D.I.A.N.A.

Dedicated Infrastructure and Architecture for Near-Earth Astronautics

TEAM RED

MISSION STATEMENT

“ The proposed concept of the platform shall enable ***scientific operations*** *and local sorties for* ***human and robotic exploration****. The conducted scientific operations shall allow for the enhancement of our understanding of the* ***evolution of the universe*** *and in particular the Solar System.* ***In-Situ Resource Utilization*** *(ISRU) shall be integrated in the concept as much as possible.”*

WHY D.I.A.N.A?

- Long-term solution for a long-term goal
- Ambitious timeline
- Innovative design enabling sophisticated capabilities for human and robotic exploration

OUTLINE

MISSION PROFILE

LUNAR BASE

PROJECT ENVELOPE

OUTLINE

MISSION PROFILE → LUNAR BASE → PROJECT ENVELOPE

SPEAKER:
ELENA LÓPEZ-CONTRERAS GONZÁLEZ

IMPORTANCE OF THE MOON

- Further in-situ exploration needed to understand the Solar System
- Technology demonstrations for future missions to Mars and beyond
- Technology development to sustain life beyond Earth

MISSION OBJECTIVES

OBJ-00: Settle a permanently inhabited platform on the lunar surface.

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OBJ-02: The platform shall enable exploration of the local lunar environment.

OBJ-03: The mission shall demonstrate self-sustainable human presence on other bodies.

MISSION OBJECTIVES

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OBJ-05: The mission shall serve to help verify low-TRL technologies.

OBJ-06: The mission shall engage in international cooperation.

OBJ-07: The mission shall provide the opportunity for public-private + partnerships.

MISSION REQUIREMENTS

MR-00: The mission operations shall start by 2030.

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MR-03: The platform shall support a radio astronomy facility.

MR-04: The mission shall enable direct human exploration of the lunar environment.

MR-05: Autonomous robotics shall supplement lunar surface exploration.

MISSION REQUIREMENTS

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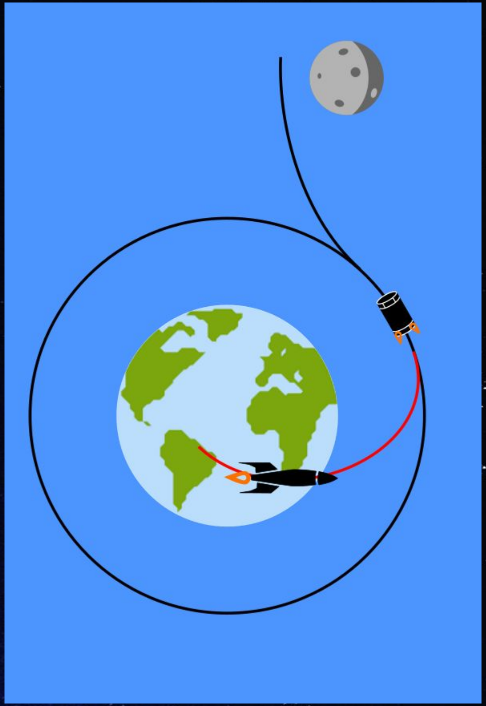
MR-09: The platform shall integrate measures that promote astronaut psychology.

MR-10: The platform shall continually increase in financial self-sustainability.

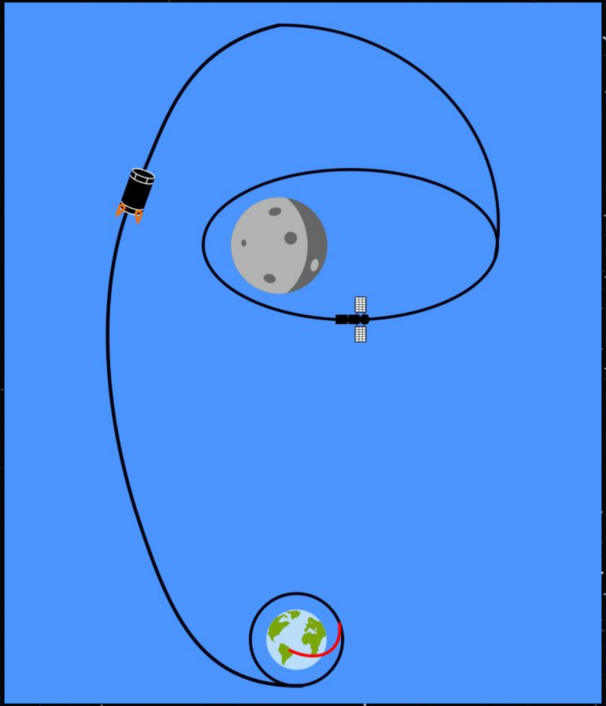
MISSION ANALYSIS & PROPULSION

MA - CARGO TRANSPORT

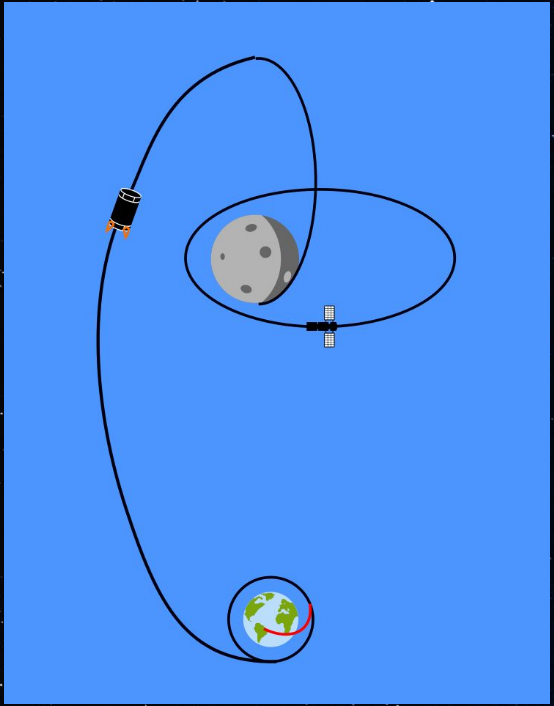
PHASE 1



PHASE 2a



PHASE 2b



MA - CARGO TRANSPORT

PHASE 1

Earth to LEO

Falcon 9 Heavy

m_{PL} = 63,800 kg

PHASE 2a

LEO to Lunar Gateway

Bi-Elliptic Transfer - 109 days / m_{PL} = 16,851 kg

PHASE 2b

LEO to Moon Base (Descent to surface)

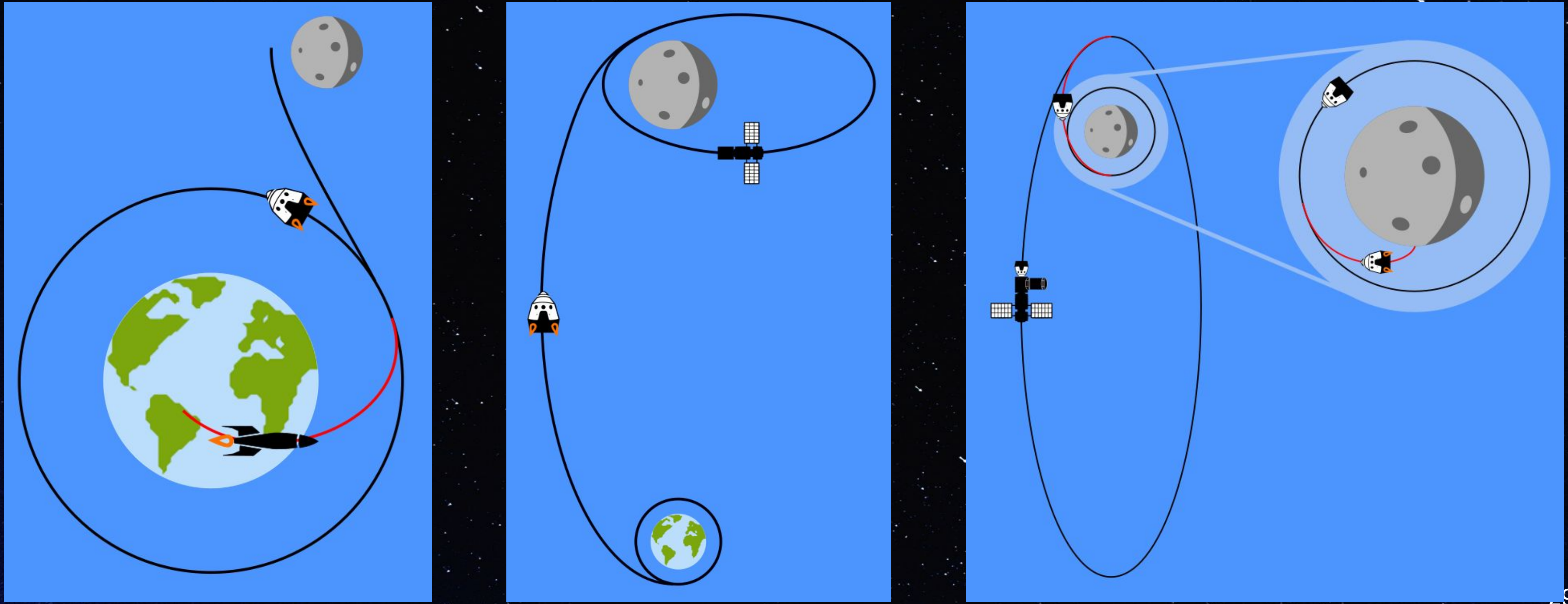
Bi-Elliptic Transfer - 109 days / m_{PL} = 6,994 kg

MA - CREW TRANSPORT

PHASE 1

PHASE 2

PHASE 3



MA - CREW TRANSPORT

PHASE 1

Earth to LEO

Falcon Heavy

m_{PL} = 63,800 kg

PHASE 2

LEO to Lunar Gateway

Direct Transfer in 5 days with modified Crew Dragon

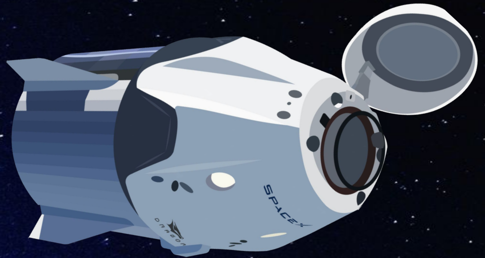
m_{PL} = 14,954 kg

PHASE 3

Lunar Gateway to Base

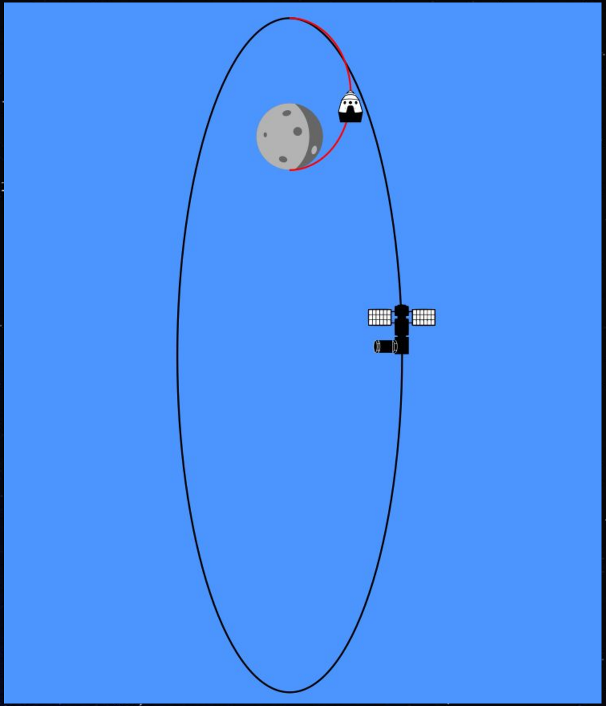
Transfer to lower LLO
Descent with Lunar Lander

m_{PL} ≃ 9,000 kg

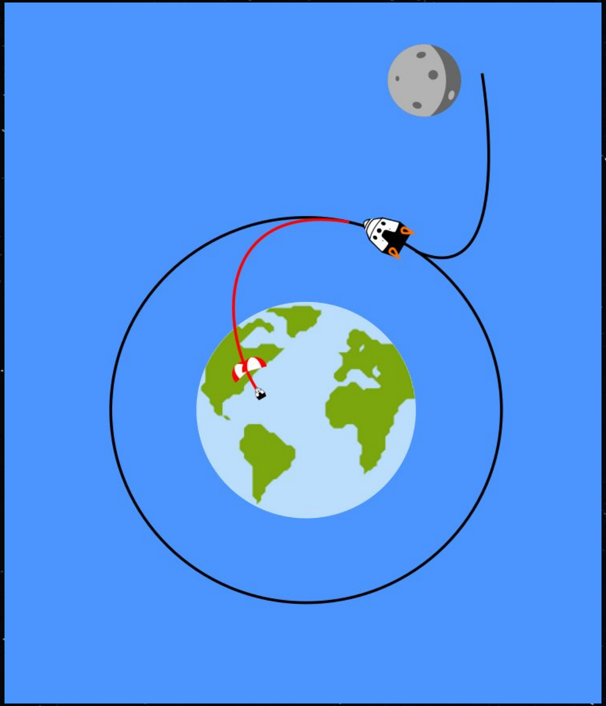


MA - CREW TRANSPORT

PHASE 4



PHASE 5



MA - CREW TRANSPORT

PHASE 4

Base to Lunar Gateway

Ascent with Lunar Lander

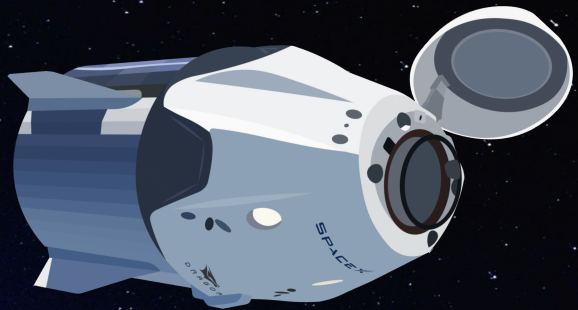
$m_{PL} \approx 3{,}000$ kg

PHASE 5

Lunar Gateway to Earth

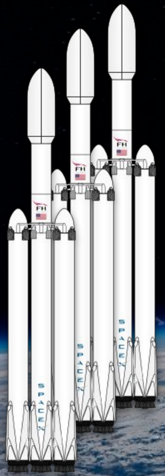
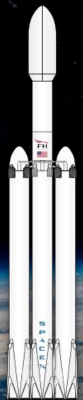
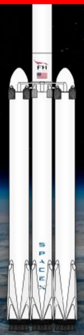
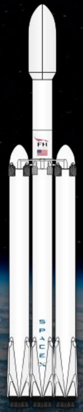
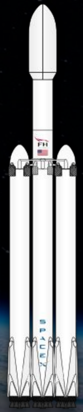
Direct Transfer back to Earth (with refuelled capsule)

$m_{PL-LEO} = 15{,}259$ kg



MA - LAUNCHES REQUIRED

Station	Supplies	Crew - 4 astronauts	Landers	Wine cellar
34	1/year	144 launches + 3-24 launches/year	2 (1 redundant)	1

MA - CREW TRANSPORT VEHICLES

CREW DRAGON

Transport to the Lunar Gateway and back to Earth

Chemical Propulsion with LH_2/LOX Thruster

LUNAR LANDER

Transport to Lunar Surface and start

Chemical Propulsion with CH_4/LOX Thruster (Refuel LOX on Lunar Surface)

MA - TRANSPORT VEHICLE THRUSTERS

CREW DRAGON/ CARGO VEHICLE

RL-10

LH_2/LOX

Thrust: 110 kN

Mass: 301 kg

I_{sp}: 465 s

LUNAR LANDER

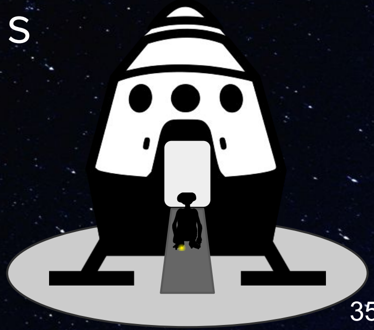
Raptor (modified)

CH_4/LOX

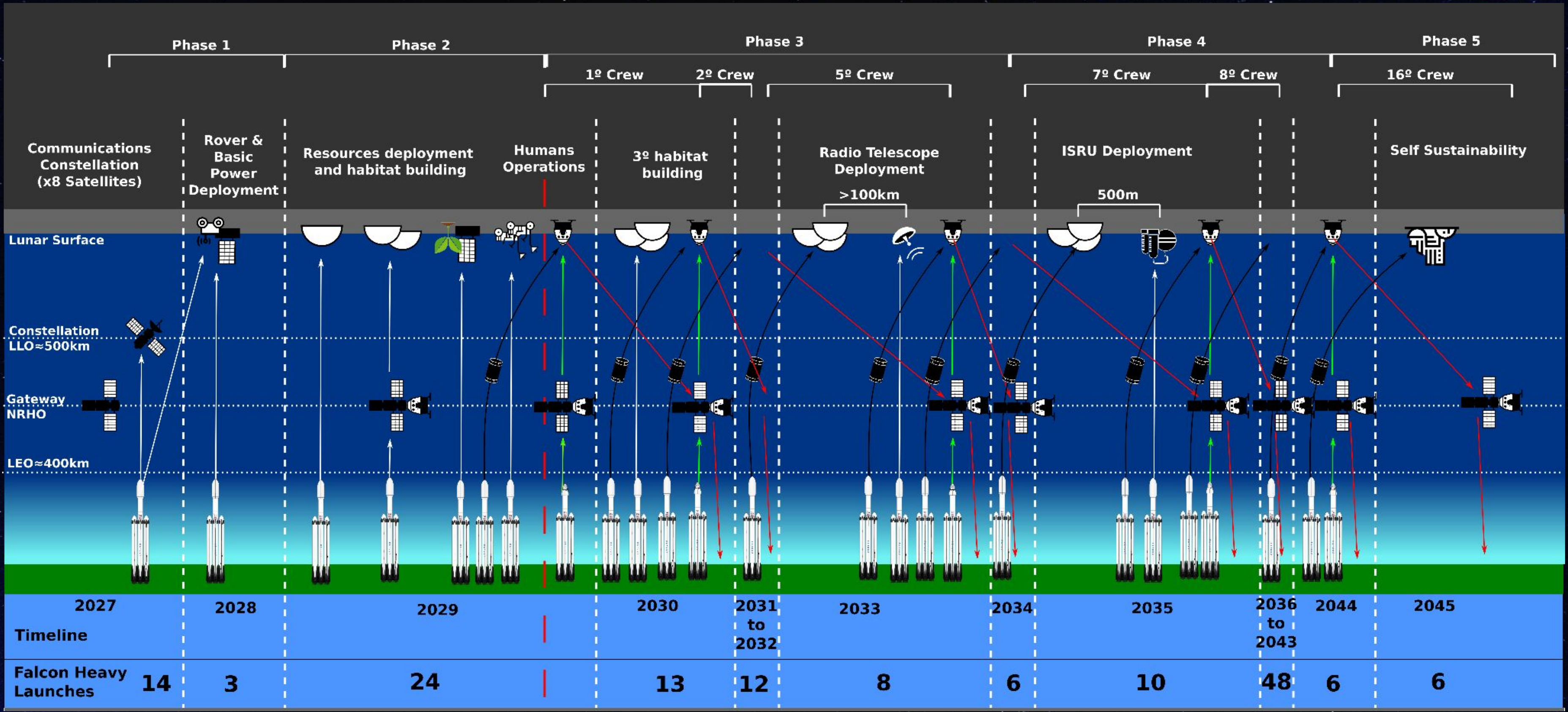
Thrust: 90.5 kN

Mass: 300 kg

I_{sp}: 378 s



MA - D.I.A.N.A. BAT DIAGRAM



MA - DELTA-V BUDGET

Cargo to Gateway / 16,851 kg		
Phase	Delta V (m/s) Margins	Route covered
1	9.4	Earth-LEO
2	3909	LEO-Gateway
Total	3918.4	(m/s)

Cargo to MoonBase / 6,994 kg		
Phase	Delta V (m/s) Margins	Route covered
1	9.4	Earth-LEO
2	3909	LEO-LLO
3	1995	LLO-MoonBase
Total	5913.4	(m/s)

Crew		
Phase	Delta V (m/s) Margins	Route covered
1	9.4	Earth-LEO
2	4147	LEO-Gateway
3	537	Gateway-LLO
4	1900	Gateway-Surface
5	3003	Surface-Gateway
6	4147	Gateway-Earth
Total	13743.4	(m/s)

LOCATION

LUNAR SOUTH POLE

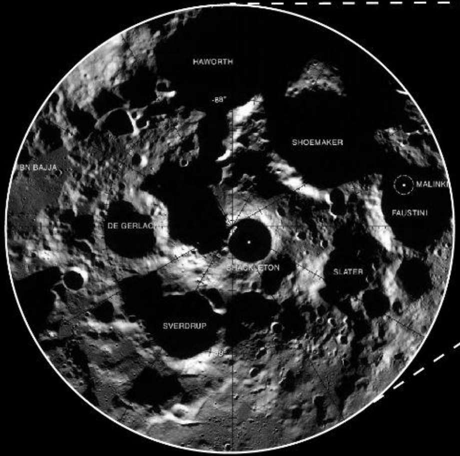
The south polar region is a **heavily cratered terrain** with dramatic topography

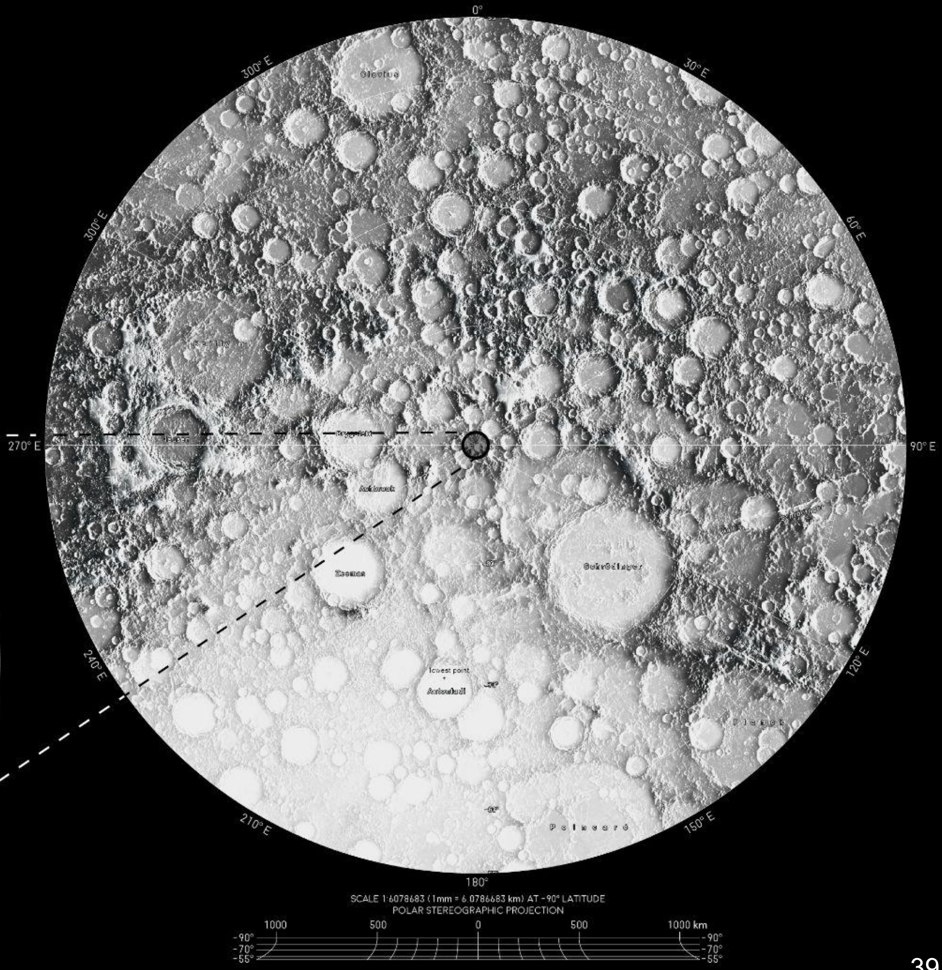
Even though the Moon tempereture goes from -173 to +127 C, the south pole temperature averages at approximately - 13 °C

Its craters have been **untouched by sunlight for billions of years** - offering an undisturbed record of the solar system's origins

Its permanently shadowed craters are estimated to hold nearly **100 million tons of water**

Its regolith has traces of hydrogen, ammonia, methane, sodium, mercury, and silver - making it an **untapped source of essential resources**

