DRAFT

Life Support System Technologies for NASA Exploration Missions

Mike Ewert

Deputy Project Manager, Exploration Life Support Project

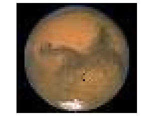
NASA Johnson Space Center

Army Research Office

Workshop on Base Camp Sustainability

September 12, 2007

National Astronautics and Space Administration



The Vision for Space Exploration

- Complete the International Space Station

The Vision for Space Exploration

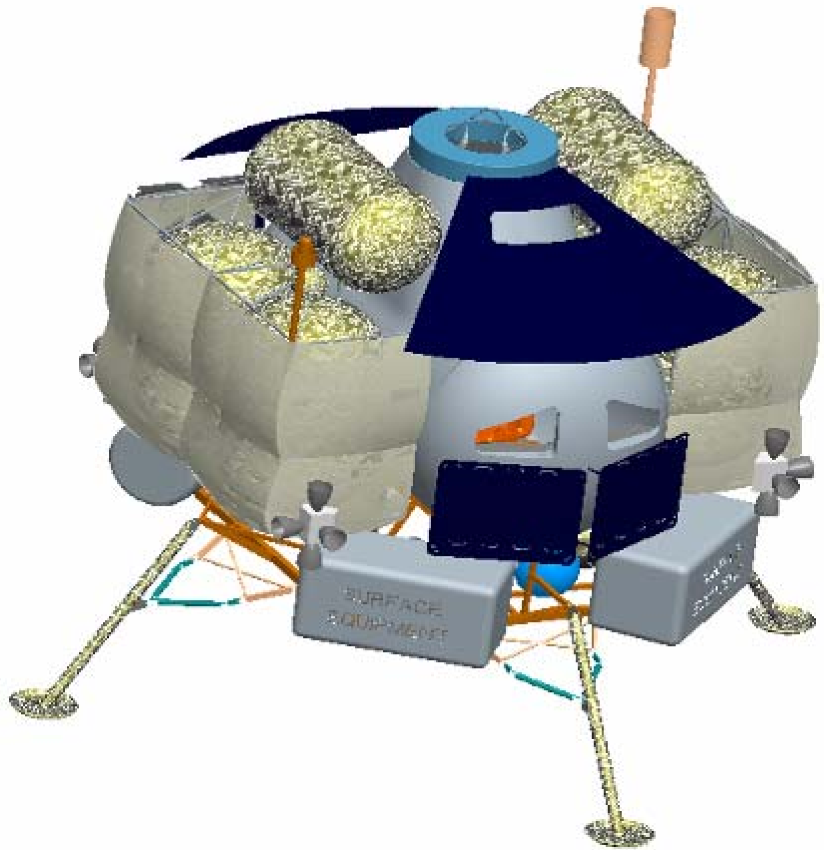
- **Safely fly the Space Shuttle until 2010**

The Vision for Space Exploration

Develop and fly the Crew Exploration Vehicle no later than 2014

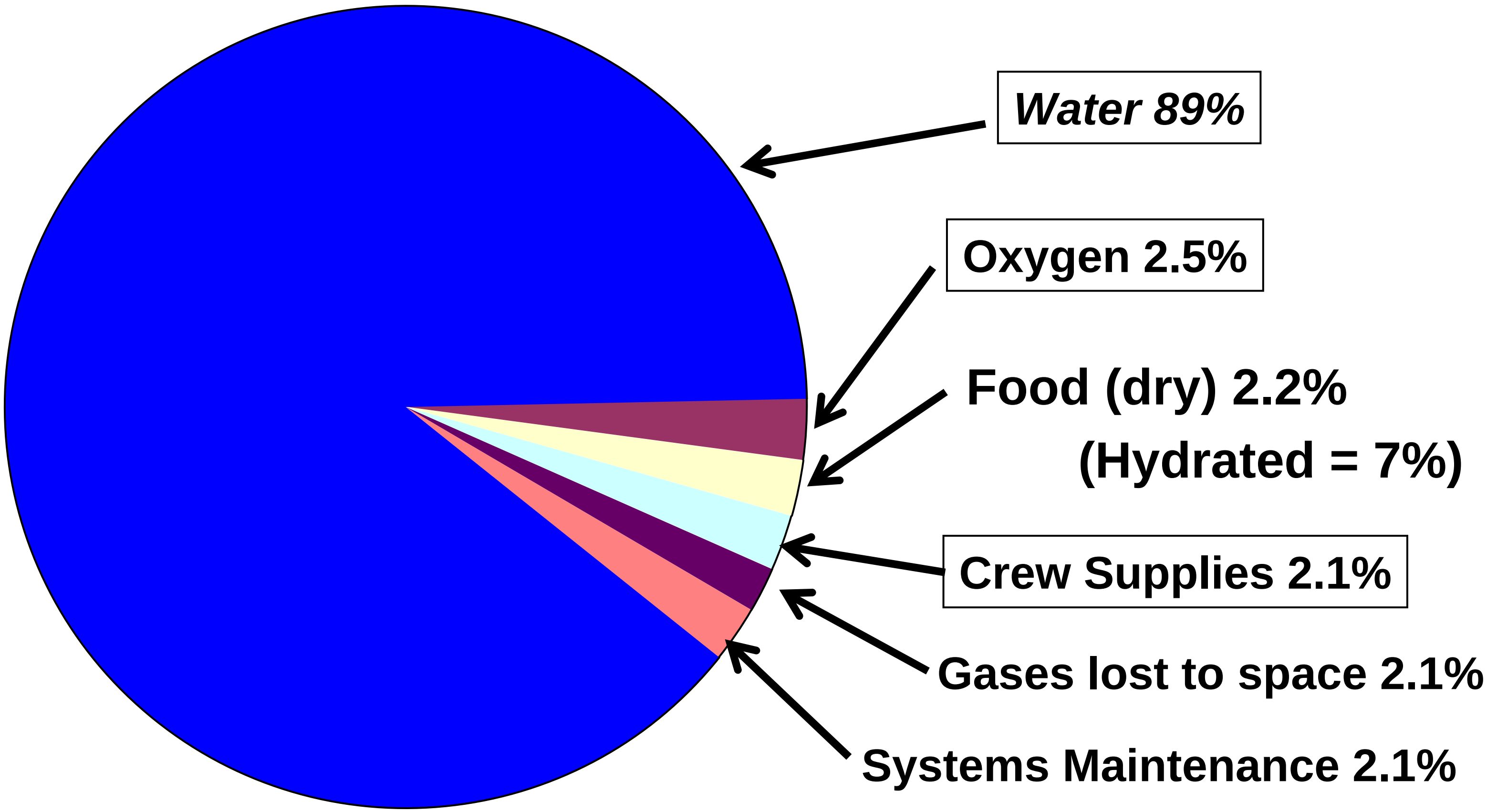
The Vision for Space Exploration

Return to the Moon no later than 2020



Human Life Support Requirements

Open-Loop Life Support System
Resupply Mass - 12,000 kg/person-year
(26,500 lbs/person-year)



