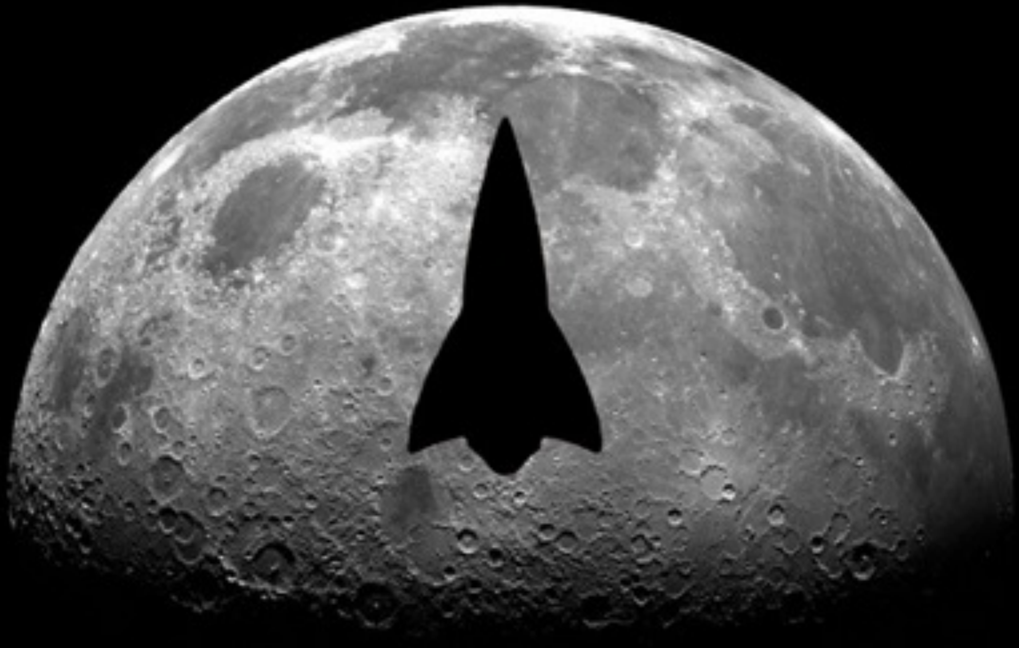
Team

Voyager



LUNARPORT

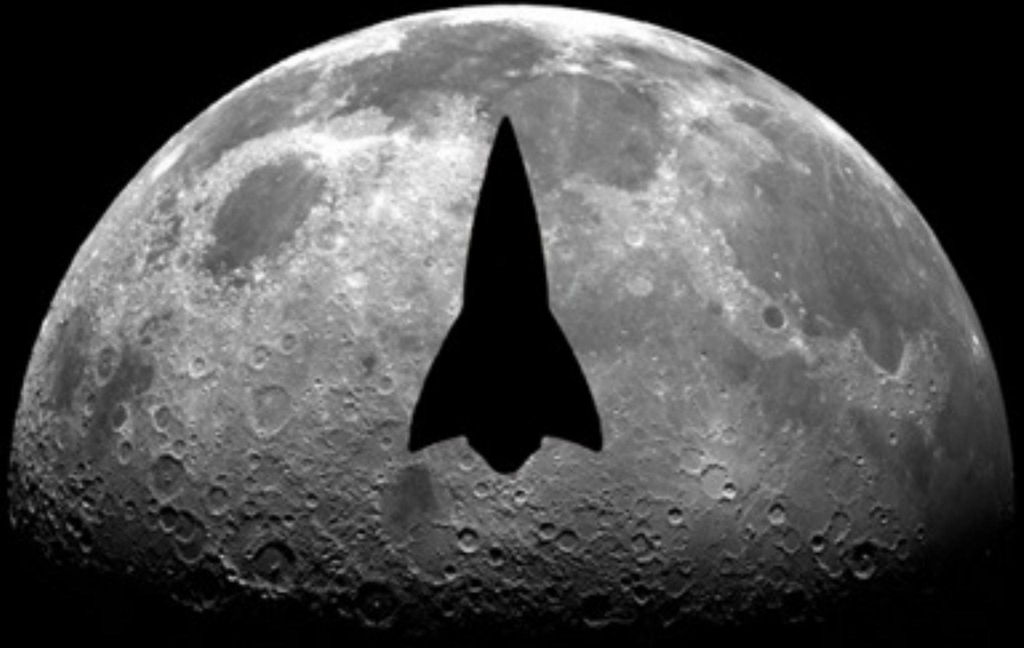
A launch and supply station for deep space mission

'ICE RUSH'

Caltech
SPACE CHALLENGE
March 26-31, 2017
sponsored by AIRBUS DEFENCE & SPACE

GALCIT

Caltech

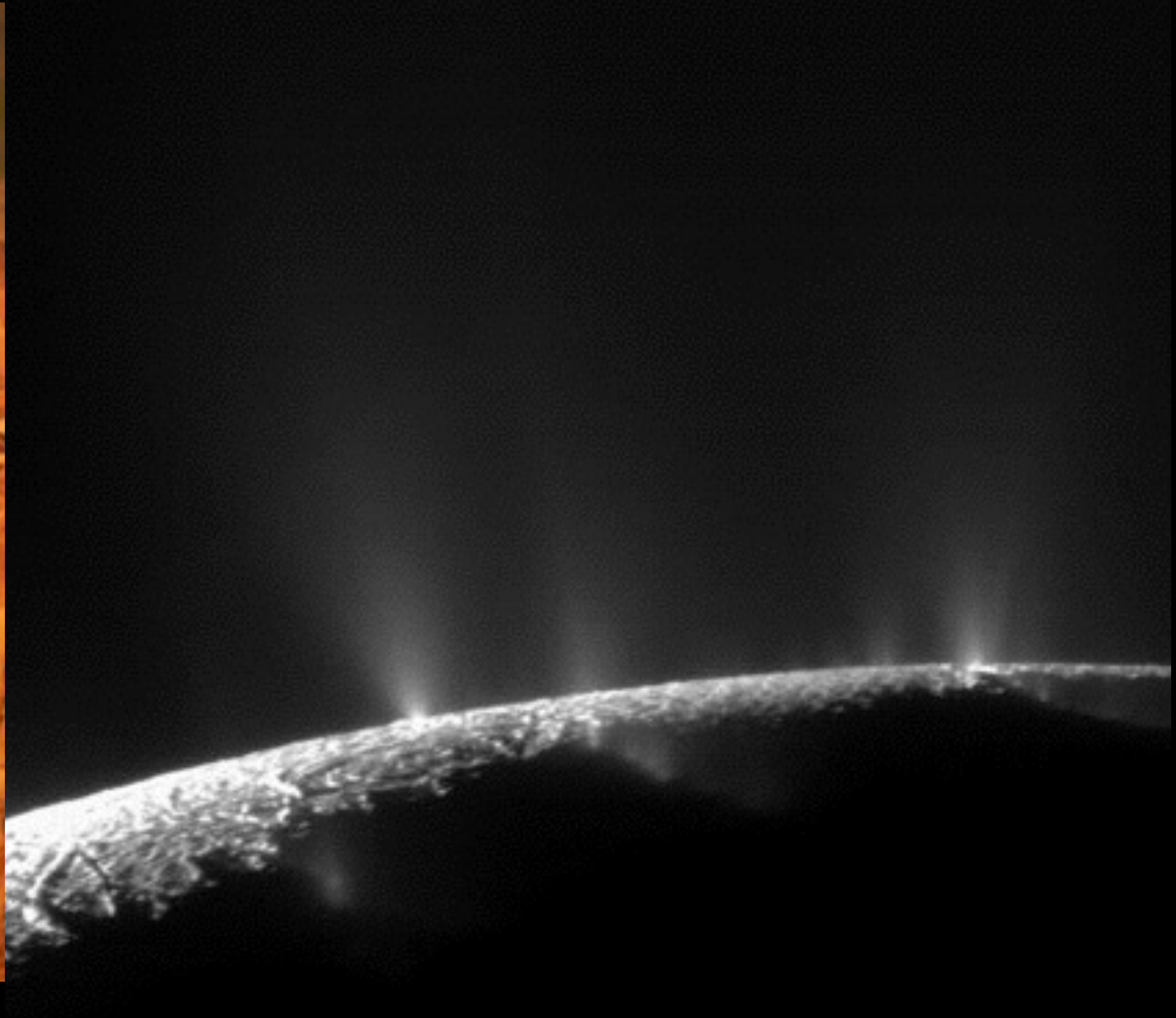


‘ICE RUSH’

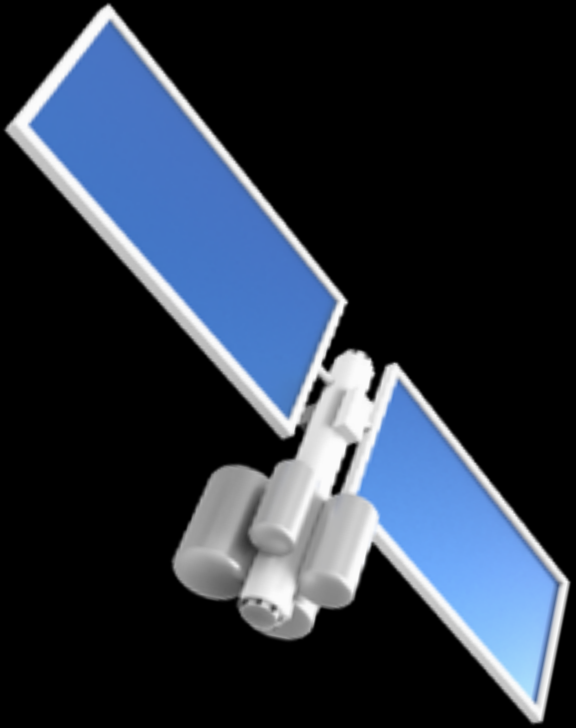
Lunarport will be a launch and supply station for deep space missions.
Lunar in-situ resource utilization will allow larger (more massive) payloads to be launched from Earth, bringing deep-space a little closerfor human exploration.

Landing humans on Mars, Europa, or even an asteroid will be the near future with Lunarport.

(credit: Caltech Space Challenge 2017)

Our science and exploration goals need interplanetary transport of large masses.

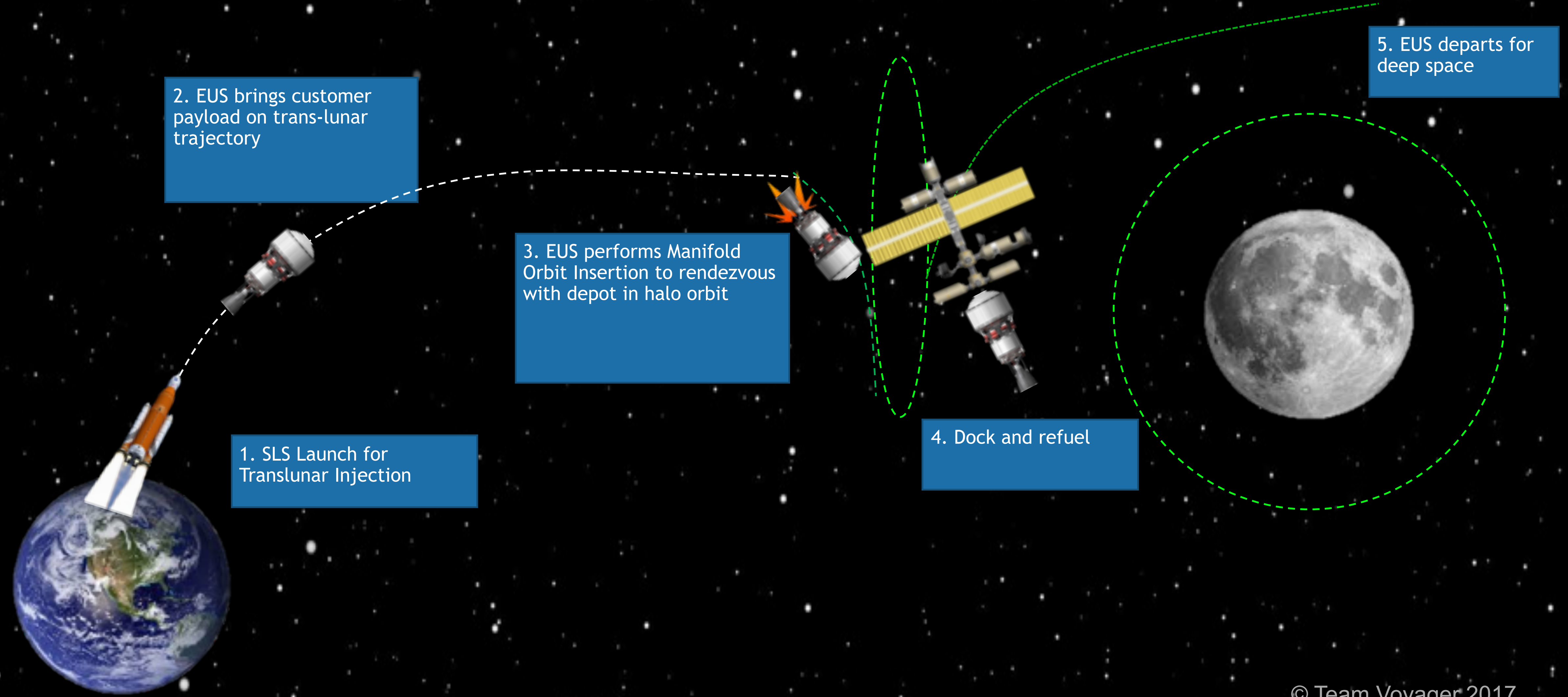


Lunarport will <u>triple</u> the mass that interplanetary missions can carry.

$1 billion per year.

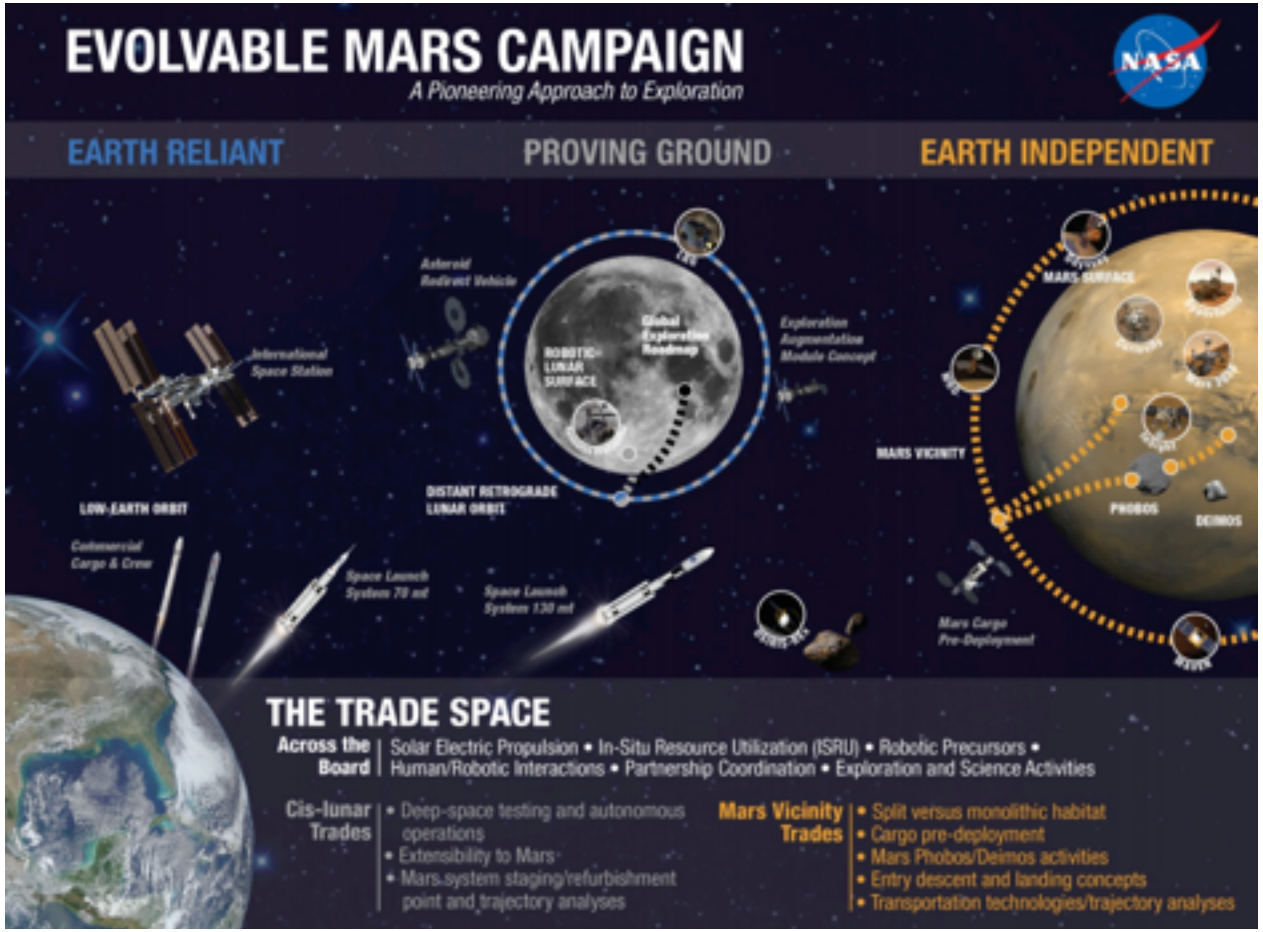
Mining resources at Lunar pole.

Autonomous construction and operation.