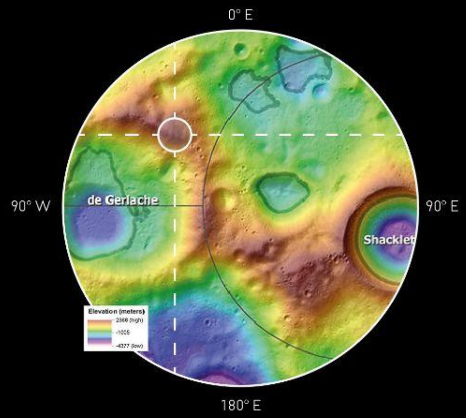




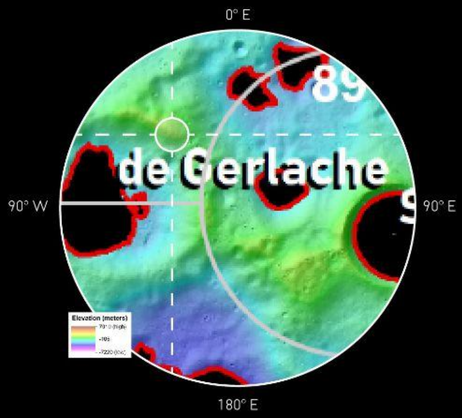
LUNAR SOUTH POLE

Location Candidates:
De Gerlache crater ridge

+ already investigated as a lunar station site by ESA



TOPOGRAPHY AND PERMANENTLY SHADED REGIONS



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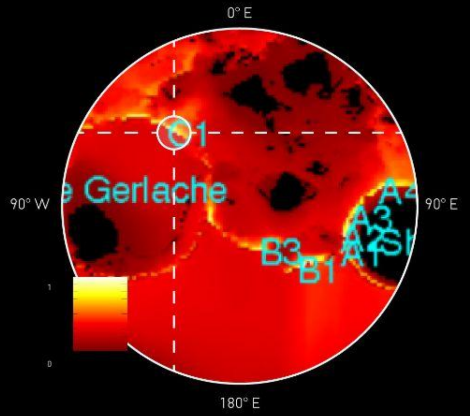
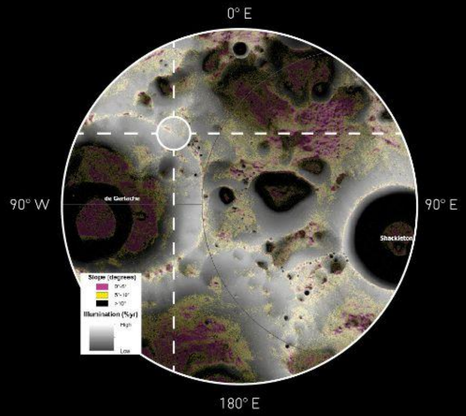
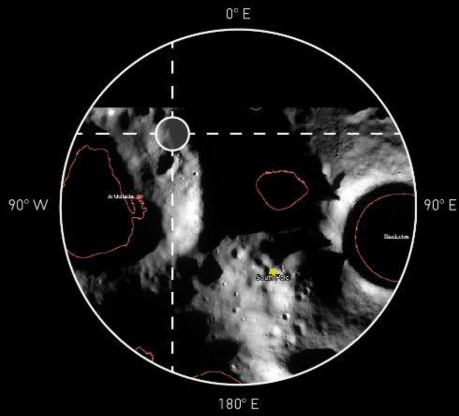


LUNAR SOUTH POLE AVERAGE SOLAR ILLUMINATION

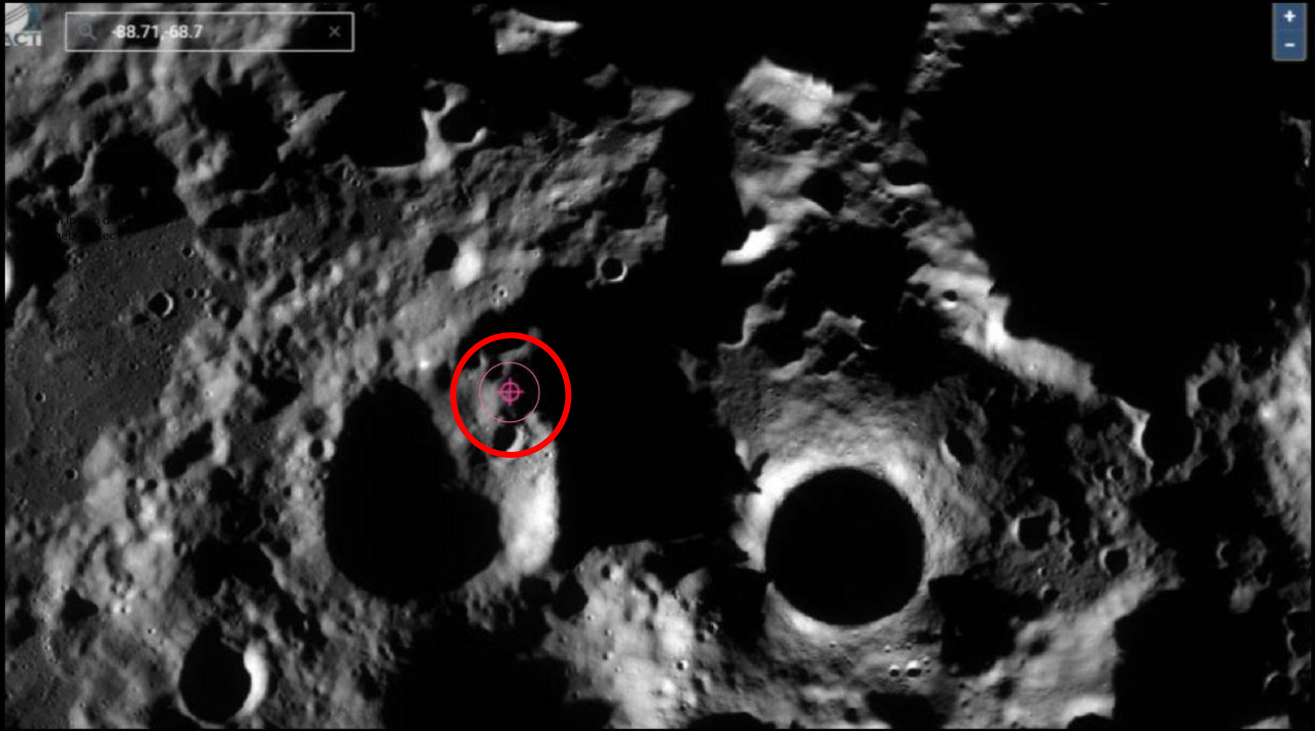


ANNUAL ILLUMINATION AND TOPOGRAPHIC SLOPE



PERMANENTRLY SHADED REGIONS

LAT 88.71 S, LON 68.77 W



Min: 64% light per lunar day

Max: 98% light per lunar day

~6 days darkness followed by ~7 days of intermittent light and darkness periods

OUTLINE

MISSION PROFILE → **LUNAR BASE** → PROJECT ENVELOPE

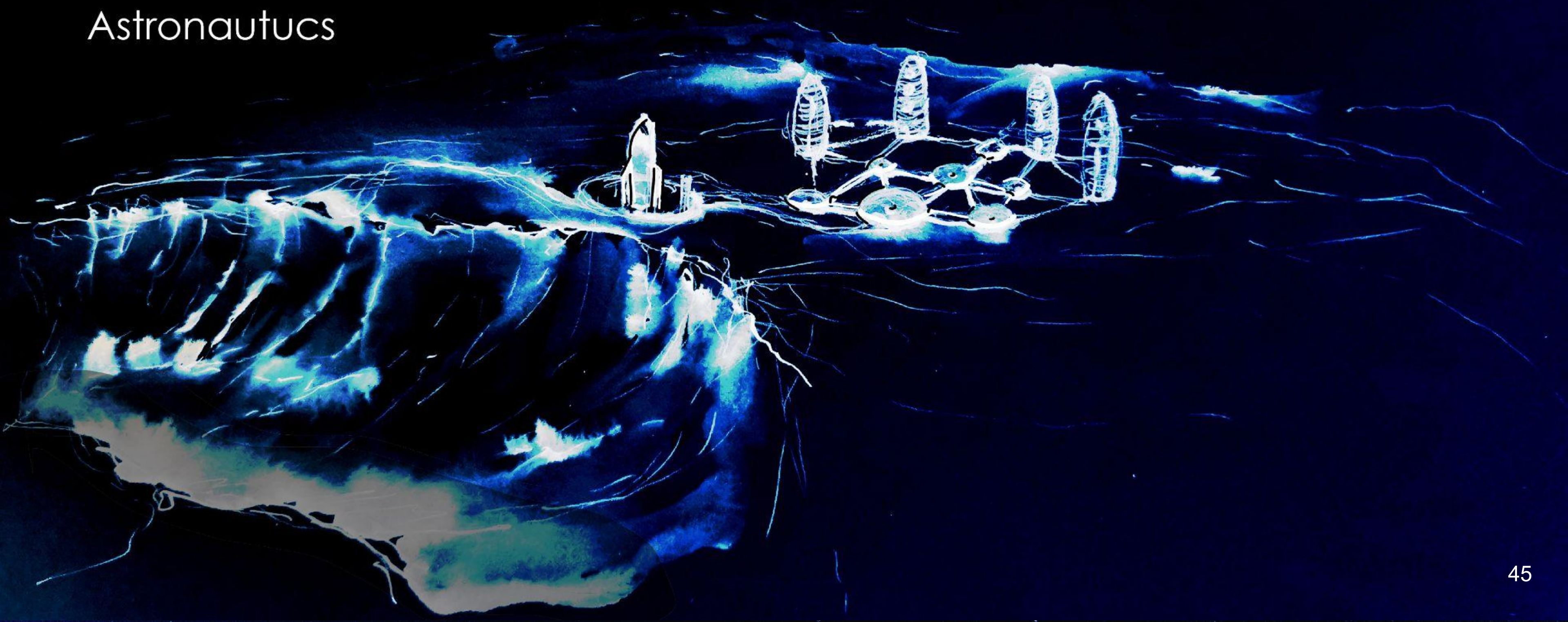
SPEAKERS:
ALMA KUGIC
LEON TEICHRÖB

OVERVIEW OF SUBSYSTEMS

ARCHITECTURE AND INNER DESIGN

D.I.A.N.A

Dedicated Infrastructure and Architecture for Near-Earth Astronautucs



TIMELINE

2027

INFRASTRUCTURE DEPLOYMENT

Initial habitat components have been launched to the Moon and are robotically assembled before the arrival of astronauts

2029

CREW ARRIVAL 1ST PHASE

4 astronauts arriving to the Moon and connecting the habitat with life support systems and power supply

2030

EXPANSION 1 2ND PHASE

Expanding the settlement for future astronauts by adding more inflatable modules; sleeping quarters, science labs and additional greenhouse

2045

EXPANSION 2 3RD PHASE

Expanding the Lunar base by constructing a sustainable settlement by using enhanced in-situ 3D printing methods using regolith as material

FIRST PROGRAM LAUNCH TO THE MOON:

- Telerobotics & autonomous systems for the initial infrastructure of the lunar base
- Inflatable modules for science and living shielded using in-situ regolith
- Prepare the lunar base for arrival of astronauts

ASTRONAUTS LAUNCH TO THE MOON WITH:

- Relevant scientific payload
- EVA robotics
- Higher capacity construction robotics for a more sustainable infrastructure

HABITAT CONCEPT

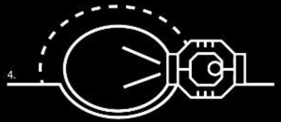
1 ST PHASE

preparing the site for the arrival of the first 4 people on the Moon

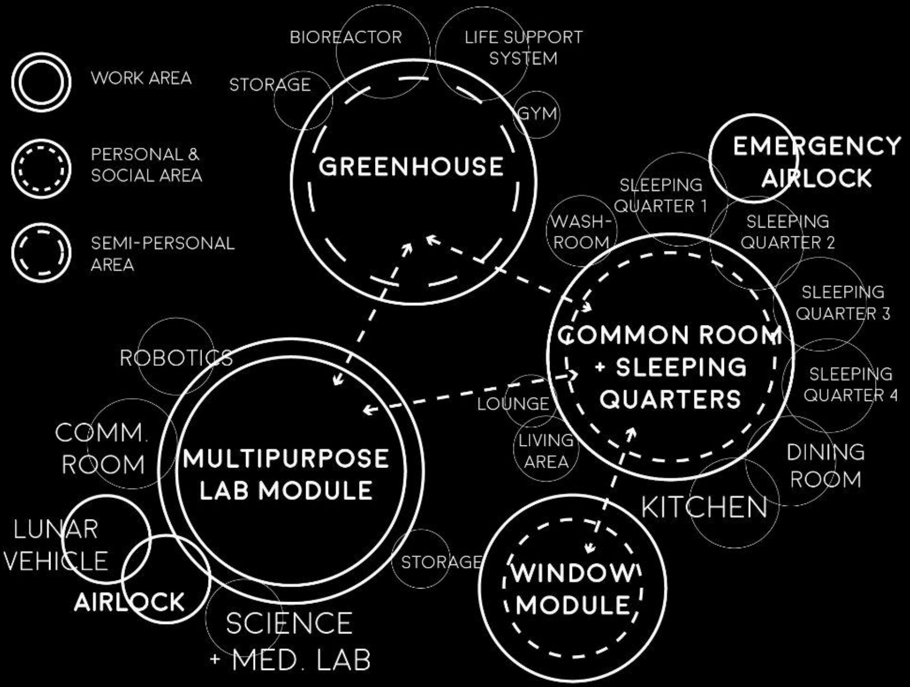
Initial infrastructure components of the settlement have landed on the Moon

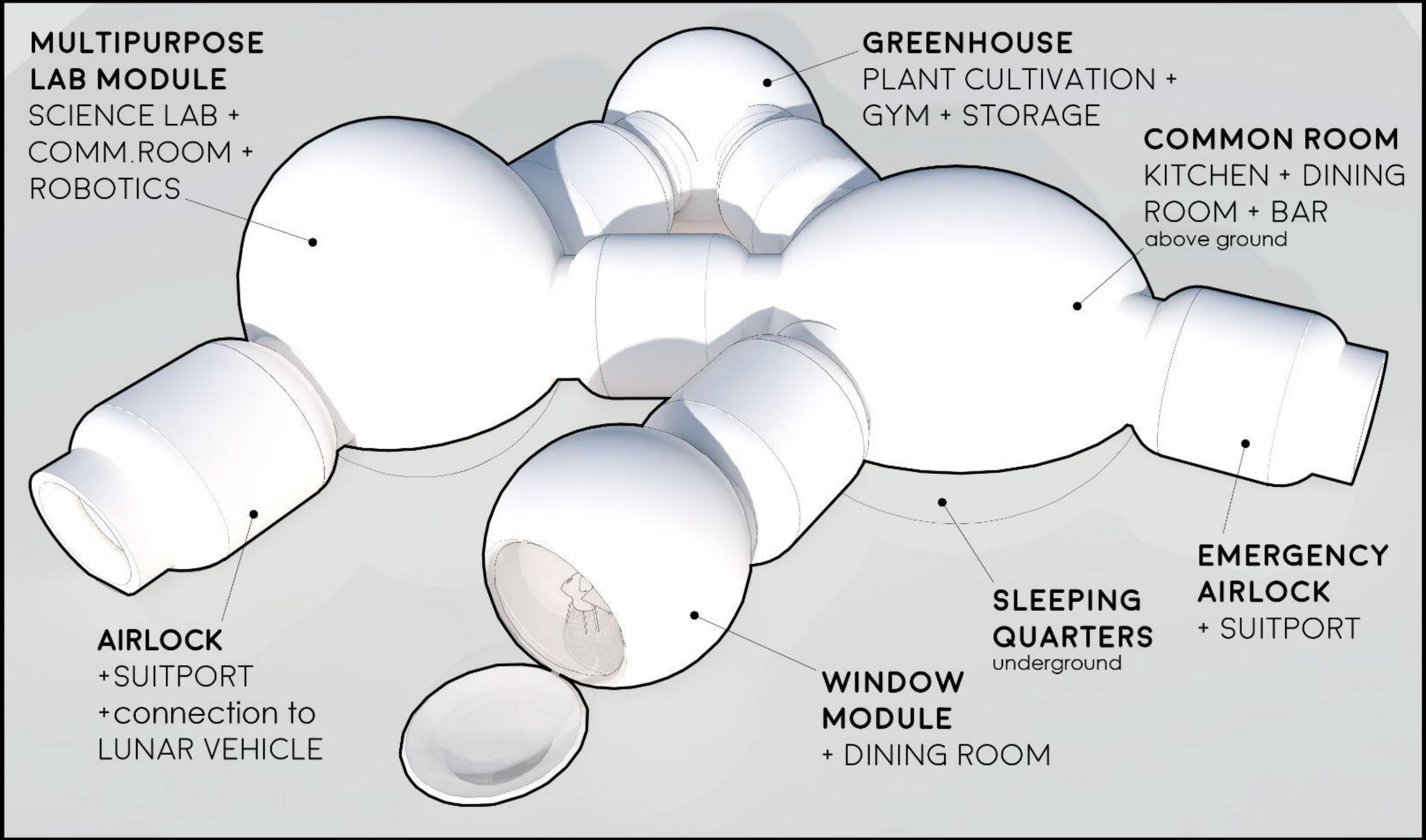
Excavating the regolith from the lunar surface

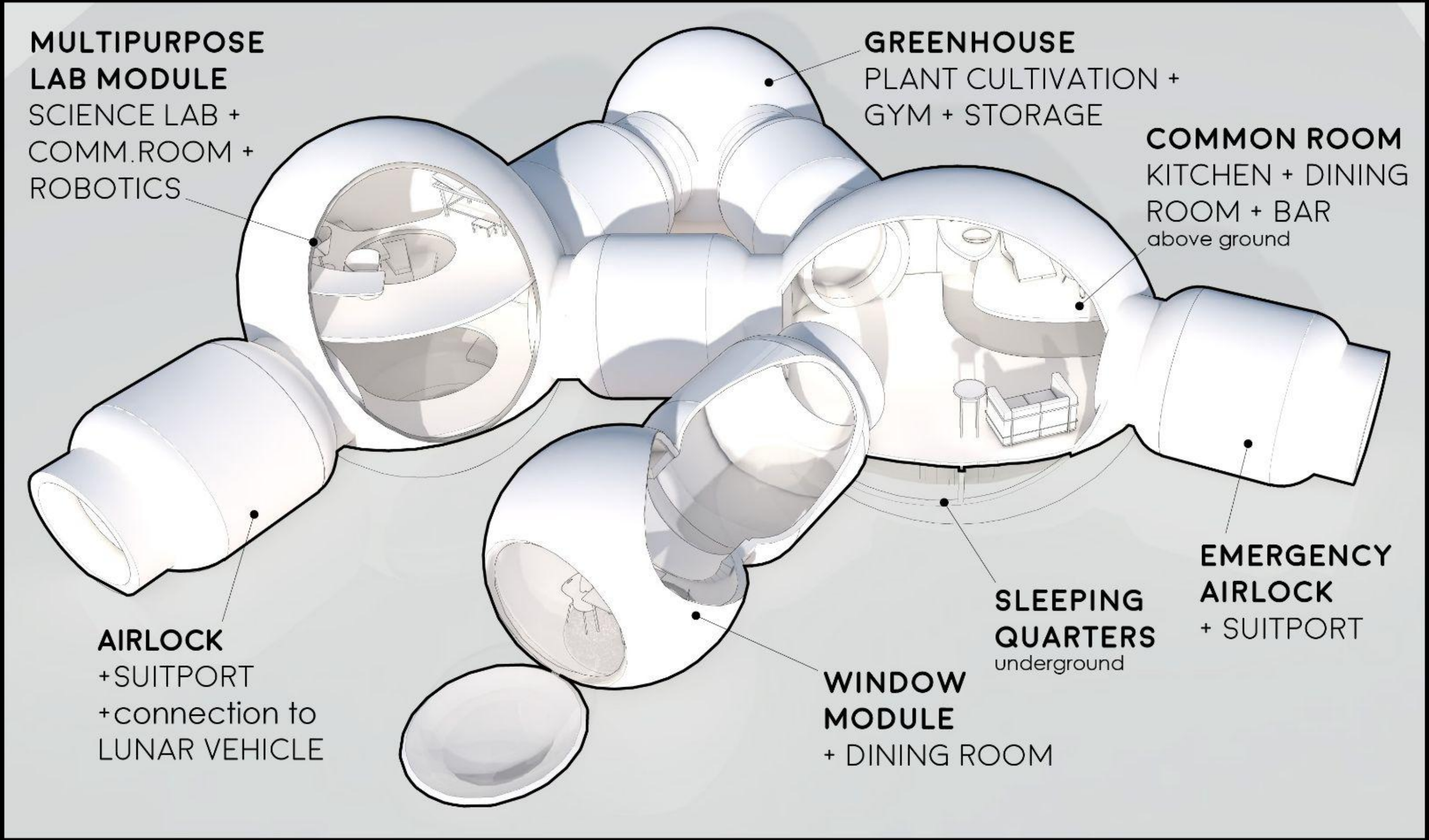
Placing a prefabricated airlock and inflating the modules



Contour crafting above the inflatable modules as a radiation protection




MULTIPURPOSE LAB MODULE
SCIENCE LAB + COMM.ROOM + ROBOTICS
GREENHOUSE
PLANT CULTIVATION + GYM + STORAGE
COMMON ROOM
KITCHEN + DINING ROOM + BAR
above ground
AIRLOCK
+SUITPORT
+connection to LUNAR VEHICLE
WINDOW MODULE
+ DINING ROOM
SLEEPING QUARTERS
underground
EMERGENCY AIRLOCK
+ SUITPORT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+ SUITPORT
SLEEPING QUARTERS
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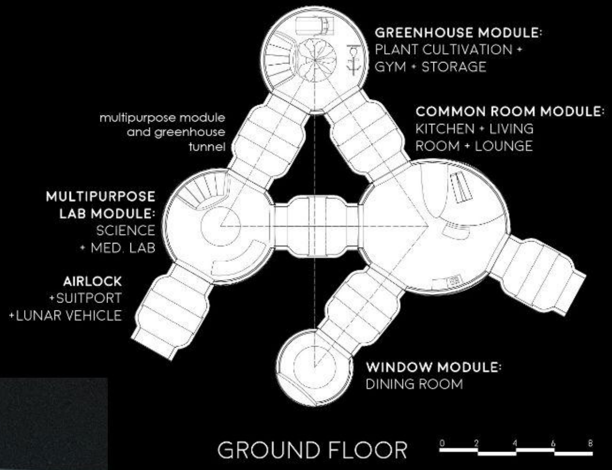
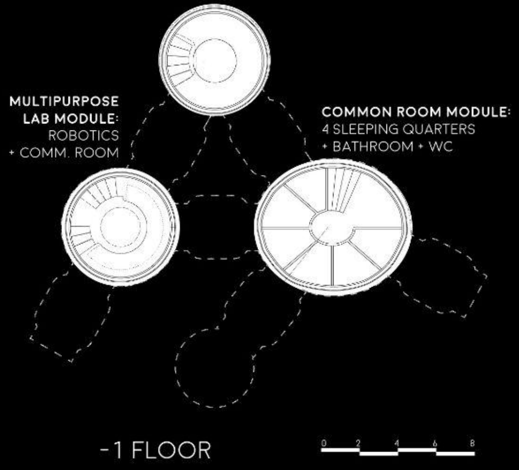
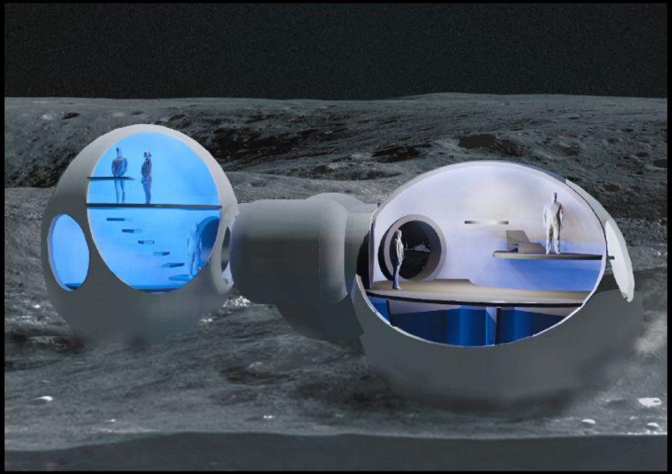
+ DINING ROOM
AIRLOCK
+SUITPORT
+connection to LUNAR VEHICLE

