



Water Walls: Highly Reliable, Massively Redundant Life Support Architectures

NASA Ames Research Center

Renée L. Matossian and Marc M. Cohen.

Astrotecture™

*Sherwin Gormly
Desert Toad LLC.*

Rocco L. Mancinelli
*Bay Area Environmental Research
Institute
(BAERI)*

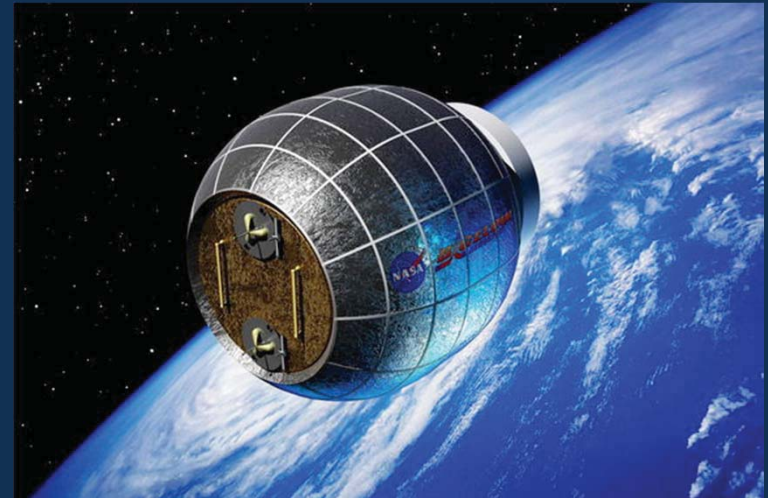
Motivation

- 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.

