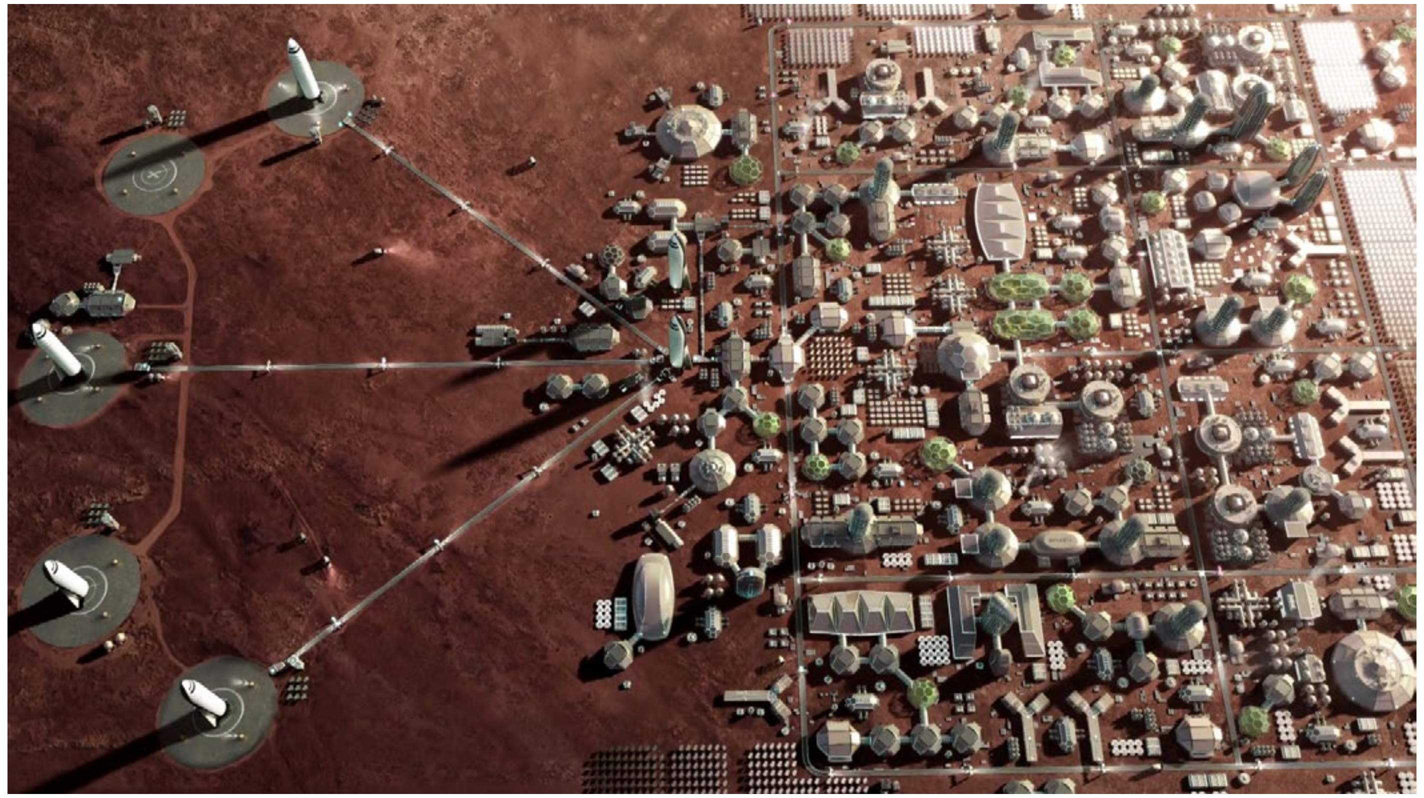
Hyper Inflatables: Prefabricated Membranes and 3D Printed Exoskeletons in Space

Sasakawa International Center for Space Architecture

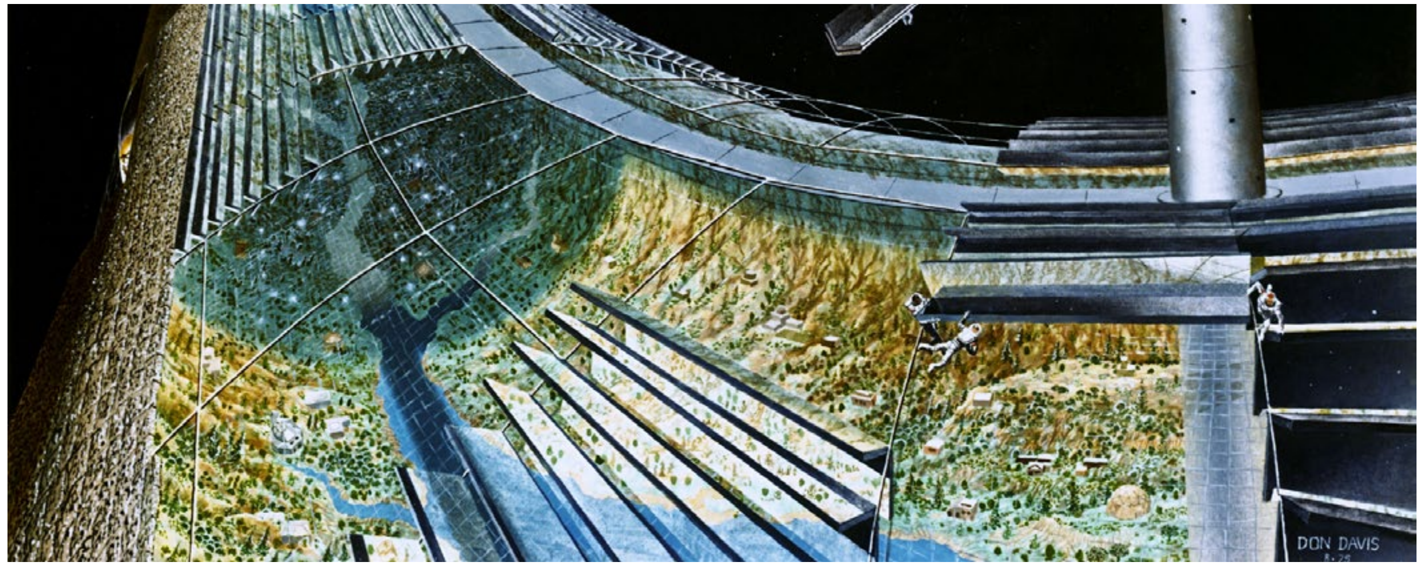
Zachary Taylor

credit: NASA

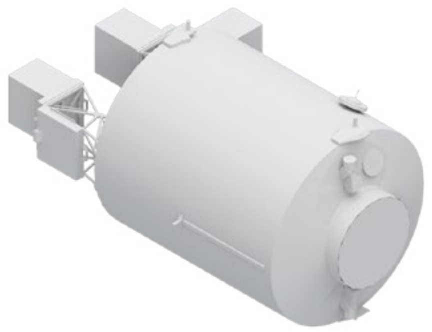


credit: SpaceX

credit: Foster & Partners / ESA



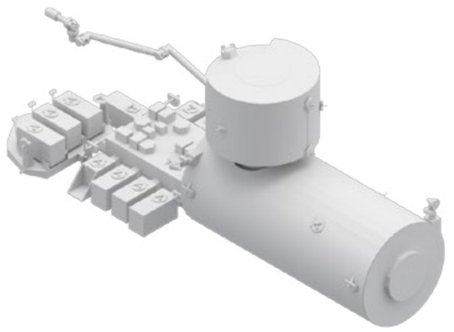
credit: NASA



Columbus

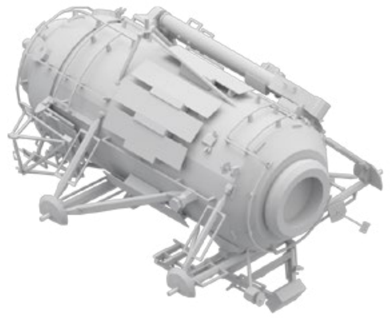
Destiny

Harmony



Kibo

MLM



MRM1

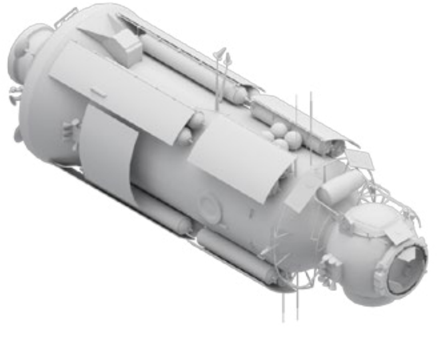
MRM2

MPLM

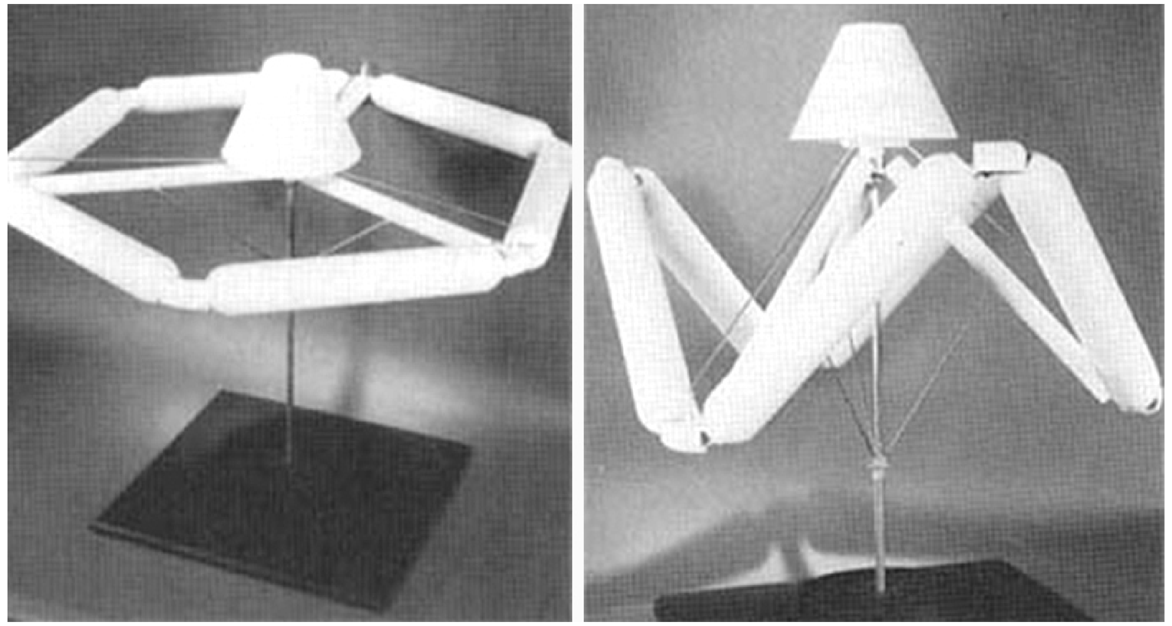
PMM

Tranquility

Unity



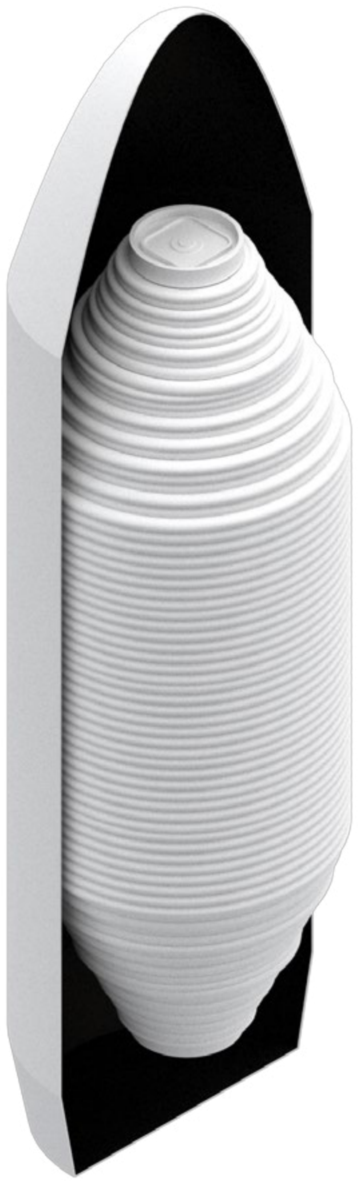
Zarya



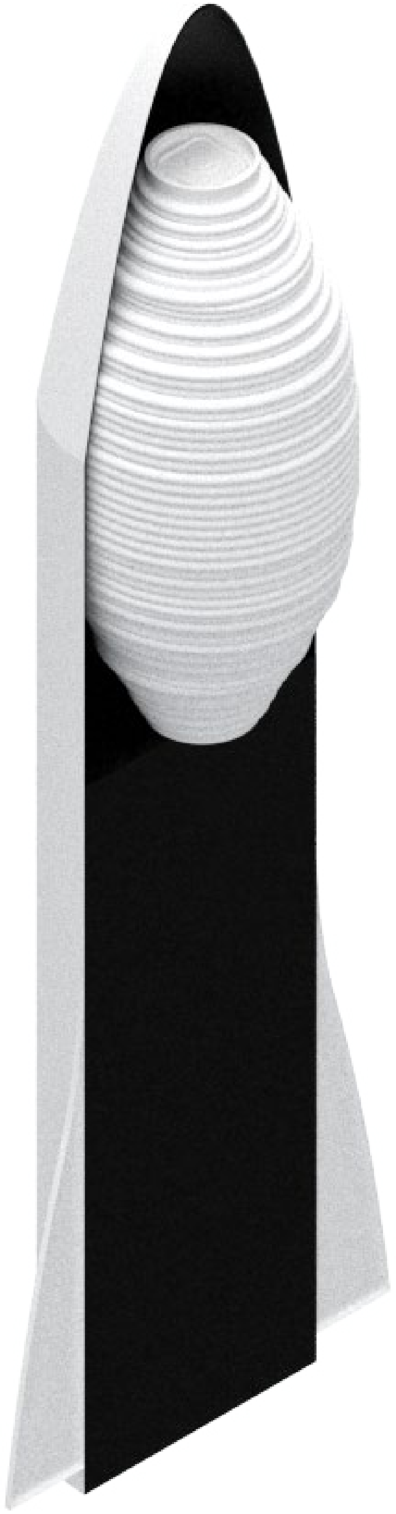
Proposed Apollo-Era Station
credit: NASA