Challenge in Space

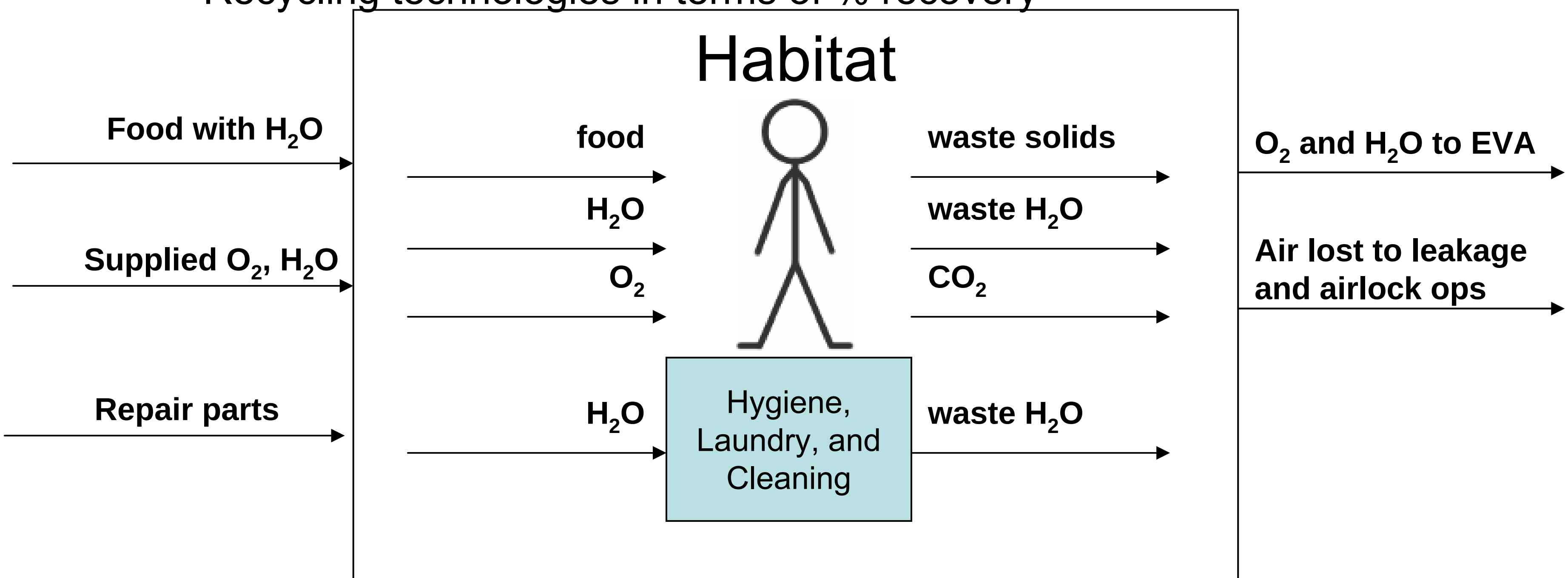
Human Life Support Requirements For Exploration Missions (25 kg/person-day)

Consumables	
Gases	
Oxygen	0.84
Water	
Drinking	1.62
Water content of food	1.15
Food preparation water	0.79
Shower and hand wash	6.82
Clothes wash	12.50
Urine flush	0.50
Solids	
Food	0.62

Wastes	
Gases	
Carbon Dioxide	1.00
Water	
Urine	1.50
Perspiration/respiration	2.28
Fecal water	0.09
Shower and hand wash	6.51
Clothes wash	11.90
Urine flush	0.50
Humidity condensate	0.95
Solids	
Urine	0.06
Feces	0.03
Perspiration	0.02
Shower & hand wash	0.01
Clothes wash	0.08

Loop Closure

- Desirable loop closure would minimize the supplied O_2 and H_2O as well as recovery of resources from solid waste
- The solution is sensitive to
  - O_2 and H_2O resources consumed (not recovered) by EVA (large driver)
  - Moisture content in delivered food
  - Recycling technologies in terms of % recovery



Exploration Life Support – Recycling & Closure

Recovery = mass recycled/ resources available Closure = mass recycled & used/ total resources needed	**91-Day LMLSTP Phase 3 Test**	**ISS (complete)**	**Mars Technology Projections**
Air Revitalization Systems			
% Recovery from CO_2	56%	0% (≤69%?) [b]	≥ 97% [c]
% Closure	~ 100% [a]	~ 100 % [a]	~ 100%
Water Recovery Systems	Note: No EVA		
% Recovery	~ 100%	93% [d]	93 - ~ 100% [e]
% Closure	~ 100%	63% [a]	See slide 7
Solid Waste Management			
% Recovery (H_2O)	92% [g]	0 %	90 to ~ 100 % [f]
Volume Reduction [h]	100:1 [g]	0 %	10:1 to 100:1
Waste Stabilization	Yes [g]	No	Yes
Clothing Laundry	Yes	No	Yes

[a] *Recycled wastewater was/will be electrolyzed; thus O2 is not re-supplied (hit to water closure, but some made up with water in stored food)*

[b] *Up to 69% if a Sabatier reactor is implemented to perform CO_2 reduction*
$CO_2 + 4H_2 \rightarrow CH_4 + 2\ H_2O + CO_2\uparrow + H_2\uparrow$

[c] *Complete CO_2 reduction to C and O_2 (assumes technology addition beyond Sabatier; e.g., Bosch reactor)*

[d] *RISS Regenerative ECLSS*

[e] *Add brine recovery to water or via solid waste system to recover additional water*

