Here to Ceres

Immediately Advancing a Solar System Economy

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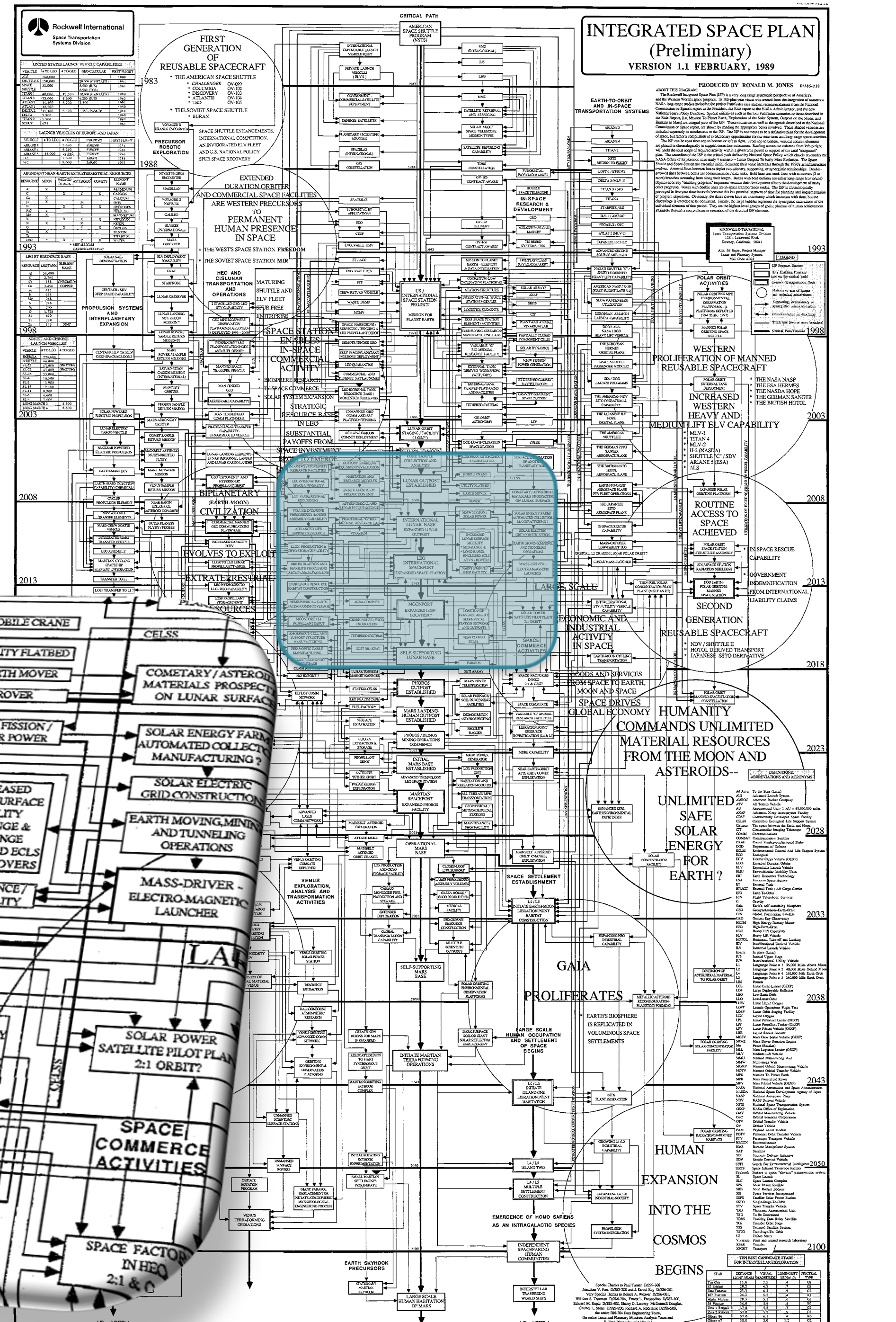
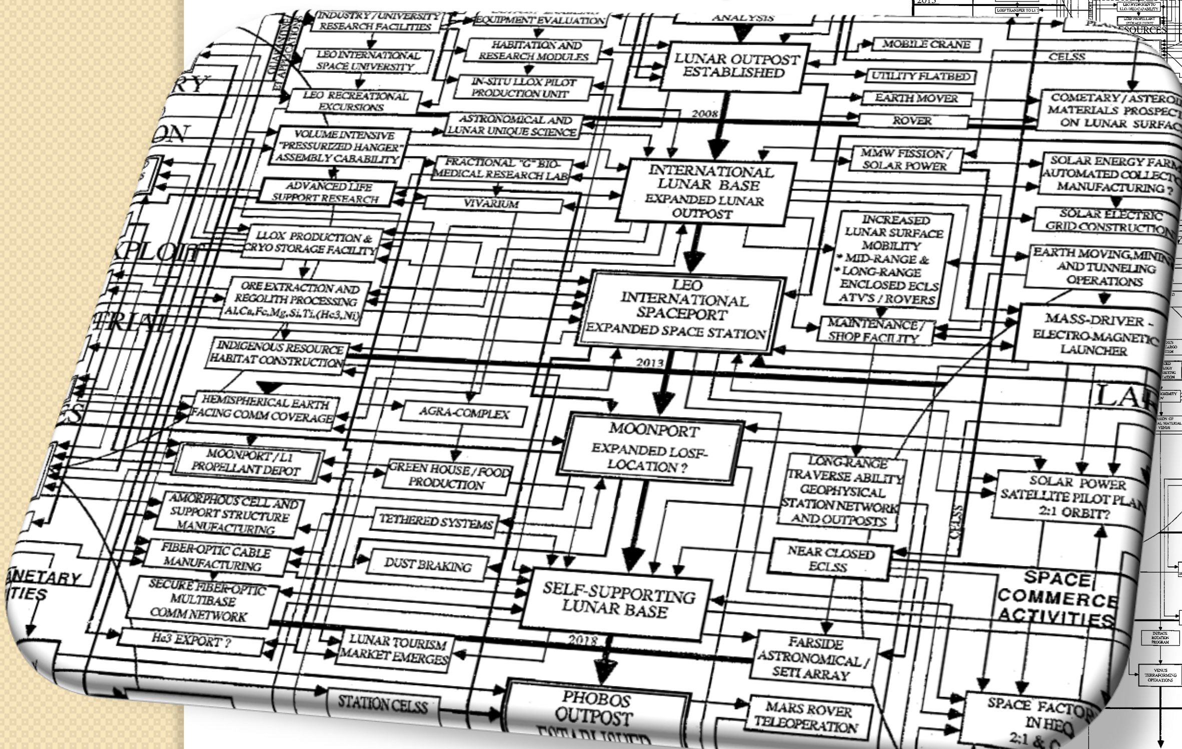
Coherence and Focus