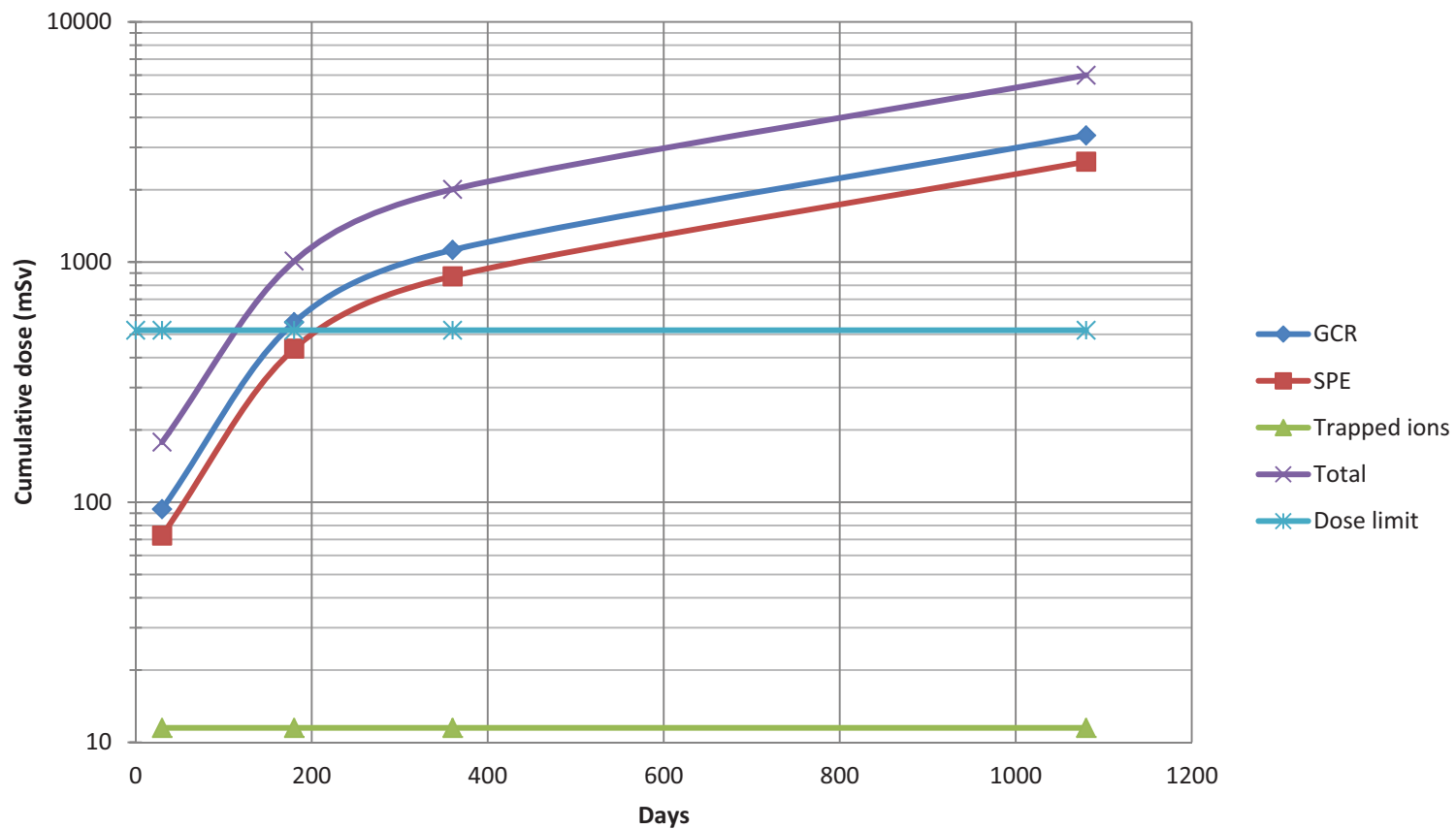


Habitat Water Walls Architecture

- 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



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	Advanced Technology	ELS R&TD Metric
	ESM [kg]	ESM [kg]	
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

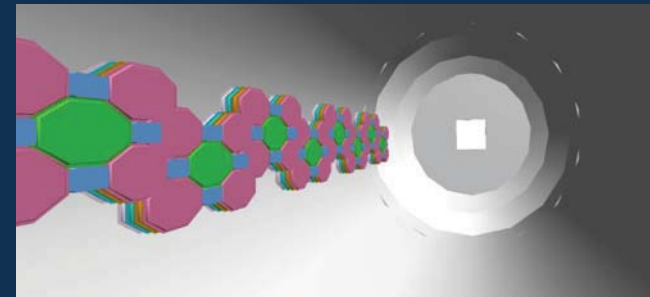
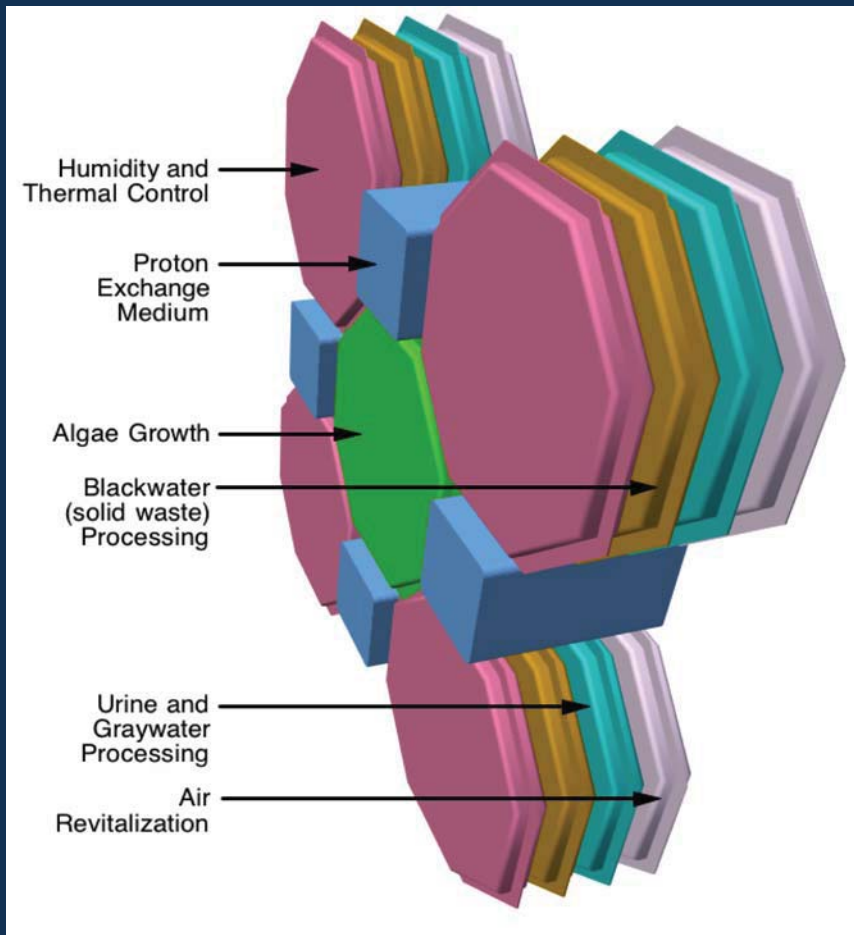
Nature uses no compressors, evaporators, lithium hydroxide canisters, oxygen candles, or urine processors to revitalize our atmosphere, clean our water, process our wastes, and grow our food.