2. EUS brings customer payload on trans-lunar trajectory
3. EUS performs Manifold Orbit Insertion to rendezvous with depot in halo orbit
1. SLS Launch for Translunar Injection
4. Dock and refuel
5. EUS departs for deep space

Mission Justification - Evolvable Mars Campaign



(Crusan, 2014)

Lunarport

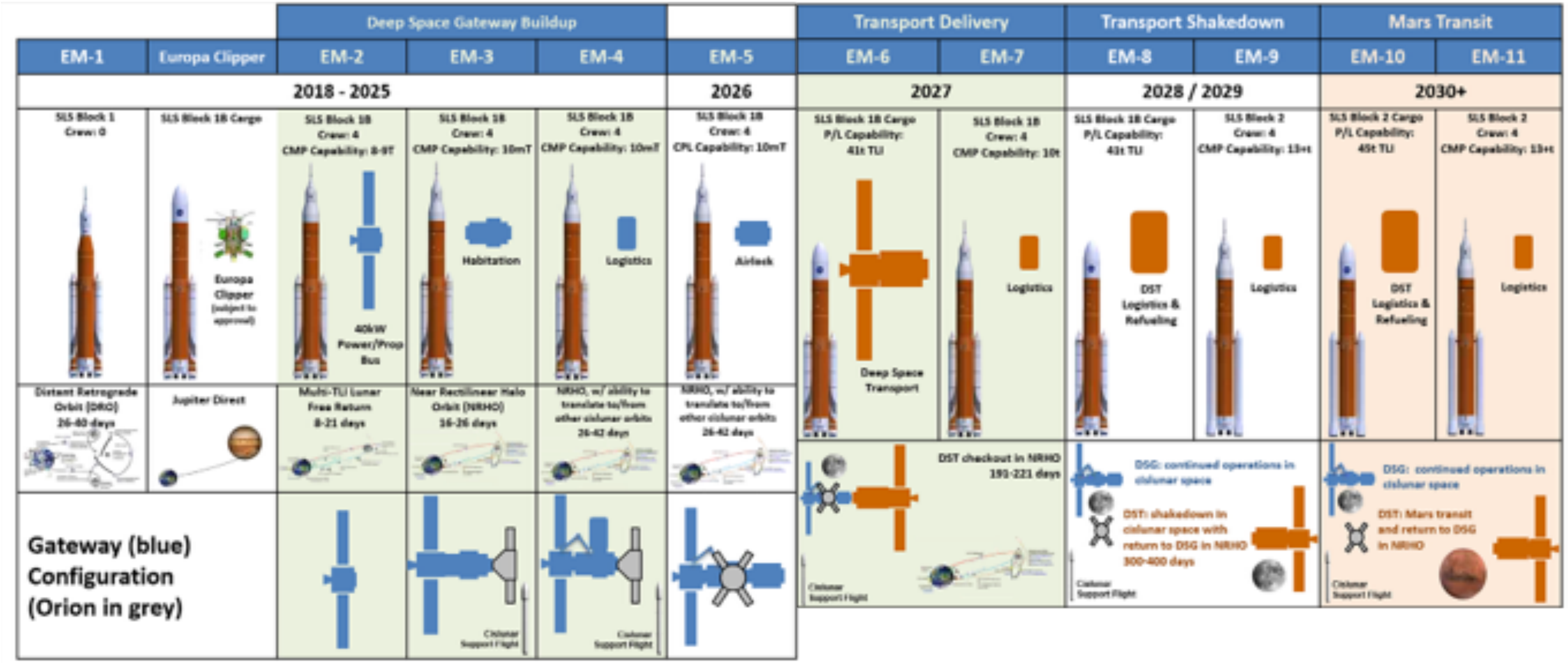
NASA Transition Authorization Act of 2017

Rep. Culberson (R-Tex):
As Eisenhower was remembered for creating the interstate highway system, Trump will be remembered for creating an interplanetary highway system

"The United States should have continuity of purpose for the Space Launch System and Orion in deep space exploration missions, using them beginning with the uncrewed mission, EM–1, planned for 2018, followed by the crewed mission, EM–2, in cis-lunar space planned for 2021, and for subsequent missions beginning with EM–3 extending into cis-lunar space and eventually to Mars [in the 2030s]"

Lunarport

Mission Justification - Deep Spaceway Gate to Mars Transit



William Gerstenmeier, presentation to NASA Advisory Council committee, 3/28/2017

Lunarport

Lunar Human Exploration Strategic Knowledge Gaps Addressed

Strategic Knowledge Gap		LP Relevance
I. Understanding the Lunar Resource Potential		
D-3	Physical characteristics of entrained volatiles	VH
D-4	Understand slopes, elevations, block fields, cohesiveness of soils, trafficability	VH
D-5	Landed missions to understand the charge reservoirs (plasma or ground) in the low conductivity environment	VH
D-6	Determine the form, concentration and distribution of volatiles, how they vary from depths 0-3 m over distances of 10-100m scales.	VH
E	Understand the volatile contents of RDMDs, as well as their depth and distribution	LM
G	Measure the actual efficiency of ISRU processes in the lunar environment.	M
III. Understand How to Work and Live on the Lunar Surface		
A-1	Collect raw materials; create trenches, roads, berms, etc.; enables ISRU, surface trafficability, and ejecta plume mitigation.	VH
A-2	Load, excavate, transport, process, and dispose of regolith; enables ISRU, surface trafficability, and ejecta plume mitigation.	VH
A-3	Crush, grind regolith; understand effects of comminution; enhances ISRU process efficiency.	VH
B3	Ability to remotely traverse over long distances enables a) prepositioning of assets, and b) robust robotic precursor missions.	H
B4	Autonomous landing capability for robotic missions similar to that demonstrated by Chang'e-3 lander.	VH
C2	Characterization of geotechnical properties and hardware performance during regolith interactions on the lunar surface.	H
D4	Multiple landings at the same location on the lunar surface may scour or damage systems and equipment already emplaced at that location. Ejected regolith velocity, departure angles, and energy in engine plume exhaust need to be measured in situ to better understand mitigation strategies	M
F2	Polar missions may be positioned in areas with extended solar availability; blackouts may extend to 3-5 days requiring 100s of kWhours; batteries will be prohibitively expensive	VH

ISRU

Mining Life Cycle and Development Plan

Identify
New Prospects

Exploration

Feasibility Studies

Mine Planning and Construction

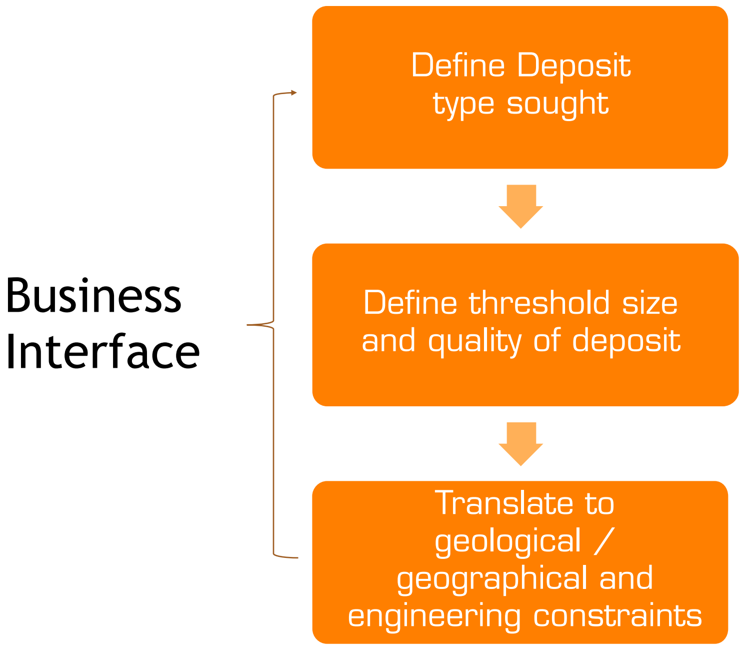
Mine Development and Operation

End of Life / Mine Closure

- Decrease geological uncertainty
- Decrease engineering risk
- Decrease financial risk

ISRU

Establishing and Exploration Target



Type of resource sort: Water ice

Size and Quality: > 4wt% water and able to supply propellant to support cargo and crewed flights to Mars by the mid-late 2030's

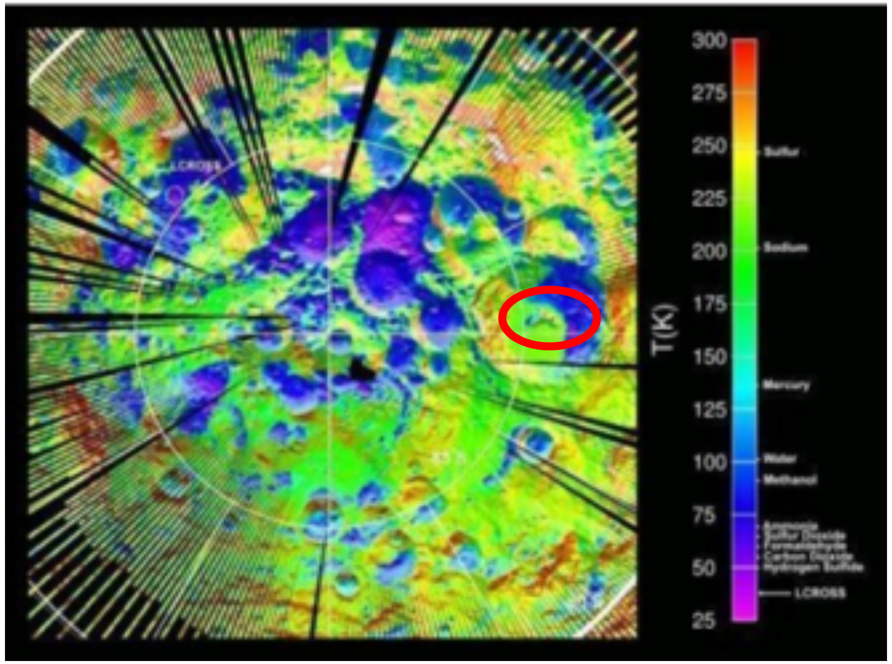
Geographical Parameters: Lunar south pole

Geological Parameters: Permanently Shadowed Region (PSRs) – Approx. less 100K with potential for stable ice at the surface, distribution likely governed by small impact cratering

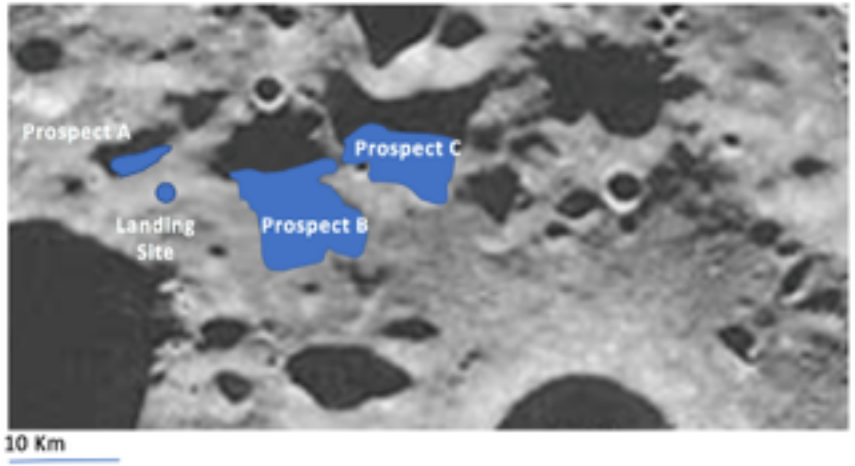
Engineering constraints: Located in proximity to appropriate landing / base construction site, traversable terrain

ISRU

Site Selection



LRO Diviner South Pole Temperature Map (Credit: NASA/JPL)



Ice Rush Mission Site Selection

ISRU

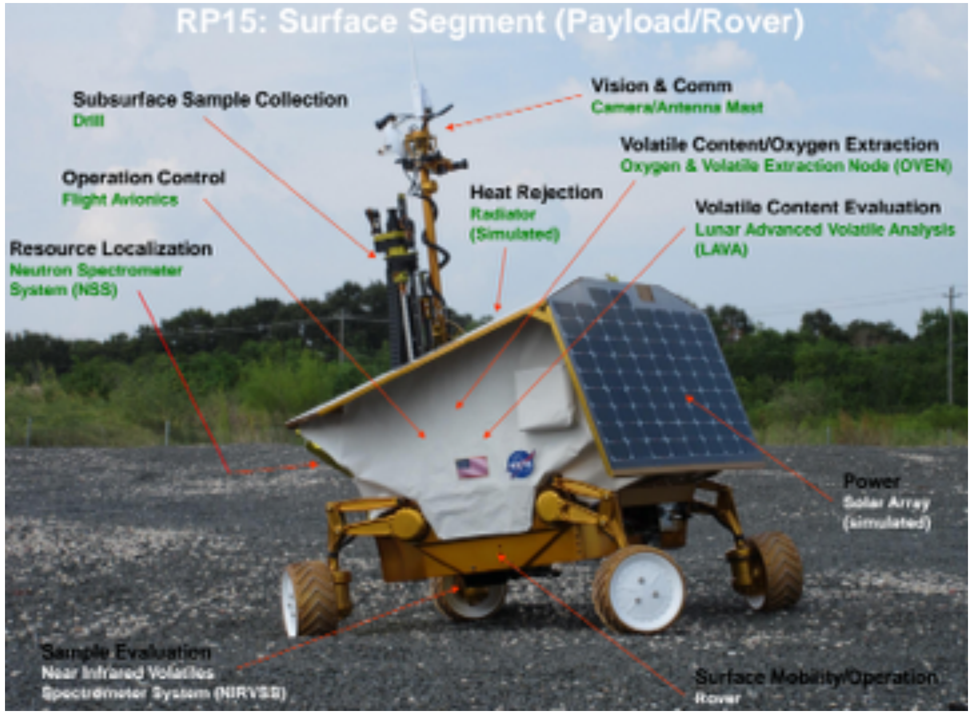
“Scout” Lunar Resource Prospector Requirements

Primary Requirement:
- Identify water-rich deposits (>4wt%) for future mining missions

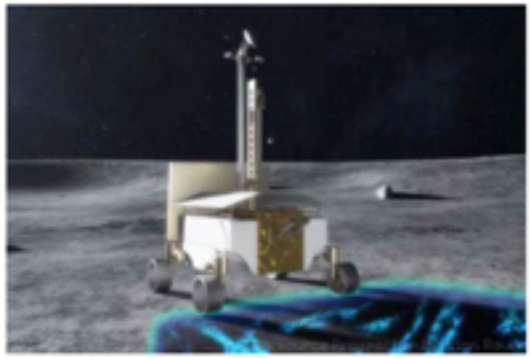
Secondary Requirements:
- Define composition, water content and extent of the of the water rich deposits;
- Characterize terrain and environment (i.e. slope, identify geo-hazards, trafficability, temperature);
- Define accessibility / extractability of the (geo-mechanical properties of regolith, depth to resources)

ISRU

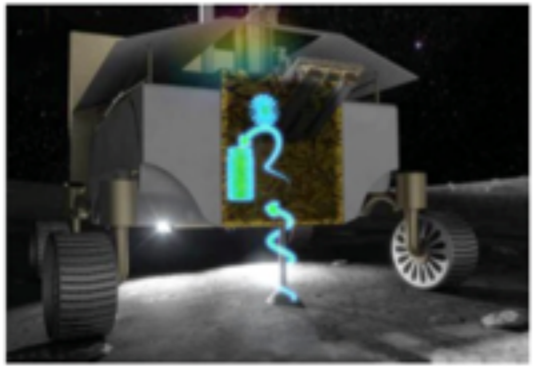
“Scout” Lunar Resource Prospector



Lunar Resource Prospector (Credit: NASA JPL)



RP Neutron Spectrometer (Credit: NASA/JPL)



RP subsurface drill and sampler (Credit: NASA/JPL)

Lunar Miners Requirements

Primary Requirements:

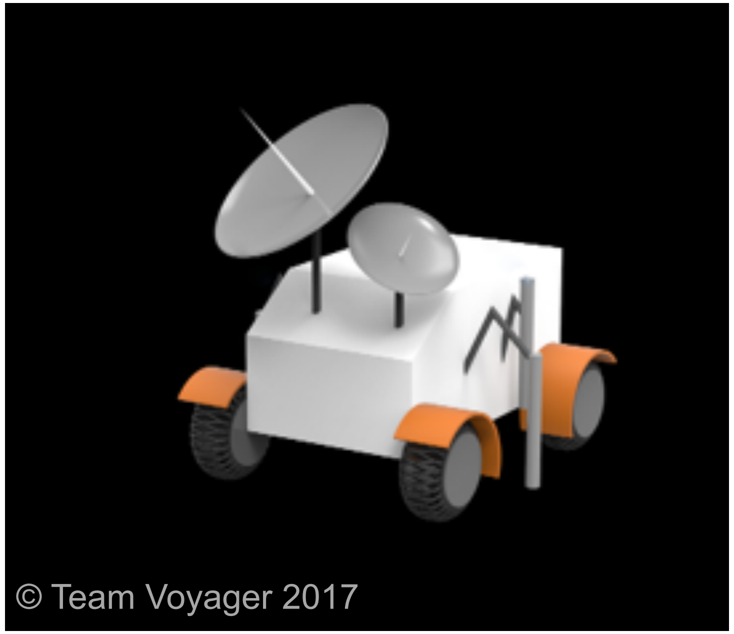
- Produce 19.5 tons of water by 2026 (LRS propellant transfer technical demonstration)
- Produce 45.2 tons of water by 2028 (technical demonstration of propellant transfer between LRS and orbiting propellant depot)
- Produce 703.8 tons of water by 2032 (1st two cargo missions to Mars)
- Produce 175.9 tons of water by 2034 (1st crewed mission to Mars)

Secondary Requirements:

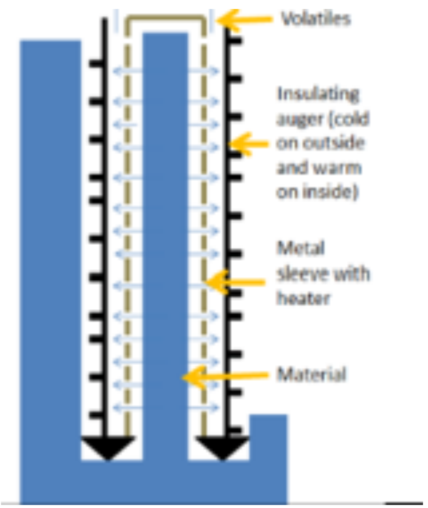
- Continue refueling two cargo and one crewed mission to Mars every four years

ISRU

Lunar Miner



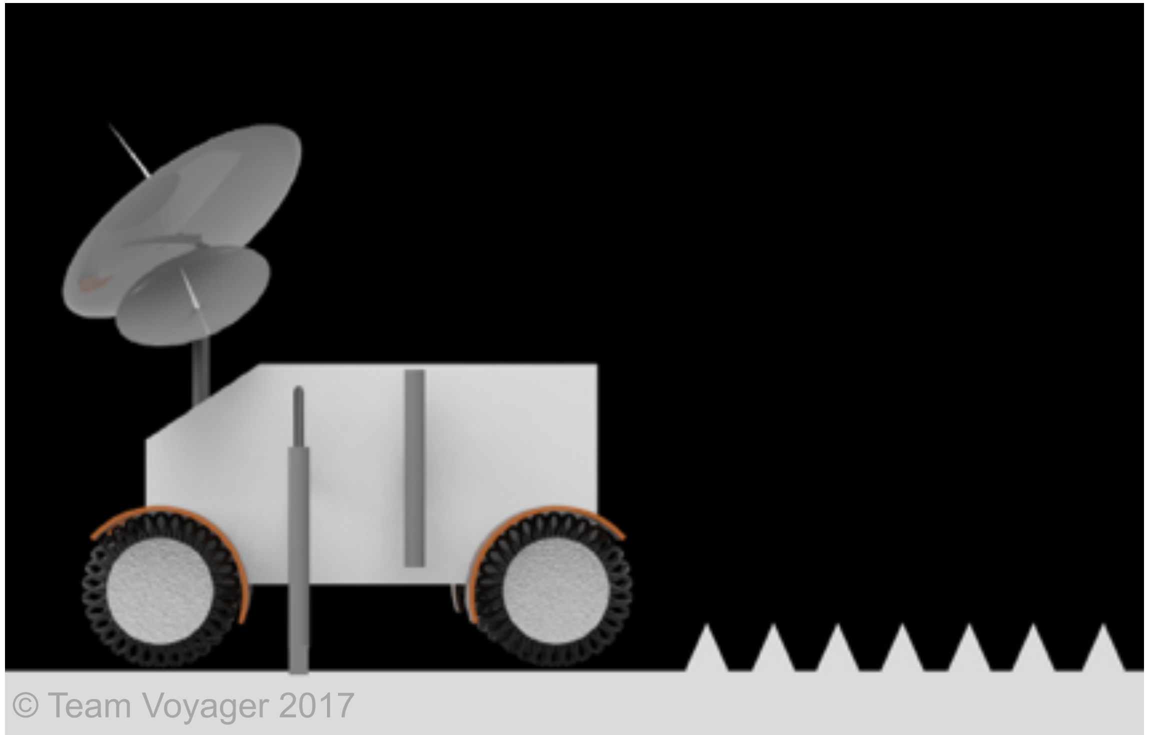
Lunar Miner



Honeybee Robotics PvEX Corer
(credit: Zacny et al 2015)

The proposed structure of the lunar miner is based Apollo lunar roving vehicle.
For the coring and processing system the Honeybee Robotics Planetary Volatiles Extraction (PVEx) Corer will be used.