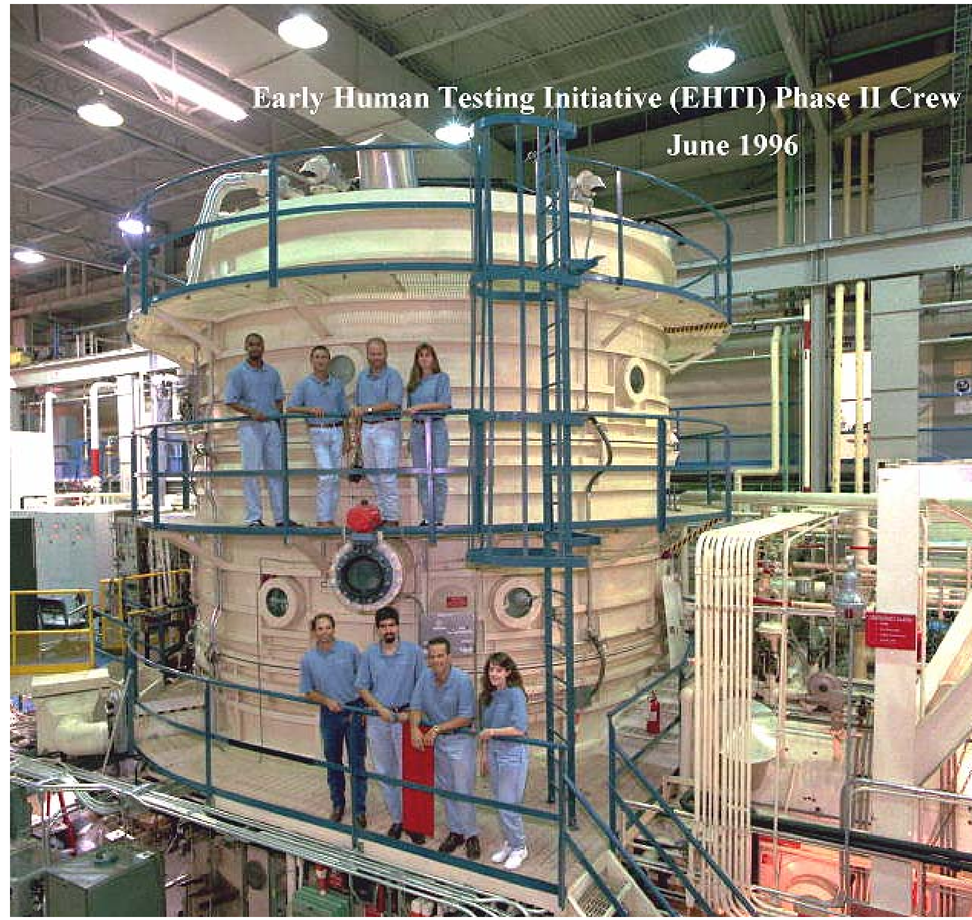
[f] *Water Recovery*

[g] *Only feces were incinerated, producing additional water*

[g] *Reduced beyond hand compaction*

Lunar - Mars Life Support Test Project

Phase I: 15-day, 1-Person Test
March 1995

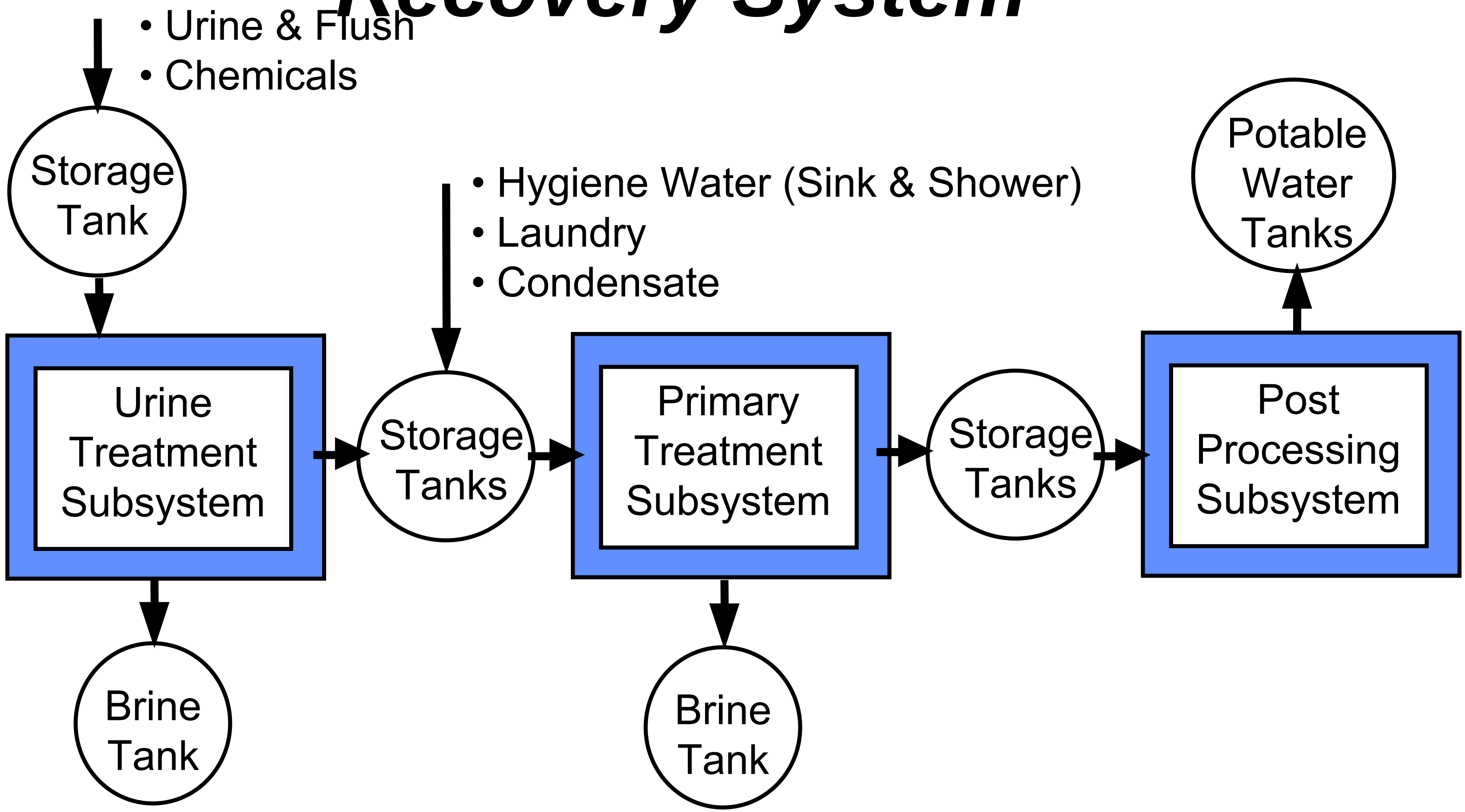


Phase II: 30-day, 4-Person Test - June 1996
Phase IIA ISS: 60-day, 4-Person Test - January 1997
Phase III: 90-day, 4-Person Test - September 19, 1997

LMLSTP Phase II: Water Recovery System Requirements

Water Requirement (kg/person/day)	**kg**	**Wastes Generated (kg/person/day)**	**kg**
Shower water	6.36	Waste shower water	5.93
Hand wash	3.64	Waste hand wash	3.53
Clothes wash	12.50	Waste clothes wash	11.91
Urine flush	0.50	Urine flush	0.50
Food preparation water	0.68	Feces (solid)	0.03
Drinking water	1.77	Fecal water	0.09
Oral hygiene water	0.36	Sweat solids	0.02
		Urine	1.91
		Urine solids	0.06
		Waste oral hygiene	0.36
		Condensate	3.01
Totals, per person	**25.81**	**Totals, per person**	**27.35**
Totals, crew of four	**103.24**	**Totals, crew of four**	**109.40**

LMLSTP Phase II: Water Recovery System



Urine Treatment Subsystem

Vapor Compression Distillation (VCD)

Primary Treatment Subsystem

Ultra Filtration/Reverse Osmosis (UF/RO)

Post Processing Subsystem

Volatile Removal Assembly (VRA)
Ion Exchange & Activated Carbon
Iodination

LMLSTP Phase II Test Results: Water Recovery System Performance

Subsystem Performance Over the 30-day test:

- Urine Treatment Subsystem: Vapor Compression Distillation (VCD)

Mass of urine and flush water processed:	182 kg
Mass of processed water produced:	179 kg
Water recovery rate for the subsystem:	98.5 %

- Primary Treatment Subsystem: Ultra Filtration/Reverse Osmosis (UF/RO)

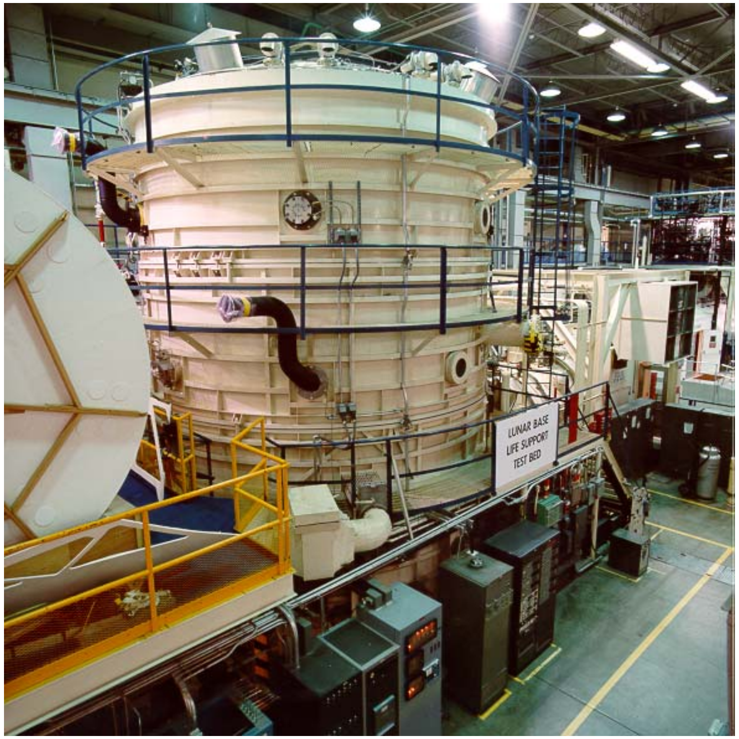
Mass of water processed:	3,090 kg
Mass of purified water produced:	2,957 kg
Water recovery rate for the subsystem:	95 %

Brines generated by both VCD and UF/RO over the 30 day test totaled ≈136 kg.

- Expected Quantities based on Nominal Human Requirements

Urine and flush water (4 crew * 30 d * 2.47 kg) =	296 kg
Wastewater (4 crew * 30 d * 24.88 kg) =	2986 kg

LMLSTP Phase III: Overview



- 4 crew members for 91 days
- Demonstrated an integration of advanced regenerative biological and physicochemical (P/C) technologies for life support.
- Two chamber facilities were interconnected
- <u>Air revitalization System</u>
  - Higher plants compliment P/C systems
- <u>Water Recovery System</u>
  - Microbial cell bioreactors were used for the primary treatment step

- <u>Food System</u>
  - The stored food system was supplemented with wheat grain for bread and fresh lettuce grown *in situ*
- <u>Waste Management System (Demonstrations)</u>
  - Incineration of human feces
  - Biodegradation of plant inedible materials