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

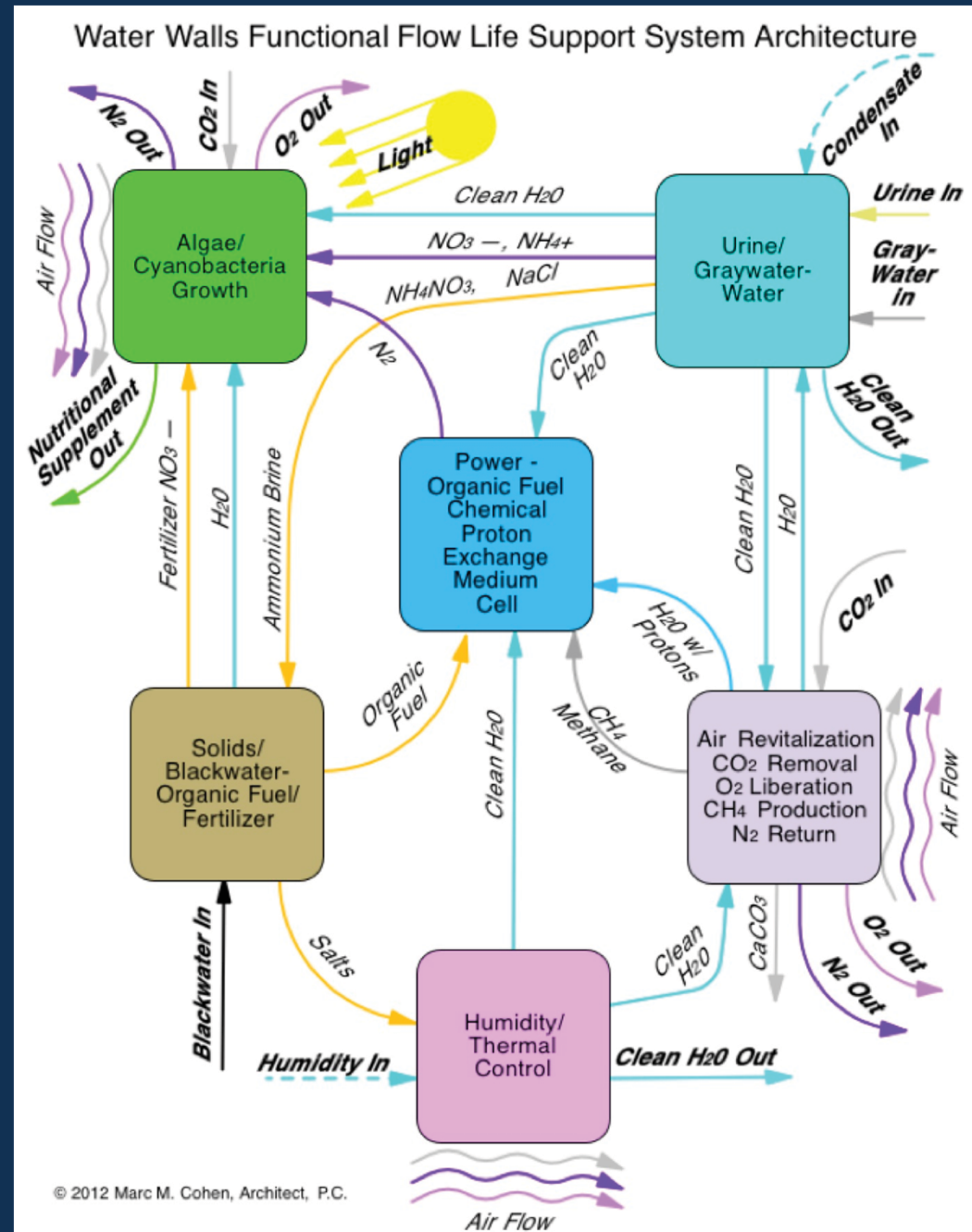
In comparison, Nature's passive systems do not depend upon machines and provide sufficient redundancies so that failure is not a problem.