1. Identify the barriers to space settlement
2. Design solutions that are…
   - Affordable
   - Integrated
   - Modular
   - Have near-term revenue stream potential
   - Evolvable from near-term practical solutions to long-term settlement solutions
   - More than one critical path

Integrated Space Plan (What **Focus** Does NOT Look Like)





Identify the Grand Challenges

- Getting to Orbit
- Crewed Missions to Deep Space
- Moon/Mars Landings/Bases
- Universal Issues

Group 1: Launch and Orbit

Challenge	Maturity	Standard Bearer	Date
Affordable Launch	25 percent	Space-X, NewSpace	2016
Large Vehicle Launch	20 percent	Space-X (MCT)	2020?
Mass Fraction beyond Earth Orbit	No refueling or docking on orbit	- - - - - - - -	TBD
Space Junk	Hazard to large assemblies	- - - - - - - -	Negative Trend
Microgravity	Health Hazard	NASA/ISS: medication + diet + exercise	Mature
		Mars Society: Centrifuge	TBD
Reusable Vehicles	To Orbit	Space-X	2018
	Beyond LEO	Space-X (MCT)	2025?

Group II: Deep Space and Crew

Challenge	Maturity	Standard Bearer	Date
Solar Flares	10-20 cm/water	Bigelow?	2020
GCR: Cell Damage	4-5 meters/water	None	None
GCR: Cataracts?	Should be tested in deep space	Replace one lens on early missions	TBD
GCR: Medication/Food Lifespan	Shield meds like crew	Needs testing	TBD
Life Support Loop	180 days?	NASA/Insp. Mars	2018?
Mechanical and Medical Entropy	180 days?	NASA/Insp. Mars	2020?
Psychology	500+ days in a minivan	Inspiration Mars, Various Analogs	2020?

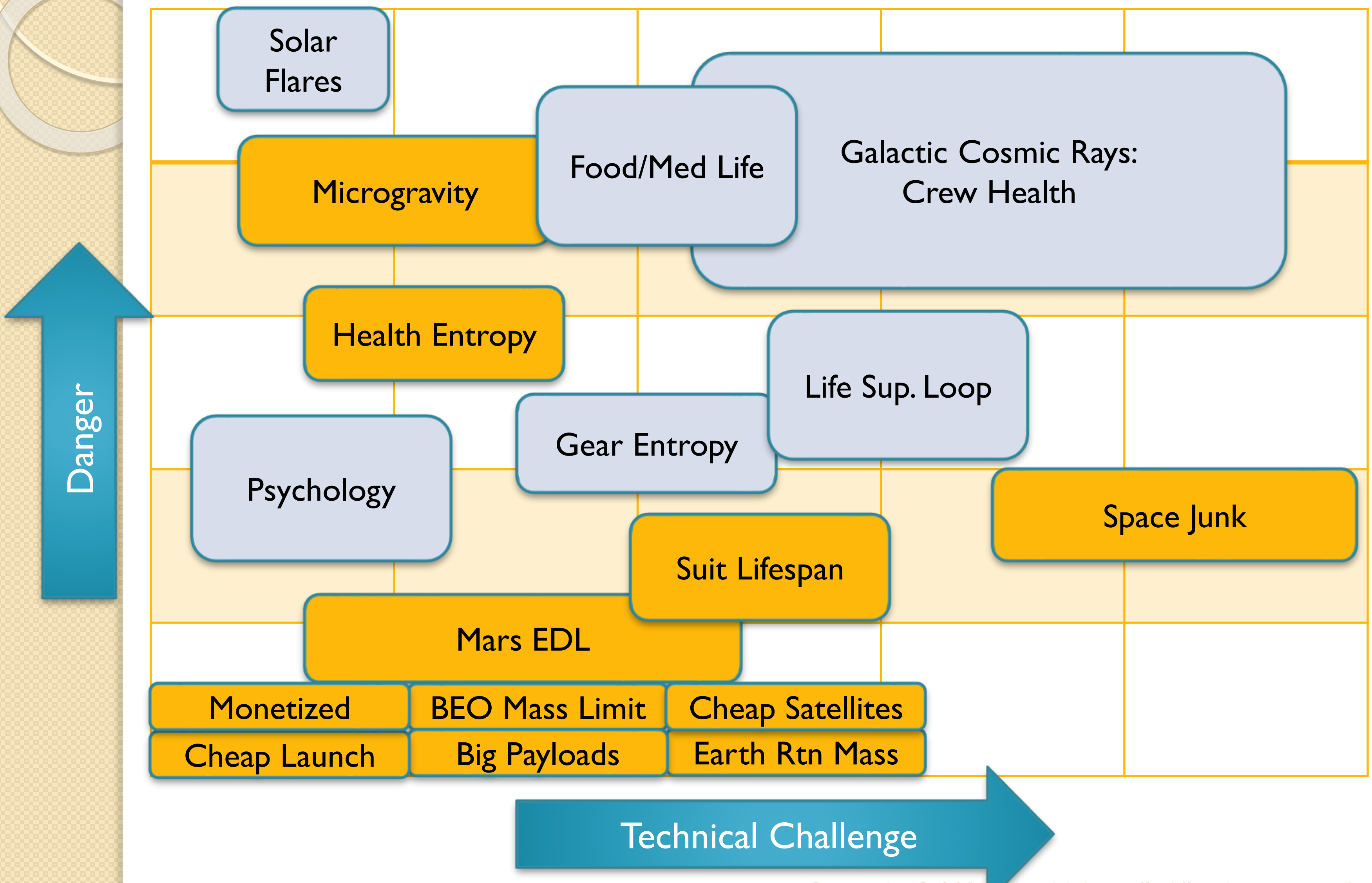
Group III: Moon/Mars Surface

Challenge	Maturity	Standard Bearer	Date
Moon Landing	Being re-invented	Several players	2020?
Mars EDL	1 ton/ need 25 ton	NASA/ Space-X	TBD
Spacesuit Lifespan	Grit issues limit life to a few days	NASA/ Contractors	TBD
Reliable Ascent Vehicle	Leave alone and be ready for return	NASA (rovers 10 years operational)	Mature?
Reliable Return Vehicle in Orbit	Leave alone and ready for return	Done with robotic vehicles	Mature
Flight to Earth	Need fuel, supplies	None	TBD
Earth Reentry	Operational	NASA, Space-X	Mature