LMLSTP Phase III: Water Recovery System Requirements

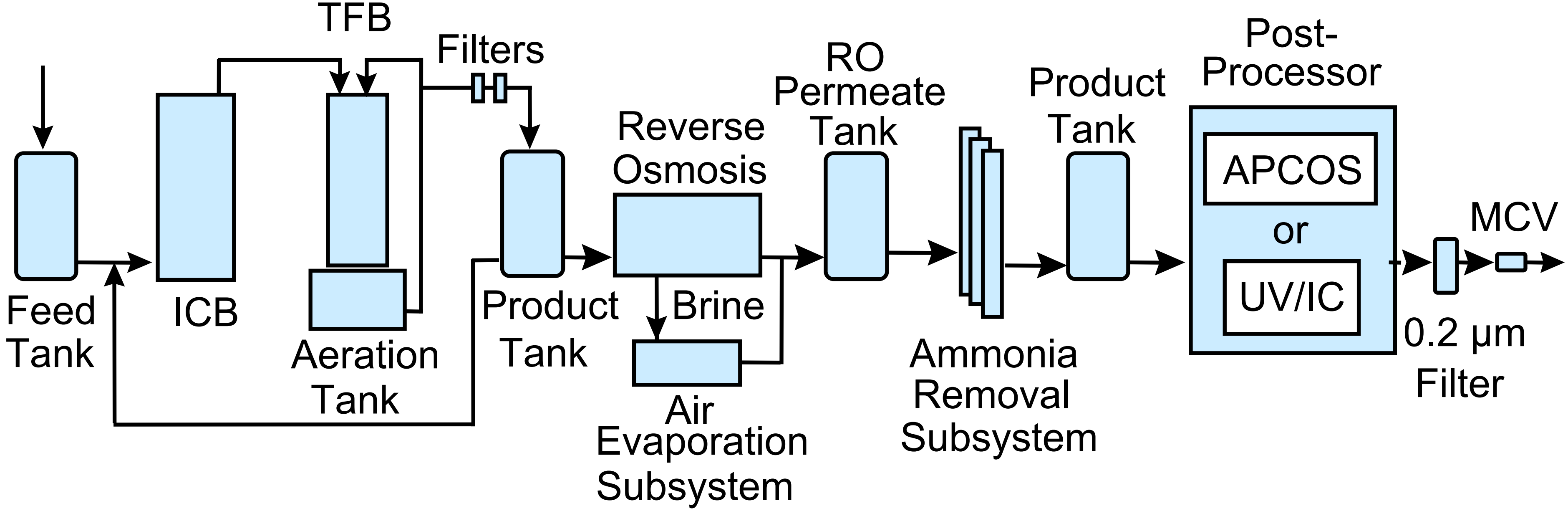
Water Use/Waste Water Source	**Water Allotment (kg/crew of 4/day)**	**Waste Water Generation (kg/crew of 4/day)**
Laundry	50.00	47.64
Shower	25.44	23.72
Hand Wash	14.56	14.12
Oral Hygiene	1.44	1.44
Drinking	7.08	0.00
Food Preparation	2.72	0.00
Dish Washing	2.00	2.00
Urine Flush	2.00	2.00
Urine	0.00	7.64
Condensate	0.00	12.04
Total	**105.24**	**110.6**

LMLSTP Phase III: Water Recovery System

Primary Treatment
- Immobilized Cell Bioreactor (ICB)
- Trickling Filter Bioreactor (TFB)

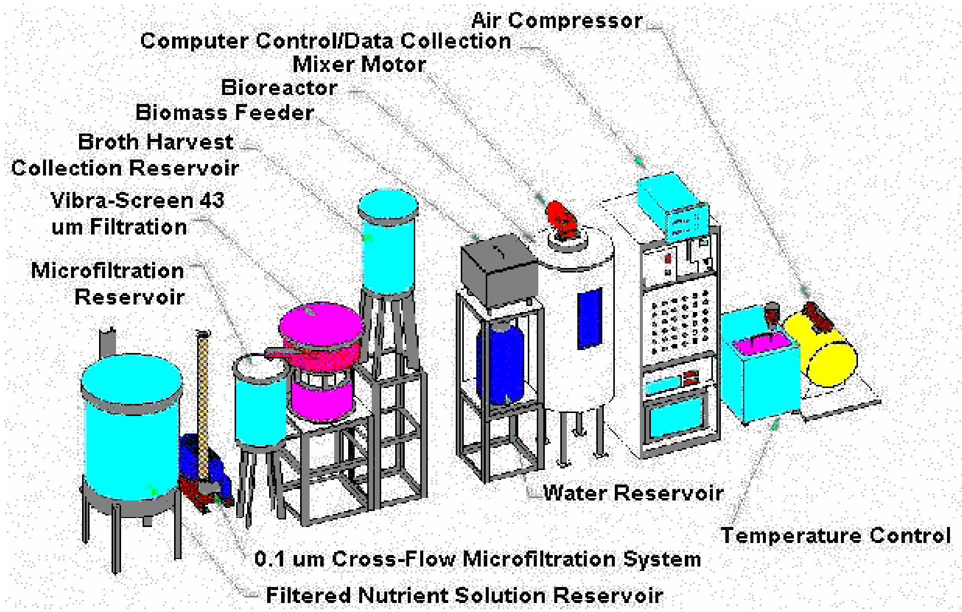
Secondary Treatment
- Reverse Osmosis (RO)
- Air Evaporation Subsystem (AES)

Post Processing
- Ammonium Removal Subsystem
- Aqueous Phase Catalytic Oxidation (APCOS)
- Ultraviolet/Ion Exchange (UV/IC)
- Cold Sterilization (0.2 µm)
- Microbial Check Valve - Iodination (MCV)



- A total of 8797 liters of potable water was produced by the system (96.7 L/day)
- The starting volume of 878 L was cycled through the system 10 times
- With the inclusion of the AES, recovery of water was essentially 100%

LMLSTP Phase III: Waste Management System Demonstrations



Biological Degradation of Inedible Biomass and Recovery of Nutrient Salts

- ½ of the wheat's inedible biomass was mineralized using a stirred tank aerobic bioreactor.
- Recovered nutrient salts were returned to the plant growth systems.
- Wheat grown using recovered nutrient salts showed no difference in productivity compared to controls.
- Average degradation of total solids: 45% (≈ 26 kg biomass was treated)
- Average salt recovery: 80%.

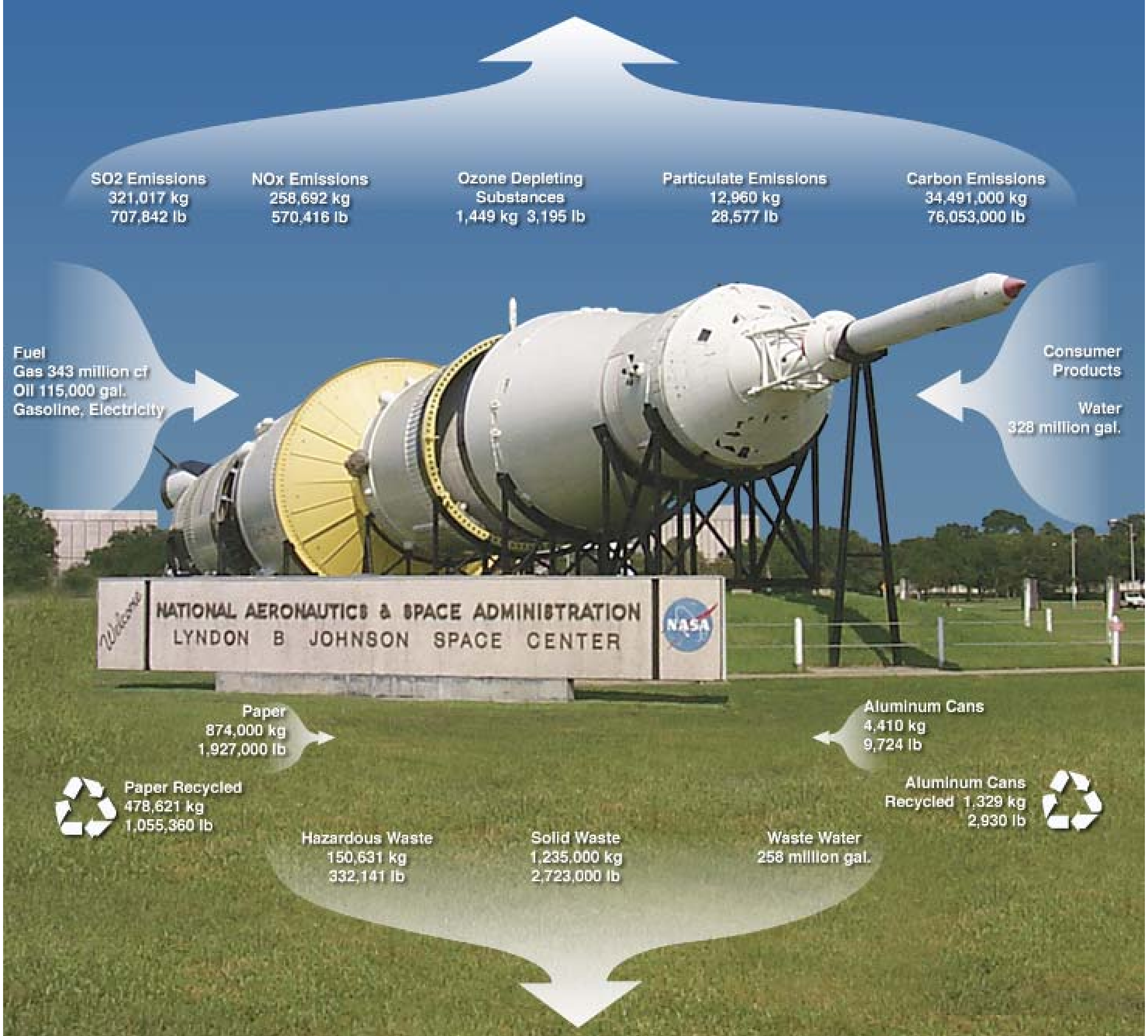
Incineration of Human Feces and Recovery of Carbon Dioxide

