Environmental Control and Life Support, the Long View

ECLSS Environmental Engineering in the Broad Context

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What is ECLSS and Why Should We Care

Environmental Control and Life Support (ECLSS) is supporting humans in space through engineered habitat design

What is the value?

- It is required for any human space activity, and is particularly important if humans are to ever make space home
- It is also the most relevant branch of space science for providing a direct contribution to truly sustainable design and engineering on Earth

Areas of Interest

- ECLSS Engineering: Designing mass balanced human habitats
- ESM (Equivalent System Mass), the ultimate case study in life cycle cost (ECLSS justification math)
- Commercial ECLSS and a Cislunar volatile trade

ECLSS: Environmental Engineering in Space

ECLSS, Mass Balance and Real Sustainability Science

- Is the total accounting for metabolic mass balance, bio-geochemical cycling
- It includes as a subdiscipline systems and unit process design for real toilet to tap water engineering.
- By the numbers, and by the contaminant class, destruction methods for water resource recovery

Why is Water Recycle/Reuse Critical for Space?
Life Support Requirements - Mass Breakdown (Per Person-Day)

Exploration Relevance Initial Reference Assumptions

DAILY INPUTS - NOMINAL

	kg
Oxygen	0.84
Food Solids	0.62
Water in Food	1.15
Food Prep Water	0.76
Drink	1.62
Subtotal	***4.99***
Hand/Face Wash Water	4.09
Shower Water	2.73
Clothes Wash Water	12.50
Dish Wash Water	5.45
Other	0.35
TOTAL	***30.60***

≈ 5 to 30 kg H_2O per person-day

Minimum viable life support 75% water, 20% air and 5% dry solids available for recovery.

Probably more like 96% is water for reasonable quality of life

DAILY OUTPUTS - NOMINAL

	kg
Carbon Dioxide	1.00
Respiration and Perspiration Water	2.28
Urine	1.50
Feces Water	0.09
Sweat Solids	0.02
Urine Solids	0.06
Feces Solids	0.03
Subtotal	***4.98***
Hygiene Water	12.58
Clothes Wash Water	11.90
Clothes Wash Latent Water	0.60
Other Latent Water	0.60
Food prep. Latent Water	0.04
Flush Water	0.50
TOTAL	30.60

Mass Balance Chemistry

Primary Reaction Equations:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

$C_xH_xO_xN_x$ gives Urea, CO_2, and Trace Organics

$CH_4N_2O + O_2 \rightarrow CO_2 + NH_3 + H_2O$

2 step protein reduction NH_3 then N_2

$CO_2 + H_2 \rightarrow CH_4 + O_2$

Sabatier recovering the O_2 but lose the C_s

$H_2O \rightarrow H_2 + O_2$

Electrolytic (Hydrolysis) Water Separation

$CH_4 \rightarrow 2H_2 + C$ or CX

Bosh or Bio in future (now wasting CH_4)

Notes: Current O_2/H_2O Closure nearing completion, but H_2 closure sacrificed for mass efficiency and simplicity. Next priority, H_2 closure. C and trace is a long-term priority, representing about 2% by mass