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

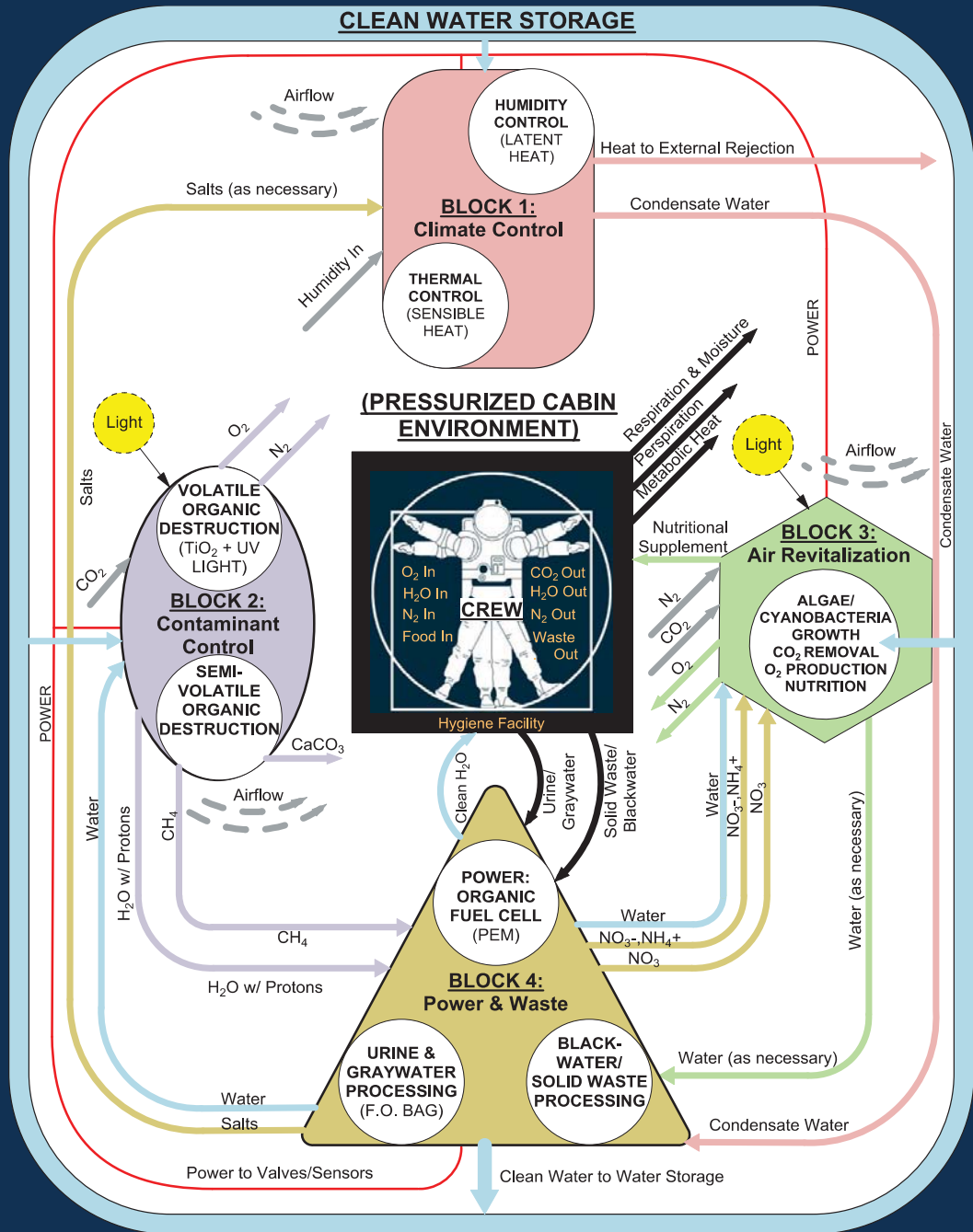
Water Walls Modular Construction



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/ H2O 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: CO₂ Sequestration & O₂ Production