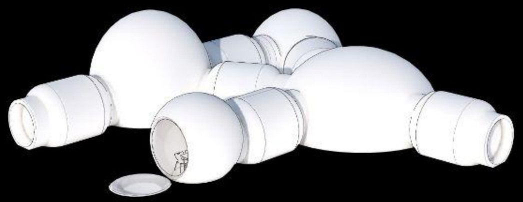
1 ST PHASE

All modules connected and inflated



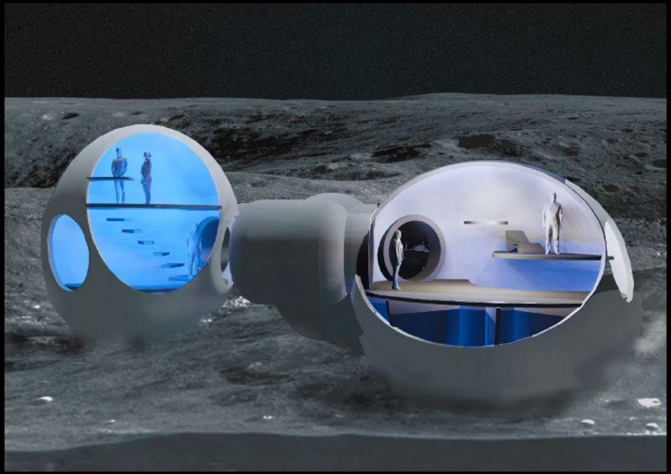


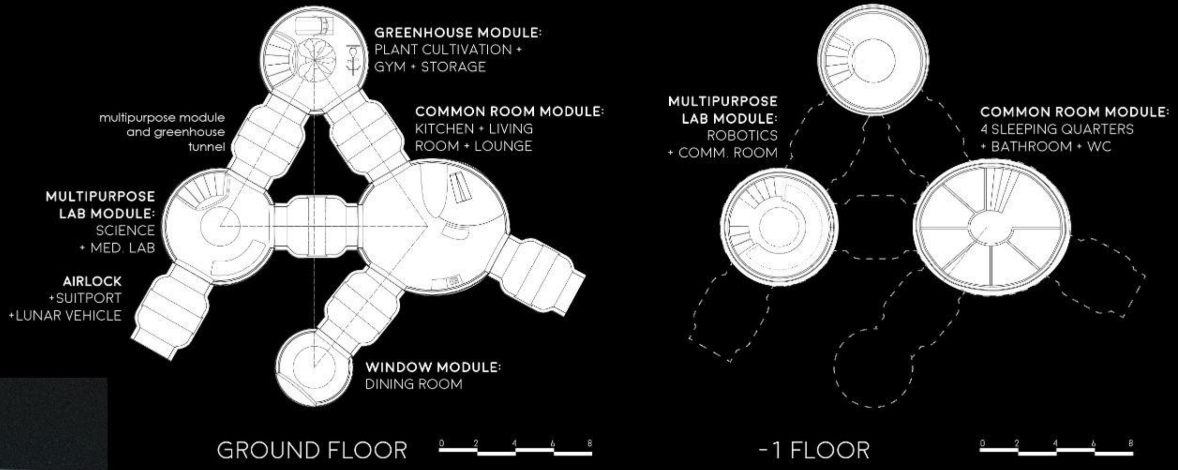


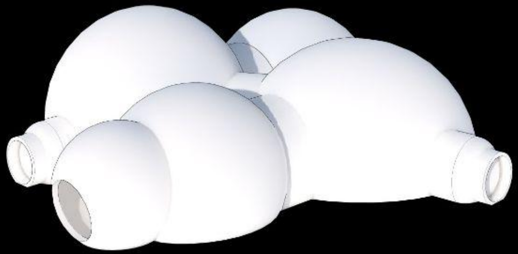


1ST PHASE

Contour crafting above the inflatable modules as a radiation protection

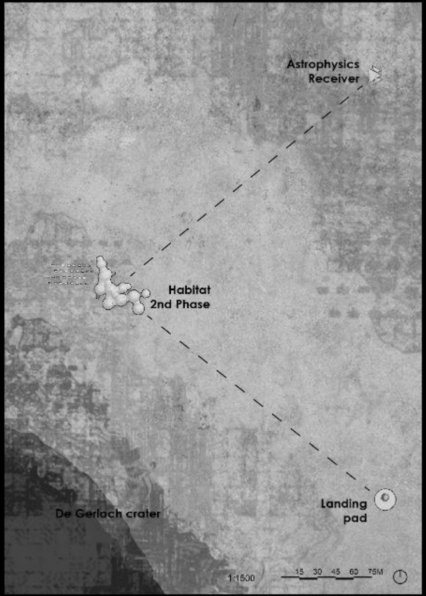




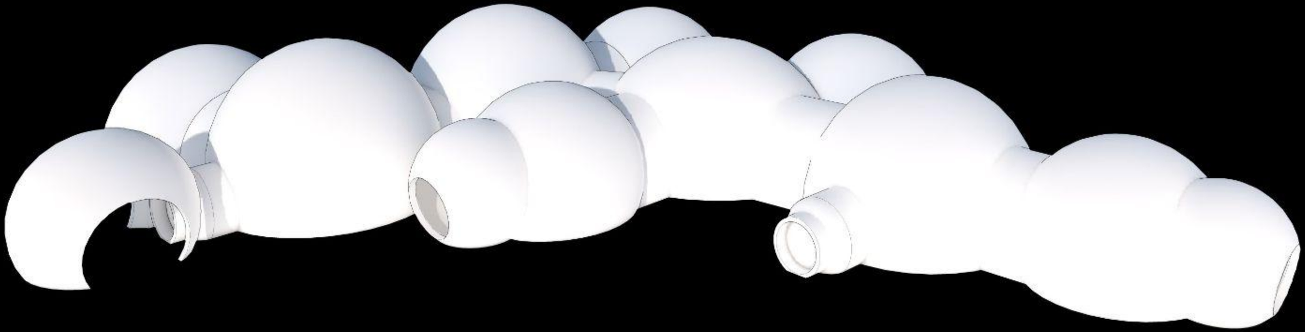


2ND PHASE

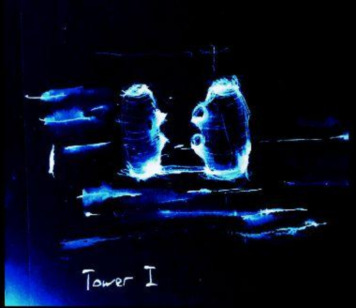
Adding additional modules to expand the habitat for 8 people



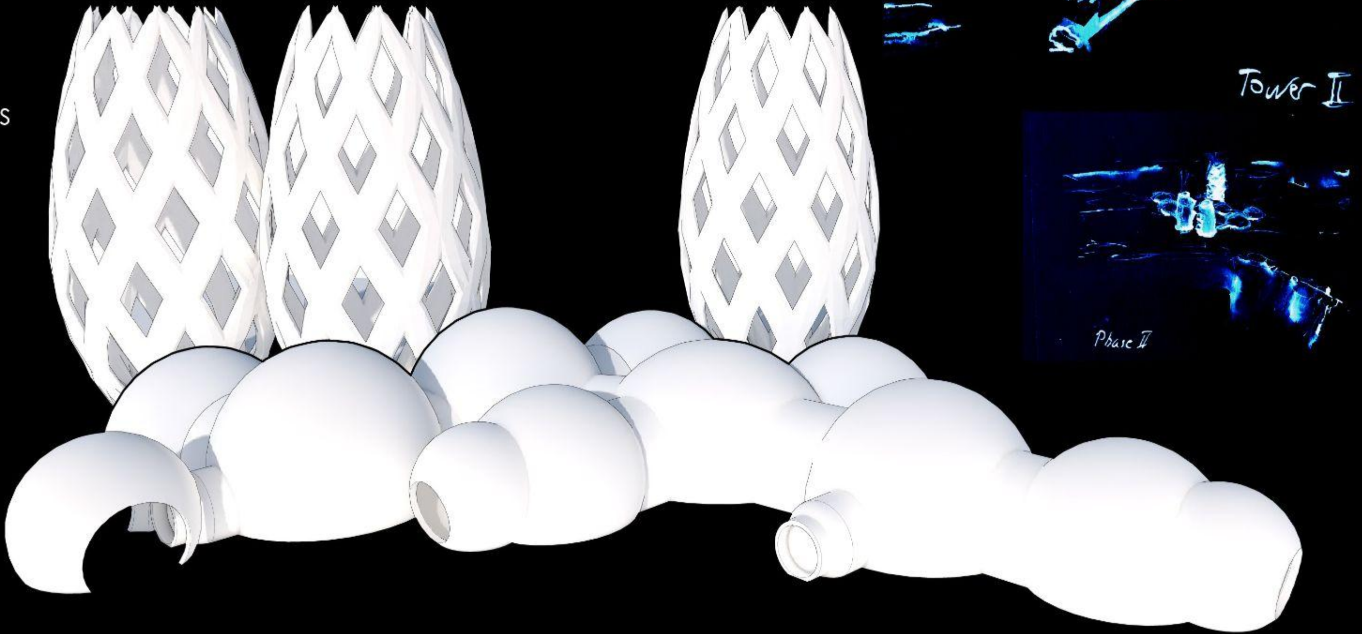
+ Science Laboratory
+ Greenhouse
+ Sleeping quarters
+ Storage

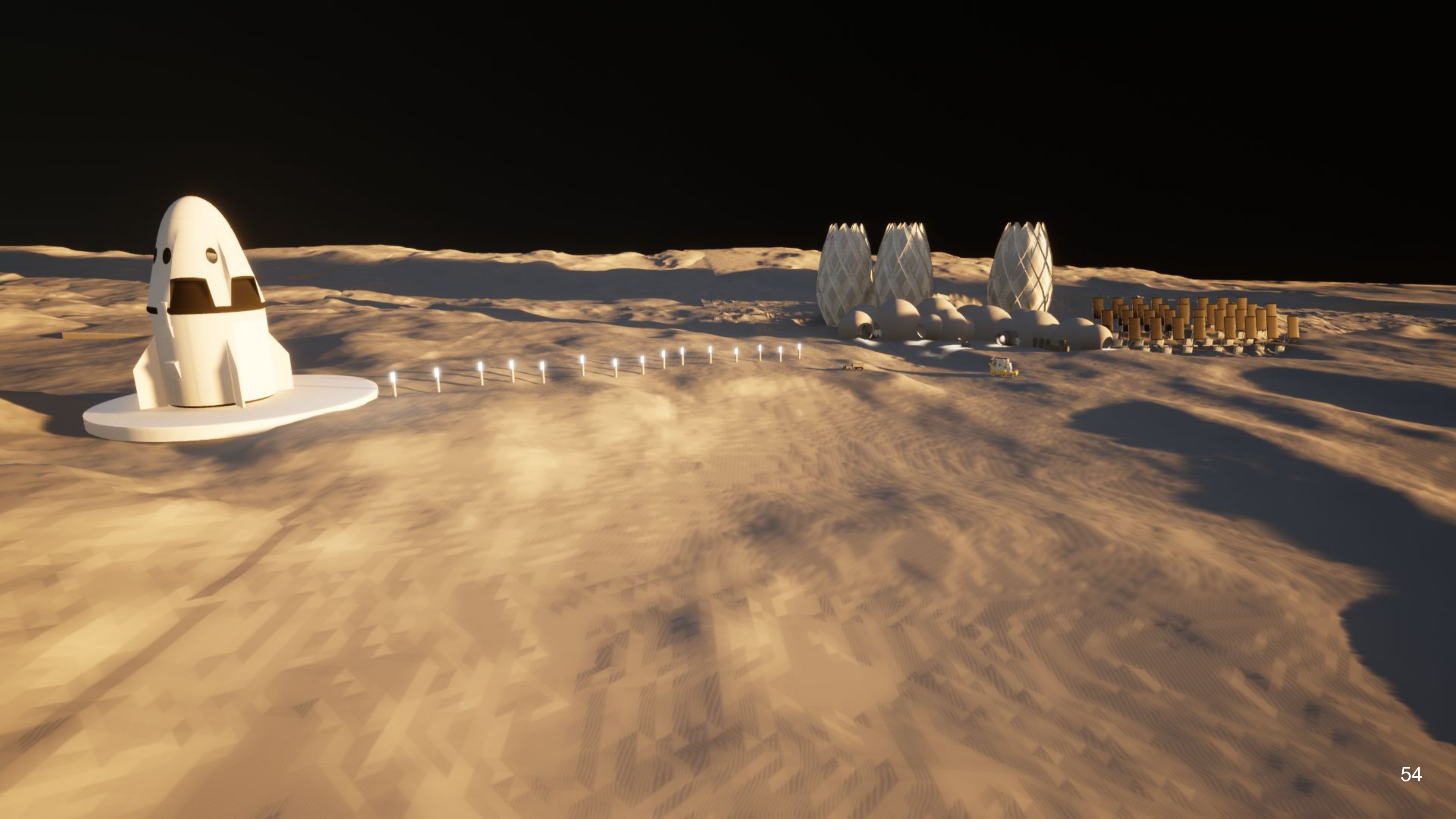


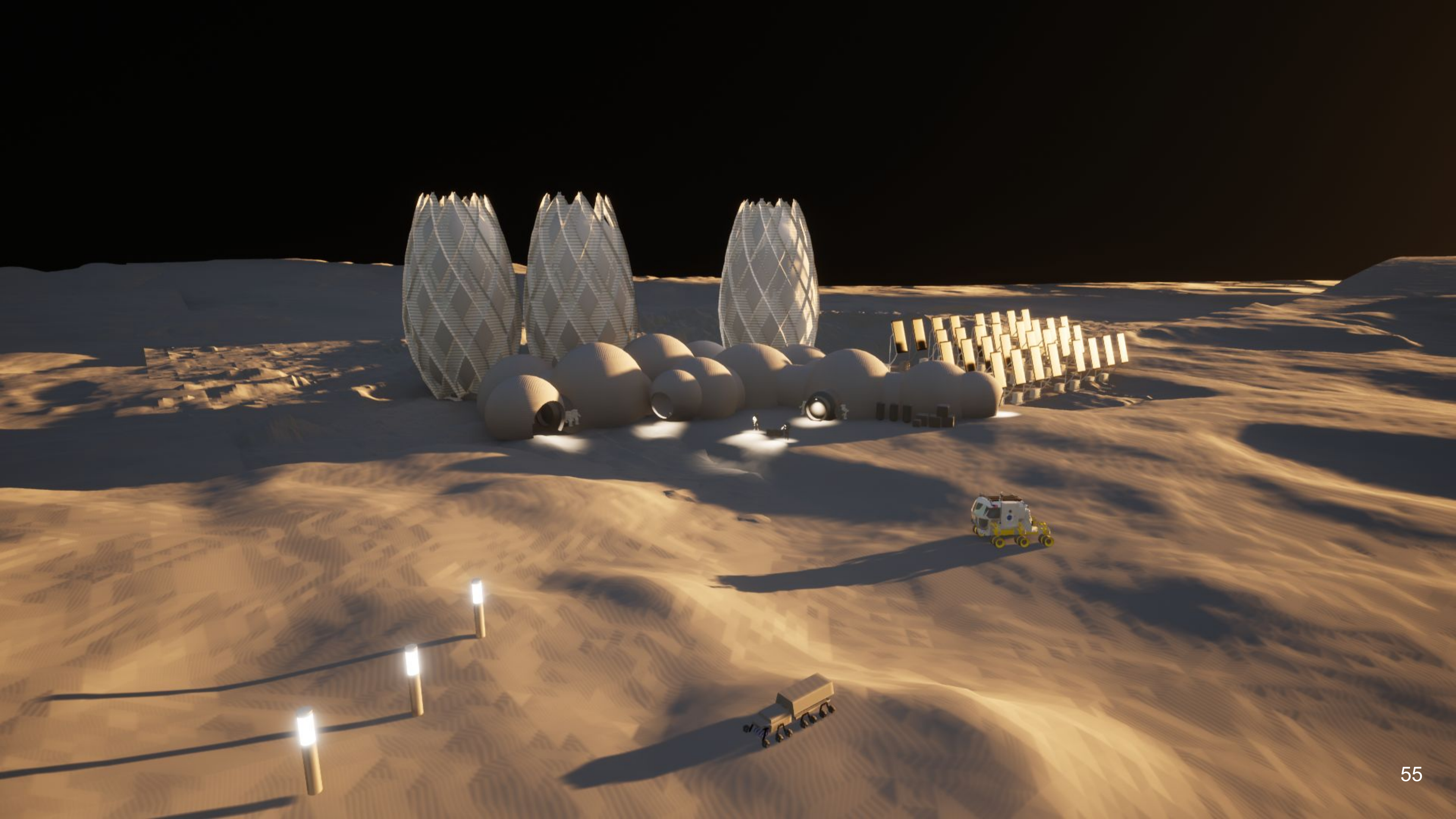
3RD PHASE
expanding the habitat under the supervision of 8 crew members

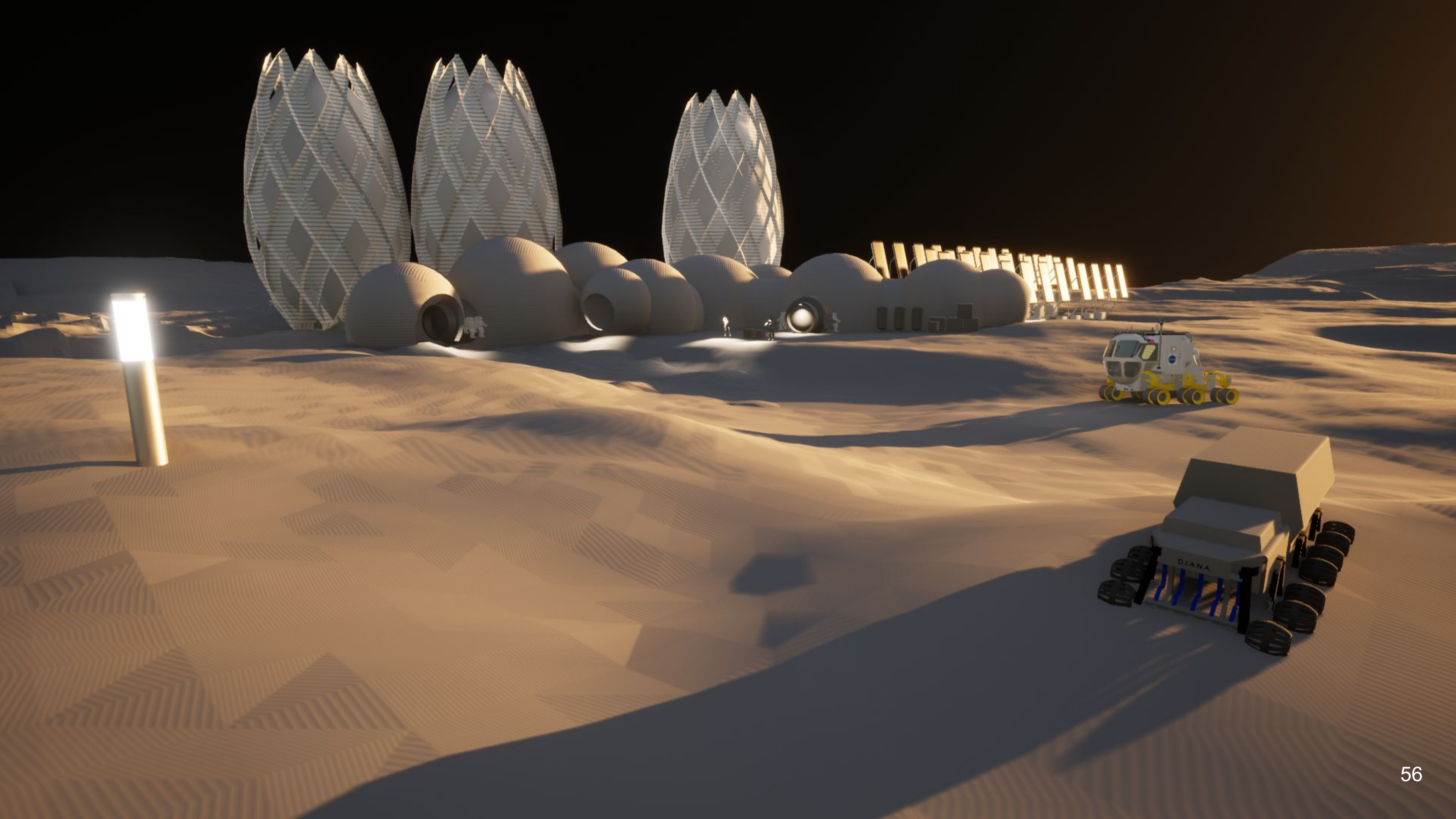


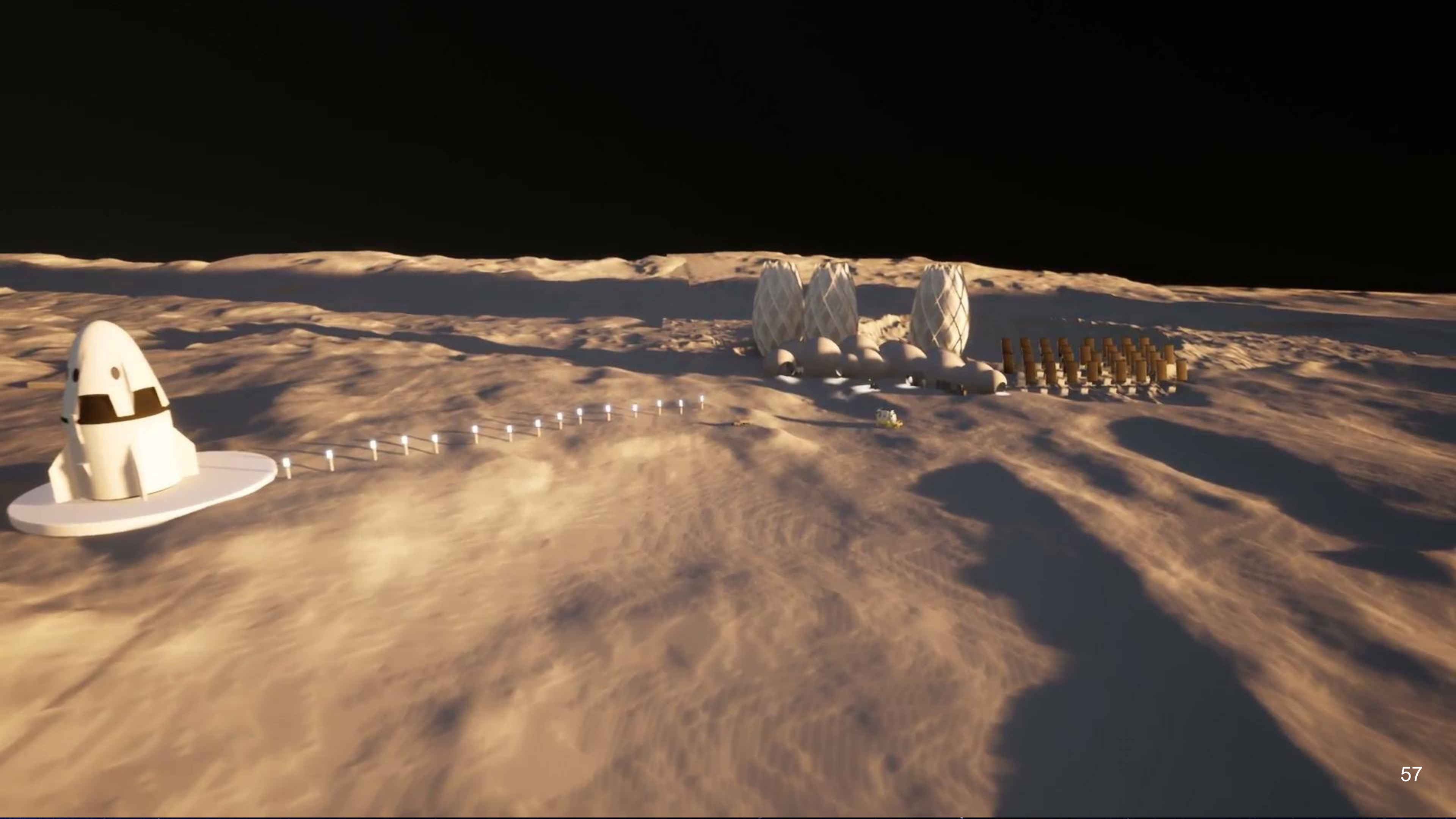
+ 3D printed habitat that offers better living conditions
+ Adding sleeping quarters + better social activities
+ Expanding Science lab + Robotics + adding more modules for storage
+ Expanding the Greenhouse



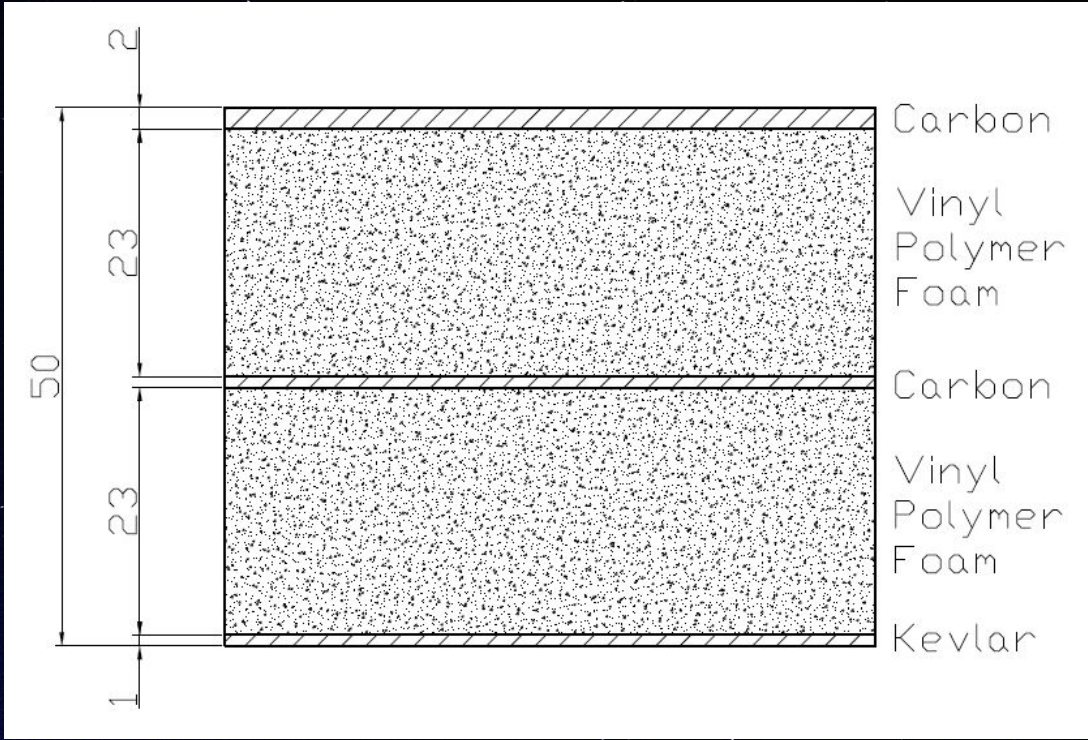





D.I.A.N.A.



