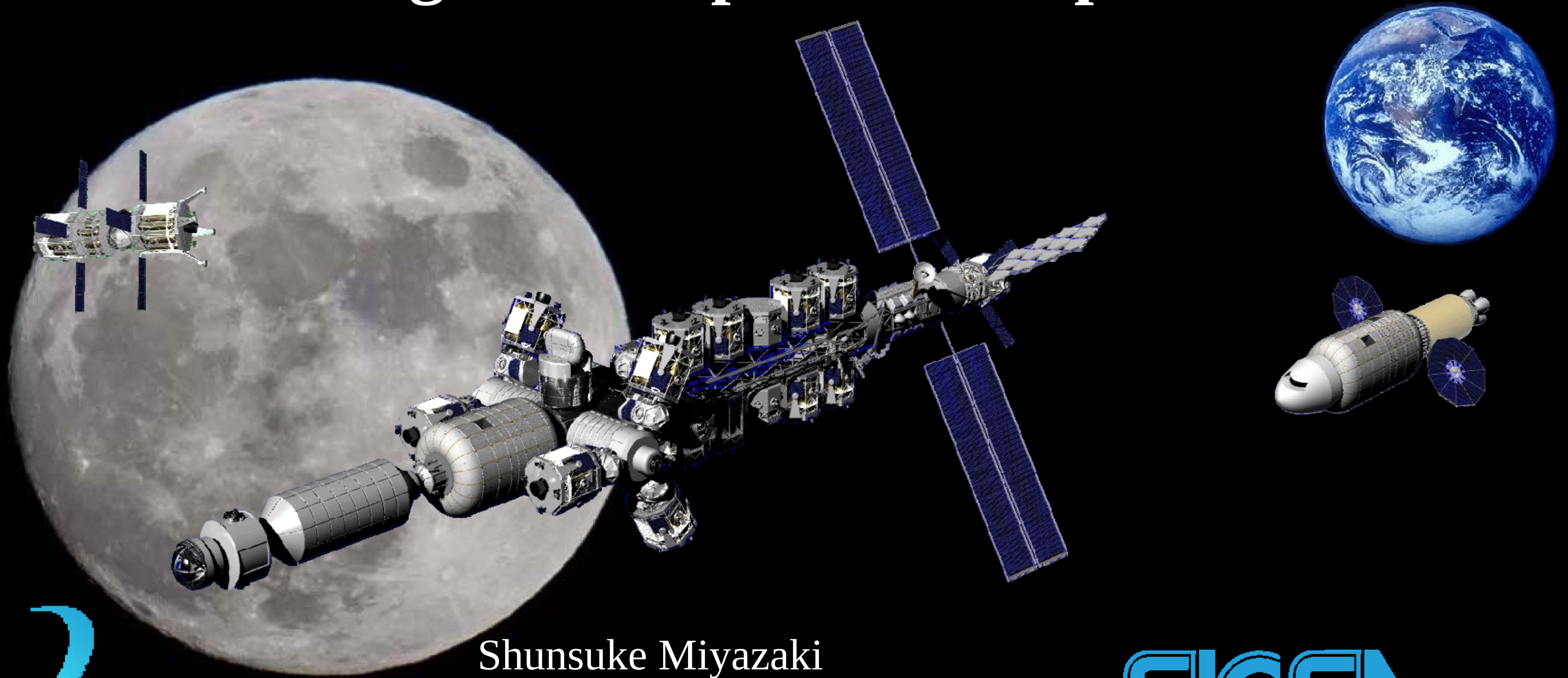
Conceptual Design of Commercial Cislunar Space Station for Large Scale Space Development



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Prof. Larry Bell

Sasakawa International Center for Space Architecture
Cullen College of Engineering
University of Houston

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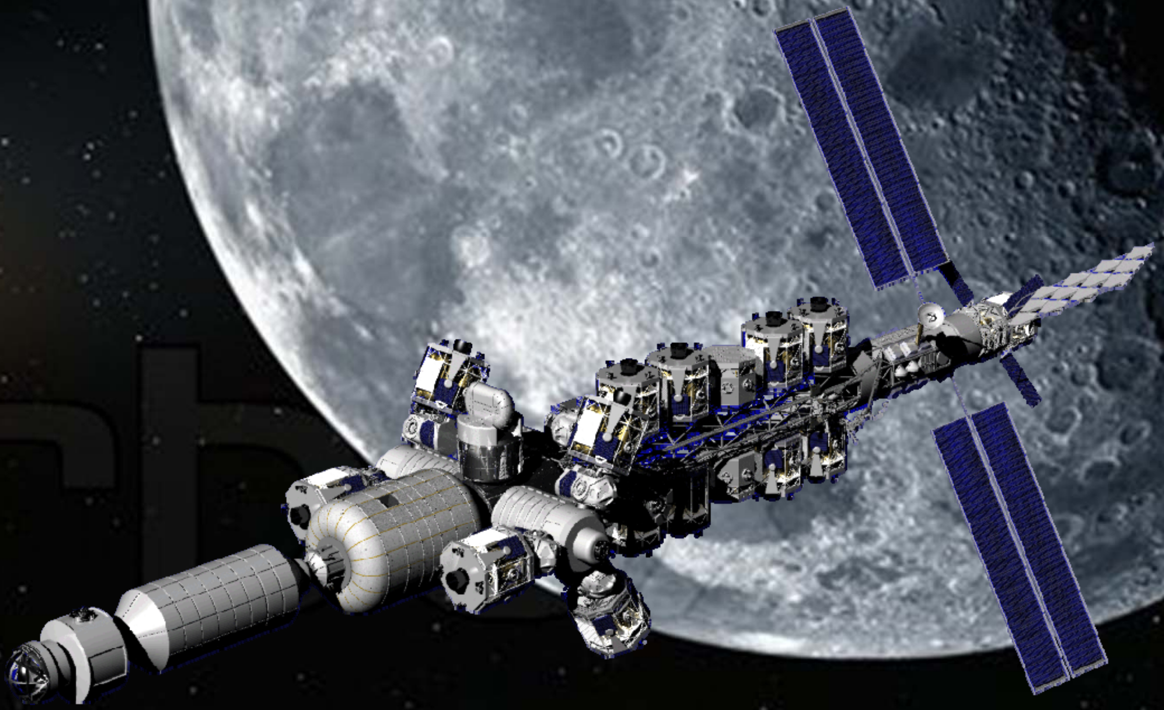
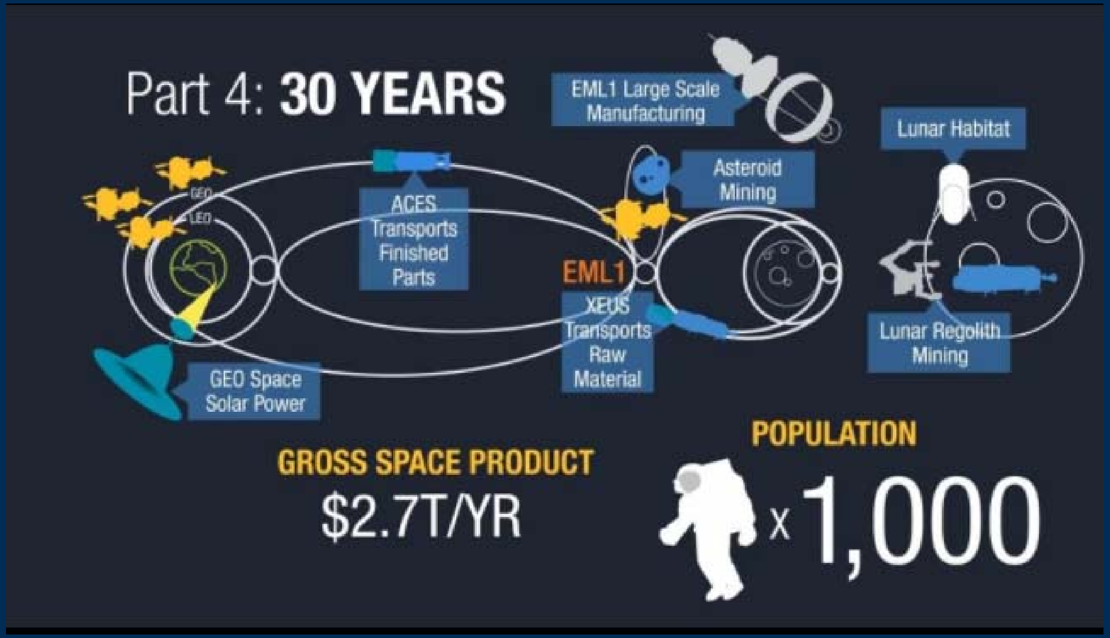


Introduction: Mission Statement and Goal

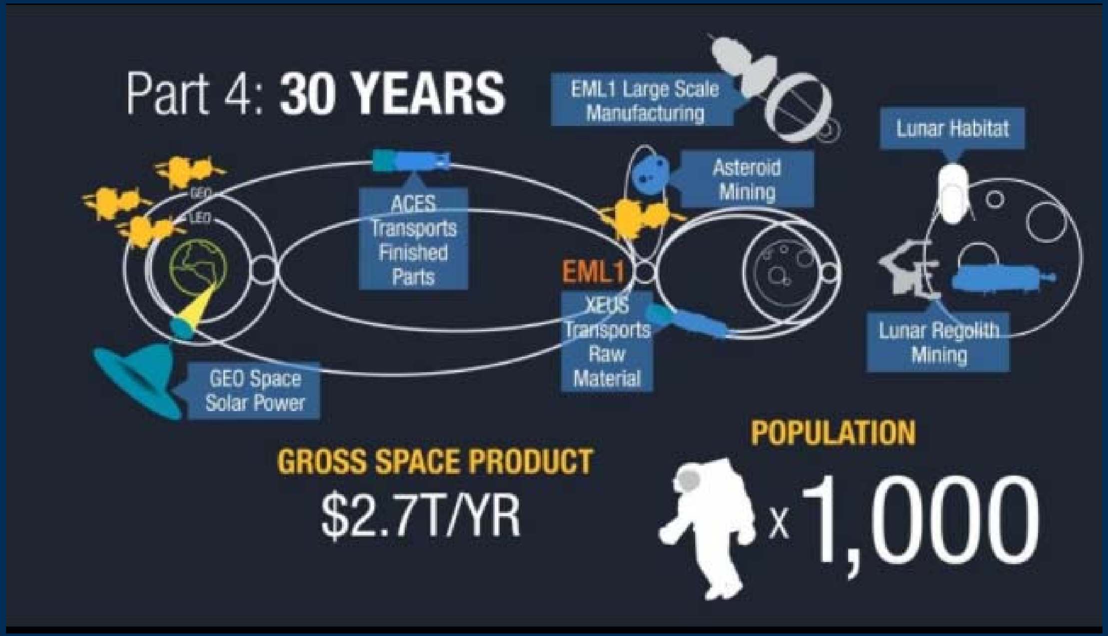


- Mission Statement:
  Design, Build, and Deploy Commercial Lunar Orbit Station by 2040

- Mission Objective: Support ULA's Cis-Lunar-1000 after 2045

1. To study and develop Future technology
2. To develop testbed to study future long-human space flight
3. To develop waystation to enable to access to various destination
4. To encourage commercialization of Cis-lunar space

Introduction: Mission Assumption

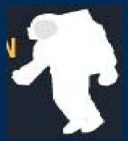


❑ Assumption
- LOP-Gateway will start building and operating from 2025
- Initial unmanned and manned lunar and mars exploration has started

❑ Environment Assumption
- ➢ ISRU on the Moon

>400mT/year by 2037

- ➢ Population on the Moon at 2045 through a year



×170

42 tourists (1month stay)
128 crew (3~6 month)

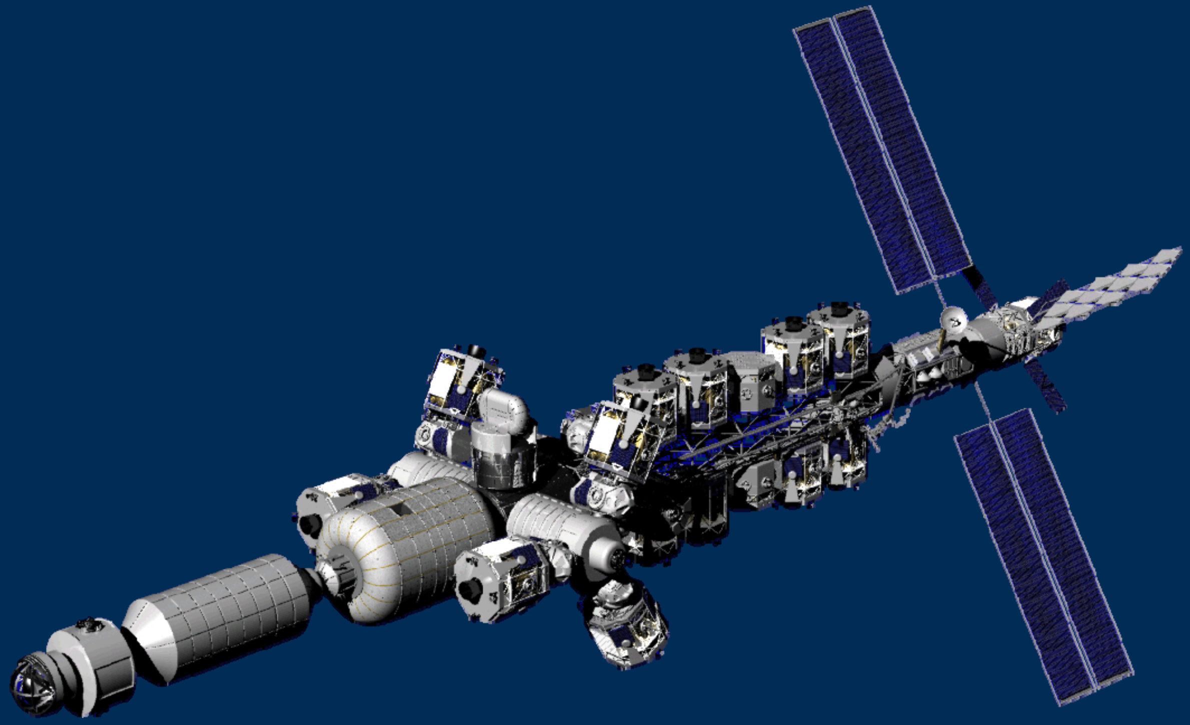
Need 50 people Transition every month

Design Requirements

- AXIS Design Requirement

=15yrs

12 crew members (nominal), for 180 days without Resupply

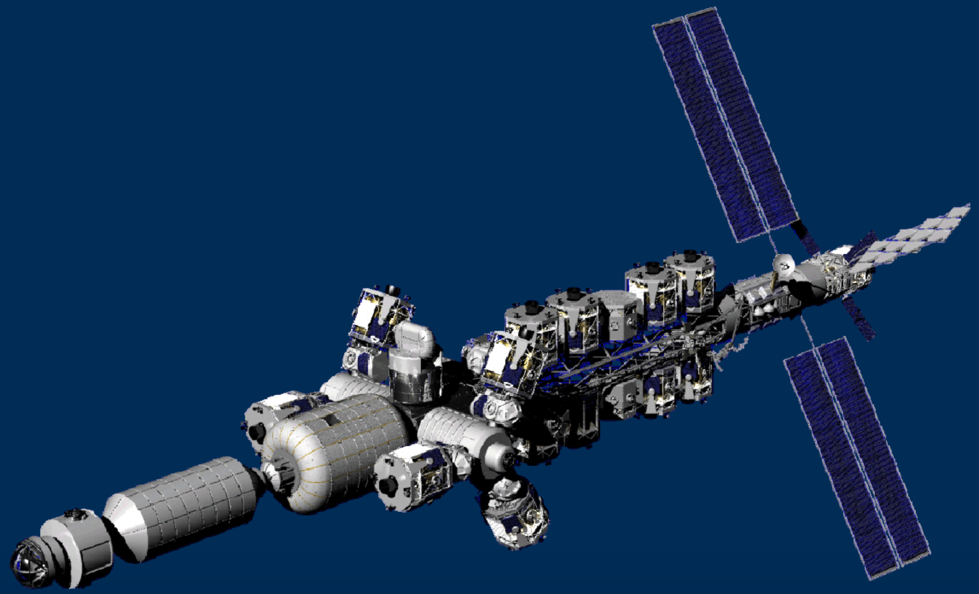


- Closed-Loop ECLSS (95% Water Recovery, >85% CO2 recovery)
- Depends on both Earth and Lunar resupply
- Friendly User Interface
- Well designed for

- Protect Crew from SPE, GCR

- Allow to berth/ docking following vehicles concurrently;
  - 2 × Cycler
  - 4 × Lunar Lander
  - 2 × Cargo
- Allow to berth following vehicles on the truss;
  - 10 × Modular Lander
  - 2 × Crew Vehicle
  - 1 × Cargo