Testing using OptiCells™ Cyanobacteria and *Synechococcus*

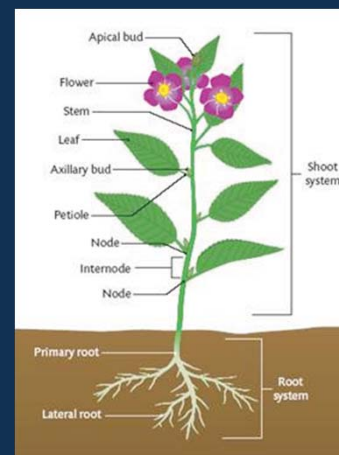
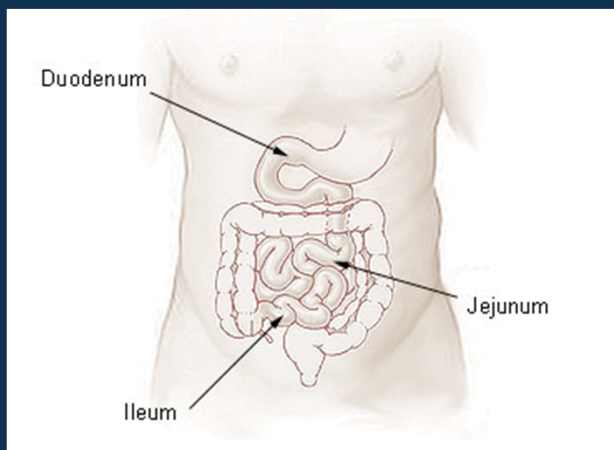
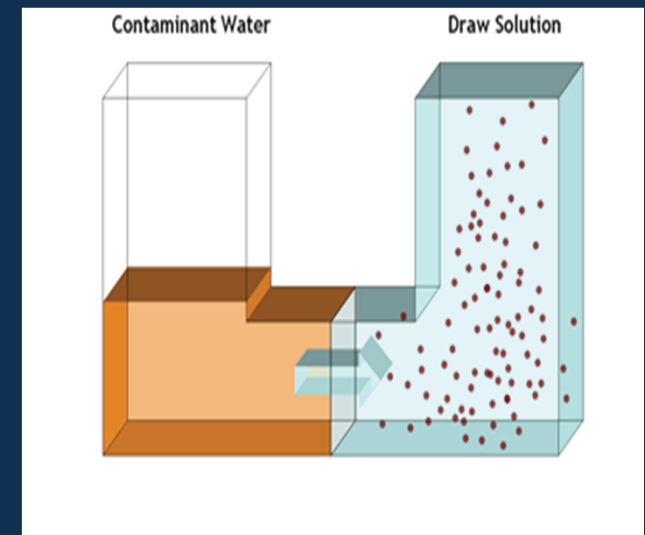
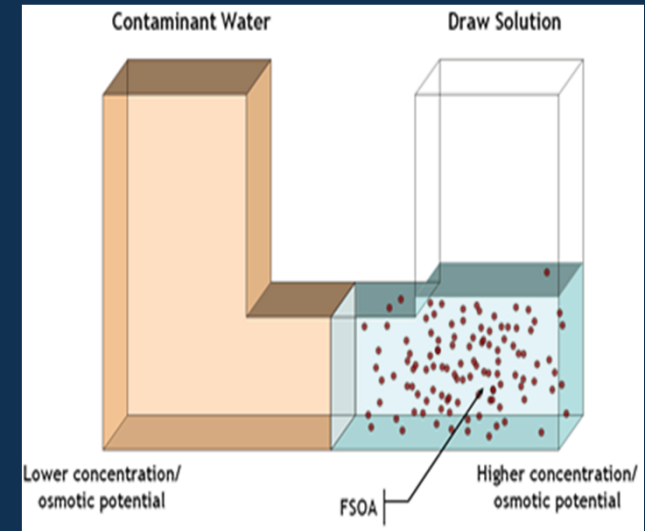
