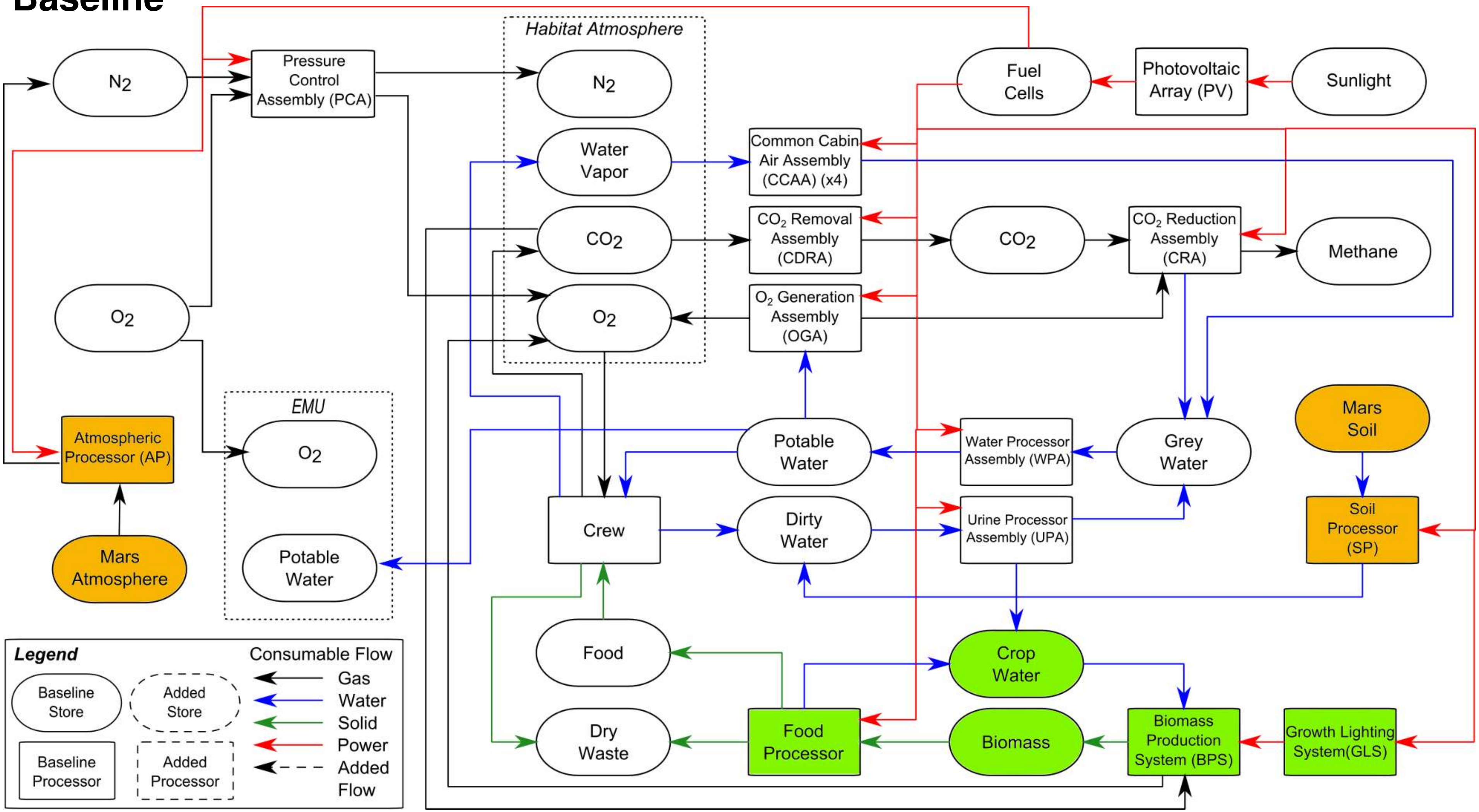
Simulation Case 1



Simulation Case 2 – SF Case: Zero Plant Growth / All Carried Food

ISS Baseline – all carried food – no plant growth

Baseline

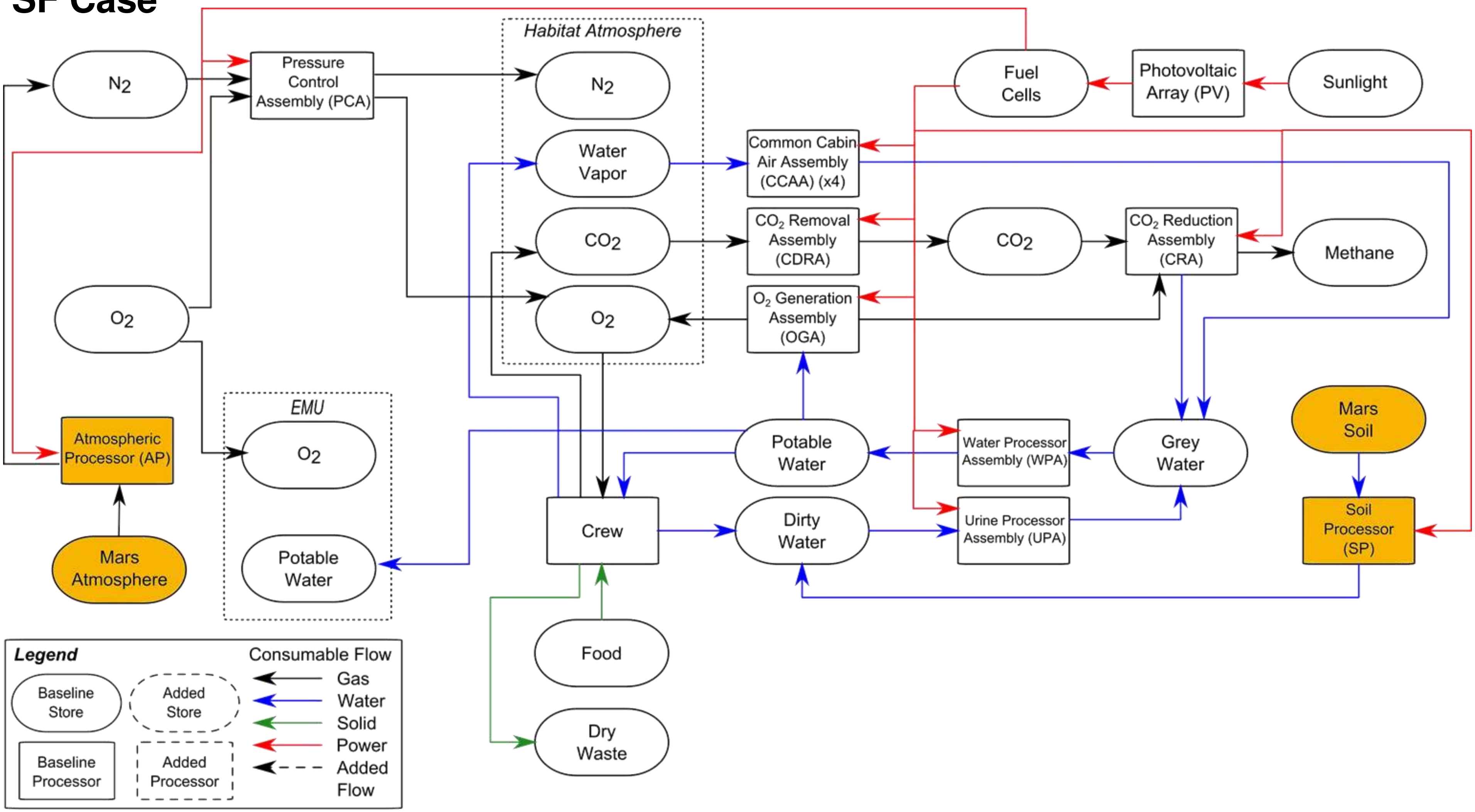