Introduction: High-Level Requirements



- Science and Technology Requirements

Science & Technology

Remote Operations Support

Human Factor and Health

Small Satellite Service & Communication

Orbit Manufacturing

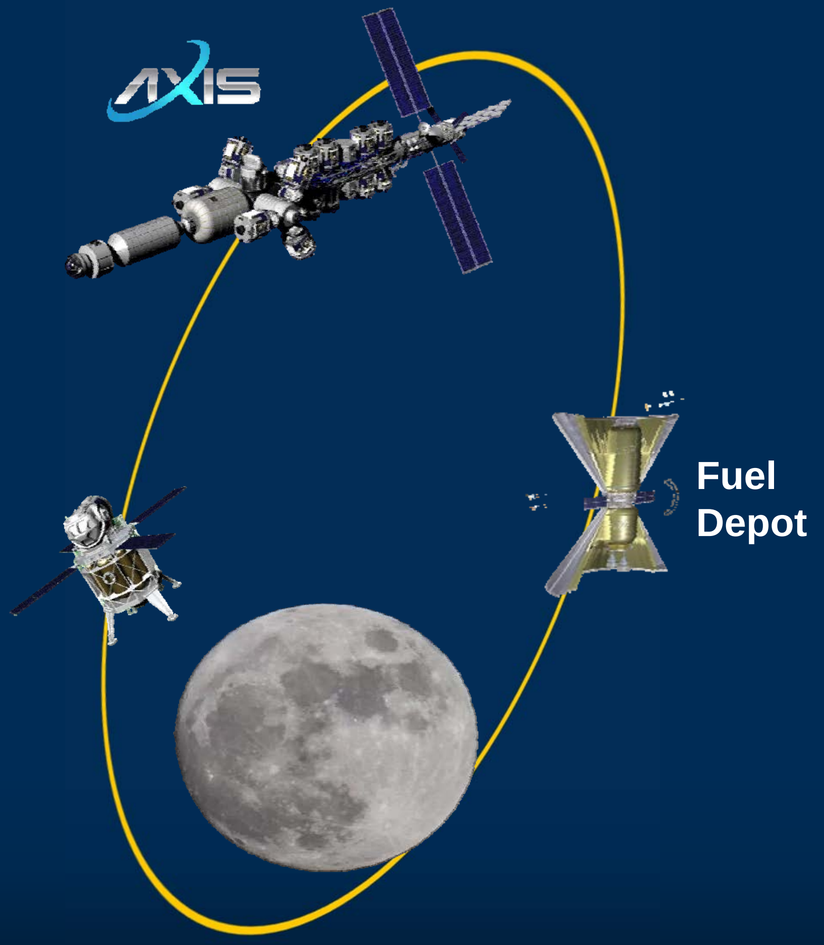
Safe Heaven & Rescue Operation

On Orbit Assembly & Maintenance

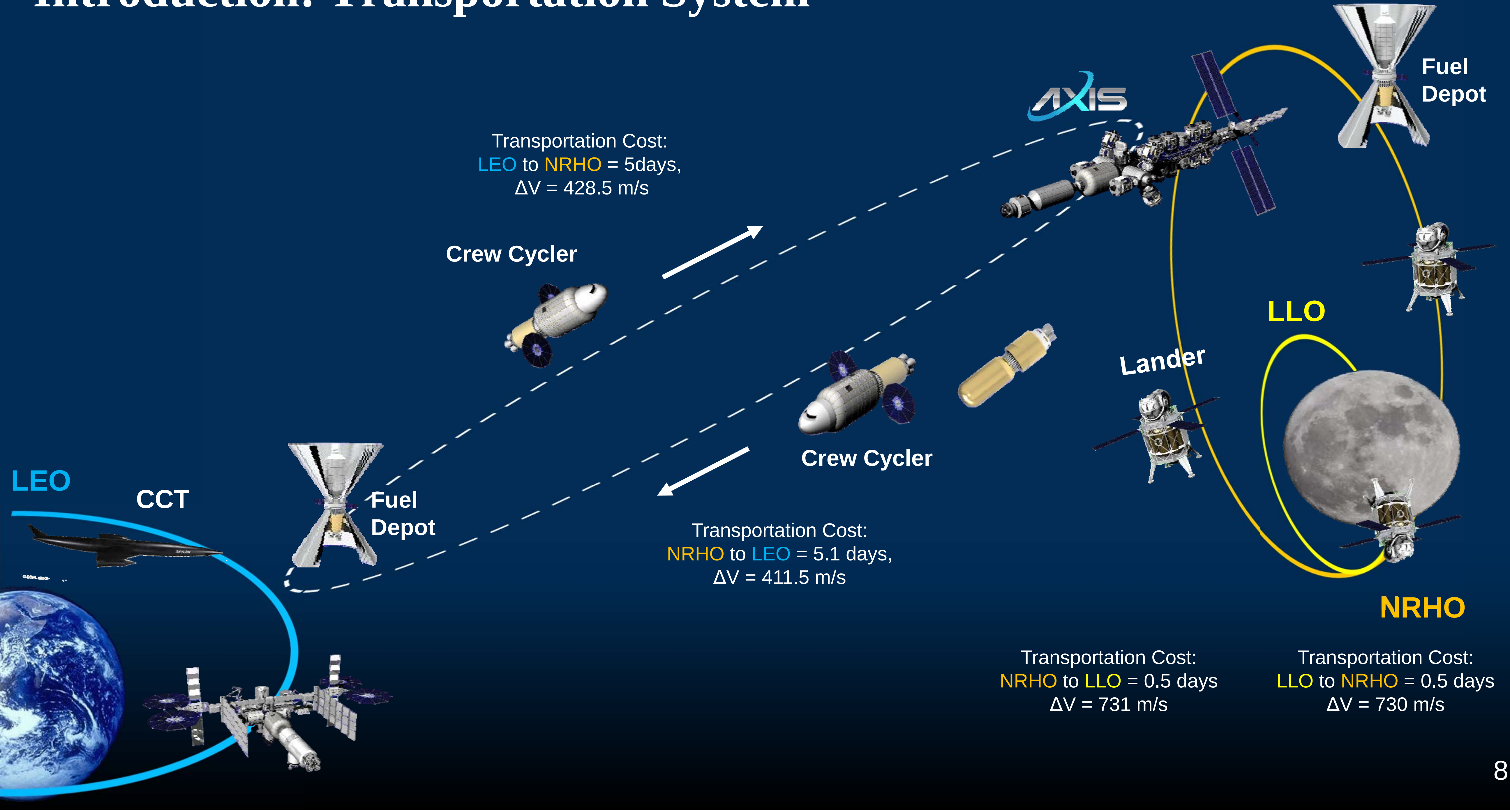
Design Overview: Orbit Selection

- Near Rectilinear Halo Orbit

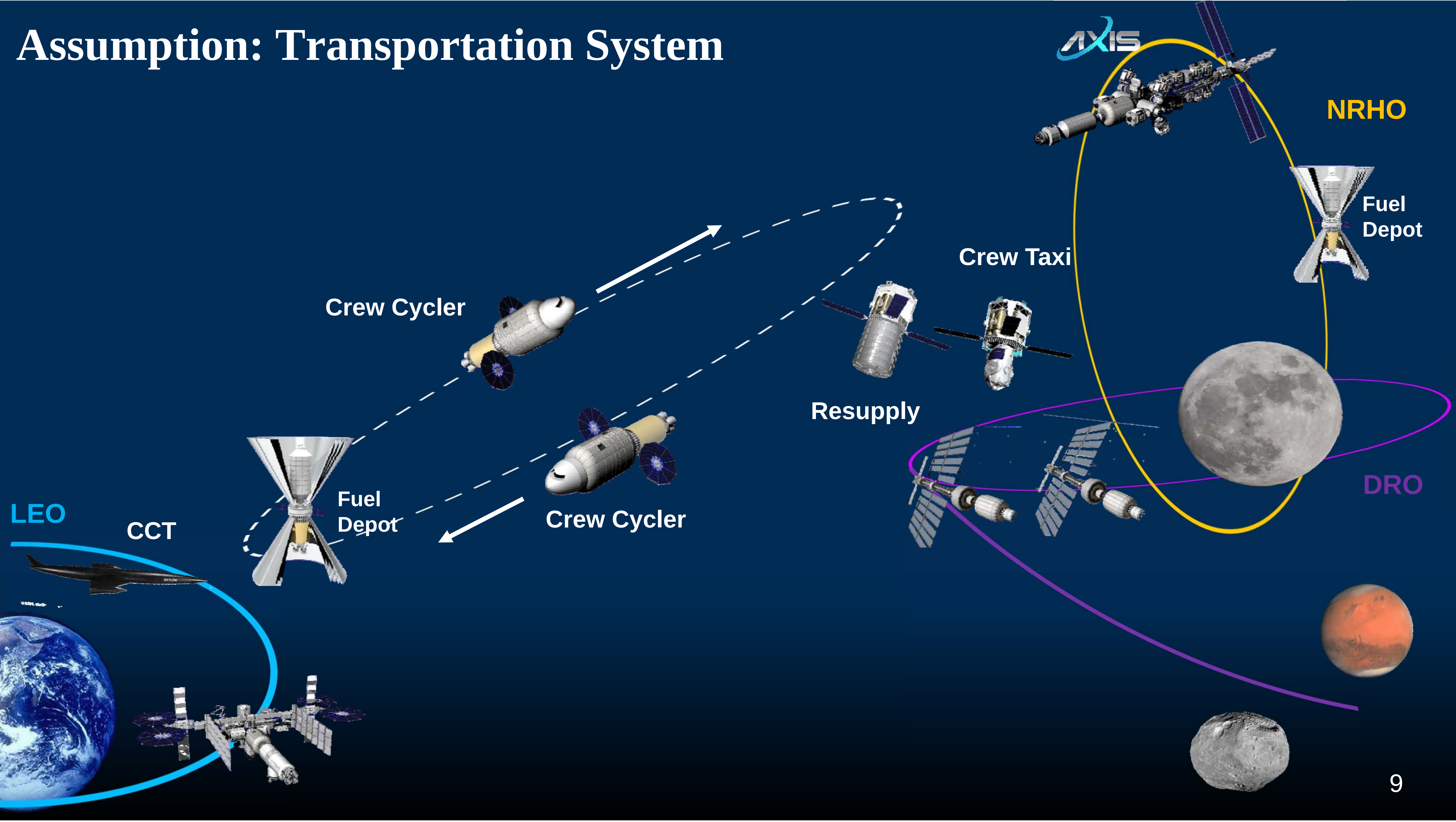
Orbit Characteristic	
Orbit Period	6-8 days
Lunar Amplitude Range	2000-75000km
Station Keeping	10 m/s per year
No communication Occultation	
Radiators are sufficient for Heat Rejection (62W/m^2)	



Introduction: Transportation System

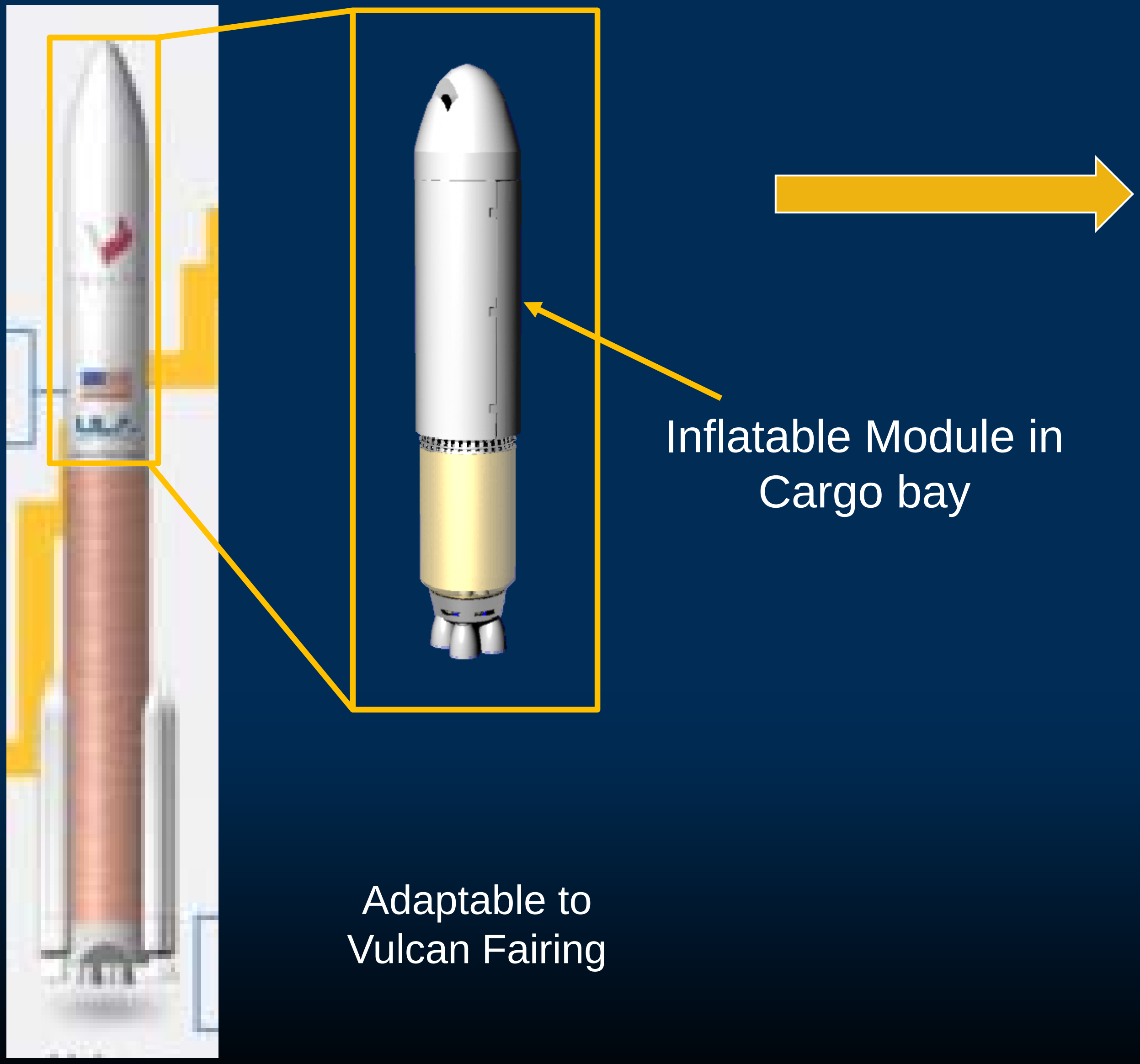


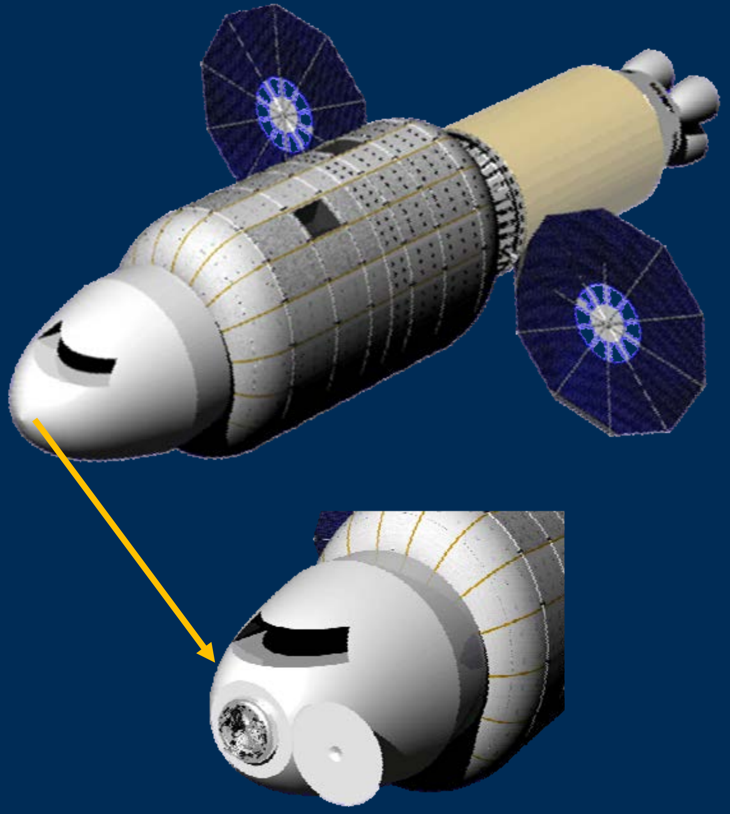
Assumption: Transportation System



Assumption: Available Elements

- Lunar Crew Cycler





Adaptable to
Vulcan Fairing

Lunar Cycler	
# of Crew	15
Support Duration (days)	30
Pressurized Volume (m^3)	400

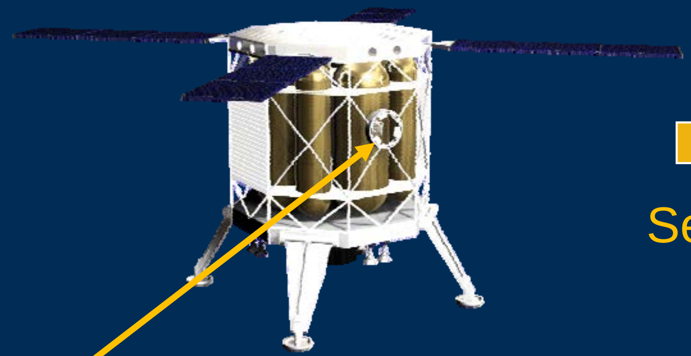
Design Overview: Available Element

- Modular Systems

Modular System	
Mass of Structure	2783 kg
Mass of Propellant	6748 kg
Max. Mass of Cargo	8370 kg