Toroid inflatable station concept
credit: NASA

The Echo 1a
credit: NASA

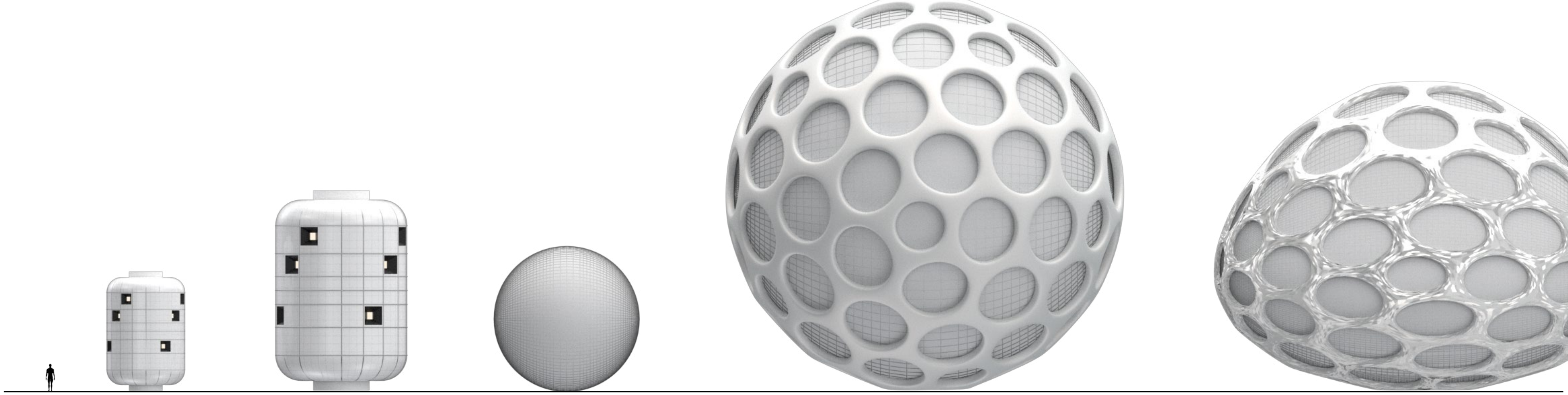


SLS Block II Fairing
Volume: 1,166 m³
Weight: 100,000 kg



BFR Cargo Fairing
Volume: 780 m³
Weight: 70,000 kg

Volume: 80,563 m³
Ø: 53 m



B330
330 m^3

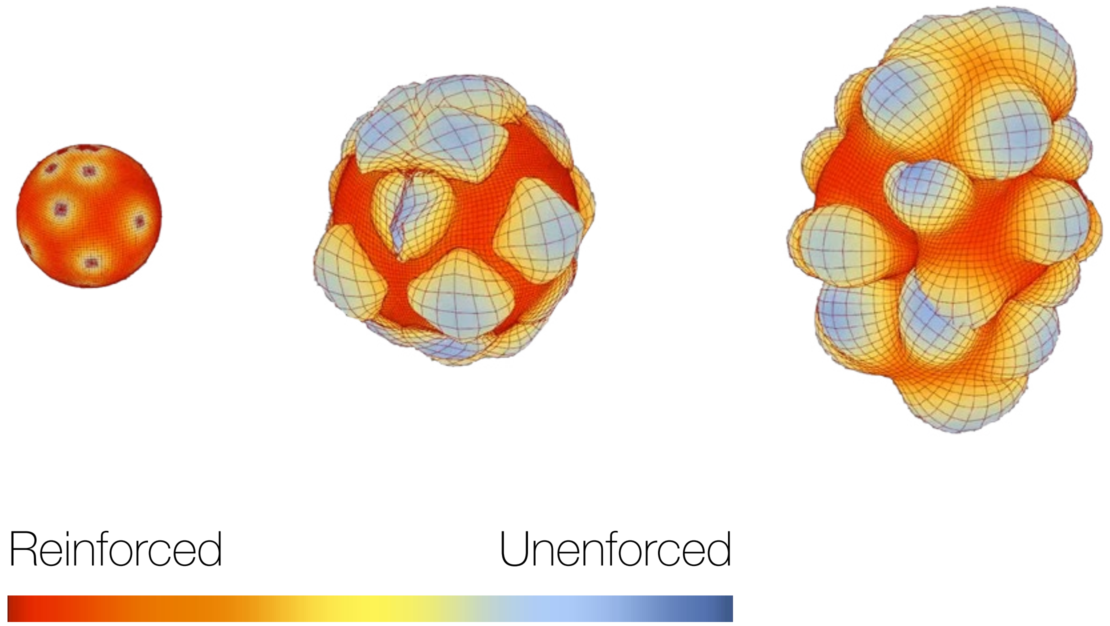
B2100
2100 m^3

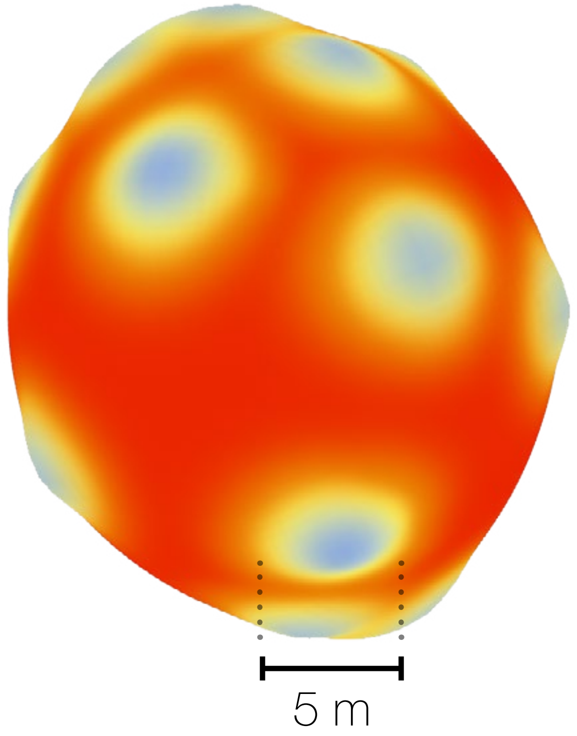
No Exoskeleton
1500 m^3

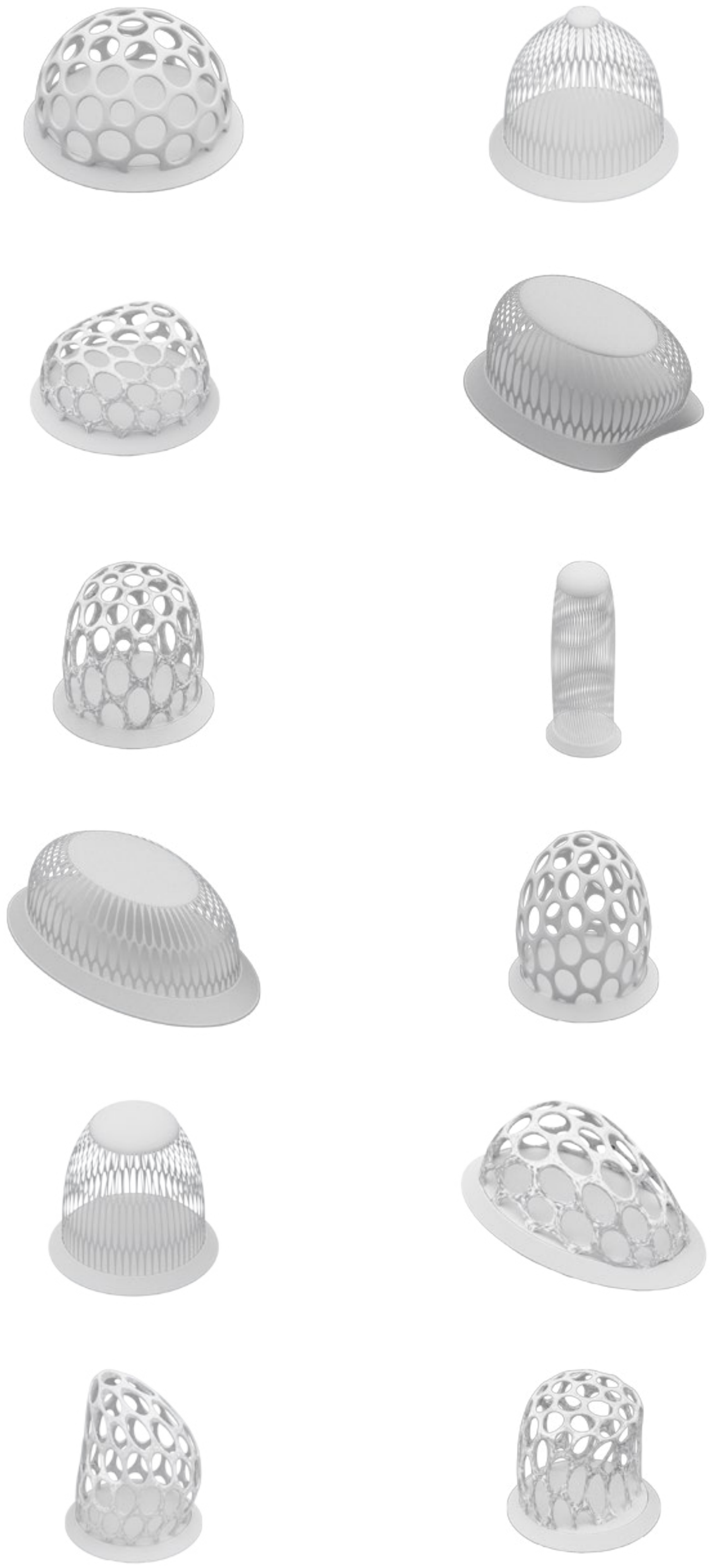
Exoskeleton
25000 m^3

Manipulated Volume
20000 m^3

Grasshopper Simulation







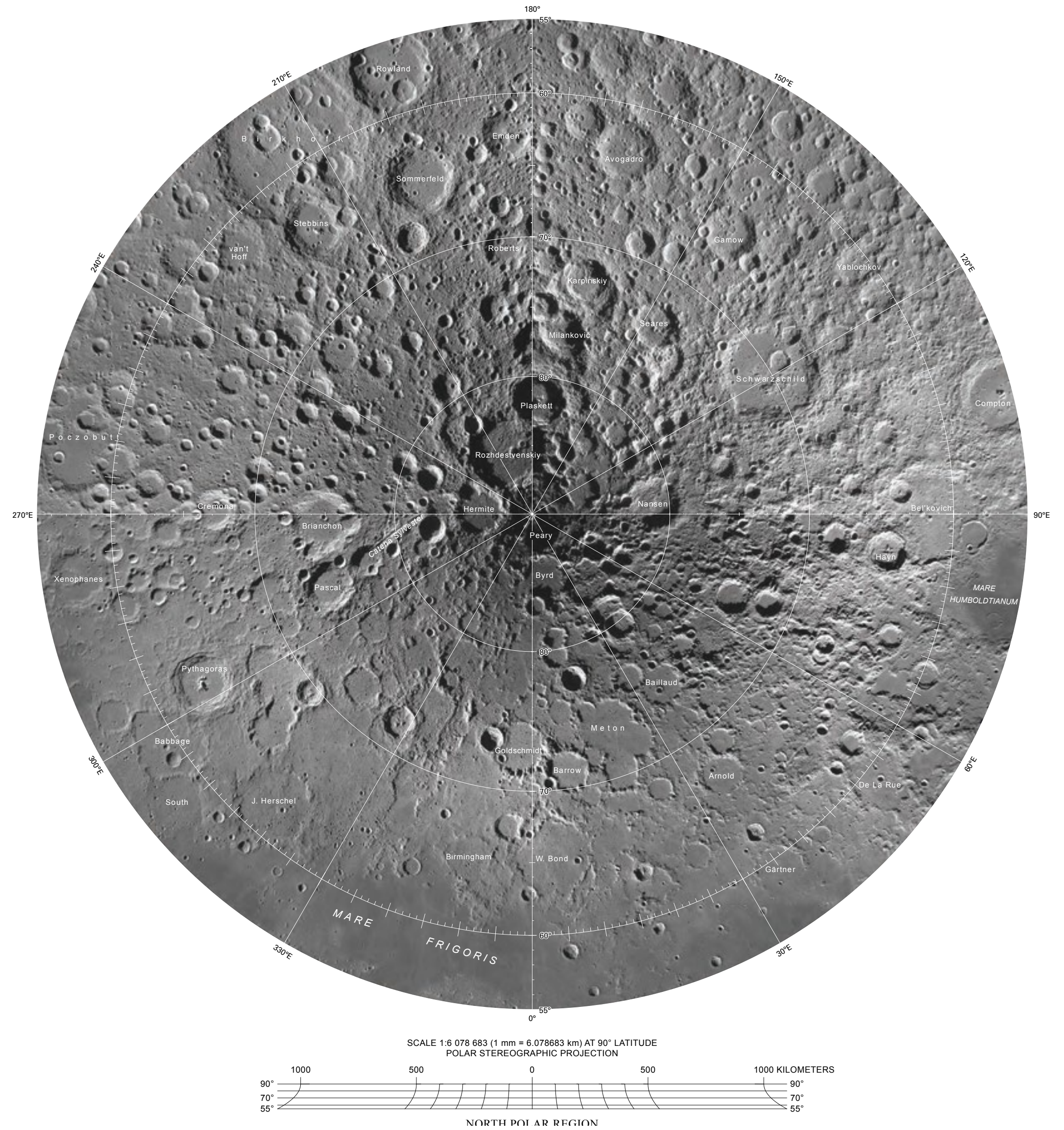
Membrane Composition

Polytetrafluoroethylene (PTFE) Coating
Purpose: UV stabilizer
Density: 2.19 kg/m³ Thickness: 0.04 cm

Demron Fabric
Purpose: high energy gamma radiation, micrometeroid protection
Density: 3.14 kg/m³ Thickness: 5.04 cm

Hydrogenated Boron Nitride Nanotube (BNNT)
Purpose: neutron radiation protection
Density: 2.10 kg/m³ Thickness: 4.12 cm

Précontraint 402 N Membrane
Purpose: water and air seal
Density: 1.00 kg/m³ Thickness: 0.04 cm



Mission Outline

Objectives

Study the long-term effects of 1/6th gravity on humans, astronomical study during dark phases, act as a construction material hub for projects in and around cis-lunar space, serve as a fuel depot, EVA capabilities for exploration, and a testbed for permanent space agriculture.

Site

Permanent base at the Peary Crater in the Lunar North Pole.

Crew

The base can support a rotating crew of 20-30.

Architectural Program

20 separate crew quarters, galley, science stations, exercise facility, medical facilities, 6 bathrooms, hygiene stations, manufacturing shop, greenhouse, laundry, at least 2 airlocks, operations control room, recreation facility.

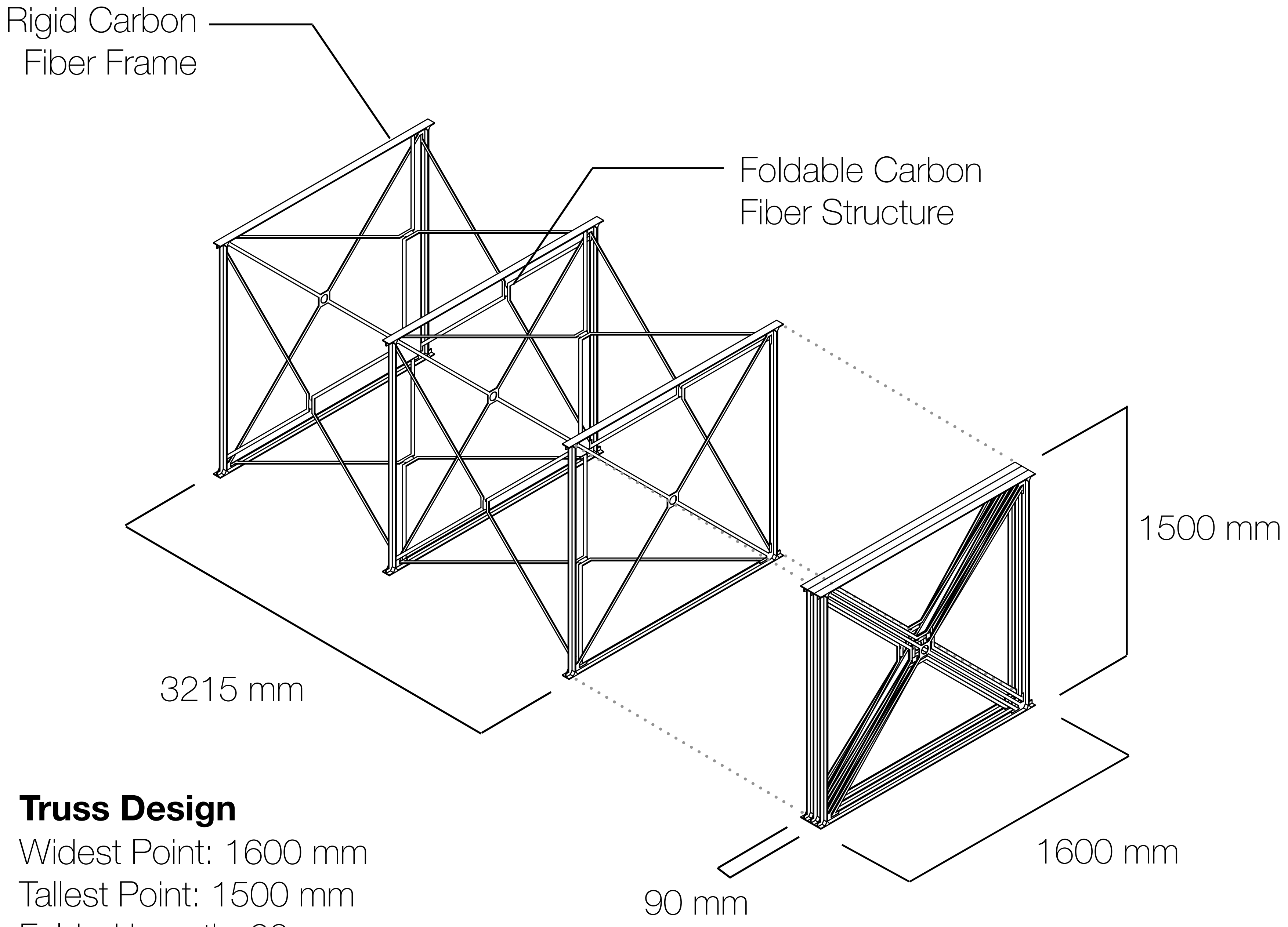
Assumptions

- The fully realized BFR rocket is relative in size and function to the version presented at IAC 2017 conference.
- The remaining fuel of the BFR rocket on the moon’s surface is around 110 tons (half empty).
- Advances in space-applicable robotics continue, particularly ones for construction which are an aspirational element of the project.
- There is a growing commercial and industrial demand for space in the Cis-lunar region.
- An inflatable membrane thickness of 8-12 cm utilizing advanced materials is sufficient to block out micro-meteorites and most radiation.
- The inflatable will have two means of egress.