MIT Massachusetts Institute of Technology

Simulation Case 2 – SF Case: Zero Plant Growth / All Carried Food

ISS Baseline – all carried food – no plant growth

SF Case



Simulation Case 2

Legend

- Technologies (rectangle)
- Stores / Tanks (oval)
- Grey: Zones

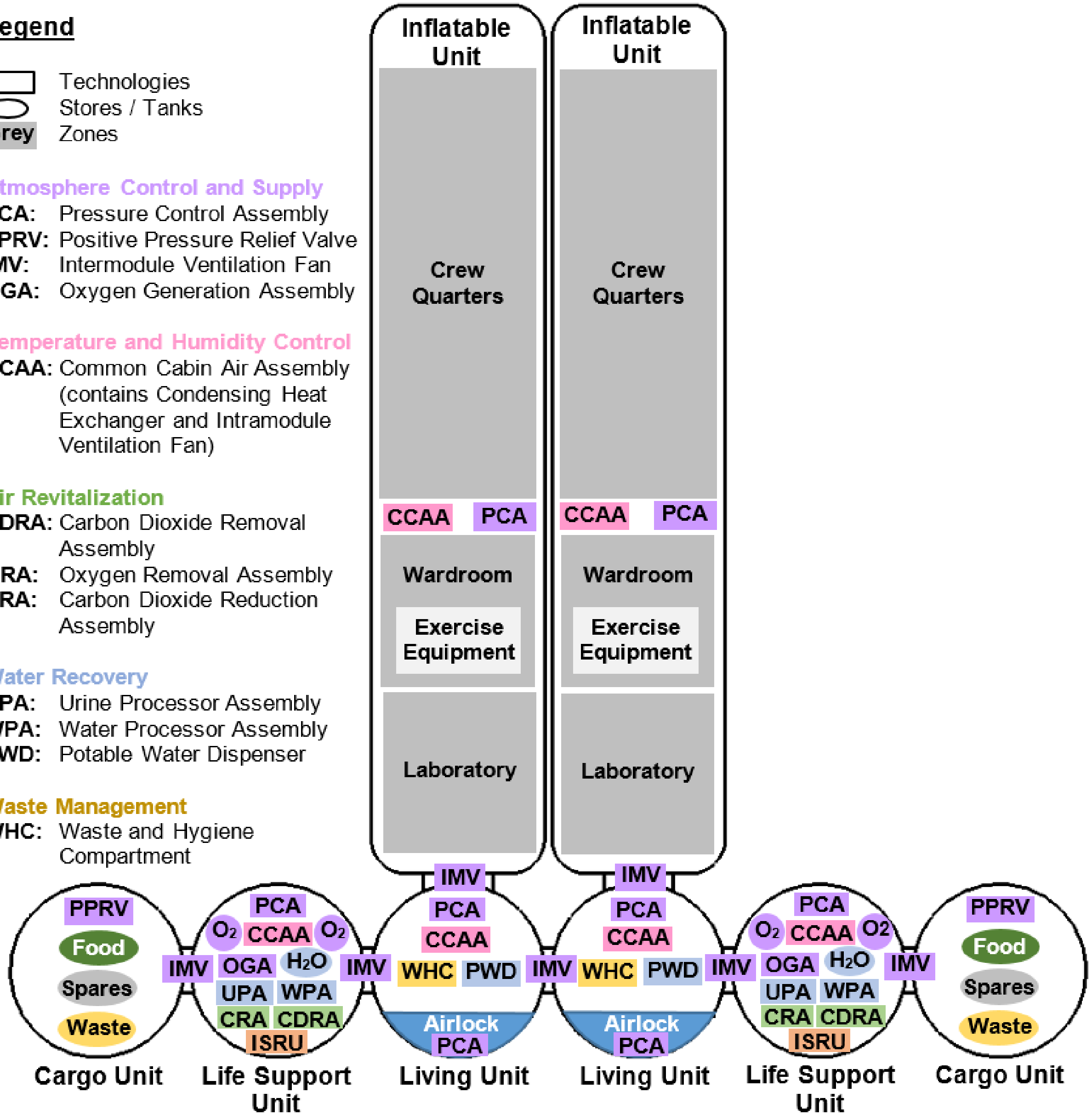
Atmosphere Control and Supply
PCA: Pressure Control Assembly
PPRV: Positive Pressure Relief Valve
IMV: Intermodule Ventilation Fan
OGA: Oxygen Generation Assembly