Crew Lander	
# of Crew	8
Support Duration	7 days
Pressurized Volume	20 m^3

Modular Lander

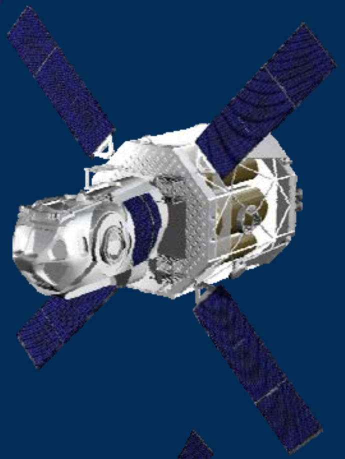


Androgynous Connection

Service Module

Crew Lander

Cargo Transporter



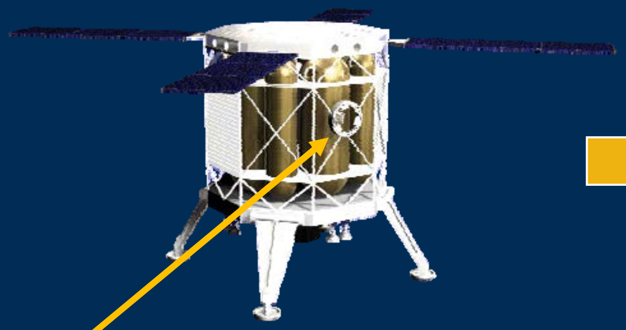
Crew Transfer Vehicle

Space Tug

Mission Assumption: Available Element

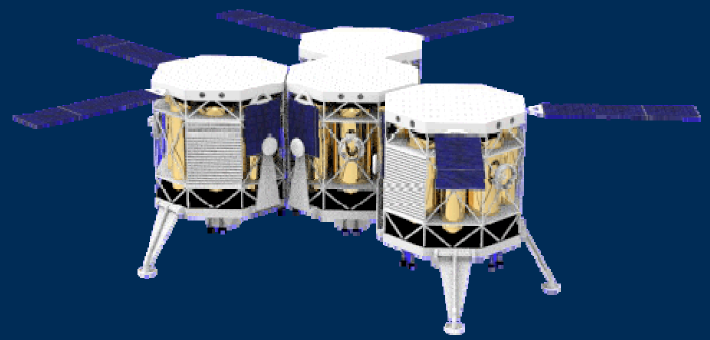
- Modular Systems

Modular Lander

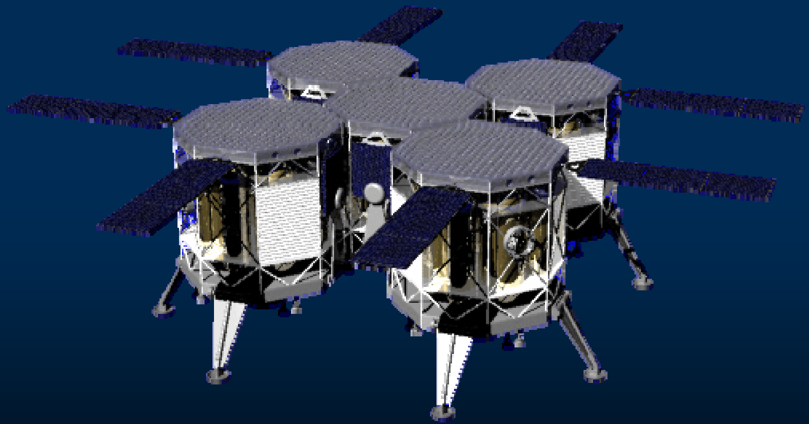


Androgynous Connection

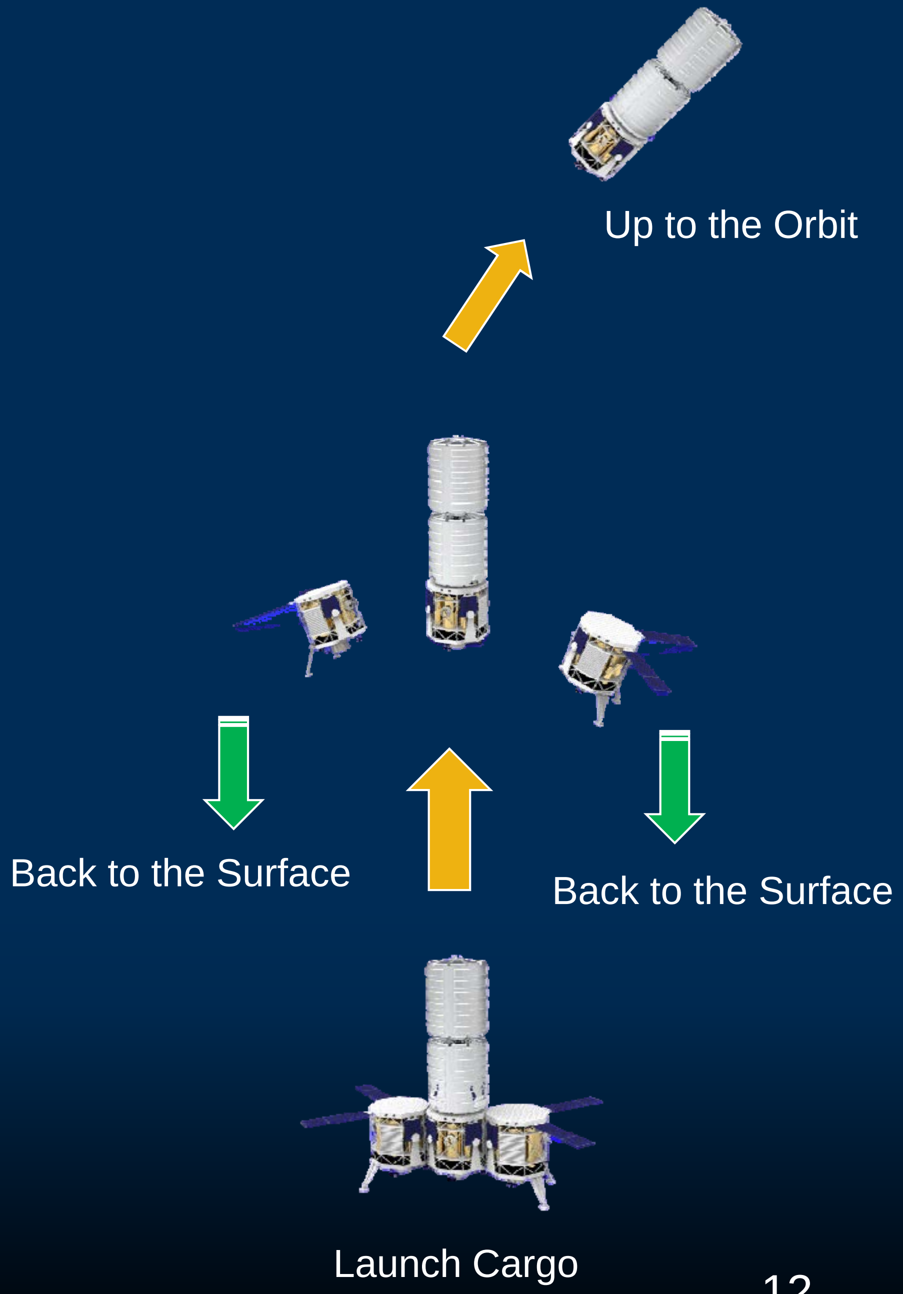
Cargo Lander/ Launcher



33,480kg Class Cargo

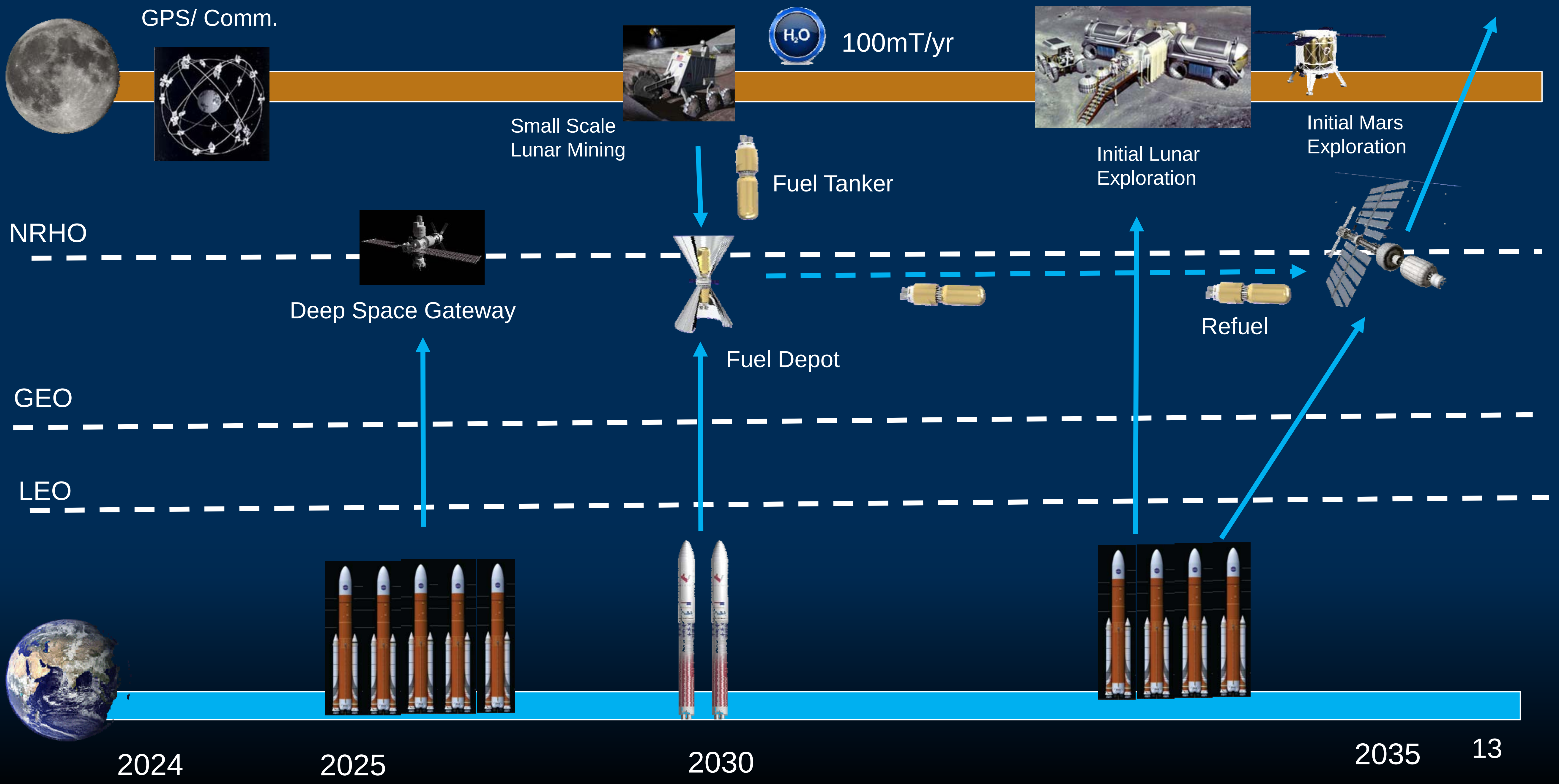


41,350kg Class Cargo

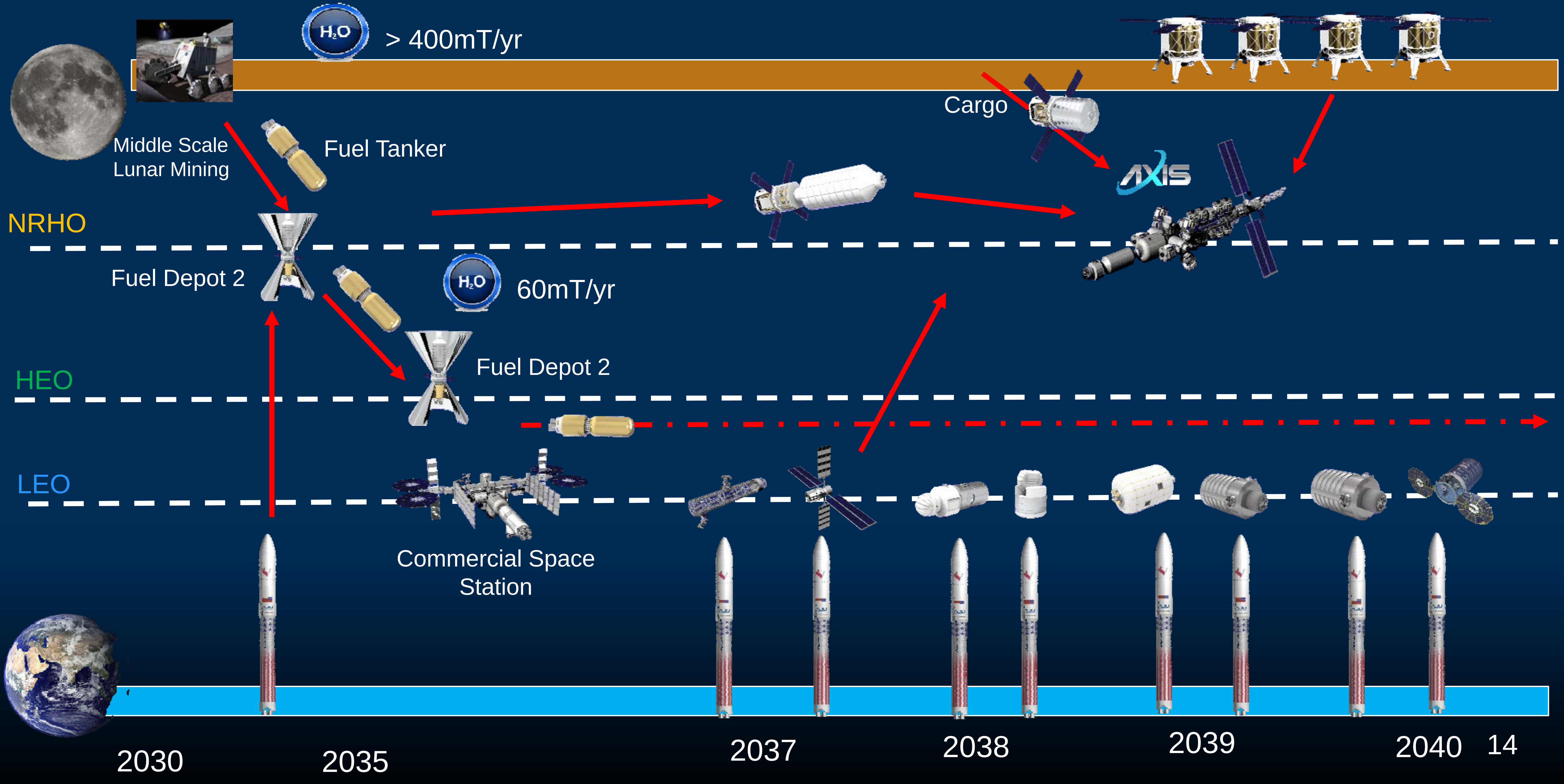


Modular System	
Mass of Structure	2783 kg
Mass of Propellant	6748 kg
Max. Mass of Cargo	8370 kg

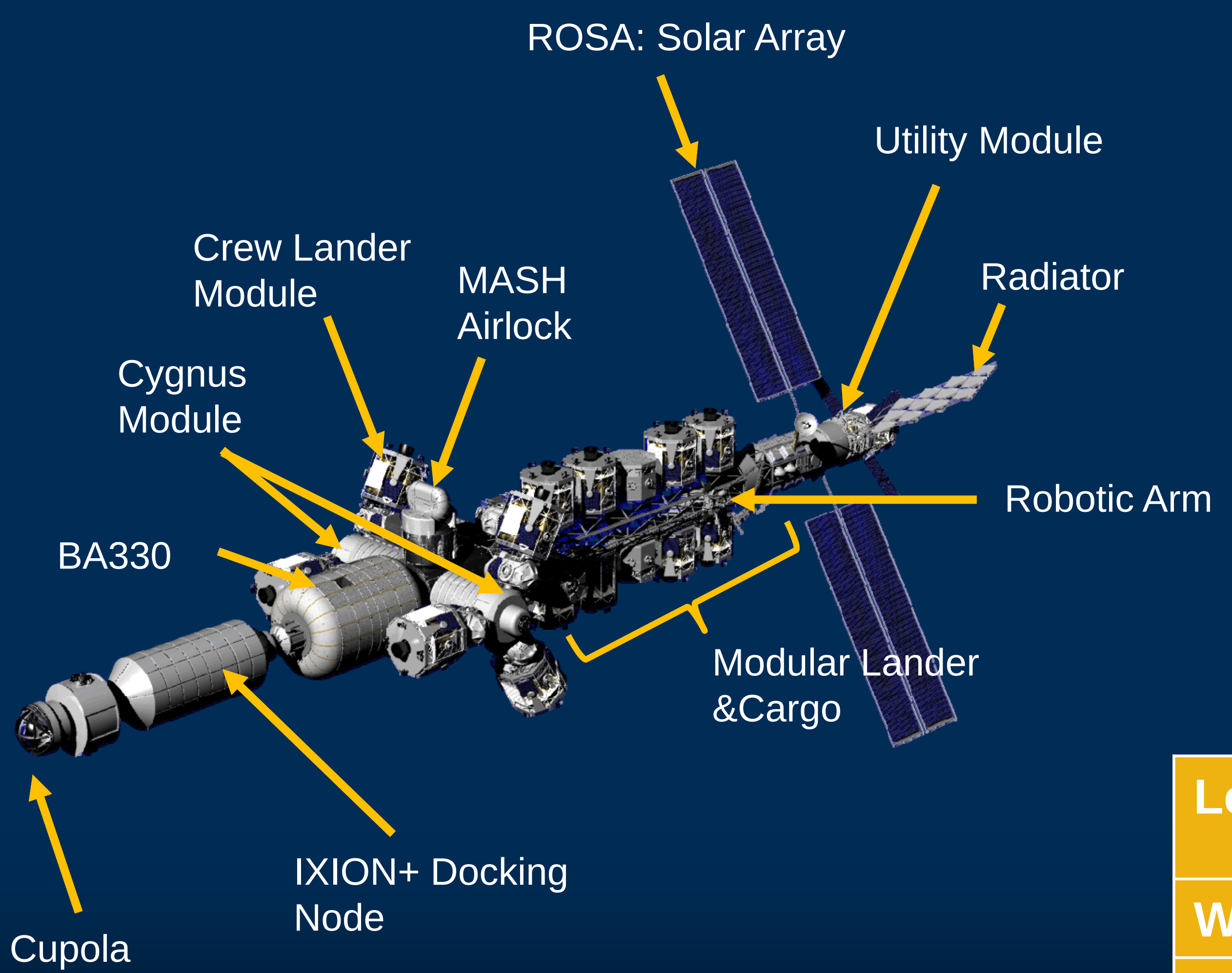
Introduction: Mission Timeline, Phase 1 Preparation