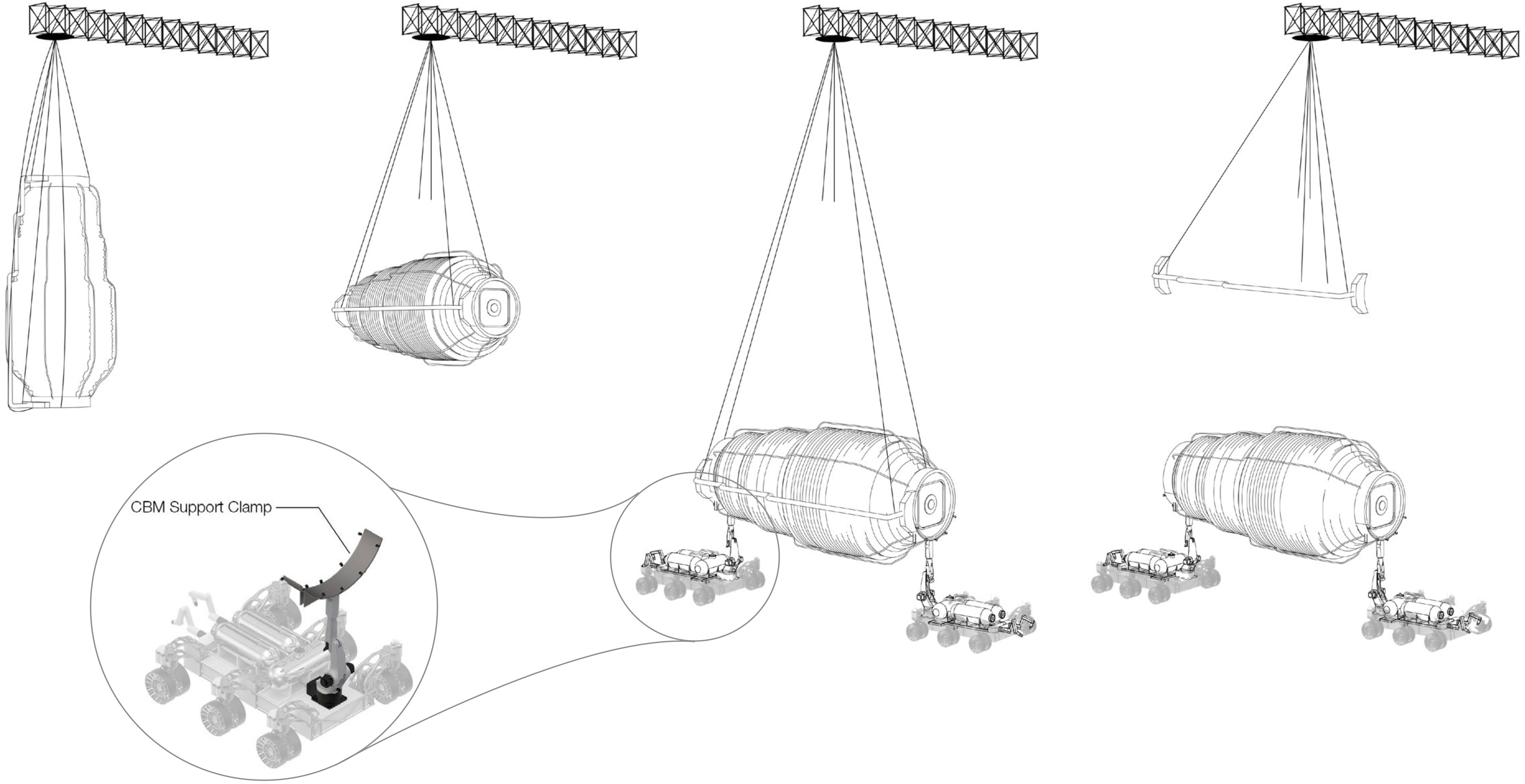
Crew Configuration

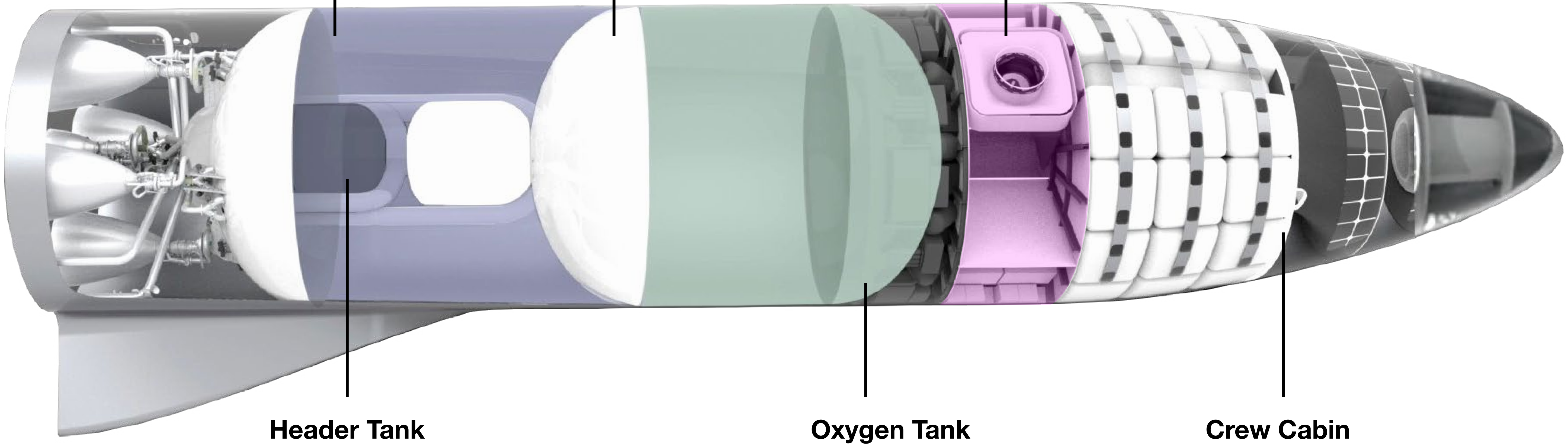
Cargo Configuration

Cargo + Crew Configuration



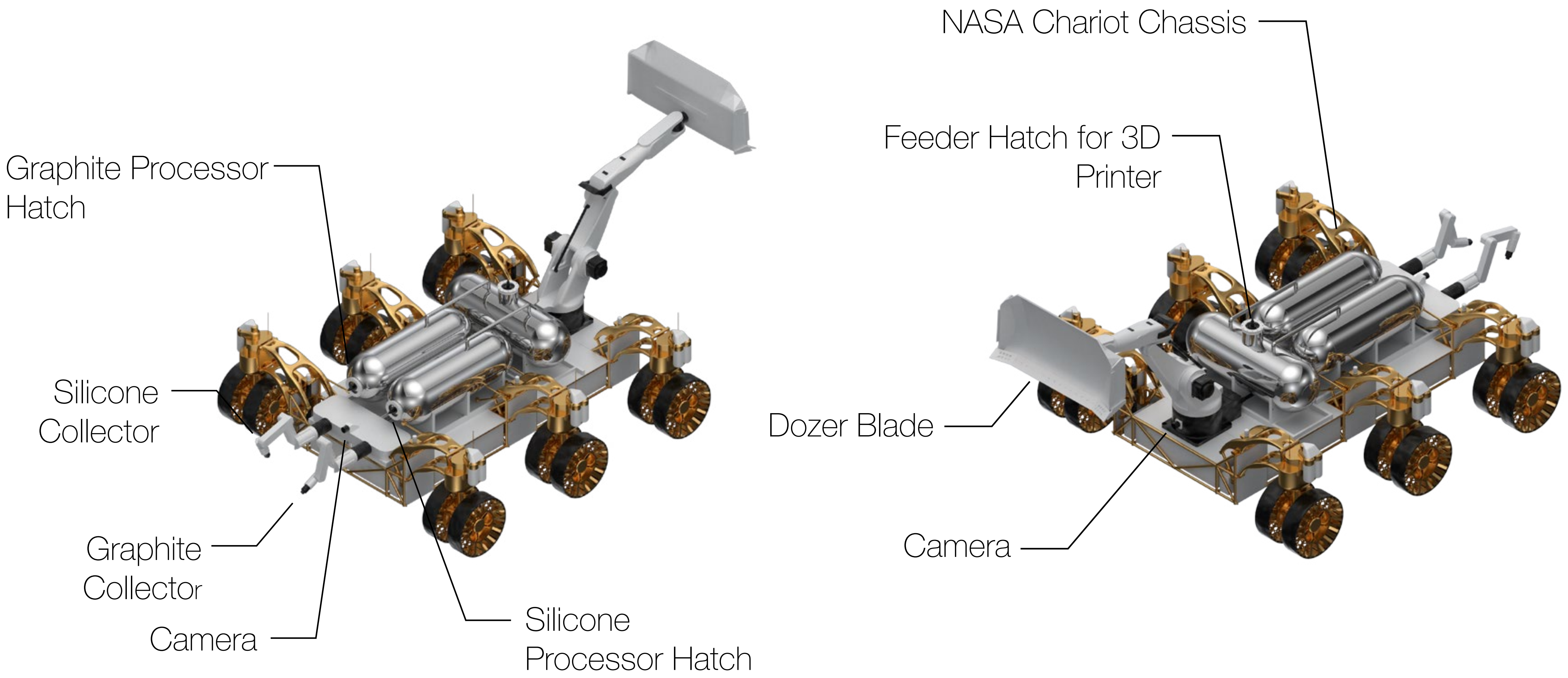
Truss Design
Widest Point: 1600 mm
Tallest Point: 1500 mm
Folded Length: 90 mm
Deployed Length: 3215 mm


CBM Support Clamp


Fuel Tank
Holds 240 tons of CH_4
Common Dome
Separates CH_4 and 0^2
Cargo Bay
Pressurized to unpressurized volume
Header Tank
Holds landing propellant during transit
Oxygen Tank
Holds 860 tons of liquid 0^2
Crew Cabin
Pressurized volume

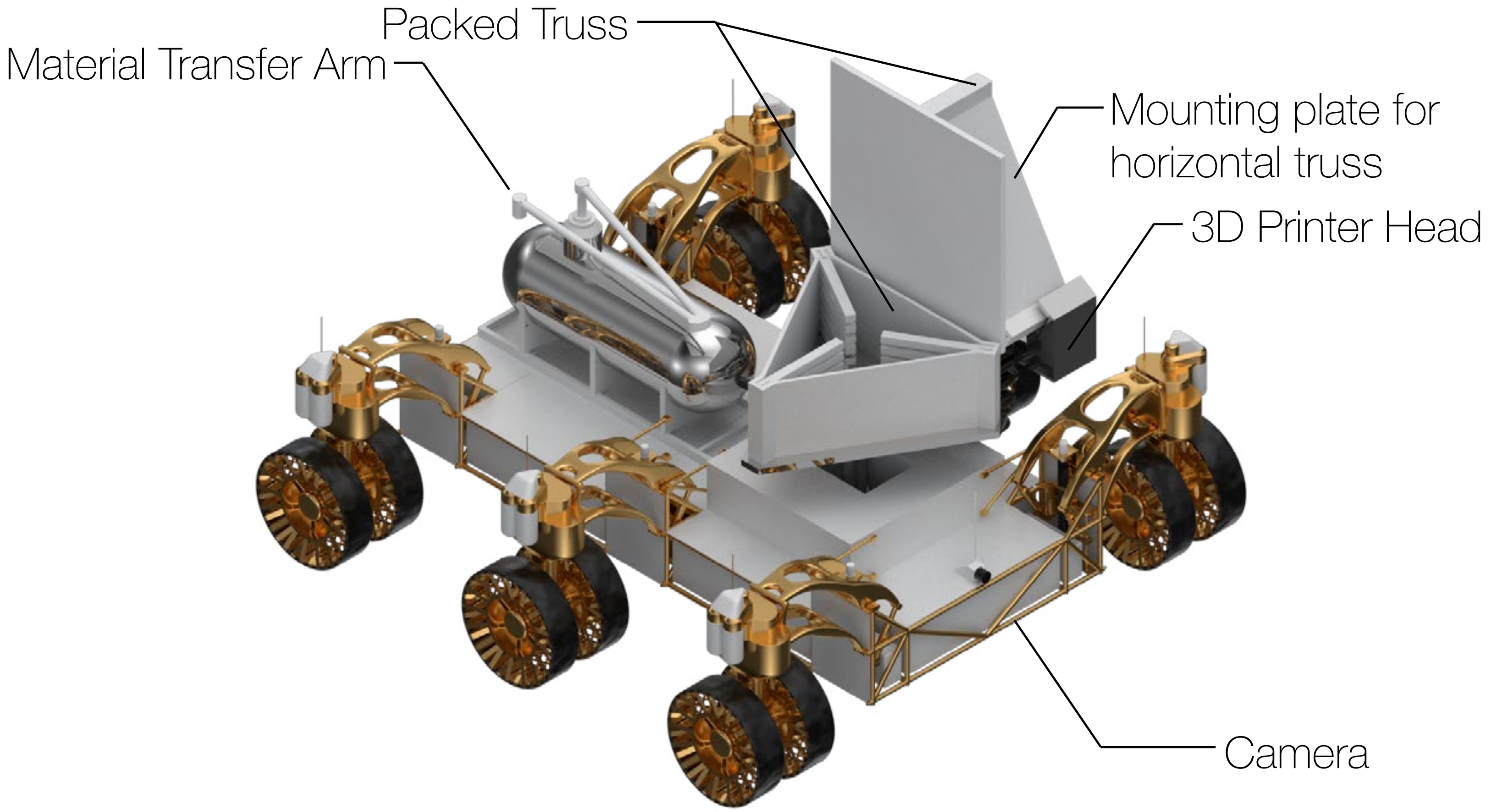
3D Printing Material (AlSiC)

