Water Walls: Highly Reliable, Massively Redundant Life Support Architecture

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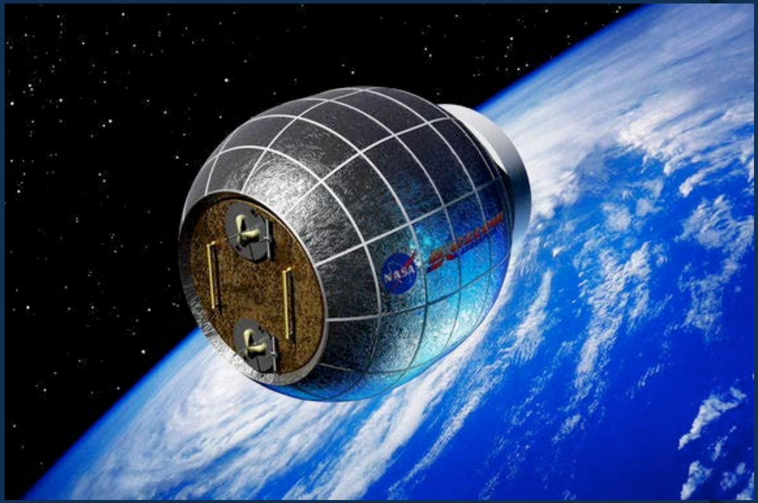
Motivation

- The cost of human space flight today is prohibitive.
- Cost is a major impediment to the frequency and duration of future exploration missions.
- What is needed is to reduce the cost of human spaceflight by an order of magnitude.
- We need a new approach to sustaining humans in space.

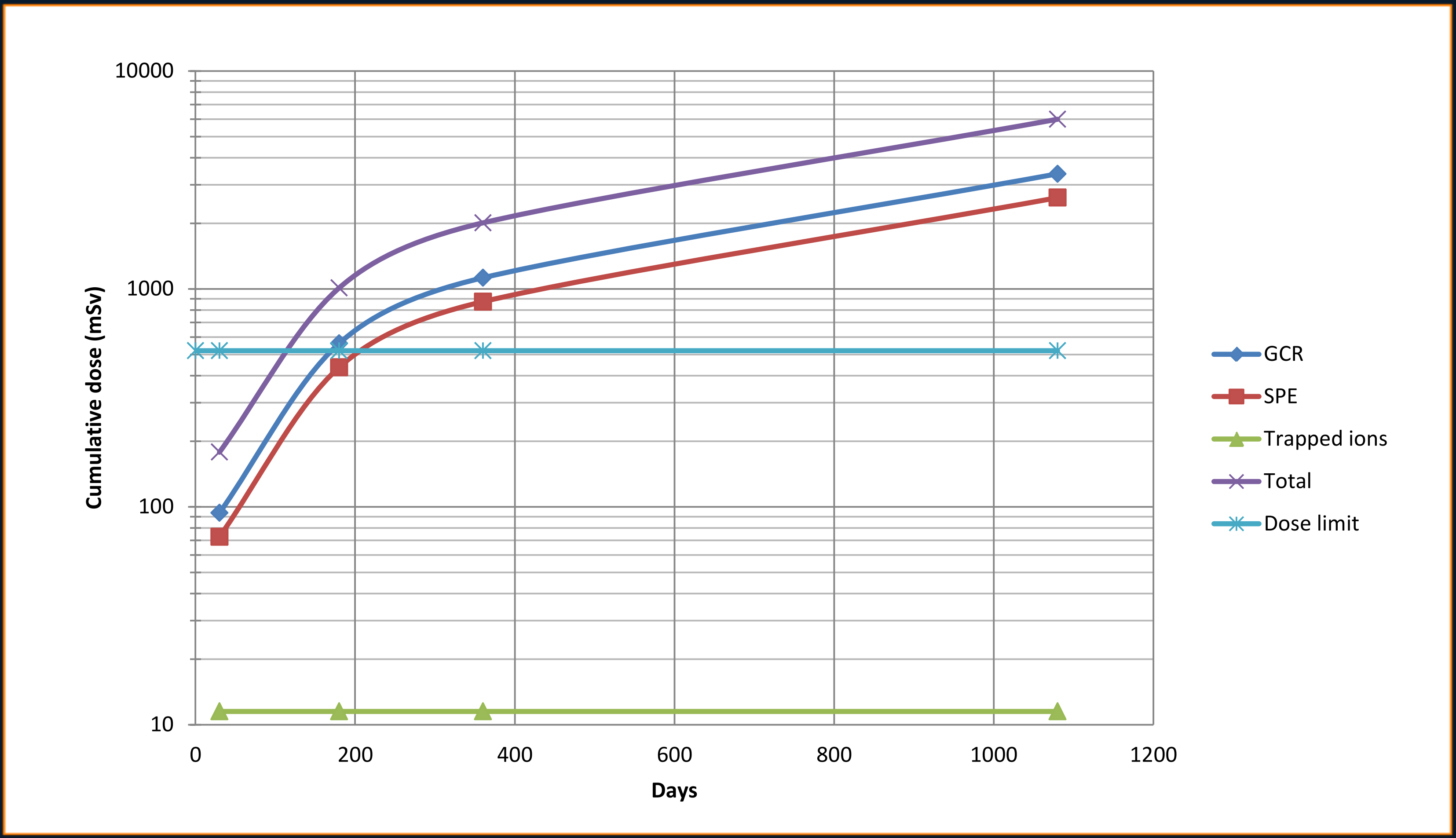
Habitat Water Walls Architecture

- Our approach integrates
  life support,
  thermal,
  structural,
  and radiation protection
  functions into the walls of the spacecraft.