Group IV: Universal Issues

Challenge	**Parameters**
Earth-Mars Flight Time	6-9 months
Earth-Mars Launch Windows	Stays can be 14 or 500 days – nothing else
Temperature Ranges	Moon: Hot/Cold Mars: Cold/Colder
Sunlight Drop-Off	Mars is 40 percent as much sun as Earth (solar panels, greenhouses)
Light Time	Time communications at speed of light

Attacking The Problems



Observers > Explorers > Settlers

Basic Mitigation

- Full theoretical knowledge of risks
- Minimize Risk
- 180-500 days
- Test Pilot Phase

Practical Knowledge

- Risks well understood and experiments completed
- Strong technology base
- Good for Space Tourism, early bases.

Mastery

- Risk reduced to level of airliner
- Common civilian use
- Settlements

Modular Development Cycle

First Mission Concept

Break into Simplified Modules

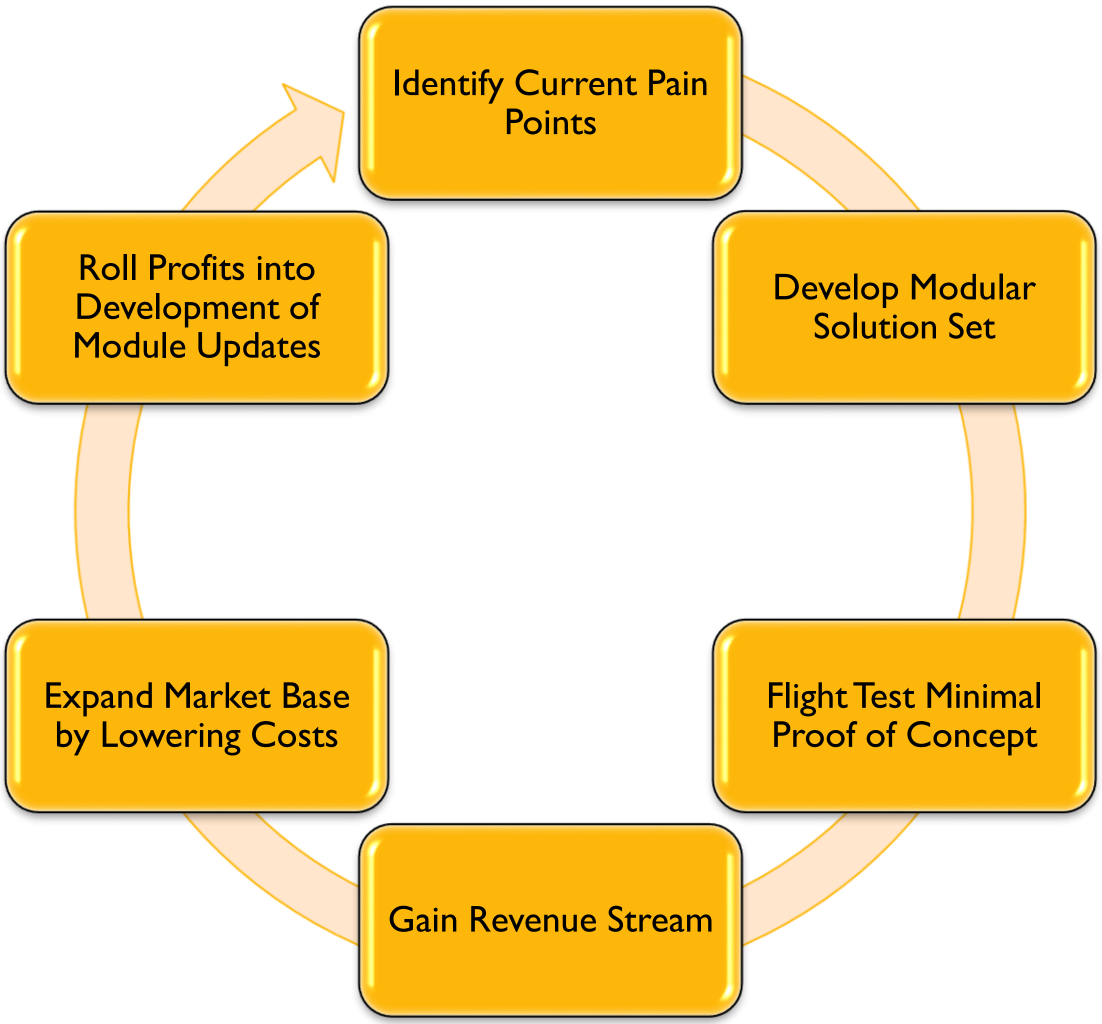
Find other uses for Module combinations

Match I/O Across System

Identify Cost Effective Improvements

Determine Next Modules to Expand Missions Possible

Marketing 101 (Space-X, etc.)



Phase 1

- Focus on:
  - Early monetization
  - Current and Near-Term Pain Points
  - Low Development Cost
  - Existing or Near-Term Technologies
  - Industries with High Growth Potential

Phase 1 Opportunities

Challenge	**Parameters**
CubeSat Too Small	• Big cost jump for anything that doesn't fit in a CubeSat 3U.
CubeSat Too Expensive	• Could cluster cheaper CubeSats (sensor/etc. only) on a rail with common power/communications.
GEO Comsats too underpowered, expensive, short lived, risky	• Create modular platform with in-flight servicing and upgrades
Space Junk Risk	• Develop tug to go after kick stages, large defunct satellites, and either de-orbit or recycle them
NEO Risk/Mining	• System to scale up the above options to capture NEOs, mine NEOs and recycle satellites for metals/etc.