ISRU Collector & Processor

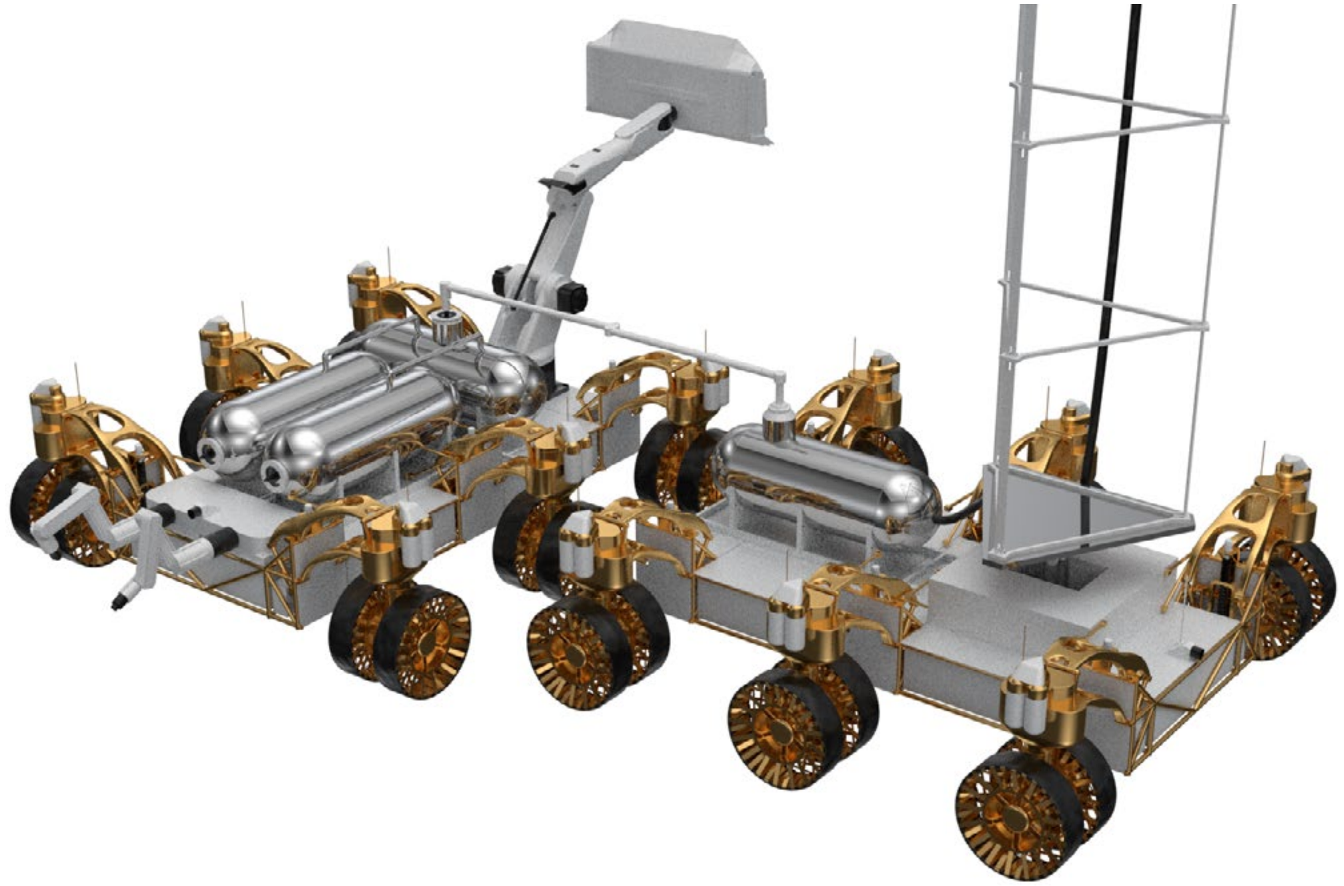


	Content	Tensile Strength	Density	Melting Point	Young's Modulus	Key Advantages
Aluminum Silicon Carbide (AMC640XA)	40% Silicon Carbide, 60% Aluminum	570 MPa	2.90 g/cm³	400°C	40 GPa	Wear resistance, Low coefficient of thermal expansion, crack-resistance, class 1 grade material by ESA testing, very high chemical and corrosion resistance, no porosity.

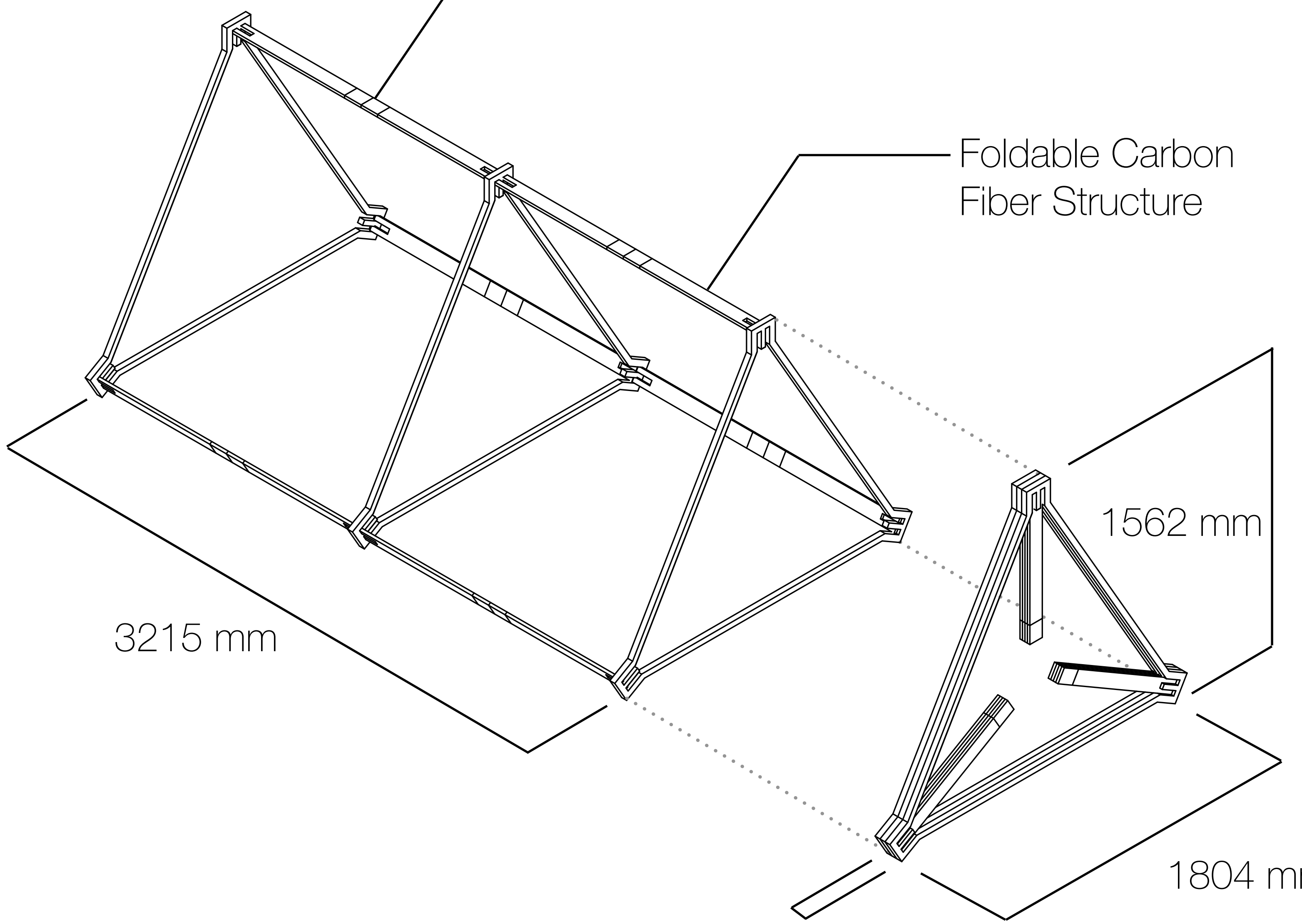
3D Printer Rover



ISRU to 3D Printer Transfer



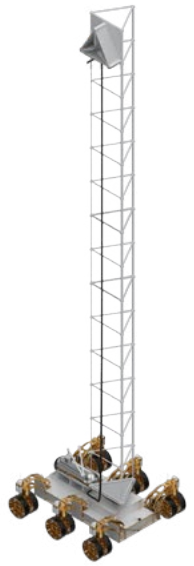
3D Printer Truss

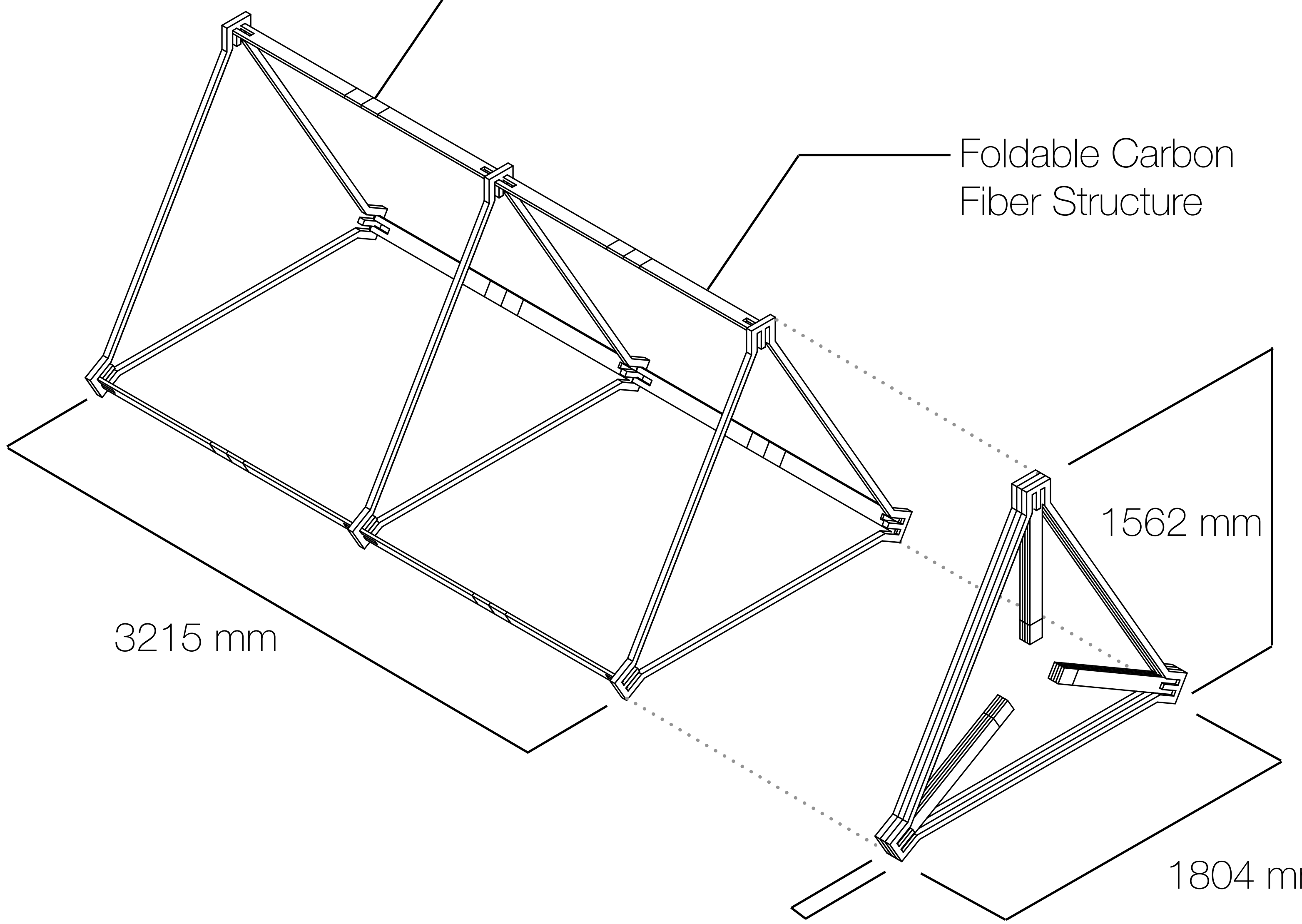


Heat Panels
Made of Minco Polyimide Thermofoil, which work in (-200)°C to 200°C temperature ranges and are NASA approved. The panels require 17.49 watts per 1 unit (as drawn) to heat to 130°C, the necessary temp to cause the carbon fiber to revert to its original position. It takes 15 minutes for each section to be deployed.

Truss Design
1 unit (as drawn to the right)
Volume: 8,714.78 cm3
Total Weight: 15.60 kg
22 meter length (20 meter structure): 0.630 meters folded (7 Units)
Total Weight: 109.20 kg

3D Printer Truss





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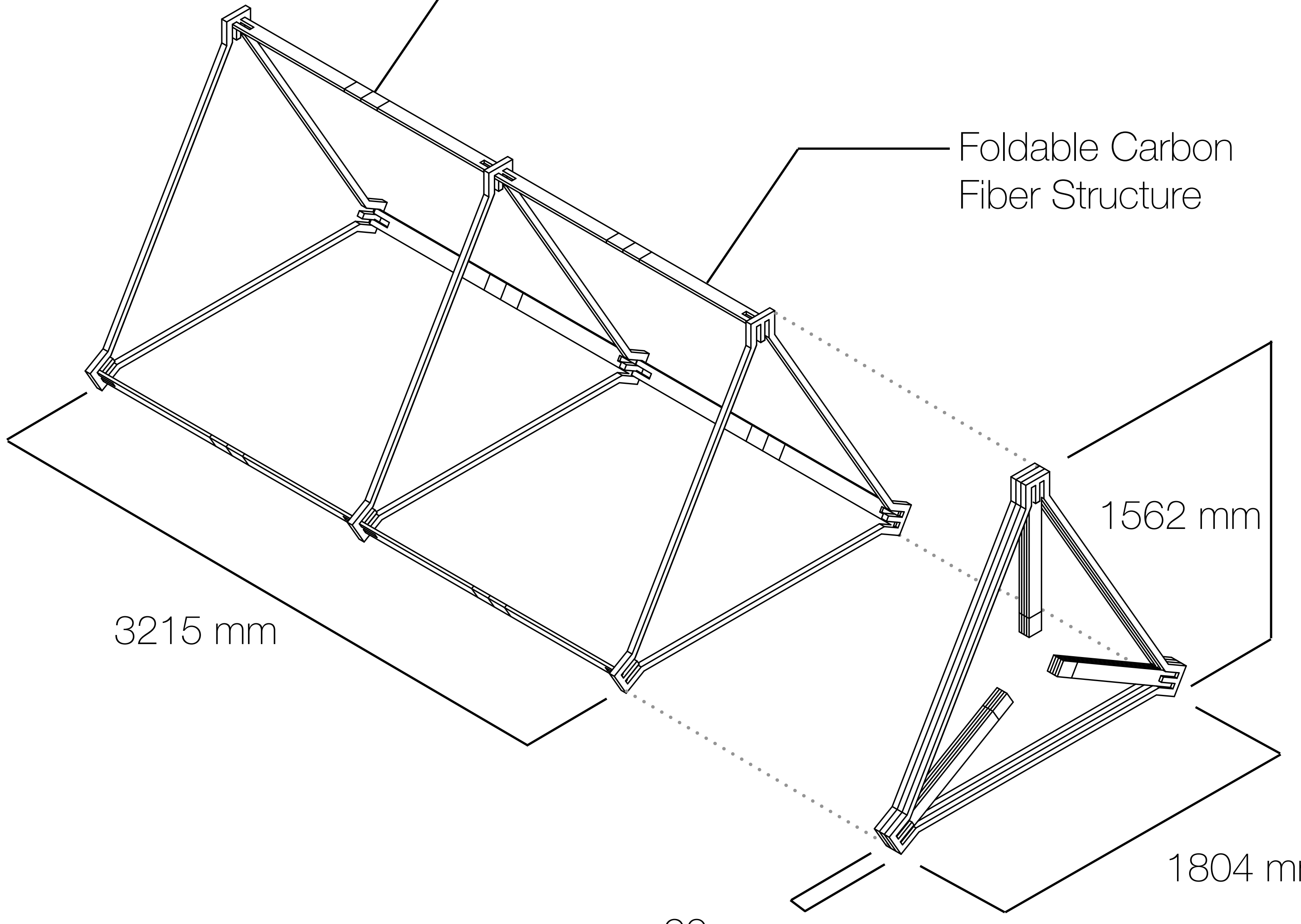