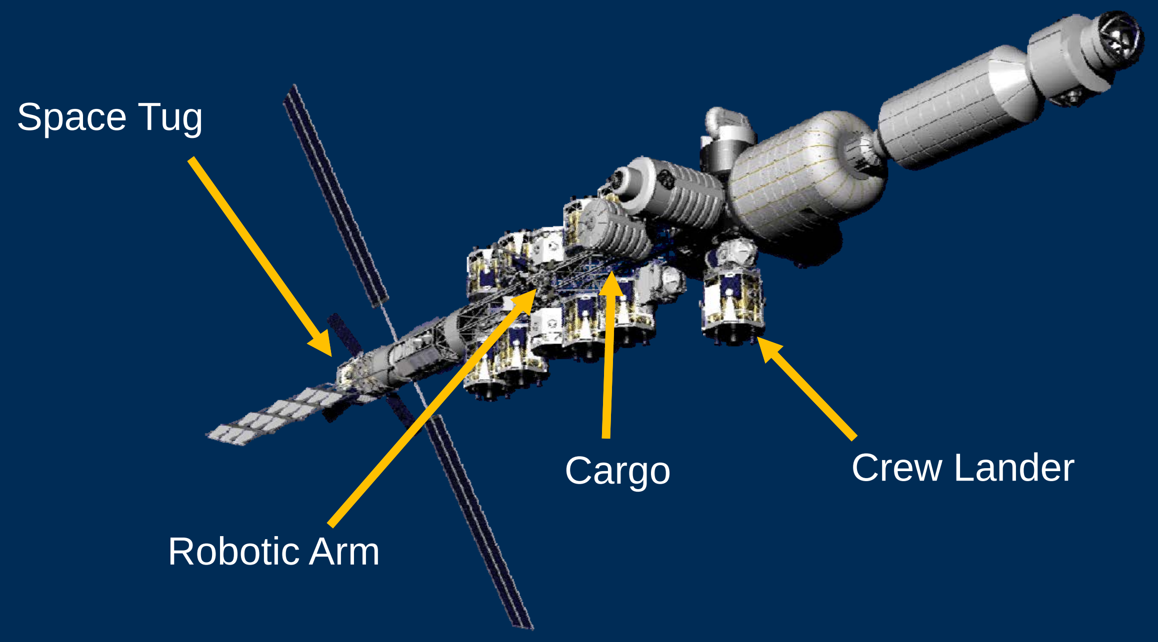


Introduction: Mission Timeline, Phase 2 Building



Overview Design of Axis Station

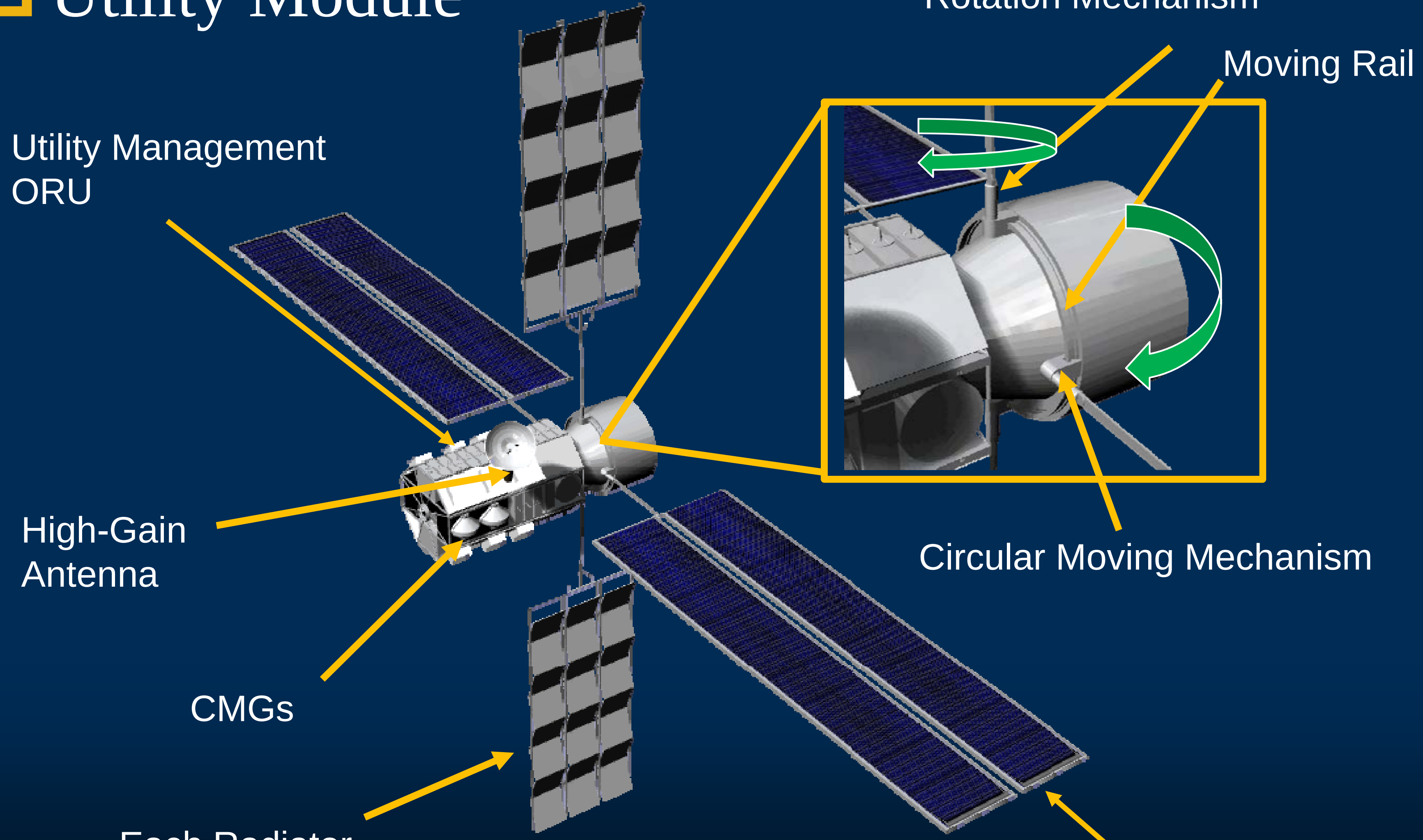




Length (+S.Tug) (m)	81m (94.8m)
Width (m)	36.4m
Height (m)	43m
Pressurized volume (m^3)	913
Pressurized Docking Port	11

Design Overview: Utility Module

❑ Utility Module



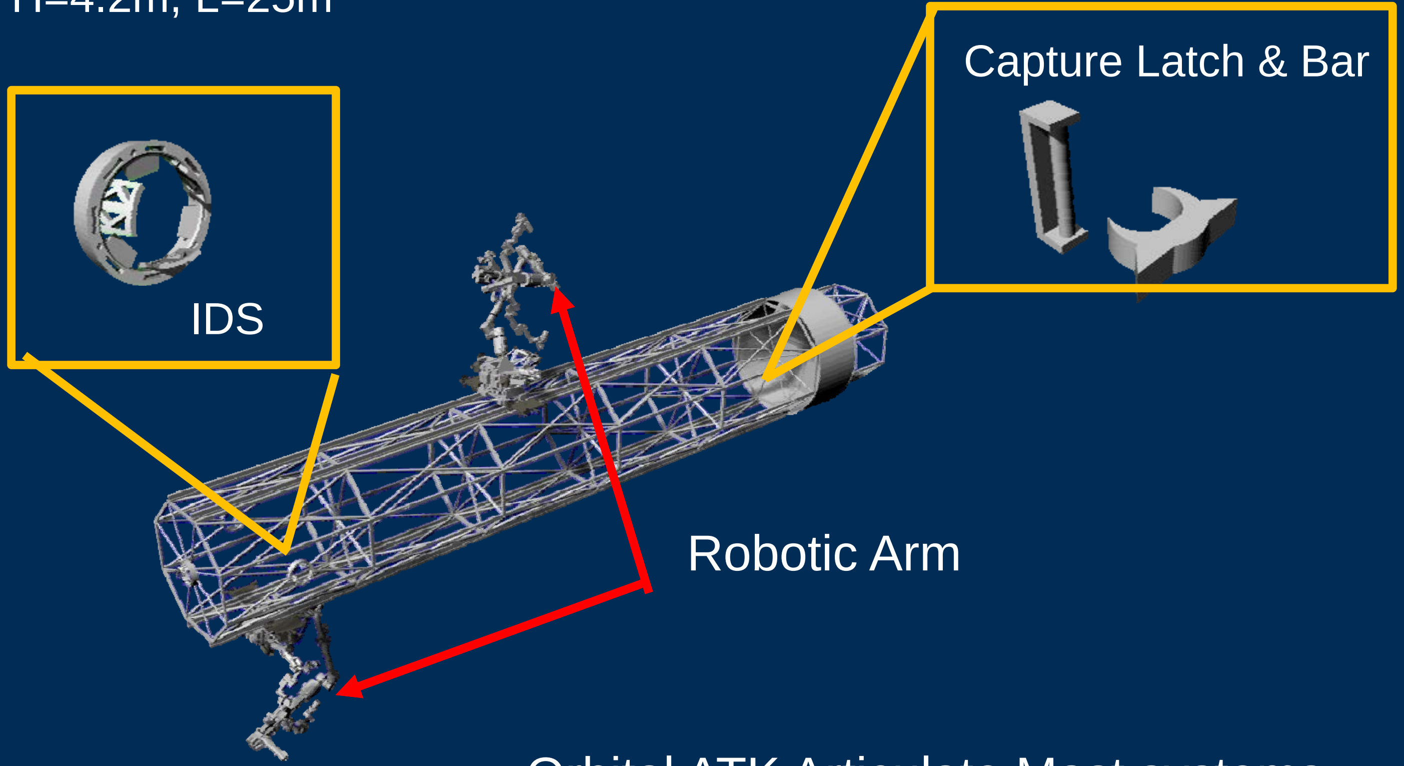
Solar Array: 4 ROSA, W=3m,L=22m Each
Total Power Generation = 130kW

❑ Li-Ion Battery

- NRHO Total Eclipse Time = Max. 3hours
- Baseline Power = 80kW
- Total Required Capacity = 240kWh
- # of Li-Ion Battery Cell = 1367 cells
- Mass = 783kg

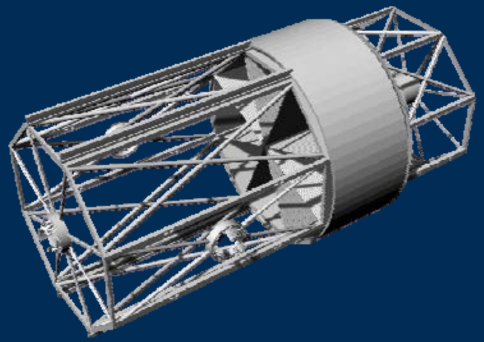
Design Overview: Articulated Octa. Truss Systems

Truss Configuration: Octagonal
H=4.2m, L=25m

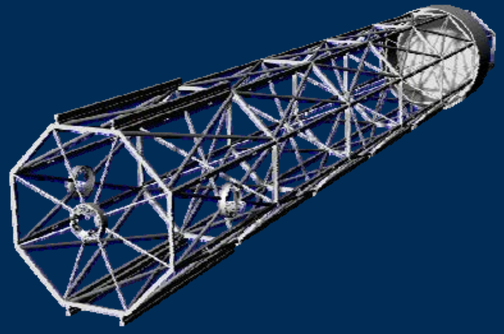


Orbital ATK Articulate Mast systems

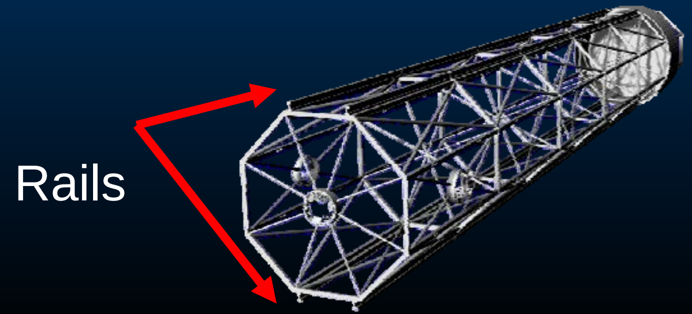
1. Fold At Launch



2. Deploy at LEO



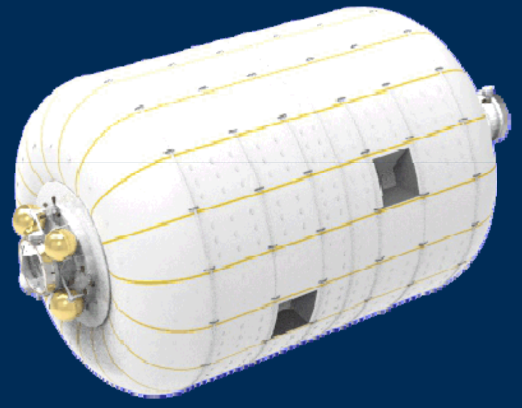
3. Deploy Rail and Install On Truss



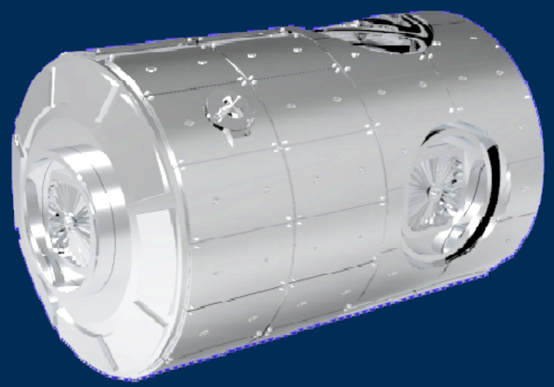
Design Overview: Design Concept of Habitation

- ISS or DSG derived Habitation Modules

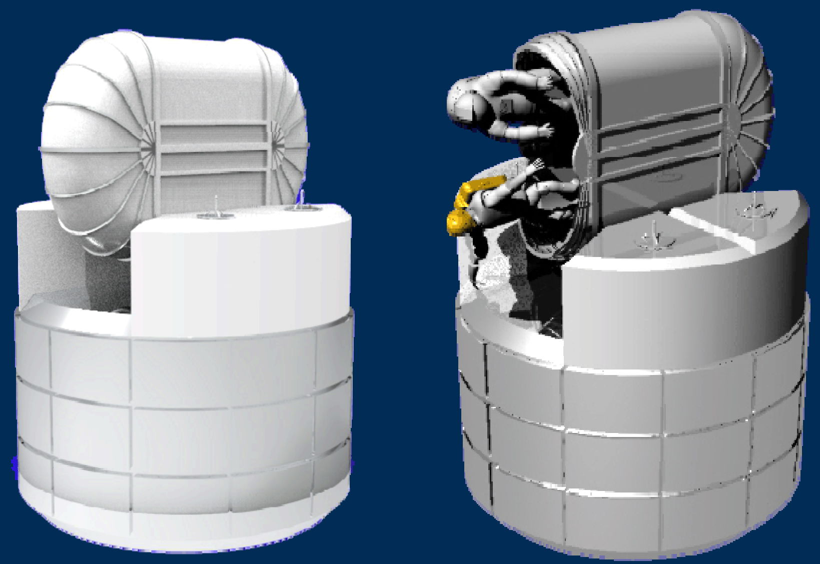
BA330



Node



Airlock: MASH (Minialistic Soft Structure Hatch)



BA330	
Length (m)	13.6
Diameter (m)	6.7
Volume (m^3)	330

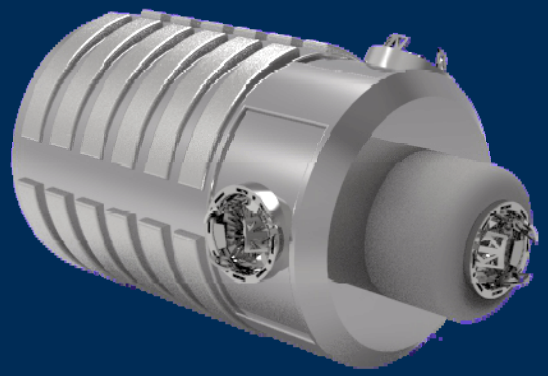
Node	
Length (m)	6.5
Diameter (m)	4.4
Volume (m^3)	97.2

MASH Airlock	
Length (m)	5.3 m (MASH: 2.3 m)
Diameter (m)	4.4 m
Volume (m^3)	75.76

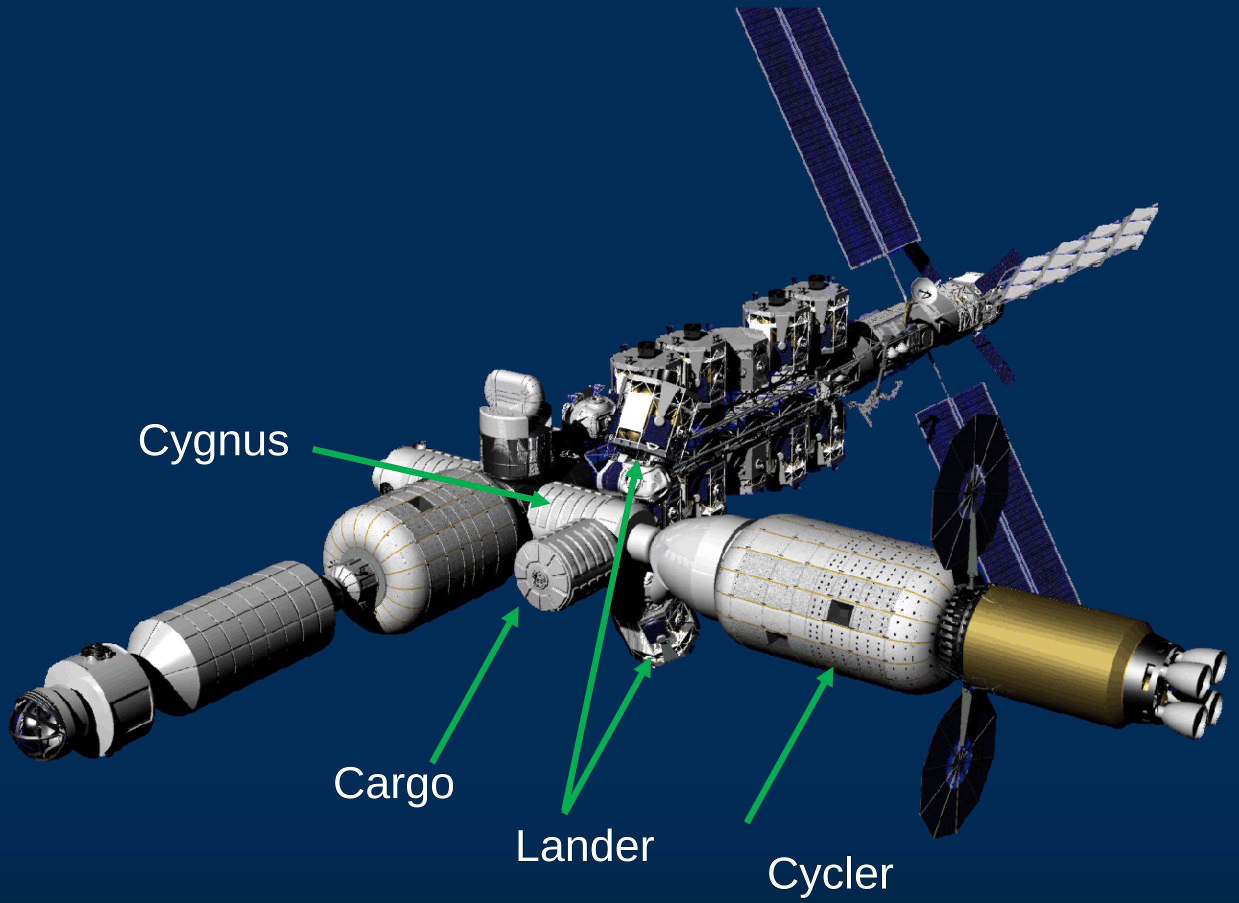
Design Overview: Design Concept of Habitation