STRUCTURES



Layer	Material type	Thickness (cm)
Outer layer	Carbon	2
Upper foam	Vinyl Polymer Foam	23
Middle layer	Carbon	1
Lower foam	Vinyl Polymer Foam	23
Base layer	Kevlar	1

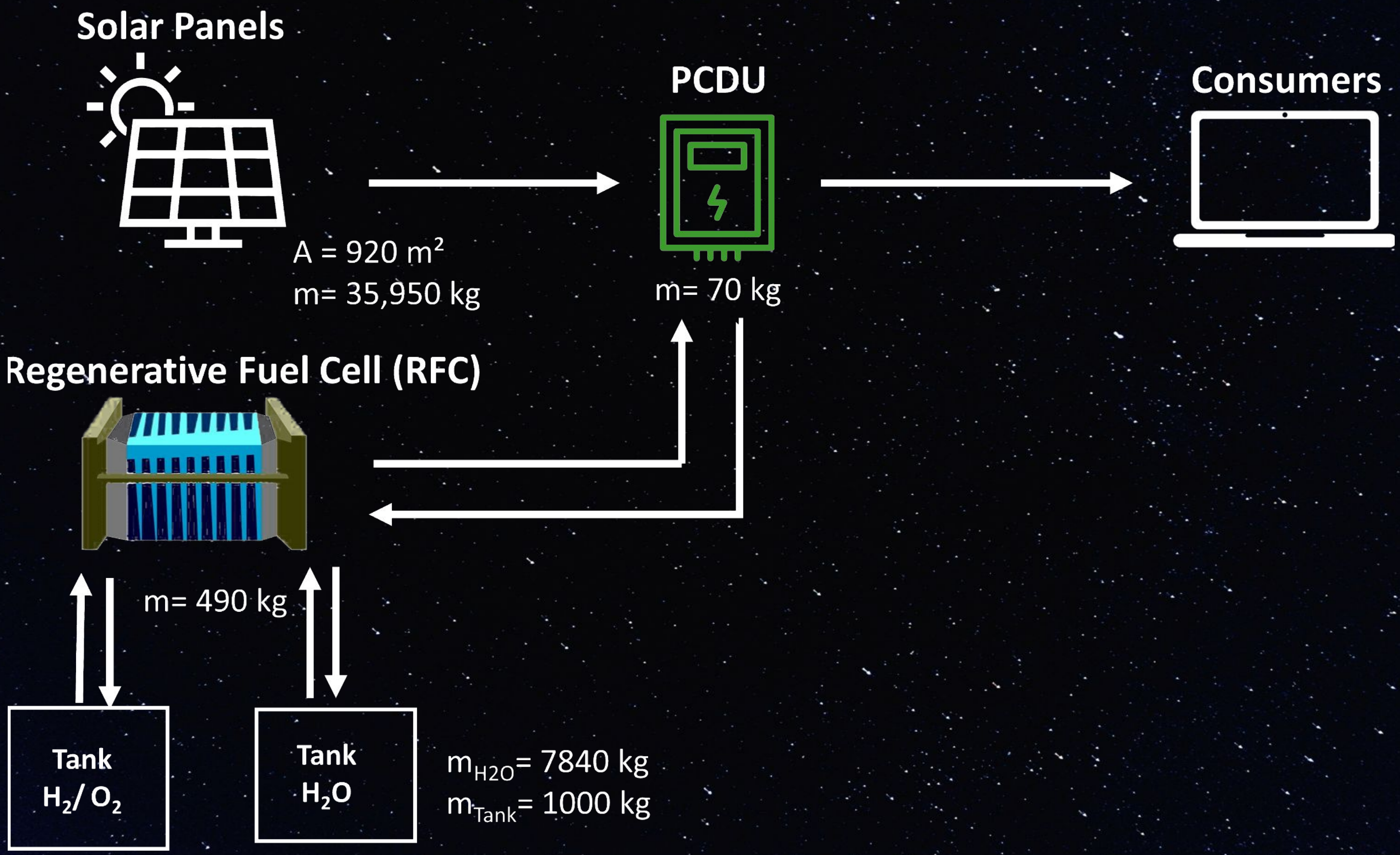
STRUCTURES

Habitation	33,777
Communication	189
External modules	16,941
ECLSS	6,584
Radiation	47,723
Robotics	63,752
Science	4,391
TCS	8,250
EPS	45,395
Summary	227,003 kg

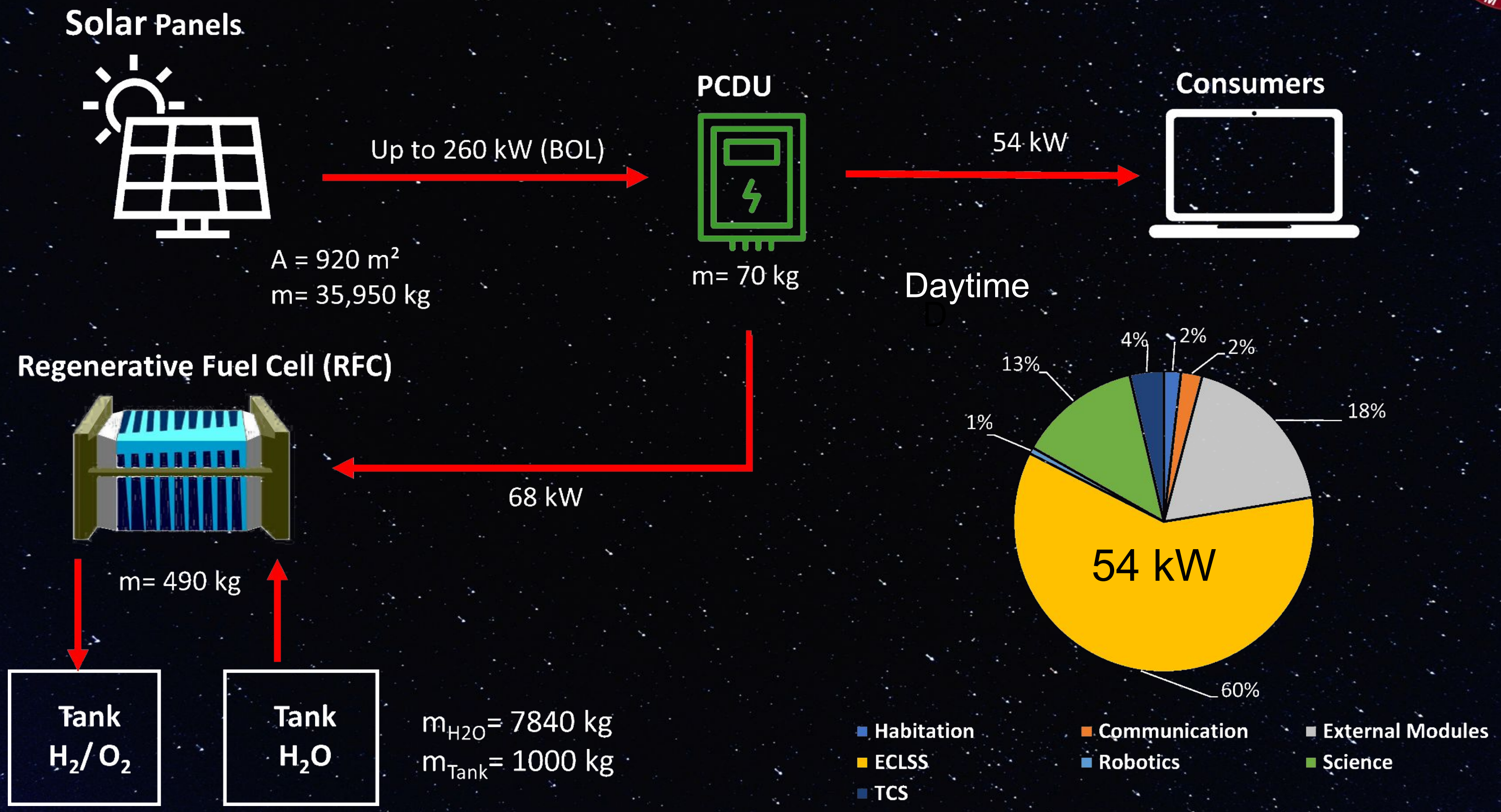
Station Mass Budget

in [kg]

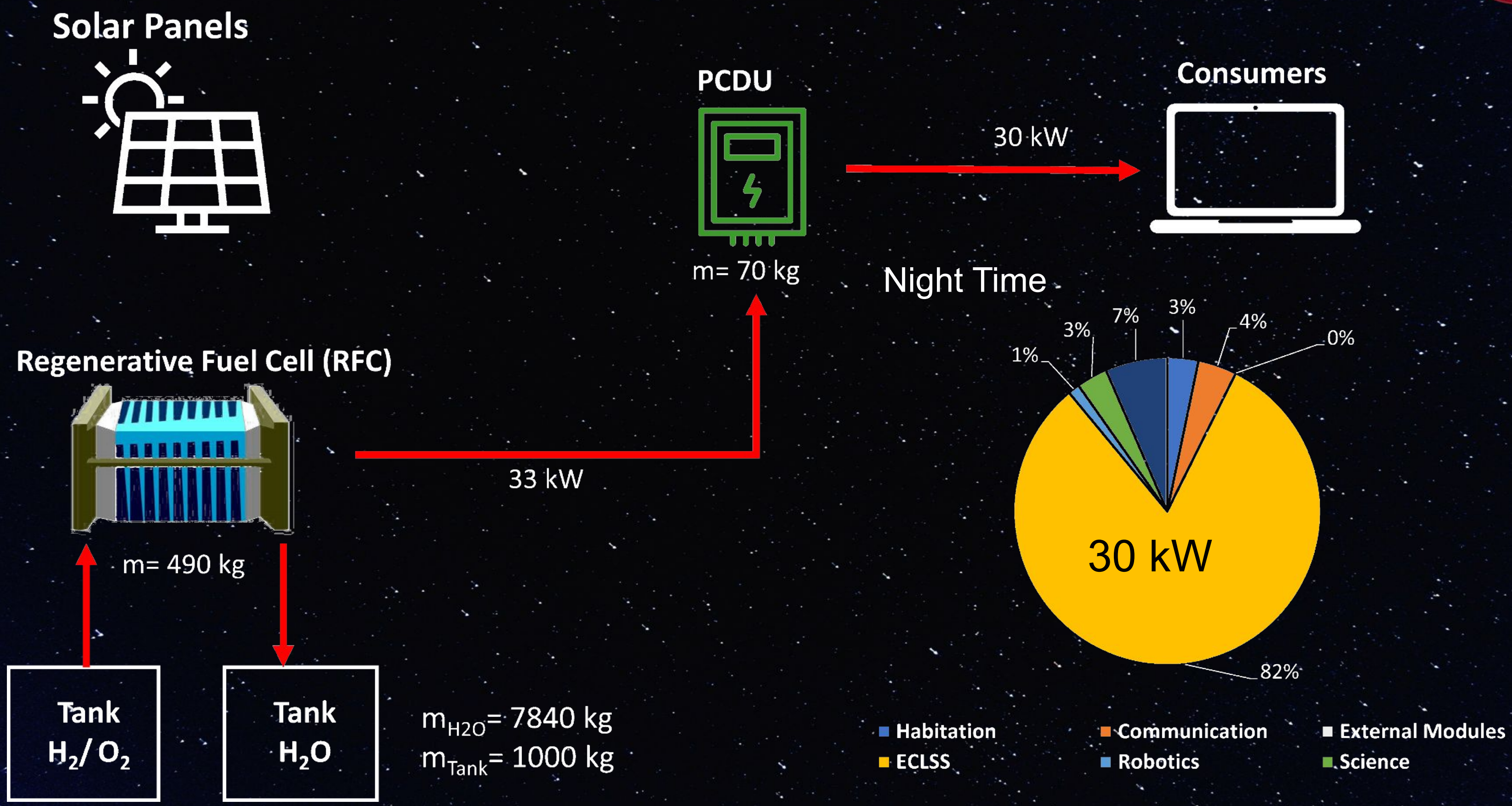
ELECTRICAL POWER SYSTEM



ELECTRICAL POWER SYSTEM



ELECTRICAL POWER SYSTEM



ELECTRICAL POWER SYSTEM

System Power Consumption Budget in [W]

ECLSS	32,841
External Modules (ISRU)	10,000
Science	7,200
Communications	1,250
Robotics	375
Summary	51,666 W

THERMAL CONTROL SYSTEM

Regolith → Insulating properties → Interior remains insensitive to external environment

Insulating properties ↓ Only 2% of needed heat dissipation

Interior remains insensitive to external environment ↓ Coldest internal temperatures 20°C

TCS must be able to dissipate **at least 60 kW** of heat

THERMAL CONTROL SYSTEM

Internal environment temperature will sustain its uniformity with cold plates in each module transporting the heat of the equipment

Dual phase water loop connecting the cold plates to a central heat exchange bus

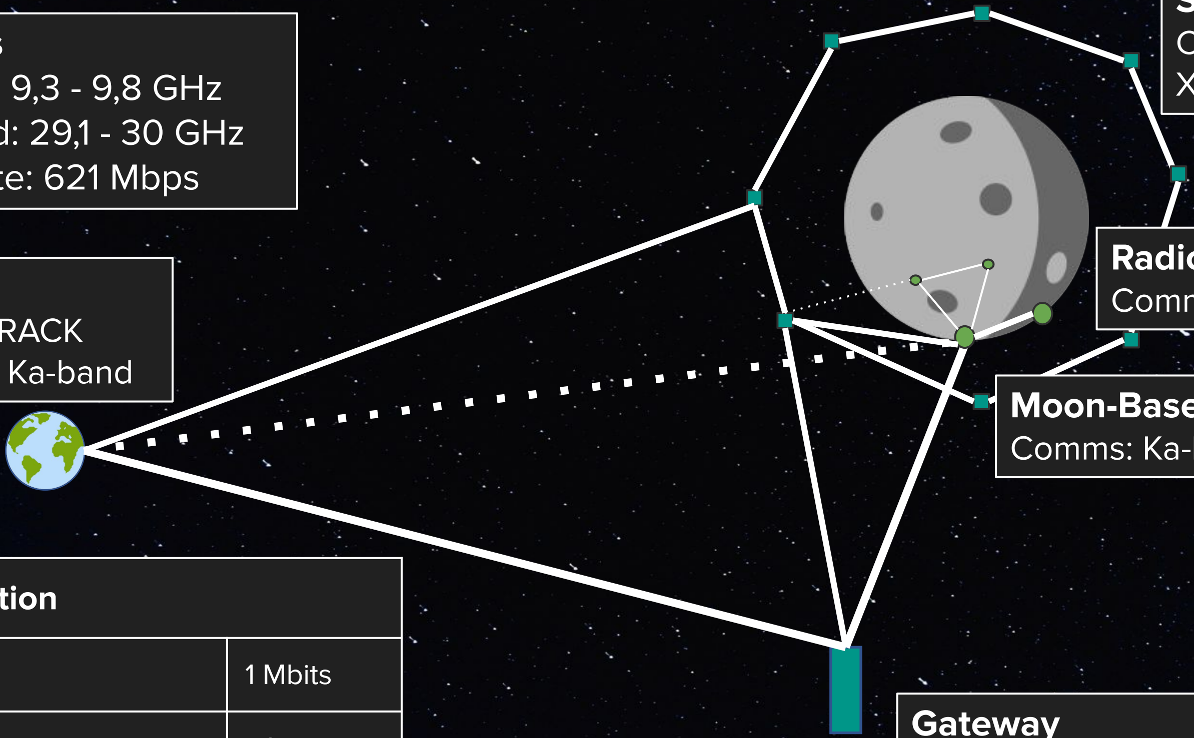
Secondary dual phase ammonia loop connects the heat exchange bus to heat pipe radiators

Radiators are covered with Optical Solar Reflective tiles so that even at their EoL conditions, they sustain their radiative capacity

COMMUNICATIONS

Comms
X-band: 9,3 - 9,8 GHz
Ka-band: 29,1 - 30 GHz
Data rate: 621 Mbps

Earth
GS: ESTRACK
Comms: Ka-band



Satellites constellation
Comms: Ka-band, optical link, X-band

Radio Telescope
Comms: Optical fiber

Moon-Base
Comms: Ka-band, X-band

Gateway
Comms: S-band, Ka-band, optical link

Data generation	
TTC	1 Mbits
Manned mission support	40 Mbits
Scientific data	580 Mbits

COMMUNICATIONS

GROUND STATIONS

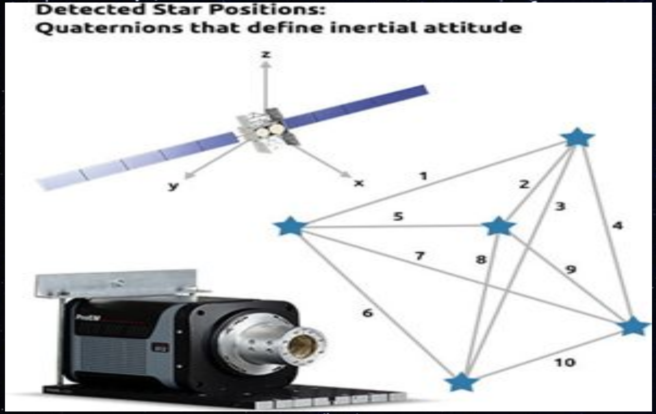
ESTRACK network

LINK BUDGET

Symbol	Parameter	Best case value	Worst case value	Unit
P_T	Transmitter power	17,78	17,78	dBW
G_T	Transmit antenna gain	51,0	47,9	dBi
L_S	Free space loss	-175,70	-178,63	dB
L_A	Channel loss	-0,1	-3,0	dB
G_R	Receiving antenna gain	50,8	47,7	dBi
k	Boltzmann constant	1,38E-23	-	J/K
R	Data rate	621	621	Mbps
$\frac{E_b}{N_0}$	Energy per bit to Noise-density	59,76	49,74	dB
-	Margin	54,51	41,99	dB

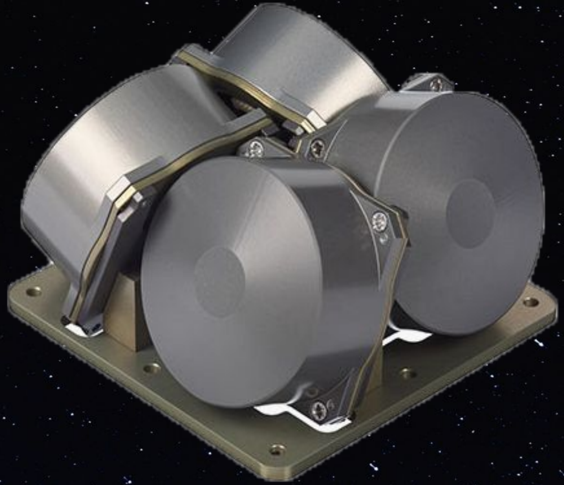
Attitude & Orbit Control System (AOCS)

The lander module attitude and orbit controls are controlled by a system consisting of sensors, actuators and software.



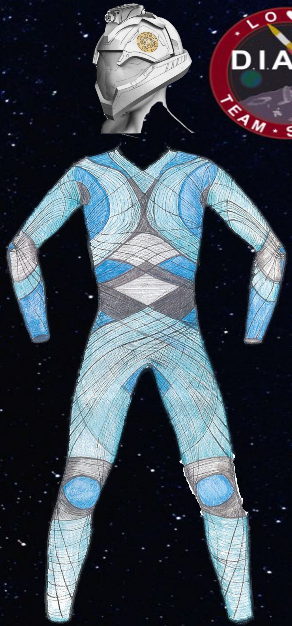
The selected sensors and actuators:

- Star trackers
- Sun sensors
- GPS receiver
- Reaction wheels
- Thrusters (22 N)



ROBOTICS & EVA

Lunar Base Construction



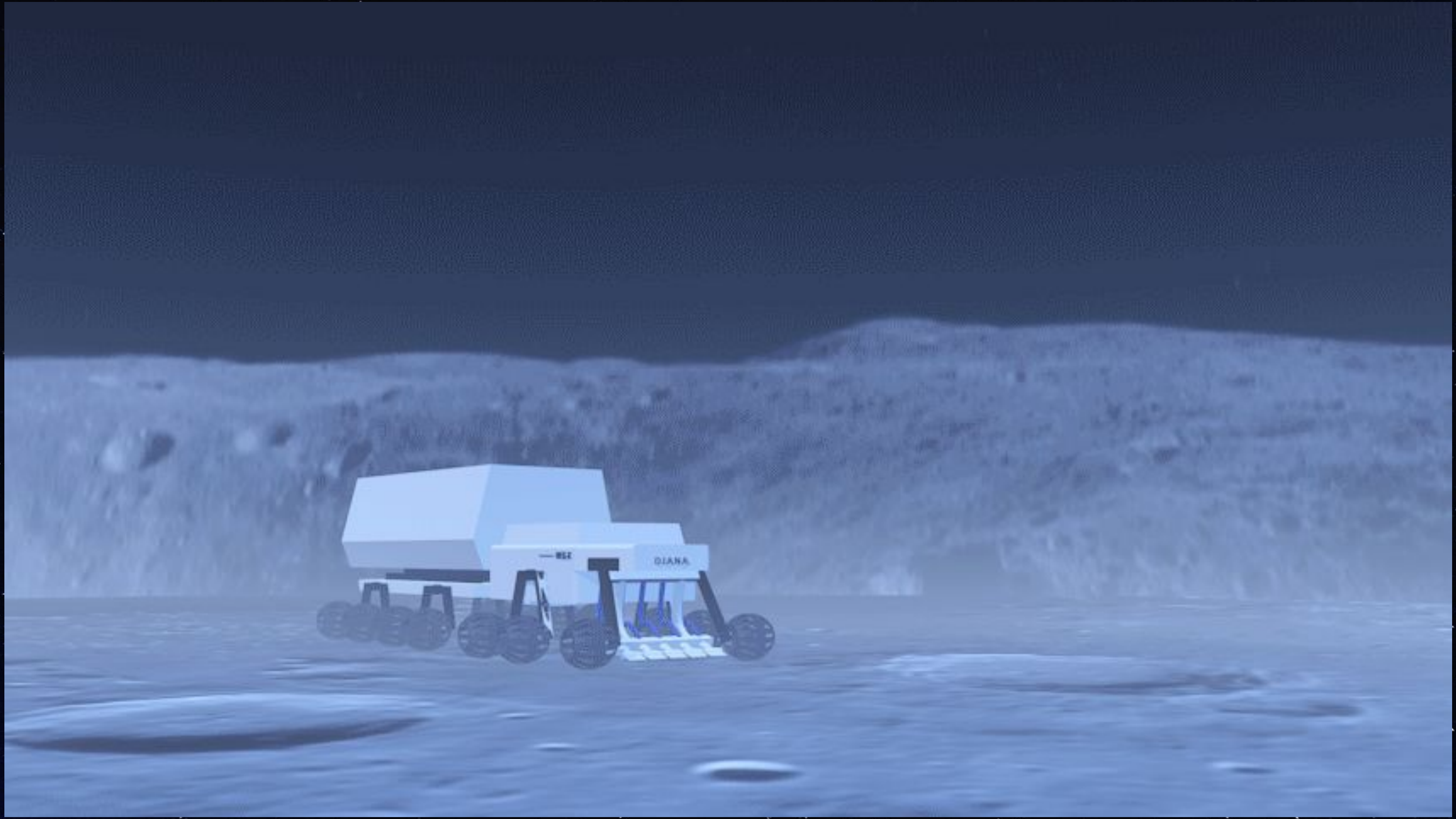
Spacesuits

Tasks

Human Assistance for EVAs

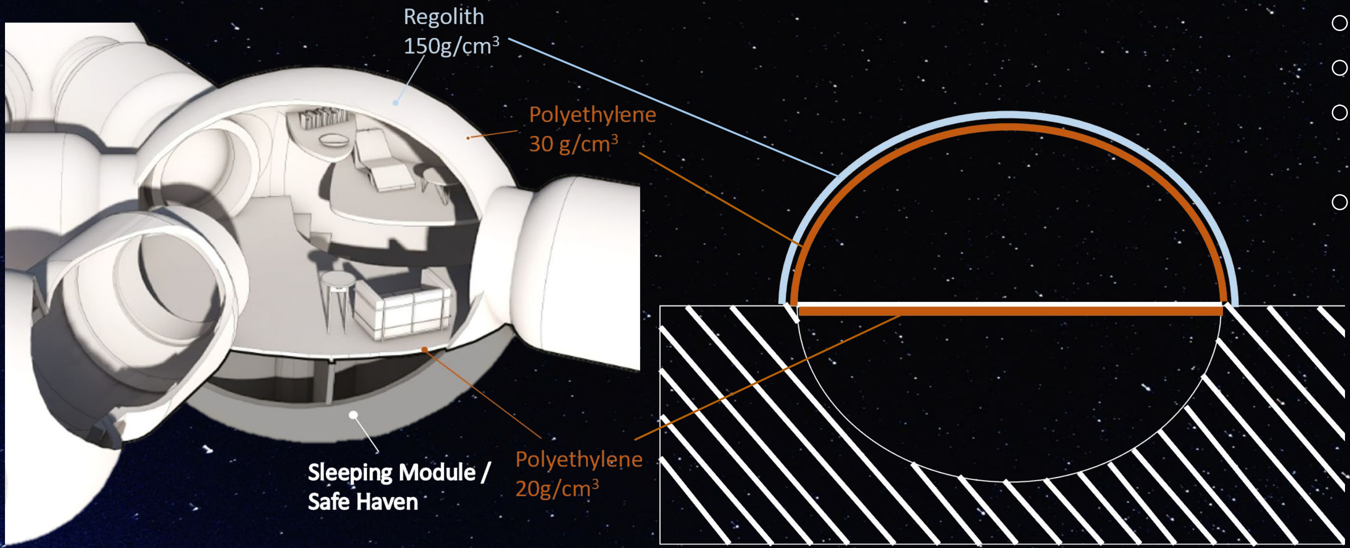
Science

ROBOTICS & EVA



RADIATION

- Shielding by Mass: ISRU: Overall Base shielding Regolith 200g/cm^2
- Safe Haven: Regolith 150g/cm^2 and Polyethylene 30g/cm^2 outer surface + Polyethylene Floor 20g/cm^2