Practical Mass Balance

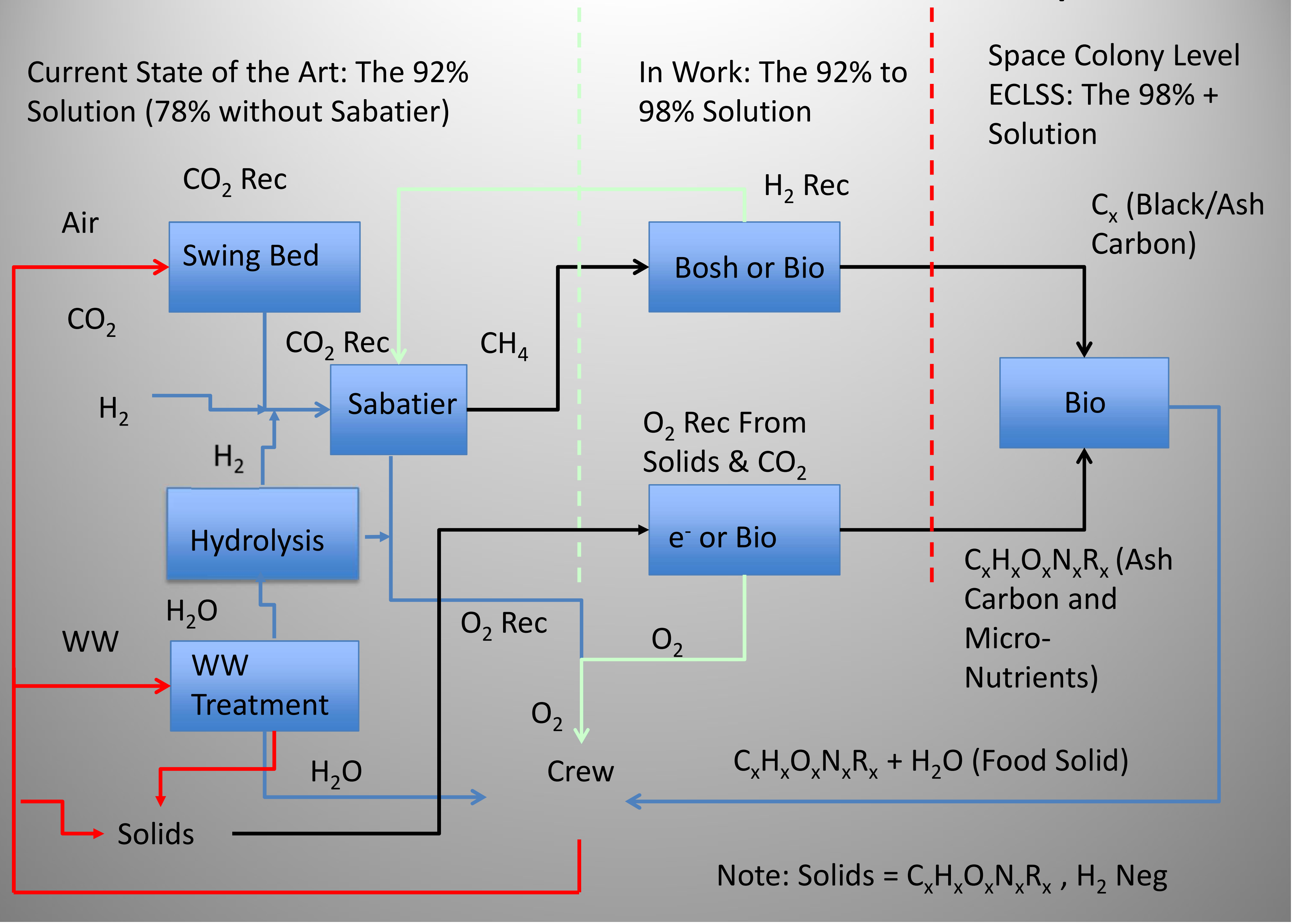
DAILY INPUTS - NOMINAL		DAILY OUTPUTS - NOMINAL	
Oxygen	0.84	Carbon Dioxide	1.00
Food Solids	0.62	Respiration and Perspiration Water	2.28
Water in Food	1.15	Urine Water	1.50
Food Prep Water	0.76	Feces Water	0.09
Drinking Water	1.62	Sweat Solids	0.02
		Urine Solids	0.06
		Feces Solids	0.03
Flush Water	0.49	Flush Water	0.50
Totals	5.48		5.48

(Wieland 1994,. Hanford and Ewert, 2006)

2% solids, the rest water and gas, 5% C in CO_2.

Thus, ≅ 93% closure potential for water

Mass Closure of The Current Baseline Assumption



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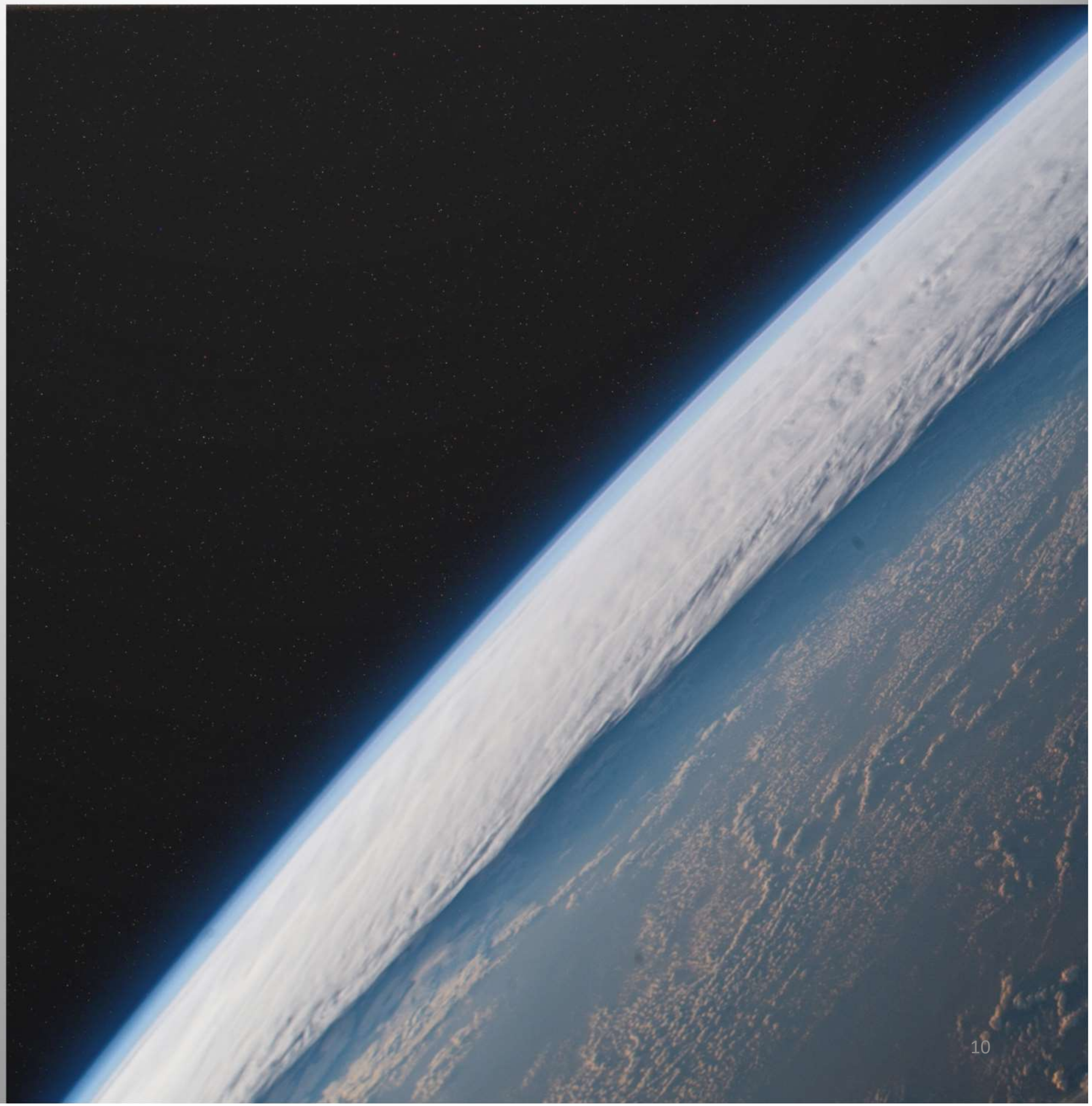
Developing circular systems for complete recovery of water in space