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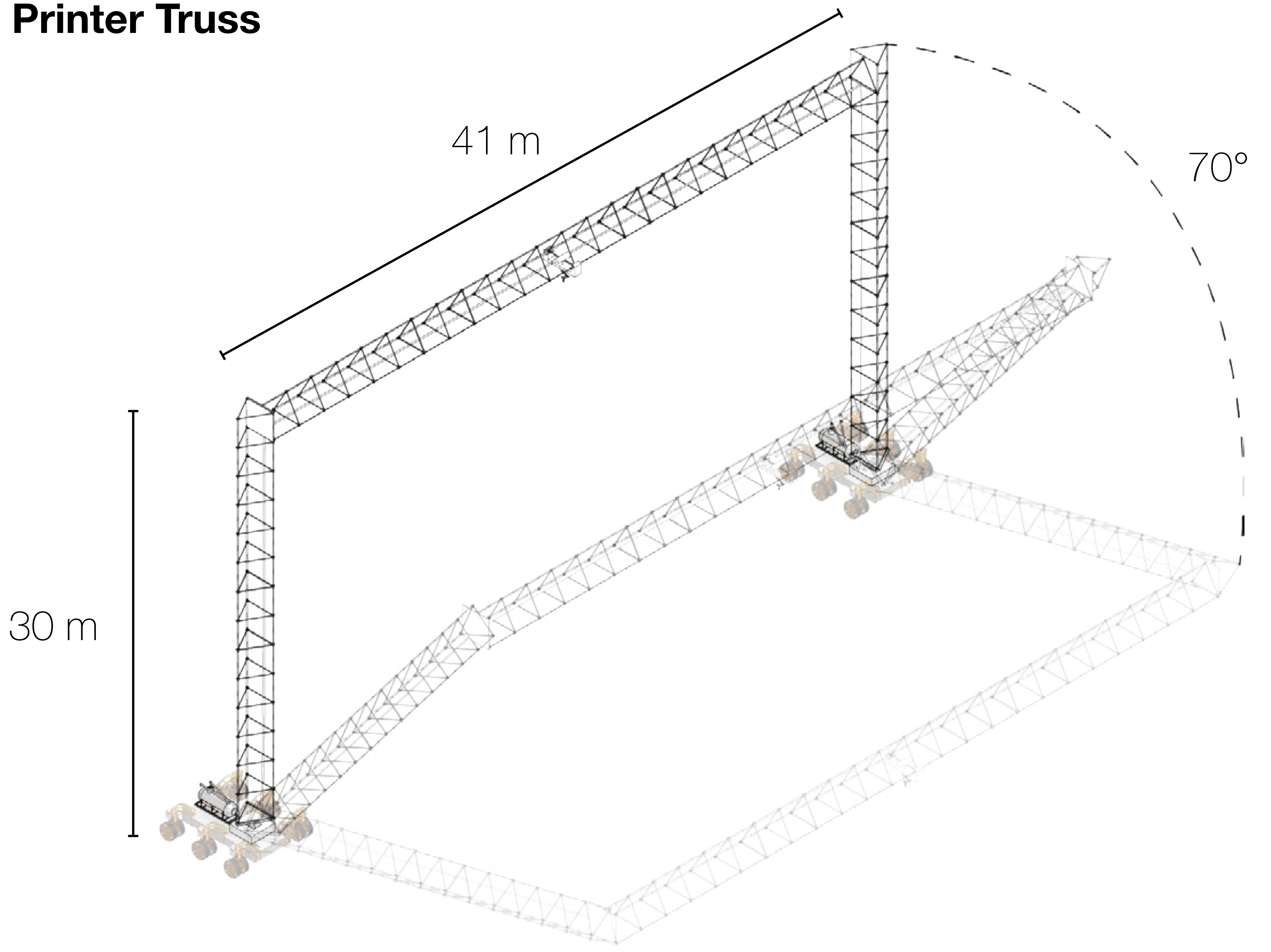

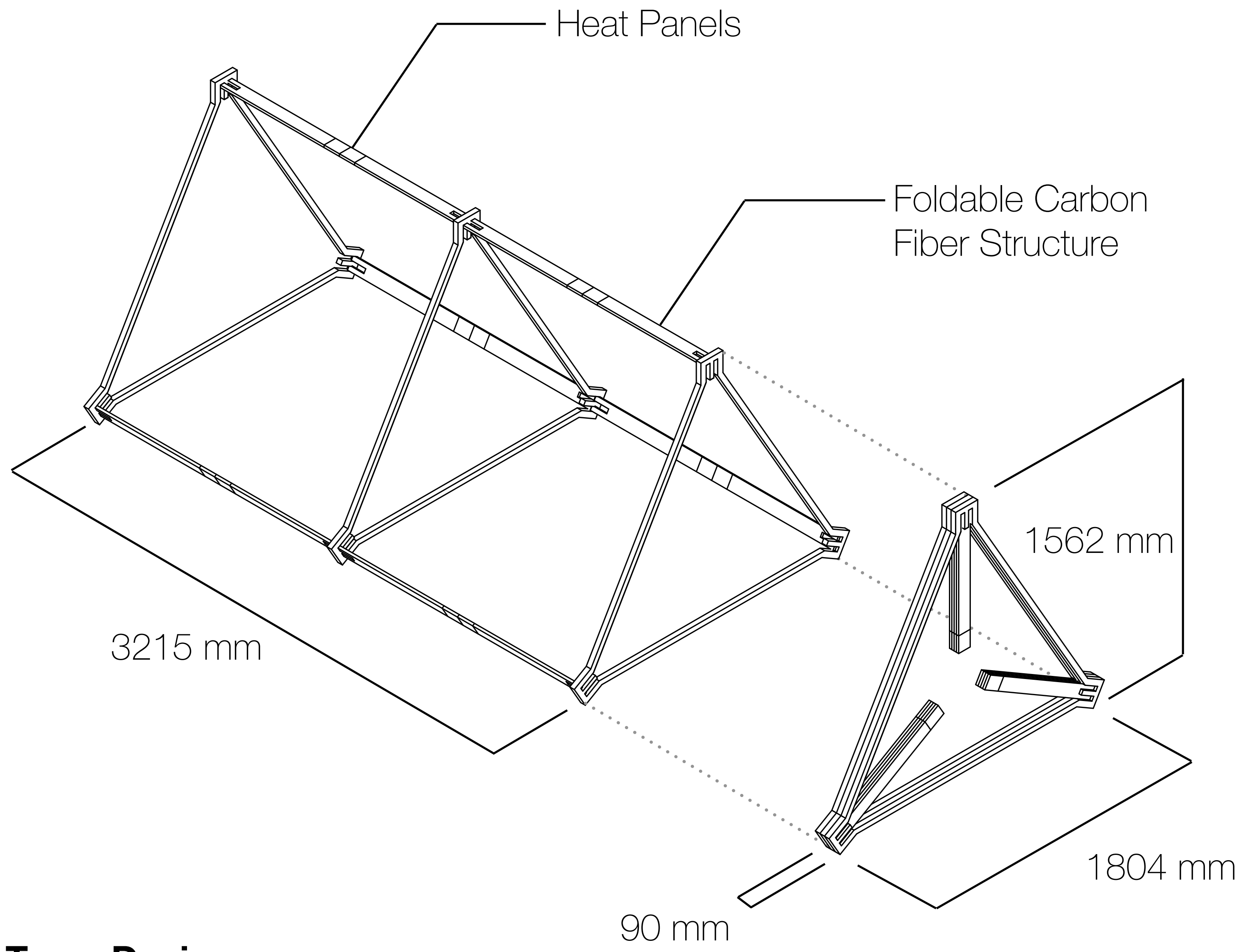

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Truss Design

1 unit (as drawn to the right)
Volume: 8,714.78 cm3
Total Weight: 15.60 kg
30 meter length (20 meter structure): 0.630 meters folded (7 Units)
Total Weight: 109.20 kg

Science
Hygiene
Maintenance & EVA
Life Support
Power Supply
Public & Private Areas

Air & Water Contaminant Detectors
5 square meters

Waste Recovery and Treatment
10 square meters

Thermal Control and Waste Heat Rejection
15 square meters

Laundry
5 square meters

3 Toilets
15 square meters

Humidity Control
5 square meters

Medical Facility
35 square meters

Recreation
30 square meters

2 Hand Washing Stations + 4 Shower
40 square meters

Crew Quarters
100 square meters

Exercise Chamber
50 square meters

Galley + Dining
120 square meters

Food Production
200 square meters

General Laboratory
50 square meters

Base Operations Control Room
60 square meters

Astronomical Observatory
20 square meters

Workshop
50 square meters

Equipment Storage
20 square meters

2 Shower + 2 Hand Washing Stations
20 square meters

Food Storage
40 square meters

Fuel Depot
100 square meters

EVA Vehicles
100 square meters

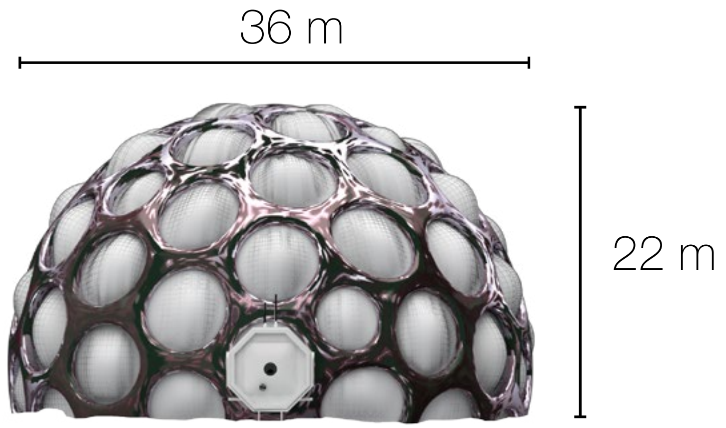
Airlock Nodes
10 square meters

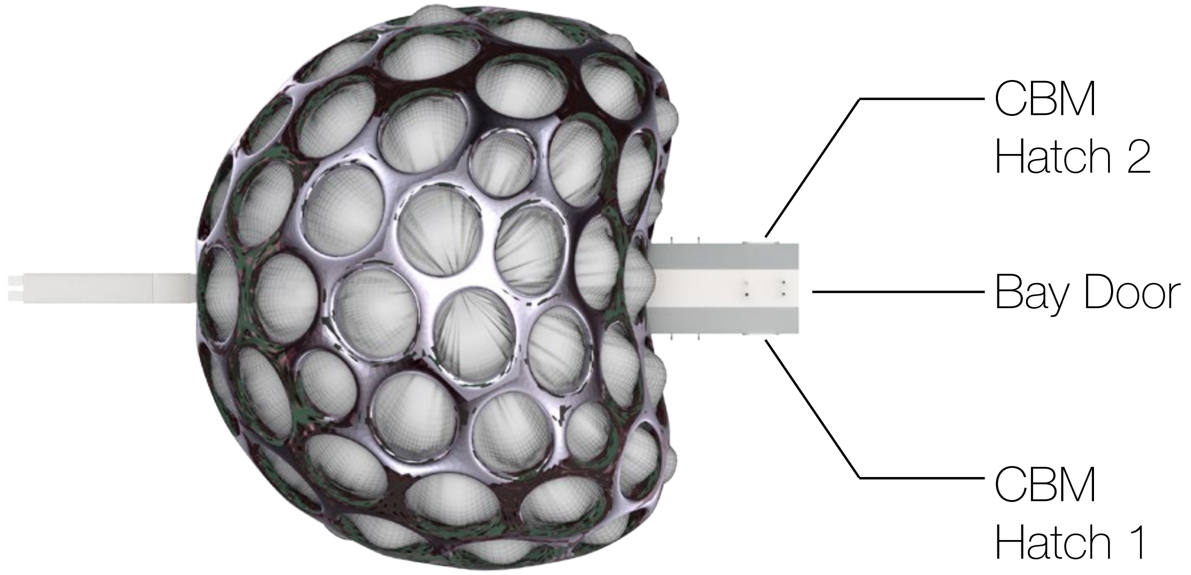
ISRU Collection (Water)
10 square meters