- EVA => SPE => about 20 min time => HDPE Blankets /Pressurized Car/ EVA suit
- Secondary Approaches:
  - Pharmaceutical
  - Infrastructural Approaches
  - Mission Scheduling
  - Crew Selection (Gender and Age)
  - Monitoring (Active & Passive Dosimeter)

ECLSS

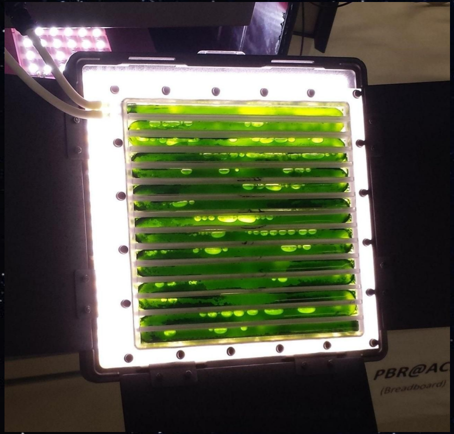
Water Recovery Systems

Advanced Closed Loop System

Physico-Chemical LSS

Photobioreactor

Figure 6.7: NASA: Water Recovery System. Credit: NASA



End of 2029

TRL 9

ECLSS

Water Recovery Systems

Advanced Closed Loop System

Physico-Chemical LSS

Photobioreactor

End of 2029

TRL 9

Greenhouse

2030

TRL 7

Figure 6.11: The Prototype Lunar Greenhouse from the outside [Credits: ag.arizona.edu/lunargreenhouse/]

ECLSS

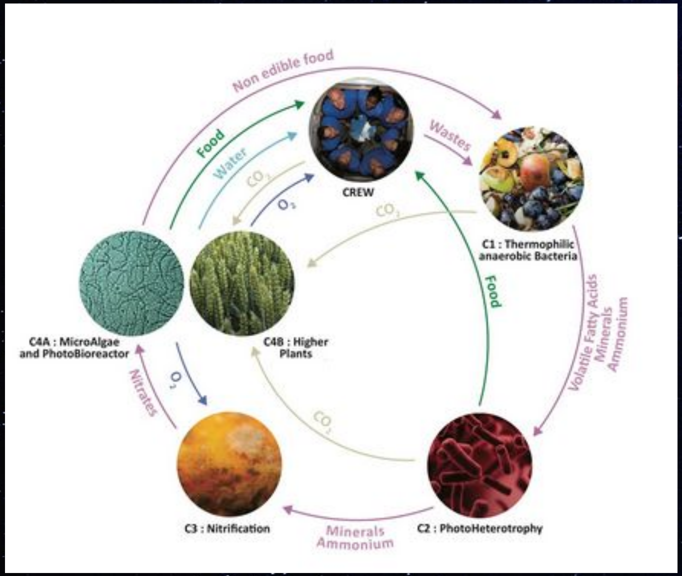
Water Recovery Systems

Advanced Closed Loop System

Physico-Chemical LSS

Photobioreactor	Greenhouse	ISRU (O2, H2O)
End of 2029	2030	2035
TRL 9	TRL 7	TRL 4

ECLSS



Water Recovery Systems

Advanced Closed Loop System

Physico-Chemical LSS

Photobioreactor	Greenhouse	ISRU (O_2, H_2O)	MELiSSA concept
End of 2029	2030	2035	2037
TRL 9	TRL 7	TRL 4	TRL 5

ECLSS

Water Recovery Systems

Advanced Closed Loop System

Decreasing reliance on supply

Increasing self-sustainability

End of 2029	2030	2035	2037	2045
Physico-Chemical LSS Photobioreactor	Greenhouse	ISRU (O_2, H_2O)	MELiSSA concept	Further development & expansion
TRL 9	TRL 7	TRL 4	TRL 5	

HUMAN FACTORS

optimize

- crew performance
- well-being
- mission success

balance

work output & productivity

holistic astronaut health

Key Principles: **sustainability, variation, adaptability**

HUMAN FACTORS

Interior Configuration & Design

natural cues & privacy

zoning & windows

personalization & flexibility

Habitability

water & food & trash

exercise

individual control

Key Principles

SUSTAINABILITY

VARIATION

ADAPTABILITY

Crew Dynamics

meaningful work

surprises & celebrations

training

Activities & Schedule

scheduled recreation

entertainment choices

freedom of scheduling

HUMAN FACTORS

Emergency Plans

Safe Haven

Emergency Lighting

Pathways Large Enough for Suited Crew Members

Medical Strategy

Physician

Crew Medical Training

Equipment – Sharing Strategy

Telemedicine

RADIO ASTRONOMY

Scientific Drivers for Radio Observations

- red-shifted spectral lines
  → research on evolution of the universe

- planetary & solar radio emission
  → learn about magnetic fields, ionospheres, ...

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Scientific Drivers to go to the Moon

- astronomical radio signals are very faint
  → far side of moon = low noise environment

- radio signals have long wavelengths
  → lots of space for large apertures or baselines

RADIO ASTRONOMY

Scientific Drivers for Radio Observations

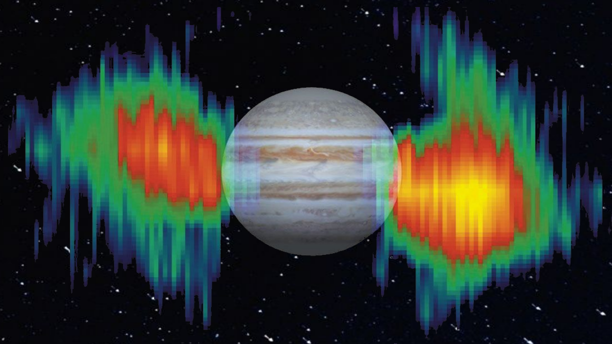
- red-shifted spectral lines
  → research on evolution of the universe
- planetary & solar radio emission
  → learn about magnetic fields, ionospheres, ...

Implementation

- **V**ery **L**ong **B**aseline **I**nterferometry
  → high resolution, with 500 km baseline already better than ALMA on earth
- Phased Array Antennas
  → autonomous deployment by unfolding

Scientific Drivers to go to the Moon

- astronomical radio signals are very faint
  → far side of moon = low noise environment
- radio signals have long wavelengths
  → lots of space for large apertures or baselines



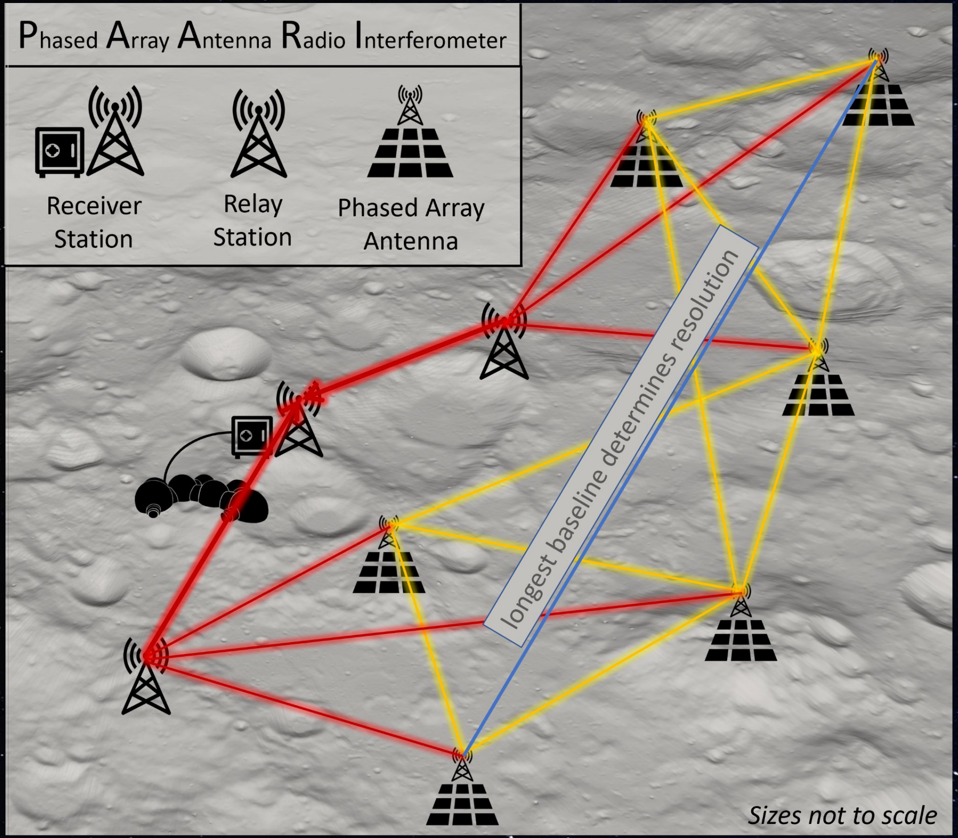
RADIO ASTRONOMY

Laser Optical Communication
- science data transfer

Laser Time-of-Flight Measurement
- distance between antennas

Very Long Baseline Interferometry
with Super Computer at Base

+ modular design
+ easily expandable
+ encourages international collaboration



OUTLINE

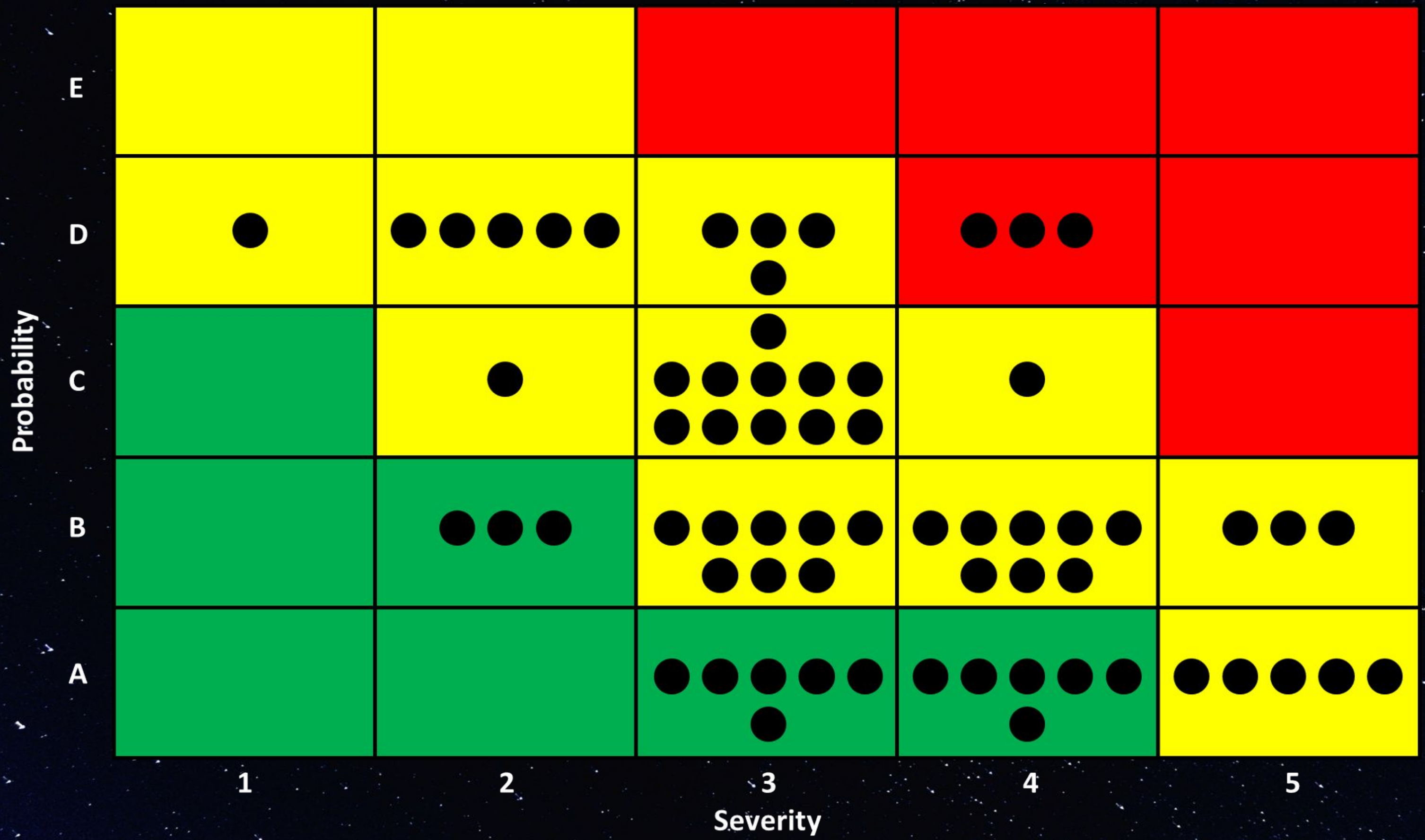
MISSION PROFILE

LUNAR BASE

PROJECT ENVELOPE

SPEAKER:
TIM LUKAS KIRSCH

RISK MANAGEMENT



RISK MANAGEMENT

RISK MANAGEMENT

Failure Situations	Mitigation
53 Unstable Requirements	Regular communication

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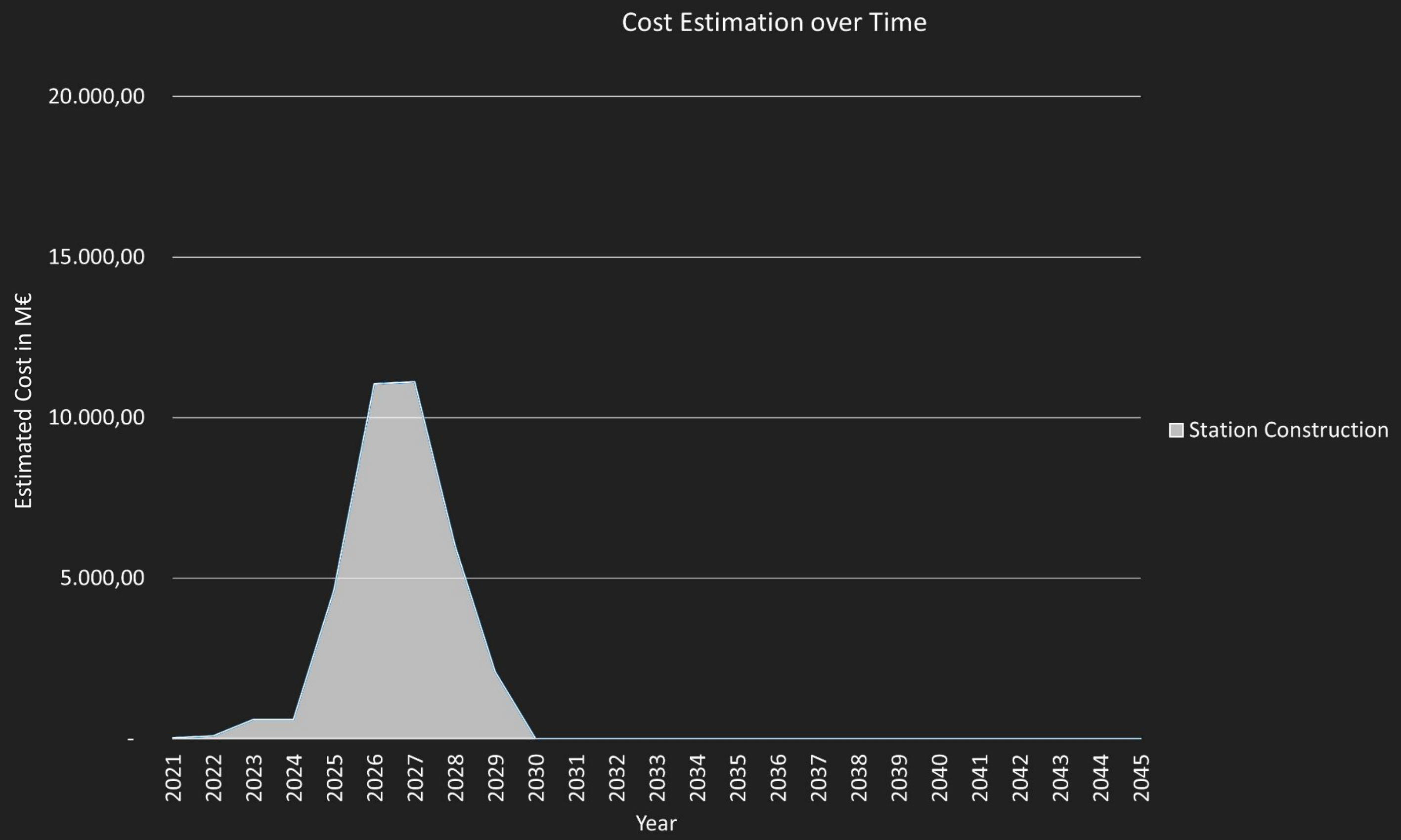
59 Cost overrun	Regular data collection and evaluations of current spending, other time costing methods

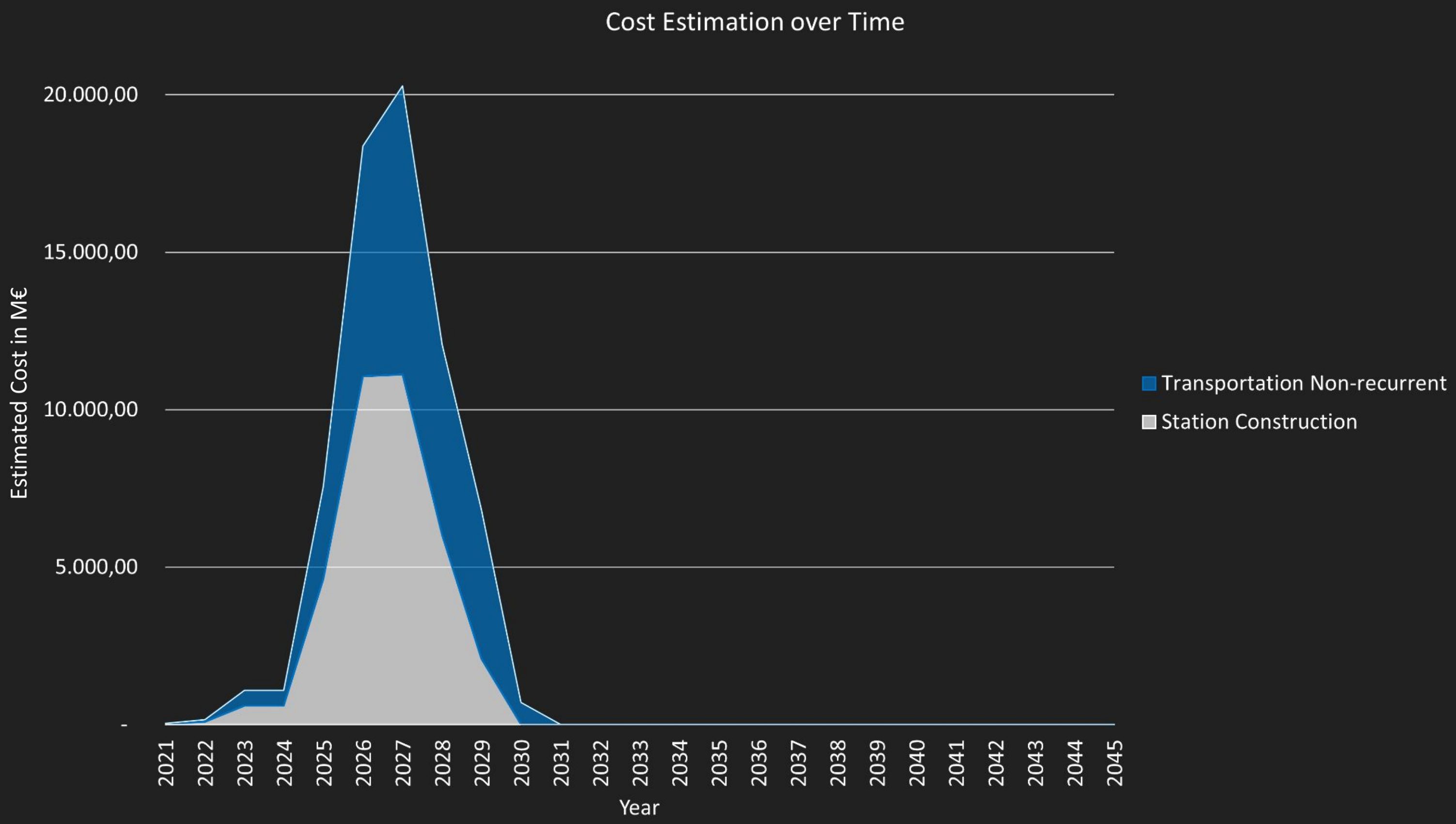
RISK MANAGEMENT

Failure Situations	Mitigation
53 Unstable Requirements	Regular communication
59 Cost overrun	Regular data collection and evaluations of current spending, other time costing methods
60 Schedule overrun	Regular process analysis comparable time mananagement methods

COST BREAKDOWN ESTIMATION



COST BREAKDOWN ESTIMATION



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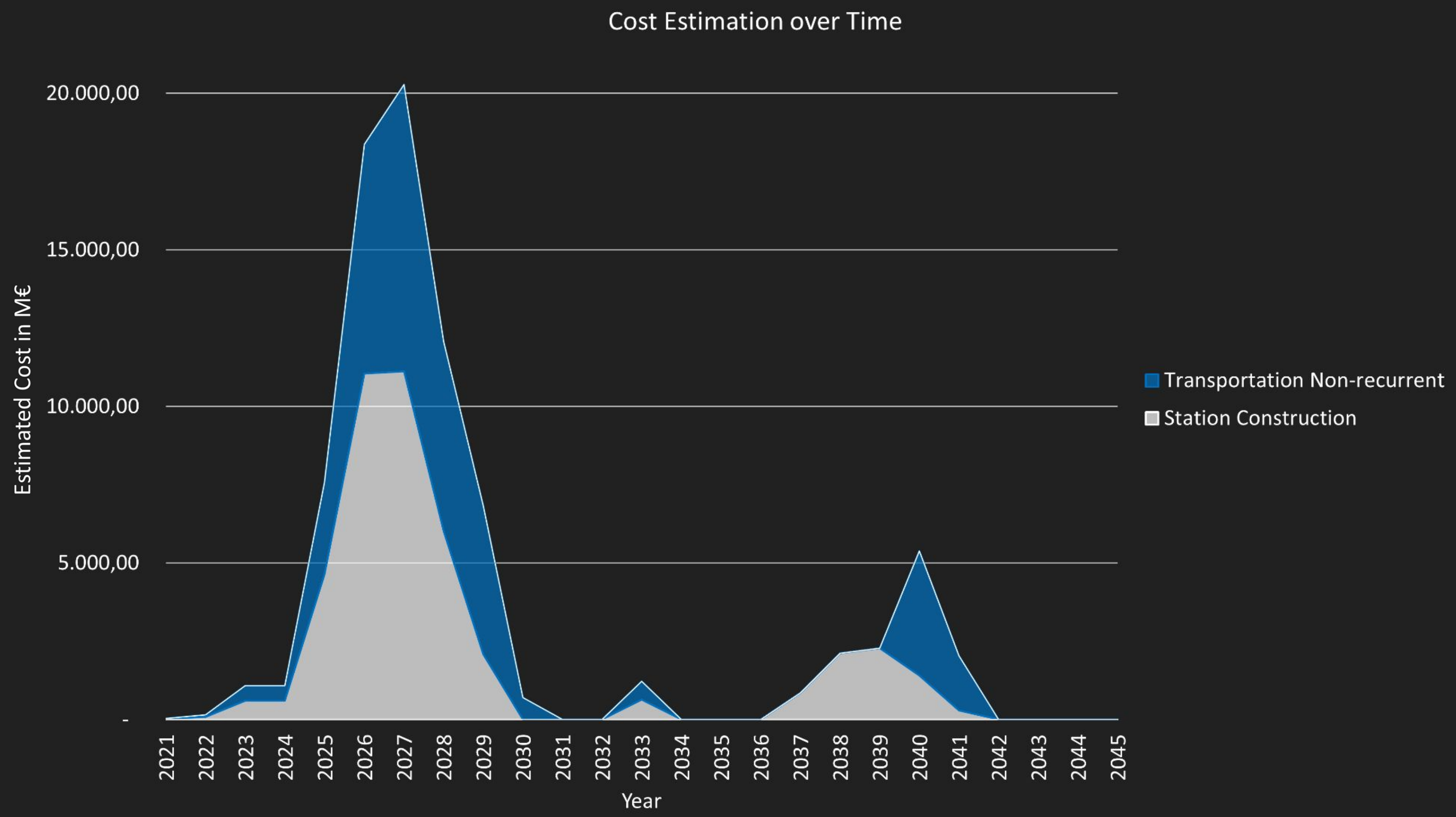