Specifically, Urine recovery water and Nutrient resource exploitation concepts

Note; Ends up being total water recover as humidity condensate return acts is a low contaminate level (near dilution) component



Hydromars Next Step: Integrating Water and Nutrient Recovery

- Project Funded by SNSA

Rymdstyrelsen
Swedish National Space Agency

- Partners

hydromars

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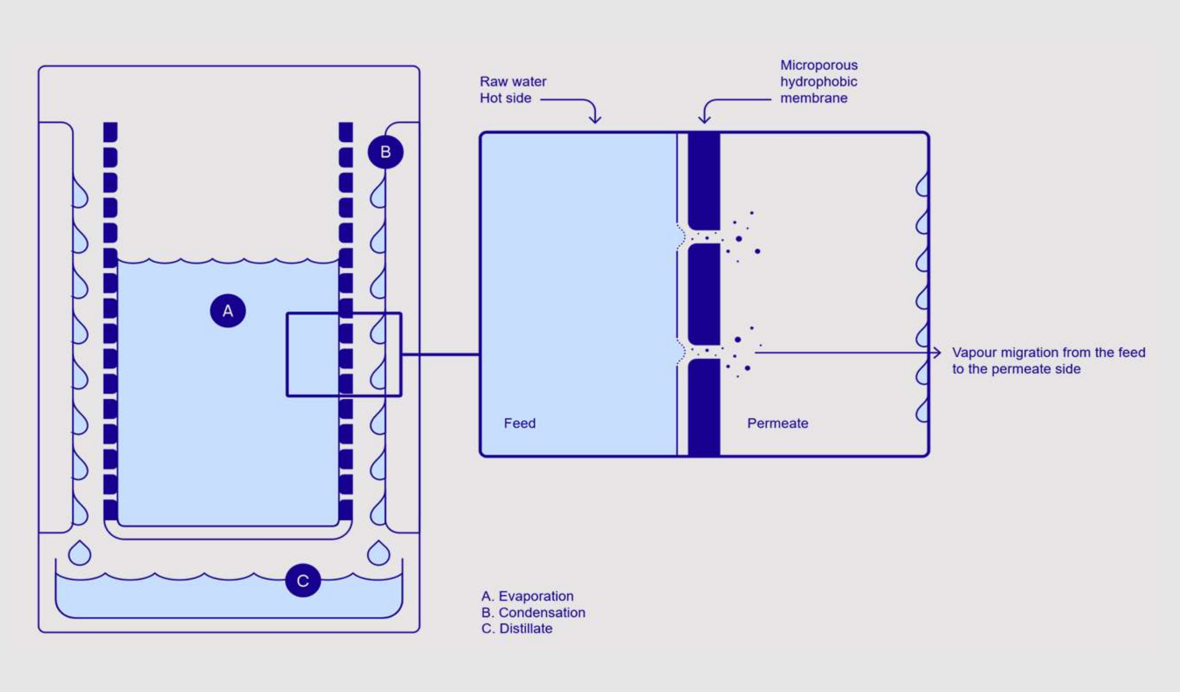
Core Technology

→ Harnessing the principle of **pervaporation** under **controlled conditions**
→ **Sustainable** water production by enabling **resource circularity**



Heated feed water releases **individual** water **molecules** – not droplets

↓

The **molecules** escape through a membrane to gather and condense on a **cool** surface