Lunar Miner

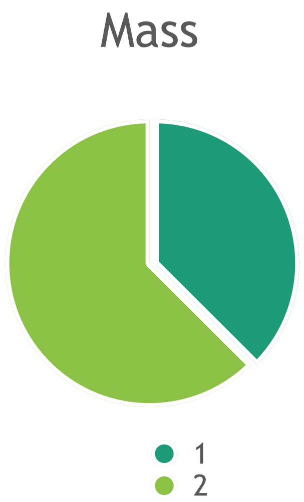


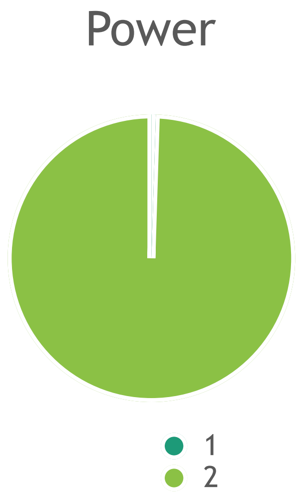
Lunar Miner in Operation

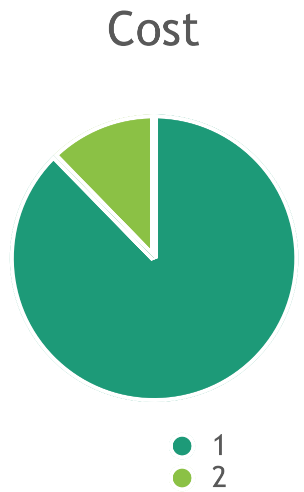
ISRU

Subsystem Breakdown

Component	TRL	Analog
Scout	*5*	*Lunar Resource Prospector with RTG and Lidar*
Miner	*9* *6*	*Structure - Apollo lunar roving vehicle* *Drill and Processing unit*
Total:		







ISRU

Scout and Lunar Miner - Tech Development

Scout (Lunar Prospector Rover)

Current Technological Development:

- Prototype RP15 built
- Undergone environmental and stress testing on the OVEN, LAVA and DRILL subsystems

Future Studies

- Integrating RTG and Lidar system

Lunar Miner

Current Technological Development:

- Prototype of PvEX corer built by honeybee robotics
- Laboratory testing under lunar analog conditions of corer and processing unit
- All tests were conducted using JSC-1A lunar simulant mixed with water at 6 wt% or 12w t% saturation level.

Future Studies:

- Integrating design with Apollo Lunar Lander
- Integrating design with microwave beamer technology

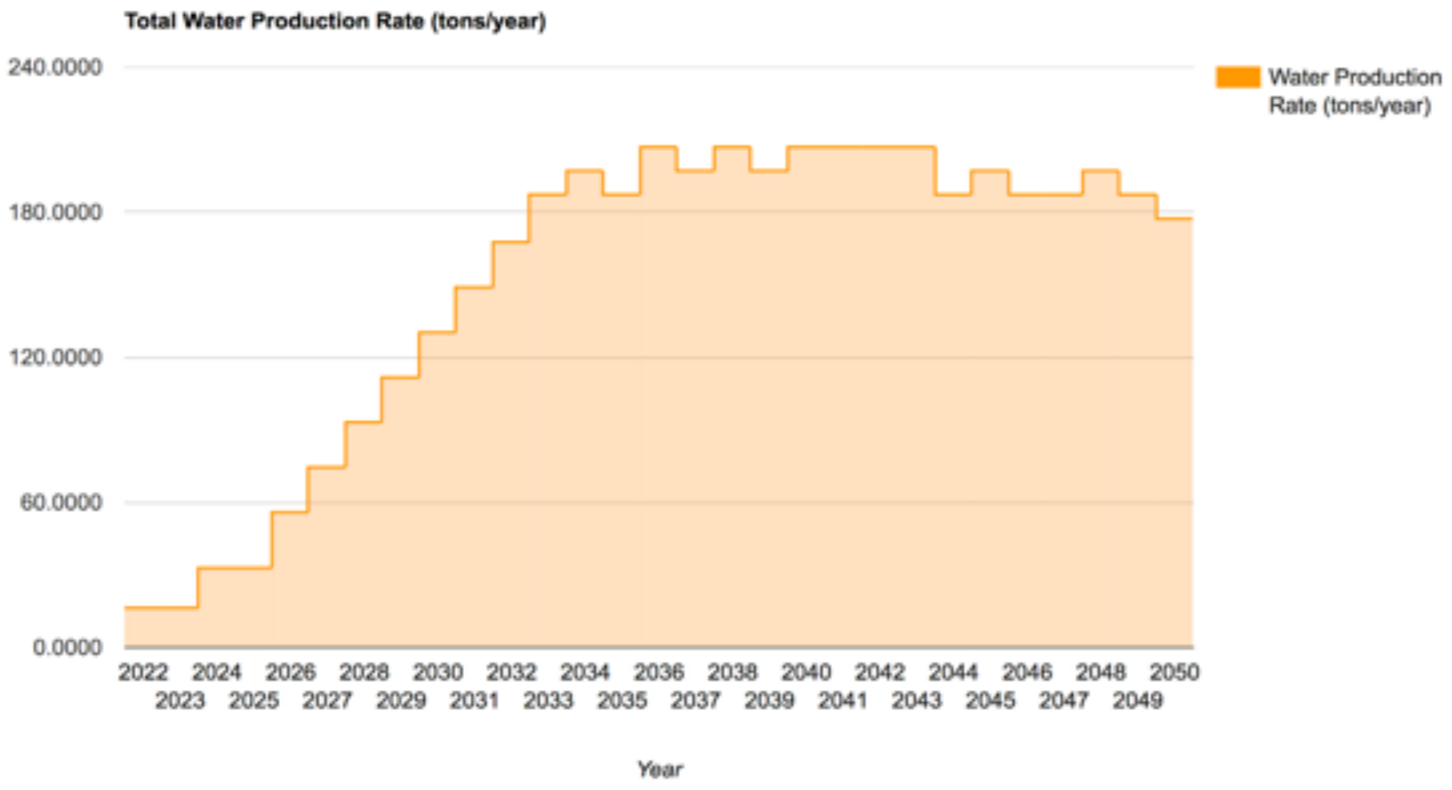
LIKELIHOOD		1			
		2			
		3	4 & 5		
			6		
				7	
	CONSEQUENCES				

Risk Assessment

1. Thermal Effects
2. Miner rover drill bit stick in hole or damaged
3. Geo - mechanical properties exceed drill capabilities
4. Rock or obstructions block power pathway
5. Miner / Prospector Rover fault
6. Total loss of communication with rover
7. Prospector drill stuck in hole
8. Micro - meteorite
9. Solar flare