Temperature and Humidity Control
CCAA: Common Cabin Air Assembly (contains Condensing Heat Exchanger and Intramodule Ventilation Fan)

Air Revitalization
CDRA: Carbon Dioxide Removal Assembly
ORA: Oxygen Removal Assembly
CRA: Carbon Dioxide Reduction Assembly

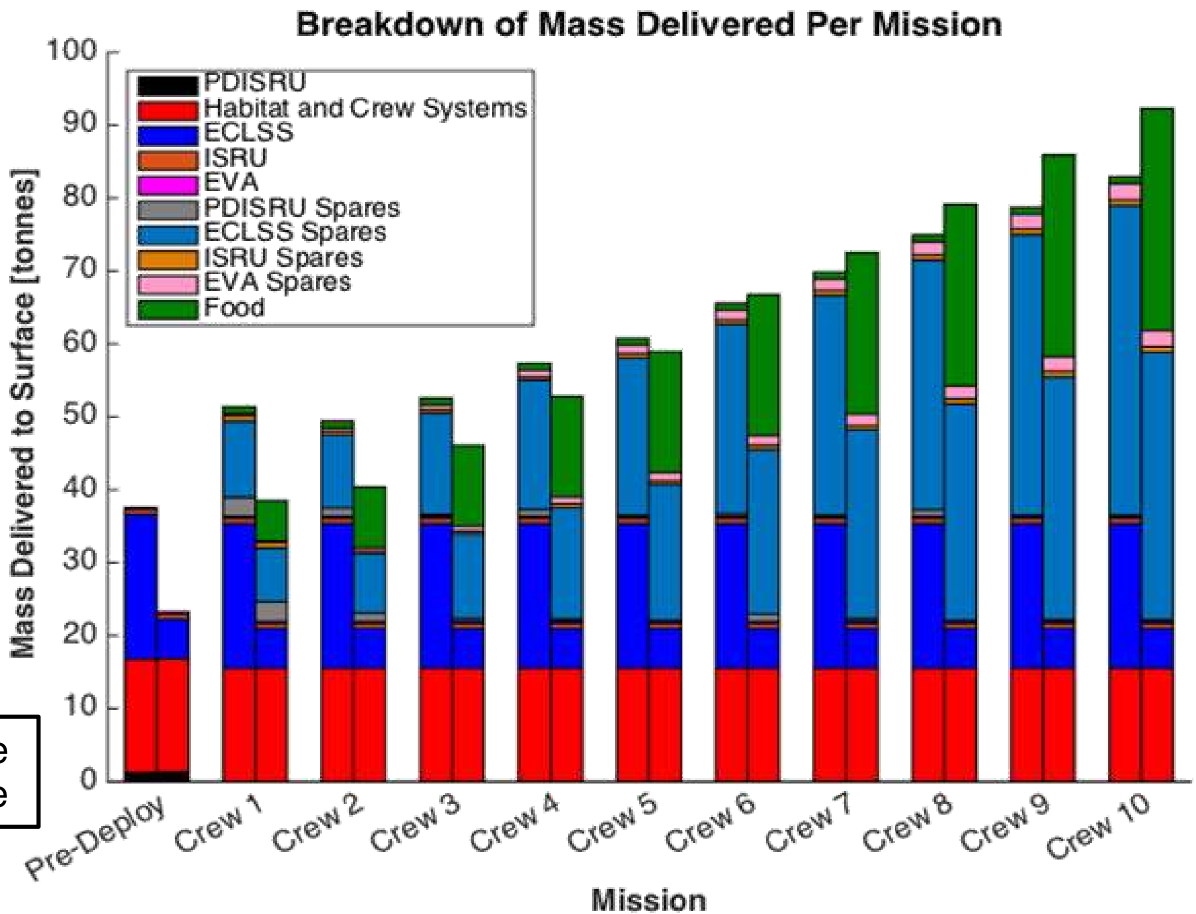
Water Recovery
UPA: Urine Processor Assembly
WPA: Water Processor Assembly
PWD: Potable Water Dispenser