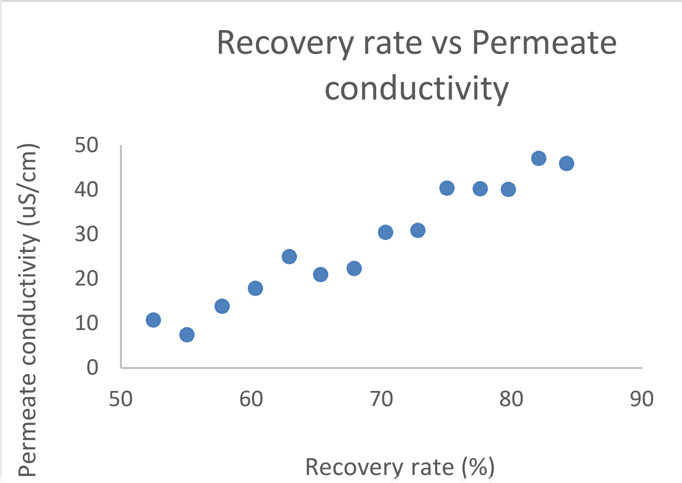
↓

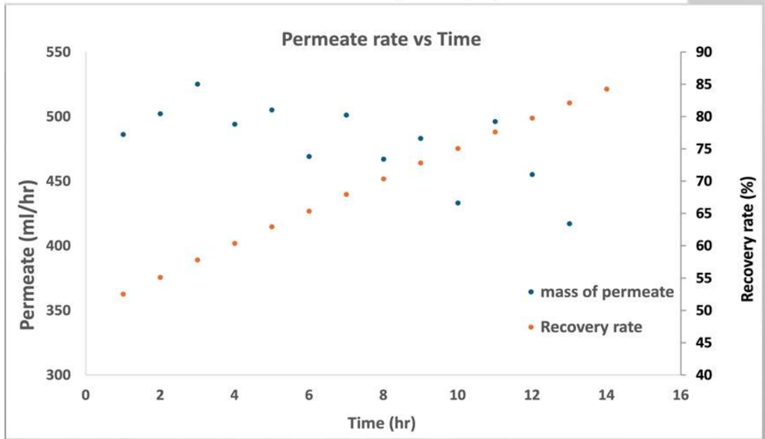
The **highly-pure condensate** is dispensed from the module

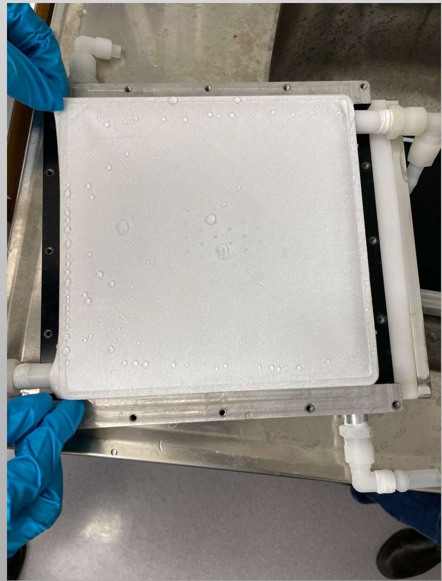
↓

Simultaneously, a **material-rich retentate** is made available for reuse of **nutrients** and **precious compounds**

Demonstrating greater than 85% recovery for the urine component of space water recovery (translates to better than 92% when mixed with humidity condensate).