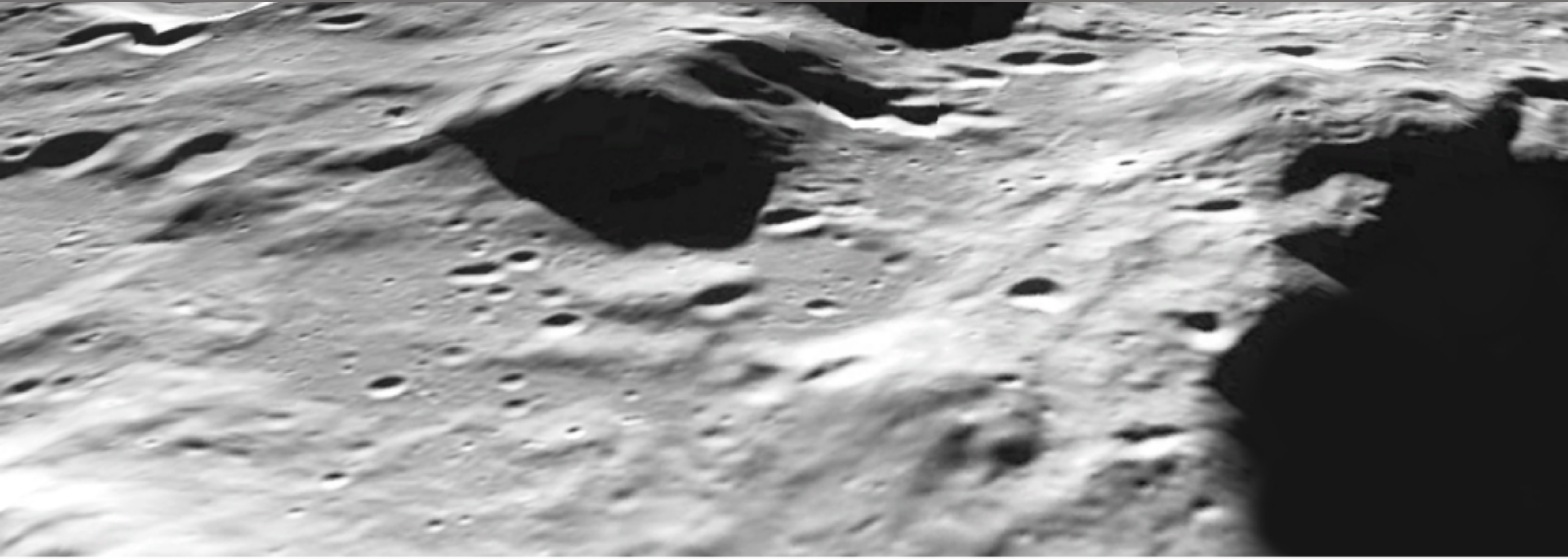
ISRU

Mining Schedule

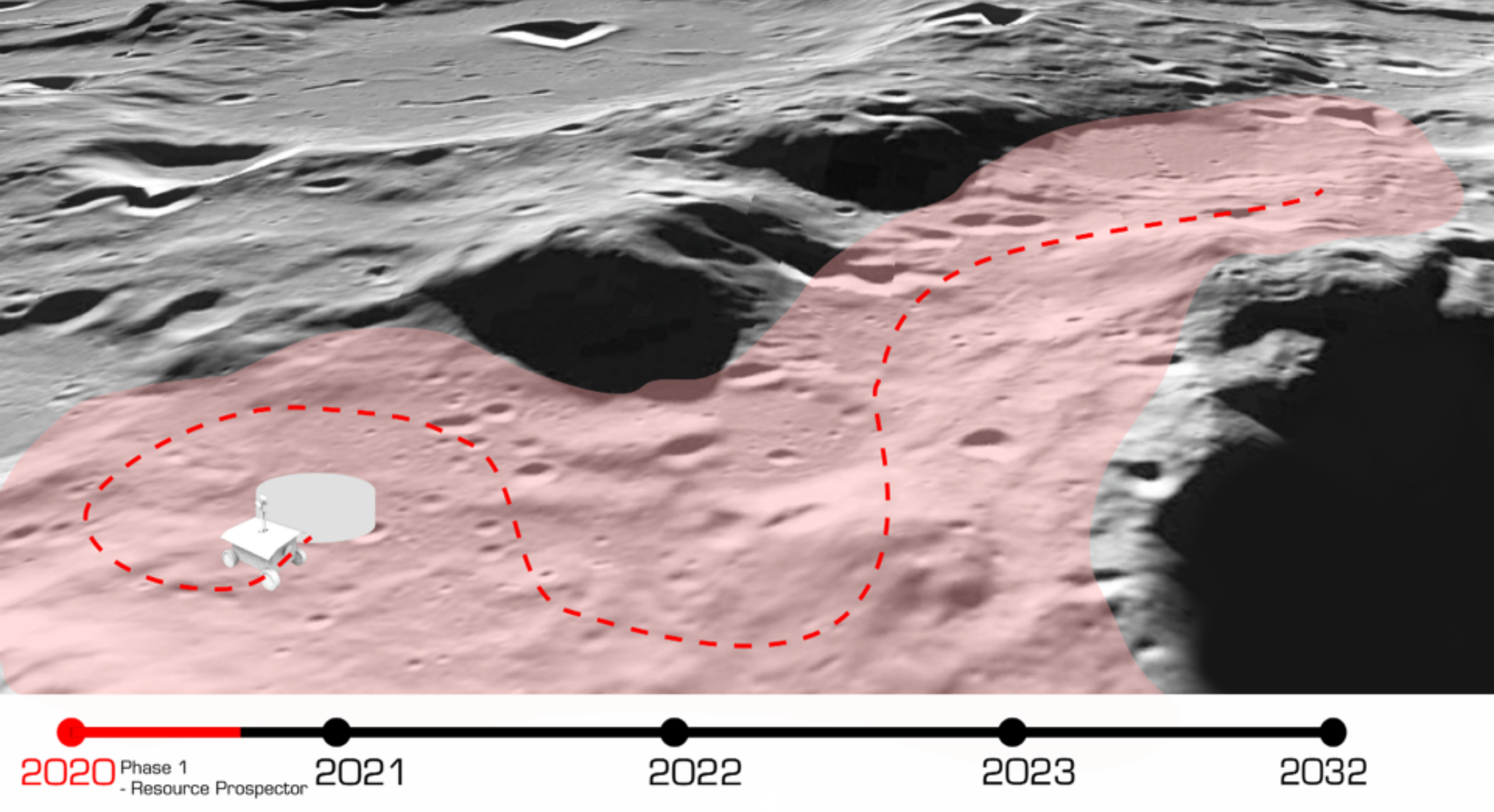


Base

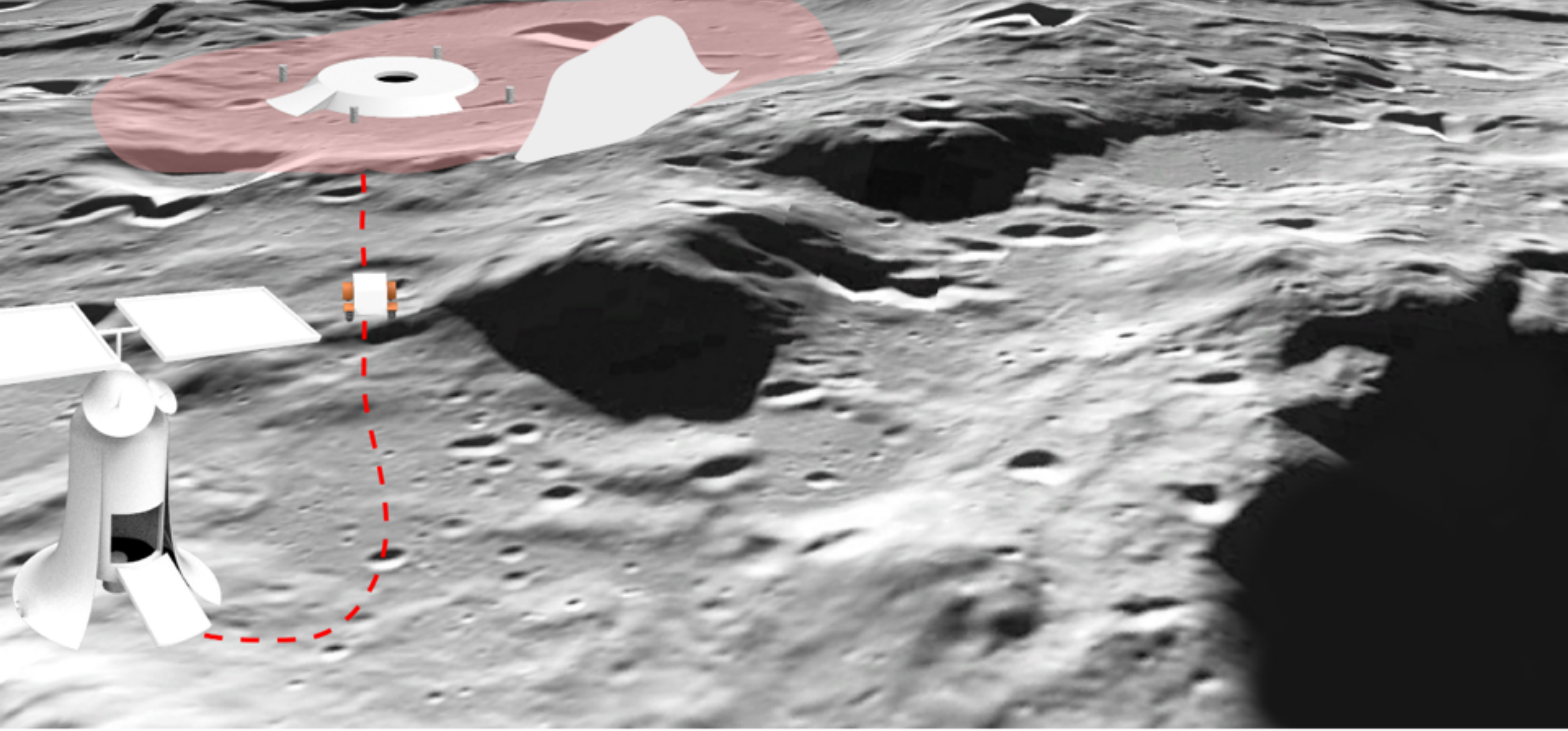
Lunarport Construction



2020 — 2021 — 2022 — 2023 — 2032

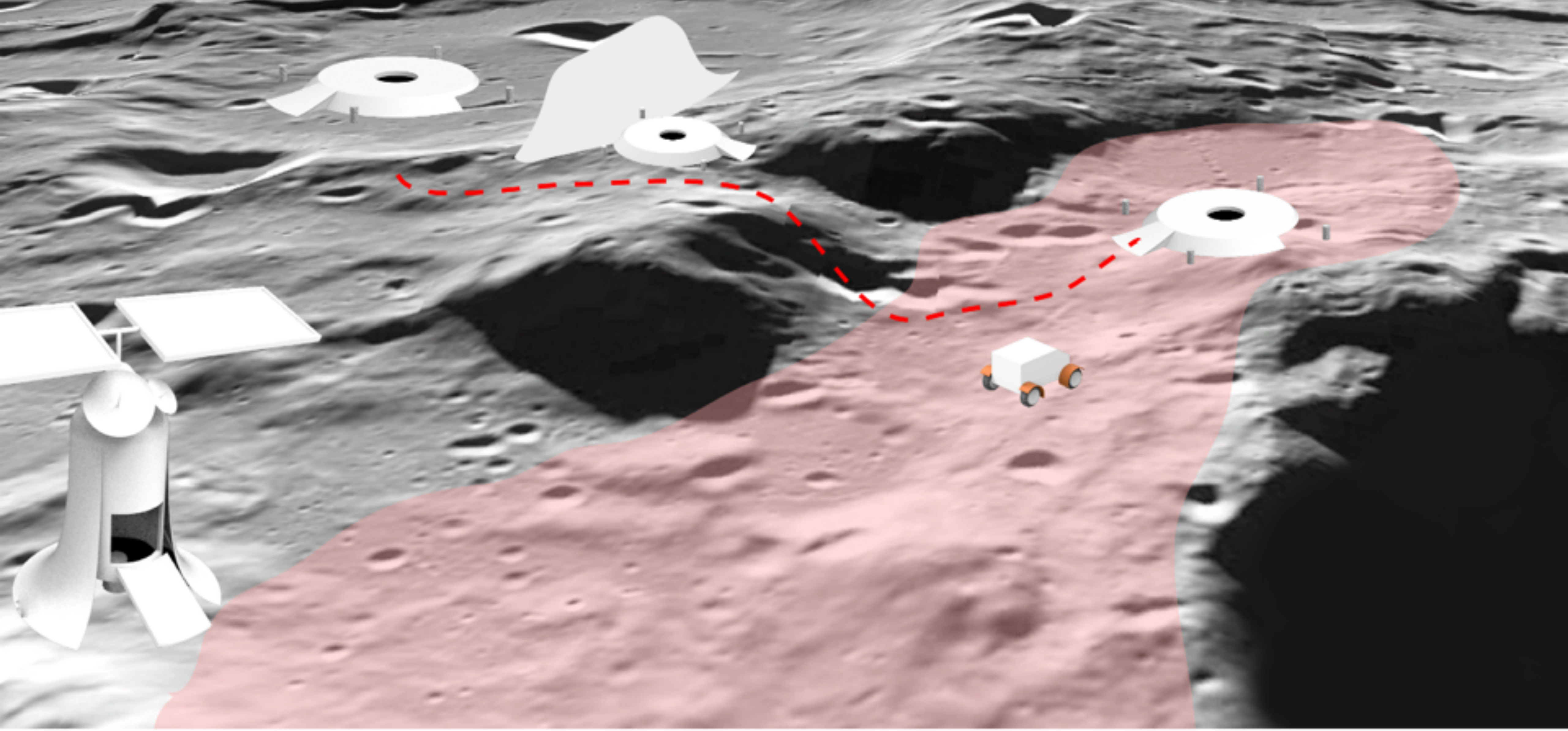


2020
Phase 1
- Resource Prospector
2021
2022
2023
2032



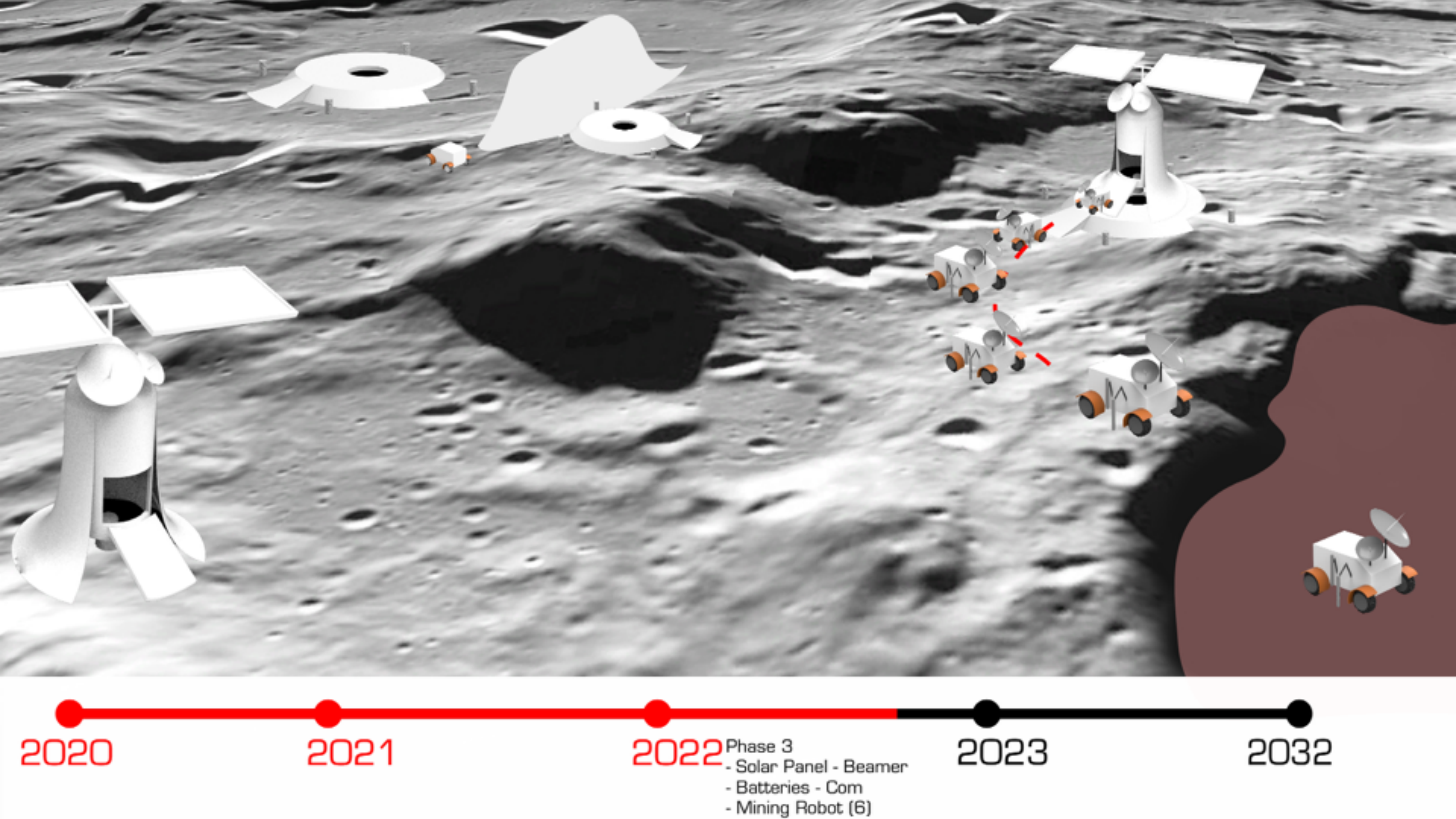
2020 2021 2022 2023 2032

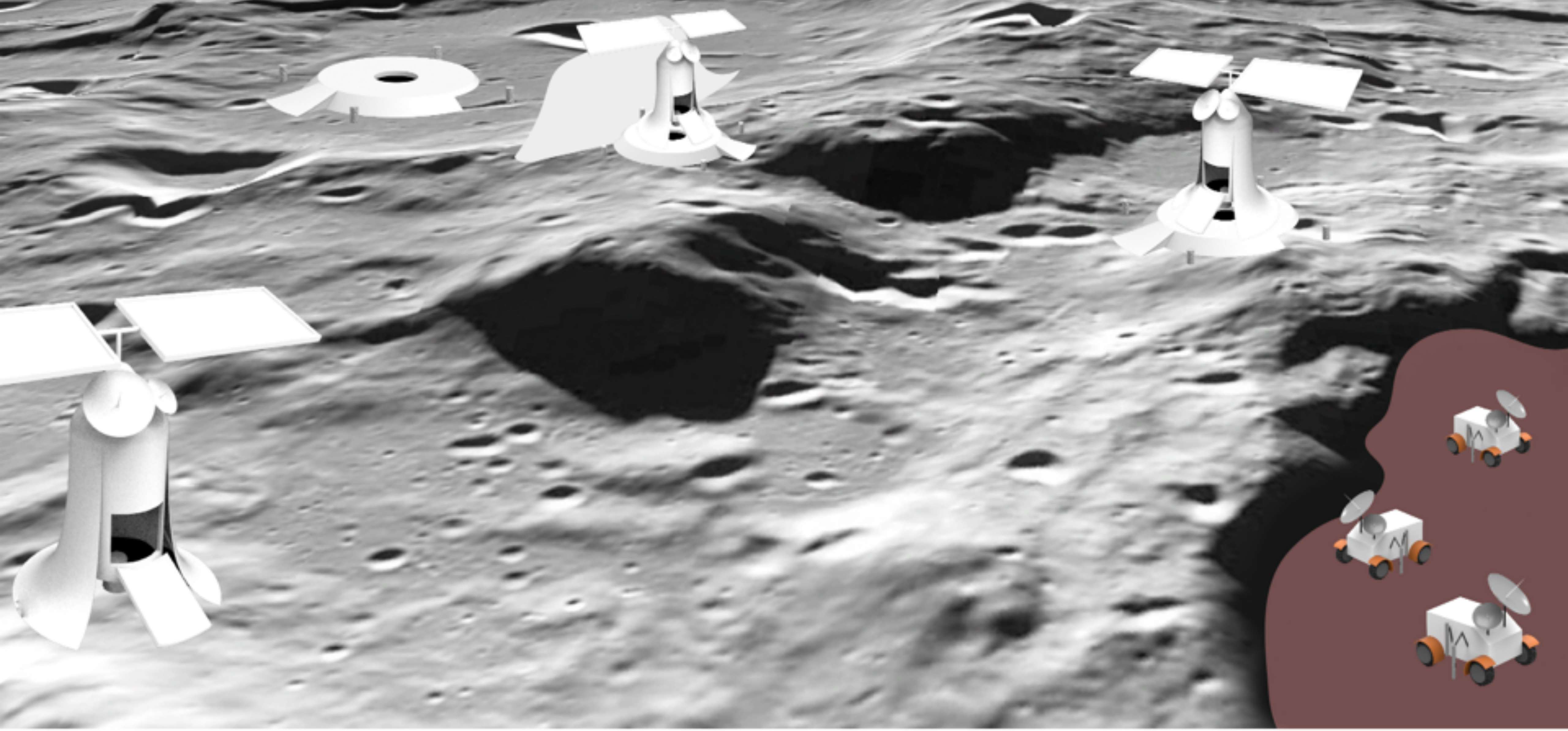
Phase 2
- Solar Panel - Beamer
- Batteries - Com
- Sintery



2020 — 2021 — 2022 — 2023 — 2032

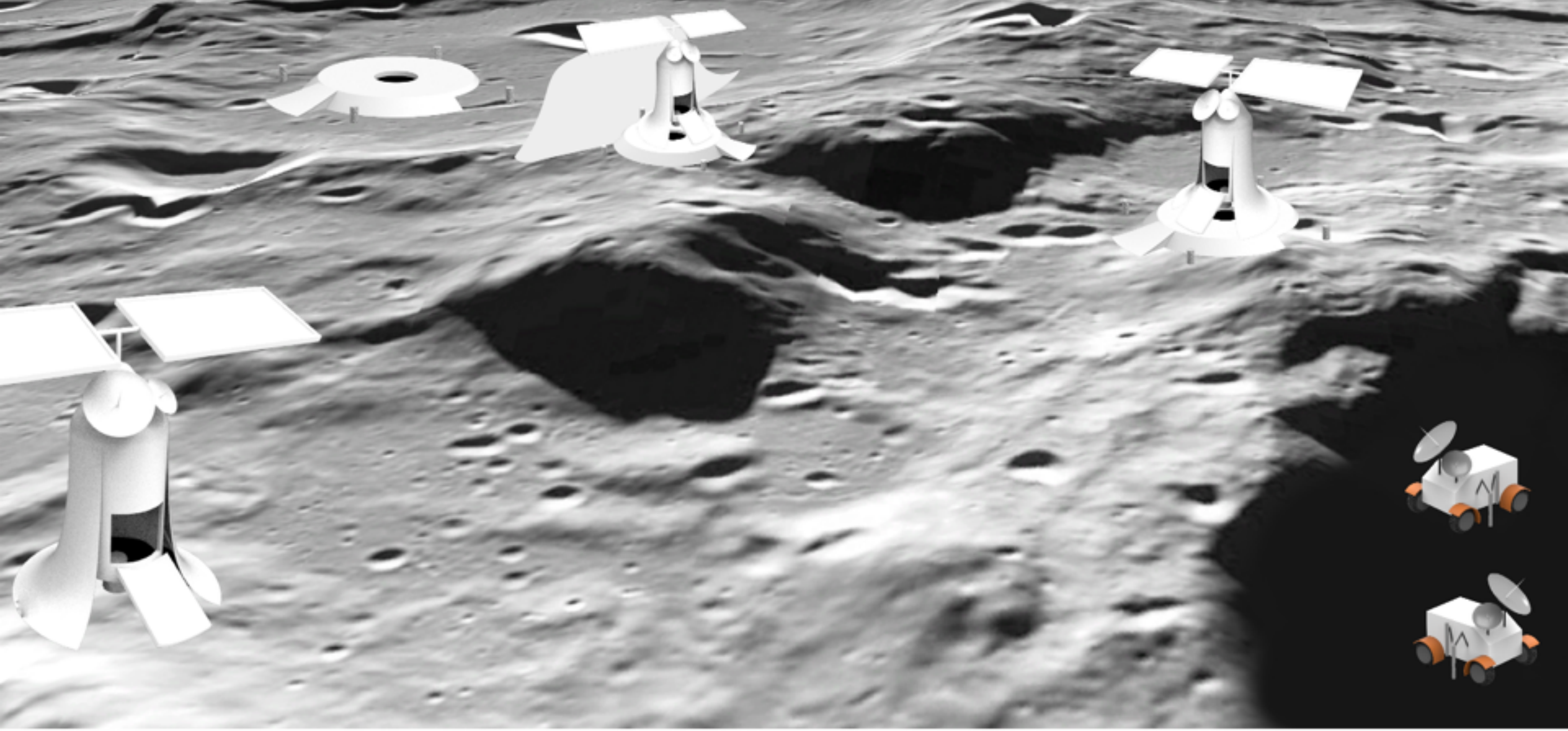
2021 Phase 2
- Solar Panel - Beamer
- Batteries - Com
- Sintery


2020
2021
2022
Phase 3
- Solar Panel - Beamer
- Batteries - Com
- Mining Robot (6)
2023
2032



2020 — 2021 — 2022 — 2023 — 2032

Phase 4
- Solar Panel - Beamer
- Batteries - Com
- Electrolysis



2020 Phase 1
- Resource Prospector

2021 Phase 2
- Solar Panel - Beamer
- Batteries - Com
- Sintery

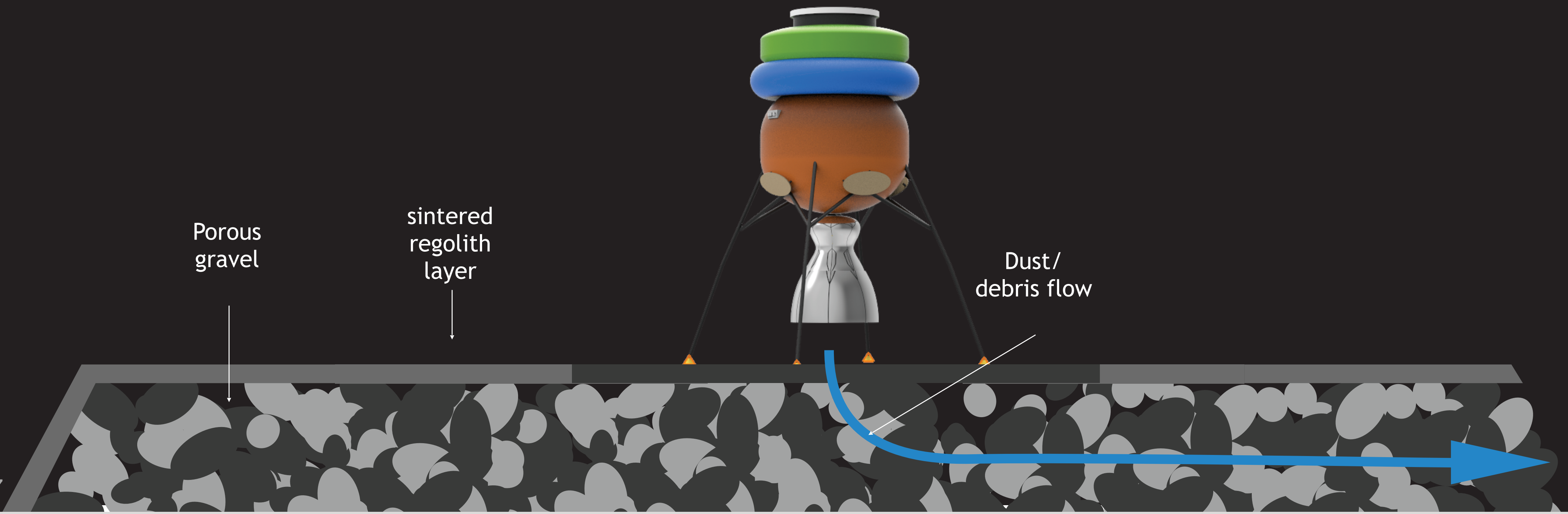
2022 Phase 3
- Solar Panel - Beamer
- Batteries - Com
- Mining Robot (6)

2023 Phase 4
- Solar Panel - Beamer
- Batteries - Com
- Electrolysis

2032 Capable of supporting Mars Mission

Base

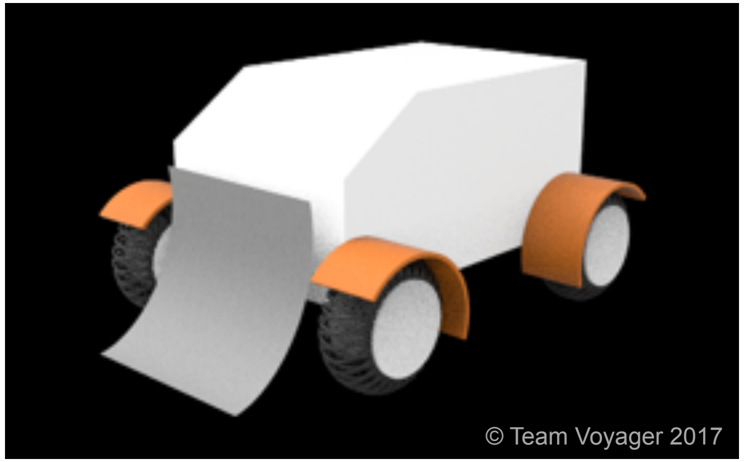
Landing Panel Diagram



Base

Construction Requirements

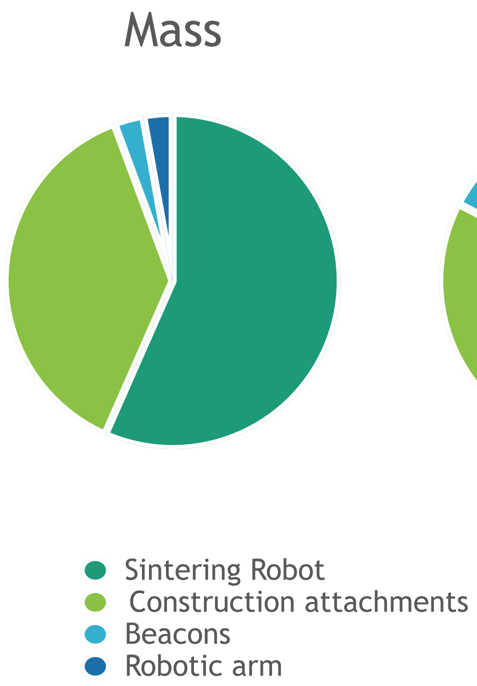
- **Primary Requirements**
  - Constructing a Launchpad for the LRS
  - LH2, LO2 and H2O connection interface
- **Secondary Requirements**
  - Miner road infrastructure
  - Protective regolith berm