- ISS or DSG derived Habitation Modules

Cygnus Docking Node



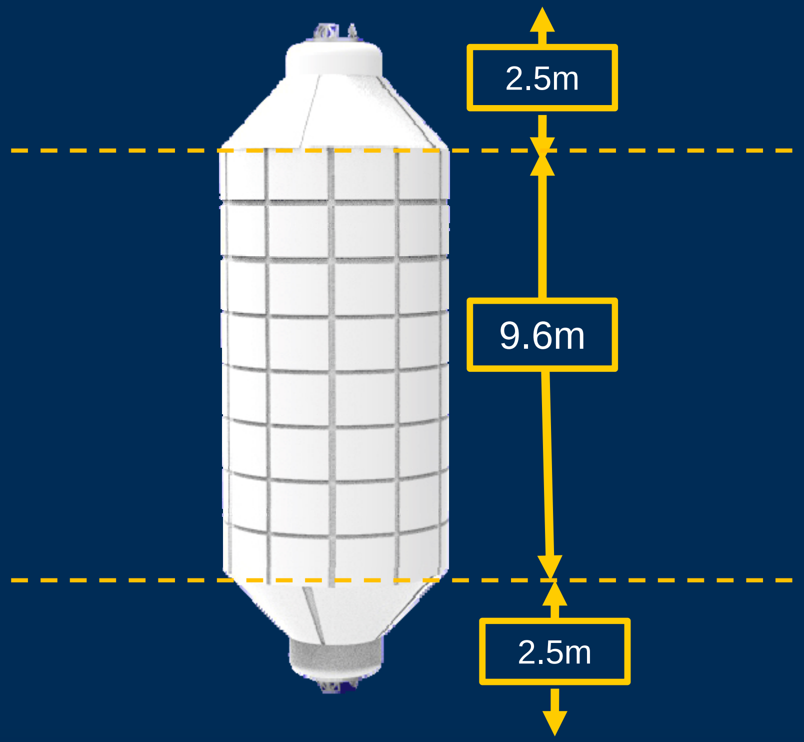
Node	
Length (m)	7.7
Diameter (m)	4.4
TRL	6



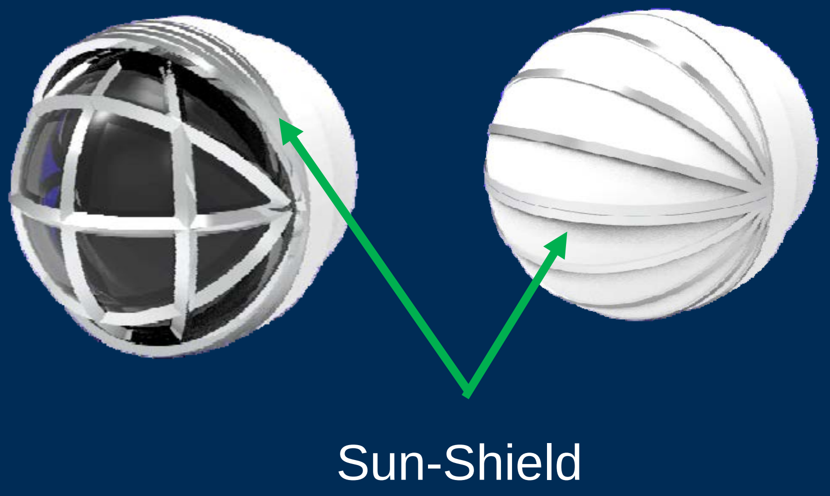
Design Overview: Design Concept of Habitation

- ISS or DSG derived Habitation Modules

Ixion LH2 fuel Tank



Cupola



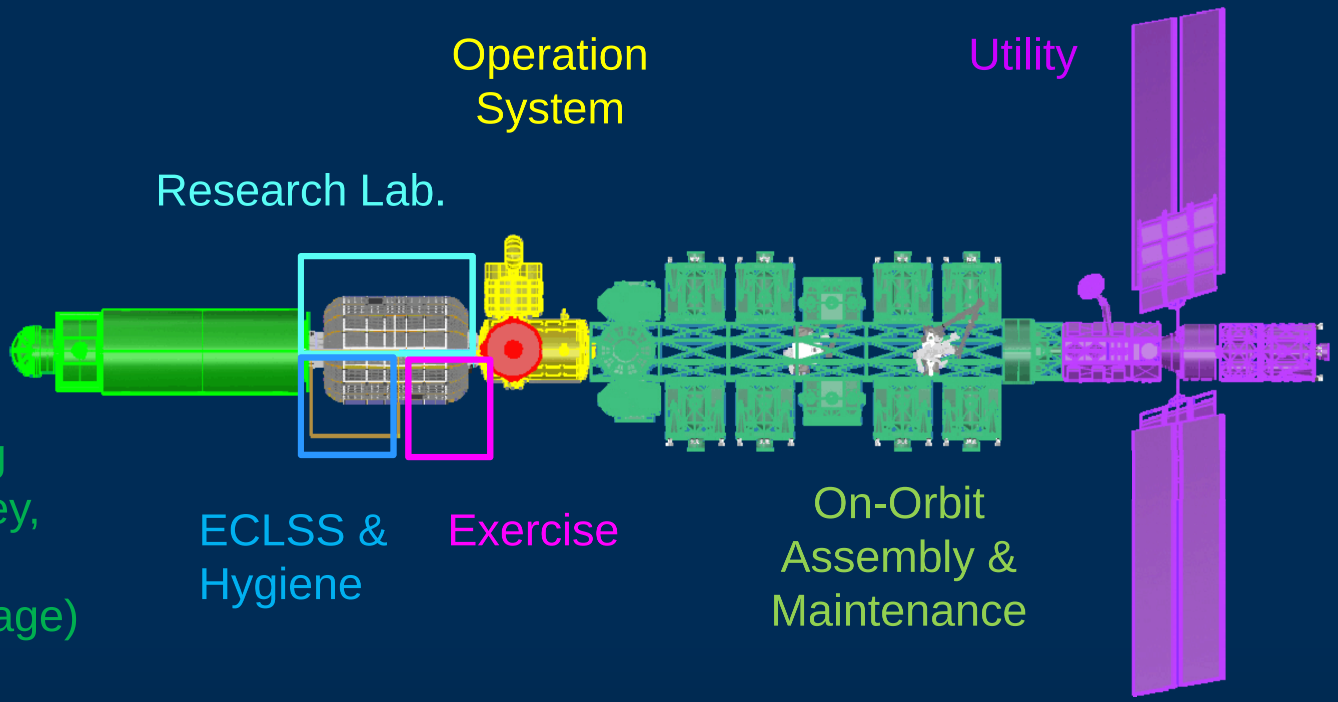
Ixion Tank	
Length (node to node)	14.7m
Diameter	4.8m
Volume	242m^3