Hydro4M2 – Initial flight demonstration experiment 6/2025

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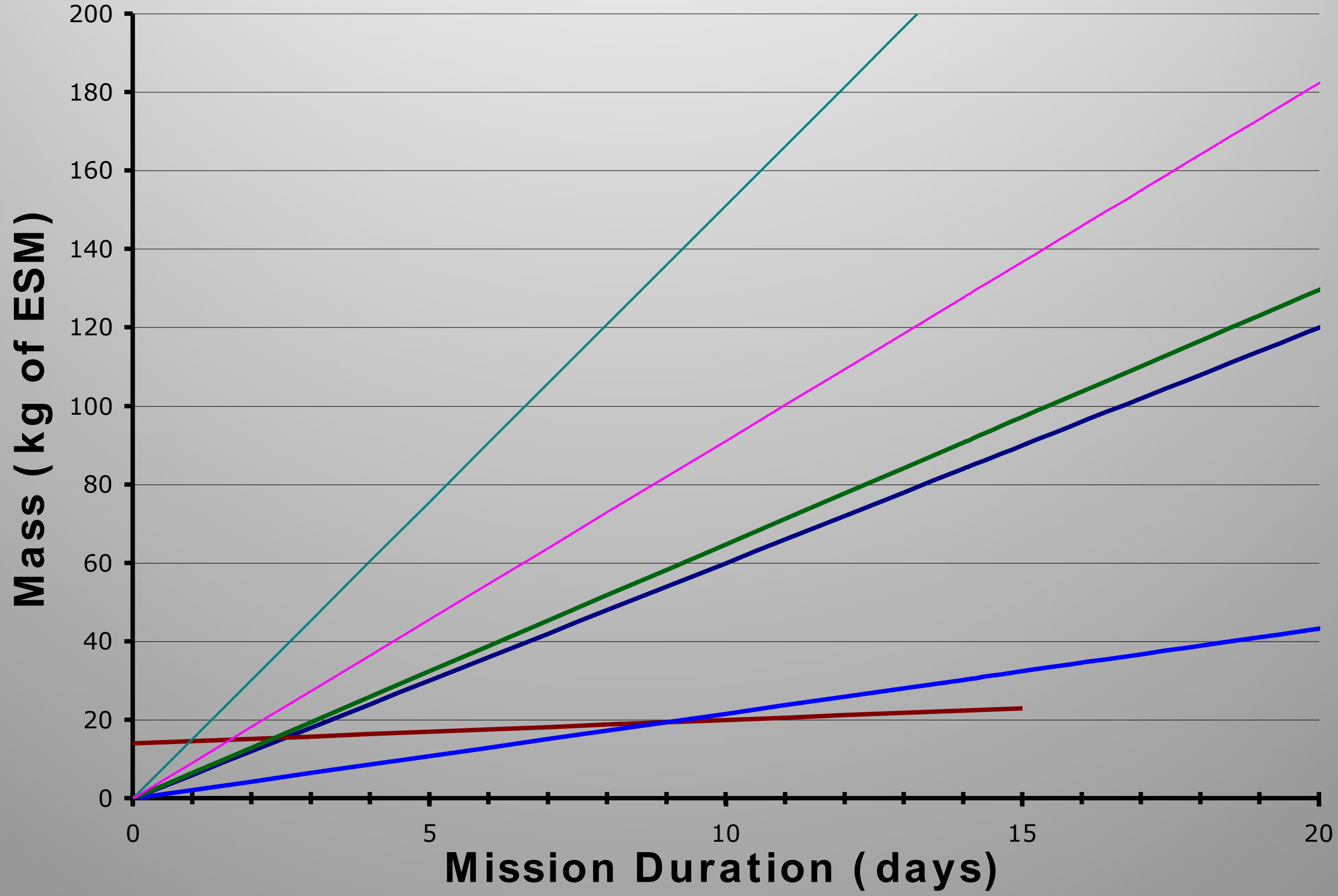
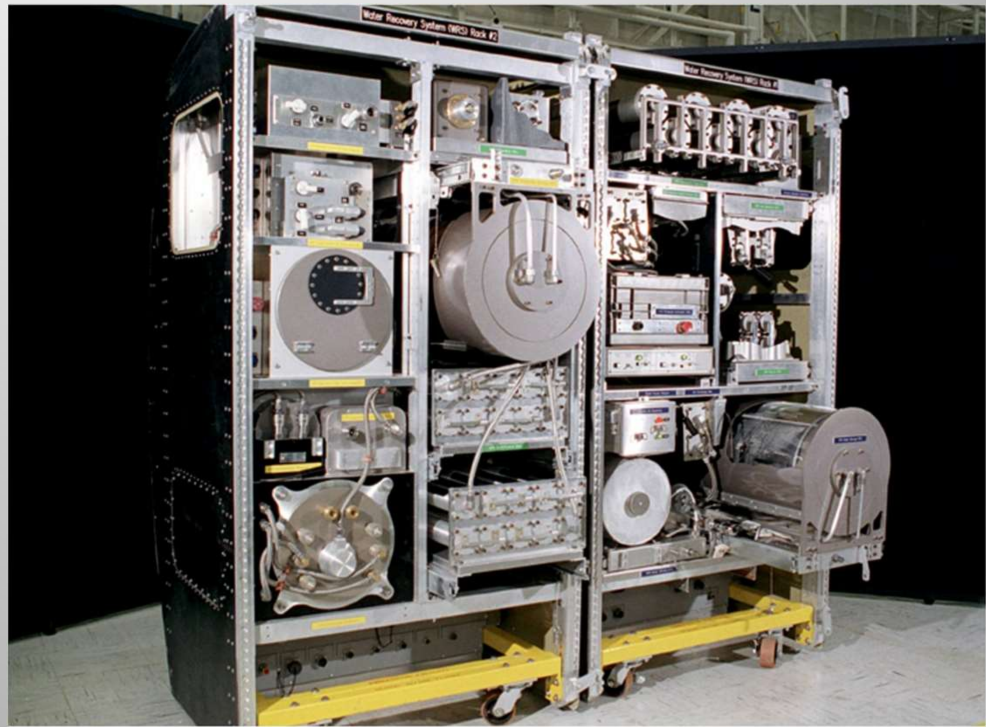
ESM and Space Sustainability Math

= the ROI/Why for Life Support



ESM = The ROI of Launch Mass For Water

(And Air/O_2)



At launch everything has a mass, and that mass has a cost. All must be summed to a single number to make sense in system design.

- Food, Water and Air (Mass Returned per Day vs Supplied)
- The ECLSS Hardware Mass
- Power (Watt/Power Supply System Mass)
- System Resupply Mass (Chemicals and Parts Mass)

So, for a water or air regeneration system one calculates the mass to supply the crew for the mission duration with water and/or air as a sum of all 4 necessary mass numbers on a per crewmember day basis.