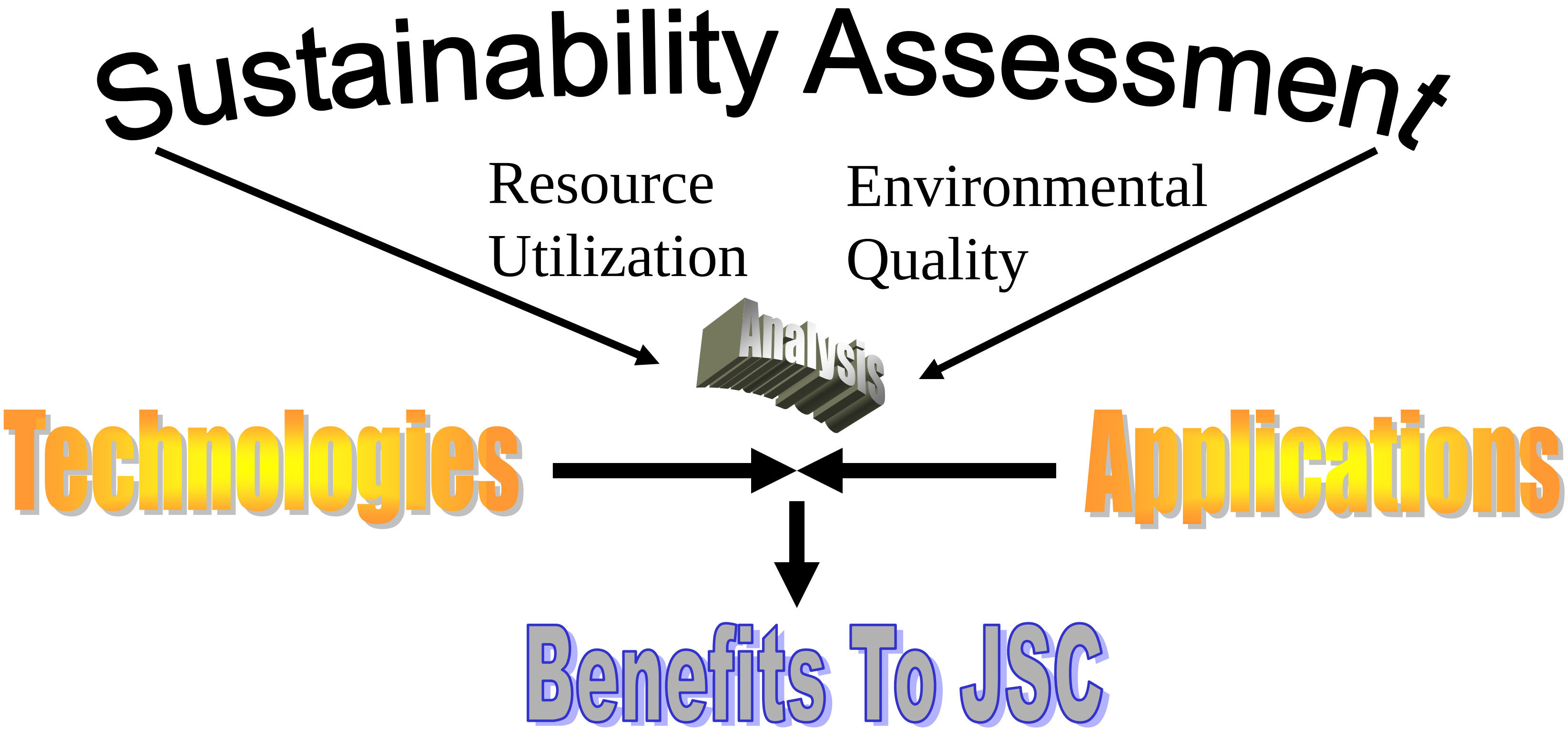
- Human feces (8.2 kg total) were incinerated in a fluidized bed incinerator.
- Carbon dioxide exhaust was injected into the wheat chamber after treatment for trace contaminants

Summary & Lessons Learned

- The Lunar Mars Life Support Test series successfully demonstrated integration and operation of advanced technologies for closed-loop life support systems, including physicochemical and biological subsystems.
- Increased closure was obtained when targeted technologies, such as brine dewatering subsystems, were added to further process life support system byproducts to recover resources.
- Physicochemical and biological systems can be integrated satisfactorily to achieve desired levels of closure.
- Imbalances between system components, such as differences in metabolic quotients between human crews and plants, must be addressed.
- Each subsystem or component that is added to increase closure will likely have added costs, ranging from initial launch mass, power, thermal, crew time, byproducts, etc., that must be factored into break even analysis.
- Achieving life support system closure while maintaining control of total mass and system complexity will be a challenge.

JSC 2002 MASS BALANCE




Sustainability Assessment
Resource Utilization
Environmental Quality
Analysis
Technologies
Applications
Benefits To JSC

Formation of the Sustainability Partnership at JSC

NASA/TM—2004–212069

Johnson Space Center's Role in a Sustainable Future

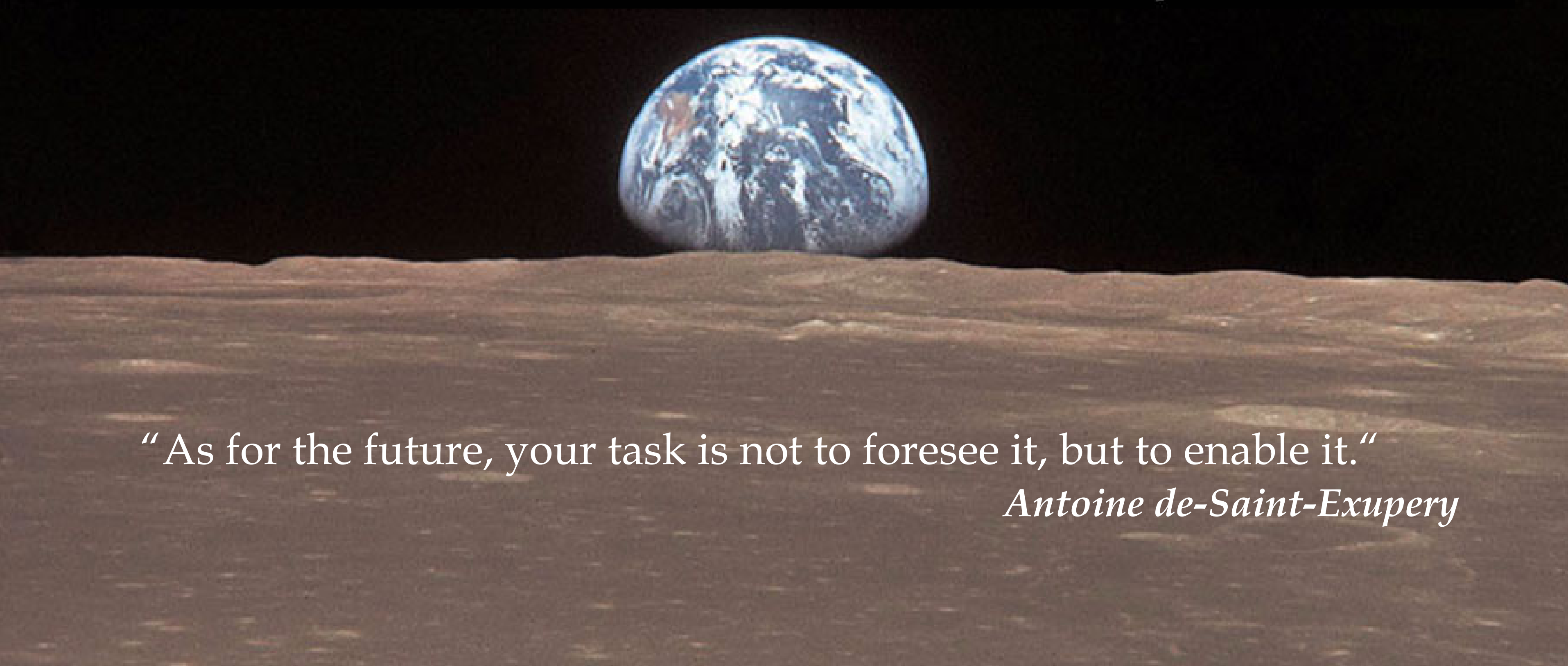
Michael K. Ewert
Lyndon B. Johnson Space Center
Houston, Texas

- Partnership established in 2004 between Engineering and Center Operations
  - " NASA…promotes technological advances that can result in spin-off technologies"
  - "NASA policy directives compel JSC to take action to reduce environmental impact"
  - "The purpose of the Sustainability Partnership is to bring forward, coordinate and advertise innovative sustainability ideas and projects and to share the responsibility for environmental sustainability at JSC."

www.