- Cyanobacteria 53.6 mg CO₂ fixed L⁻¹ hr⁻¹,
- *Synechococcus* 250 mg CO₂ fixed L⁻¹ hr⁻¹.



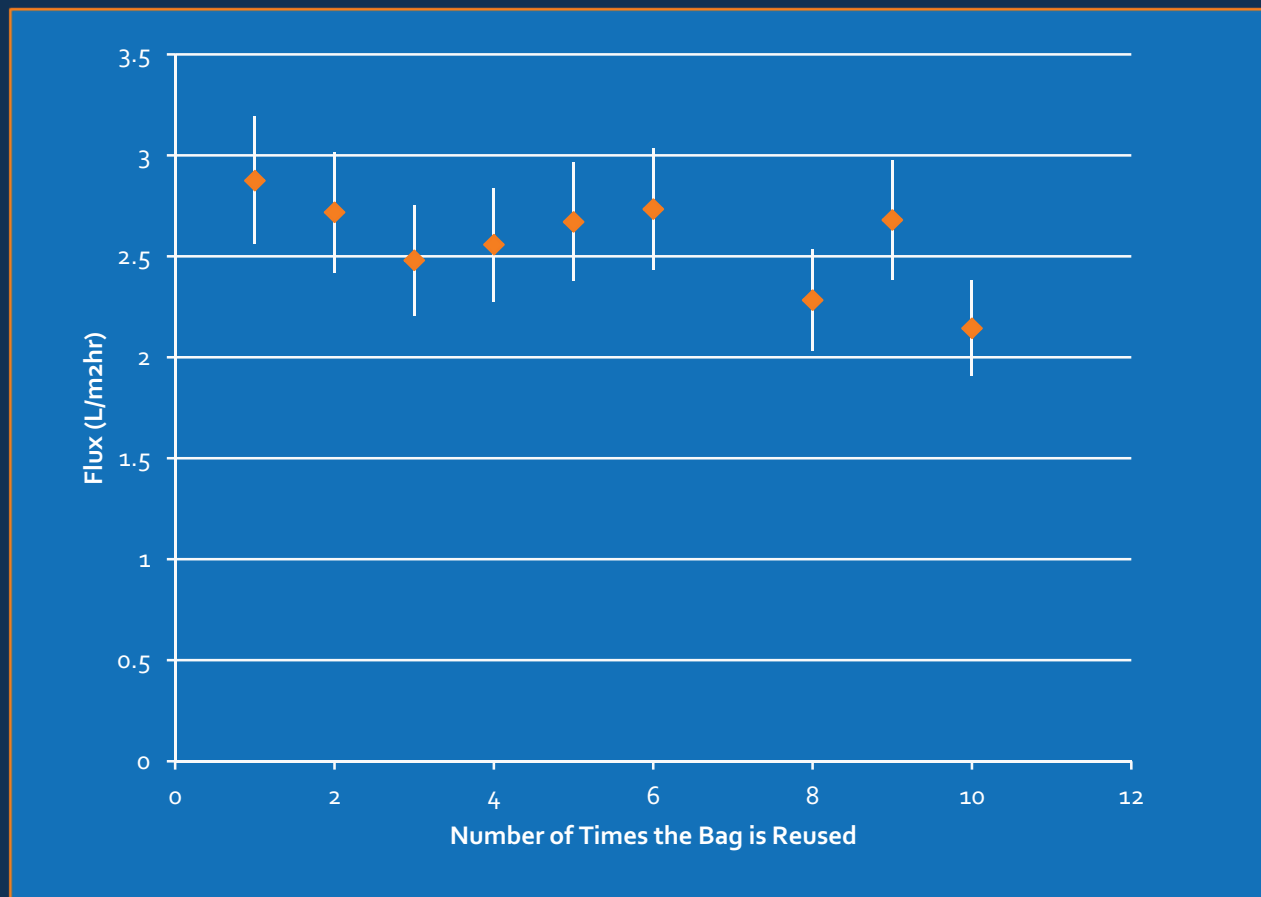
Future tests will use green alga *Chlorella*, and the edible cyanobacterium *Spirulina*. As well as determining O₂ production.