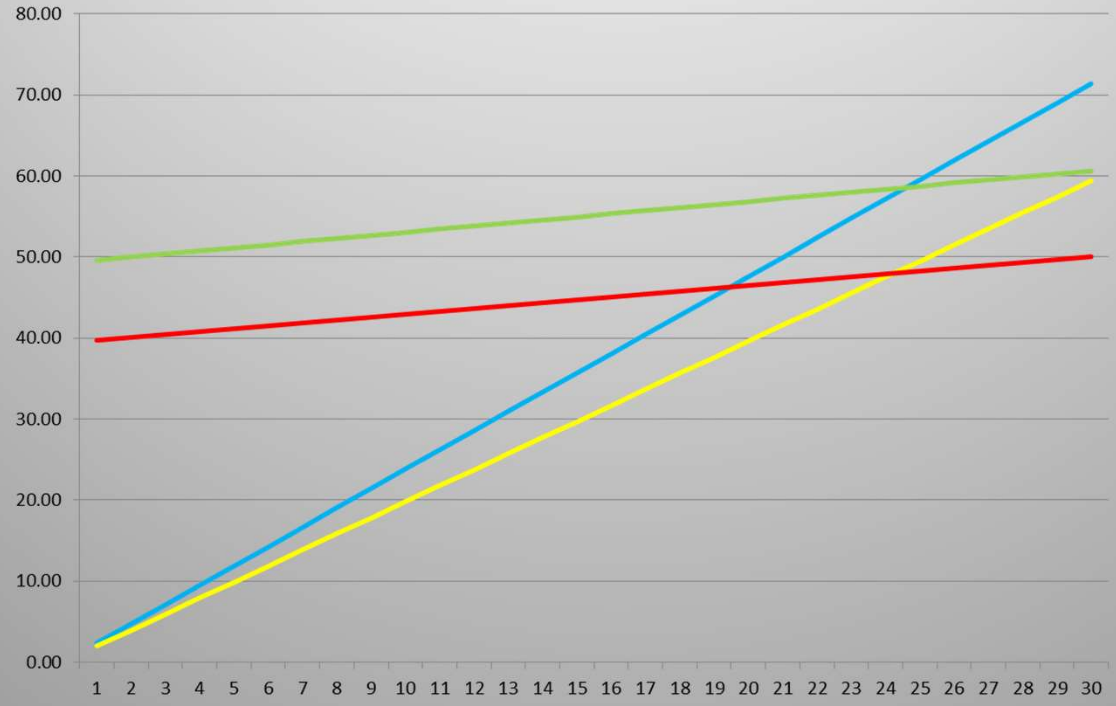
The Picture for Short Term Missions in Cislunar Space (Water)

Water in Food 1.15 In the food so N/A for ESM if hydrated food is used [Remember met. makes H2O]

Food Prep Water 0.76

Drink 1.62 = 2.38 kg per crewmember day or 71.4 kg in 30 days

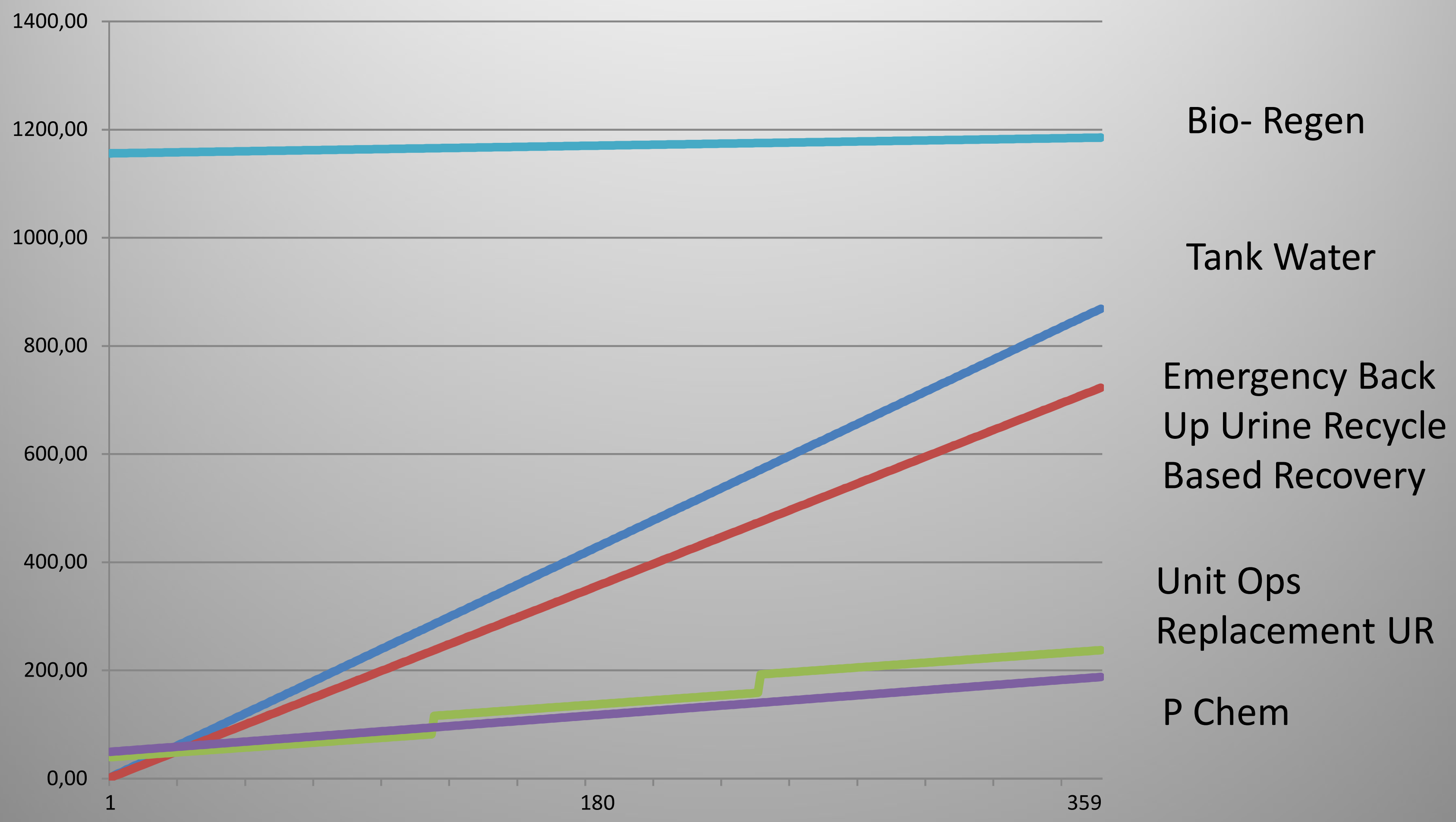
Total launch mass needed per crewmember in Kg