- We achieve a mass savings by combining the mass and function of all subsystems within the mass allocation of a radiation protection water wall.

The Need for Radiation Protection Calculated for an ISS Aluminum Module



Water Walls Applied to a TransHab-type Inflatable Module

Radiation Protection

Providing "parasitic" radiation protection is prohibitively massive and expensive.

- For a 240 day deep space mission with 150 mSv career dose limit and an ISS derived cylindrical habitat 130,000 Kg will be required.
- For the same mission where solar radiation protection is all that is required a 20 cm thick water wall in an ISS sized element will require more than 25,000 Kgs of water

But do we need to provide this water from Earth?

- A 6 person crew producing 15 l/person-day of wastewater with a 80% recovery ratio will produce 6500 Kg/year of wastewater.
- It would require 4 years of operation to accumulate enough water to provide a solar water wall for a single ISS element.

Life Support Equivalent System Mass (ESM) DURATIONS

Equivalent System Mass and Metric Values for a Range of Missions and Technologies

Mission / Vehicle	Baseline Technology ESM [kg]	Advanced Technology ESM [kg]	ELS R&TD Metric
Near-Term Exploration Mission:	**19,973**	**13,553**	**1.47**
Crew Exploration Vehicle	3,316	2,258	1.47
Lunar Surface Access Module	2,323	1,982	1.17
Lunar Outpost	14,334	9,313	1.54
Independent Exploration Mission:	**52,996**	**29,208**	**1.81**
Mars Transit Vehicle	16,643	10,890	1.53
Mars Descent / Ascent Lander	4,894	3,039	1.61
Surface Habitat Lander	31,459	15,279	2.06

Reliability for Long Duration Missions

Mars Mission	Transit Mission		Surface Stay Time	
Days	Min	Max	Min	Max
Conjunction	400	500	500	600
Opposition	570	700	30	90
Flyby	500	650		

Experience from operation of the life support system on Mir and ISS has demonstrated significant reliability issues for conventional systems.

The Water Walls concept uses a more passive approach than the mechanical systems used on ISS

Reliability – A More Passive Approach to Life Support is Better than all Mechanical

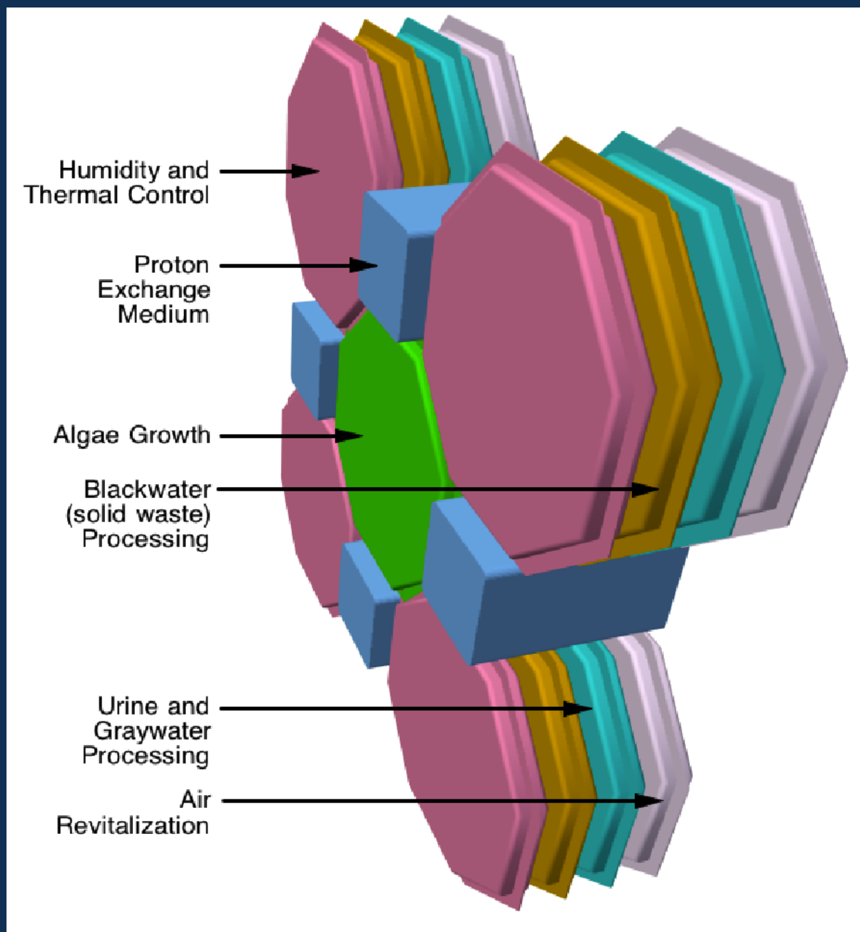
Nature uses no compressors, evaporators, lithium hydroxide canisters, oxygen candles, or urine processors to revitalize our atmosphere, clean our water, process our wastes, and grow our food.

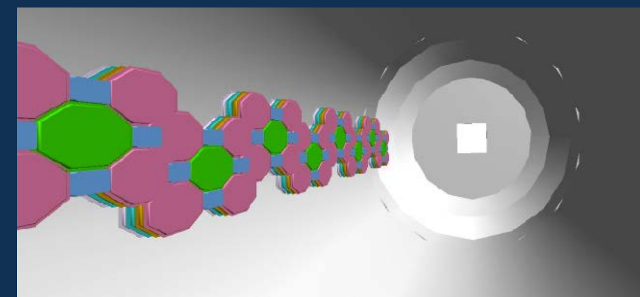
Conventional NASA approach is to use electro-mechanical systems which tend to be failure prone .