Portable Water Supply
40 square meters

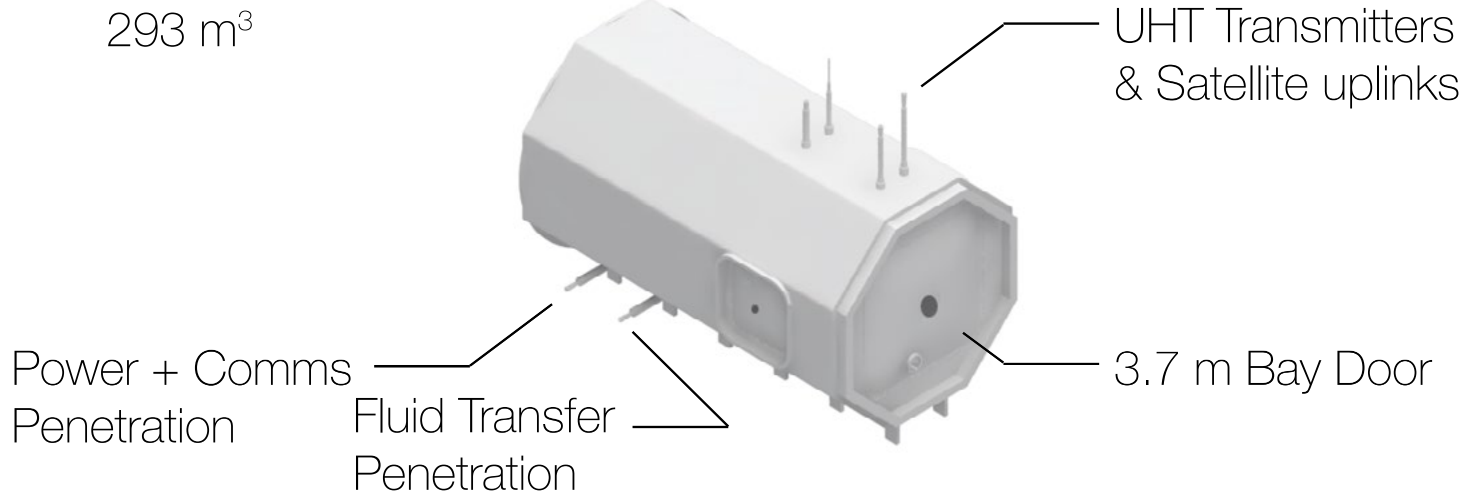
Solar Array Field
550 square meters

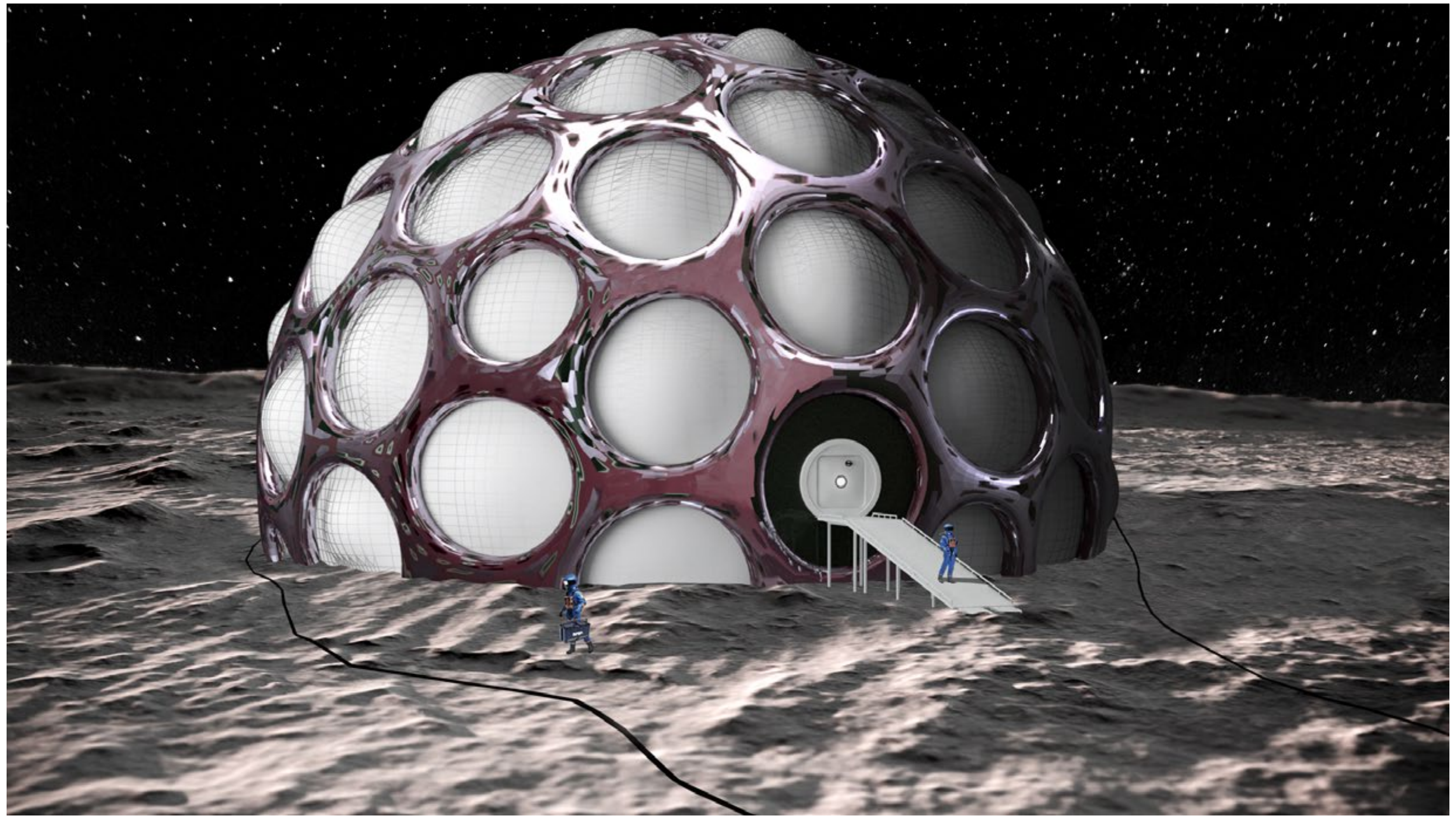
Total Volume
23000 m^3

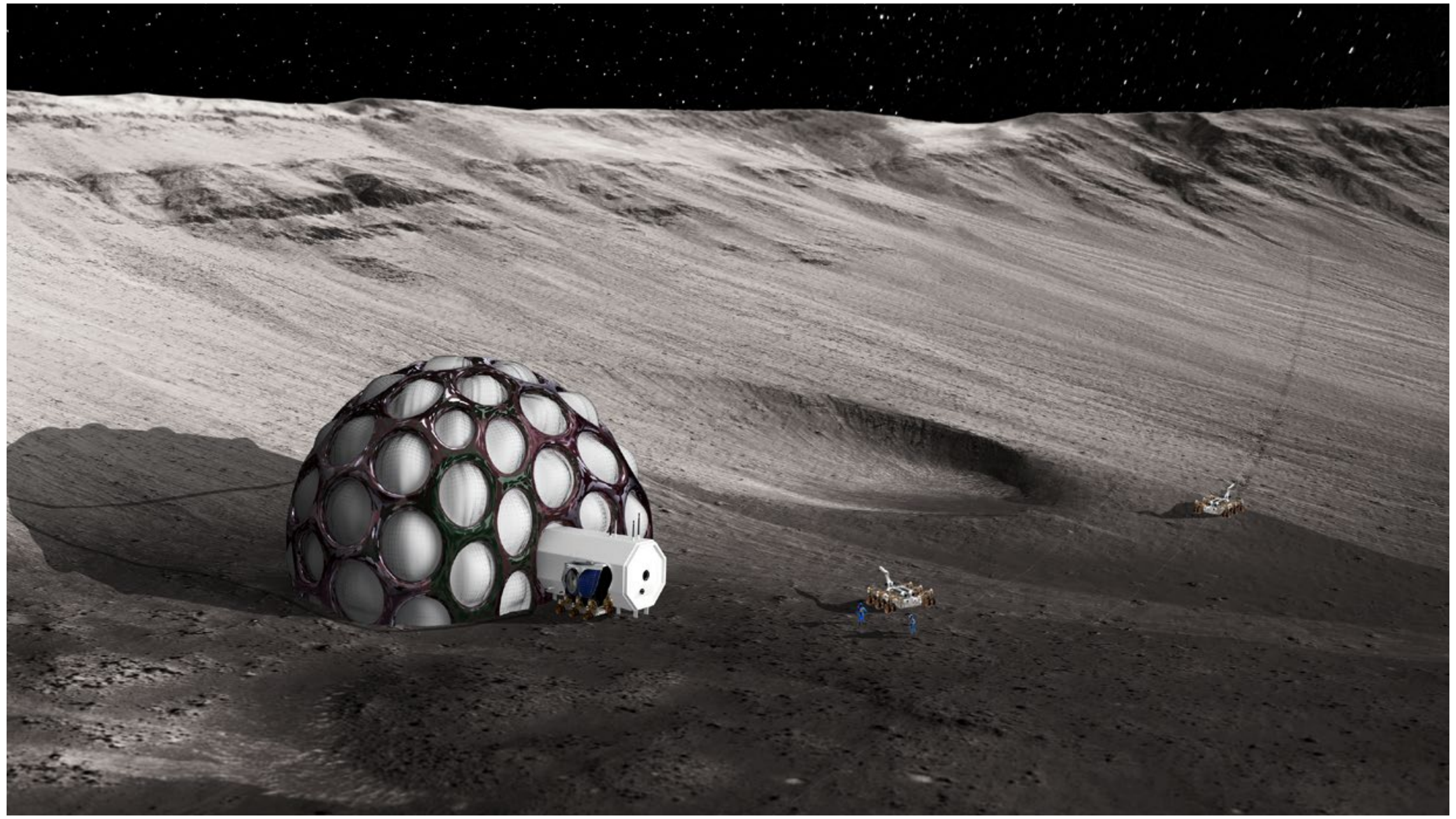




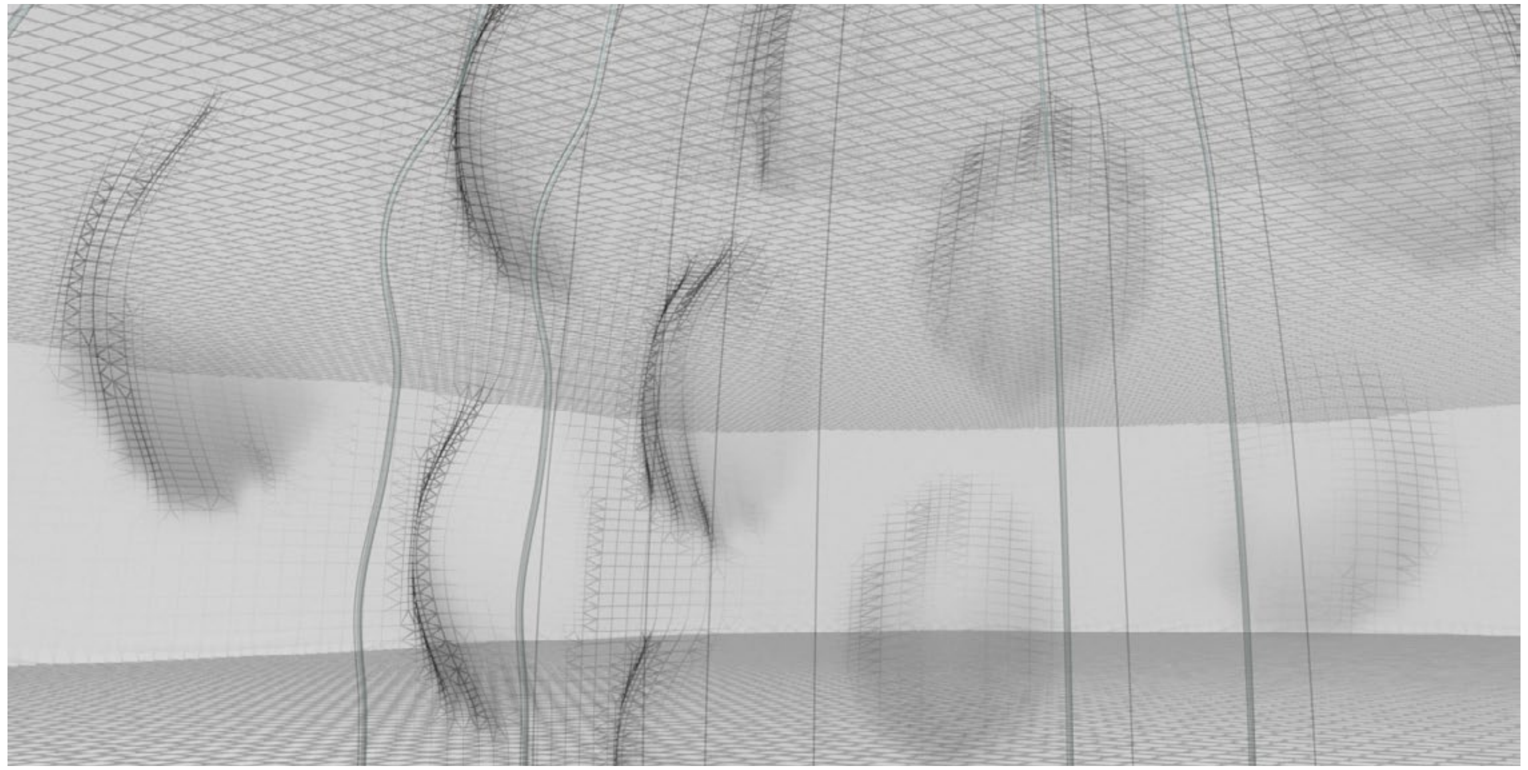
Total Volume
293 m^3

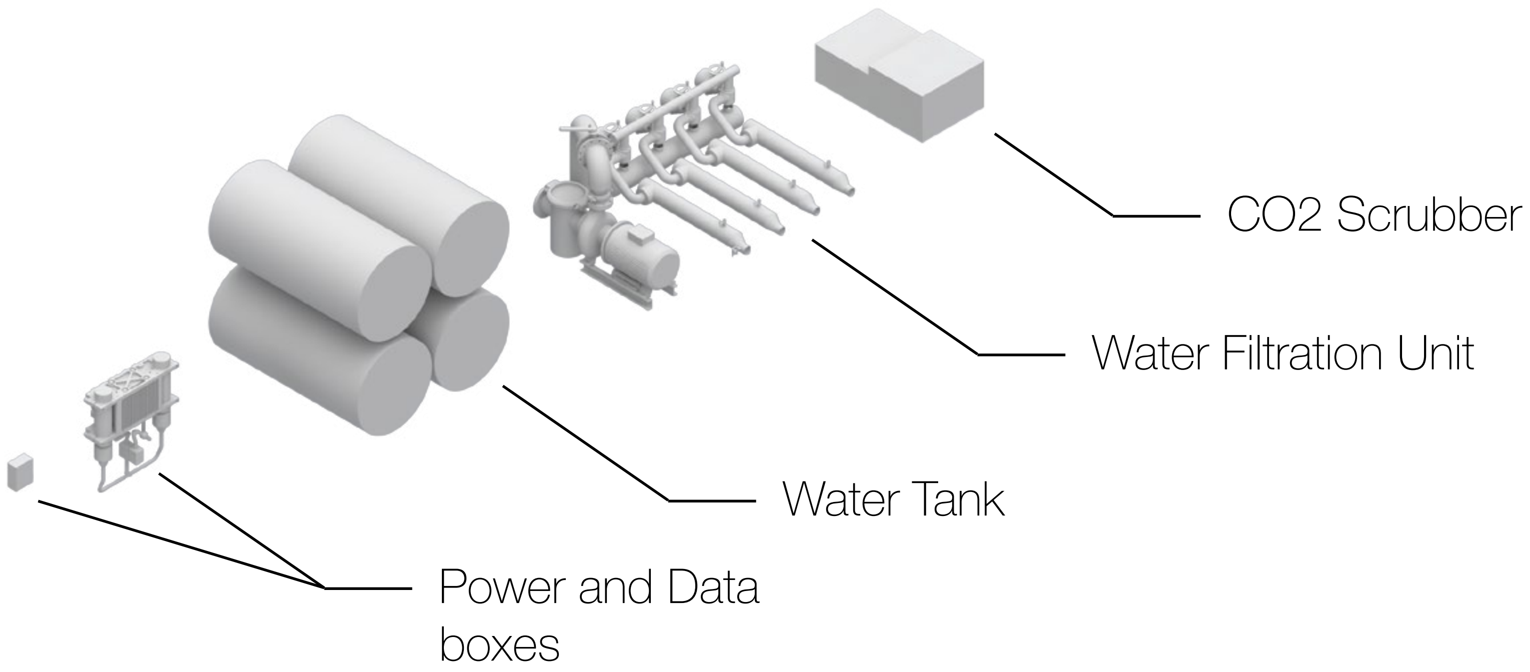


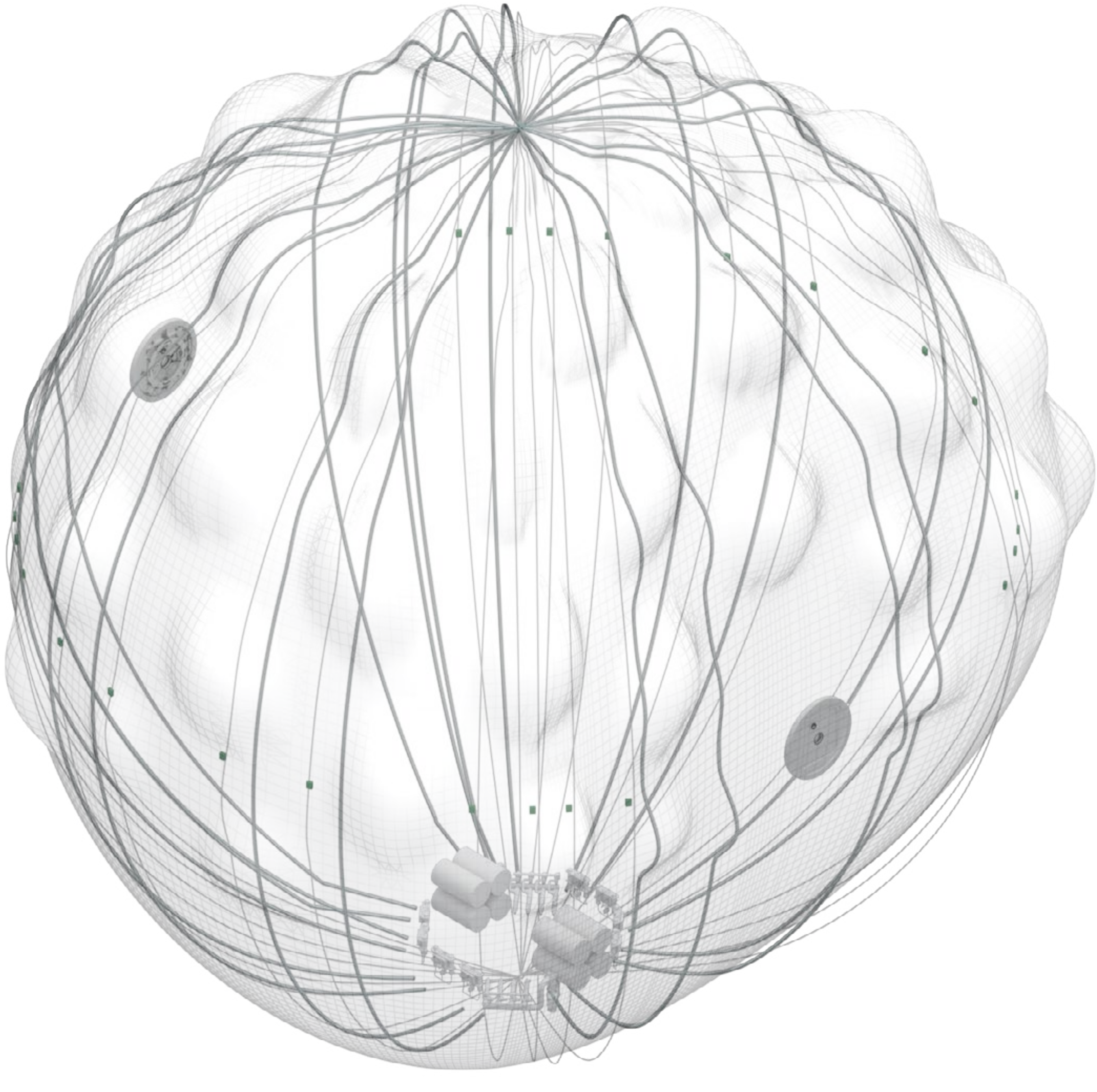




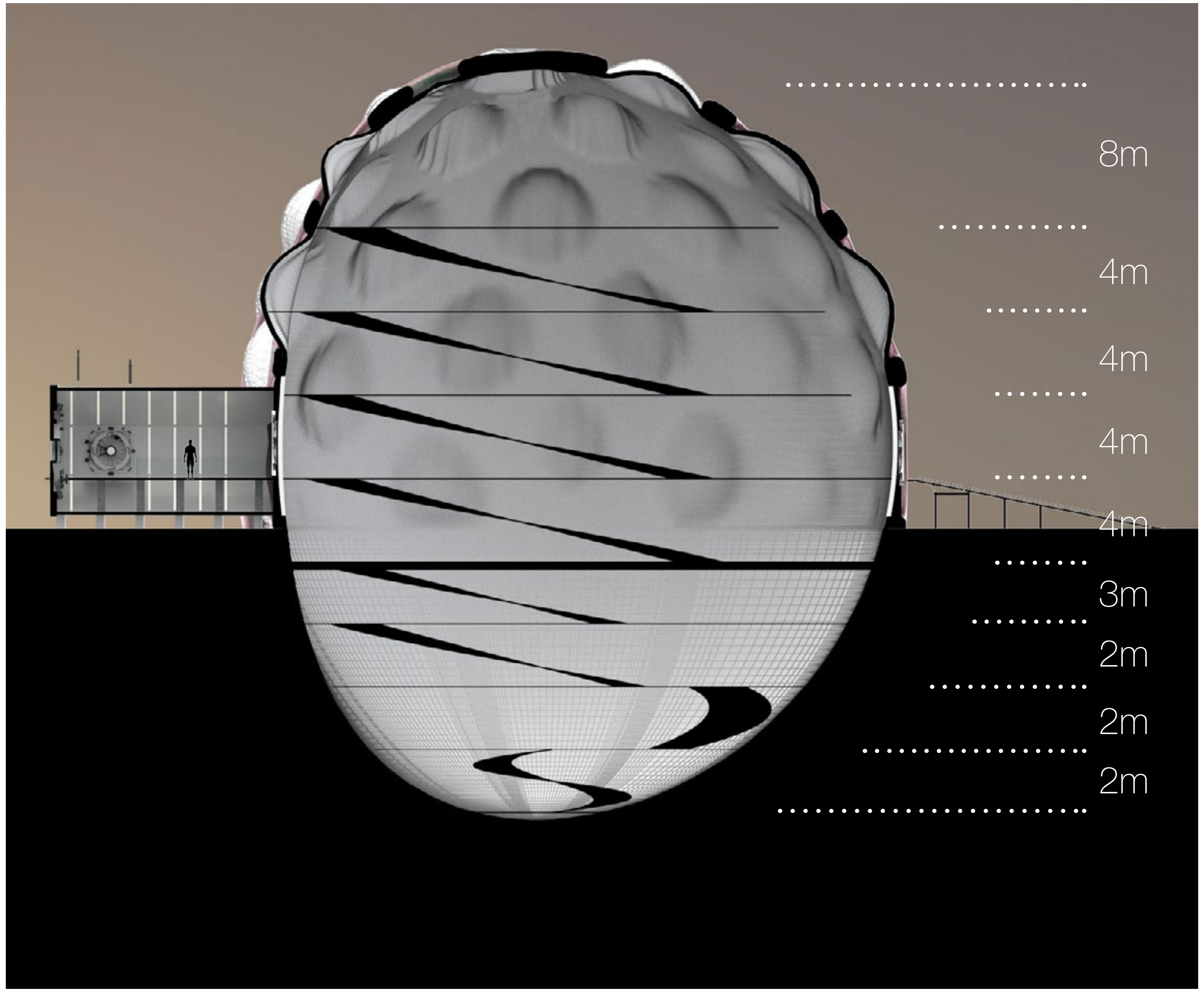
ECLSS & Subsystems

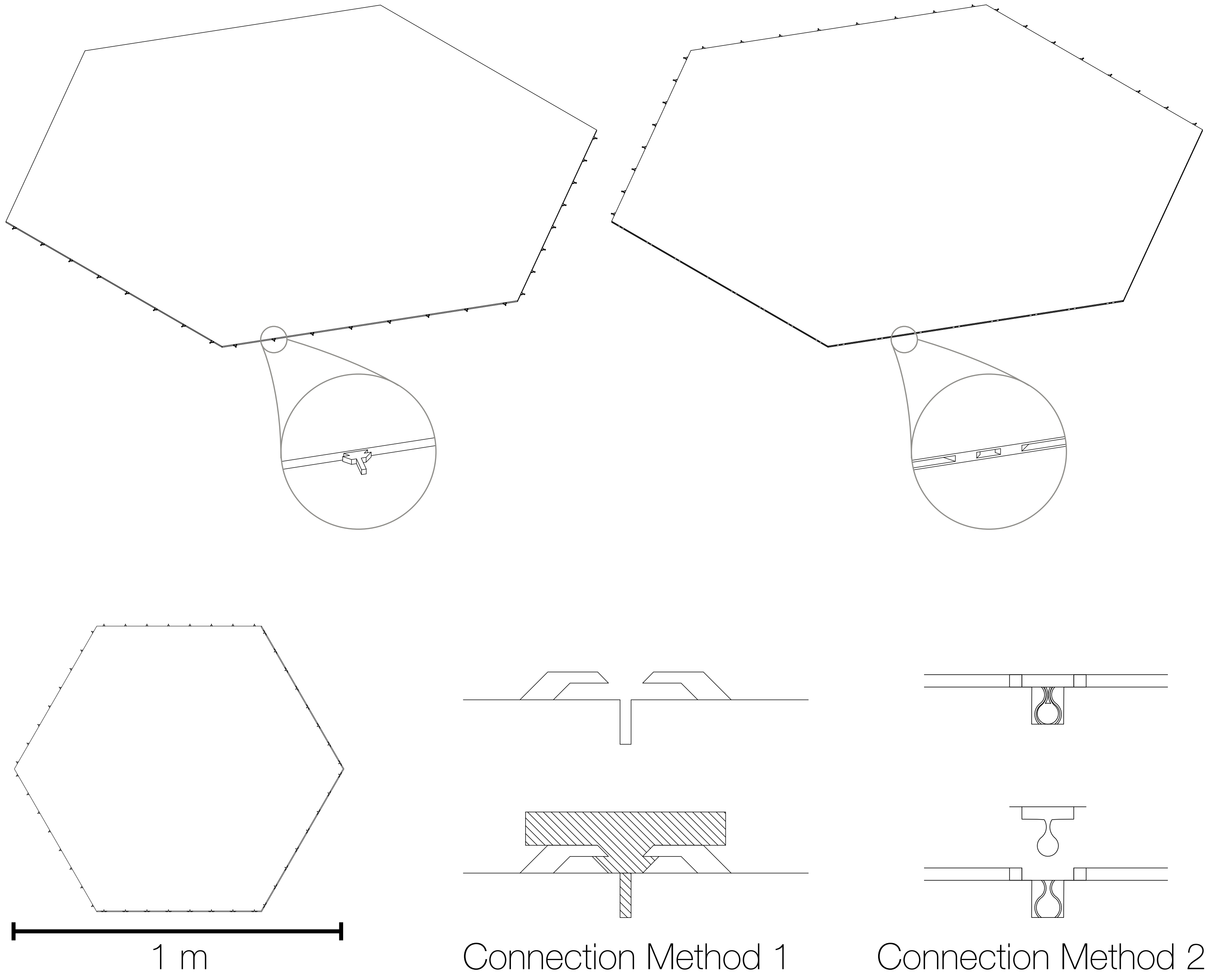




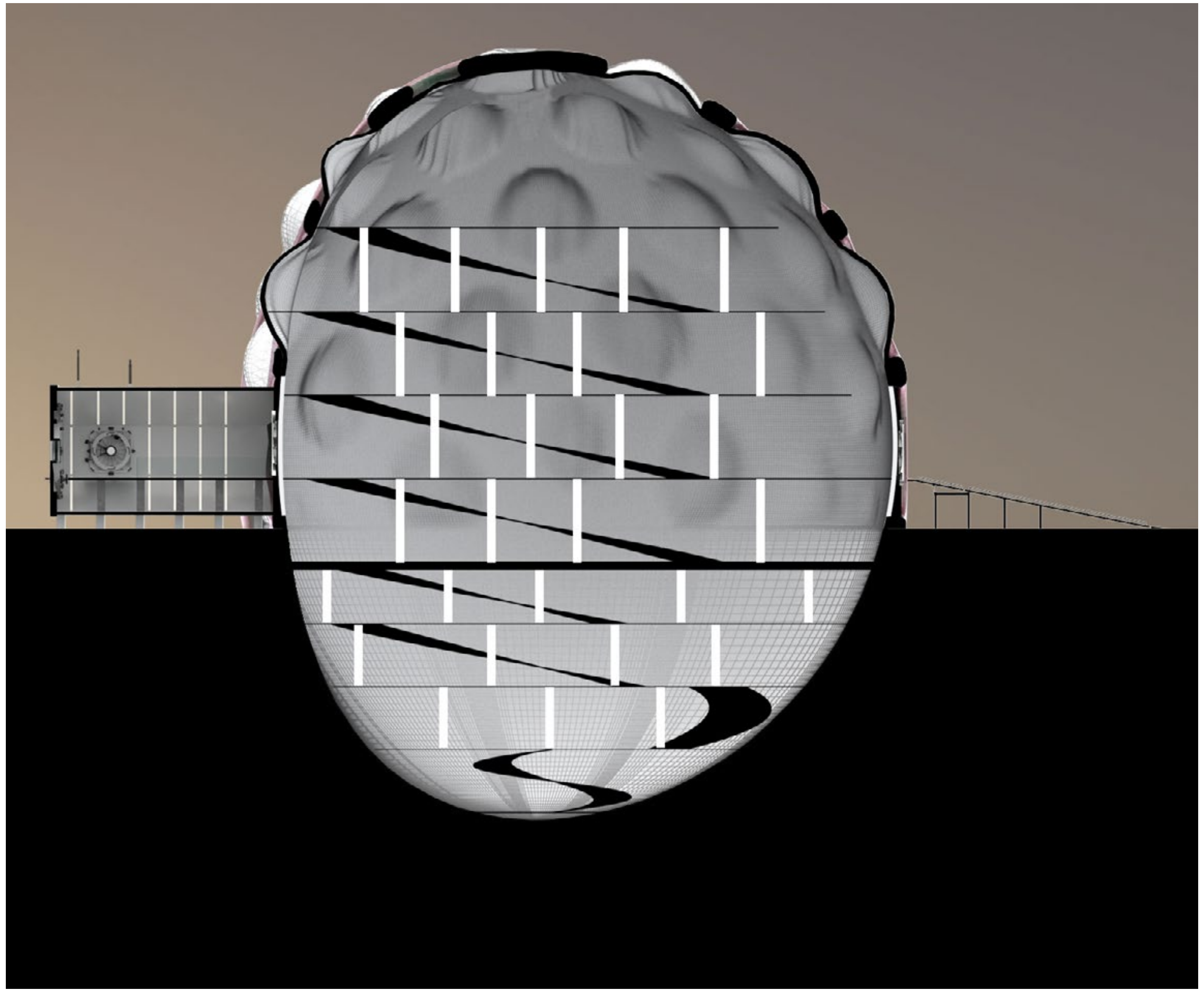


Floor Panels + Levels

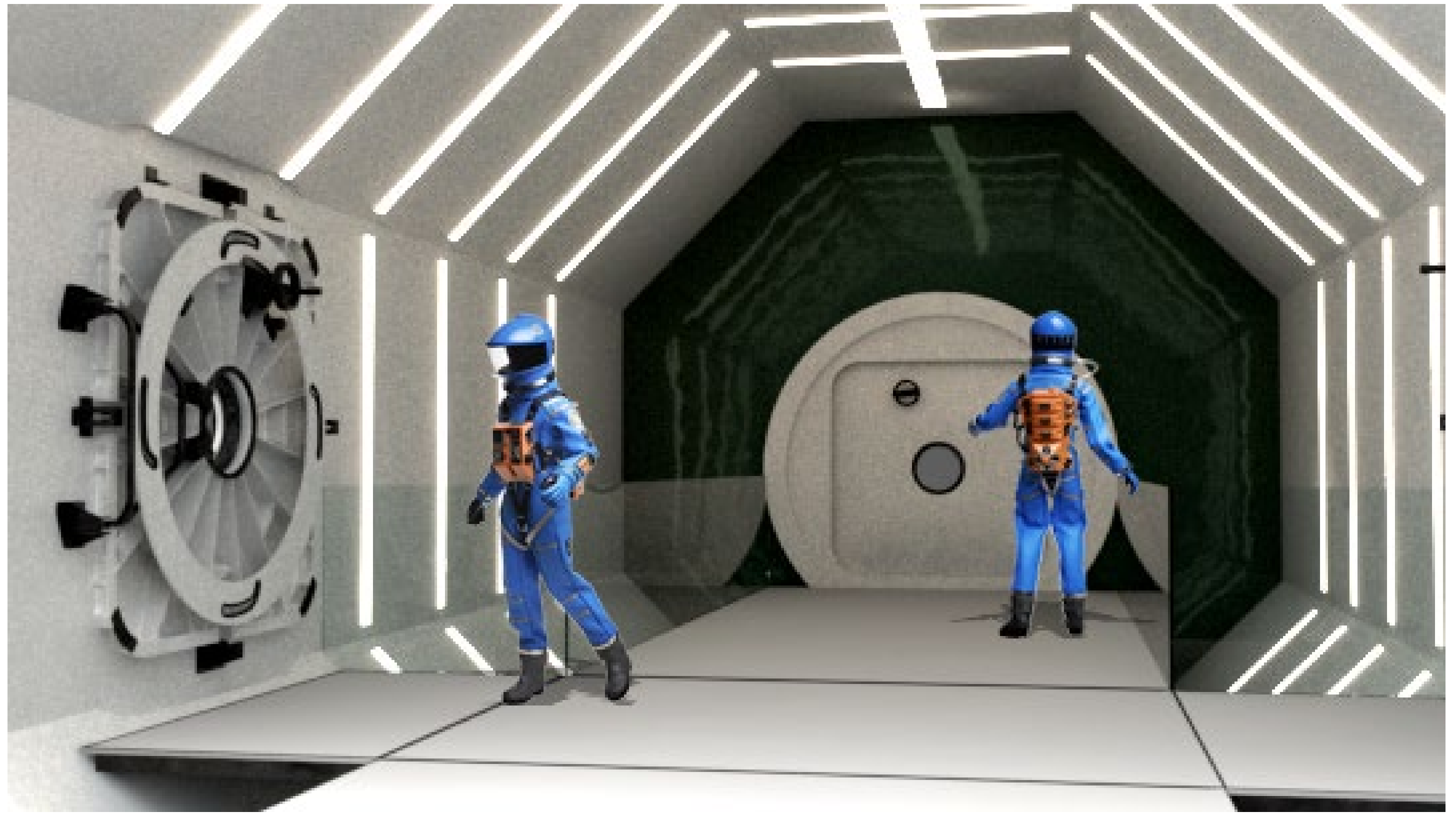


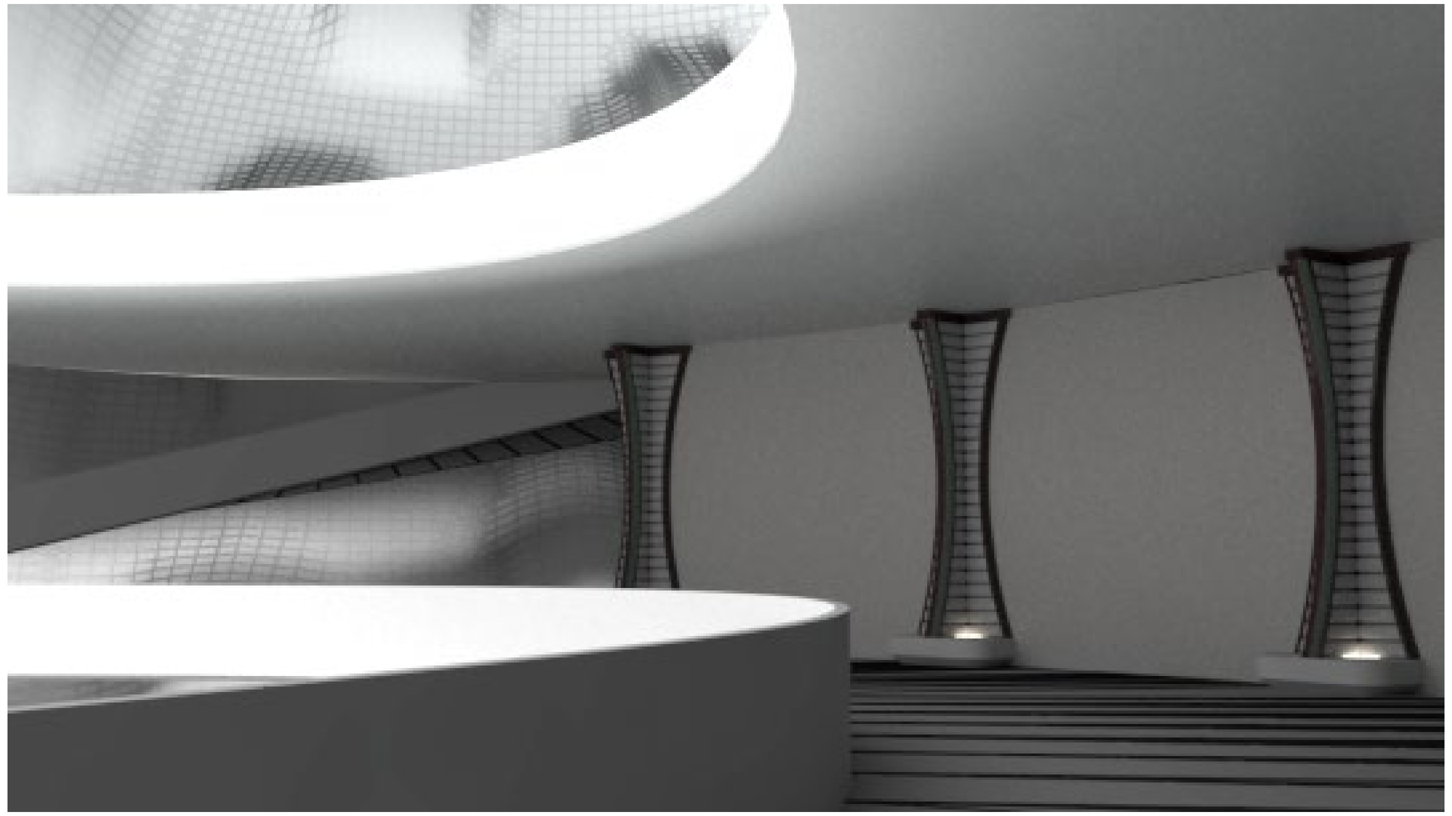


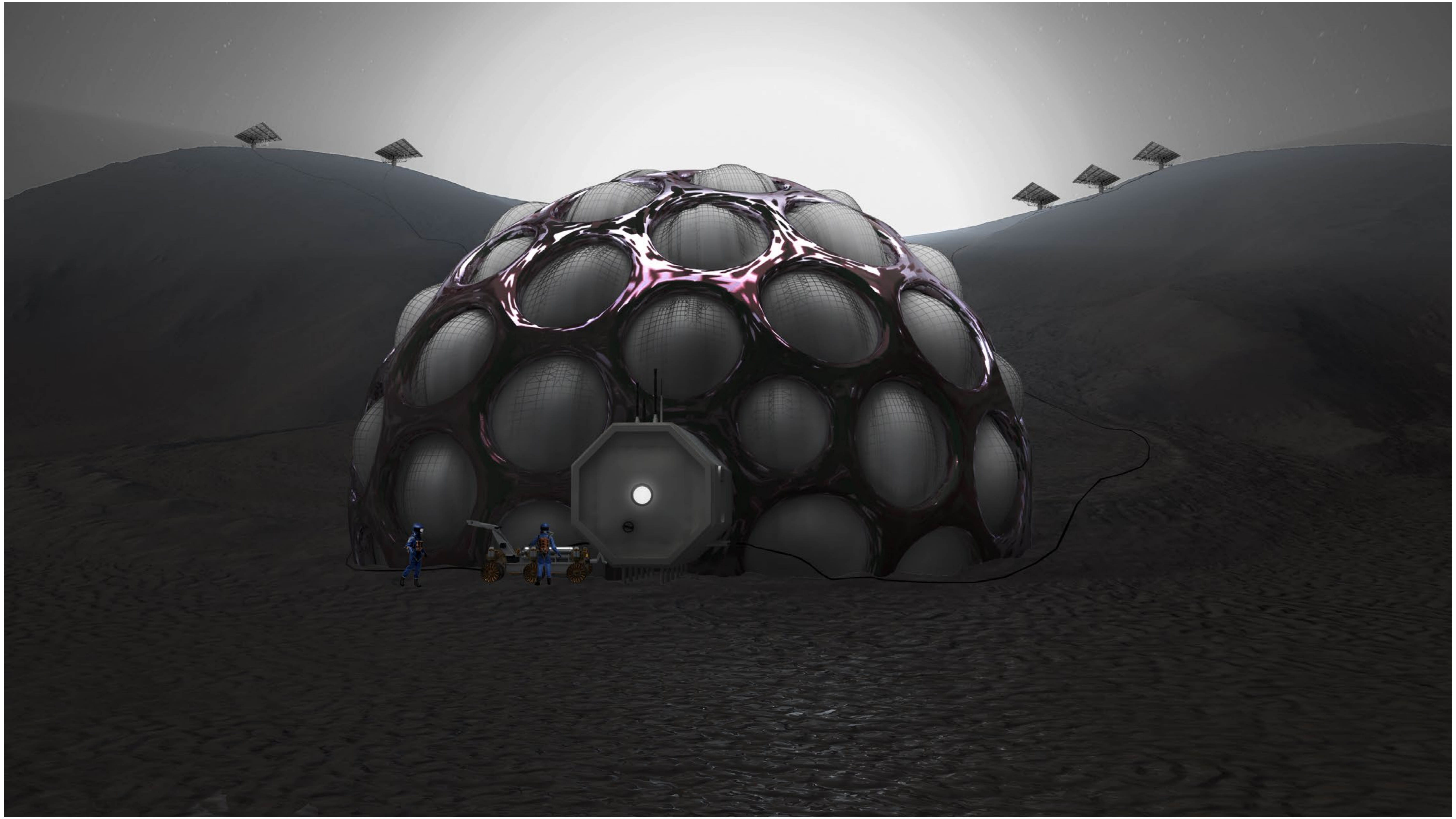
Columns + Levels



Interior Perspectives

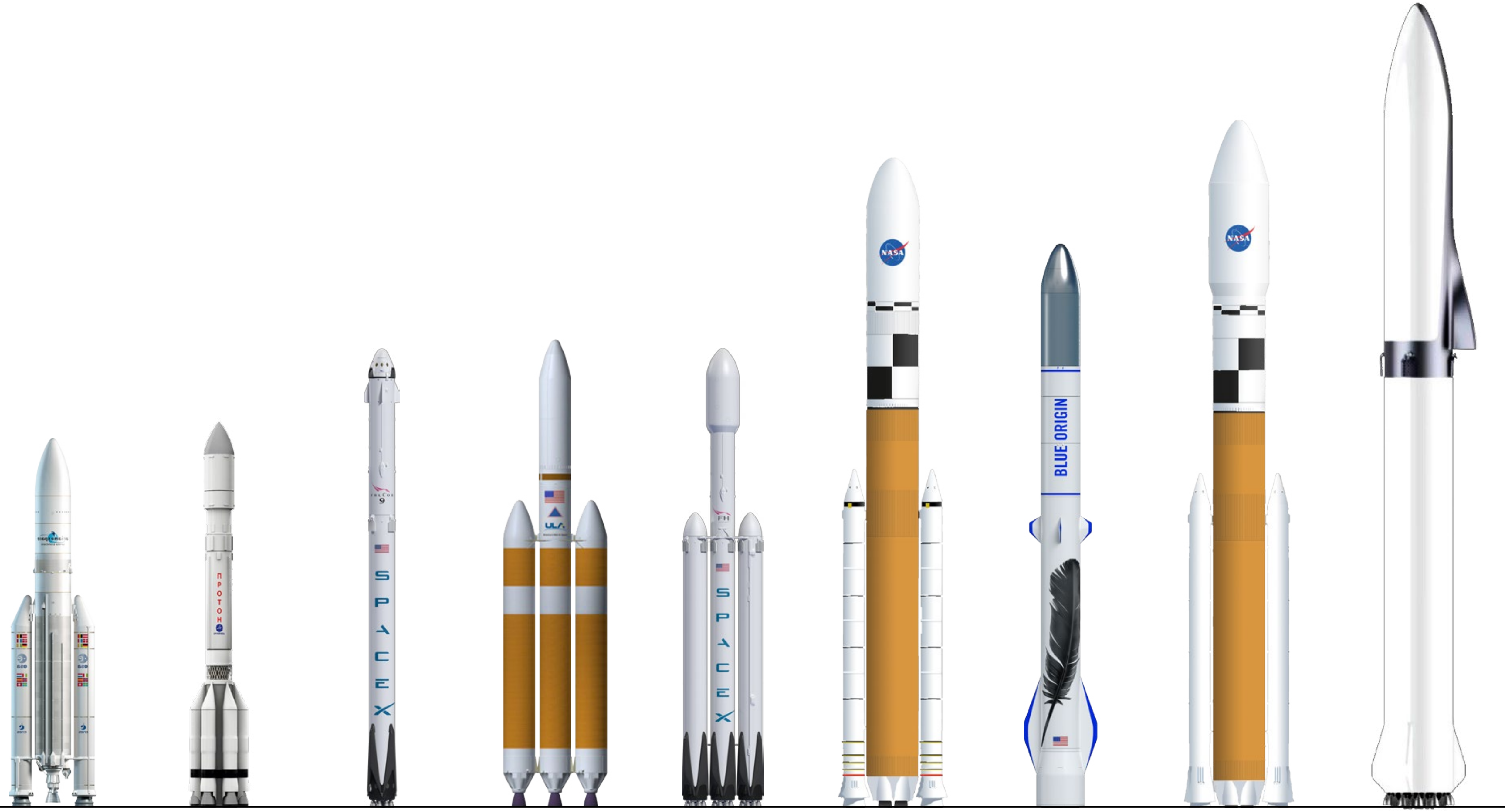






Thank You

Future and Current Rocket Arsenal



	Ariane 5	Proton Briz-M	Falcon 9	Delta IV Heavy	Falcon Heavy	SLS Block IB	Glenn 3	SLS Block II	BFR Cargo Variant
deliverable to LEO (kg)	20,000	22,226	22,800	28,790	63,800	70,000	86,350	130,000	500,000
deliverable to Moon (kg)	10,000	6,320	8,300	14,220	26,700	35,000	38,600	65,000	150,000
fairing size (m)	5.4 x 17	4.35 x 9.75	5.2 x 13.1	5 x 19.1	5.1 x 13.7	8.4 x 31	5.4 x tbd	10 x 31	9.6 x ~17