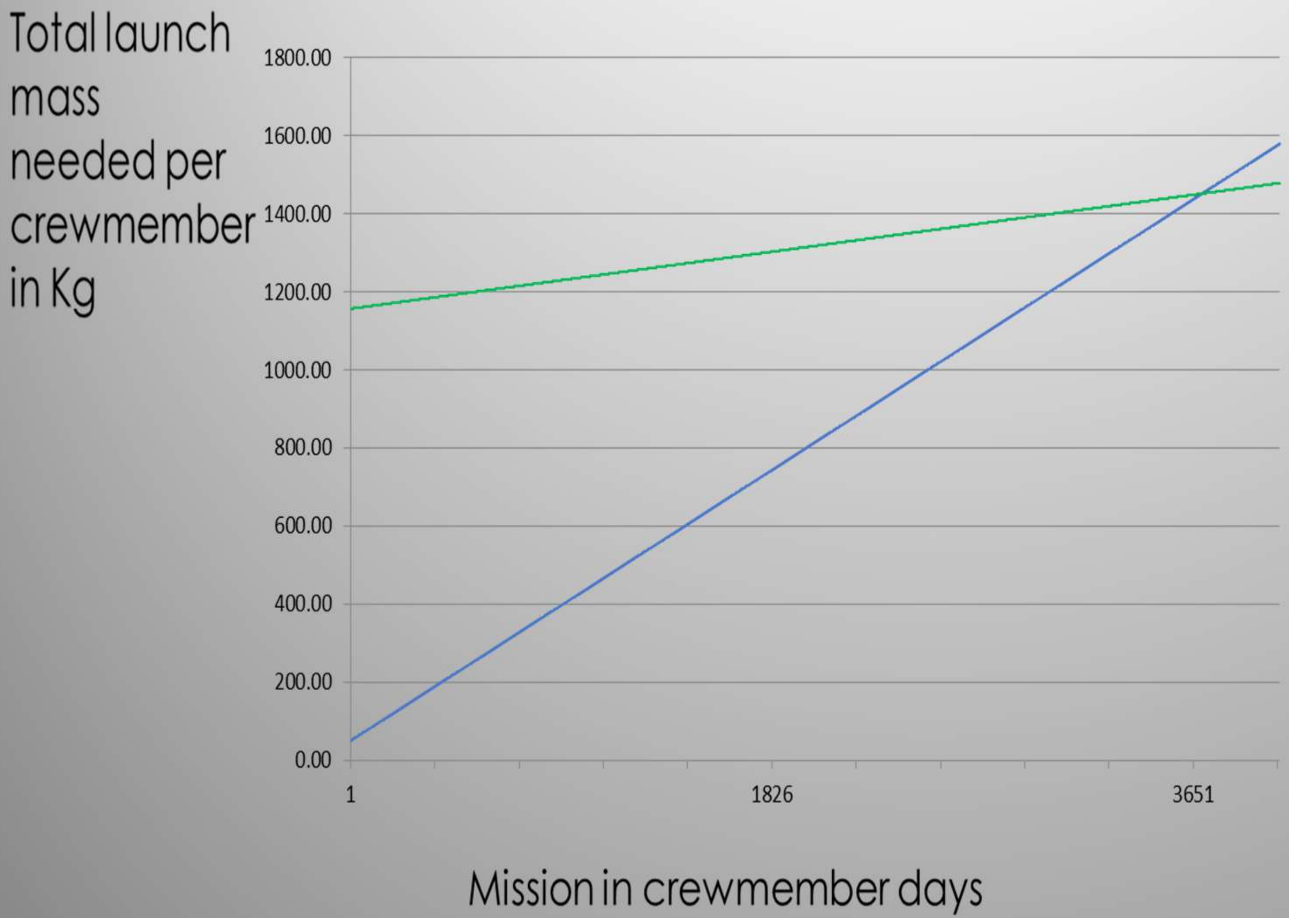
Mission in crewmember days

File notes for the online reader: Comparison for mass metrics for bottled water (Blue), emergency disposable urine recycle (Yellow), partially expendable regenerative water processer (Red, 120 day, expendable membrane water processer), and ISS sustainable water processer (in Green).