In comparison, Nature's passive systems do not depend upon machines and provide sufficient redundancies so that failure is not a problem.

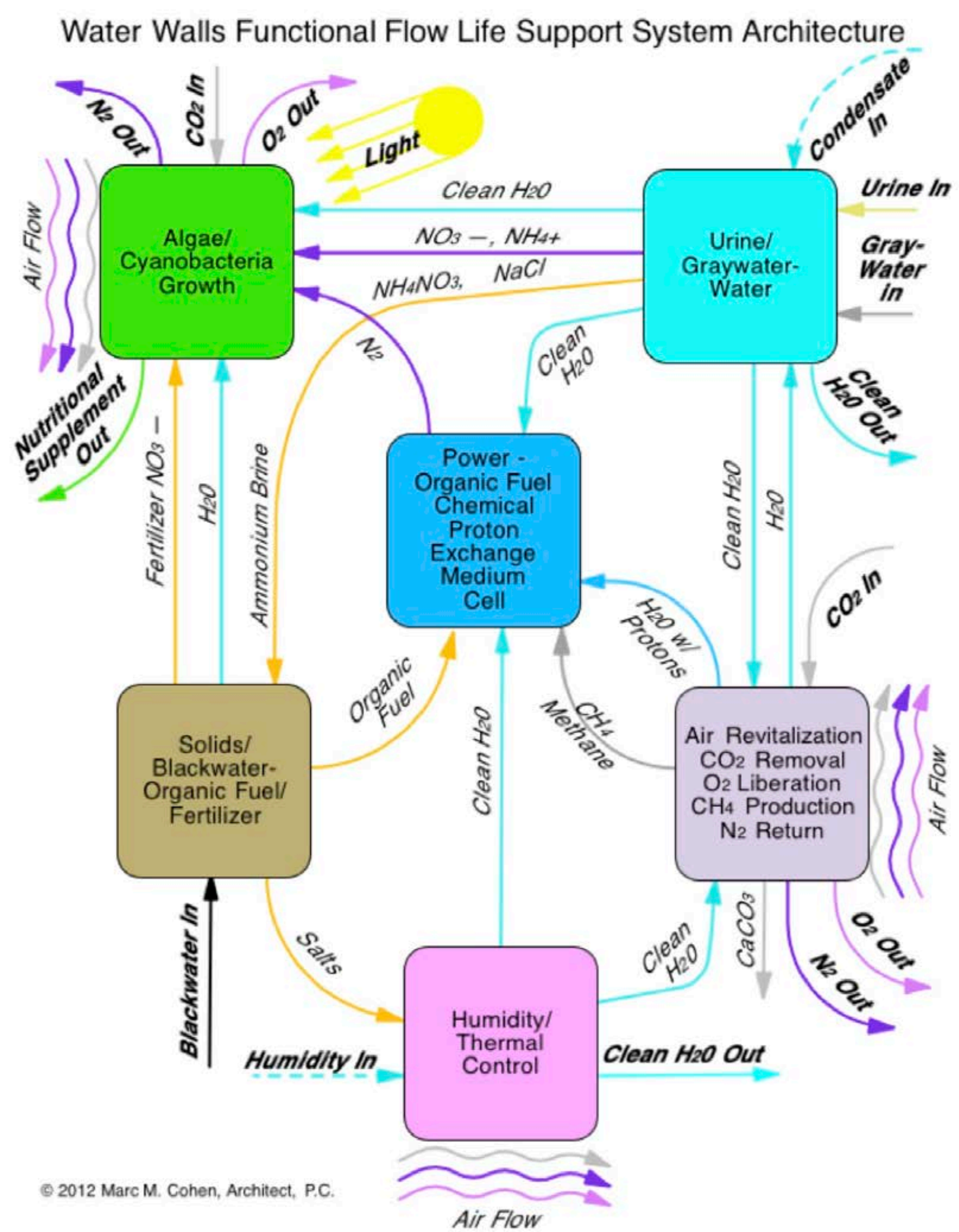
The Water Wall concept takes an analogous approach that is biologically and chemically passive and massively redundant.