Immediate Markets

New Product Base	**Parameters**
Modular LEO Satellite	• CubeSat Hex-Rail for systems too big or too little for CubeSat form factor. • Common Power/Communications/Processing. • Expand both ends of market.
Modular GEO Satellite	• Reduced development cost • On space service (triple lifetime) • On space upgrades (incremental investment value boost)
LEO/GEO Satellite Tug	• Double the mass of a satellite to GEO
Satellite Servicer	• Able to replace propulsion, modular electronics, solar panels, etc. on above
Space Junk Collector	• Target kick stages first • Initially de-orbit with electrodynamic tethers • Later collect for scrap recovery

Current > Phase 2 Deltas

Current	~2020 Environment
Expensive launches	• Standard Launch Affordable • 50 MT Launch Affordable (Falcon 9H)
Satellites 20 MT, 30 kW	• Can launch satellites twice that size • Moore's Law – 8 times the capacity • More small/close nanosat constellations
Space Economy	• Network of things + Sat links • Early orbital space tourism • Private lunar probes/rovers • Post ISS-world with several small stations • Early deep space missions
Risks	• Economic and Geopolitical Instabilities • More space junk- will push crewed missions beyond LEO partly for safety
Risk Mitigation through space	• More drivers for asteroid mining, BEO crewed flight, and small sat launch

Module/Mission Breakdown

BEO Mass Limit Gear Entropy Cheap Satellites Space Junk Monetized	Frame	Solar Panels	RCS	Ion Drive	Robot Arm	"Enfolder"
LEO Satellite Frame for Modular Subsystems	1	1				
GEO ComSat with Modular Frame/Subsystems	1	2	1	1		
Space Tug for Cooperative Satellites	1	4	2	3	1	
Space Servicing Platform (swap modules, solar panels, Ion Drive Module units)	2	4	2	2	2	
Space Junk Collector	3	6	2	4	2	1
Small NEO Capture (ARM, mining)	4	12	4	8	2	2

Module Descriptions

Frame	Rail Dimensions Frame Dim Unit Mass	10 cm base hex-beam, 20 cm diag. 2.4 m base, 6.4 m long 600 kg (carbon fiber)
Solar Panels	Power Dimensions Unit Mass	20 kWe (constant) 6.4 by 10 meters 100 kg
RCS	Description Capacity Unit Mass	Modular pods with frame mount Central propellant supply Enough for 20-50 MT unit 50 kg per unit
Ion Drive	Description Unit Mass	Hall Effect, 20 kWe power 100 kg
Robotic Arm	Description	For docking with stable satellites
“Enfolder”	Description	For tumbling satellites or NEOs

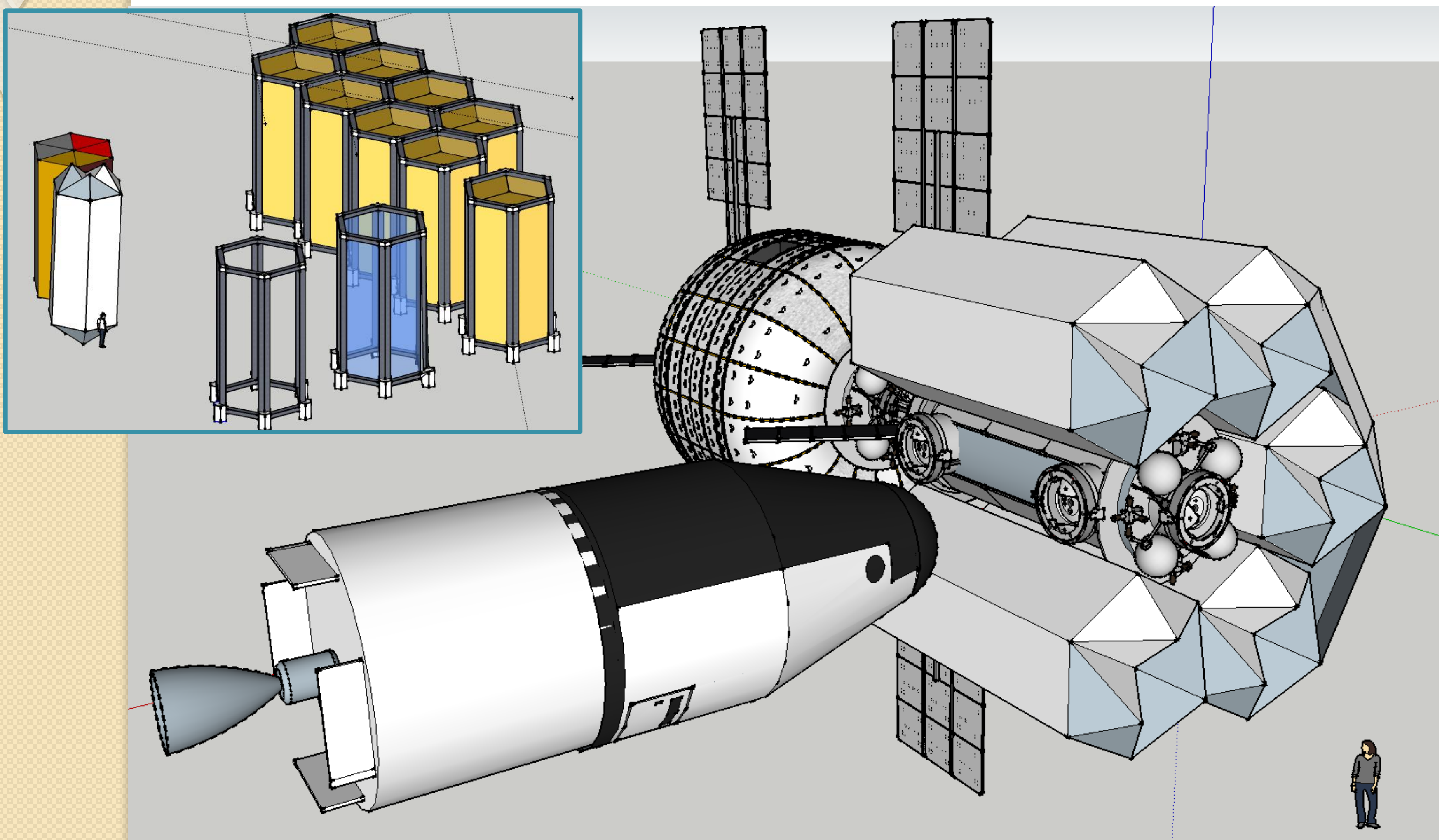
Phase 2 Markets (2020+)

New Product Base	Parameters
Small, Inexpensive Crewed Space habitats	• Hexagonal/Inflatable Crewed Habitat modules
Space Junk Collector	• Expand the market for this to reduce risks to crew modules
Crewed stations designed for 500 day deep space missions	• Driver to start crewed missions beyond LEO • Need to resolve the remainder of the deep space challenges
Push for Lunar/Mars Landers/Bases	• Need to resolve the remainder of the deep space challenges
Push for deep space stations	• Able to close remaining risks for crewed deep spaceflight