Sustained Operation up to a Year
Transit Missions/Exploration System



When Does Bioregenerative Start Paying for itself by Water Mass



File notes for the online reader: Where bioregenerative catches up with strictly physical/chemical water processing is about at 7 years, but likely would require spin gravity and massive scale before consideration. Likely in the near term even larger habitats and population will be served by non-biological volatiles reprocessing. Not until permanent off world habitation and food production will you see plant based systems

ECLSS Specific Engineering Issues Checklist

- Hydraulic efficiency scales badly for small systems So large-scale terrestrial water and wastewater hydraulic power assumptions break down [Also true for distributive water treatment on Earth]

- Microgravity limits process options, particularly ones involving multiphase processes and convective heat and mass transfer

- Effects of partial gravity like lunar 1/6 G and Martian 1/3 G on capillary effects and viscosity effects poorly understood and not currently amenable to precision process and hydraulic analysis

- To date the extremely limited number of systems actually built and employed in space is critically limited and not sufficient to justify an assumption of technical maturity (if even operation competent) as MIR and ISS are effectively our only truly working examples

ECLSS and the Long View

Transitional from Space Mission Design a Commercial Cislunar Volatiles Economy and Integrated Permeant Habitat Design for Space Industrialization and Settlement

Water and Air, and the Way Ahead

- Applying emerging environmental engineering methods from off the shelf (particularly membrane water treatment) to integrate ELCSS and Sustainable Design.

- Become accumulators in LEO and Cislunar space rather than resorting to discussions of remote resources 1st.

- Repurpose waste as resources in a LEO and Cislunar volatiles trade.

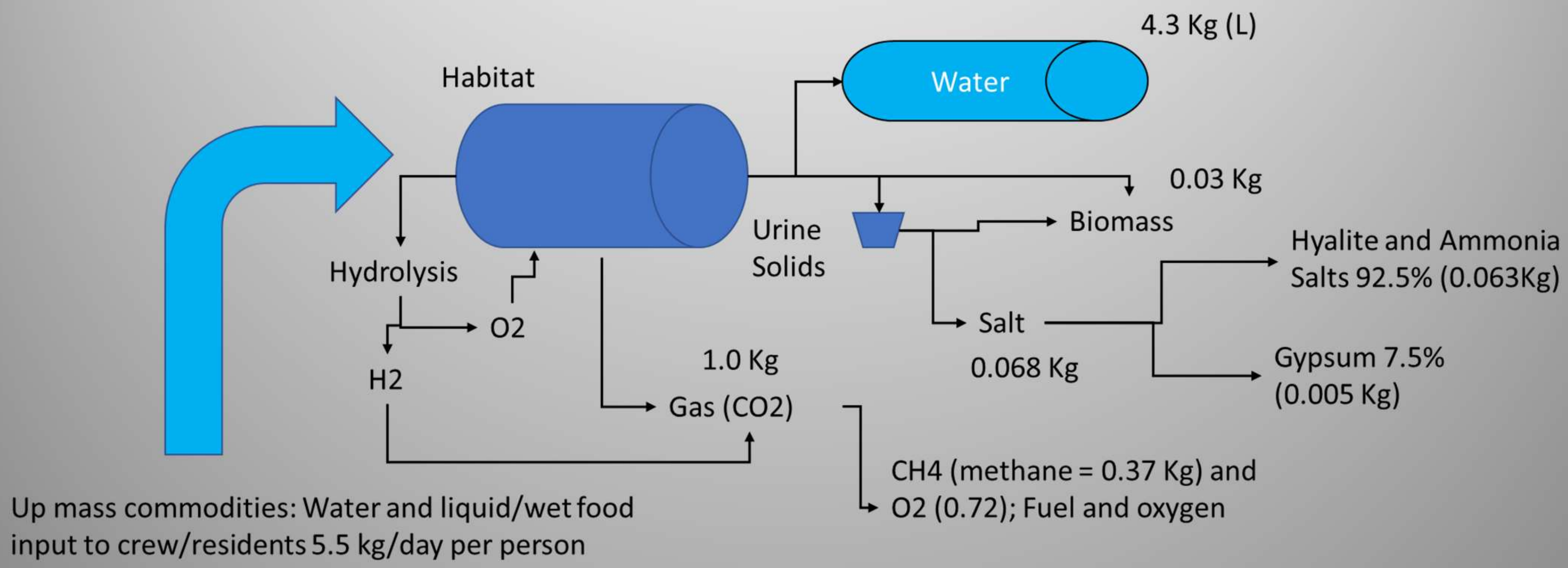
- Making ECLSS a profit center commercial space development.

The Cislunar Commodity Market for Water Related Products

Source Material	Relevant resource	Upcycled commodity	End use
Urine and humidity condensate	Water	Clean industrial grade water	Shielding (temporary storage), air regeneration, fuel/oxidizer production, industrial process water, fuel cell working fluid
Urine/mixed wastewater	Urine salts	Gypsum and hyalite	Shielding mass for building elements (radiation and impact protection), structural concrete
Biosolids	Biosolids	Biochar	Stable wall insolation, plant growth substrate for aesthetic elements
Water and air treatment reject gasses	CO_2 and NH_4 (Methane)	Fuel	Fuel
Plastic solid wastes	Melt Plastic	Stable Plastic Bricks and/or Char feed	Insolation and shielding bulk plastic

Mass Flow of Reuse Materials in a LEO Bulk Commodity Market

This mirrors our earlier mass balance system diagram but puts it in a commercial commodity context



Addressing the Primary Limitations for Human Space Activity in Near Space

- Metabolic Mass; Primarily Water and Air; Making better ECLSS Pay
- Radiation: The sleeping giant, Addressing the need for shielding mass, and an opportunity for synergy in sustainable water design
- Gravity (Lunar, Mars and Spin): Designing water processes that can work optimally in multiple gravity environments (not just 1G or just zero G)

Discussion