Water Walls Modular Construction

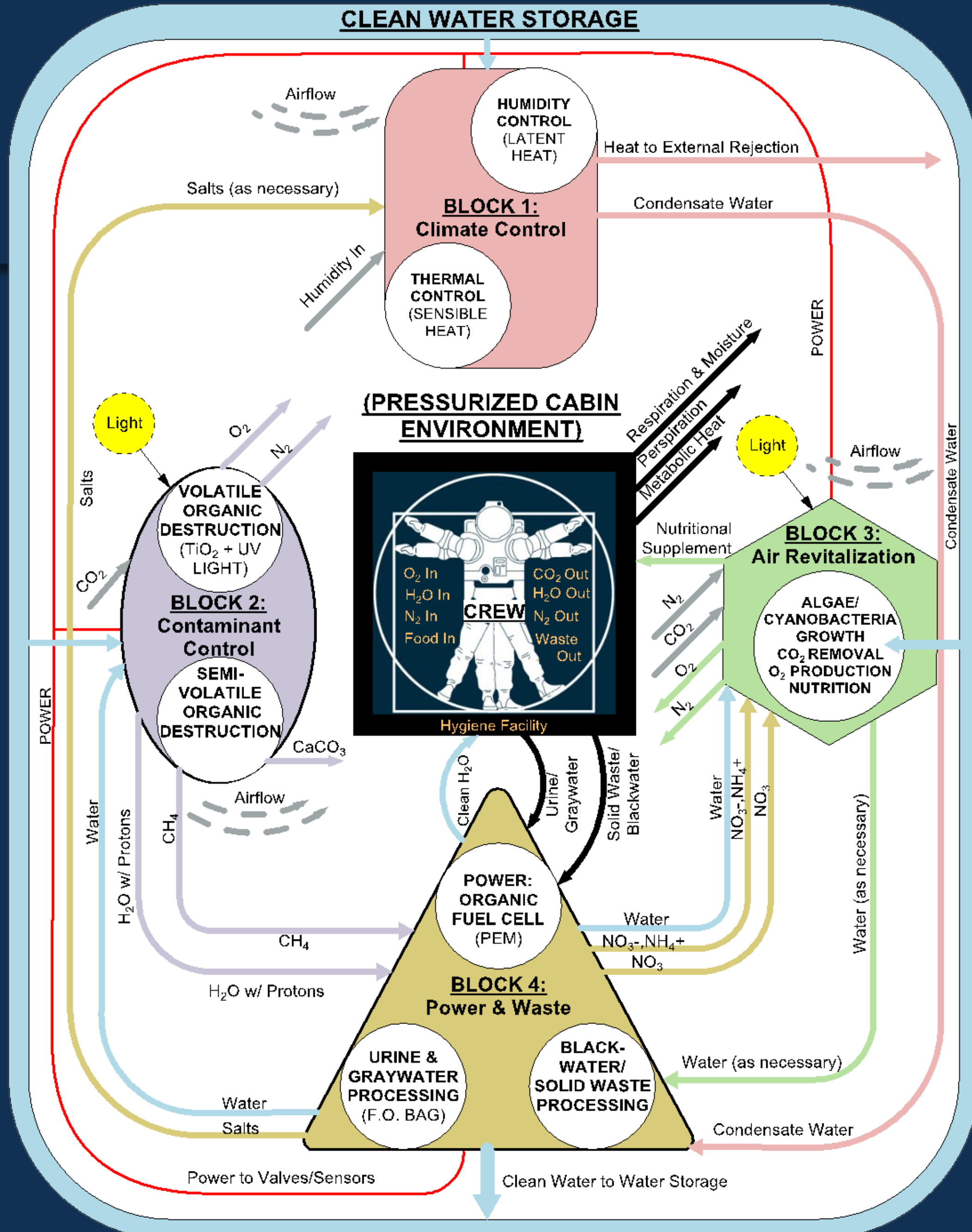




Water Walls *Initial* **Functional Flow** Diagram



Water Walls **Process Block** Integration Diagram



Allocation of Life Support Functions to Water Walls Elements

TABLE 1. Water Walls Life Support Functions and Systemic Redundancies					
WW Primary Functions (Based on Inputs and Outputs)	**Algae Growth Bag**	**Blackwater/ Solids Bag**	**PEM Fuel Cell**	**Urine/ H20 Bag**	**Humidity & Thermal Bag**
O2 Revitalization	X				
CO2 Removal	X				
Denitrification/Liberation of N2		X	X	X	
Clean Water Production				X	X
Urine & Graywater Processing				X	
Semi-Volatile Removal	X				
Blackwater Processing	X	X			
Humidity & Thermal Control					X
Nutritional Supplement Production	X				
Electrical Power Production			X		

Development Approach

1. Fabricate and test functions, processes and units at the bench scale.
2. Scale up to a sub-scale functional prototype such as a Forward Osmosis bag.
3. Test Functional Prototypes in a controlled (e.g. closed chamber) and field environments.
4. Microgravity Flight Testing on ISS, and
5. Integrated System Test in the Bigelow Inflatable Module.

Core Air Revitalization Process: CO_2 Sequestration & O_2 Production

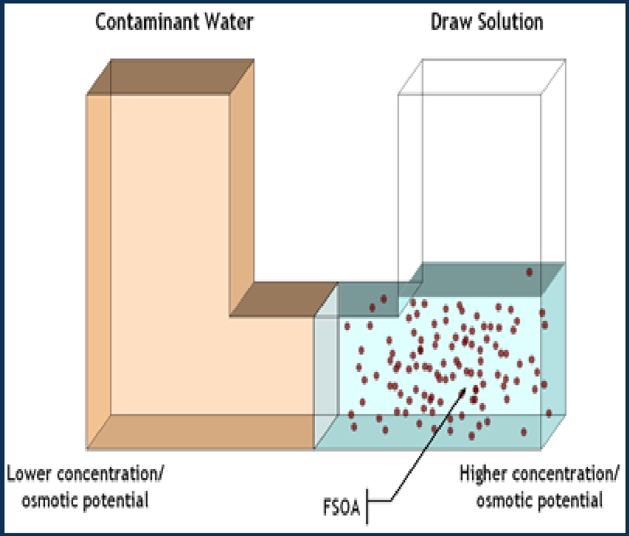
Testing using OptiCells™ Cyanobacteria and *Synechococcus*

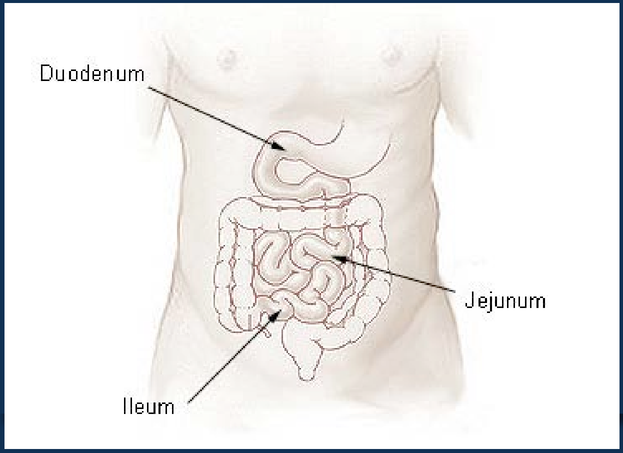
- Cyanobacteria 53.6 mg CO_2 fixed L^{-1} hr^{-1},
- *Synechococcus* 250 mg CO_2 fixed L^{-1} hr^{-1}.