Hexagonal Frame System

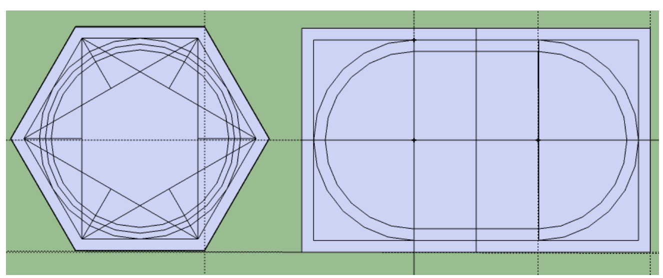
New Module	Parameters
Cryopropellant Engine	• LH2/LOX, Methane/LOX, or hybrid
Pressurized Inflatable	• A miniature inflatable hab in a frame
Water Inflatable	• Water bags within the shell that can be frozen with reinforcement (Pykrete) for strength
Hybrid Module	• Cryo-capable tank in the middle of a set of water bags to protect the tank from space debris, aid in cosmic ray shielding
Cryopropellant Plant	• Takes water from tanks and turns into hydrogen and oxygen, then connects to liquefaction hardware. • Also stabilizes boil-off. • Uses waste heat to melt the ice in the water bags.

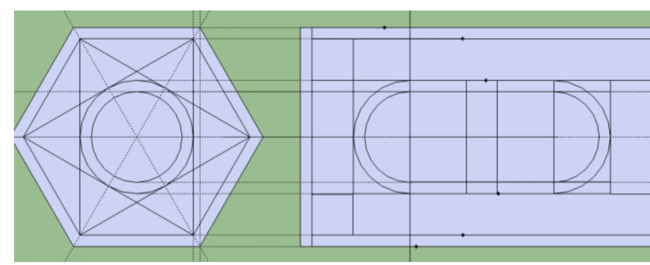
Original Design (2011)



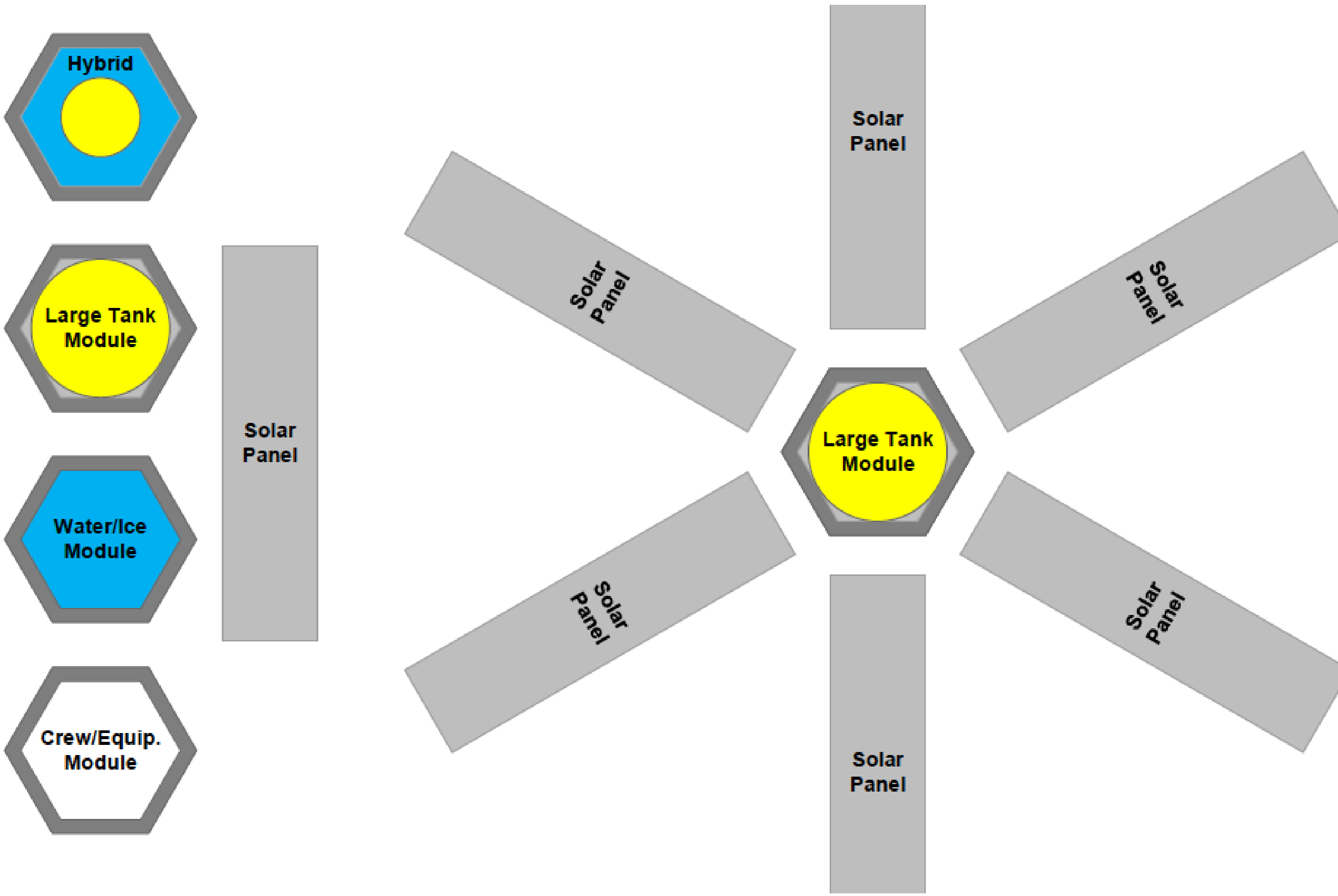
Module Types

- Module for just air (cargo, crew space)
- Water Module (Pykrete matrix, 50 MT)
- Water + Cryo Tank
- Cryo Only