Algae/cyanobacteria needs to offset 1Kg CO₂/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 was taken after 4 hours of operation for each data point. Error bars are 11 %.

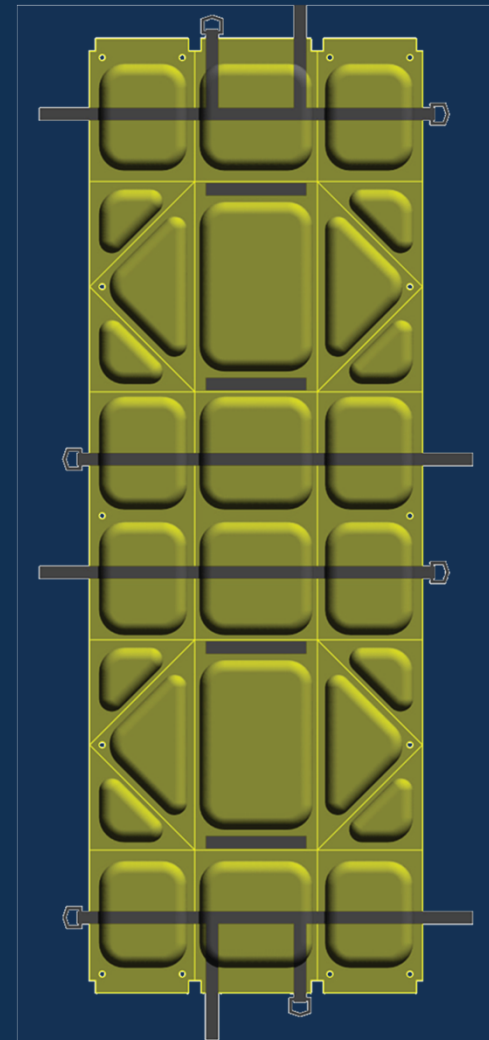
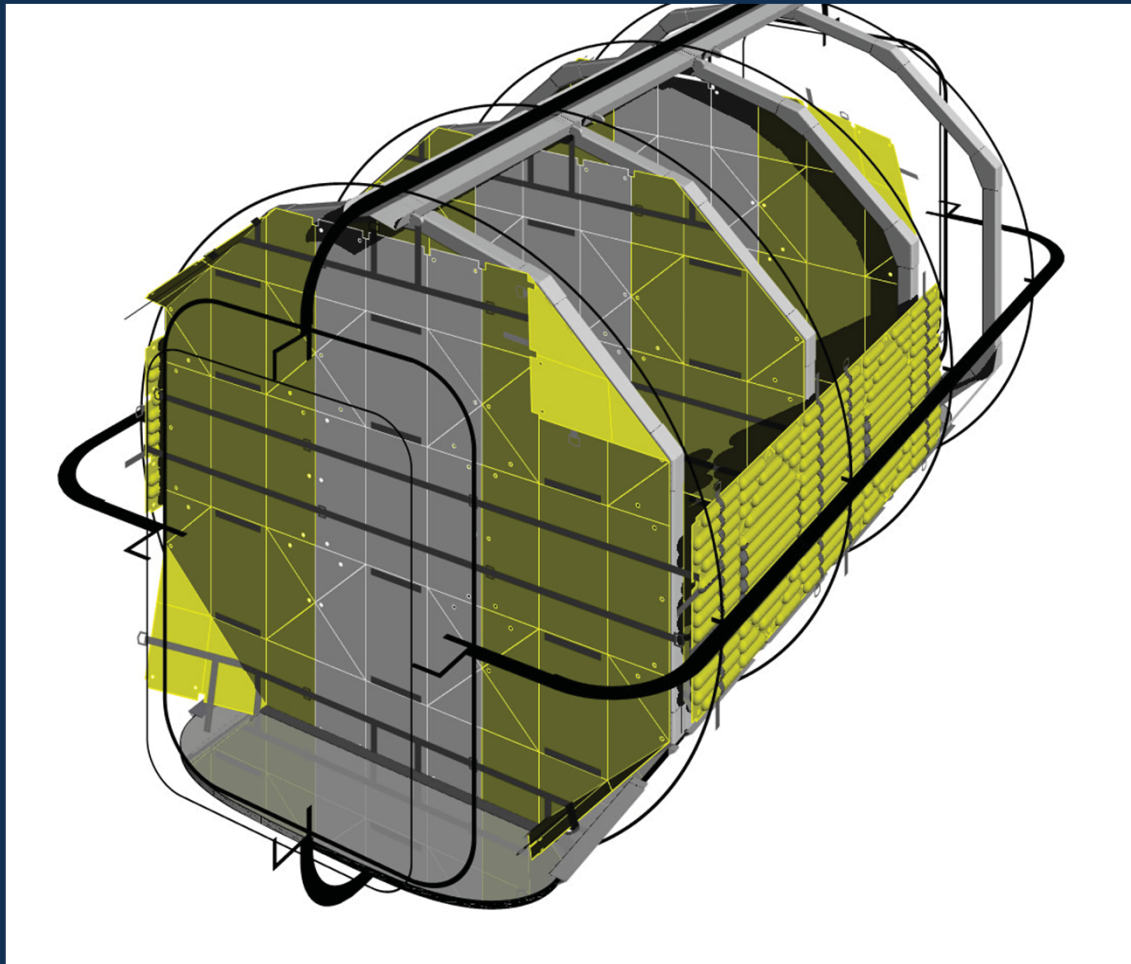
STS 135 Forward Osmosis Bag Flight Test



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



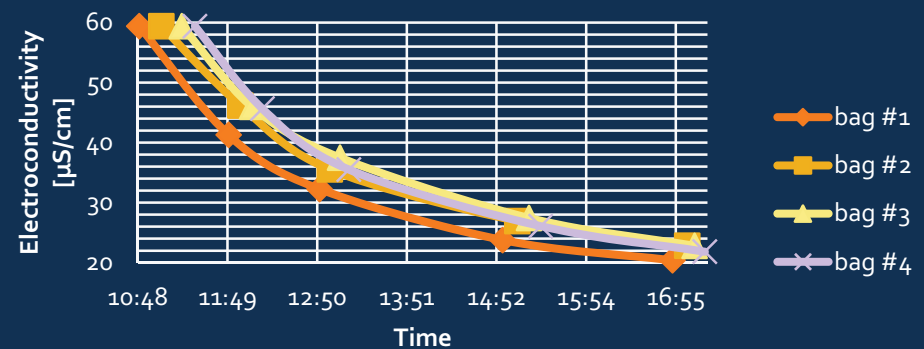
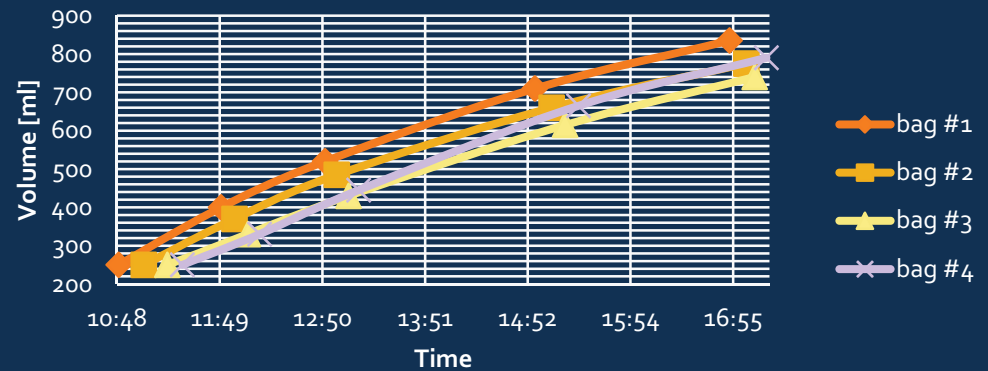
D-RATS 2011