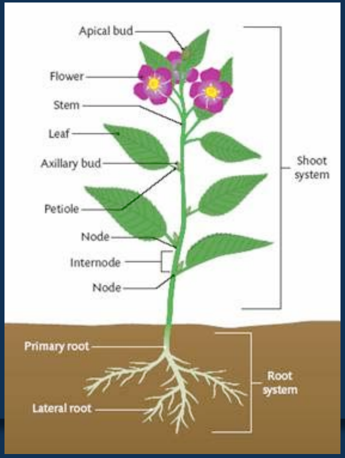
Future tests will use green alga *Chlorella*, and the edible cyanobacterium *Spirulina*. As well as determining O_2 production.

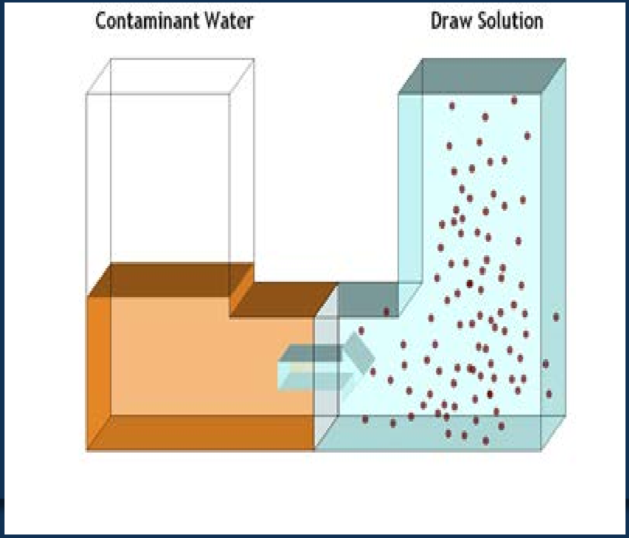
Algae/cyanobacteria needs to offset 1Kg CO_2/person-day