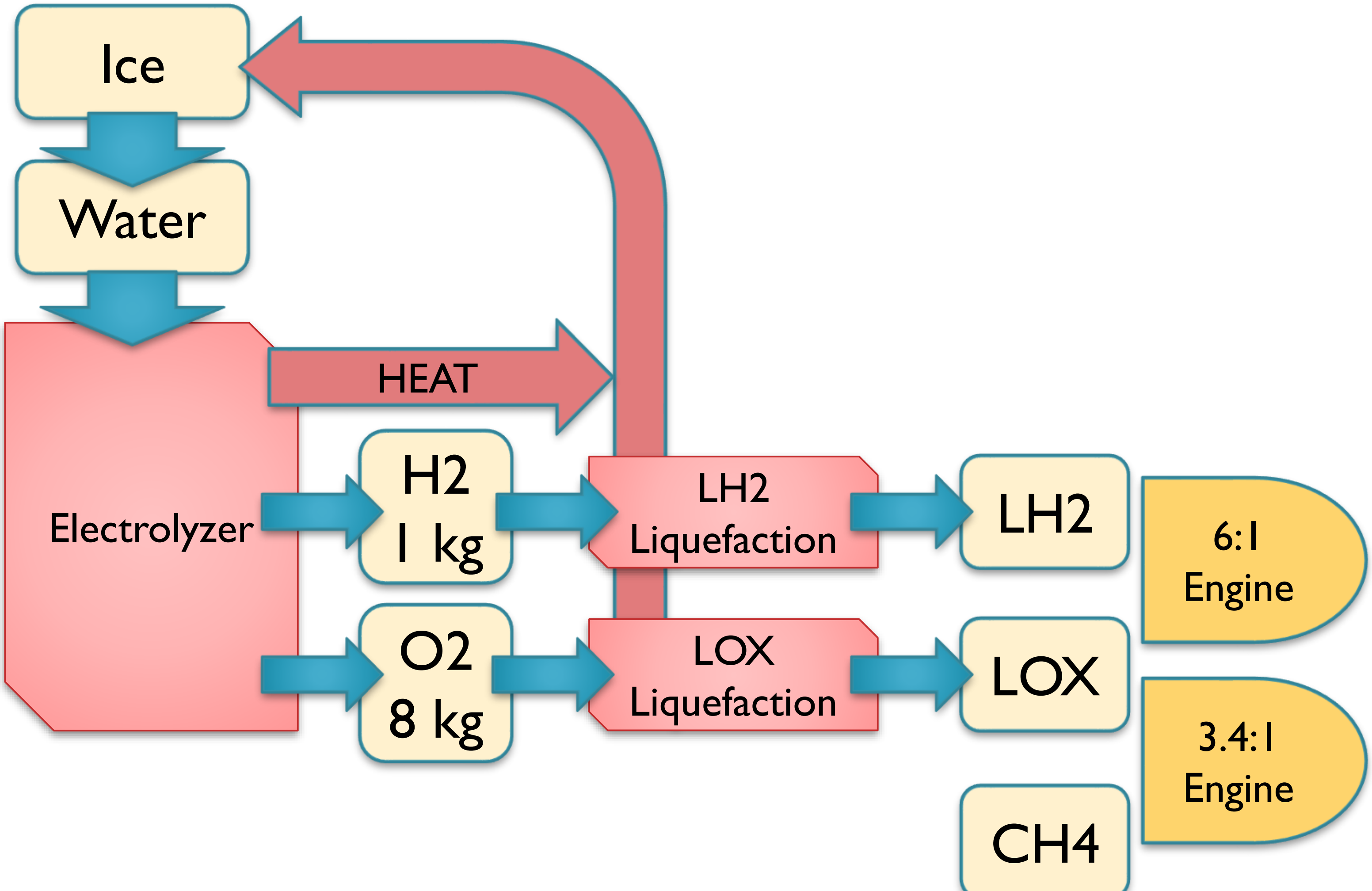




Modules: Legos for Settlement



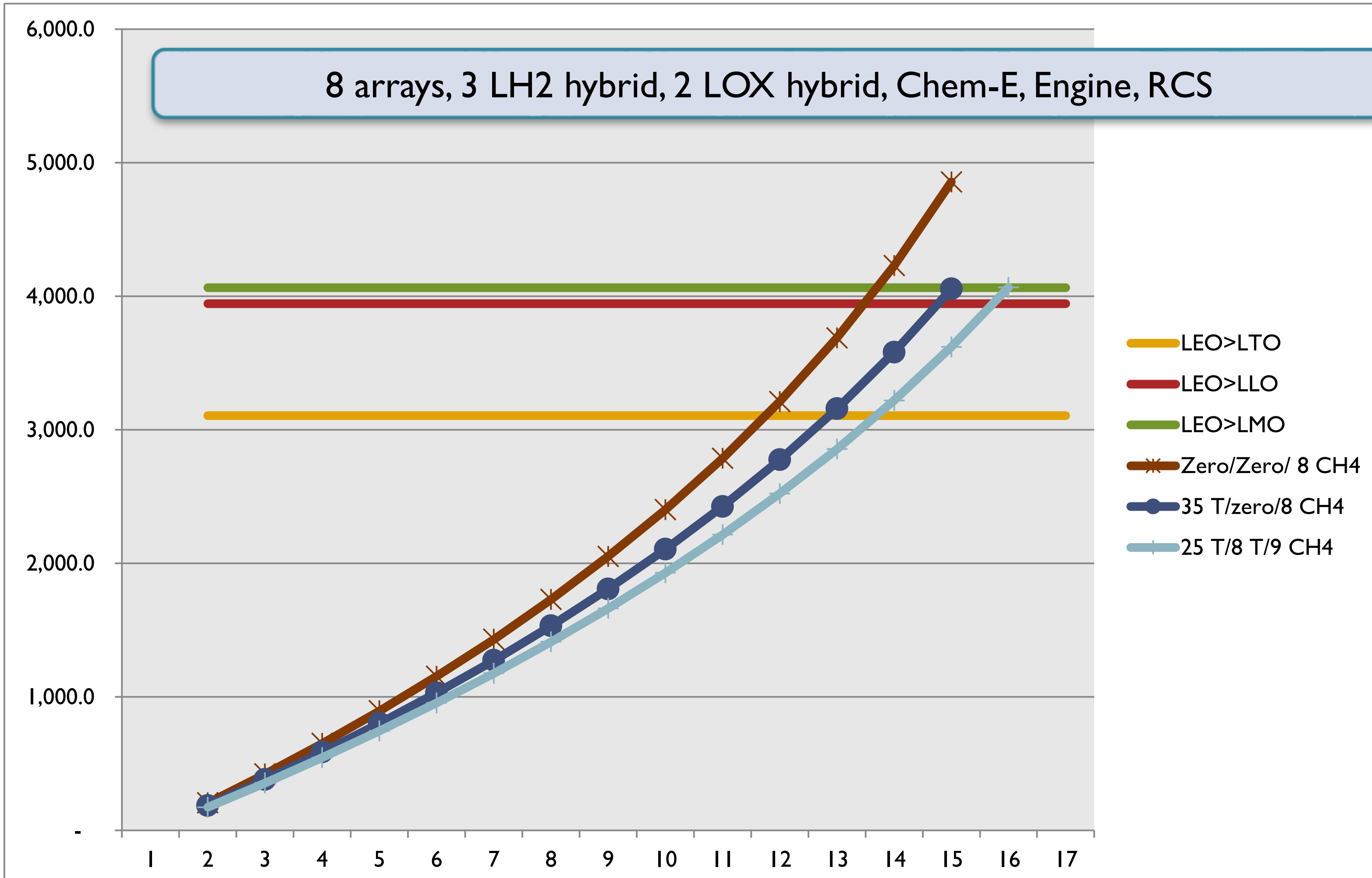
Propellant Station Workflow



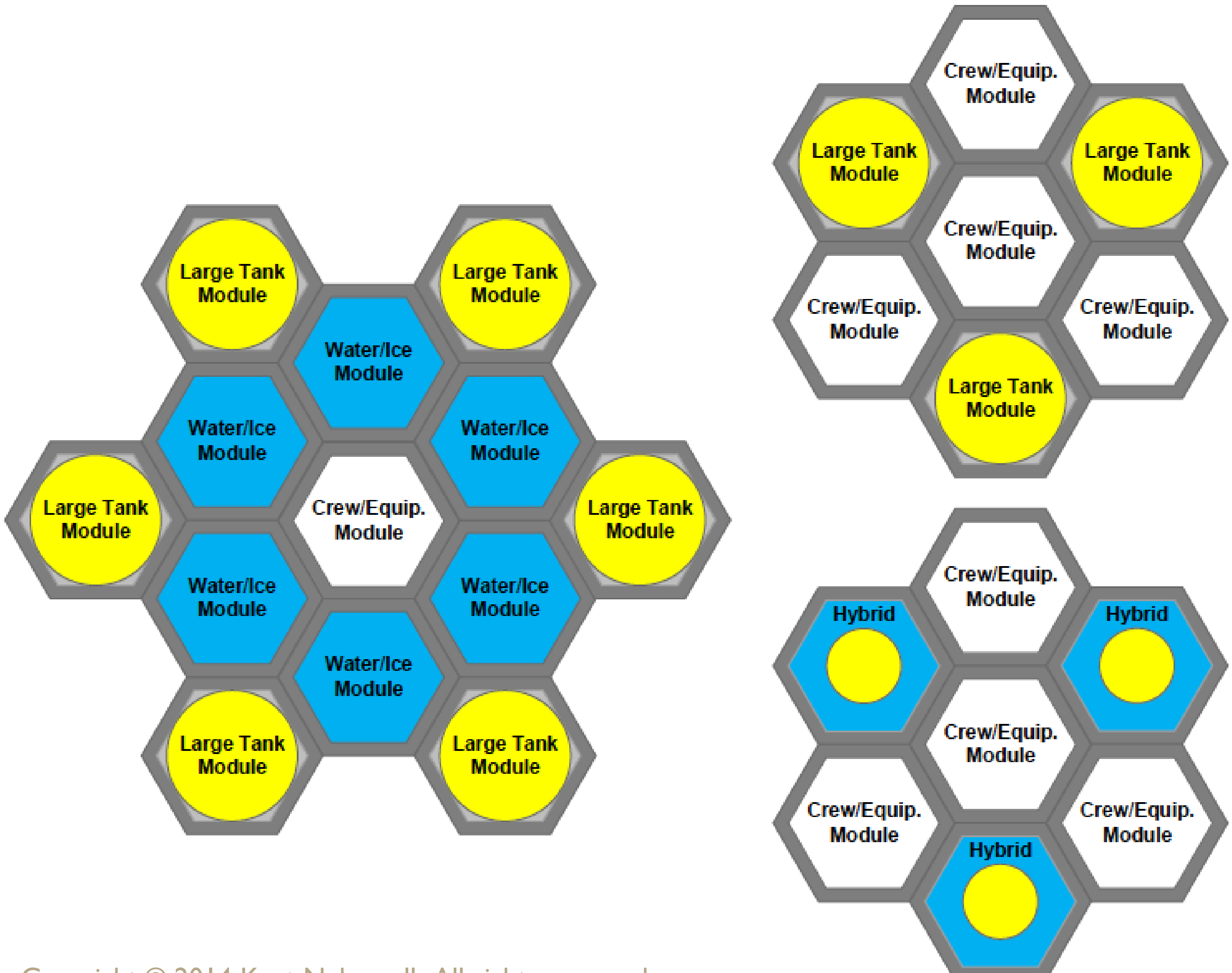
Ice-craft System

	Mass	Tot.	kWe	Parameters
Chemistry Module	4000	1	80	Needs 80 kWe continuous Expels 3601 kWt/h Earth Orbit: 4 panels Mars Orbit: 10 panels
Solar Array	100	8	800	Each 6.4 by 10 meters
LH2 Tanks (dry)	5885	3		LH2: 361 kg Water: 23,274 kg
LOX Tanks (dry)	5885	1		LOX: 6526 kg
Cryo Engine Block	2000	1		Dual LH2/Methane Engine

Ice Station Transfer to Mars



Flexible Design Regardless of GCR Risk



Chem-E Module Parameters

	Mass	kWe	Parameters
Chemistry Module	4000	80	Earth Orbit: 4 panels Mars Orbit: 10 panels
Frame	500		2 meters
Electrolizer Baseline: ProtonSite HOGEN H6m	773	58	Proton Exch. Membrane 30 bar output Heat: 23.7 kWt/hour 1 x 2 x 2 meters H2: 116 kg/Day, O2: 928 kg/day 75.67 kWh/kg (others 53-60)
Liquefaction (2-4 of these units)	250 per unit	2	Acoustic-Sterling/HTS coldfingers Oxygen: 7.274 kWh/kg Hydrogen: 15 kWh/kg Heat 1 kWt continuous 240 kg/day
Chemistry Module	4000	1x2	Needs 80 kWe continuous Expels 3601 kWt/h