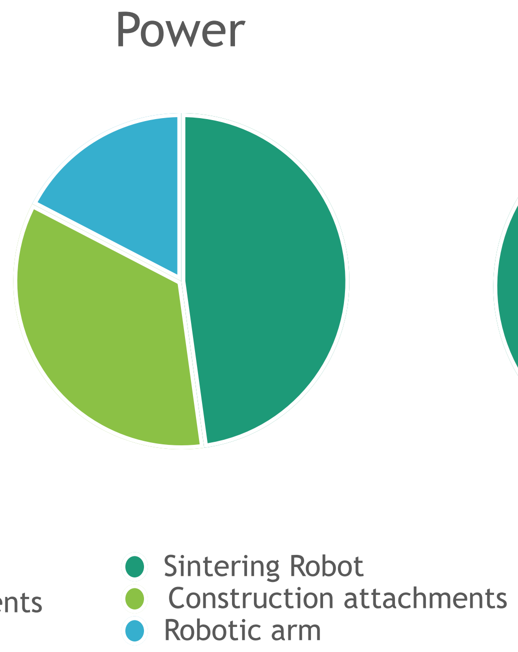


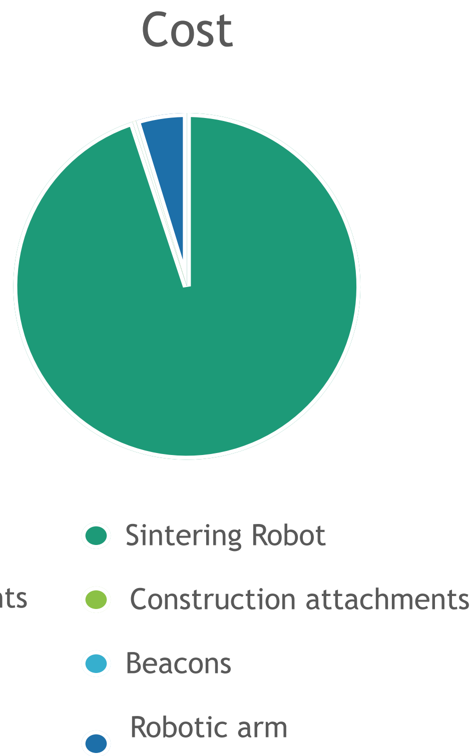
Base

Construction Subsystem Breakdown

Component	TRL	Analog
Sintering Robot	*6*	*The Athlete robot*
Construction attachments	*8*	*Filler, excavation blade, vibration*
Beacons	*9*	*Corner cube retro reflector*
Launch pad wall	*7*	*Embankment*
Rover roads	*8*	
Robotic arm	*6*	*ISS*
Total:		







LIKELIHOOD					
		Overestimate vehicle lifetime			
		Cannot develop technology in time	Berm slope failure		
			Road failure	Docking failure	Sintering robot failure
	CONSEQUENCES				

Risk Assessment

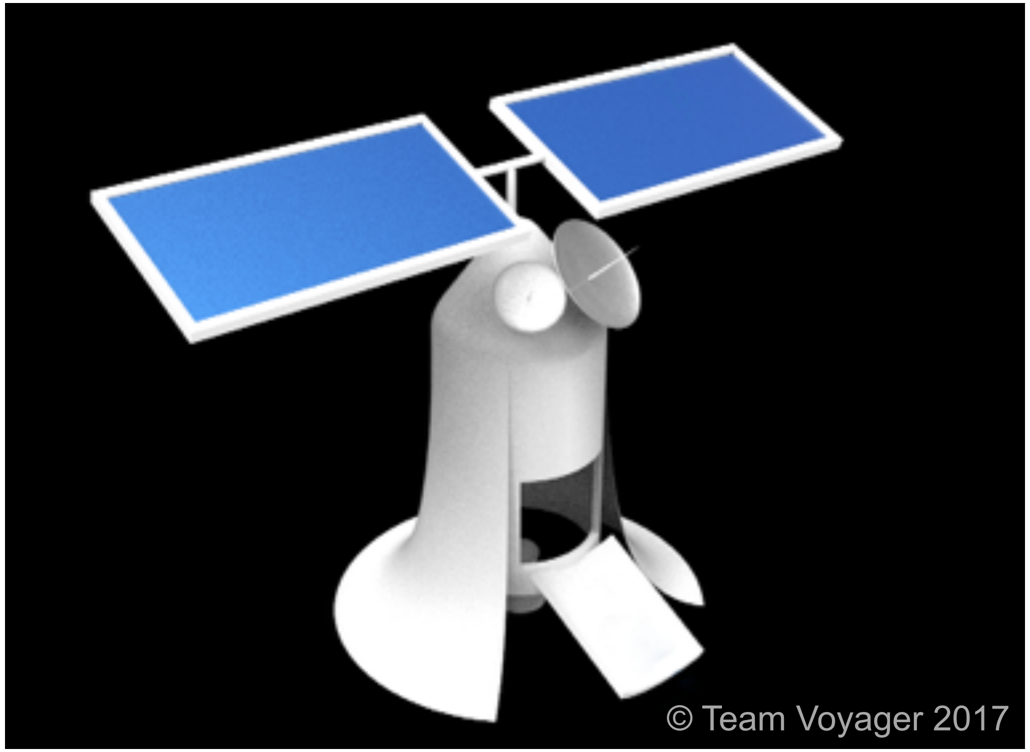
- use of sintered soil roads are well within the industry specifications, and hence durability, performance, stability and safety can be assured
- The covering berm will act as a shield against radiation and asteroid impacts on lunar structures and rovers
- The landers will initially be covered by a carbon fiber deployable structure

Base

Power Requirements

- **Primary Requirements**
  - Solar panels (100kW/miner)
  - RTG's (300W for prospector)
  - Lander batteries
  - Rover batteries
  - Cables
  - Microwave beaming

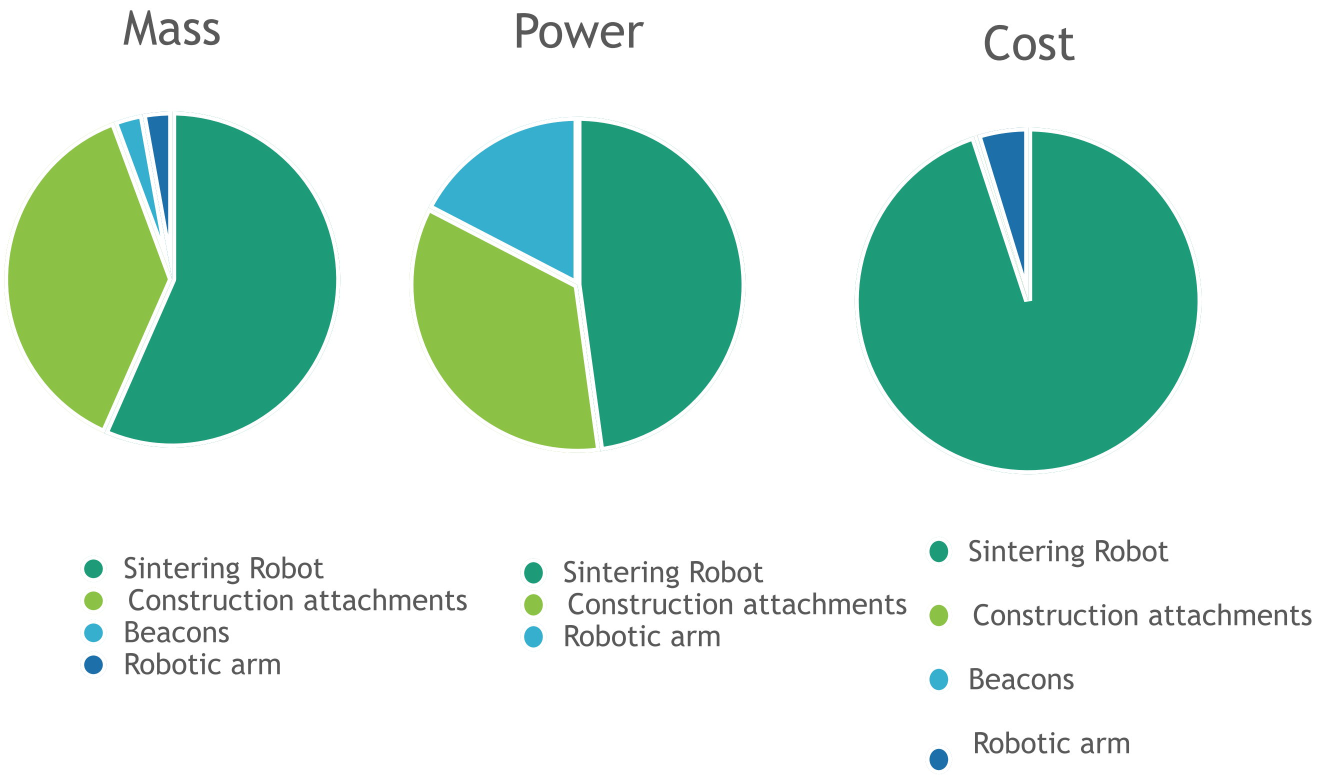
- **Secondary Requirements**
  - Power another lander
    - Cable or beaming



Base

Power Requirements

Component	TRL	Analog
Solar panels	*9*	*Proven*
Cables	*9*	*Proven*
RTG's	*9*	*MSL*
Microwave beaming	*5*	*NASA Suntower*
Total:		



Base

Power

LIKELIHOOD					
				Solar power deployment	
		Power cable disconnect		Microwave beaming failure	
				Battery leakage	
	CONSEQUENCES				

Risk Assessment

- Solar panels and nuclear does not present significant technology development risks
- Operational risks include the deployment of the solar arrays and microwave transmitter from the lander
- Transmission of energy can be decreased in case of block of line of sight
- Rovers are equipped with emergency batteries to handle the block of line of sight risk

Environmental Risk Mitigation

Thermal Control

Potential Problems

- Operability at 40K-180K temperature range
- Radiation heat transfer

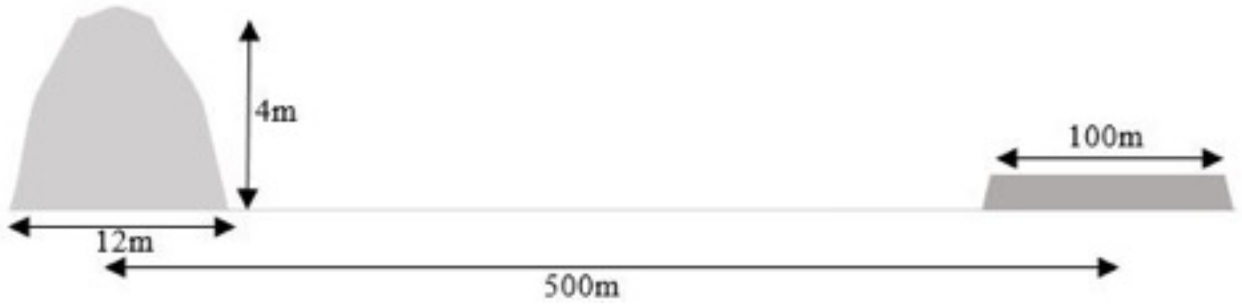
Solutions Proposed

- 2x dual heat spreaders with heat pumps
- Attachment of temperature sensors and heaters on required components
- Copper thermal straps
- Passive and active thermal control systems
  - Ammonia circulated radiator
  - Coatings, heaters, heat pipes, RHU

Environmental Risk Mitigation

Regolith Protection

Potential Problems
- Clogging of dust in robotic joints
- Abrasive dust on solar panels
- Ejection of regolith when shuttle lands
- Sinking of robots



Solutions Proposed
- magnetic straps around seals
- Highly flexible conformal covers similar to ATHLETE
- Electro magnetic vibrators for solar panels
- Deployable structure on landers to avoid dust
- Compacted regolith layers on structures
- Construction of a covering berm
- Bigger wheels with ribs for more area

Environmental Risk Mitigation

Radiation

Potential Problems

- Ionized radiation penetrations
- Increased temperatures

Solutions Proposed

- Regolith covering on structures
- Covering berm
- Radiation-hardened electronics
- Electrostatic shielding

Environmental Risk Mitigation

Asteroids

Potential Problems
- Crashing onto structures
- Rover damage

Solutions Proposed
- Regolith cover on structures to absorb kinetic energy
- Construction of the covering berm

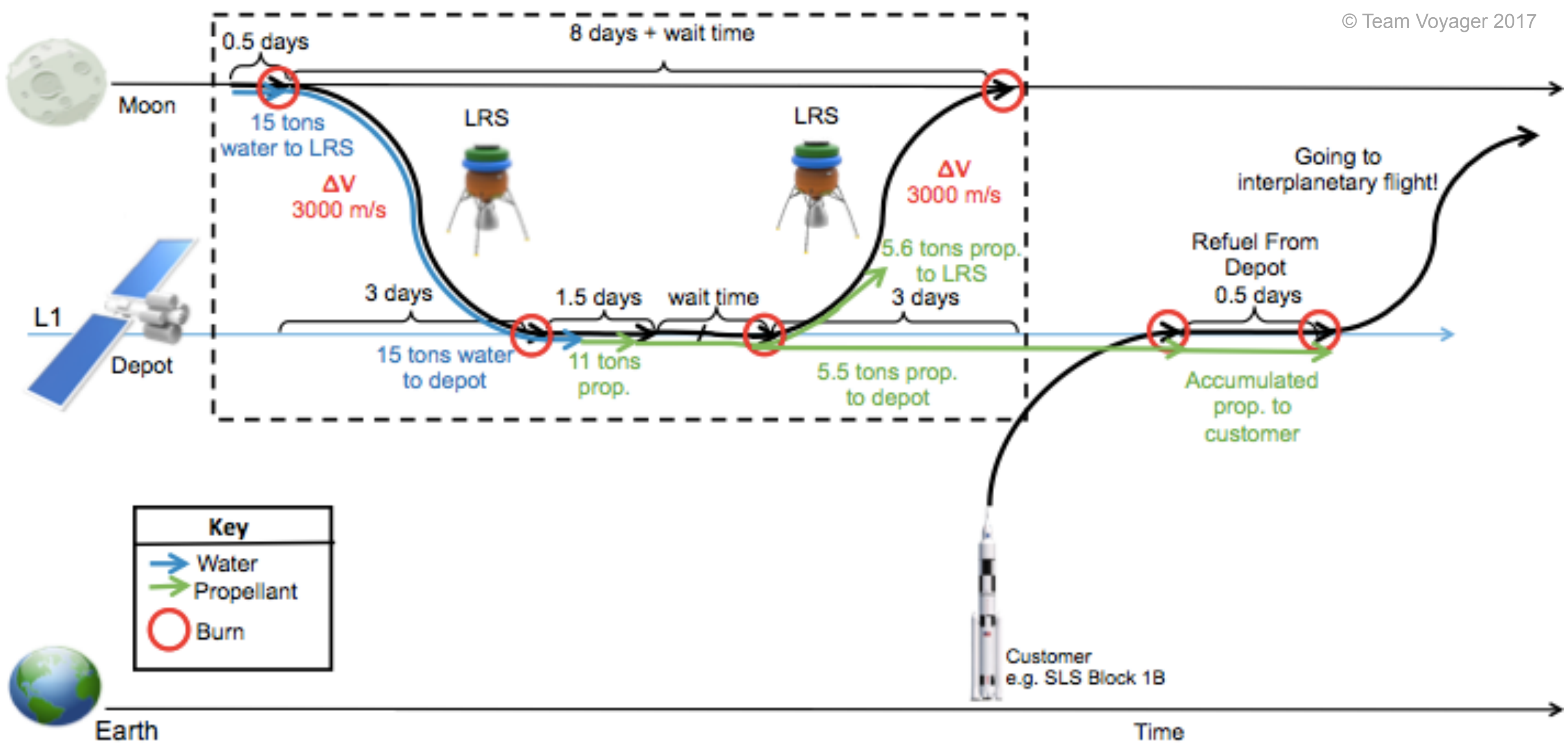
Space System - Lunar Resupply Shuttle (LRS)

Requirements

- Transport propellant resources from lunar surface to depot in cis-lunar space
- Reuse for multiple Moon-L1 trips
- Minimal risk and cost
- Develop in <9 years