Forward Osmosis: A Natural Process -- X-Pack™ forward osmosis bag

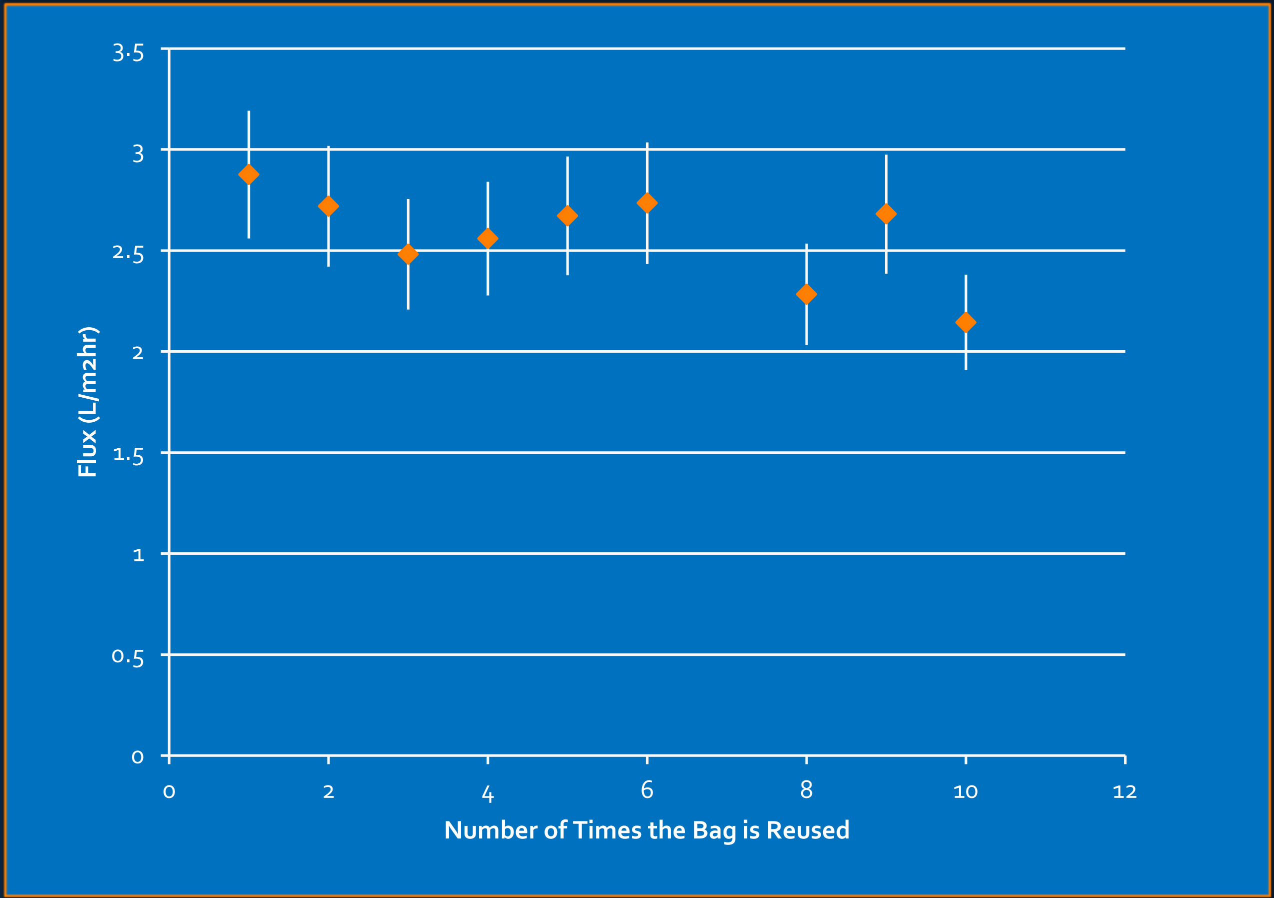








Example of Water Walls Research: Reduction in flux as a function of the number of times a bag has been reused.

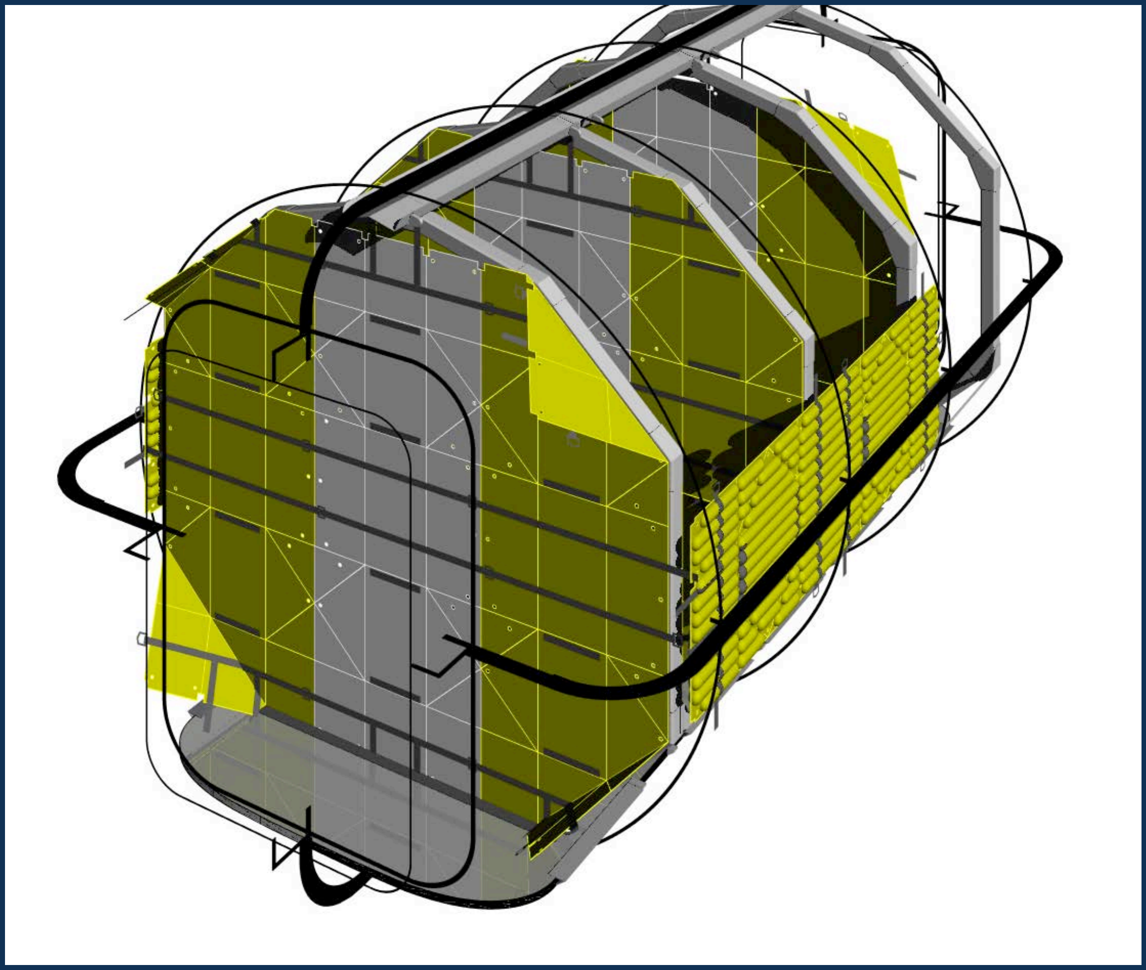


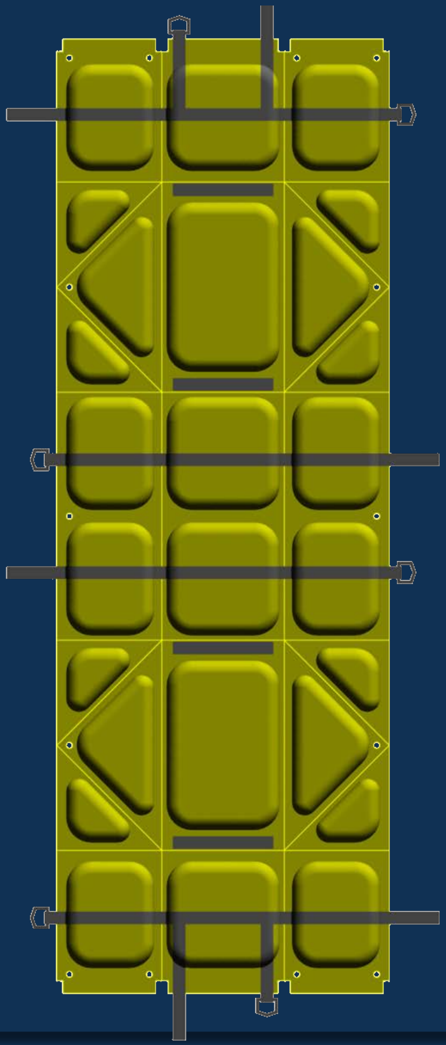
Data <u>was </u>taken after 4 hours of operation for each data point. Error bars are 11 %.