Waste Management
WHC: Waste and Hygiene Compartment



Massachusetts Institute of Technology

Logistics Demands for First 10 Crews

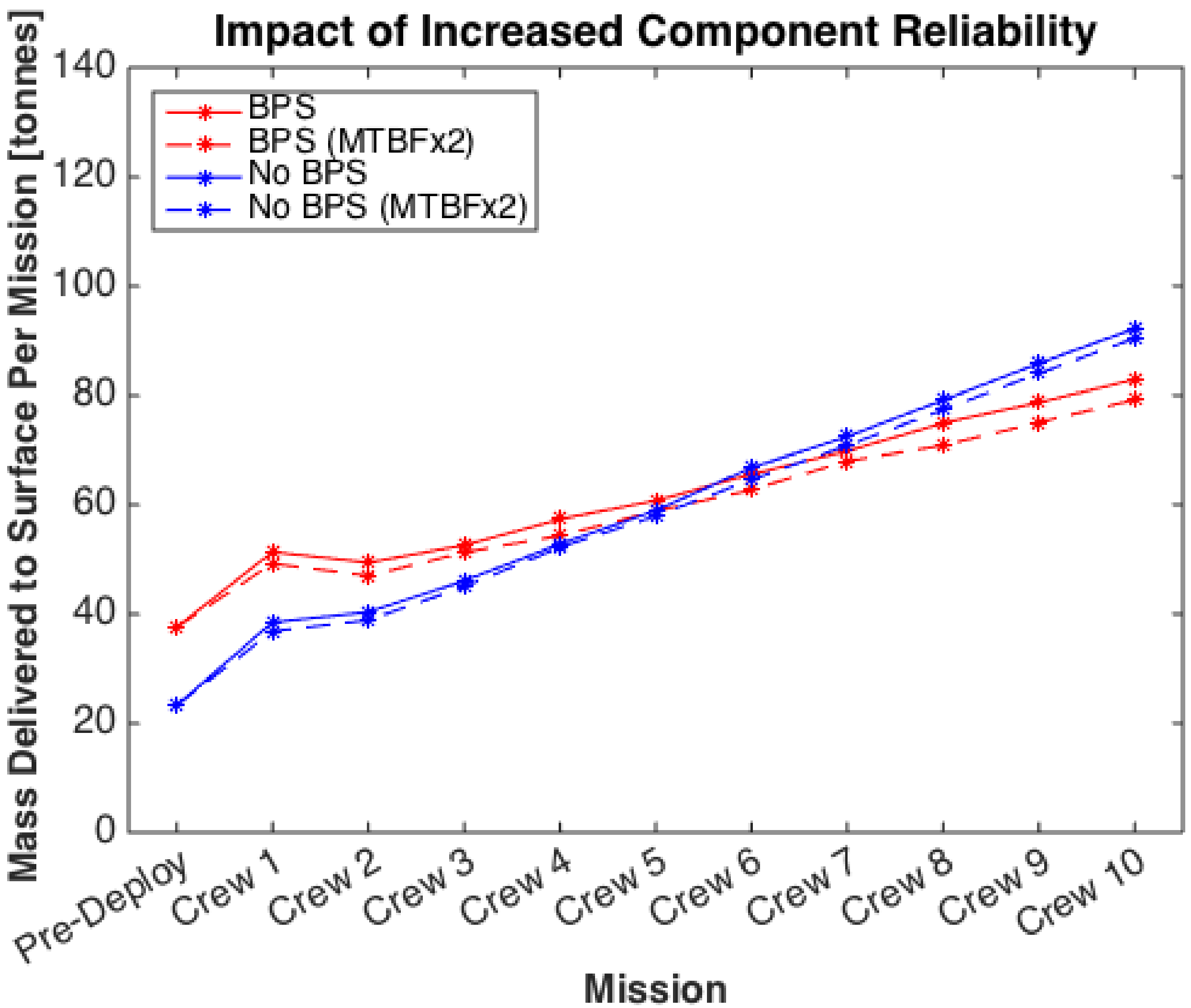


Left Column: BPS Case
Right Column: SF Case

Findings:

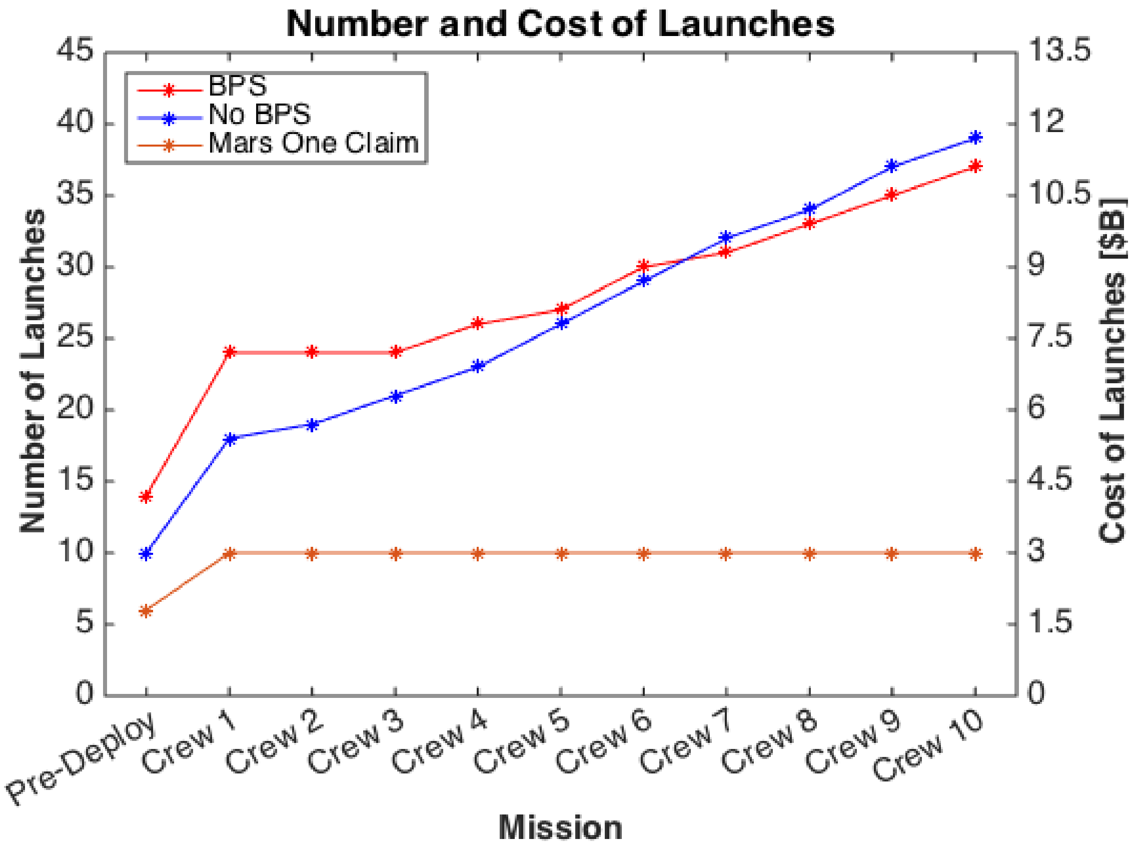
- ECLS Spares dominates in later campaigns because spares are needed to sustain the current crew, as well as the total crew and equipment that is already on the surface
- Crossover point in resupply mass occurs at 6th crew, when resupplied food requirement exceeds ORA, CO_2 injector and LED spares requirements of BPS

Sensitivity of Required Spares to MTBF



Observation: For a fixed probability of having sufficient spares to sustain the mission, doubling MTBF reduces spares requirement by only 2-4% since enough spares need to be provided for **all** potential failures (random and life limited) – specific failed components are not known a priori