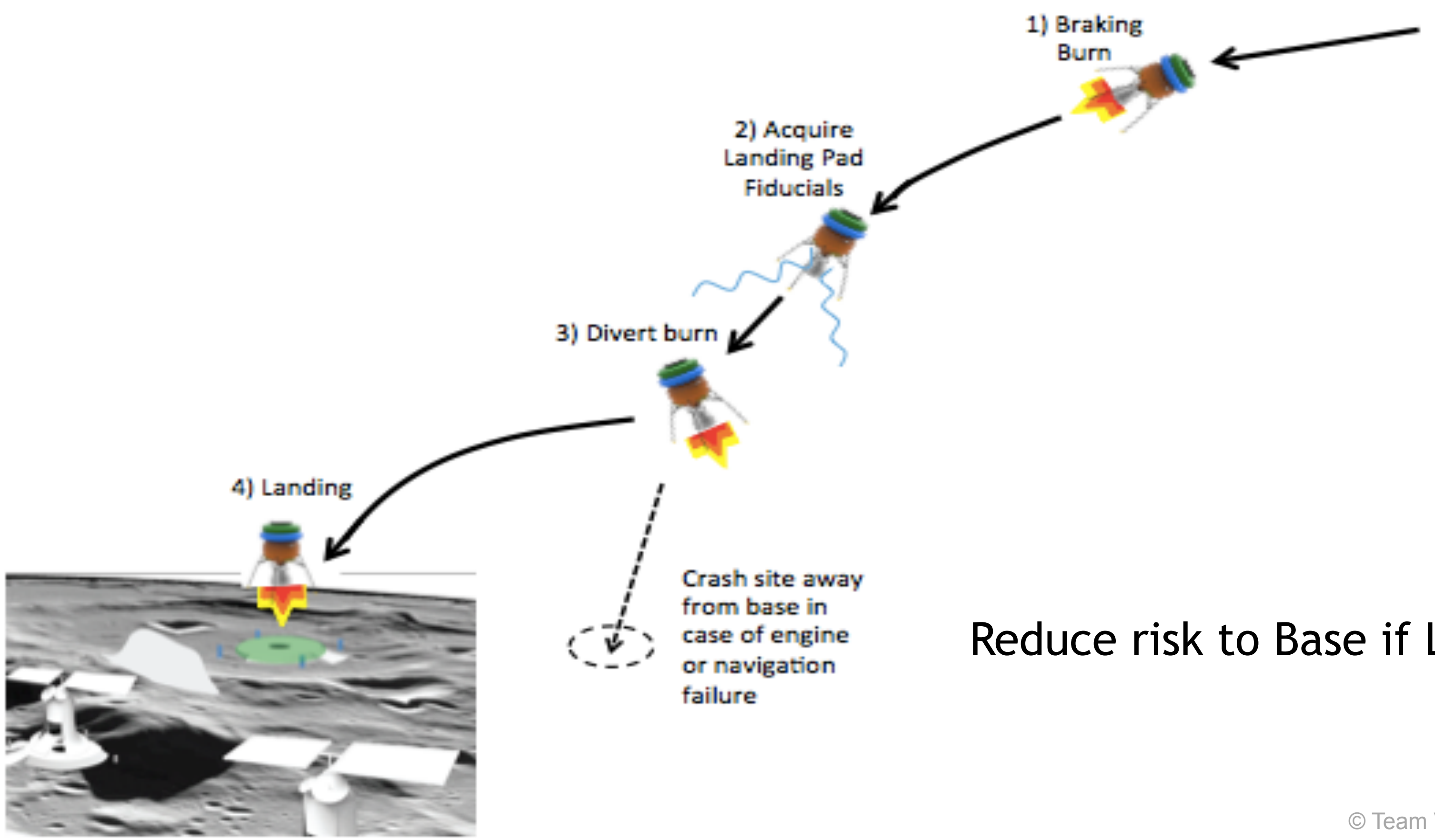
Space System - LRS

Timeline



Space System - LRS

Descent and Landing

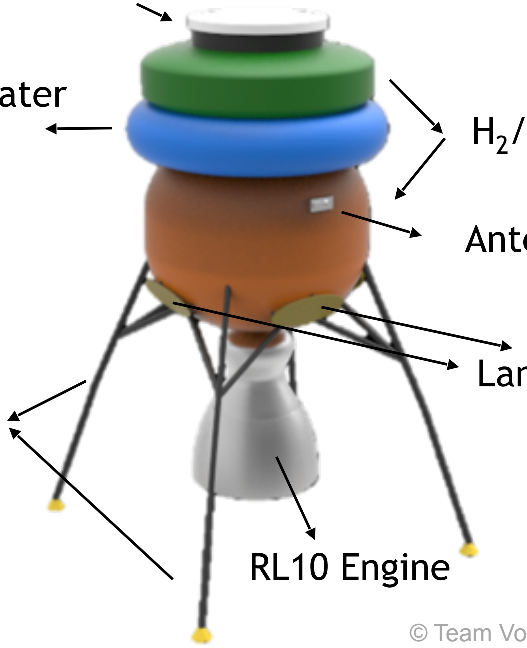


Reduce risk to Base if LRS fails

Space System - LRS

Components

Stowed for launch on Falcon Heavy

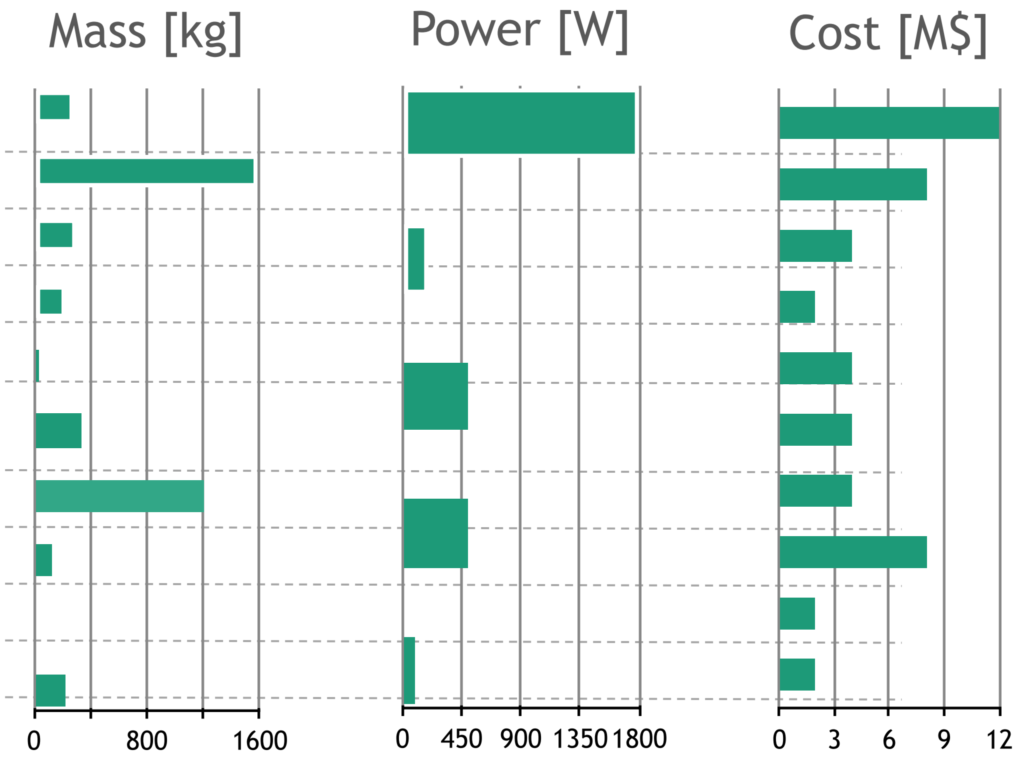


LRS

Space System - LRS

Subsystem Components

	Component	TRL	Analog
1	*Main Engine*	*9*	*RL10*
2	*H_2*	*9*	*Centaur*
3	*Landing Legs*	*9*	*Apollo LM*
4	*RCS Thrusters*	*6*	*Space Station*
5	*GNC*	*6*	*JPL ALHAT*
6	*Docking and Propellant Transfer*	*6*	*Shuttle APAS-95*
7	*Bladder for Water Storage*	*4*	*TransAstra's APIS*
8	*Thermal System*	*6*	*Centaur*
9	*Communications*	*9*	*S-Band Antenna*
10	*Power*	*9*	*H_2*
	Total:	*7*	

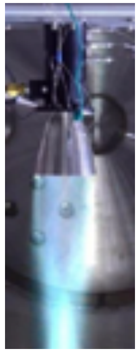


Space System - LRS

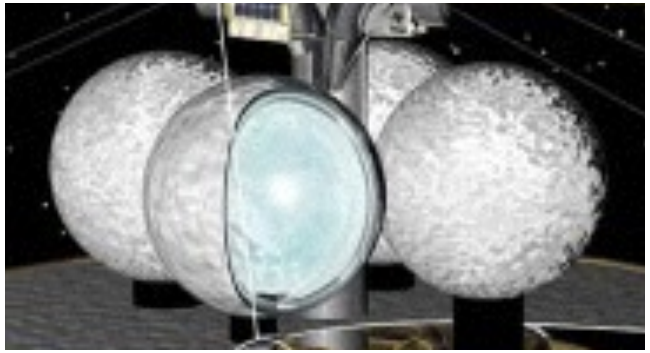
Technology Development

2017-2022: Mature mid-TRL technologies

Precision landing
JPL



H_2/O_2 RCS
ULA



Water bladders
TransAstra

→ 2021-2023: Design vehicle and issue contracts

→ 2023-2025: Integrate test vehicles

→ 2026: Test in demonstration flight

→ 2028: Production

Images from NASA, ULA, TransAstra

Space System - LRS

Lunar Resupply Shuttle

LIKELIHOOD					
		Overestimate Vehicle Lifetime			
		Cannot develop technology in time	Refueling Failure		
			LRS Crashes on Landing	LRS Crashes into Base	
	CONSEQUENCES				

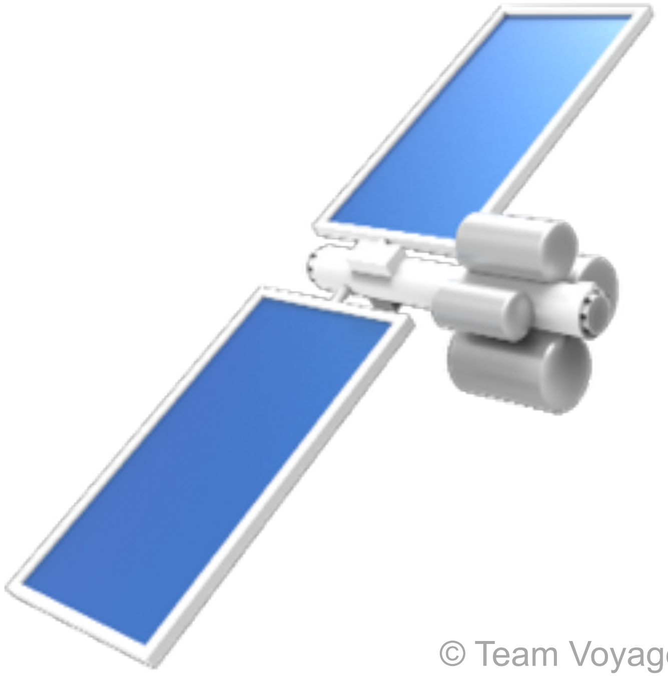
Risk Assessment

- The highest-consequence risk is an LRS crash which destroys base equipment
- The likelihood of this risk is reduced through a clever choice of landing trajectory
- The most probable risk is that the estimate vehicle lifetime estimate cannot be achieved

Space System - Refueling Depot

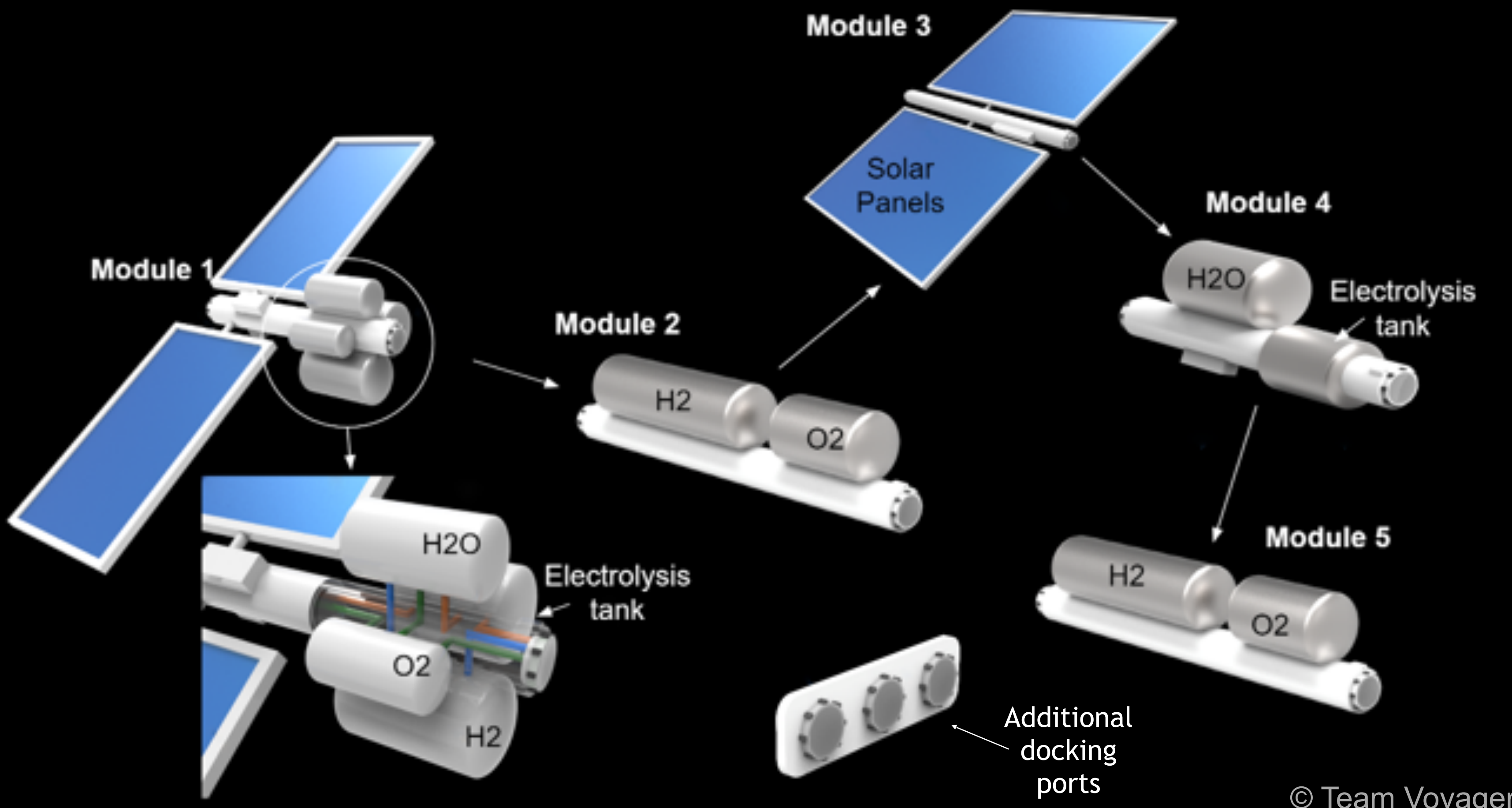
Requirements

- Receive H_2O from the LRS and convert to LO_2 and LH_2 through electrolysis
- Store water and propellants at necessary conditions (warm for H_20 and cryogenic for LO_2 and LH_2)
- Design to minimize risk and costs
- Total development time of 5-10 years or less
- Provide docking capability for commonly used spacecraft
- Modular design for scalability and sustainability



Space System - Refueling Depot

Design Architecture Flow



Space System - Refueling Depot

Subsystem Breakdown

Component	TRL	Analog
Propellant Generation System with Electrolysis	*7*	*Modified version of ISS Oxygen Generation System (OGS)*
Cryogenic Storage tanks	*6*	*NASA Composite Cryogenic Tank*
Fuel Transfer Device	*9*	*Robotic Refueling Mission (RRM) plus improvements*
Foldable Solar Array and Power System	4	Based on Miura Fold with 9.26 fold ratio
ADCS	7	*Moog ISP DST-11H Bi-Propellant thruster modified to utilize LO2 and LH2*

Space System - Refueling Depot

Technology Development

Propellant Generation System with Electrolysis

- Baselined with the ISS Oxygen Generation System (OGS)
- Depot design modified to produce propellants
- Assume large-scale improvement over time

http://www.esa.int/var/esa/storage/images/esa_multimedia/images/2010/01/mockup_of_the_oxygen_generation_system_rack

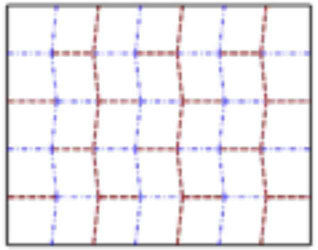
Storage Tanks

- Cryogenic cooling tanks based on small-scale demonstrated NASA composite tanks (must scale up)

http://www.compositesworld.com/articles/nasaboeing-composite-launch-vehicle-fuel-tank-scores-firsts

Solar Array and Power System

- Baselined with the Miura Fold
- Fold ratio = 9.26
- Scale to achieve side length of 18.5 m



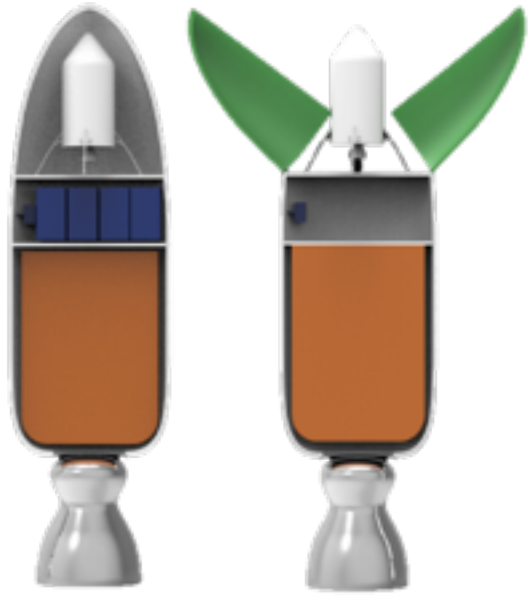
https://upload.wikimedia.org/wikipedia/commons/thumb/1/13/Miura-Ori_CP.svg/1200px-Miura-Ori_CP.svg.png

Space System - Refueling Depot

Schedule

Module	Purpose and Description	Launch Departure and Arrival
1	Small Standalone Module	2022
2	Propellant Tank Module (1)	2024
3	Solar Panel Module	2026
4	Electrolysis and Water Tank Module	2028
5	Propellant Tank Module (2)	2032

Lunar Transfer Vehicle Design



Lunar Transfer Vehicle

	LTV - Compact	LTV - 5T Plus	LTV - 20T Plus
Payload	*1 Astrobotic Lander + P-POD deployer with 6U CubeSats*	*5 Astrobotic Landers + Ground Deployment Mechanism*	*Depot Carrier with Full 20T Depot.*
Objective	*Transfer from LTI to LLO + Lander and CubeSats Deployment into LLO*	*Transfer from LTI to LLO + 5 Landers Deployment into LLO*	*Insertion into Halo L1 orbit and full 20T Full Depot Deployment.*
$M_{payload}$	$M_{TOTAL\ PAYLOAD}$ - M_{Astrob_LL} - $M_{P\text{-}POD\ +\ CubeSats}$	*11*	*23*
$M_{TOT\ LTV}$	*3*	*16*	*26*
Launch Oportunity	*Shared Falcon Heavy Expandable (4T share)*	*Falcon Heavy Expandable (16T Full Payload capacity)*	*SLS B1b*

SEP Tug Design Notes

Element Concept	Element Name	Dry Mass, kg	Maximum Wet Mass, kg	Dimensions
	300kW SEP Tug	6,000	36,000	5m dia., 8m overall length (OAL), Stowed
	600kW SEP Tug	8,000	76,000	5m dia., 10m overall length (OAL), Stowed

	Concentric Channel HET (3 channels)
Input Power	200 kW
Specific Impulse	1300 – 5000 s
Thrust	5 – 14 N (25 – 70 mN/kW)
Mass Flow Rate	100 – 1100 mg/s (Xe)
Efficiency	45% – 64%
Specific Mass	0.5 kg/kW (thruster) 1.4 kg/kW (thruster, PPU)
Major Thruster Dimensions	0.65-m diameter 0.10-m length

Isp	m1	m_prop1	dM_prop	# trips/tank	m_tank (mt)	m_refuel (mt)	Price Refuel	mdot (kg/s)	t (days)	t (mo)
1000	88.39218	-24.6078	89.60782	0.7253832	5.81152	70.81152002	$ 150,120,250.00	0.0036735	282.33	9.41
2000	125.4345	12.43448	52.56552	1.236552				0.0018367	331.24	11.04
3000	140.9563	27.95634	37.04366	1.7546864				0.0012245	350.14	11.67
4000	149.4233	36.42335	28.57665	2.2745843				0.0009184	360.15	12.00
5000	154.7458	41.74577	23.25423	2.7951899				0.0007347	366.34	12.21
6000	158.399	45.39896	19.60104	3.3161498				0.0006122	370.54	12.35

Space Systems

Technology Development

- **Lunar Lander (Astrobotics Griffin)**
  - Under Development for Google Xprize missions ~ 2020
- **Lunar Lander (Masten Space Systems XEUS expendable)**
  - Estimating completion by ~2025
- **Lunar Transfer Vehicle (in-house)**
  - Completed by first launch 2020
- **Astrobotics Lander Deployer (in house)**
  - Completed by 2022
- **L1 Transfer Vehicle**
  - Completed by 2030

Space System

Fueling Depot

	Propellant boil-off				
LIKELIHOOD					
		Missed docking		Pipeline misalignment	
			Inaccurate thermal control	Failure of solar panel deployment	
	CONSEQUENCES				