STS 135 Forward Osmosis Bag Flight Test

2013 New Design for Forward Osmosis Cargo Transfer Bag (CTB) that Accommodates Flight Demonstrations of Functional Cell Elements

Cargo Transfer Bag Placement in an ISS Module for Functional Process Use and Radiation Shielding





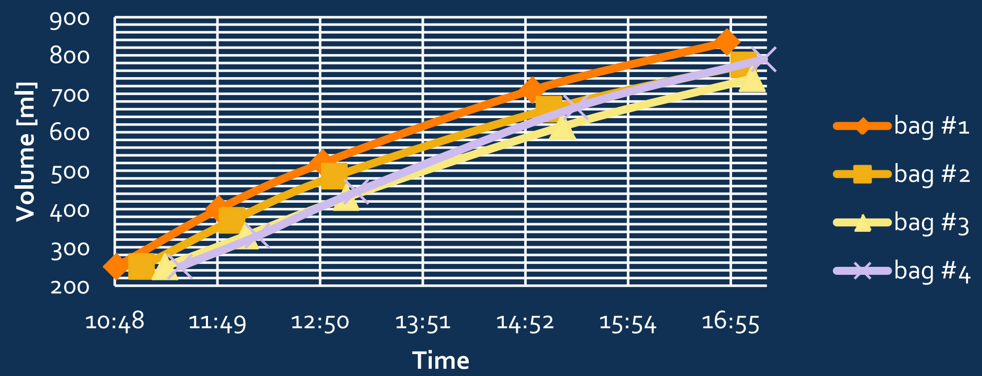
FO – CTB Field Tests at Desert-RATS

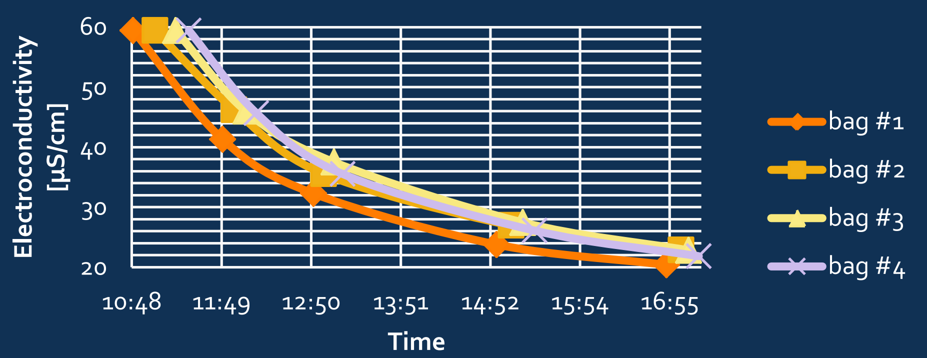
D-RATS 2011

D-RATS 2012

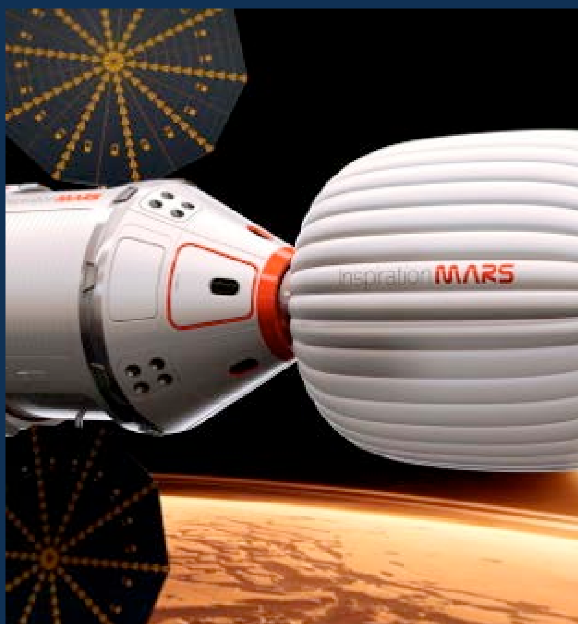
Results of D-Rats Field Tests Measured Recycling Ability for Hygiene Water

	Product at Start	Product at End, 5 ht	Feed at Start	Feed at End, 5 ht
Na	12737.0	3377.0	49.9	440.0
NH4	nd	nd	23.0	25.1
K	nd	15.1	38.4	92.6
Mg	nd	2.0	9.0	23.4
Ca	nd	3.2	36.0	90.3
Cl	21555.0	4656.0	54.4	406.0
PO4	nd	nd	4.7	7.8
SO4	nd	4.6	39.0	242.0
TOC	0.6	65.0	272.0	343.0
TIC	<0.5	<0.5	41.0	87.0
TN	<0.5	<0.5	36.3	41.5
pH	5.6	6.9	6.7	5.4
Cond.	54.4 mS	2.7 mS	639 µS	5.39 mS