Small Node	
Height (m)	3
Diameter (m)	4.4

Cupola	
Height (m)	3.5
Diameter (m)	2.5

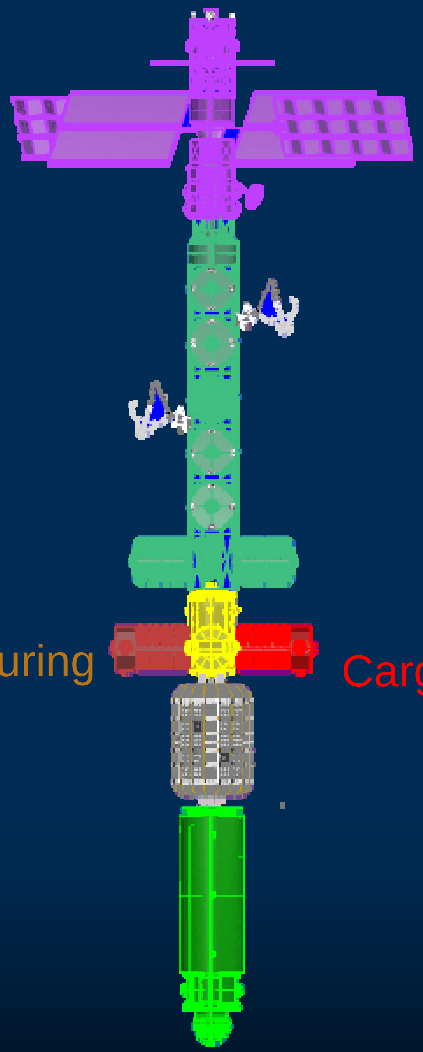
Design Overview: Functional Layout

- ❑ Functional Proximity

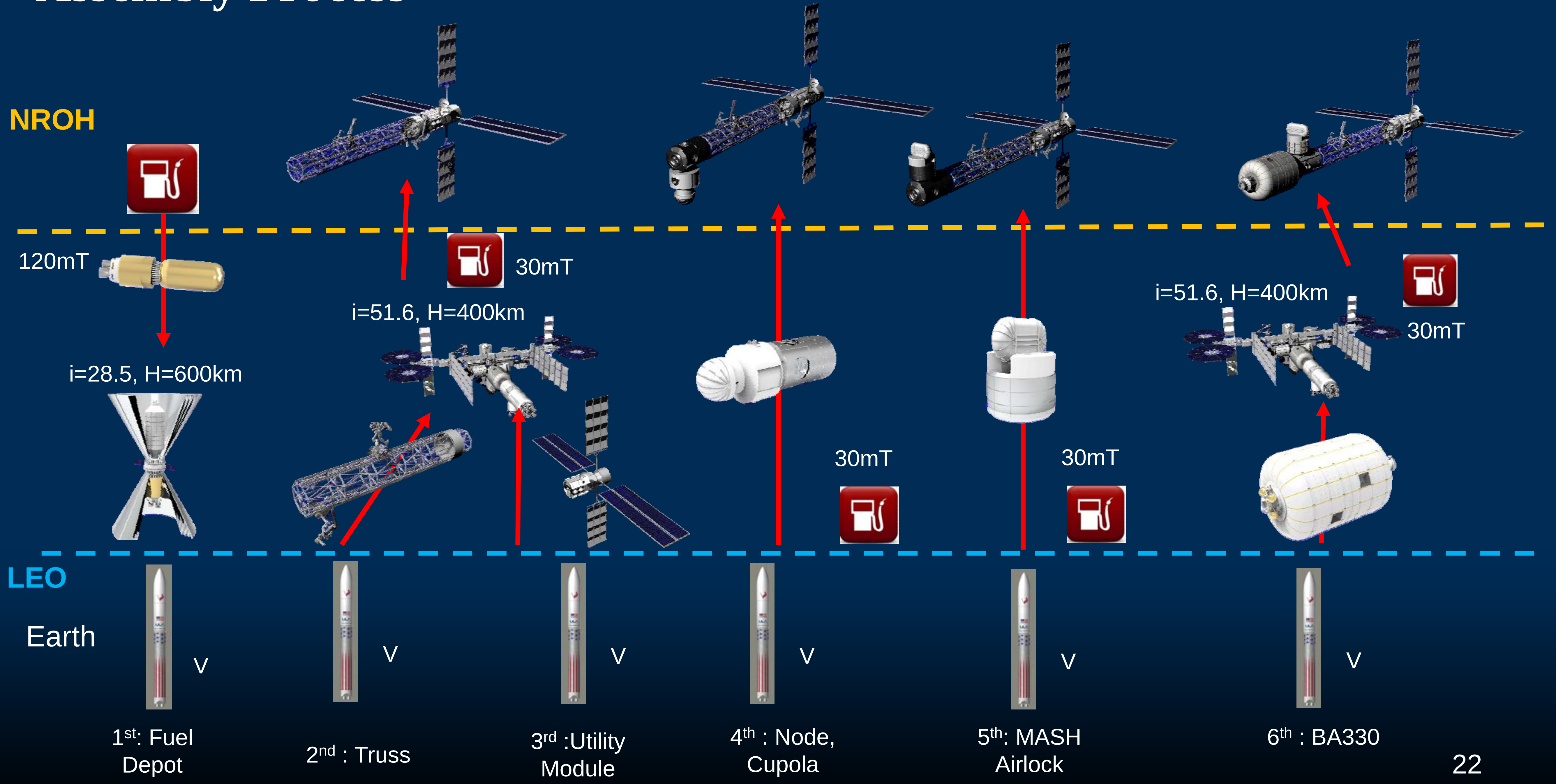


Side View

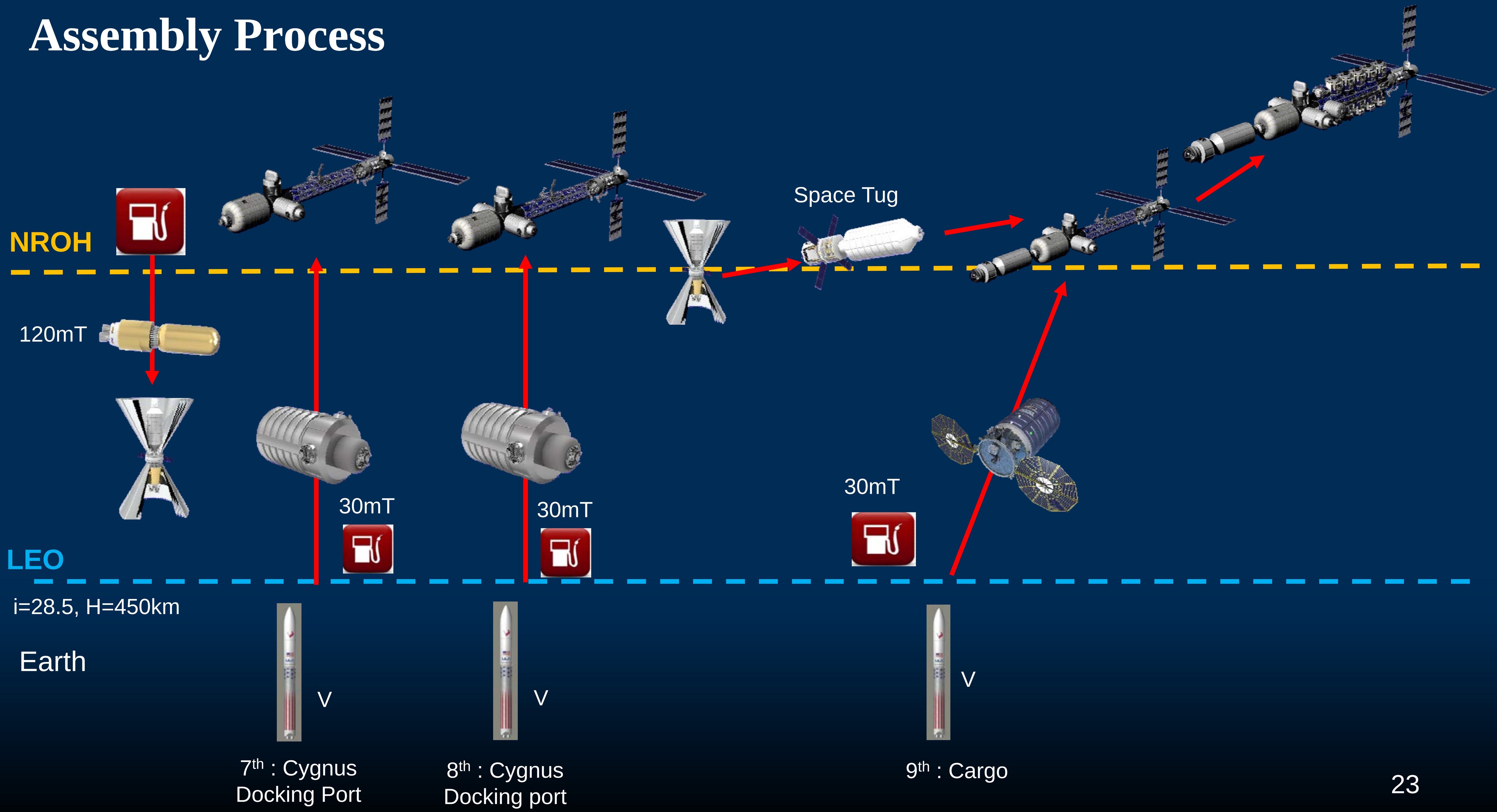
Top View



Assembly Process



Assembly Process



Mission Objective : Ixion Module

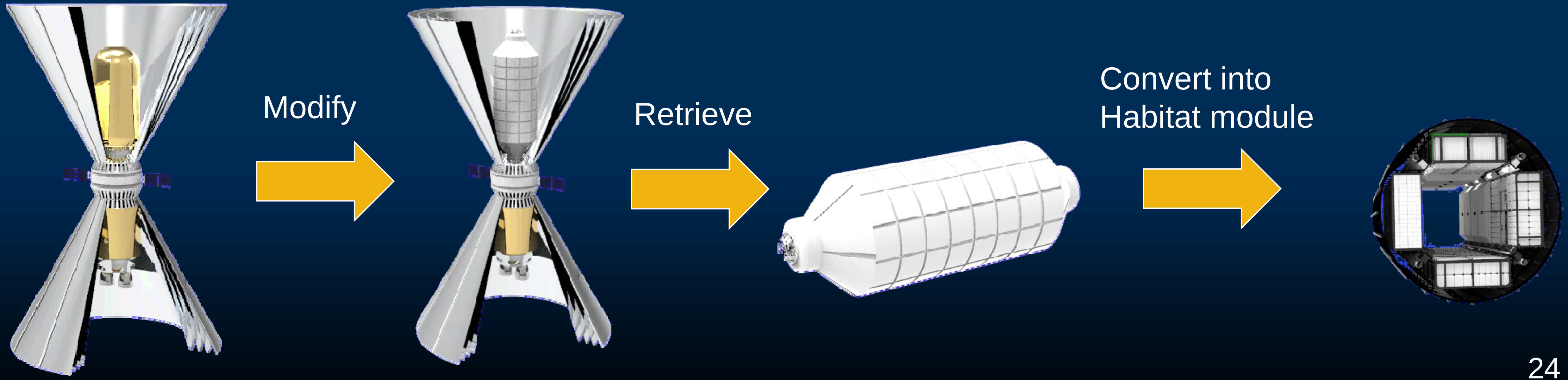
- **Ixion Module**

Goal: Convert LH2 tank into habitation module

Objective: Crew Quarters, Kitchen, Wardroom, Hydroponics, and stowage

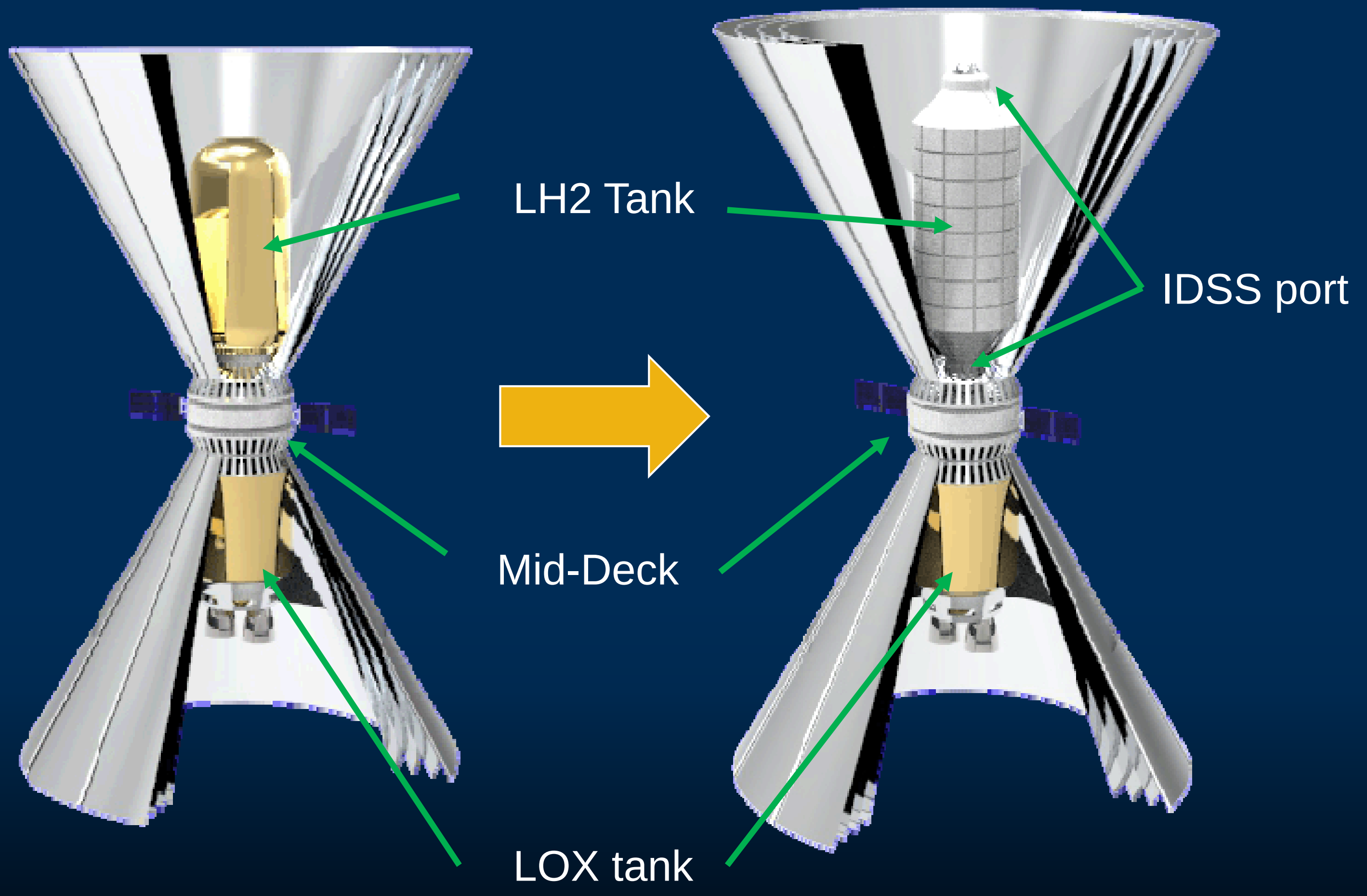
Functional Requirement: Air ventilation, ECLSS sensor, fire suppression, LED light, Communication system, Power, water line

Assembly Method: Autonomous Robot with partially human support



Structure Modification: Ixion Module

- ❑ Fuel Depot Modification



- ❑ Customized Ixion Detail

  - ➢ IDSS port at the each end of the fuel tank
  - ➢ One end node attached on the mid-deck

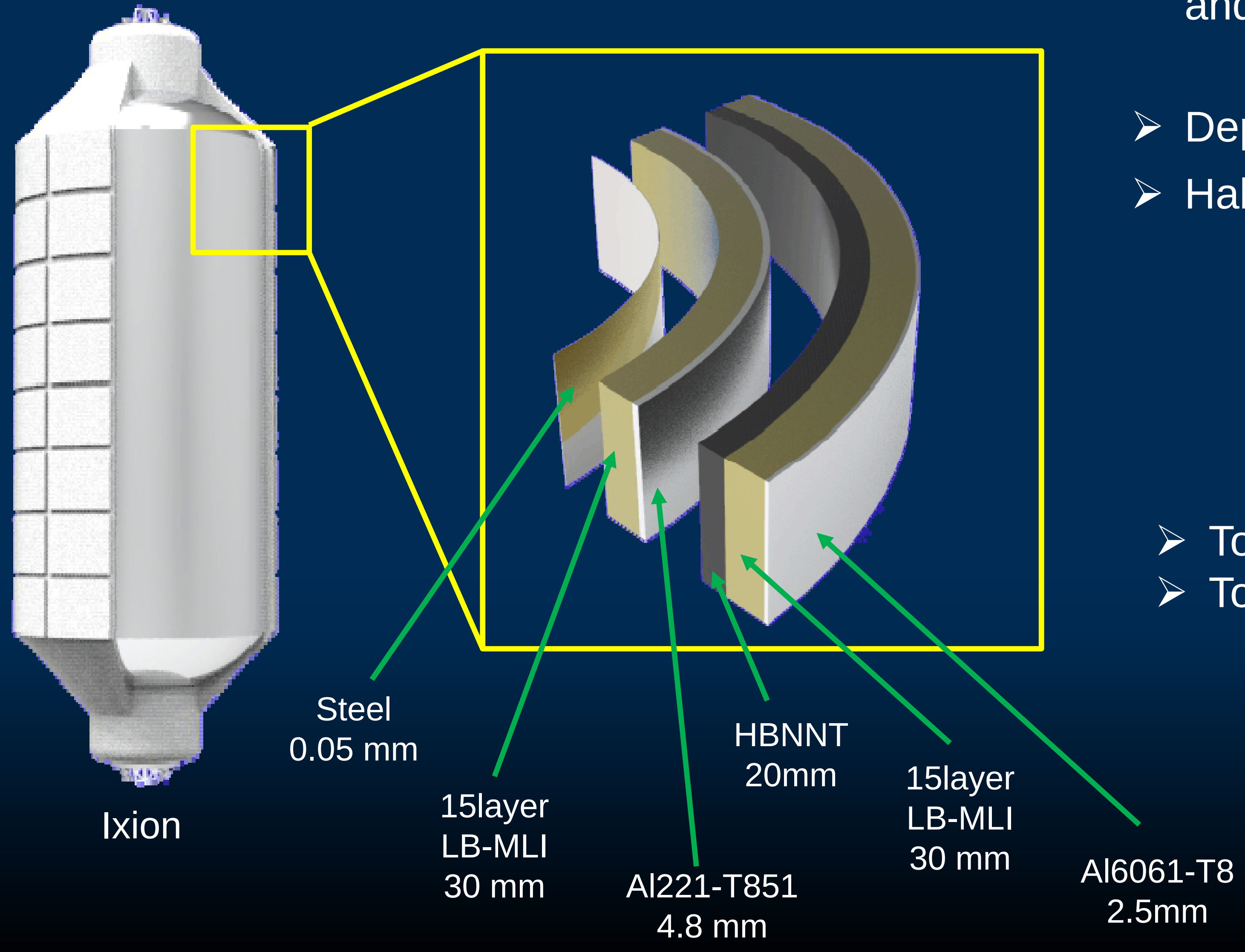
Length (node to node) = 14.7m

Dry mass = 12.8mT

Volume = 242m^3

Structure Modification: Ixion Module

- ❑ Fuel Depot Outer Shell Modification



- ❑ Functional Requirement for both fuel depot and habitat
  - Depot: < 0.1%/ day LH2 boil-off rate
  - Habitat: Protect from GCR and SPE

    10g/cm^2 Al equilibrium

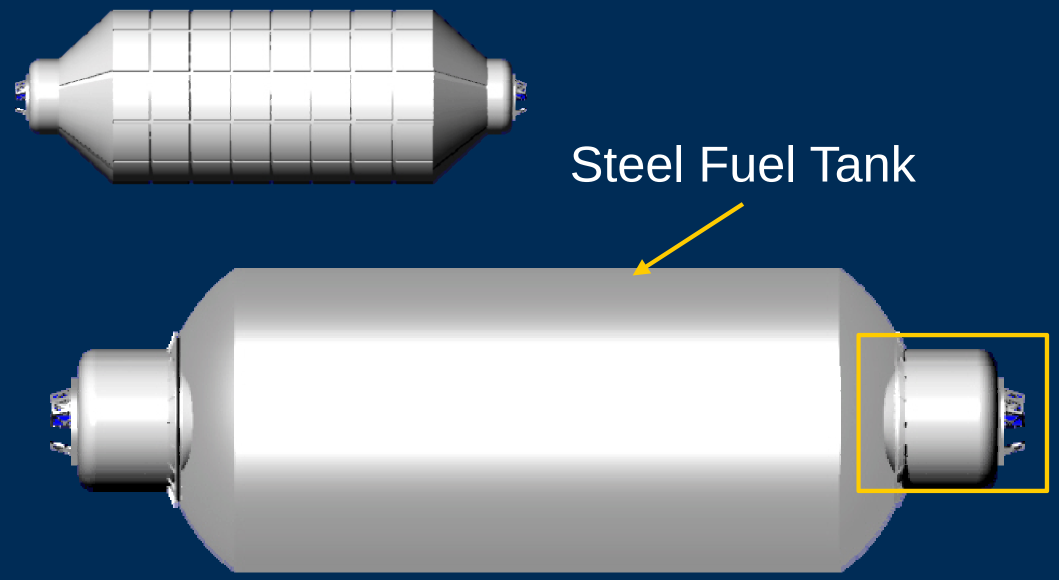
    Internal pressure = **101 kPa**

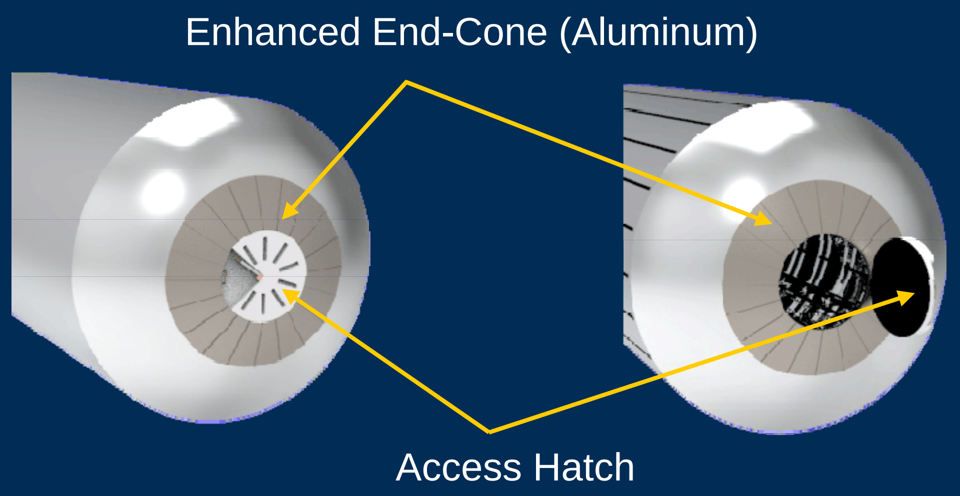
    Safety factor = **2.5**

  - Total Mass of External wall = 12.18mT
  - Total Tank Mass = 13.9mT

Design Overview: Ixion Module

- Node and Hatch Design





Design Overview: Ixion Module

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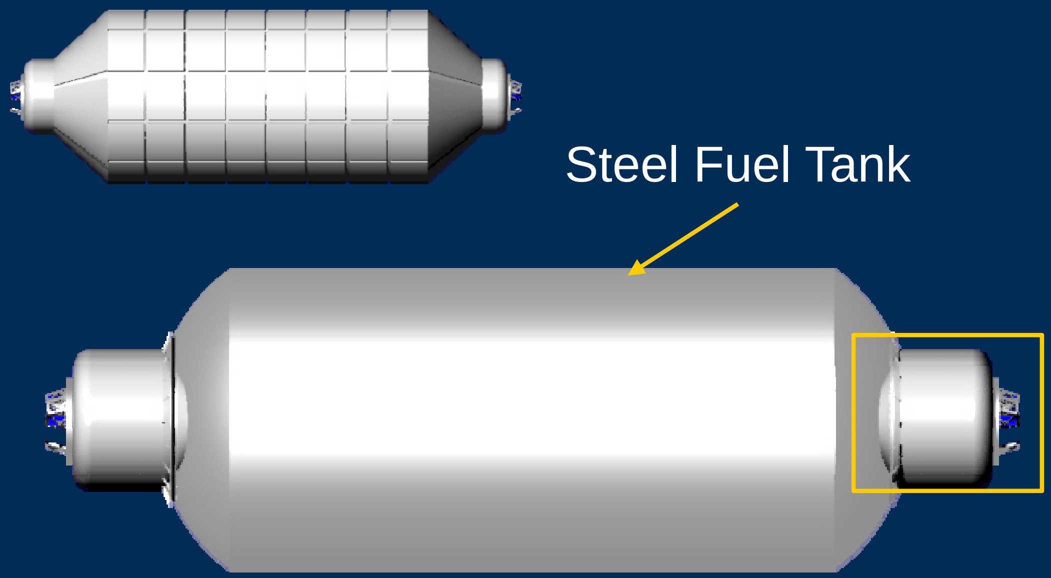
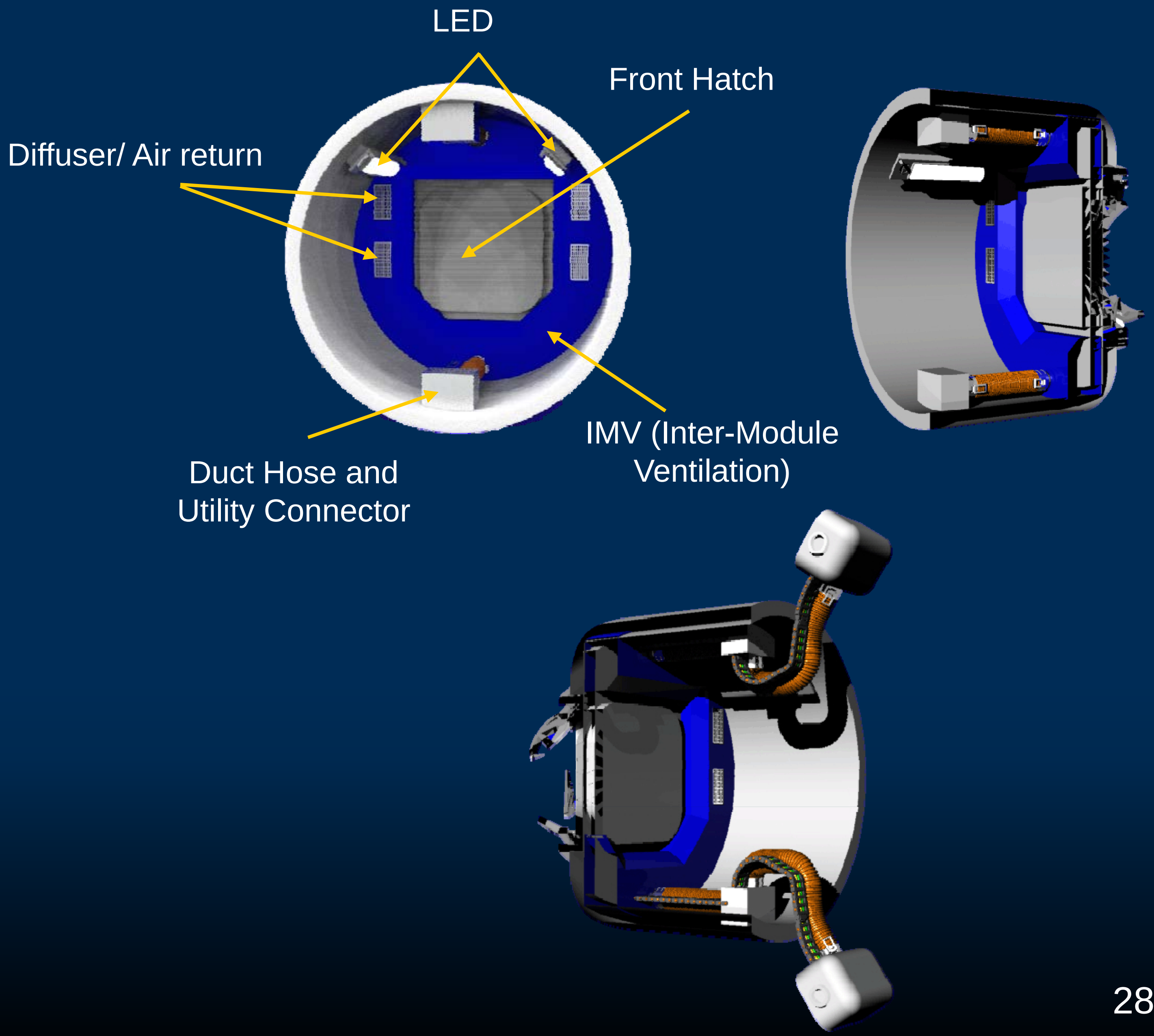
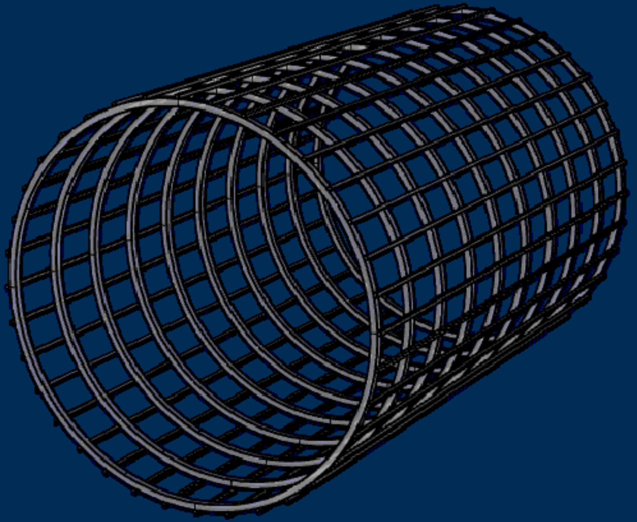