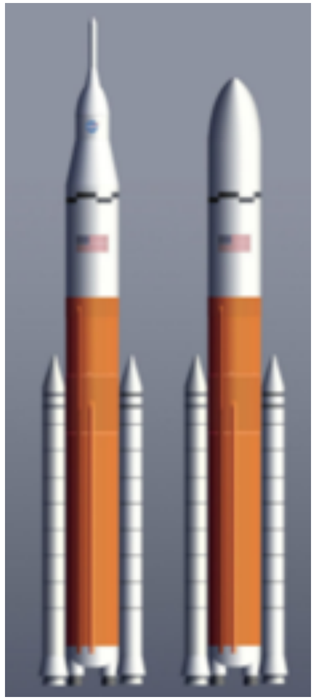
Risk Assessment

- The insignificant risks that will happen is the process of propellant boil-off
- The possibility of a missed docking of one module to the next when delivered
- The potential of an inaccurate thermal control event occurring on any one of the storage tanks
- The failure of the the deployment of the solar panels, especially in the third module
-

Mission Design - Orbital Operations

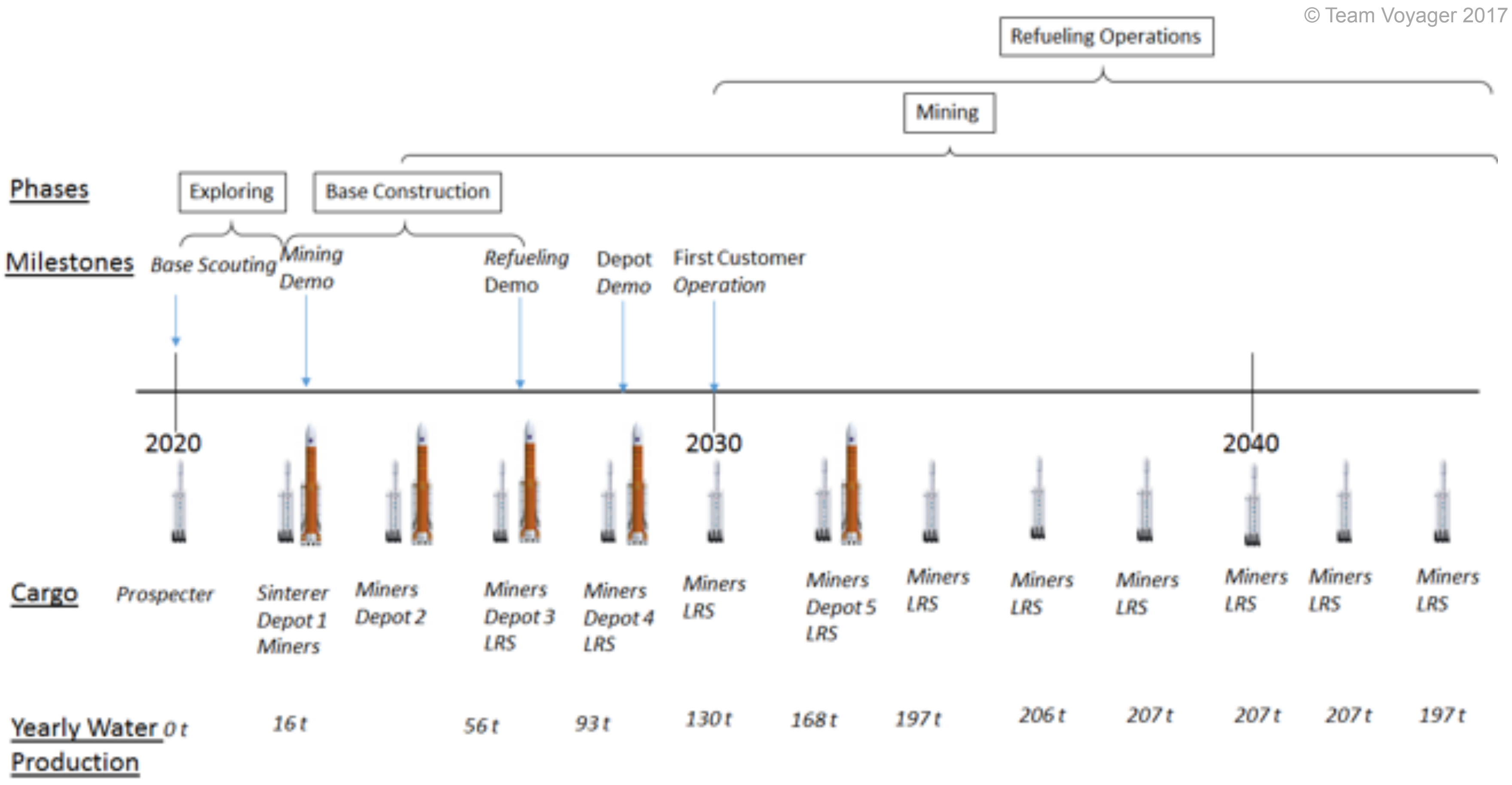
Requirements

- Cargo delivery to lunar surface will provide:
  - 0.3 mt payload capability by 2020
  - 1.5 mt payload capability by 2022
  - 5.0 mt payload capability by 2024
  - 10.0 mt payload capability by 2030
- At least 20 mt payload to EM L_1 halo orbit by 2030
- Constraint on cadence requirement, max:
  - 1 Falcon Heavy/yr from 2020 - 2028
  - 3 Falcon Heavy/yr from 2029 - 2050
  - 0.5 SLS/yr from 2022 - 2032