“We leave as we came, and God willing, as we shall return, with peace and hope for all mankind.”

— Eugene Cernan, Commander of the last Apollo mission



“As for the future, your task is not to foresee it, but to enable it.“

Antoine de-Saint-Exupery

Backup Information

NASA's Response

- Administrator O'Keefe has endorsed an Environmental Management System (EMS) at NASA and committed us to Sustainability principles
- Federal Executive Orders Require:
  - Solid waste reduction of 35% between 1997 and 2010
  - Energy reductions of 20-35% between 1990 and 2010
  - Installation of solar energy systems
  - Greenhouse gas reduction of 30% between 1990 and 2010
  - Reduction of toxic chemicals by 40%
  - Phase out of ozone depleting substances

Systems Engineering & Analysis Approach

- Ex. If energy saving lights and computers are used in a new building, the cooling system can be reduced, thus reducing the building volume, which saves more cooling and power
- Devised 15 Environmental Sustainability Indicators for JSC
  - ***Air Pollution:*** *SO_2 , NO_x , Particulates, Carbon, Ozone depleting substances*
  - ***Resource Use and Waste:*** *Solid waste, Water, Hazardous waste, Paper, Aluminum cans*
  - ***Energy:*** *Electricity, Natural gas, Diesel, BTU/GSF, Non-renewable energy %*
- Ex. If a refrigerant additive can save JSC 3 million kWh/yr in energy, it also reduces
  - SO_2 by 4,900 kg/yr
  - NO_x by 3,400 kg/yr

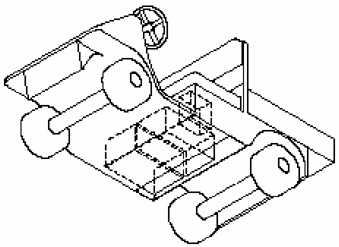
Future Technologies Considered

- Air
  - Advanced air monitors
- Agriculture & Food
  - Crop based foods requiring little energy
- Energy
  - Higher efficiency motors
  - Clean coal & carbon sequestration
  - Nuclear fusion
  - Solar (inc. lunar PV power)
  - Bio-fuels
  - Various energy storage options
- Fuel Cells
  - PEM
  - Regenerative
  - Fuel cell landscape cart & mower
- Sustainable Habitats
  - LED lighting
- Thermal Control
  - Micro-electromechanical systems (MEMS) cooling devices
  - Better refrigerants
  - High efficiency centrifugal chiller
  - Desiccant cooling systems
  - Solar powered refrigeration
  - Vacuum insulation
  - Refrigerator efficiency improvements
- Transportation
  - Fuel cell vehicles
  - Hypercar
  - Aerial vehicles
- Waste
  - Composting
  - Super-critical water oxidation
  - Disposable cup/utensil alternatives
- Water
  - Reuse for irrigation

Note: Those in blue were analyzed quantitatively

Recommendation: R&D Investment in

- Energy Efficient Habitability
  - Motors, computers, cooling, lighting, food preparation and storage, “green building”
- Waste Reduction/Reuse
- Water Purification/Reuse
- Renewable Energy Technologies
  - Solar
  - Regenerative fuel cells
- Electric vehicles
  - Fuel cell & solar powered



➢ We must move these from laboratory to daily life

Recommendation: Integrate Sustainability in Workplace

- Renewable Energy
  - Ex. Solar @ Mars field test site
- Energy Efficiency
  - Efficient air-conditioning
  - LED Stoplights
  - High reflectivity roofs
- Sustainable Buildings
- Alternative Fuel Vehicles
- Fuel Cell Cart for Landscapin

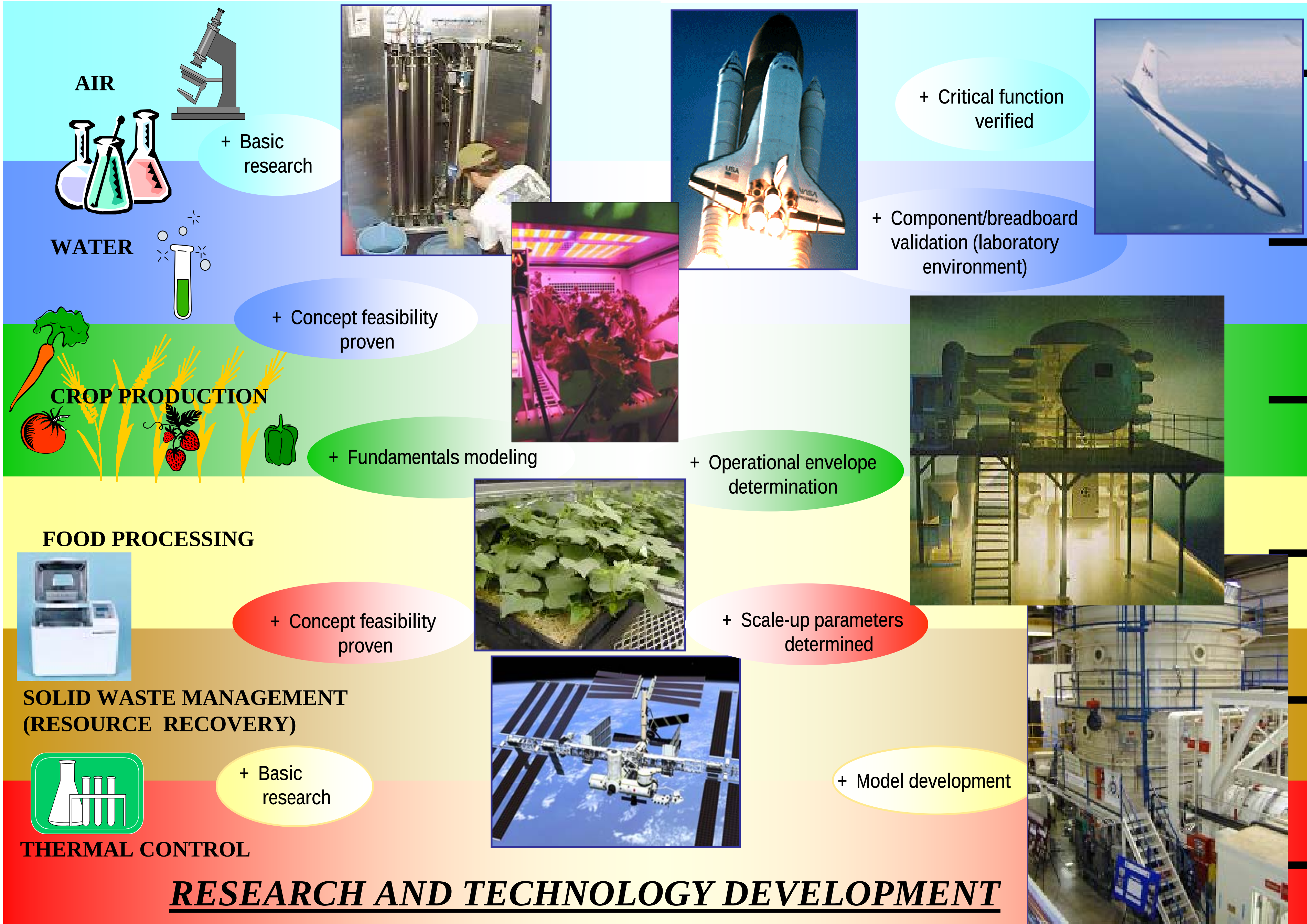
➢ Commercial & Experimental

Sustainability On Site (cont.)