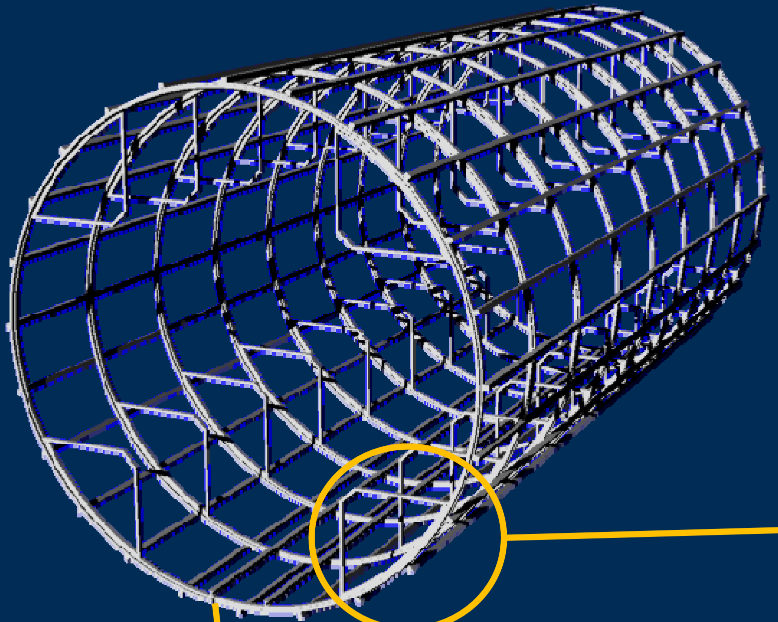
Internal Tank Structure

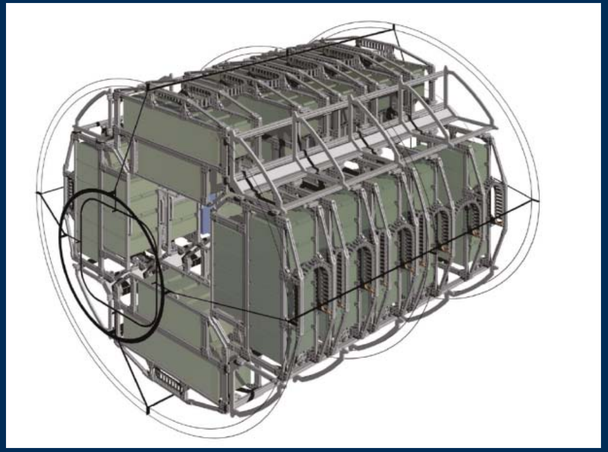
- Overview of Internal Tank Structurel

Typical Fuel Tank inner frame



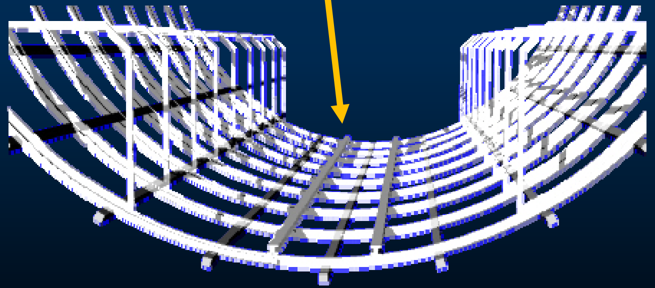
Skin-Stringer





Random Access Frame (RAF)

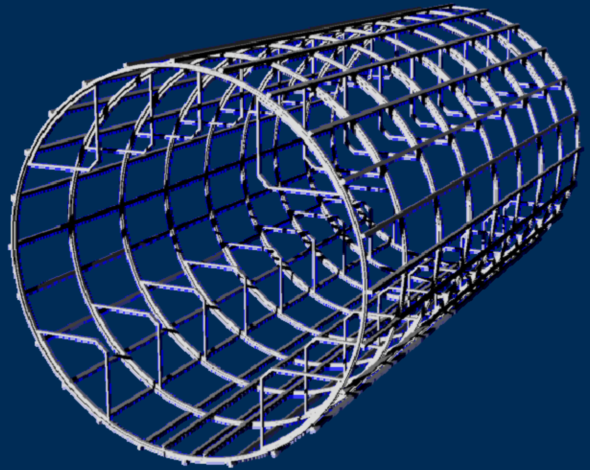
RAF Edge Frame



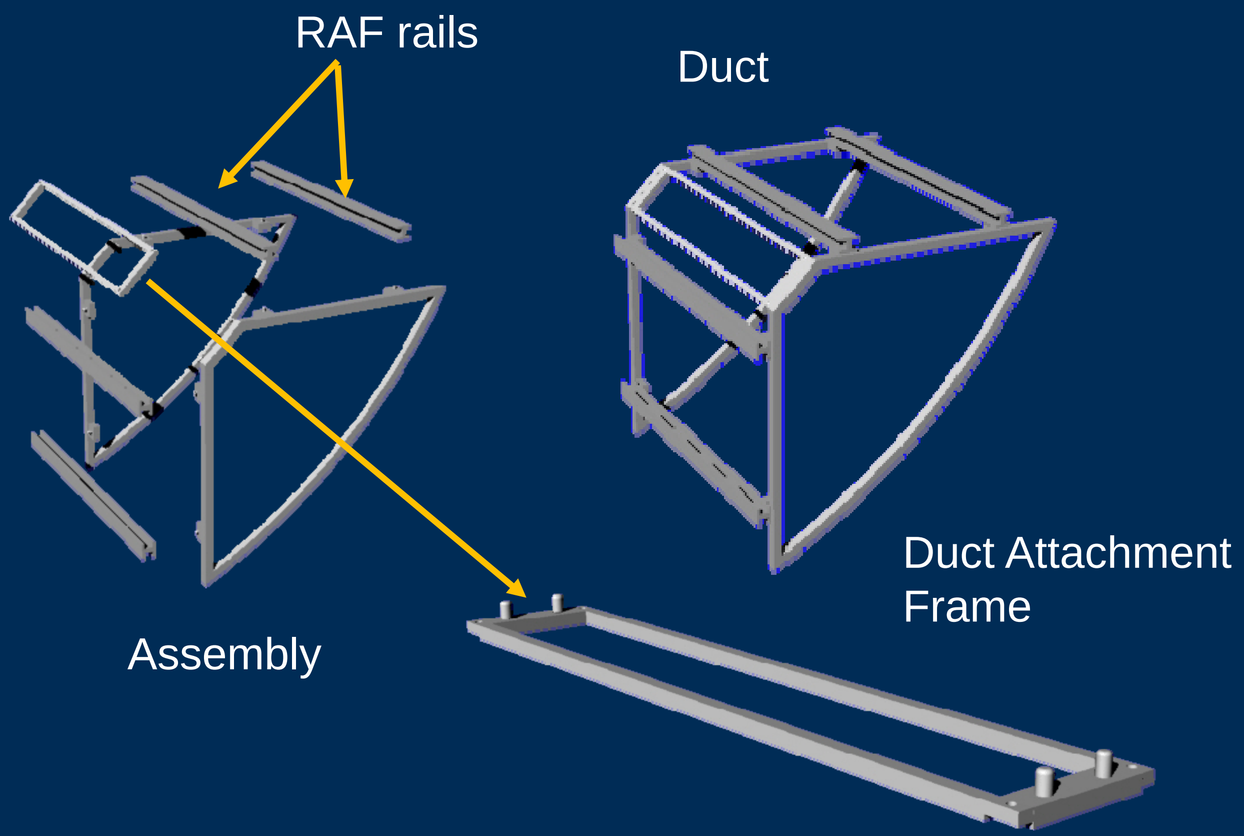
Mobil transfer rail

Internal Tank Structure

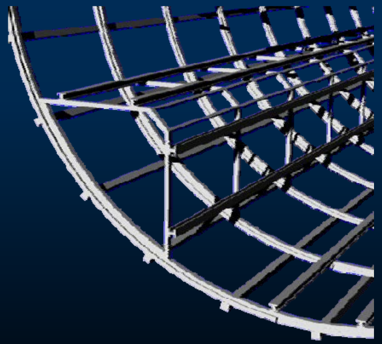
- Overview of Internal Wall

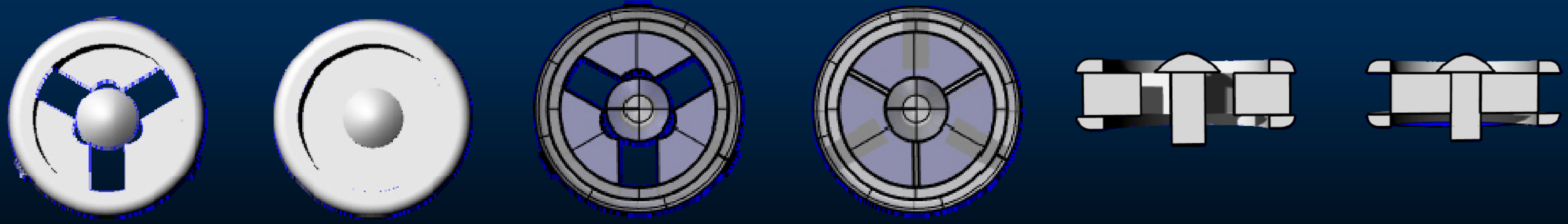


Edge Frame



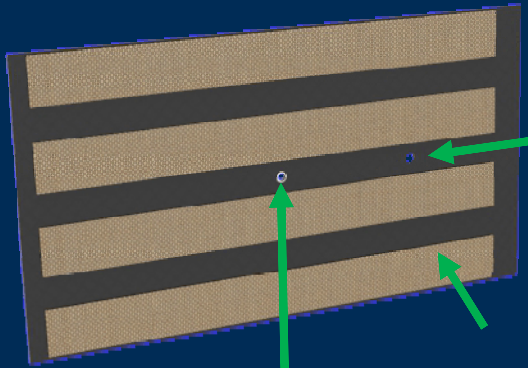
- Attachment and secure Mechanism

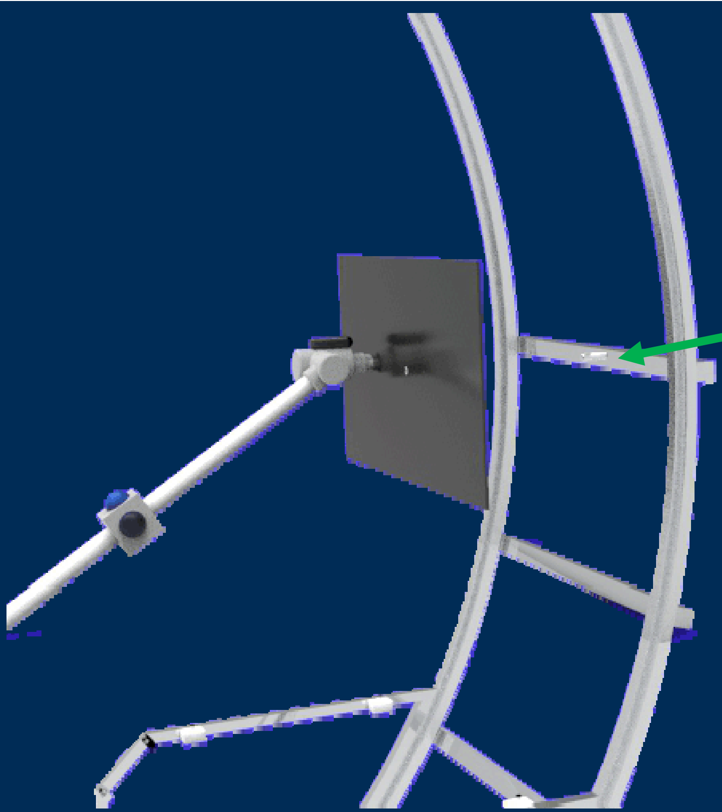




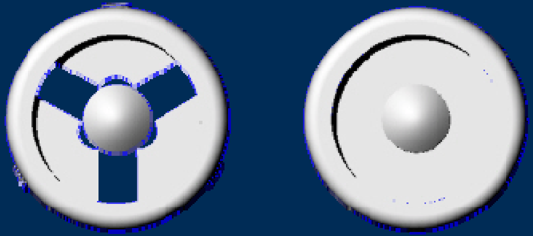
Internal Wall

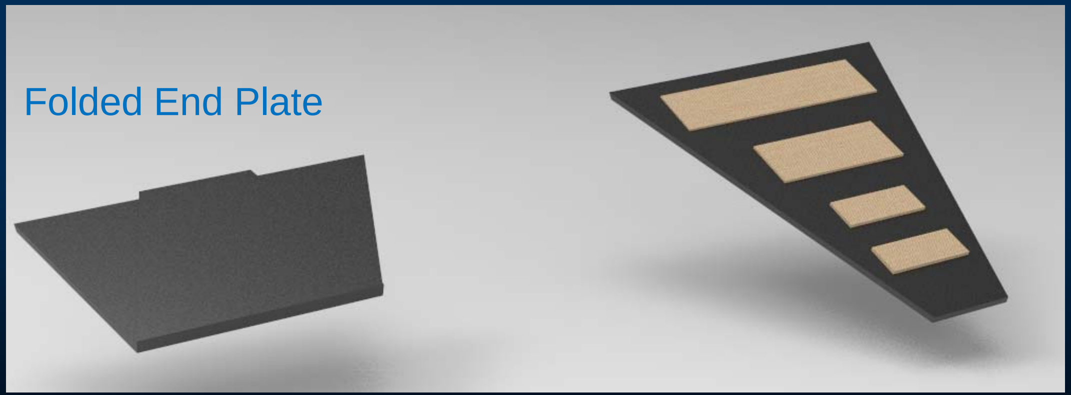
- Carbon Fiber Reinforcement (CFR) Plate



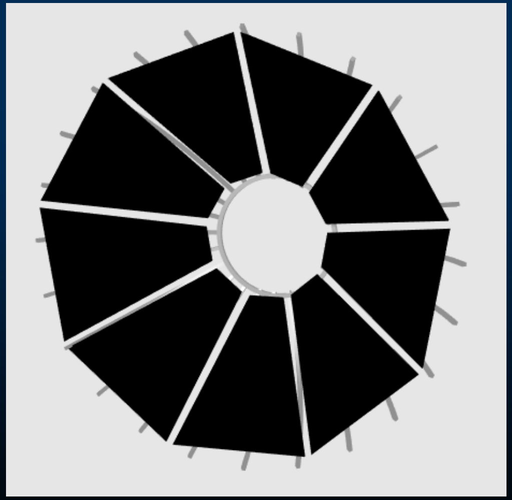


Attach Mechanism





End Dome CFR plate



End Dome CFR plate

Internal Wall

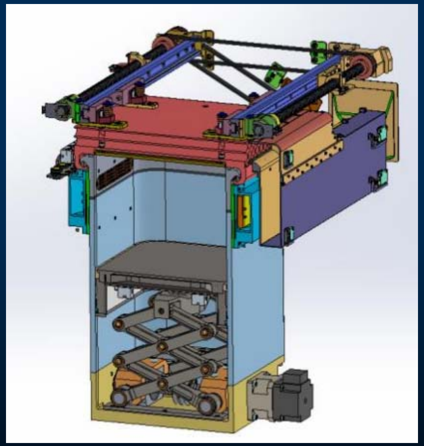
- Radiation Shield: Heat Melting Compactor (HMC) Plate

- Outer Shell Shield =10 g/cm^2 Al equilibrium
- Inner Shell Shield > 13 g/cm^2 Al equilibrium
- HMC plate = 60% of PE equilibrium
- Total thickness of HMC tile = 11.4cm (n=3) = 9.86 g/cm^2 Al
- Estimated Compressed MCTB Thickness = 5cm = 7 g/cm^2 Al
- Total inner radiation shield = 16.86 g/cm^2 Al

HMC tile: **40.6×40.6×3.8cm**

- Input = 1100kg garbage, Output = 800kg HMC tile
- Required: 6336 kg HMC = 8,712kg garbage
- 4 crew for 10 years at DSG from 2025
  = 16,060kg garbage
- 4 crew for 5 years on the Moon from 2030
  = 8,030kg garbage