Phase 2 Modules

Solar Flares CSR Health Food/Med Life Life Sup. Loop Psychology Earth Rtn Mass Mars EDL Health Entropy	Solar Panels	Crew Hab	All-Water	All-Cryo	Water/Cryo	Engine	Chem Plant	Docking
LEO Refueling Station	8		5				1	2
Transfer Orbit Refueling Station	8		2	8	4	1	1	1
Lunar/Mars Orbit Refueling Depot	8	1		8	5	1	1	1
LaGrange Point Base (GCR/Flare Lab)	8	4	4	8	5	1	1	1
Fast "Deep Space Shuttle"		1				1		1
Surface Lander (20 MT)						1		1
Space Habitat (Spinning, shielded)	10	8	4				1	2
Surface Habitat (Cosmic ray shielded)	10	4	5				1	2

Hex Module Variations (kg)

Component	Air	Ice	Ice/Cryo		Cryo
Envelope	2000	2000		2000	
Framework	600	600		600	600
Water bags/Plumbing/Pykrete.		520		350	100
Cryo Tank/Insulation/Frame				2935	6700
Air	76				
Dry Mass of Module	**2676**	**3120**		**5885**	**7400**
Water/Ice Capacity		50,000		23,275	
Cryo Tank Volume (M^3)				5.1	30
Cryo/Water-Tank			LOX	5827	34,230
			LH2	361	2,125
			CH4	2165	12,720
			RP-1	4116	24,180

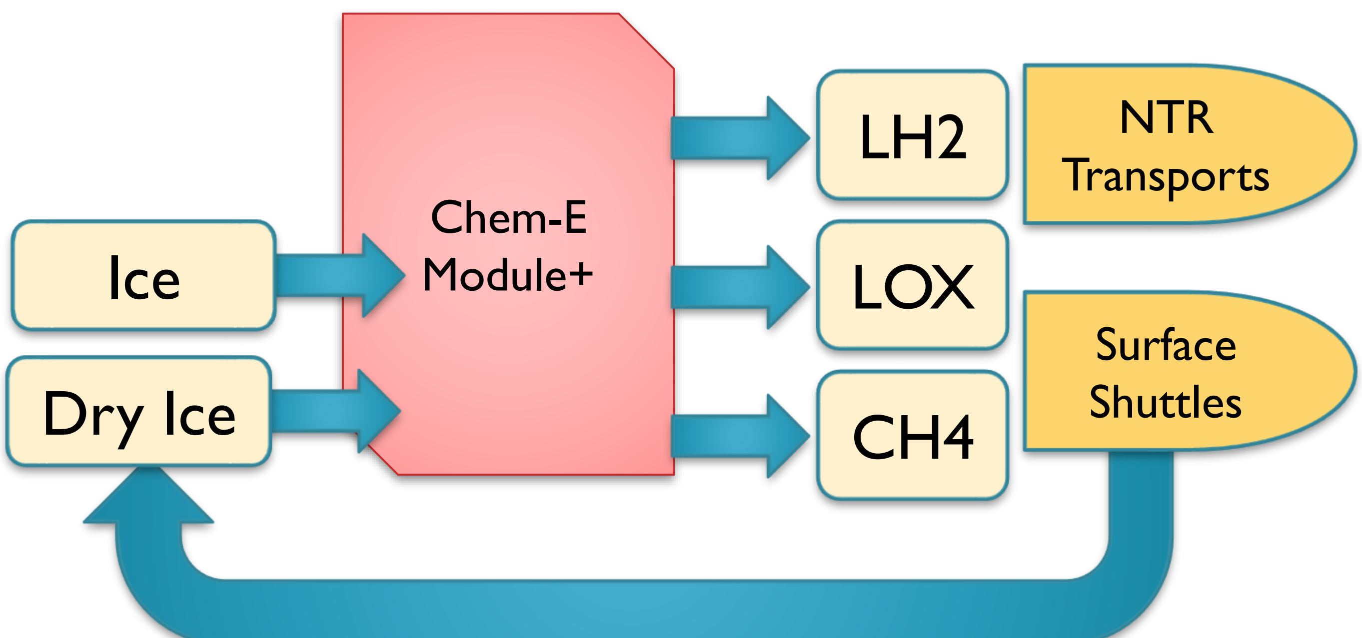
Challenge Status Update

Challenge	Current	Phase 1	Phase 2
Affordable Launch	25 %	Mature (Space-X)	Competitive
Large Vehicle Launch	20 %	In Dev	Mature (Space-X)
Mass Fraction beyond LEO	- -	30 %	Mature (Hex Base)
Space Junk	Negative Trend	Early Testing	Source Reversal
Microgravity	Medical/Diet/Exercise – 100 %?	Testing complete (NASA)	Max Effect Known
	Centrifuge – 5 %	In Dev	Mature (LEO)
Reusable Vehicles	To Orbit	Mature (Space-X)	Competitive
	Beyond LEO	Falcon Heavy	Space-X (MCT)
Solar Flares	Heat Shield, LEO	In Dev	Mature (multiple)
Galactic Cosmic Rays	Cell Damage/ Cancer/ Brain	Baseline LEO Testing	Mitigation Tested
	Cataracts? (TBD)	Baseline LEO Testing	Mitigation Tested
	Medication Shelf Life Reduced	Baseline LEO Testing	Mitigation Tested
	Food/Vitamin Shelf Life Reduced	Baseline LEO Testing	Mitigation Tested
Isolation Health Risk	180 Days	1 Year	3 Years
Psychology	180 Days	1 Year	3 Years
Surface Habitats	In Dev	Early Testing	Early Bases

Remaining Challenges

Challenge	Details	Phase 3	Phase 4
Crew Transit Vehicle (3 Yr)		Mature	Competitive
Lunar Landing Vehicle		Mature	Obsolete
Lunar Shuttle		Early Applications	Mature
Mars Landing Vehicle		Mature	Obsolete
Mars Shuttle		Early Applications	Mature
Spacesuit Lifespan		TBD	Mature
Microgravity Industry	Gas Separation	Early Applications	Mature
	Grinders (Satellites, NEOs)	Early Applications	Mature
	Smelters (Solar or Electric)	In Dev	Mature
	Casting/Additive Mfg	In Dev	Mature
	CNC/Subtractive Mfg	In Dev	Mature
Nuclear Power Plants	Surface/Space, and NERVA	In Dev	Early Applications
Surface Facilities	Living Space	Early Applications	Mature
	ISRU Chemistry Plant	Early Applications	Mature
	Greenhouse (Site/Export)	Early Applications	Mature
	Casting/Additive Mfg	In Dev	Mature

Shift to Landers/ Nuclear Deep Space Transports



Questions?

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