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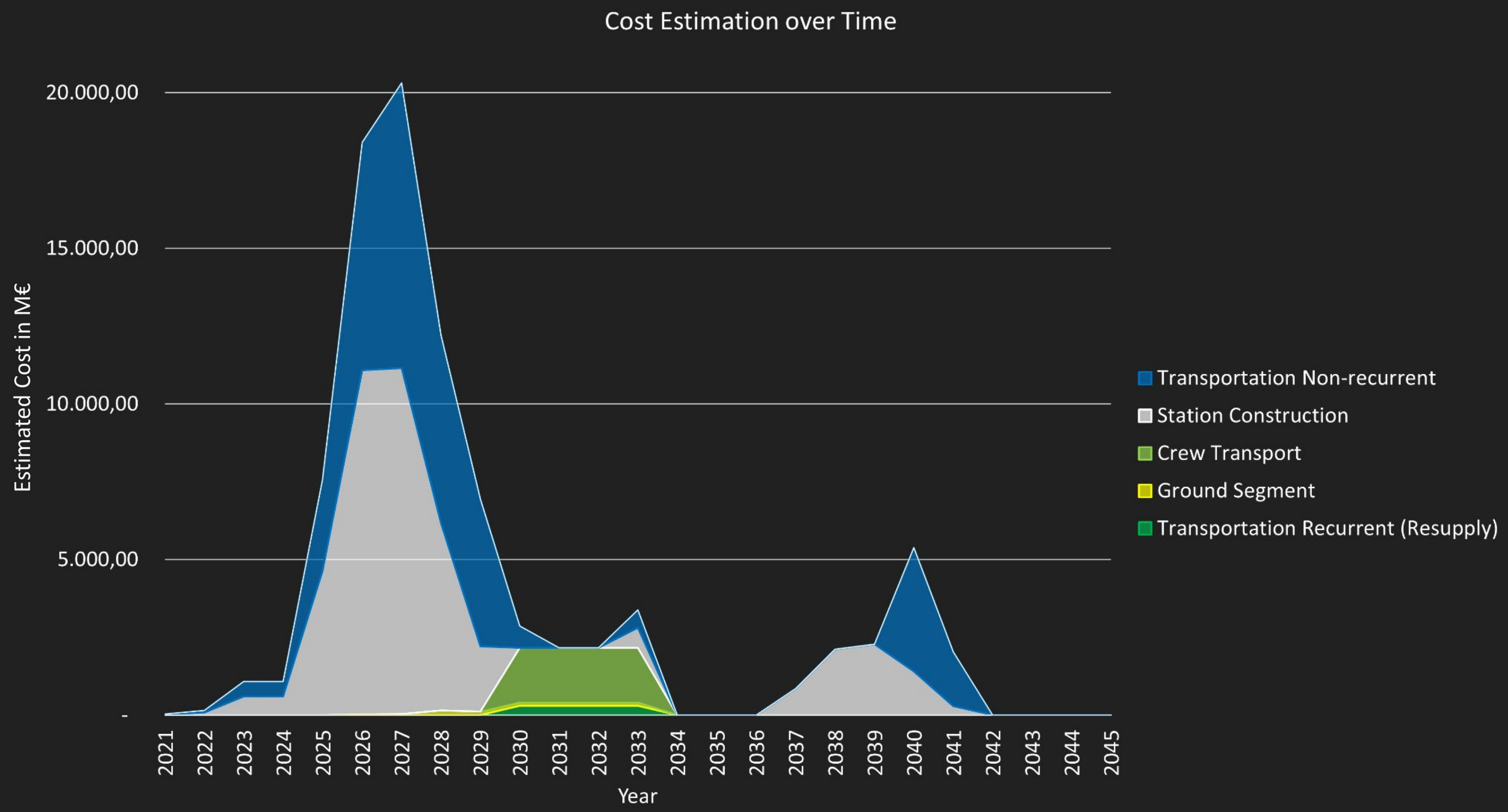

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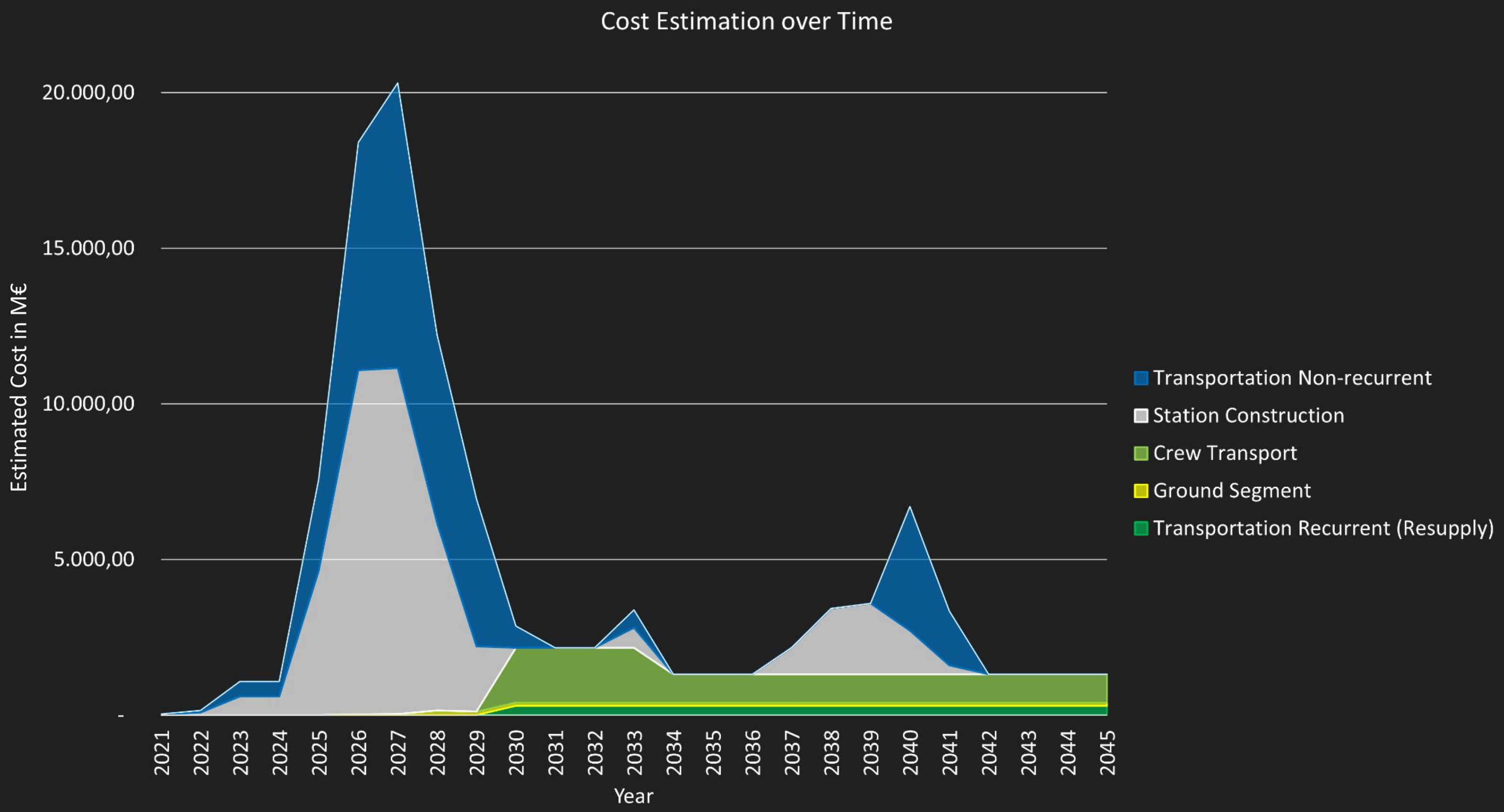

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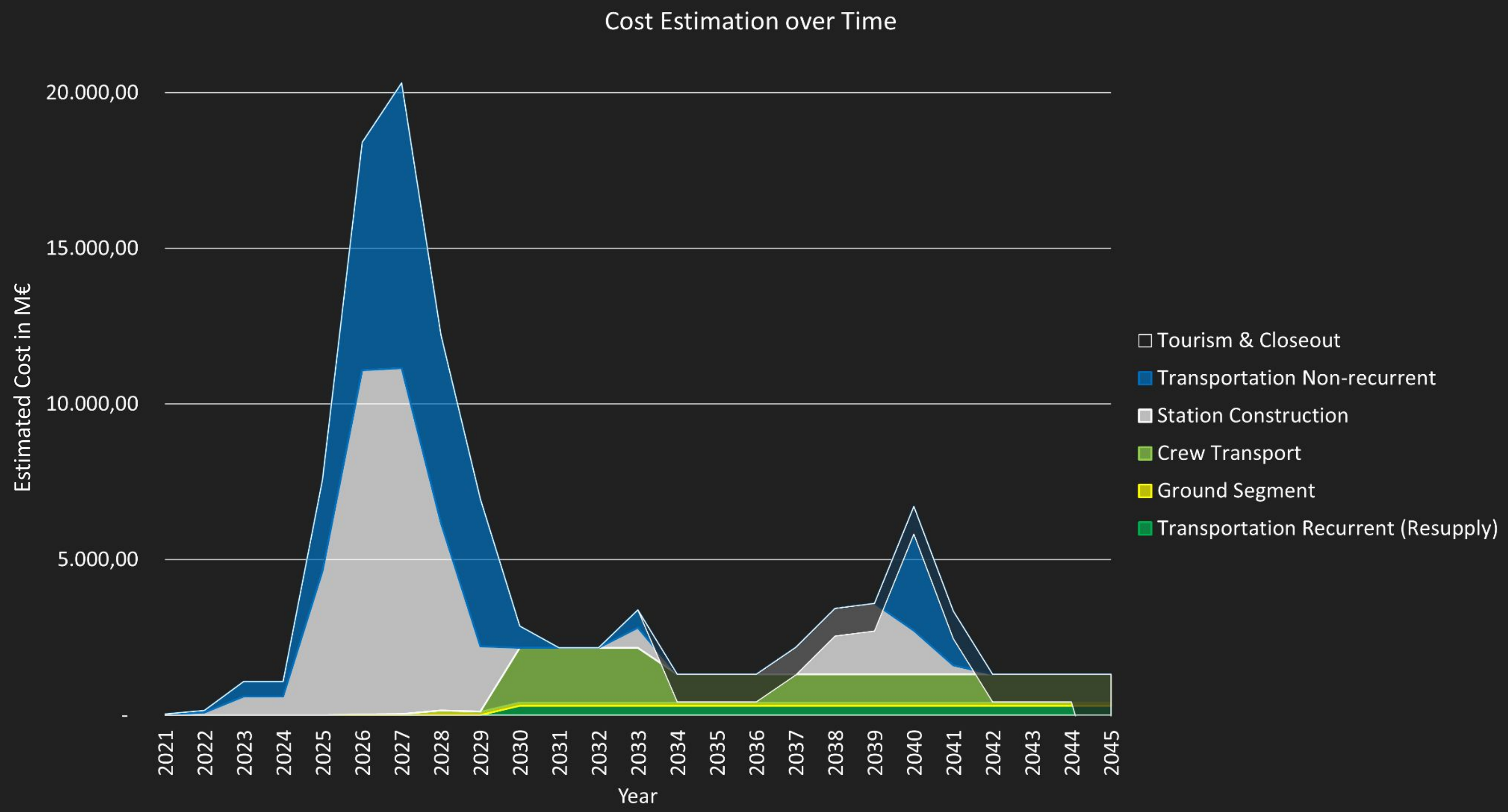

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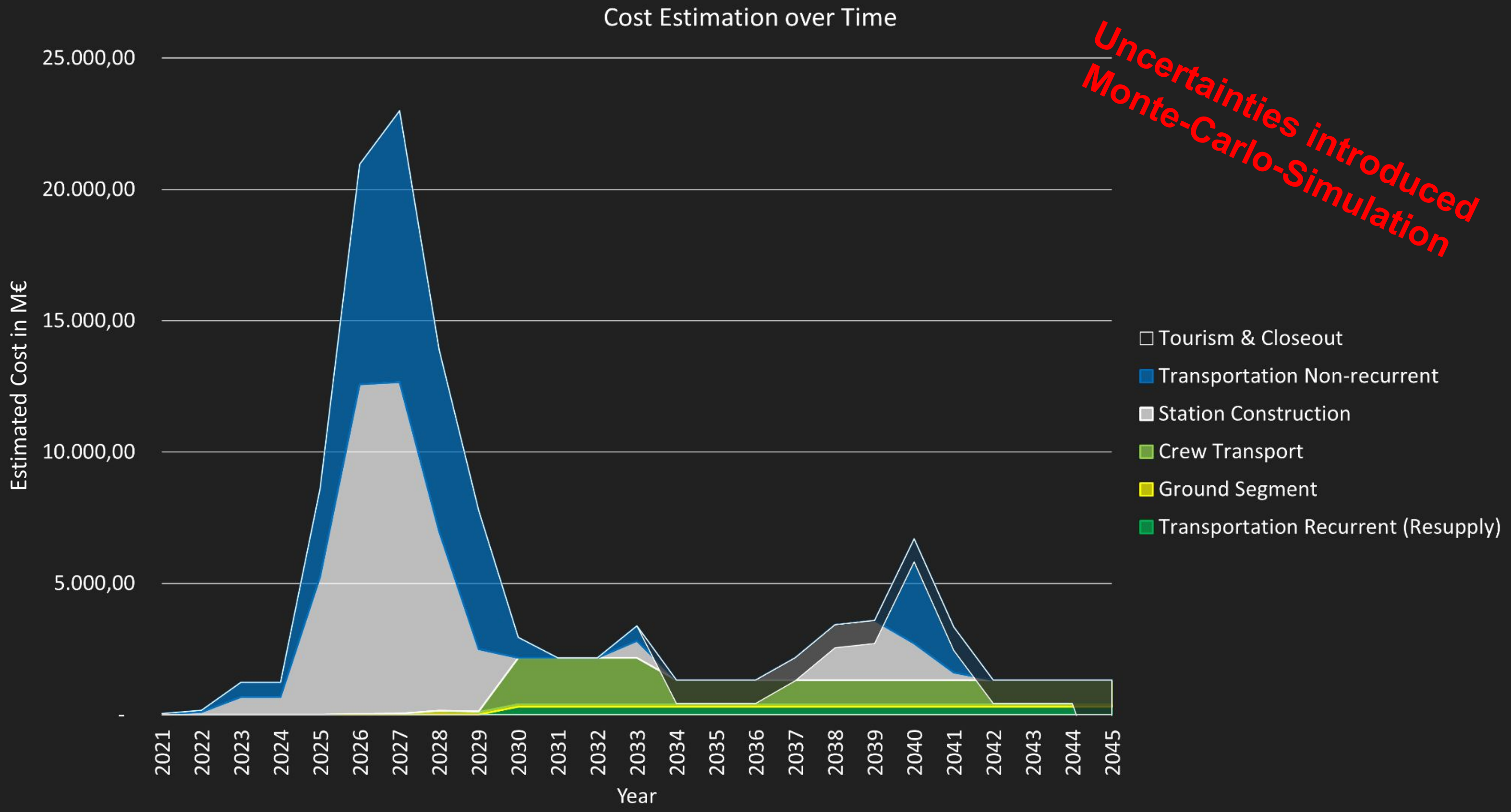

Uncertainties introduced
Monte-Carlo-Simulation

COST BREAKDOWN ESTIMATION

Cost Overview [M€]:

Station Construction	48.549
Transportation Non-recurrent	42.561
Crew Transport	17.968
Transportation Recurrent (Resupply)	4.807
Ground Segment	1.953

COST BREAKDOWN ESTIMATION

Cost Overview [M€]:

Station Construction	48.549
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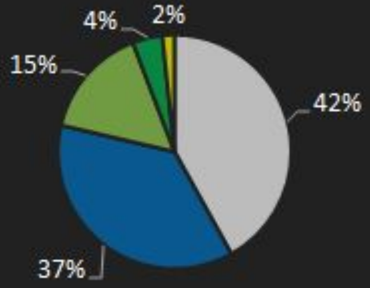
Ground Segment	1.953
Total Mission Cost without earnings	115.838



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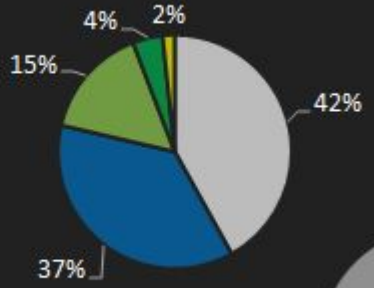
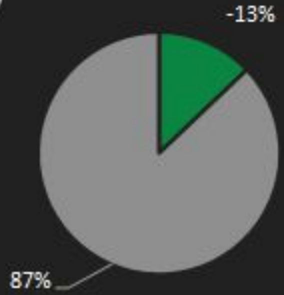
Ground Segment	1.953
Total Mission Cost without earnings	115.838
Tourism & Closeout	-14.959
Total Mission Cost	100.879





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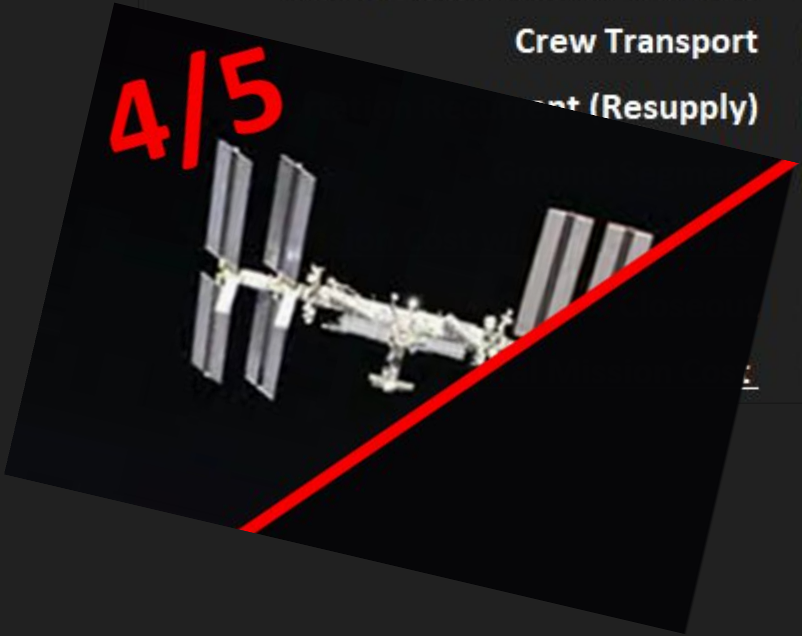
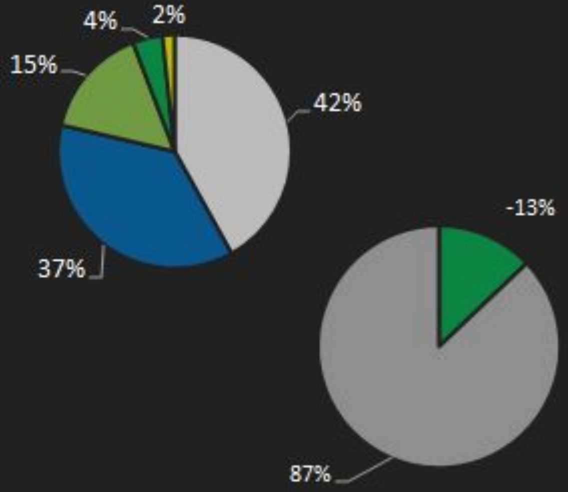
	100.879





COST BREAKDOWN ESTIMATION

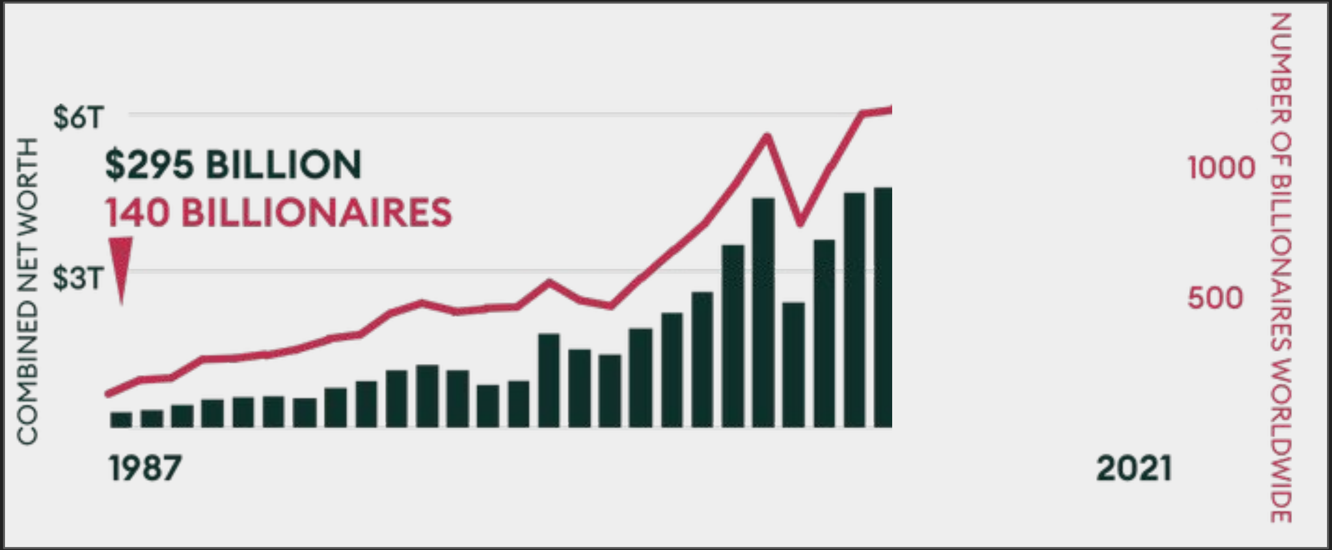
Starting in 2033:

One week on the moon

590M€

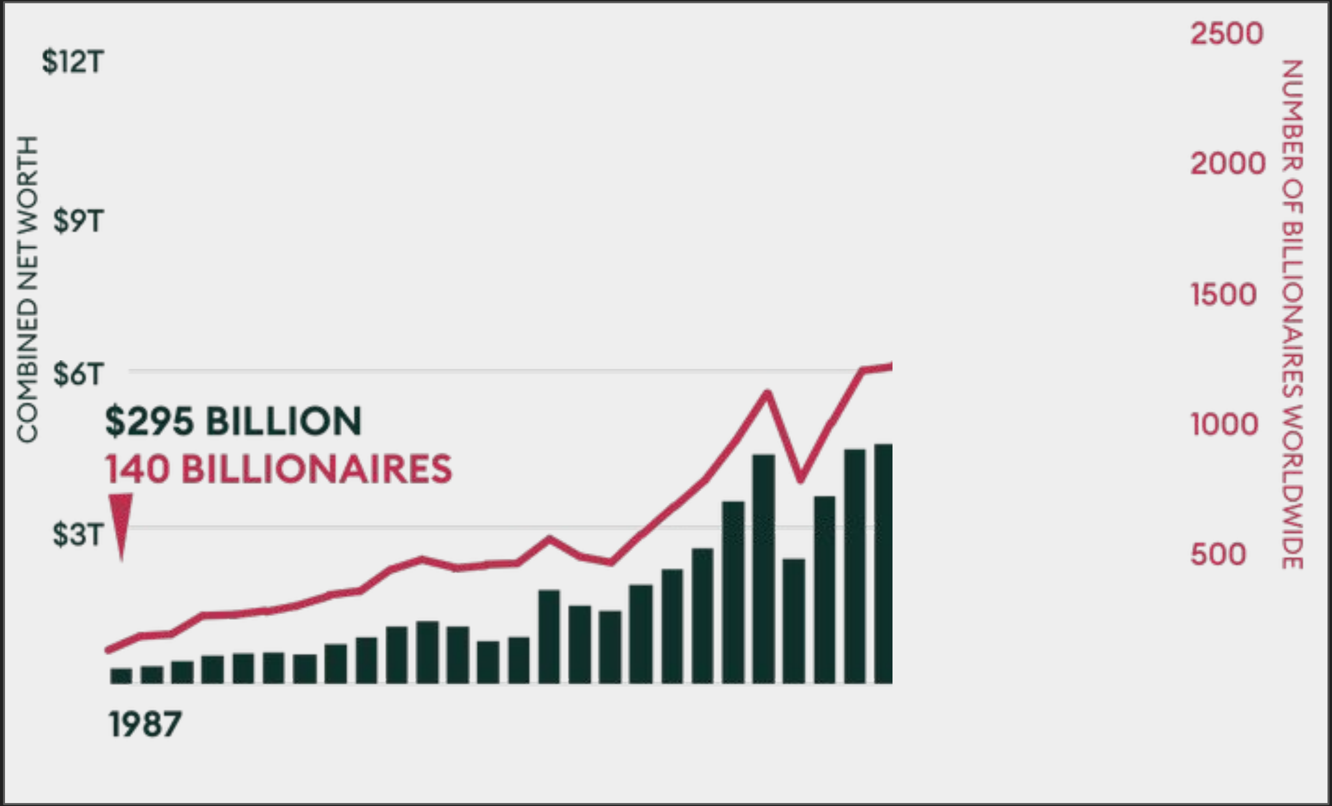
COST BREAKDOWN ESTIMATION

590M€

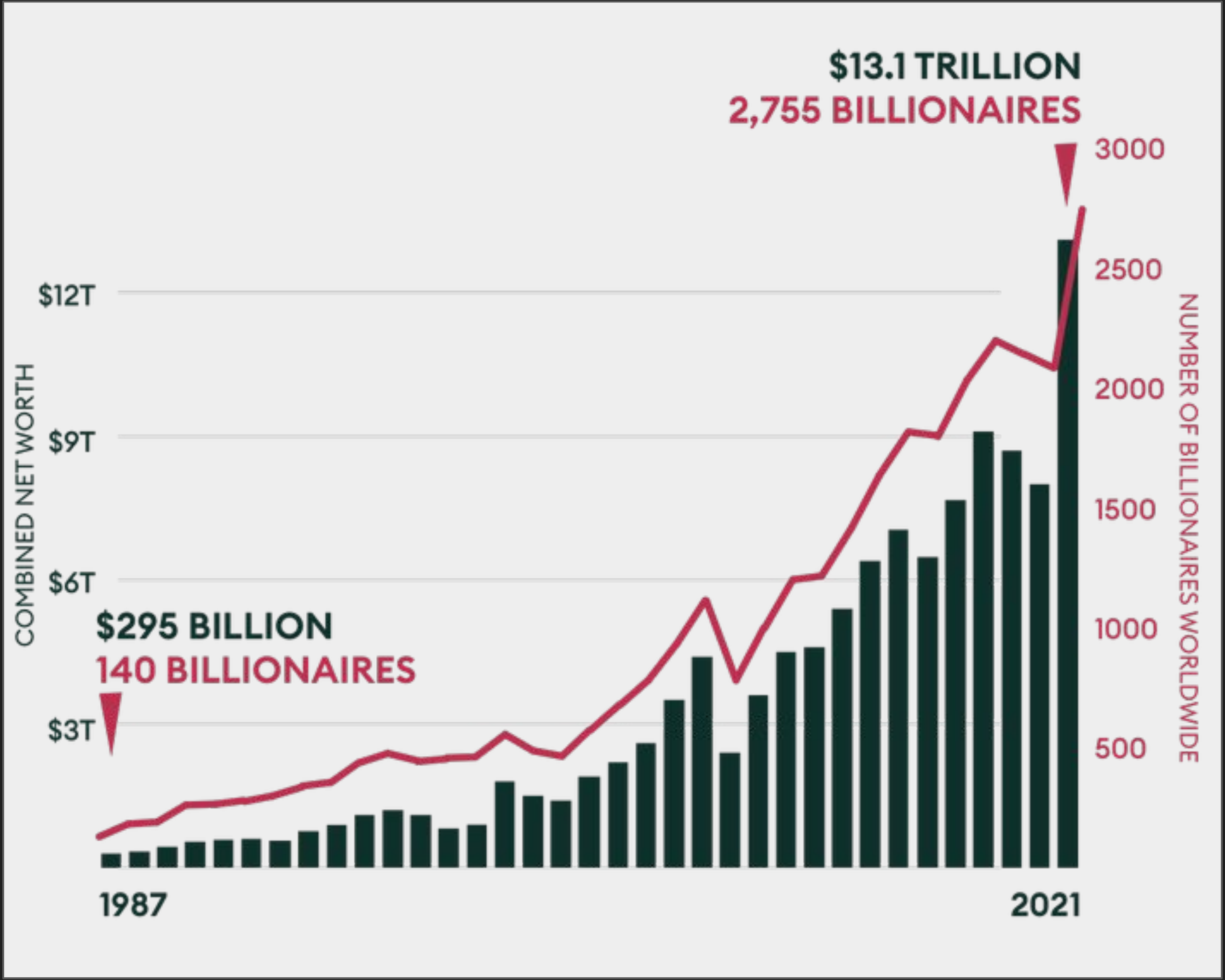


COST BREAKDOWN ESTIMATION

590M€



590M€



$13.1 TRILLION
2,755 BILLIONAIRES
$295 BILLION
140 BILLIONAIRES
COMBINED NET WORTH
$12T
$9T
$6T
$3T
3000
2500
2000
1500
1000
500
NUMBER OF BILLIONAIRES WORLDWIDE
1987
2021

OUTREACH STRATEGY - PARTNERS

OUTREACH STRATEGY - SOCIAL MEDIA!