In the News: Inspiration Mars Fly-By 2018



New Scientist – 26 FEB 2013 - Taber McCallum told *New Scientist* that solid and liquid human waste products would get put into bags and used as a radiation shield…"which is an idea already under consideration by the agency's Innovative Advanced Concepts programme, … called Water Walls, which combines life-support and waste-processing systems with radiation shielding. "

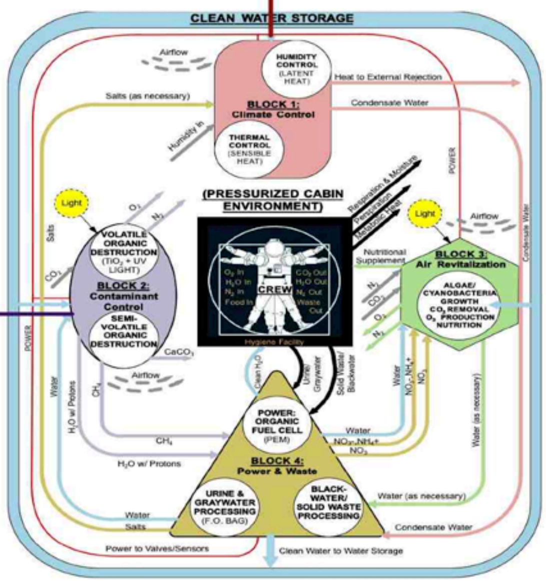
VIRAL all the way to the **Colbert Report,** etc….

Water Walls-Related Projects When We Proposed to NIAC

Funded

Proposed

Humidity Control
JPL & Ames
Air Team
Gamechanging
Darrell Jan
TRL-4



Volatile Organic Destruction
NASA Ames+
UC Santa Cruz
NASA STTR &
Ames Center
Innovation Fund
Bin Chen
TRL-3

Complementary Funding

Forward Osmosis
Cargo Transfer Bag
Logistics to Living
Advanced Exploration Systems
Sherwin Gormly
Michael Flynn, ARC
Scott Howe, JPL
Joe Chambliss , JSC
TRL-3

Past Funding

Forward Osmosis Bag
Flight Experiment for
Simulated Urine
Exploration (Joshi)
Sherwin Gormly
Dan Schultz , KSC
Monica Solor, KSC
TRL-7

Current Water Walls-Related Technology Development

Funded | **Proposed**

Water Walls Architecture
2012 NIAC to NASA Ames
Michael Flynn +
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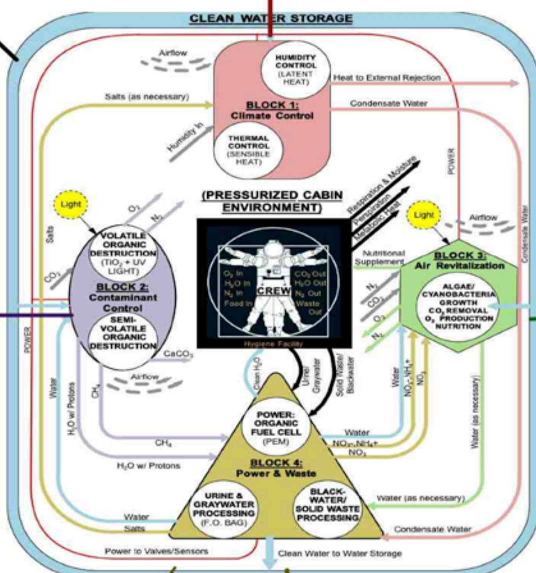

CO_2 Sequestration/ O_2 Production
NASA Ames
Director's
Matching Grant to
Sherwin Gormly
BAERI
Rocco Mancinelli
TRL-3

Forward Osmosis Secondary Treatment (FOST) Urine/Graywater Processing
Gamechanging
Michael Flynn
TRL-4

Microbial Organic Fuel Cell
2012 NASA
Synthetic Biology
John Hogan
Michael Flynn
TRL-3

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Current and Proposed Water Walls-Related Technology Development

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TRL-4

Nitrogen Economy/ Module Sizing
Astrotecture™+ BAERI
NASA SBIR Proposal
Rocco Mancinelli
Marc Cohen
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TRL2

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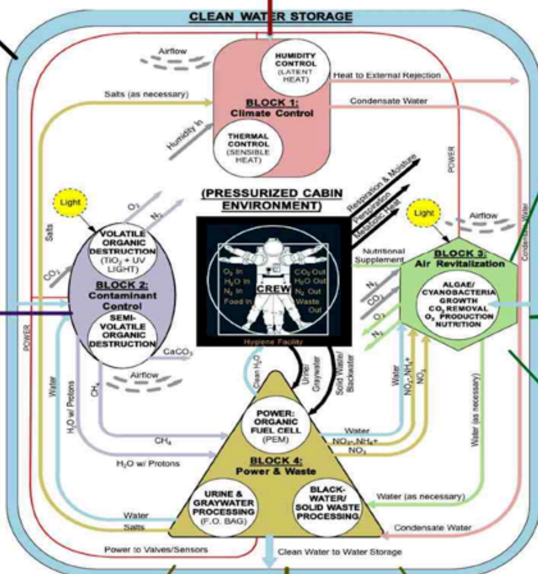

CO_2 Sequestration/ O_2 Production
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3D Food Printing from Algae & Spirulina
Astrotecture™
2013 NIAC Step A
Michelle Terfansky
Marc Cohen
Rocco Mancinelli
TRL-2

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Secondary Effluent Treament
proposal to the
Calif. Energy Commission
Environmental/Energy R&D
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TRL-2