Launch Demands for First 5 Crews



	Predeployment Launch Requirement	Crew 1 Launch Requirement	Crew 2 Launch Requirement
Mars One Claim	6	10	10
Case 1 (BPS)	14	24	24
Case 2 (No BPS)	10	18	19

Massachusetts Institute of Technology

Analysis Summary

Issue 1

- **Mars One:** *"In total there will about 50m^2 available for plant growth… There will be sufficient plant production capacity to feed about three crews of four"*
- **Finding:** 50m^2 is insufficient. 200m^2+ of plant growth area is required to feed four people
- **Recommendation/Action:** Implement at least 200m^2 of plant growth into habitat

Issue 2

- **Mars One Design:** Crops share the same working volume as that of the crew
- **Finding 1:** Excess O2 production by crops creates a fire hazard which when dealt with using existing ISS technologies, leads to depletion of N2 stores, leading to crew suffocation
- **Finding 2:** Making up this N2 depletion with ISRU will result in a prohibitively large system
- **Recommendation/Action:**
  - If plants are grown, grow them in a separate plant growth chamber and include an O_2 removal system (never before developed for flight) to recover O_2 for later use

Issue 3

- **Mars One:** *"Each stage of Mars One mission plan employs existing, validated and available technology"*
- **Finding 1:** Based on existing resupply logistics practices, the spares requirement will grow over time, thereby increasing the mission cost over time
- **Finding 2:** *"There are some fundamental issues that need to be resolved concerning additive manufacturing and its utilization for terrestrial purposes before a space-based application can be derived"* [REF: http://www.nap.edu/catalog.php?record_id=18871]

Massachusetts Institute of Technology

Summary and Conclusions

Additional Findings

- ISRU is an attractive option (spares mass requirement is 8% of consumables mass produced), but TRL is needs to be improved
- ISRU and ECLS spares requirements increase significantly as a settlement grows – after 260 months on the Martian surface, spares makes up 55% of the resupply mass
- The Mars One stated launch requirements are overly optimistic
  - 10-14 Falcon Heavy launches required for predeployment ($3B-$4.2B)
  - 21-24 Falcon Heavy launches required to supply the 3rd crew ($6.3B-$7.2B)

Note:

- This analysis focused only on the impact of habitation, ECLS, and ISRU on spares and space logistics requirements. Several other subsystems such as communications and power need to be included for a complete analysis

Recommendations

- Focus investment into increasing ECLS reliability and increasing ISRU TRL
- Work on reducing launch costs
- Investigate in-situ manufacturing capability to reduce spares resupply requirements

Upcoming Studies

One-Way versus Return Mars Mission Architectures – A Comparison of Lifecycle Operating Costs

- Comparative analysis of the lifecycle costs of developing a 20 person Mars surface base using both the one-way and return-trip architectures
- Explore impact of varying crew ramp-up profiles
- Independent analysis using the same inputs as NASA LaRC's "ISRU to the Wall Study"
  - Allows for comparison of results with NASA-developed studies