Examined Materials Chart

Proposed Material Characteristics	Content	Tensile Strength	Density	Melting Point	Young's Modulus	Key Advantages	Key Disadvantages
Aluminum (Weldalite 049-T8)	97-98% Aluminum, 2-3% Lithium	710 MPa	2.66 g/cm³	600-655°C	69 GPa	Proven for space applications, has been selected as metal of choice of Orion capsules. Corrosive resistant.	Does not take blunt forces well. Medium weight
Aluminum Magnesium Silicon Alloy	Aluminum, Magnesium, Silicon	230 MPa	1.80 g/cm³	436°C	48 GPa	Lightest structural material. Used when high strength is not necessary, but where a thick, light form is desired, or if higher stiffness is needed.	Temperatures as low as 200 °F (93 °C) produce considerable reduction in the yield strength.
Carbon Fiber (IM10)	95% carbon, 5% resin	3310 MPa	1.79 g/cm³	3652°C Resin: 260°C	30 GPa	Does not fatigue, high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, non poisonous, biologically Inert and is a shape-memory polymer, non-corrosive.	At temperatures above 66°C, carbon fiber resin strength will be reduced. Cannot easily handle Isotrophic force, strength focused on direction of fiber.
Aluminum 6061	1-4% Magnesium, <1% Silicon, 95-98% Aluminum	290 MPa	2.70 g/cm³	585°C	68.9 GPa	Great tension strength, very common aluminum product in aircraft structures. Corrosion resistant. Very wieldable. Verified as stable in ultra-high vacuum chambers.	Not very strong against brunt forces.
Aluminum 7075	2-3% Magnesium, <1% Magnese, 98-97% Aluminum	572 MPa	2.81 g/cm³	635°C	72 GPa	Corrosion resistance, no exhibit age hardening, nor does it need a precipitation heat treatment to promote hardening. Weldability is good.	Machinability is only fair to poor.
Aluminum Silicon Carbide (AMC640XA)	40% Silicon Carbide, 60% Aluminum	570 MPa	2.90 g/cm³	400°C	40 GPa	Wear resistance, Low coefficient of thermal expansion, crack-resistance, class 1 grade material by ESA testing, very high chemical and corrosion resistance, no porosity.	Very new material that hasn't been used in space structurally yet.
Ferrosilicon	Silicon, Iron	1,586 MPa	6.70 g/cm³	4892°C	206 GPa	Lighter than aluminum based alloys,	Very prone to get rusty, requires resin to protect it. Not a strong tensile material, flamable, not bendable.

Unit Legend
Mpa: Megapascals GPa: Gigapascals mm: Millimeters cm: Centimeters g: Grams °C: Celsius