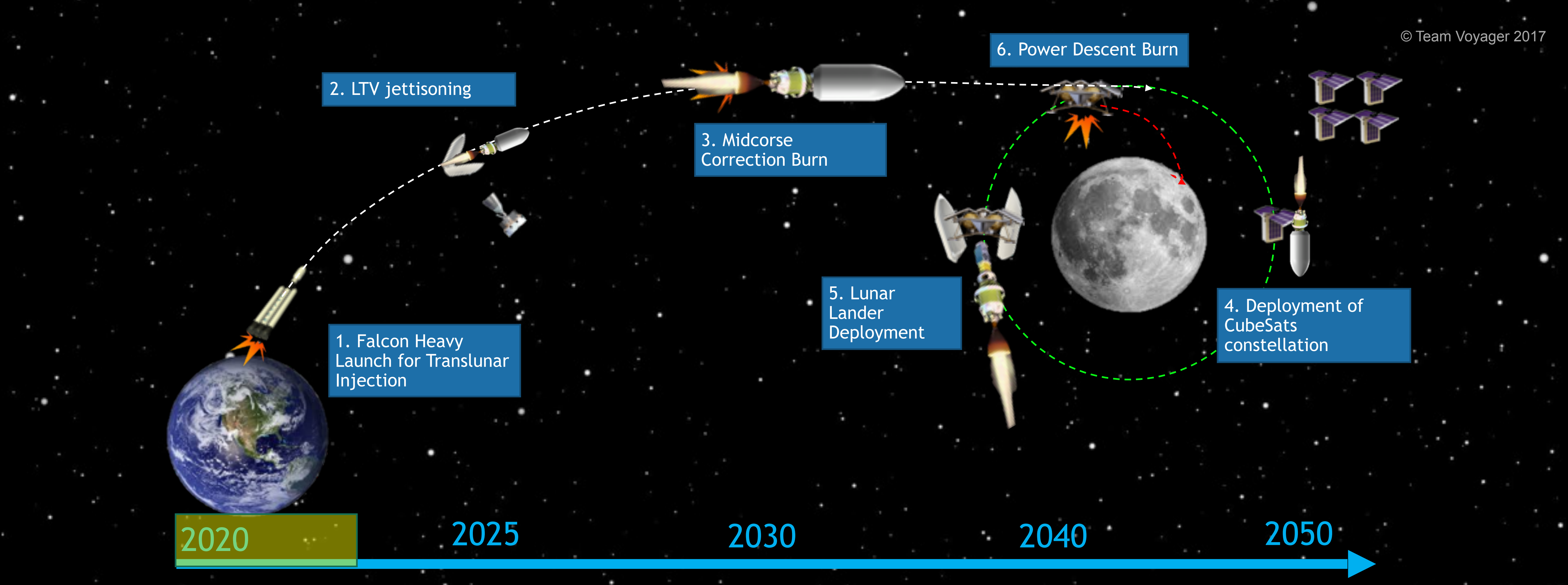
Mission Design

General Timeline



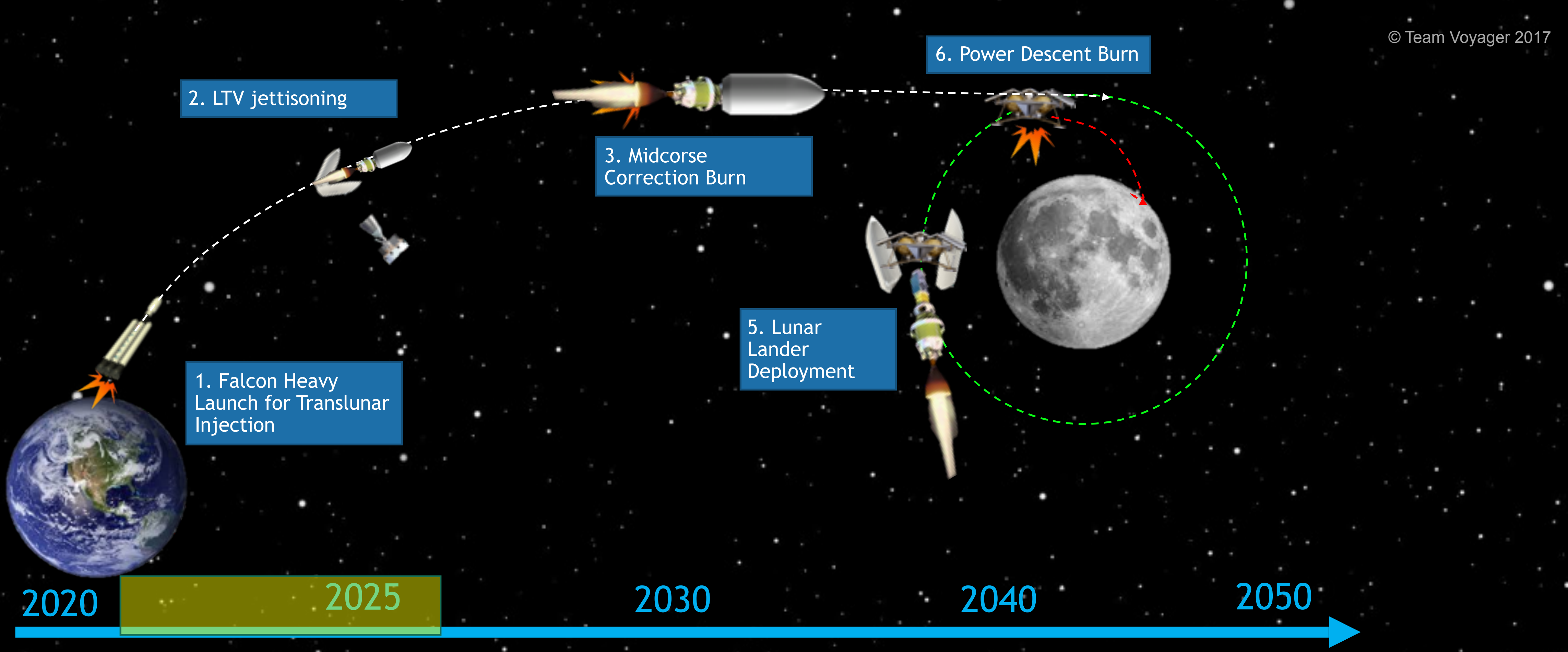
Mission Design

Prospector Delivery



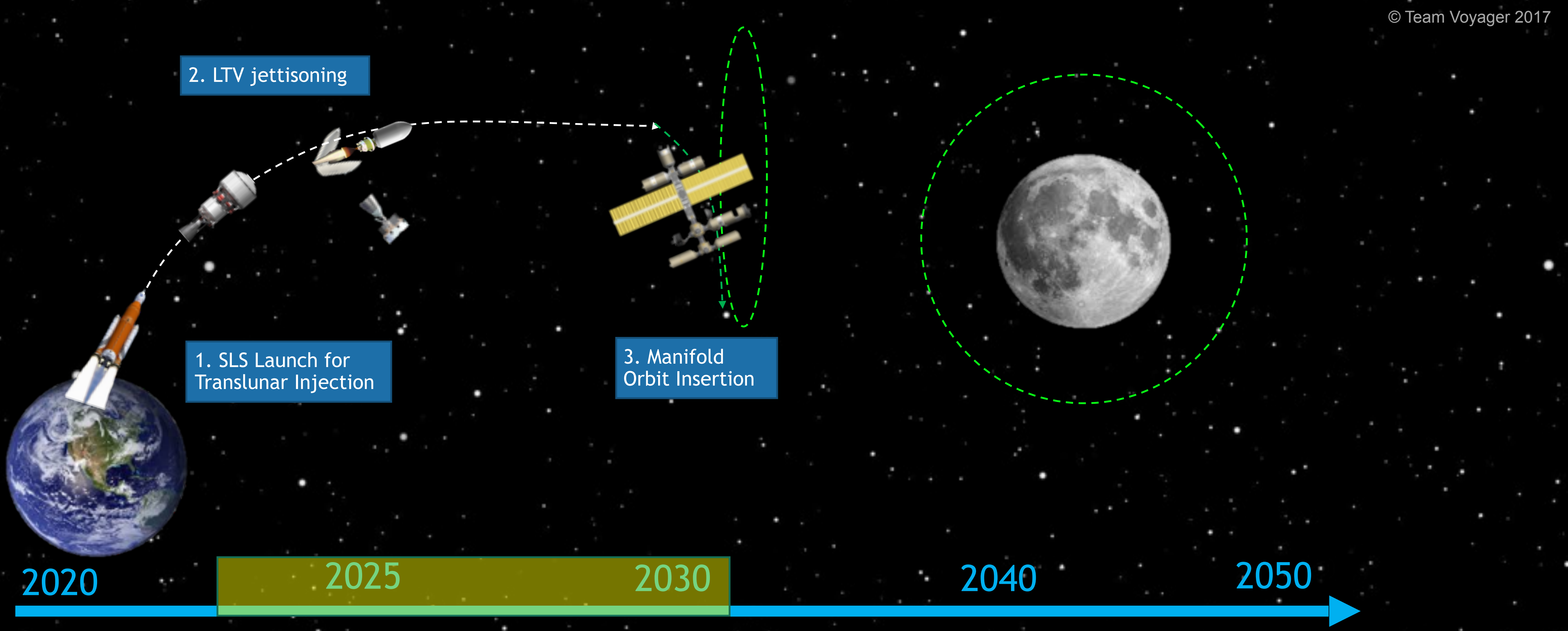
Mission Design

Construction Phase



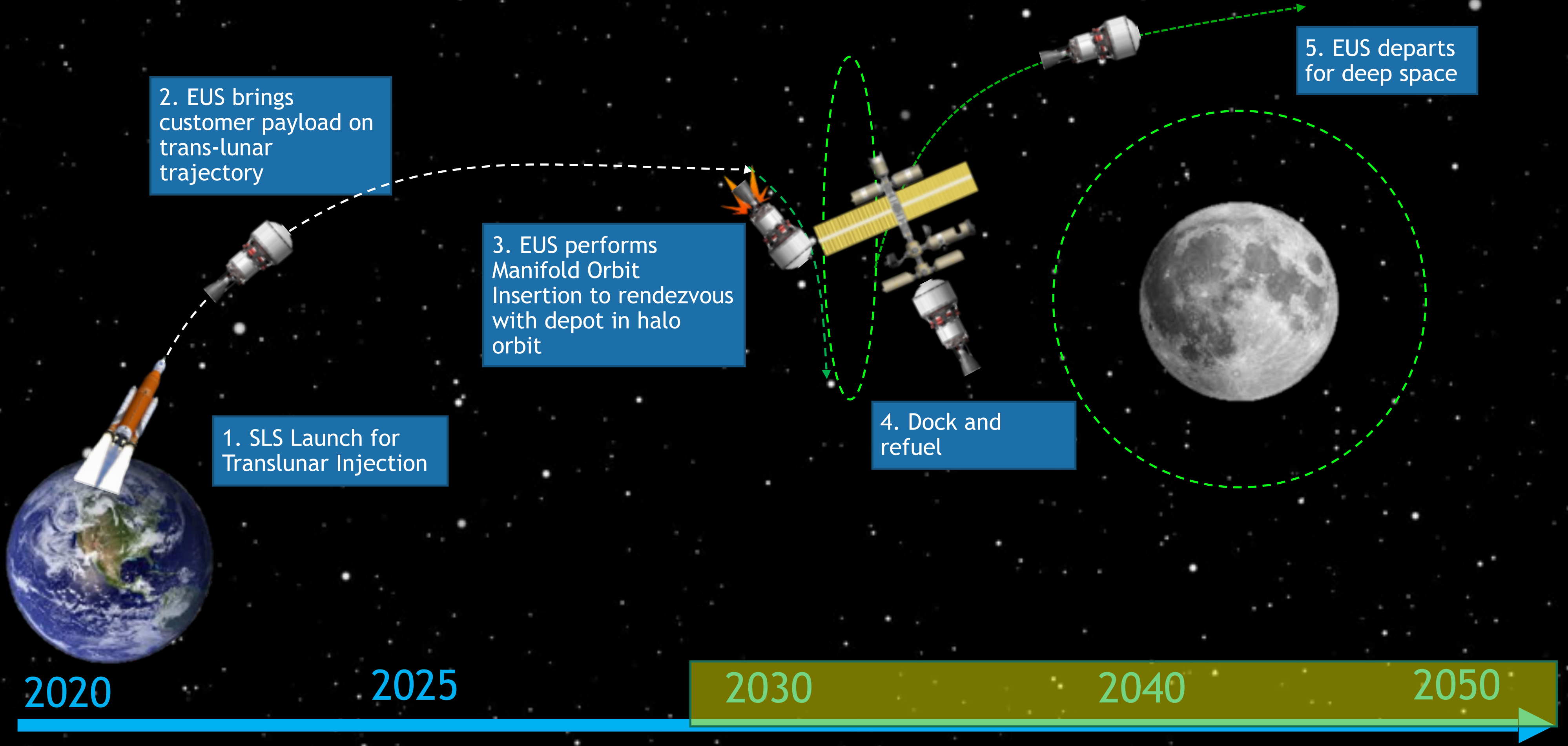
Mission Design

Depot Construction Phase



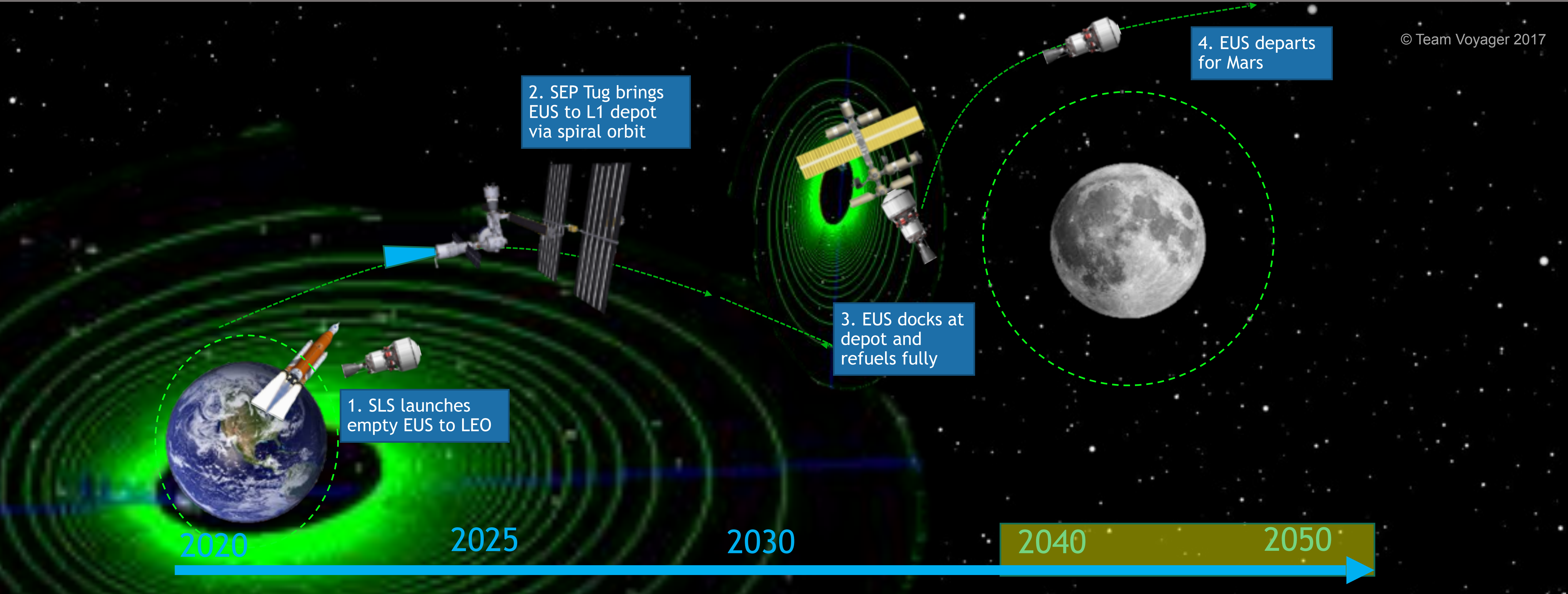
Mission Design

Operational Phase



Mission Design

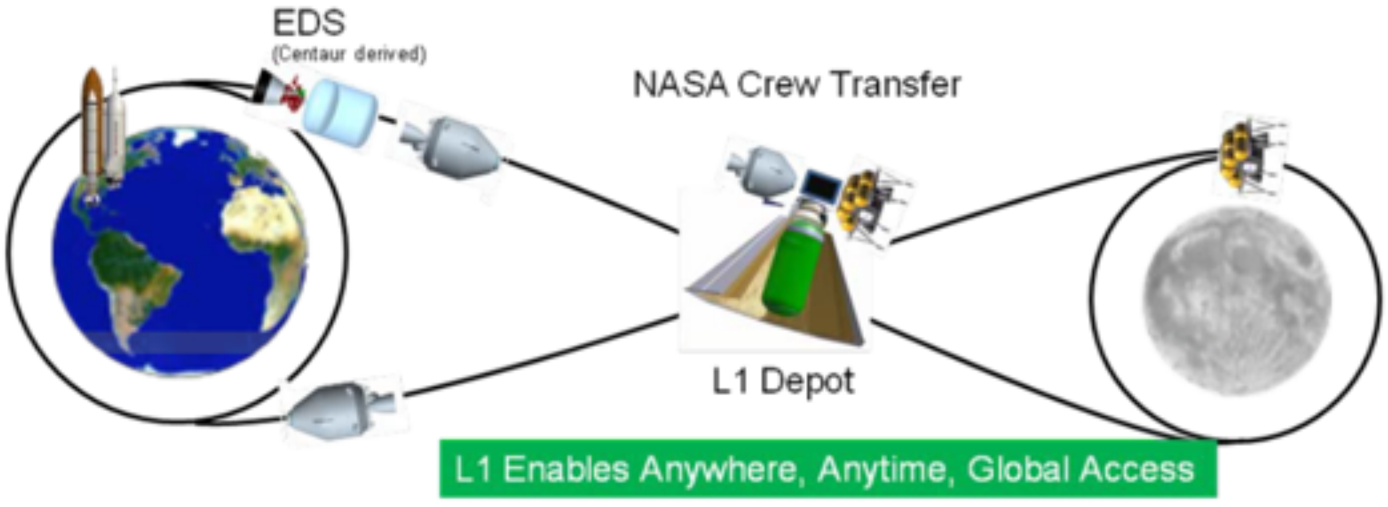
Tug - Assisted Operational Phase



Mission Design

Why a Depot?

- Establishing infrastructure as cislunar gas station
  - Rendezvous for pre-fueling of crewed Mars missions
- Enables ferry architecture
- System-level boil-off mitigation for long-term storage
- Enables ferry architecture (tug from LEO => L1)

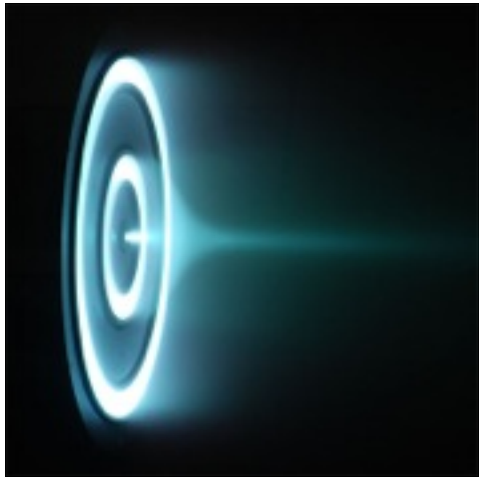


Source: Baine, M. (2010)

Mission Design

Solar Electric Propulsion (SEP) Tug

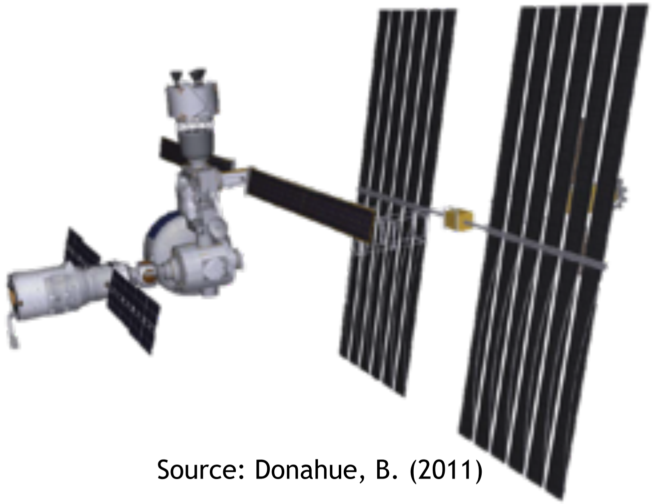
- enables **propellant cost savings** via high fuel efficiency but low thrust
- utilized for **non-time critical missions** (cargo delivery, robotic missions)
- 3x 200 kW magnetically shielded concentric channel Hall thrusters
- delivered via 2x Falcon Heavy to LEO and assembled (76 t wet mass)
- **1 yr transit** from LEO <=> L1, **2.3 trips/tank** of propellant



X2 HET (Umichigan)

Parameter	Value
HET Power	*200 kW*
Isp	*5000 s*
Thrust	*48 N*
Total Efficiency	*60%*
Lifetime	*> 50,000 hrs*

Hall thruster parameters



Source: Donahue, B. (2011)

Mission Design

SEP Tug Architecture Cost Analysis

- SEP tug cost ~$2b

(including materials cost, development, testing and evaluation)

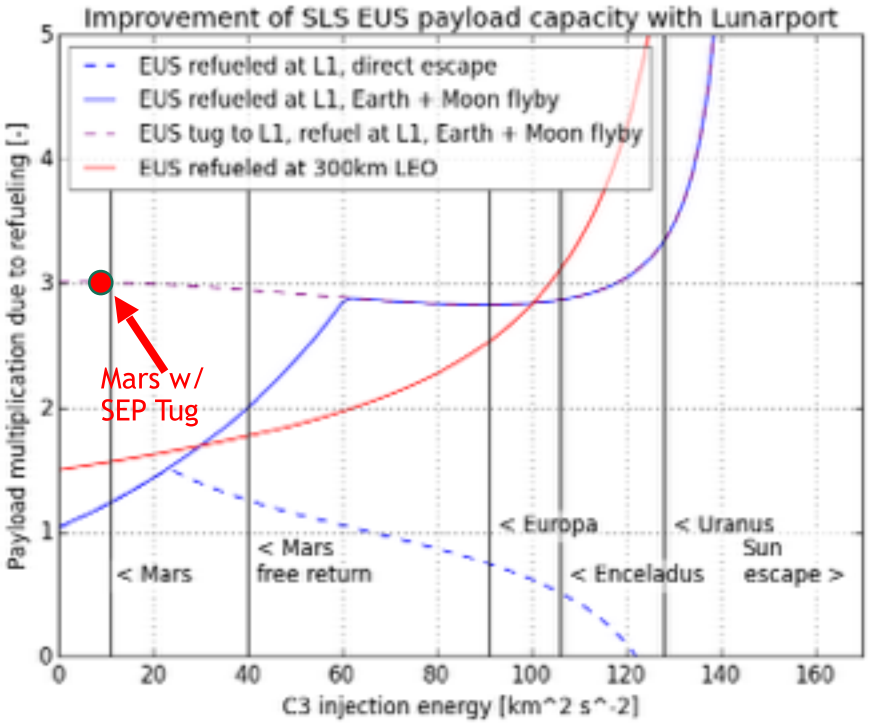
- SLS Launch ~ $500m

(76 kg to LEO, assuming cost decrease by 2040 and selling ~58% of the remaining 130 t payload mass)

- Maintenance ~$1b

(Hall thruster replacement, propellant resupply)

- Operation costs ~$1b for 2 years

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$2b - $1b - ($1.5b/5) = $700m saved per year
```

Business Plan and Political Considerations

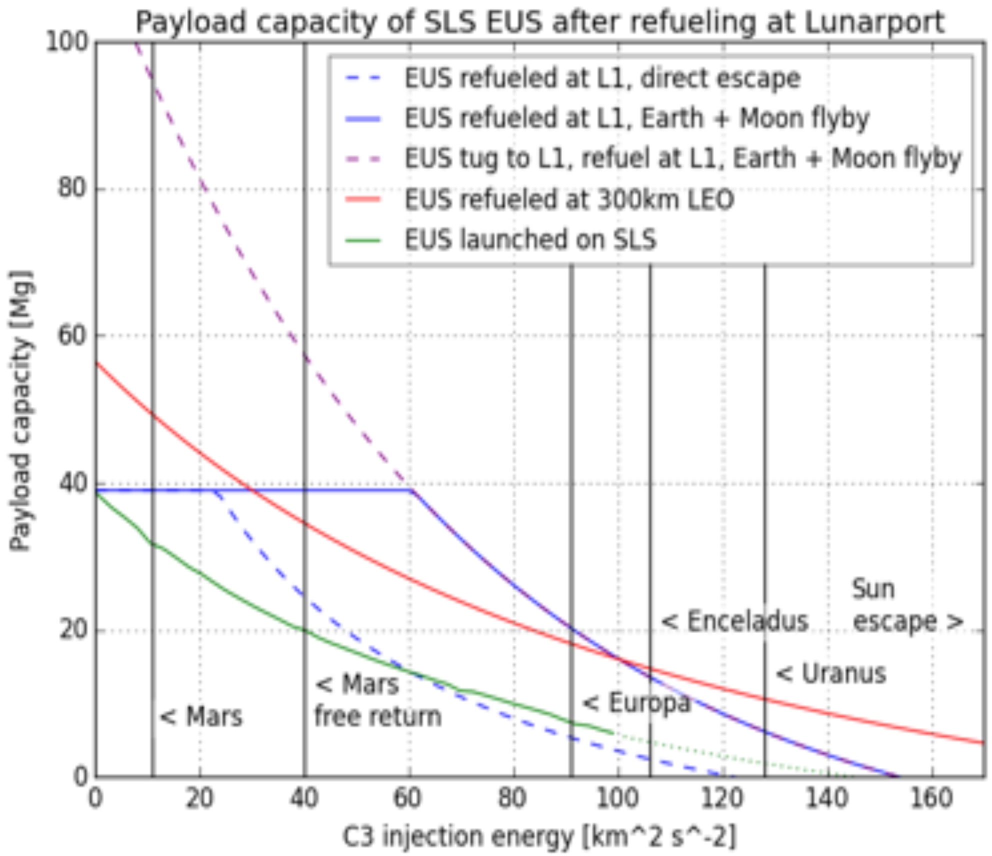
Budget

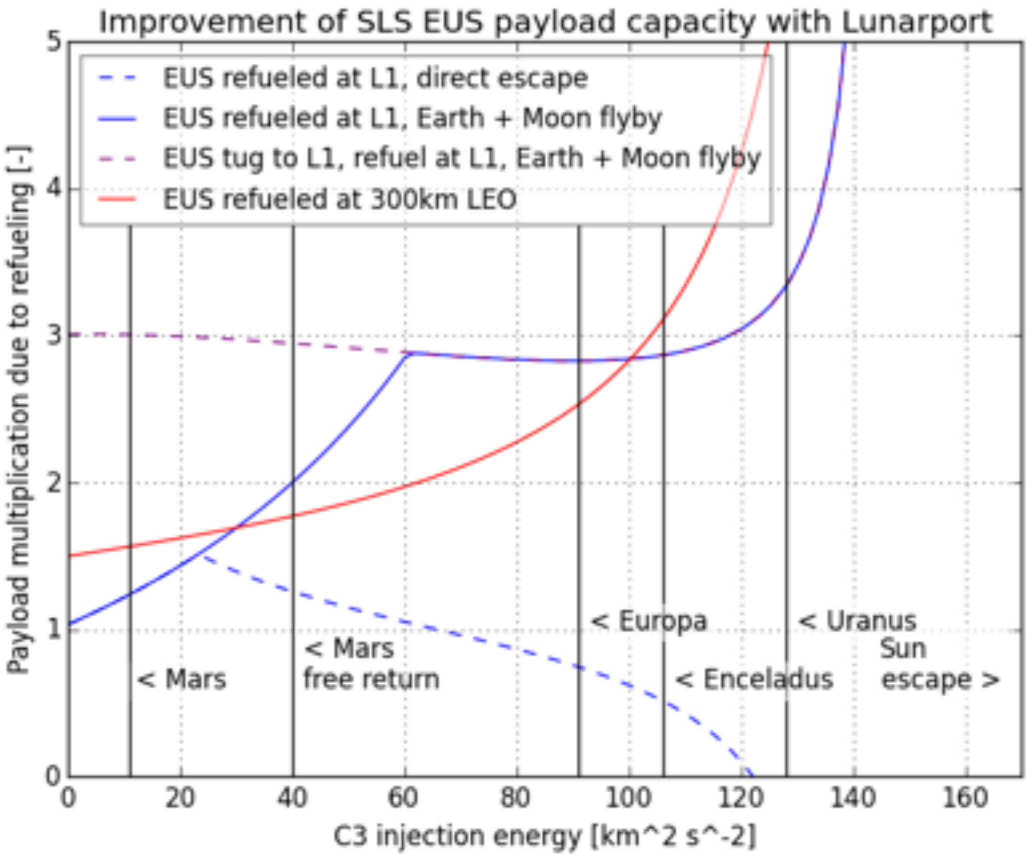
Development costs. Based on initial 2022 mission, with analog technologies listed. /

System	Source	Development and Construction Cost ($M)
Project Management, Systems Engineering, Safety and Mission Assurance	9% of all non-launch costs	$102
Mission Operations and Ground Control	10% of all non-launch costs	$114
Payload and Spacecraft	Sintering Rover— based on mass Prospector— Lunar Resource Prospector with RTG and LIDAR Miner Rover—Structure: Apollo Lunar Roving Vehicle, Drill from Honeybee Robotics Electrolysis unit—ISS Small Lander—Astrobotic lander Big Lander— Apollo lander Depot modules—NASA protype request Communications—Cubesat estimates LRS—Cargo Dragon, Cygnus, and Centaur	$2405
Systems I&T	Double Curiosity for non-recurring; same as Curiosity for recurring	$200
Launch/Vehicle Services	SLS plus Falcon Heavy	$1270
Science/Technology	5% of total cost	$57
Reserves	Fixed cost, 20% of total	$481
Total		$4629

Business Plan and Political Considerations

Payload Capacity Increase





Business Plan and Political Considerations

Future Business Plan

No-cost NASA refueling station

No-cost international collaboration refueling station

No-cost commercial and NASA refueling station for solar system exploration:

Sale of Ice Rush to net $0 cost

Sale of Ice Rush in exchange for future NASA utilization

Business Plan and Political Considerations

Political Considerations and Planetary Protection

Outer Space Treaty vague on resource utilization

U.S. and Luxembourg have authorized prospecting missions

FAA AST mission authorization currently ad hoc for non-traditional commercial missions

Category II Planetary Protection

Will submit Planetary Protection Plan prior to end of Phase B

Business Plan and Political Considerations

Risk

Technical
Production capacity is low because of unknown ice content
Send more more prospectors, add drills, refuel smaller missions, spend more resources on mapping

Cost
Landers, rover cost
Mass production will cut costs. Same mitigation as low production capacity

Schedule
SLS/Falcon/New Glenn launch cadence uncertain
Possible to mitigate by using international partners, launching smaller missions, utilizing other customer lines

Political
Budget is always uncertain, as is direction under Executive Branch transitions
Current Presidential/Congressional support is high

Adopt-a-Rover

K-12 EPO program to name and adopt a miner

Prospector Robot Program

Grades 3-12 learn to program senso robots

Mars Trail Citizen Science Program

Identify possible future mining areas, earn virtual structures
to incorporate in your own architecture to Mars (input into a Sim City-like program)

Ice Rush VR

Team Voyager 2017

Participants

Bryan Sinkovec	California Institute of Technology	Space Engineering
Daniel Pastor	California Institute of Technology	Space Engineering
Donal O'Sullivan	California Institute of Technology	Astrophysics
Gary Li	University of California, Los Angeles	Aerospace Engineering
Jack Henry de Frahan	ISAE-SUPAERO	Applied Math, Aerospace Engineering
Joseph Sparta	Georgia Institute of Technology	Aerospace Engineering
Matt Vernacchia	Massachusetts Institute of Technology	Aeronautics and Astronautics Engineering
Mercedes Herreras Martinez	Arizona State University	Aerospace Engineering
Nathan Sharifrazi	University of California, Irvine	Aerospace and Mechanical Engineering
Nick Jamieson	University of Cambridge	Aerospace Engineering
Sophia Casanova	University of New South Wales	Mining Engineering
Sumudu Herath	University of Cambridge	Civil Engineering
Sung Wha Kang	Rhode Island School of Design	Industrial Design
Sydney Katz	Washington University in St. Louis	Electrical and Systems Engineering
Therese Jones	Pardee RAND	Policy Analysis
Vinicius Guimaraes Goecks	Texas A&M University	Aerospace Engineering

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