- Sustainable Buildings
  - Astronaut Quarantine Facility was JSC's first LEED Certification ("Green Building")
  - Several more are in development!
  - A Lawrence Berkeley study estimates "direct increase in office workers' performance … between 0.5 and 5%."
- Alternative Fuel Vehicles
  - JSC has several new electric ca
  - Would like to use compressed natural gas in existing vehicles
  - Brought fuel ethanol (E85) to JSC

Education & Outreach

- Trying to increase Employee Awareness of Environmental Sustainability Issues
  - Environmental Management System (EMS)
  - Learn from NASA's Earth Science Enterprise
  - Began a Natural Step training class
- Promote Community Awareness
  - Display at public events
  - Form partnerships (e.g. City)
  - Education outreach

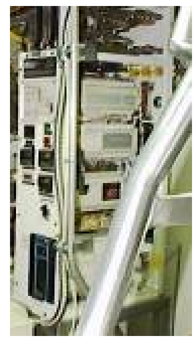

AIR
+ Basic research
WATER
+ Concept feasibility proven
CROP PRODUCTION
+ Fundamentals modeling
FOOD PROCESSING
+ Concept feasibility proven
SOLID WASTE MANAGEMENT (RESOURCE RECOVERY)
+ Basic research
THERMAL CONTROL
+ Critical function verified
+ Component/breadboard validation (laboratory environment)
+ Operational envelope determination
+ Scale-up parameters determined
+ Model development
RESEARCH AND TECHNOLOGY DEVELOPMENT

Lunar-Mars Life Support Test Project
Phase III 91-Day Test
September - December 1997