SUMMARY

A significant step for humankind towards the settlement of celestial bodies beyond the Earth

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A significant step for humankind towards the settlement of celestial bodies beyond the Earth

An international effort that extends the boundaries of current space technology

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A significant step for humankind towards the settlement of celestial bodies beyond the Earth

An international effort that extends the boundaries of current space technology

A strategic resource outpost to support the Lunar Gateway and future endeavours

SPECIAL THANKS!

To the organizers, lecturers and experts, as well as everyone involved in this workshop for this fabulous learning opportunity and for all the new knowledge, techniques and friendships we've gained along the way.

BACKUP SLIDES

ELECTRICAL POWER SYSTEM

		TRL	Performance (power density)	Costs	low risk	Environmental requirements	availabilty	political constrains	Sum	Weighting factor [%]
Criteria	TRL		-	+	0	+	-	-	2	11,1%
	Performance (power density)	+		-	+	-	-	+	3	16,7%
	Costs	-	+		-	-	-	-	1	5,6%
	low risk	0	-	+		+	0	+	3	16,7%
	Environmental requirements	-	+	+	-		0	-	2	11,1%
	availabilty	+	+	+	0	0		-	3	16,7%
	political constrains	+	-	+	-	+	+		4	22,2%
		Total number of "+"							18	
		weighting of one "+" [%]							5,6%	

		Weighting factor [%]	Solarpanels +RFC		Solarpanels + sec. Batteries		Nuclear Reactor		RTG		Solarpaneldynamic	
Criteria	TRL	11,1%	1	0,11	2	0,22	1	0,11	2	0,22	1	0,11
	Performance (power density)	16,7%	2	0,33	1	0,17	2	0,33	0	0,00	2	0,33
	Costs	5,6%	2	0,11	2	0,11	0	0,00	0	0,00	1	0,06
	low risk	16,7%	2	0,33	2	0,33	0	0,00	2	0,33	1	0,17
	Environmental requirements	11,1%	0	0,00	0	0,00	2	0,22	2	0,22	0	0,00
	availabilty	16,7%	2	0,33	2	0,33	0	0,00	1	0,17	1	0,17
	political constrains	22,2%	2	0,44	2	0,44	0	0,00	1	0,22	0	0,00
	Max perecntage	100%	11	1,67	11	1,61	5	0,67	8	1,17	6	0,83
	Sum	max. 2,00	1,67		1,61		0,67		1,17		0,83	
	Rang		1		2		5		3		4	

PROPULSION - Trade Off - Crew Trajectory

	Availability	Performance	Costs	Risk	Transfer Time	Sum	Weighting factor [%]
Availability		+	-	-	-	1	10.0%
Performance	-		+	-	-	1	10.0%
Costs	+	-		-	-	1	10.0%
Risk	+	+	+		-	3	30.0%
Transfer Time	+	+	+	+		4	40.0%
	Total number of "+"					10	
	weighting of one "+" [%]					10.0%	

	Weighting factor [%]	Direct to moon and back		Direct to moon and back with orbital stage		Refuel in Space at the Lunar Gate		Refuel on Lunar Surface		Rendesvous L1 or L2 -> WSB		Low Thrust Transfer to Moon/Lunar Gateway		Bi-Elliptical Transfer	
Availability	10.0%	2	0.20	2	0.20	1	0.10	0	0.00	2	0.20	2	0.20	2	0.20
Performance	10.0%	0	0.00	1	0.10	2	0.20	2	0.20	0	0.00	0	0.00	2	0.20
Costs	10.0%	1	0.10	1	0.10	0	0.00	2	0.20	1	0.10	2	0.20	1	0.10
Risk	30.0%	0	0.00	0	0.00	2	0.60	1	0.30	1	0.30	0	0.00	1	0.30
Transfer Time	40.0%	2	0.80	2	0.80	2	0.80	2	0.80	0	0.00	0	0.00	0	0.00
Max perecntage	100%	5	1.10	6	1.20	7	1.70	7	1.50	4	0.60	4	0.40	6	0.80
Sum	max. 2,00	1.10		1.20		1.70		1.50		0.60		0.40		0.80	
Rang		5		4		1		2		7		8		6	

PROPULSION - Trade Off - Cargo Trajectory

	Availability	Performance	Costs	Risk	Time	Sum	Weighting factor [%]
Availability		-	-	+	+	2	20.0%
Performance	+		-	-	-	1	10.0%
Costs	+	+		+	+	4	40.0%
Risk	-	+	-		+	2	20.0%
Time	-	+	-	-		1	10.0%
	Total number of "+"					10	
	weighting of one "+" [%]					10.0%	

	Weighting factor [%]	Rendesvous L1 or L2 -> WSB		Direct Transfer to moon/Lunar Gateway		Low Thrust Transfer to Moon/Lunar Gateway		Bi-Elliptical Transfer	
Availability	20.0%	2	0.40	2	0.40	2	0.40	2	0.40
Performance	10.0%	0	0.00	1	0.10	0	0.00	2	0.20
Costs	40.0%	1	0.40	0	0.00	2	0.80	1	0.40
Risk	20.0%	1	0.20	1	0.20	0	0.00	1	0.20
Time	10.0%	0	0.00	2	0.20	0	0.00	0	0.00
Max percentage	100%	4	1.00	6	0.90	4	1.20	6	1.20
Sum	max. 2,00	1.00		0.90		1.20		1.20	
Rang		2		3		1		1	

PROPULSION - Trade Off - Capsule

	TRL - Availability	Performance (Payload Mass)	Costs/Seat	Risk	Designed Life Time	Sum	Weighting factor [%]
TRL - Availability		-	+	-	+	2	22.2%
Performance (Payload Mass)	+		+	0	+	3	33.3%
Costs/Seat	-	-		-	+	1	11.1%
Risk	+	0	+		-	2	22.2%
Designed Life Time	-	-	-	+		1	11.1%
	Total number of "+"					9	
	weighting of one "+" [%]					11.1%	

	TRL - Availability	Performance (Payload Mass)	Costs/Seat	Risk	Designed Life Time	Sum	Weighting factor [%]
TRL - Availability		-	+	-	+	2	22.2%
Performance (Payload Mass)	+		+	0	+	3	33.3%
Costs/Seat	-	-		-	+	1	11.1%
Risk	+	0	+		-	2	22.2%
Designed Life Time	-	-	-	+		1	11.1%
	Total number of "+"					9	
	weighting of one "+" [%]					11.1%	

PROPULSION - Launcher

	TRL	Performance	Costs	Risk/ Reliability	Sum	Weighting factor [%]
TRL		+	+	-	2	33.3%
Performance	-		+	-	1	16.7%
Costs	-	-		+	1	16.7%
Risk/ Reliability	+	+	-		2	33.3%
	Total number of "+"				6	
	weighting of one "+" [%]				16.7%	

Crew

	Weighting factor [%]	Falcon 9 Heavy		SLS		Starship	
TRL	33.3%	2	0.67	0	0.00	0	0.00
Performance	16.7%	0	0.00	2	0.33	2	0.33
Costs	16.7%	1	0.17	0	0.00	2	0.33
Risk/ Reliability	33.3%	2	0.67	0	0.00	0	0.00
Max perecntage	100%	5	1.50	2	0.33	4	0.67
Sum	max. 2,00	1.50		0.33		0.67	
Rang		1		3		2	

Cargo

	Weighting factor [%]	Falcon 9		Falcon 9 Heavy		SLS		Ariane 64		Delta IV		Long March 5		Starship	
TRL	14.3%	2	0.29	2	0.29	0	0.00	0	0.00	2	0.29	2	0.29	0	0.00
Performance	42.9%	0	0.00	2	0.86	2	0.86	0	0.00	0	0.00	0	0.00	2	0.86
Costs	14.3%	1	0.14	1	0.14	0	0.00	1	0.14	1	0.14	1	0.14	2	0.29
Risk	28.6%	1	0.29	2	0.57	0	0.00	0	0.00	1	0.29	1	0.29	0	0.00
Max percentage	100%	4	0.71	7	1.86	2	0.86	1	0.14	4	0.71	4	0.71	4	1.14
Sum	max. 2,00	0.71		1.86		0.86		0.14		0.71		0.71		1.14	
Rang		4		1		3		5		4		4		2	

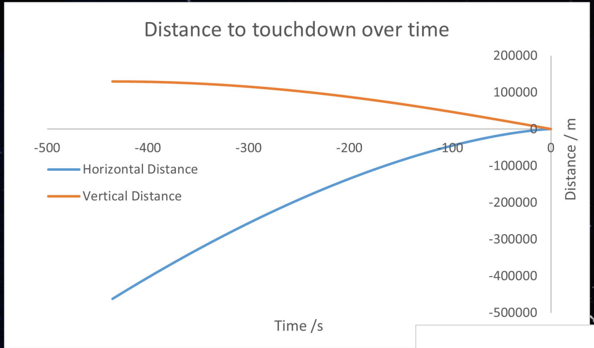
AOCS - Trade Off

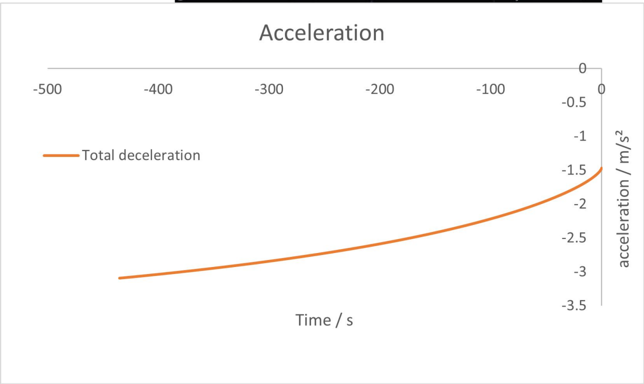
	Criteria						
	low Risk	**performance**	**cost**	**safety**	accuracy	sum	weighting factor [%]
low Risk		+	+	0	+	3	37.50%
performance	-		+	-	-	1	12.50%
cost	-	-		-	+	1	12.50%
safety	0	+	+		0	2	25.00%
accuracy	-	+	-	0		1	12.50%
	Total number of "+"					8	
	weighting of one "+" [%]					12.50%	

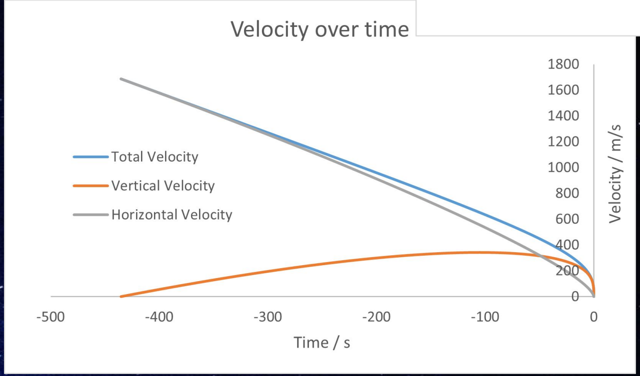
		actuator concepts					
	weighting factor	Reaction Wheels		Magnetorquer		thruster	
low Risk	37.50%	2	0.75	1	0.38	1	0.38
performance	12.50%	1	0.13	1	0.13	1	0.13
cost	12.50%	2	0.25	1	0.13	0	0.00
safety	25.00%	2	0.50	1	0.25	1	0.25
accuracy	12.50%	2	0.25	2	0.25	1	0.13
max. percentage	100.00%		1.88		1.13		0.88
sum	max. 2,00	1.88		1.13		0.88	
rank		1		2		3	

EDL

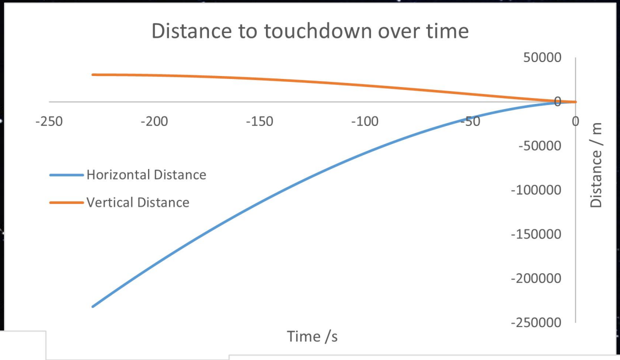
Cargo

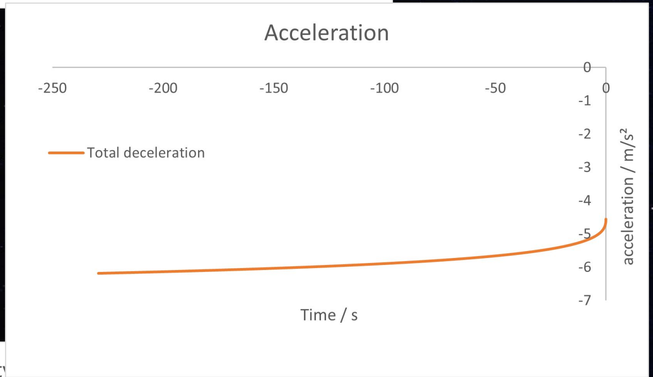


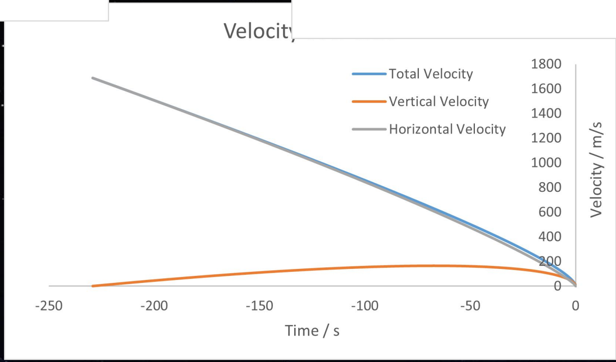




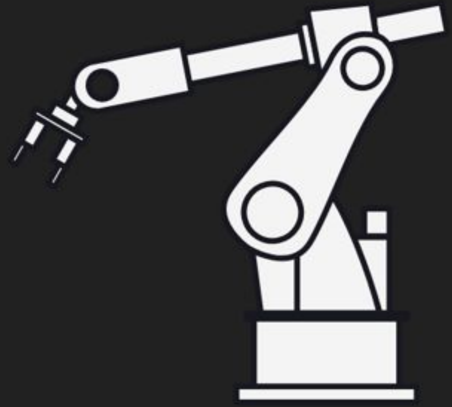
Crew







Robotics & EVA



- Shall enable lunar base construction
- Shall assist in human exploration & EVAs
- Shall enable resource prospecting & surface level research

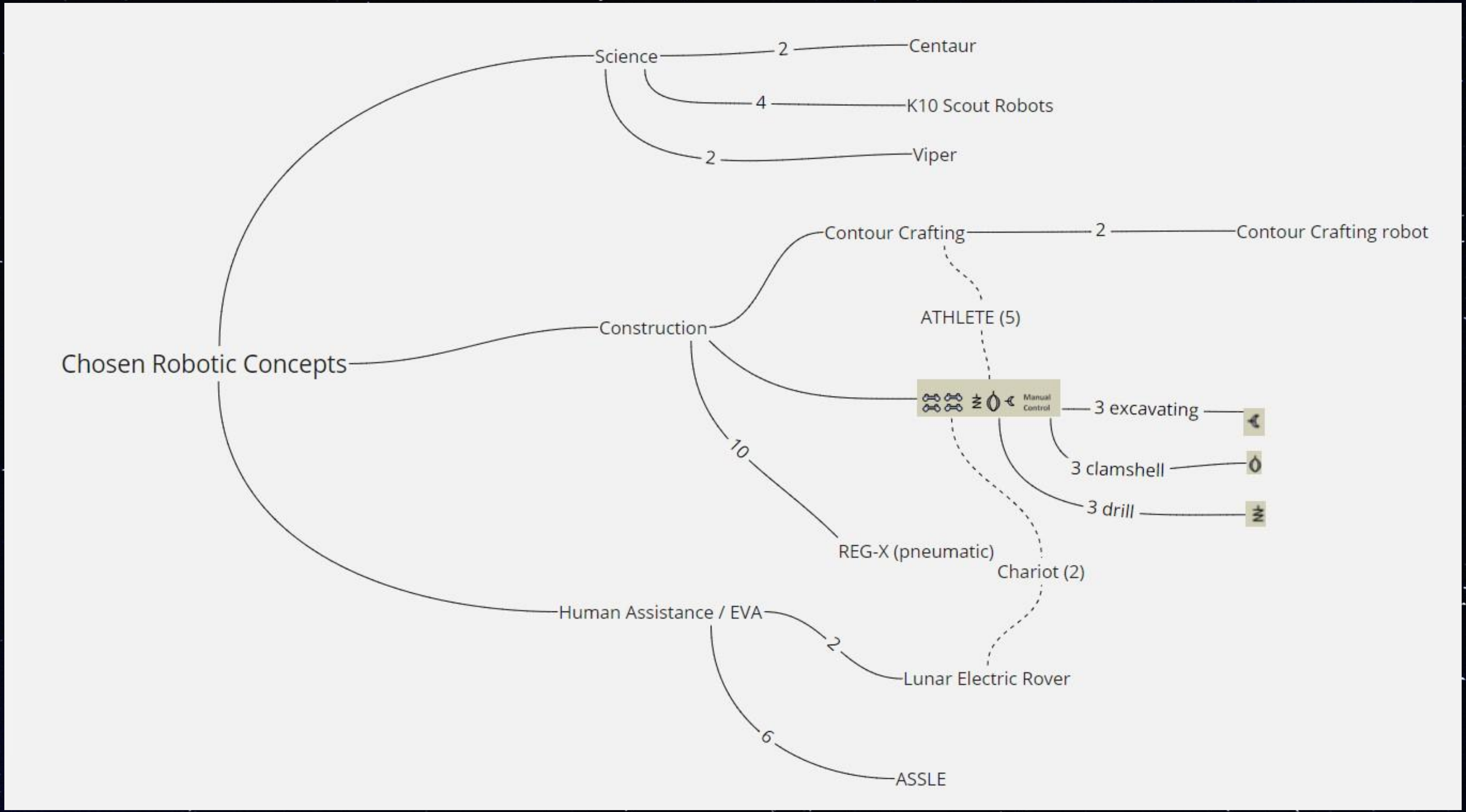
Iniitial Infrastructure Deployment

Astronaut launch to Lunar Base

SSDW LOVE

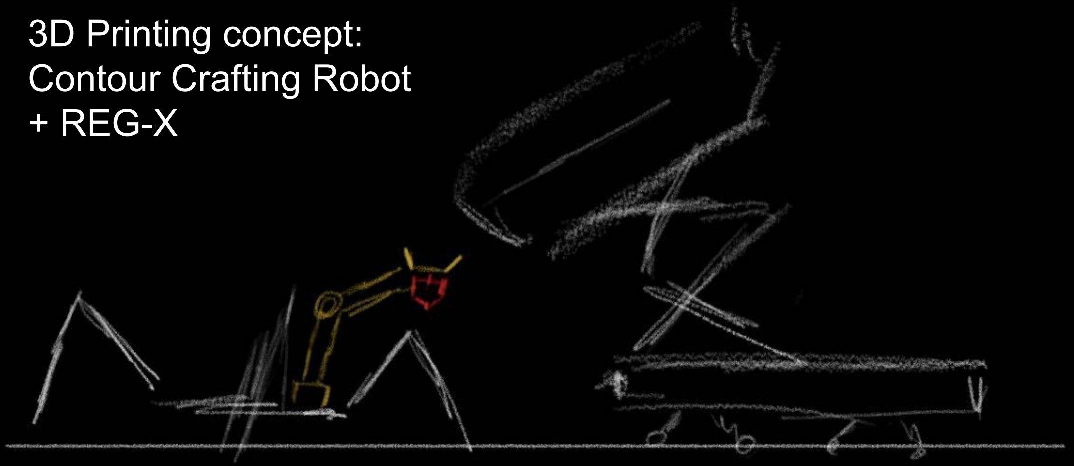
Expansion

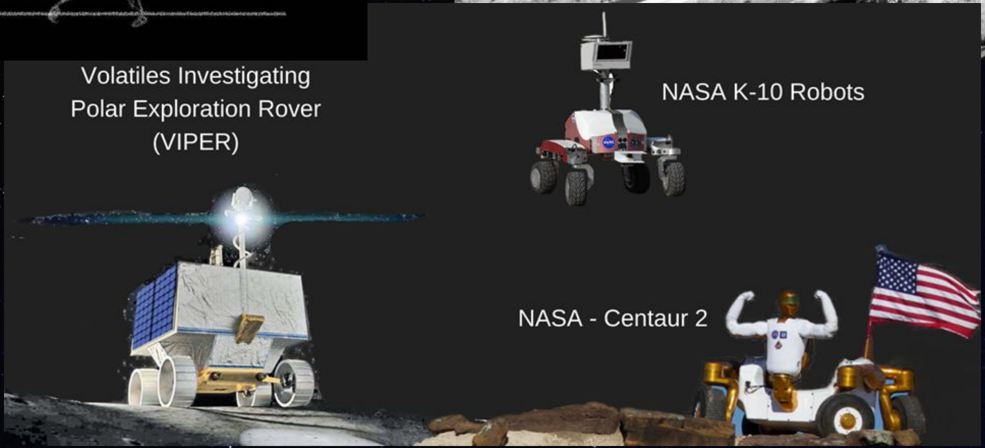
ROBOTICS & EVA



ROBOTICS & EVA

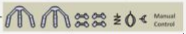
3D Printing concept:
Contour Crafting Robot
+ REG-X





ROBOTICS & EVA

Group I: Science		Concepts													
	weighting factor	SCARAB		Perserverance Lunar Concept		Lunokhod 2		YUTU-2		Pragyan		VIPER (NASA)		K10 Scout (NASA)	
low risk	15,38%	2	0,31	3	0,46	3	0,46	3	0,46	2	0,31	3	0,46	2	0,31
performance	30,77%	2	0,62	3	0,92	1	0,31	2	0,62	1	0,31	3	0,92	3	0,92
cost	0,00%	3	0,00	1	0,00	2	0,00	1	0,00	2	0,00	1	0,00	2	0,00
power	15,38%	3	0,46	1	0,15	1	0,15	2	0,31	3	0,46	2	0,31	2	0,31
mass	7,69%	3	0,23	1	0,08	1	0,08	2	0,15	3	0,23	2	0,15	2	0,15
level of autonomy	30,77%	3	0,92	3	0,92	1	0,31	3	0,92	3	0,92	3	0,92	3	0,92
max. percentage	100,00%		2,54		2,54		1,31		2,46		2,23		2,77		2,62
sum	max. 3,00	2,54		2,54		1,31		2,46		2,23		2,77		2,62	
rank		3		3		6		4		5		1		2	