Benefits of In-Situ Manufacturing for Mars Exploration

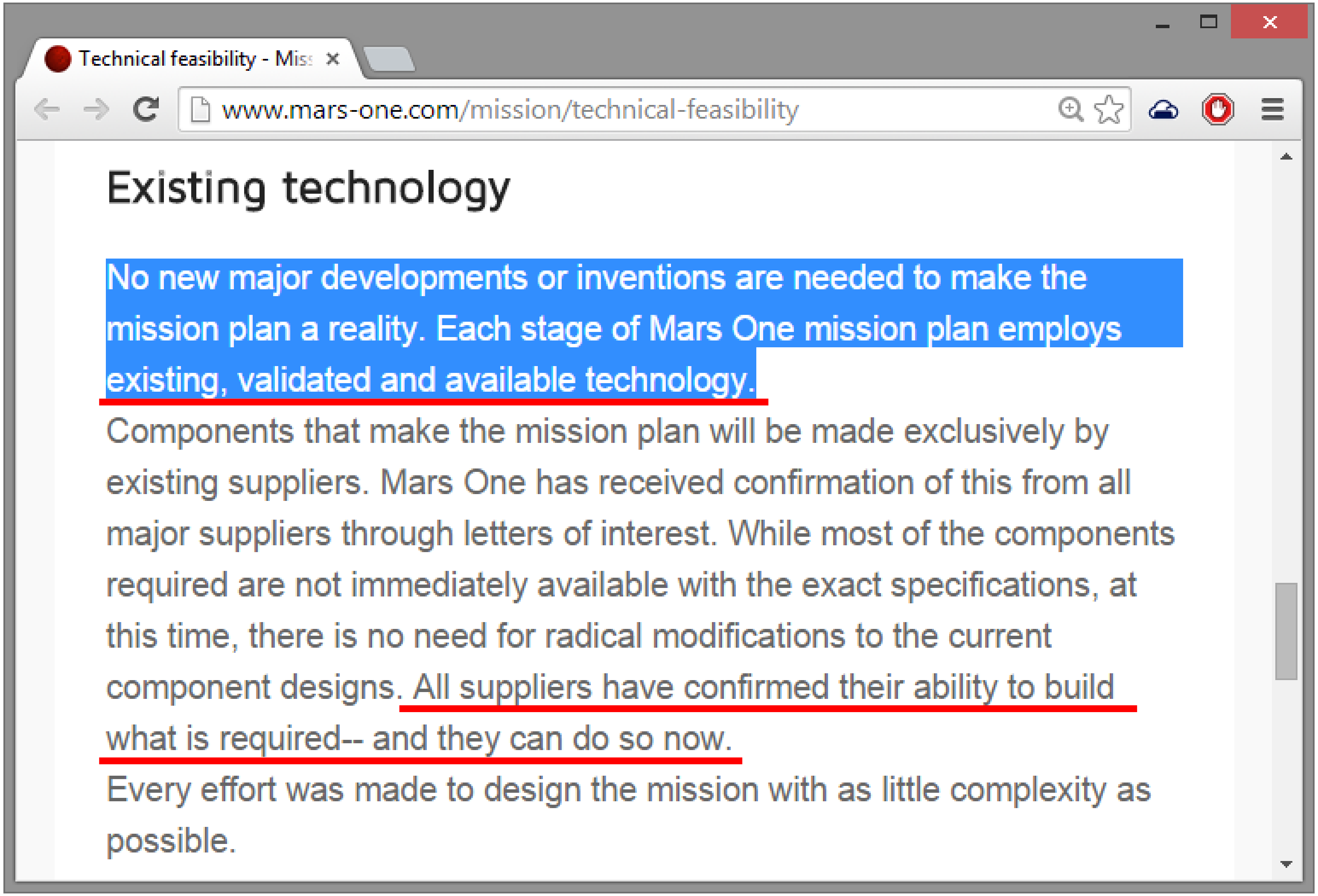
- Explore relationship between parts reliability, in-situ manufacturing performance and requirements, and availability of feedstock, and the resulting impact on overall system architecture. Includes:
  - Analysis of impact of in-situ manufacturing on spares resupply requirements
  - Analysis of impact of feedstock supply (ISRU-derived vs resupplied from Earth vs waste recycling)

Thank You

Original Paper: http://bit.ly/mitM1

Questions? Email: sydneydo@mit.edu

Back Up Slides



Existing technology

No new major developments or inventions are needed to make the mission plan a reality. Each stage of Mars One mission plan employs existing, validated and available technology.

Components that make the mission plan will be made exclusively by existing suppliers. Mars One has received confirmation of this from all major suppliers through letters of interest. While most of the components required are not immediately available with the exact specifications, at this time, there is no need for radical modifications to the current component designs. All suppliers have confirmed their ability to build what is required-- and they can do so now.

Every effort was made to design the mission with as little complexity as possible.

Massachusetts Institute of Technology

Impact of Commonality (Notional)