D-RATS 2012

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

	Product at Feed at		Feed at	
	Start	End, 5 ht	Start	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 μ S	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

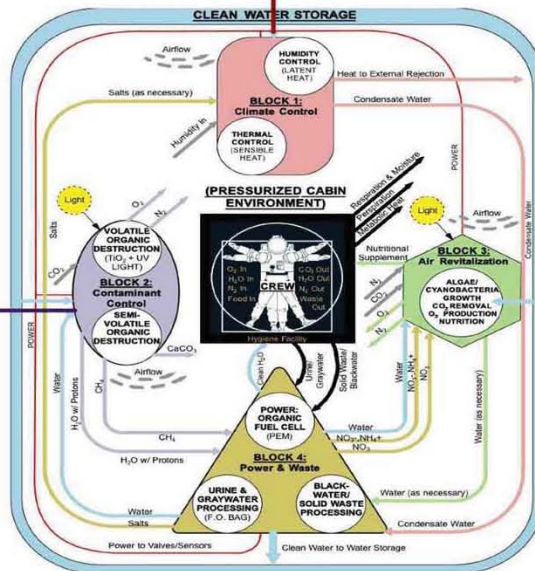
Proposed

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

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

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

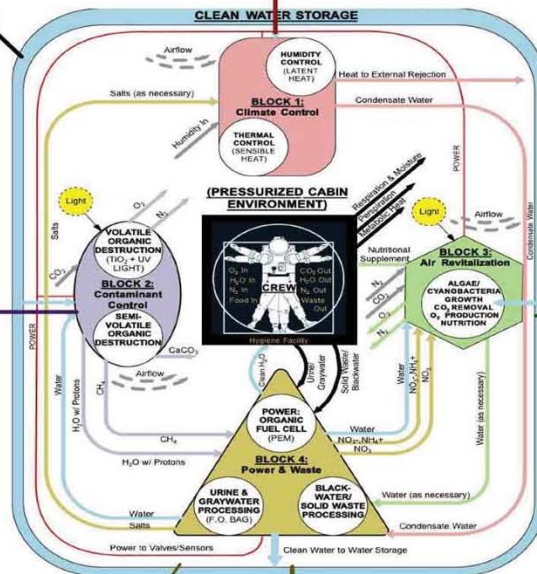
Water Walls Architecture
2012 NIAC to NASA Ames
Michael Flynn + Astrotecture™
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**CO₂ Sequestration/
O₂ Production**
NASA Ames
Director's
Matching Grant to
Sherwin Gormly
BAERI
Rocco Mancinelli
TRL-3

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

Past Funding

Forward Osmosis Bag Flight Experiment for Simulated Urine
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Current and Proposed Water Walls-Related Technology Development

Funded

Proposed

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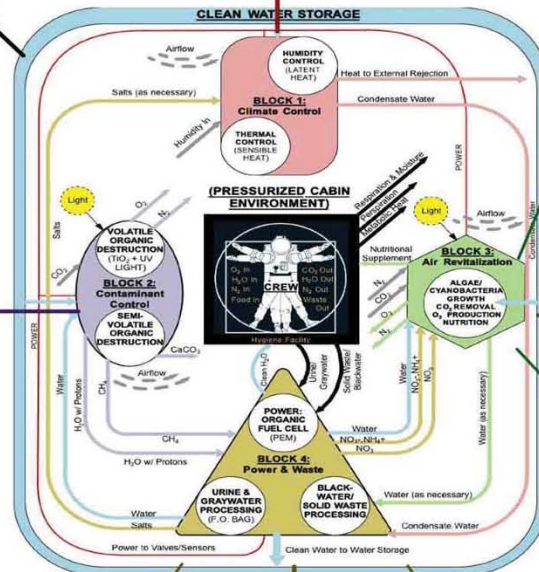
Humidity Control
JPL & Ames
Air Team
Gamechanging
Darrell Jan
TRL-4

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

Complementary Funding

Forward Osmosis Cargo Transfer Bag
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Volatile Organic Destruction
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CO₂ Sequestration/ O₂ Production
NASA Ames
Director's Matching Grant to
Sherwin Gormly
BAERI
Rocco Mancinelli
TRL-3

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

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

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

Past Funding

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