Group IIa: Construction		Concepts									
	weighting factor	 Manual and Automated Digging Control		 Manual Control		 ANT Controlled		ATHLETE +  Manual Control		REG-X (Pneumatic Excavation)	
low risk	38,46%	1	0,38	1	0,38	1	0,38	2	0,77	1	0,38
performance	23,08%	3	0,69	2	0,46	3	0,69	2	0,46	3	0,69
cost	0,00%	1	0,00	2	0,00	1	0,00	1	0,00	2	0,00
power	15,38%	1	0,15	3	0,46	1	0,15	2	0,31	3	0,46
mass	7,69%	1	0,08	3	0,23	1	0,08	2	0,15	2	0,15
level of autonomy	15,38%	2	0,31	1	0,15	3	0,46	3	0,46	3	0,46
max. percentage	100,00%		1,62		1,69		1,77		2,15		2,15
sum	max. 3,00	1,62		1,69		1,77		2,15		2,15	
rank		4		3		2		1		1	

Group IIb: 3D-Printing		Concepts									
	weighting factor	Contour Crafting Robot on ATHLETE Rover		D-Shape Technology (ESA)		ESA 3D printing rover Concept		Solar 3D Printing + support vehicle for laying down regolith		Building Blocks 3D Printing + support vehicle for laying down regolith	
low risk	38,46%	2	0,77	1	0,38	0	0,00	2	0,77	1	0,38
performance	23,08%	3	0,69	2	0,46	1	0,23	2	0,46	2	0,46
cost	0,00%	1	0,00	1	0,00	2	0,00	2	0,00	1	0,00
power	15,38%	3	0,46	2	0,31	1	0,15	2	0,31	2	0,31
mass	7,69%	1	0,08	2	0,15	3	0,23	1	0,08	1	0,08
level of autonomy	15,38%	3	0,46	3	0,46	3	0,46	2	0,31	3	0,46
max. percentage	100,00%		2,46		1,77		1,08		1,92		1,69
sum	max. 3,00	2,46		1,77		1,08		1,92		1,69	
rank		1		3		5		2		4	

ROBOTICS & EVA

Group III: Human Assistance & EVA (unpressurised)		Concepts			
	weighting factor	Lunar Roving Vehicle (LRV)		Chariot (NASA)	
low risk	15,38%	3	0,46	2	0,31
performance	38,46%	1	0,38	3	1,15
cost	0,00%	3	0,00	1	0,00
power	23,08%	2	0,46	3	0,69
mass	7,69%	3	0,23	2	0,15
level of autonomy	15,38%	0	0,00	1	0,15
max. percentage	100,00%		1,54		2,46
sum	max. 3,00	1,54		2,46	
rank		2		1	

Group III: Human Assistance & EVA (pressurised)		Concepts					
	weighting factor	PRC + ATHLETE		JAXA Lunar Cruiser		Lunar Electric Rover (NASA)	
low risk	38,46%	2	0,77	1	0,38	2	0,77
performance	23,08%	3	0,69	3	0,69	3	0,69
cost	0,00%	2	0,00	1	0,00	2	0,00
power	15,38%	1	0,15	3	0,46	2	0,31
mass	7,69%	2	0,15	2	0,15	3	0,23
level of autonomy	15,38%	2	0,31	3	0,46	2	0,31
max. percentage	100,00%		2,08		2,15		2,31
sum	max. 3,00	2,08		2,15		2,31	
rank		3		2		1	

ROBOTICS & EVA

Group IV: Space Suits	low risk	performance	cost	mass	mobility	sum	weighting factor [%]
low risk		+	+	+	+	4	40,00%
performance	-		+	+	+	3	30,00%
cost	-	-		-	-	0	0,00%
mass	-	-	+		-	1	10,00%
mobility	-	-	+	+		2	20,00%
	Total number of "+"					10	
	weighting of one "+" [%]					10,00%	

Group IV: Space Suits			Concepts					
		weighting factor	A7LB (Apollo)		Planetary Space Suit		ASSLE	
low risk		40,00%	3	1,20	0	0,00	2	0,80
performance		30,00%	1	0,30	3	0,90	3	0,90
cost		0,00%	2	0,00	1	0,00	2	0,00
mass		10,00%	1	0,10	3	0,30	3	0,30
mobility		20,00%	1	0,20	3	0,60	3	0,60
	max. percentage	100,00%		1,80		1,80		2,60
	sum	max. 3,00	1,80		1,80		2,60	
	rank		2		2		1	

ROBOTICS & EVA

Power System TradeOffs - Robotics

	Criteria										
	low risk	performance (power density)	cost	Environmental requirements	availability	political constrains	lifetime	Safety	Reliability	sum	weighting factor [%]
low risk		-	+	+	-	-	-	+	+	4	12,90%
performance (power density)	+		+	-	-	+	0	+	0	4	12,90%
cost	-	-		-	-	-	-	-	-	0	0,00%
Environmental requirements	-	+	+		0	-	+	+	+	5	16,13%
availability	+	+	+	0		-	+	+	+	6	19,35%
political constrains	+	-	+	+	+		-	-	-	4	12,90%
lifetime	+	0	+	-	-	+		+	0	4	12,90%
Safety	-	-	+	-	-	+	-		0	2	6,45%
Reliability	-	0	+	-	-	+	0	0		2	6,45%
	Total number of "+"									31	
	weighting of one "+" [%]									3,23%	

Power System TradeOffs - Robotics

		concepts							
	weighting factor [%]	Solarpanels		Solarpanels + Secondary batteries		RTG		RTG + Secondary batteries	
low risk	12,90%	3	0,39	3	0,39	3	0,39	3	0,39
performance (power density)	12,90%	2	0,26	2	0,26	3	0,39	2	0,26
cost	0,00%	2	0,00	2	0,00	1	0,00	1	0,00
Environmental requirements	16,13%	1	0,16	1	0,16	2	0,32	3	0,48
availability	19,35%	3	0,58	3	0,58	2	0,39	2	0,39
political constrains	12,90%	2	0,26	3	0,39	2	0,26	2	0,26
lifetime	12,90%	2	0,26	2	0,26	3	0,39	3	0,39
Safety	6,45%	3	0,19	3	0,19	2	0,13	2	0,13
Reliability	6,45%	2	0,13	1	0,06	3	0,19	3	0,19
max. percentage	87,10%		2,23		2,29		2,45		2,48
sum	max. 3,00	2,23		2,29		2,45		2,48	
rank		4		3		2		1	

ROBOTICS & EVA

Facts

- TRLs
- Science Payload
- Height / reach of ATHLETE 2nd gen: 15,5 m / payload mass: 14,5 t

Assumptions

- Power Systems: RTG, Sec. Batteries, Solar Arrays, Fuel Cells
- Nozzle width of 3D printing extruder: 28 mm
- Extruder velocity: 0,6 m/s
- Velocity of rovers: 1-5 m/s
- Temperatures to be covered
- Assumptions on regolith

Calculations include 30 % margin

- Duration for 3D printing of habitat: ~6 months
- Mass of regolith needed: ~ 800 t
- Mass of regolith excavatable/transportable within 2 yrs for 10 REG-X: 1200 t
- Max. coverable distance for rovers

ROBOTICS & EVA

Name of the component	Quantity [-]	Mass Static per component [kg]	Components Mass Static [kg]	Mass Consumable [kg]	Power Consumption [W]	Power Dissipation [W]	"Doesn't fit"	Margin [%]	Mass w margin	Class
VIPER	2	430	860	0				30	1118	1
K-10	4	80	320	0	200			30	416	1
Centaur 2 + Robonaut 2	2	500	1000	0	175			30	1300	1
REG-X Pneumatic Traverse Mining Rover	10	2000	20000	0				30	26000	1
Chariot	2	1000	2000	0				30	2600	1
Hauling Module (Chariot)	2	200	400	0				30	520	1
Robotic arm integrating drill, clamshell, excavating, gripping hand	3	1000	3000	0				30	3900	1
ATHLETE 2nd gen.	5	2340	11700	0				30	15210	1
Contour crafting robot	2	700	1400	0				30	1820	1
Lunar Electric Rover	2	4000	8000	0				30	10400	1
ASSLE Space Suit	6	60	360	0				30	468	1
SUMMARY	40	12310	49040	0	375	0		SUMA	63752	

RADIATION

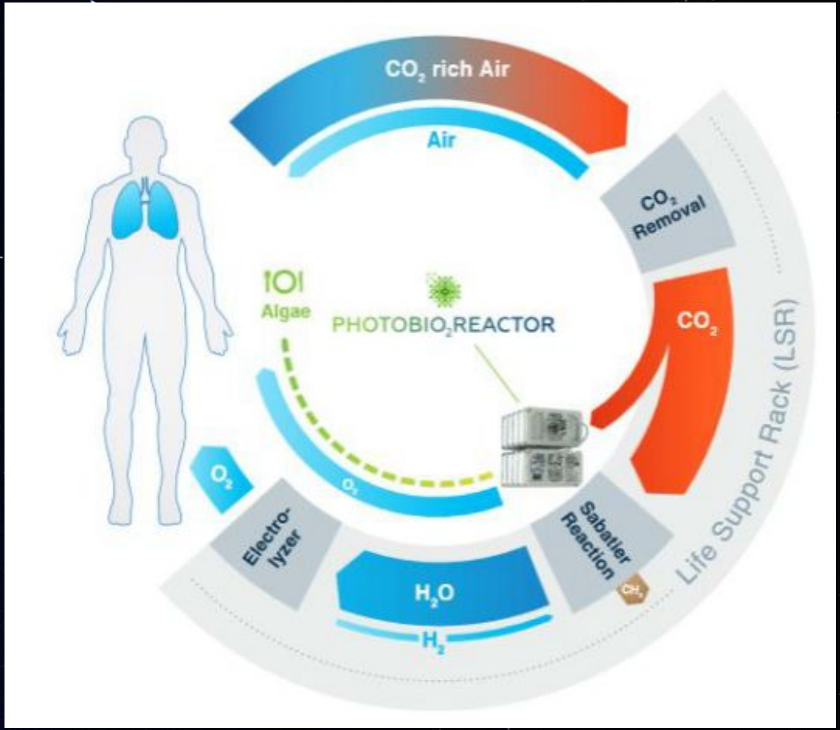
TABLE 43: Eq. dose for different Durations

	per Day	per Year/ per mission
Dose	0,3-0,4 mSv [30]	144mSv

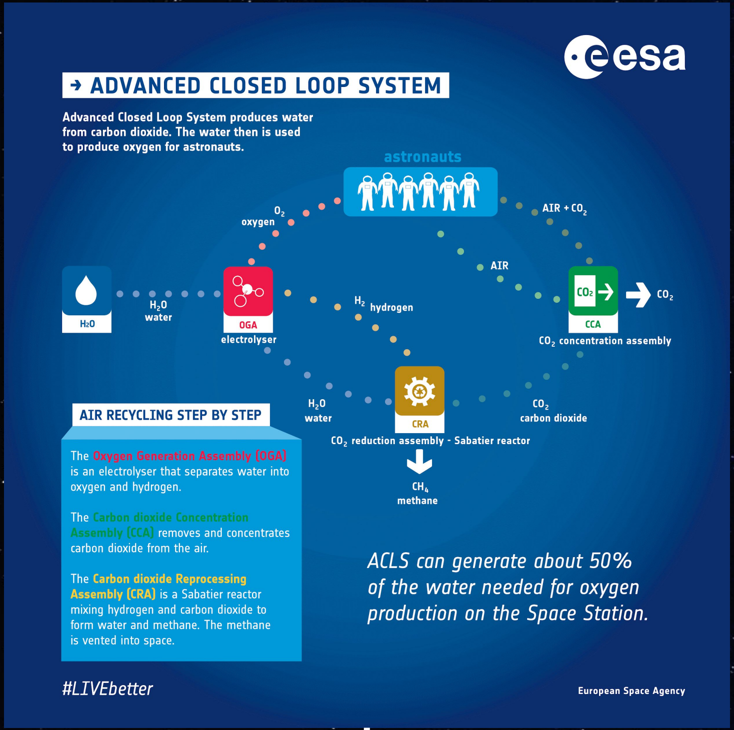
- Daily Limit: 8,5 mSv/d
- 30-Day Limit: 250 mSv
- Annual Dose: 500 mSv
- Career Limit: 1-4 Sv (Age and Gender Specific)

	No Shielding	Regolith Shielding	Bi-Layer Shielding
Thickness	[-]	$200g/cm^2$	Regolith $150g/cm^2$ Polyethylene $30g/cm^2$ & Polyethylene $20g/cm^2$
GCR 1977	1,15 mSv/day	0,6 mSv/day	0,2835 mSv/day
SPE 1972	8,2e5 mSv	41,68 mSv	2,61mSv

ECLSS



Photobioreactor (PBR)



plasma pyrolysis production PPA

$$2CH_4 \xrightarrow{\Delta} C_2H_2 + 3H_2$$

ECLSS

- LSS essential and life critical

  -> Water Recovery System (WRS) and Advanced Closed Loop System: both TRL 9

- Improving the recycling process regarding resource efficiency with a tested system

  -> Greenhouse: TRL 7

- Further development of a concept to close the resource circly even more

  -> MELiSSA project: TRL 5 in development but already partly tested

ECLSS

Greenhouse

Open Greenhouse

- the same atmospheric conditions as for humans
- psychological advantage of have time next to plants (also strawberries maybe and greenery/colors)
- not as efficient as the closed concept

↓

- humidity/water vapor->clean water
- food production
- psychological aspect (plants, colors, "zen garden")
- CO_2 removal
- O_2 production

Closed Greenhouse

- different atmospheric conditions than for humans
- higher CO_2 partial pressure
- lower O_2 partial pressure
- special light and temperature
- special mask needed for humans to in there and work on the plants (maintenance?)
- high complexity of the system
- high efficiency

ECLSS

2. Classification

Type of technology

		Cycle closure		
		Oxygen	Water	Carbon
	Storage			
Regenerative	Physico-chemical	X	X	
	Hybrid	X	X	(X)
	Biological	X	X	X

Physico-chemical

- + Well understood
- + Compact
- + Low maintenance
- + Quick response
- - No food production

Biological

- + Allows food production
- - Less well understood
- - Large volume
- - Maintenance intensive
- - Slow response

RADIO ASTRONOMY

		concepts							
	weigth	Crater Antenna		Phased Antenna Array		Crater Antenna VLBI		Phased Antenna Array VLBI	
high TRL	5.56%	1	0.06	2	0.11	1	0.06	1	0.06
high performance *	27.78%	1	0.28	1	0.28	2	0.56	2	0.56
low cost	0.00%	1	0.00	1	0.00	0	0.00	0	0.00
low risk	5.56%	1	0.06	2	0.11	1	0.06	1	0.06
high SoD	16.67%	0	0.00	2	0.33	0	0.00	1	0.17
high sensitivity	27.78%	1	0.28	1	0.28	2	0.56	2	0.56
low DoE	16.67%	0	0.00	2	0.33	0	0.00	1	0.17
max. percentage	100.00%	0	0.67	2	1.44	0	1.22	2	1.56
sum	max. 2,00	0.67		1.44		1.22		1.56	
rank		4		2		3		1	

Phased Array Antennas: computer-controlled antenna array → can be electronically steered to point in different directions without moving the antennas

RADIO ASTRONOMY

Mission Development:

- starting with 3 - 6 PAA sites, from there every year up to 8 additional sites → gradual increase of sensitivity & baseline distances, therefore resolution
- As soon as there's enough crew capacity, astronomers can join and work from the station directly

Performance Estimations for a 500 km Baseline

- 110 - 4 GHz: 43 - 38 mas
- 1.4 GHz: 110 mas
- 200 - 1 MHz: 0.8 arcsec - 115 arcsec

For comparison: human eye has 40 arcsec resolution

Possible survey topics for the telescope:

- investigation of the 21cm HI line in a radio noise free environment
- investigation of the red-shifted 21cm HI line for re-ionization period research
- investigation of the solar system planets radio emission
- investigation of the suns radio emission

RISK MATRIX

	ID	Failure situations	Probality	Severity
Robotics & EVA	01	Fail of autonomous system	3	3
	02	Malfunction of 3D printer on rover	4	1
	03	Robot falls over	1	3
	04	Failure of secondary batteries	2	2
	05	Blocking of mechanisms due to lunar dust	4	2
EPS	06	A solar panel does not unfold	2	3
	07	Solar panels severely damaged by meteorites	1	4
	09	Solar panels partially damaged by meteorites	2	3
	09	Unknown illumination factors	2	4
Mission Analysys	10	Orbital maneuver failure	1	3
	11	Launcher failure	1	4
	12	Cargo delivery delay	3	3
AOCS& EDL	13	Hard landing with cargo	2	3
	14	Hard landing with crew	2	5
	15	Take off - ignition problems (cargo vehicle)	2	3
	16	Take off - ignition problems (with crew)	2	4
ECLSS	17	Moon base depressurization	2	5
	18	Water tank leak	1	3
	19	Losses in food production outage	1	3
	20	LSS malfunction	3	2
	21	Power outage	2	4
	22	LSS modular contamination	4	2
Design and Inner Architecture	23	Design concept does not work	3	3
	24	Radiation overdose due to windows	3	3
TCS	25	Mechanical failure of louver radiator	3	3
	26	Heater malfunction	1	5
	27	Flute pumps stop working	2	3
Structure& Mechanism	28	Structural damage due to debris impact	2	4
	29	Structural damage due to seismic loading	1	4
	30	Structural damage of 3D printed construction	2	4
	31	Structural damage: manuf., transp., and depl. errors	1	4

	ID	Failure situations	Probality	Severity
Communication	32	Loss of power in communication center	4	2
	33	Destruction of antenna due to micrometeorites	2	3
	34	Damage com system: manuf., transp., and depl. errors	2	3
	35	destruction of com satellites due to micro meteorites	1	5
	36	Loss of com. with Earth due to failure of sat. const.	1	5
	37	Loss of com. with Earth due to failing Grd. Station	2	4
Human Factor Eng	38	Conflict within the crew	1	4
	39	Error in data reporting impacts the mission	1	3
	40	Manual takeover mistake	1	4
Propulsion & Transport	41	Rocket explosion - crew	1	5
	42	Rocket explosion - cargo	1	3
	43	Thrusters malfunction - cargo vehicle	2	3
	44	Thrusters malfunction - crew vehicle	2	4
Radiation	45	Destruction of electronics due to radiation	2	5
	46	Overdose of radiation during EVA due to solar activity	3	3
	47	Total annual dose of radiation is over exceeded	3	3
Astronomy	48	Losing a telescope due to deploy mech. failure	2	2
	49	Micrometeorites damage the telescope	2	2
	50	Losing a telescope due to power failure	4	3
	51	Failure of components due to galactic radiation	4	2
	52	Failure of components due to solar energetic part.	3	3
System Enginnering	53	Unstable Requirements	5	4
	54	Ambitious performance requirements	3	3
	55	Reliance on advances in low TLR technology	4	2
	56	Lack of synergy between subsystems	4	4
	57	Underestimation of the problem scale	4	3
	58	Wrong data from one subsystem impacts the rest	4	3
Project Management	59	Cost overrun	4	4
	60	Schedule overrun	4	4
	61	Loss of international support	2	4
	62	Documentation mistake	3	3
	63	Economic crisis - project discontinuation	1	5
	64	Supplier or subcontractor failure	3	4
	65	Marks ups due to economic situation	3	3

Cost per System

System Cost Overview [M€]		
System	Per Unit Price	Development Cost
Space Station	6,944.33	39,156.85
Robotic Systems	-	8,950.78
Crew Lander	2,239.97	17,324.63
Cargo Transfer & Lander not reusable	165.43	9,161.01
Reusable Crew Transfer	-	10,510.13
Crew Dragon Modified	730.71	1,559.07
Falcon Heavy	125.00	
Ground Station	30.00	

Cost

Assumption/ Reference Number	Value	Description	Source	Calculation
[1]	300	Number of Ground Operation Staff for ISS = 300	Prof. Ewald	6 - 8 Staff members per Position, at Houston 15 Positions in Control Room. And 80 Staff members in Back rooms. Columbus Lab is 2 - 3 Positions.
[2]	2; 2,3	"Cargo Transfer & Lander not reusable" und "Reusable Crew Transfer"	Dr. Eilingsfeld und Hr. Millin	Agreement to set the Non reusable Cargo Lander Specification to 2. Reusable Crew Transfer was choosen by Cost & Risk team to be set at 2,3 instead of 2,39 for a planetary transport vehicle.
[3]	1000 kg	"Modified Crew Dragon"	Assumption	Upgrade to Crew Dragon taken as a 1000kg Addition which was calculated, Crew Dragon price added, but not adjusted for included falcon 9 cost. Will be taken as an estimation of surplus cost of falcon heavy human rated certification with SpaceX
[4]	30M€	Cost of Ground Station	Wikipedia	Cebreros 35 Meter Dish Ground Station CEB (DSA 2), here build over three years
[5]	375M€	Cost of launchers for refueling crew transfer vehicle	Subsystem Information	We need three extra Launches to fuel the transfer vehicle
[6]	900M€	Cost of refueling Spacecraft	Assumption	roughly in the order of one crew dragon, minus a launcher for a refueling spacecraft
[7]	24,84M€	Cost of Astronaut Training for four Astronauts per year	Assumption	five staff support per Astronaut, 2 years training + one year in orbit
[8]	10M€	Cost of Resupplies	Assumption	Roughly 8 tons of ressuplies, mostly some food, water, clothes, meds etc.
[9]	550M€	Reduction Launcher and Refueling Spacecraft 3 to 1	Assumption	ISRU on moon surface up and running, only one refueling needed in LEO, instead of three
[10]	-4340M€	Selling 2nd Station	Assumption	Minimum Value for selling 2nd station for residual value. Resources of 1st station + residual usability surpasing planned operational lifetime not even taken into account.
[11]	100% Margin	Toursim	Assumption	Luxury good, higher price can actually have positive influence on demand due to anormal price elasticity.
[12]	Prices	Per Unit Price based on AMCM calculation	Assumption	Mass adjustments mainly effect first production badge, prices will not be adjusted with Argo, but stay as fixed

Cost

	Expected
Cargo Cost per Year	300.43
Launcher	125.00
Transfer & Lander	165.43
Cargo itself[8]	10.00
Launches per Year	1.00
Crew Cost per Year before ISRU	1,758.17
Launcher[5]	500.00
Crew Dragon with Launcher	333.33
Crew Teaching and pay[7]	24.84
Refueling Spacecraft[6]	900.00
Crew Cost per Year before ISRU [9]	908.17
Launcher	250.00
Crew Dragon with Launcher	333.33
Crew Teaching and pay	24.84
Refueling Spacecraft	300.00
Ground Segment	
Staff Cost per Year	103.50
Ground Segment Constr.[4]	90.00
Tourism per Year	
Contribution margin for one tripp	884.89
Total Cost per year:	**2,162.10**

Cost

	Station Construction	Transportation Non-recurrent	Crew Transport	Transportation Recurrent (Resupply)	Ground Segment	Tourism & Closeout	Total
2021	23.17	19.17					42.34
2022	92.68	76.70					169.37
2023	675.76	559.26					1,235.02
2024	675.76	559.26					1,235.02
2025	5,255.77	3,363.58					8,619.35
2026	12,576.47	8,361.50			30.00		20,967.97
2027	12,651.94	10,331.72	6.21		30.00		23,019.87
2028	6,845.77	6,913.67	12.42		133.50		13,905.36
2029	2,369.98	5,279.66	18.63		103.50		7,771.77
2030	-	784.38	1,758.17	300.43	103.50		2,946.48
2031	-	-	1,758.17	300.43	103.50		2,162.10
2032	-	-	1,758.17	300.43	103.50		2,162.10
2033	639.05	580.85	1,758.17	300.43	103.50		3,382.00
2034	-	-	908.17	300.43	103.50	- 884.89	427.21
2035	-	-	908.17	300.43	103.50	- 884.89	427.21
2036	-	-	908.17	300.43	103.50	- 884.89	427.21
2037	857.32	-	908.17	300.43	103.50	- 884.89	1,284.53
2038	2,115.08	-	908.17	300.43	103.50	- 884.89	2,542.29
2039	2,279.52	-	908.17	300.43	103.50	- 884.89	2,706.73
2040	1,403.98	3,982.53	908.17	300.43	103.50	- 884.89	5,813.72
2041	288.44	1,742.56	908.17	300.43	103.50	- 884.89	2,458.21
2042	-	-	908.17	300.43	103.50	- 884.89	427.21
2043	-	-	908.17	300.43	103.50	- 884.89	427.21
2044	-	-	908.17	300.43	103.50	- 884.89	427.21
2045	-	-	908.17	300.43	103.50	- 5,225.09	- 3,912.99
Total:	48,750.68	42,554.84	17,968.03	4,806.82	1,953.00	- 14,958.84	101,074.54

Assumption[10]

Cost

One week on the moon	
Launcher and Transport for one Person	294.44
Supplies roughly for one Person	negligible
Training for one Person (2 month)	0.52
100% Margin = partial contribution margin[11]	294.96
Total Price per Person:	**589.92**
Comments:	Just three at a time + pilot Only starting after 2033 and ISRU

OUTREACH STRATEGY - EDUCATION!

Science to the Moon!

Draw the D.I.A.N.A moon base!

Design a lunar module!