Biological Water Recovery System

Carbon Dioxide Removal System

Carbon Dioxide Reduction System



Oxygen Generation System

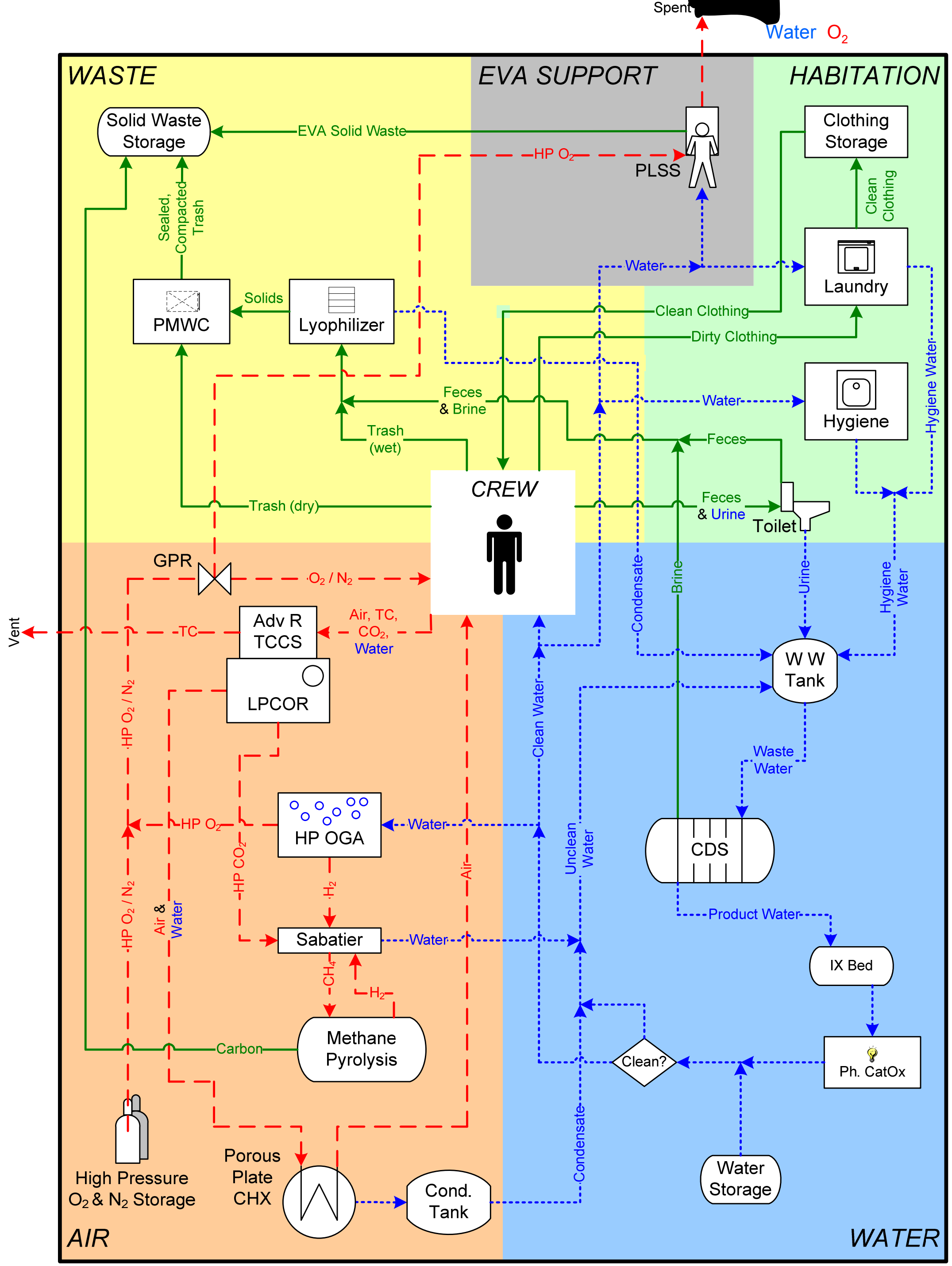
Trace Contaminant Control System

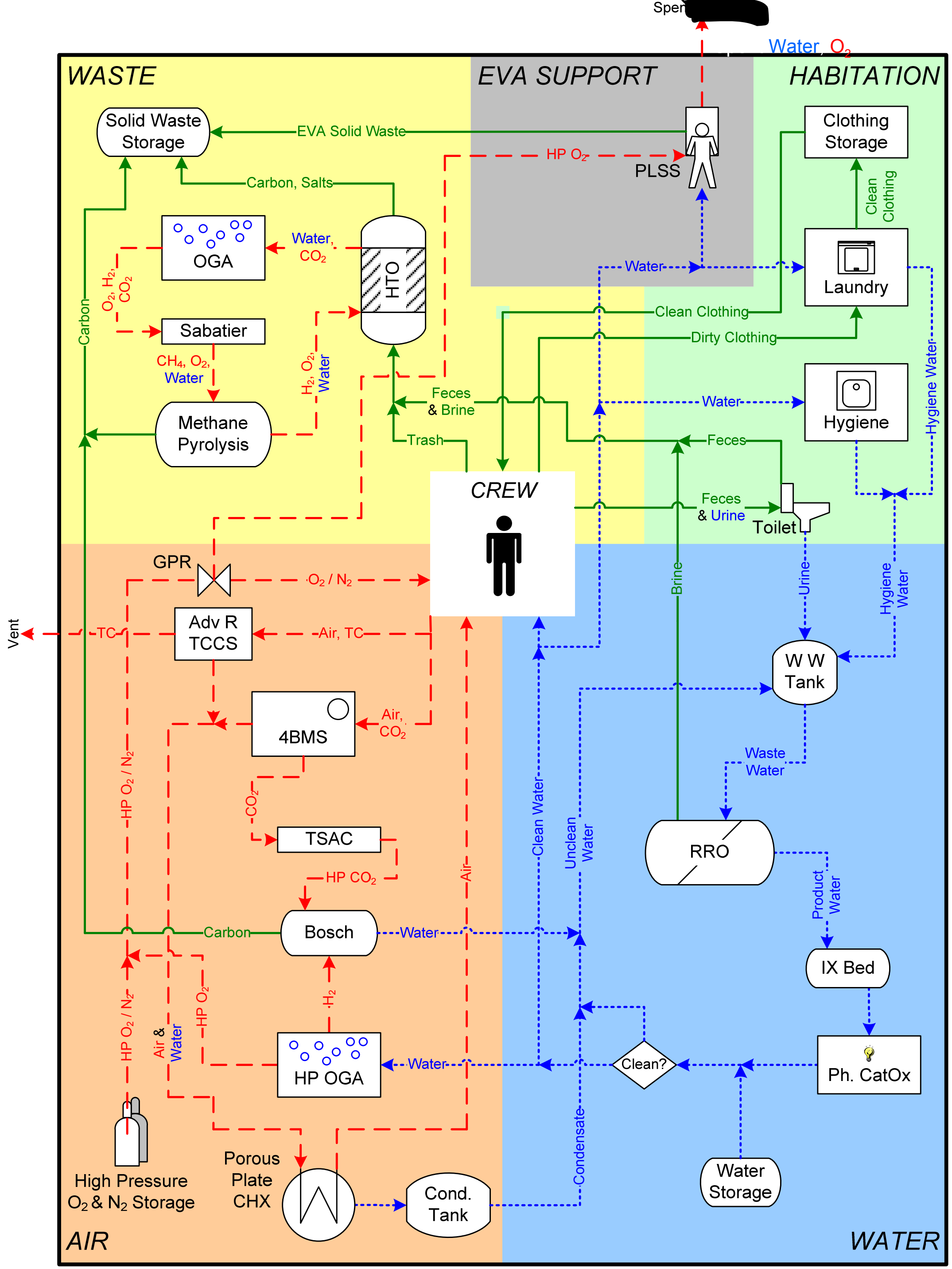
Control Room

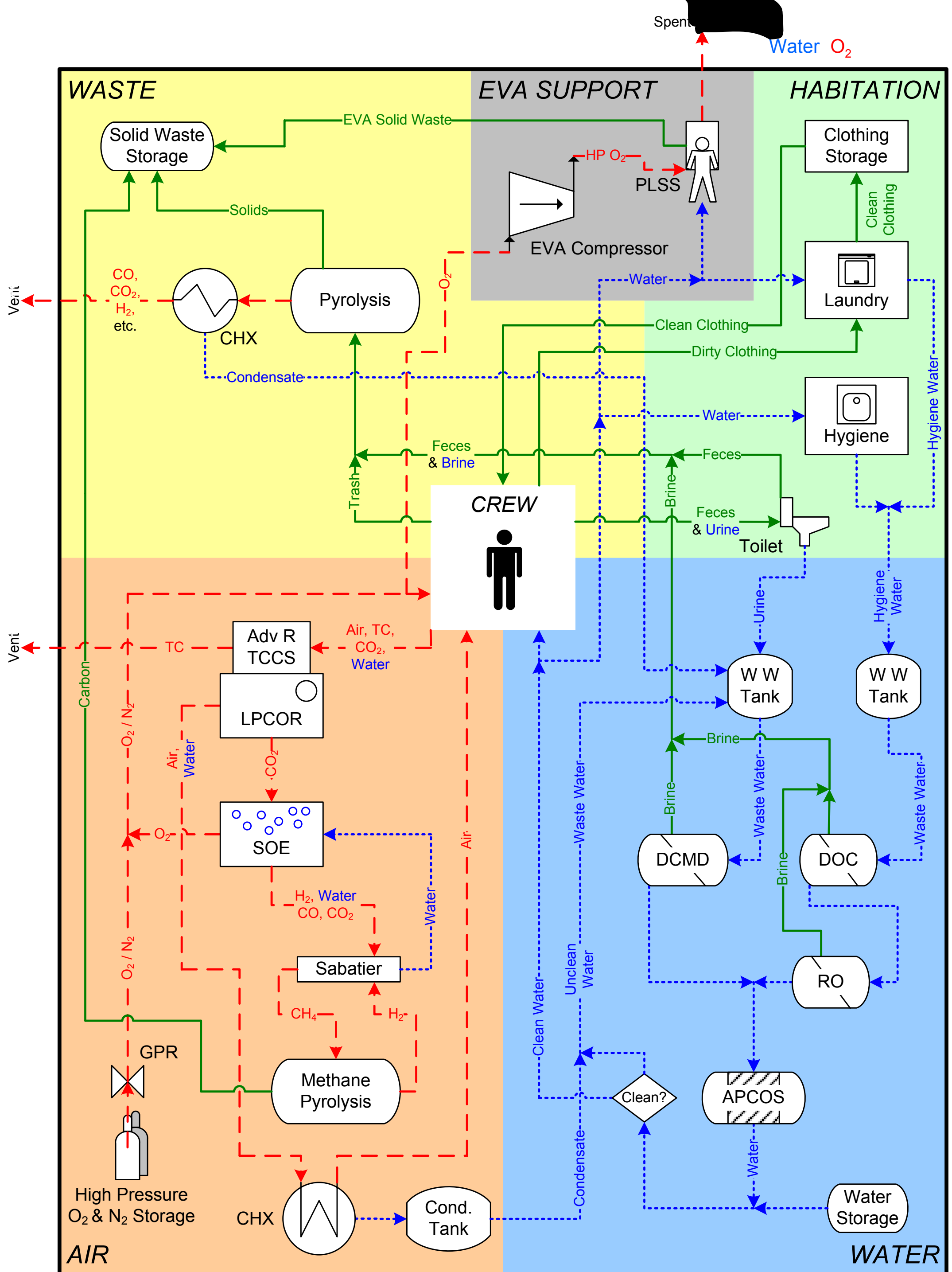
VPGC Wheat Harvest

Solid Waste Incinerator

Phase III Crew (left to right, Nigel Packham, Laura Supra, John Lewis, Vickie Kloeris)


Spent [redacted]
Water O_2
WASTE
EVA SUPPORT
HABITATION
Solid Waste Storage
EVA Solid Waste
HP O_2
PLSS
Clothing Storage
Clean Clothing
Sealed, Compacted Trash
Water
Laundry
PMWC
Solids
Lyophilizer
Clean Clothing
Dirty Clothing
Feces & Brine
Water
Hygiene
Hygiene Water
Trash (wet)
Feces
CREW
Trash (dry)
Feces & Urine
Toilet
GPR
O_2 / N_2
Condensate
Brine
Urine
Hygiene Water
Vent
TC
Adv R TCCS
Air, TC, CO_2, Water
W W Tank
LPCOR
HP O_2 / N_2
Clean Water
Waste Water
HP O_2
HP OGA
Water
HP CO_2
Unclean Water
CDS
H_2
Air
Air & Water
Sabatier
Water
Product Water
IX Bed
CH_4
H_2
Carbon
Methane Pyrolysis
Clean?
Ph. CatOx
Condensate
High Pressure O_2 & N_2 Storage
Porous Plate CHX
Cond. Tank
Water Storage
AIR
WATER


Sper[redacted]
Water, O_2
WASTE
EVA SUPPORT
HABITATION
Solid Waste Storage
EVA Solid Waste
HP O_2
PLSS
Clothing Storage
Clean Clothing
Carbon, Salts
OGA
Water, CO_2
HTO
O_2, H_2, CO_2
Sabatier
Carbon
CH_4, O_2, Water
H_2, O_2, Water
Methane Pyrolysis
Water
Laundry
Clean Clothing
Dirty Clothing
Feces & Brine
Trash
Water
Hygiene
Hygiene Water
Feces
CREW
Feces & Urine
Toilet
GPR
O_2 / N_2
Vent
TC
Adv R TCCS
Air, TC
Brine
Urine
Hygiene Water
4BMS
Air, CO_2
W W Tank
Clean Water
Unclean Water
CO_2
Waste Water
TSAC
RRO
HP CO_2
HP O_2 / N_2
Air
Product Water
Bosch
Carbon
Water
IX Bed
H_2
HP O_2 / N_2
Air & Water
HP O_2
HP OGA
Water
Clean?
Ph. CatOx
Porous Plate CHX
Cond. Tank
Condensate
Water Storage
High Pressure O_2 & N_2 Storage
AIR
WATER



Spen[redacted]
Water O2
WASTE
EVA SUPPORT
HABITATION
Solid Waste Storage
EVA Solid Waste
HP O2
PLSS
EVA Compressor
Clothing Storage
Clean Clothing
Solids
Pyrolysis
CHX
CO, CO2, H2, etc.
Vent
O2
Water
Laundry
Clean Clothing
Dirty Clothing
Condensate
Water
Hygiene
Hygiene Water
Feces & Brine
Feces
Trash
Brine
Feces & Urine
Toilet
CREW
Urine
Hygiene Water
Vent
TC
Adv R TCCS
Air, TC, CO2, Water
LPCOR
Carbon
O2 / N2
Air, Water
CO2
SOE
O2
Water
Air
H2, Water CO, CO2
Sabatier
CH4
H2
Methane Pyrolysis
GPR
High Pressure O2 & N2 Storage
CHX
Cond. Tank
W W Tank
W W Tank
Brine
Waste Water
Waste Water
Waste Water
DCMD
DOC
Brine
RO
Clean Water
Unclean Water
Clean?
APCOS
Water
Condensate
Water Storage
AIR
WATER