Garbage



HMC

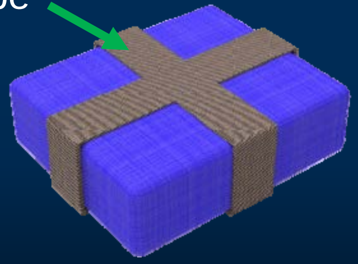
3×

HMC tile

42×50×50cm

MCTB

Velcro tape

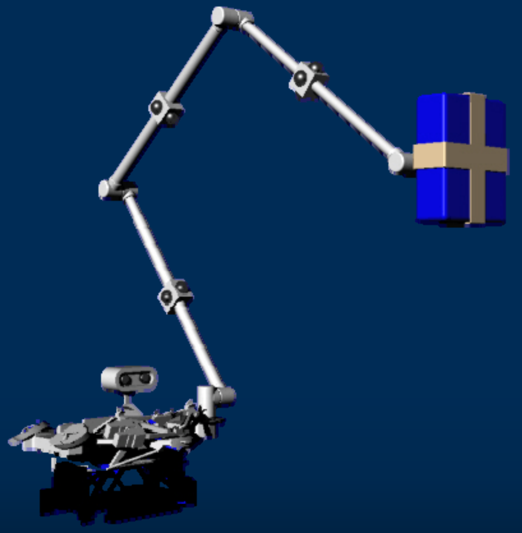


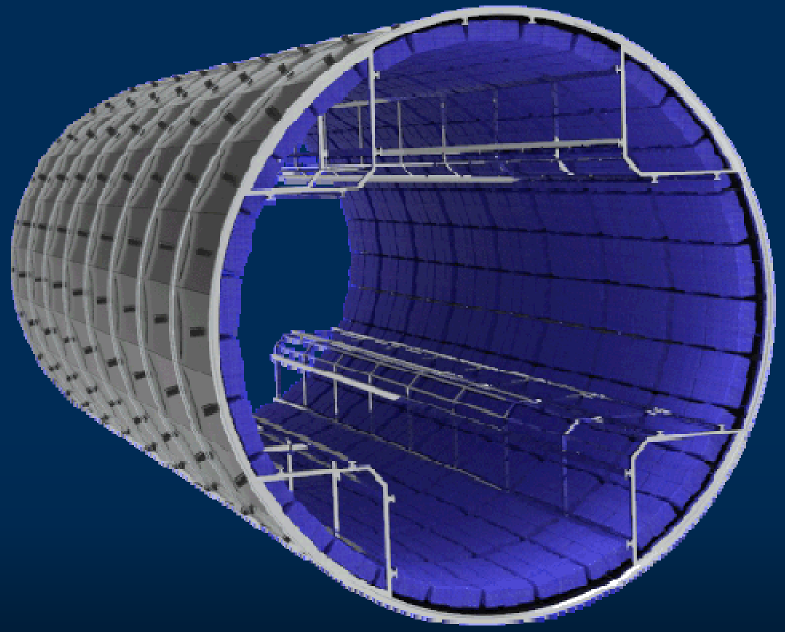
Packed HMC tile
42×20×50cm

Interior System

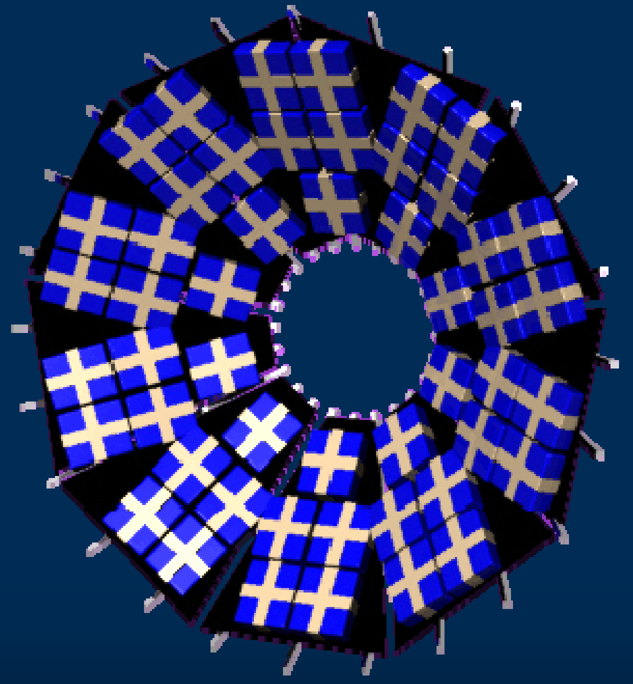
- ❑ HMC Radiation Shield

Total 570 MCTB or 1710 HMC tiles



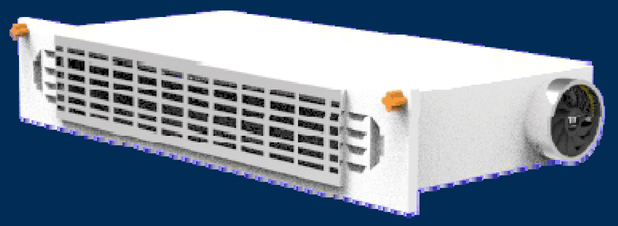


End Dome

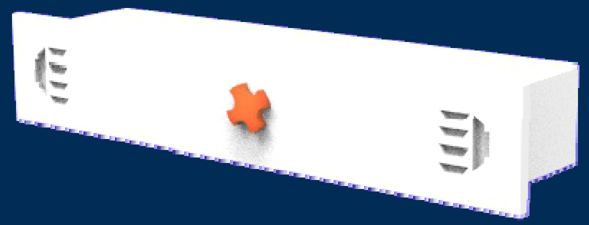


Interior System

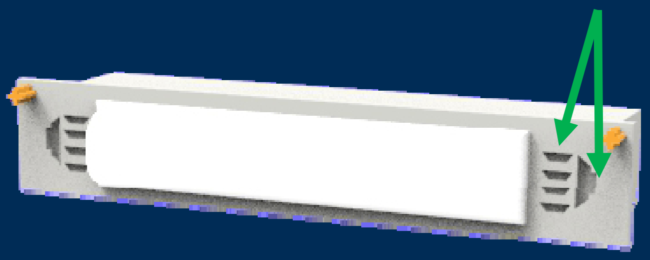
- Diffuser, LED lighting, Sensors



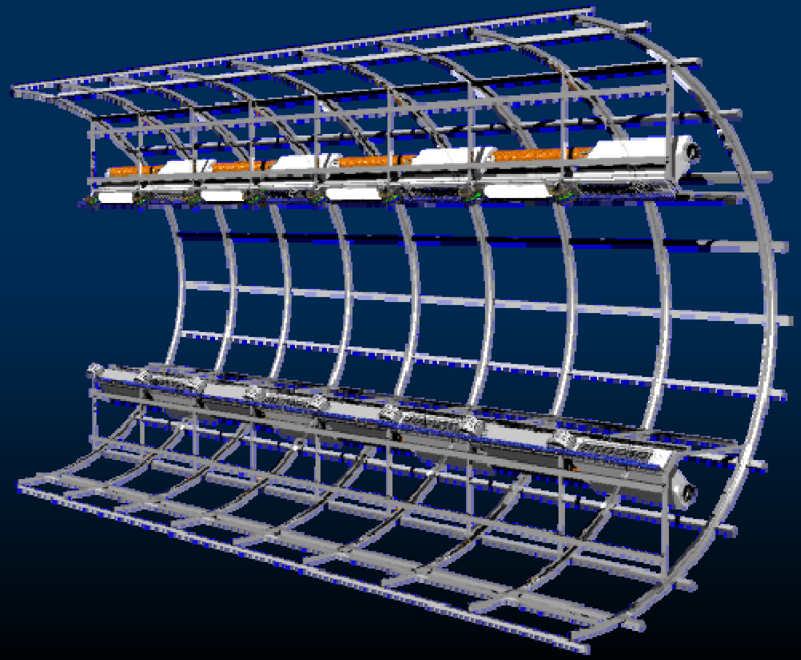
Diffuser/ Return Air Fan Assembly

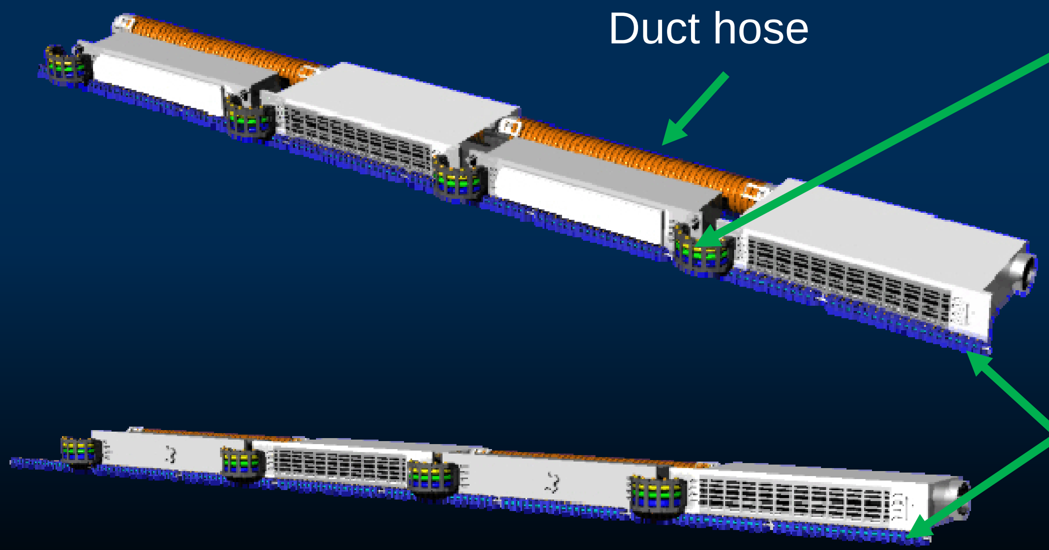


Utility Board



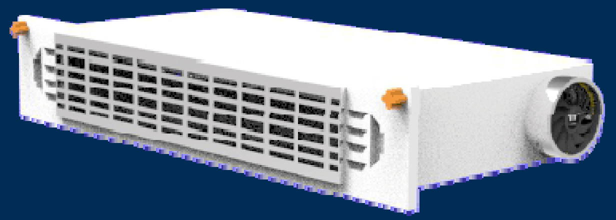
LED



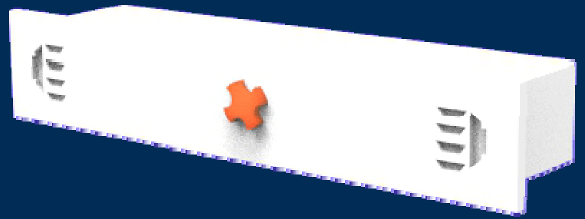


Interior System

- ❑ Diffuser, LED lighting, Sensors

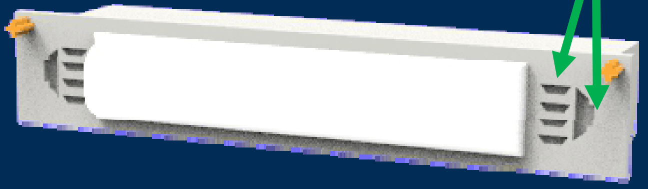


Diffuser/ Return fan Assembly

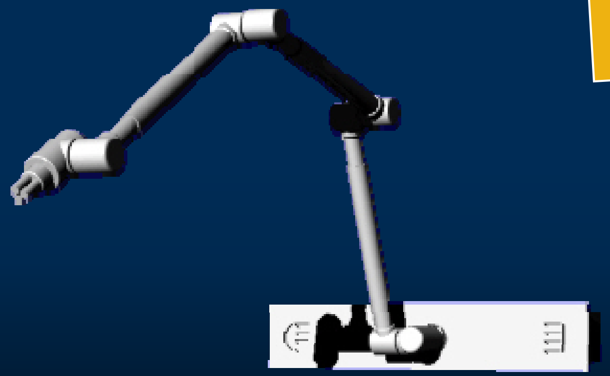


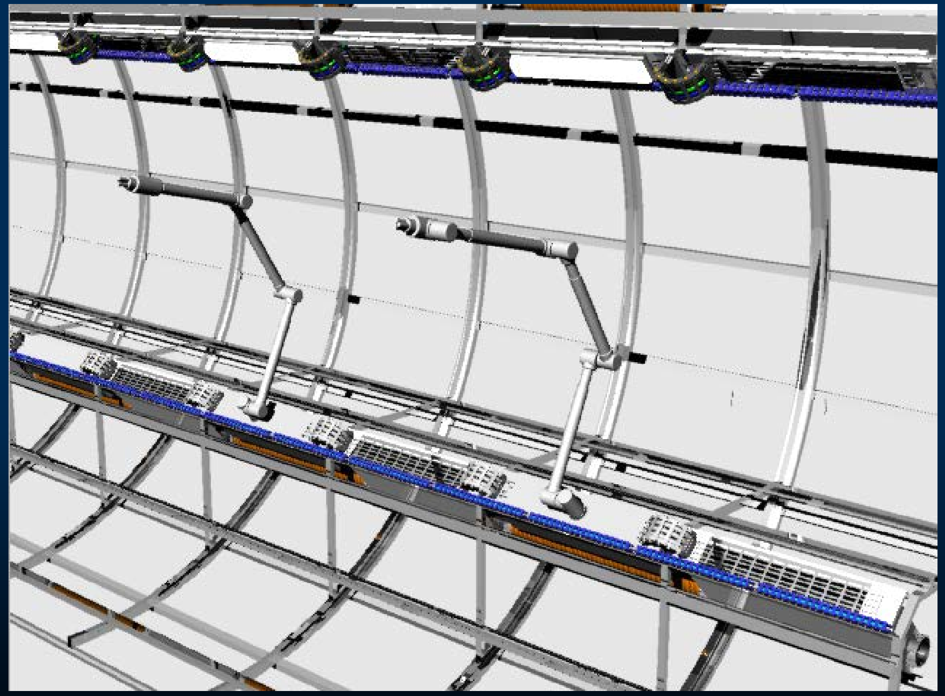
Utility Board

Utility Connector



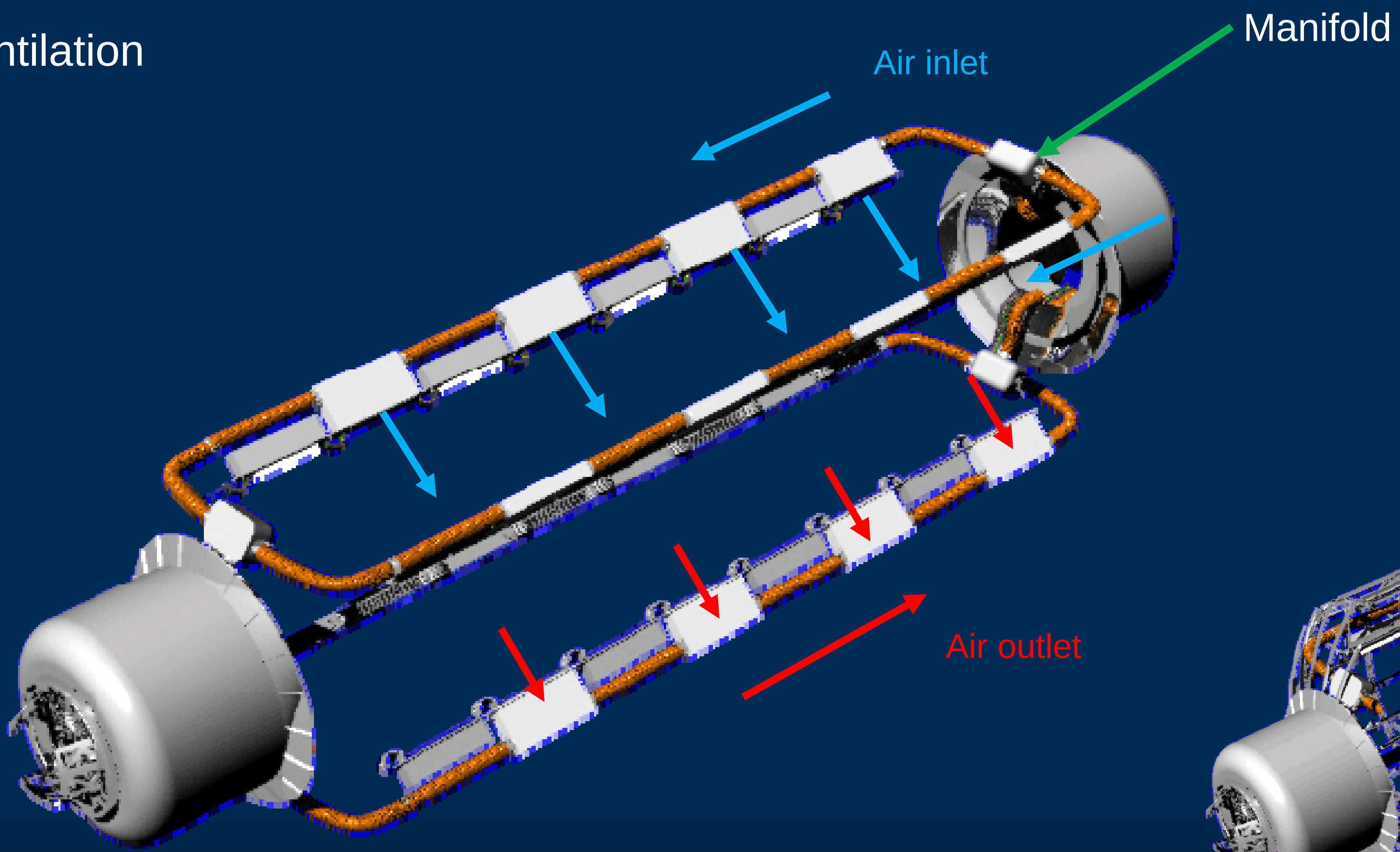
LED

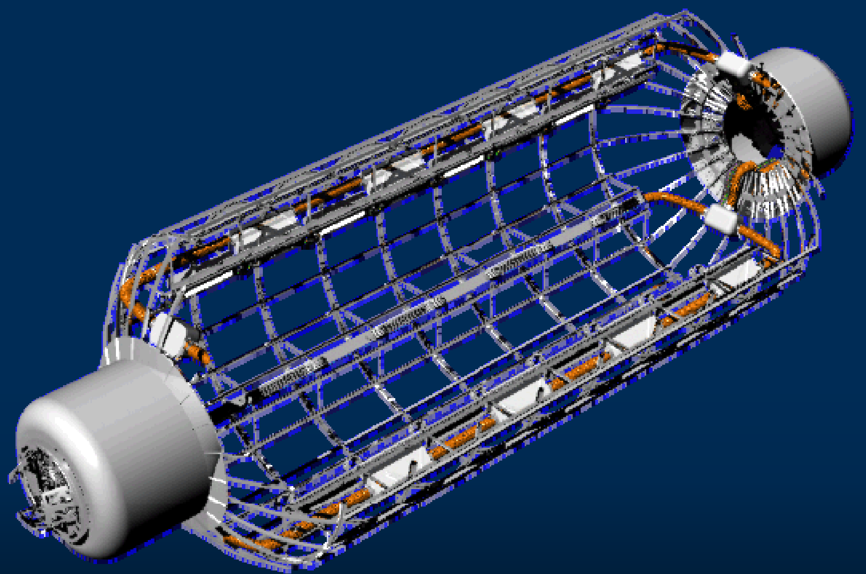




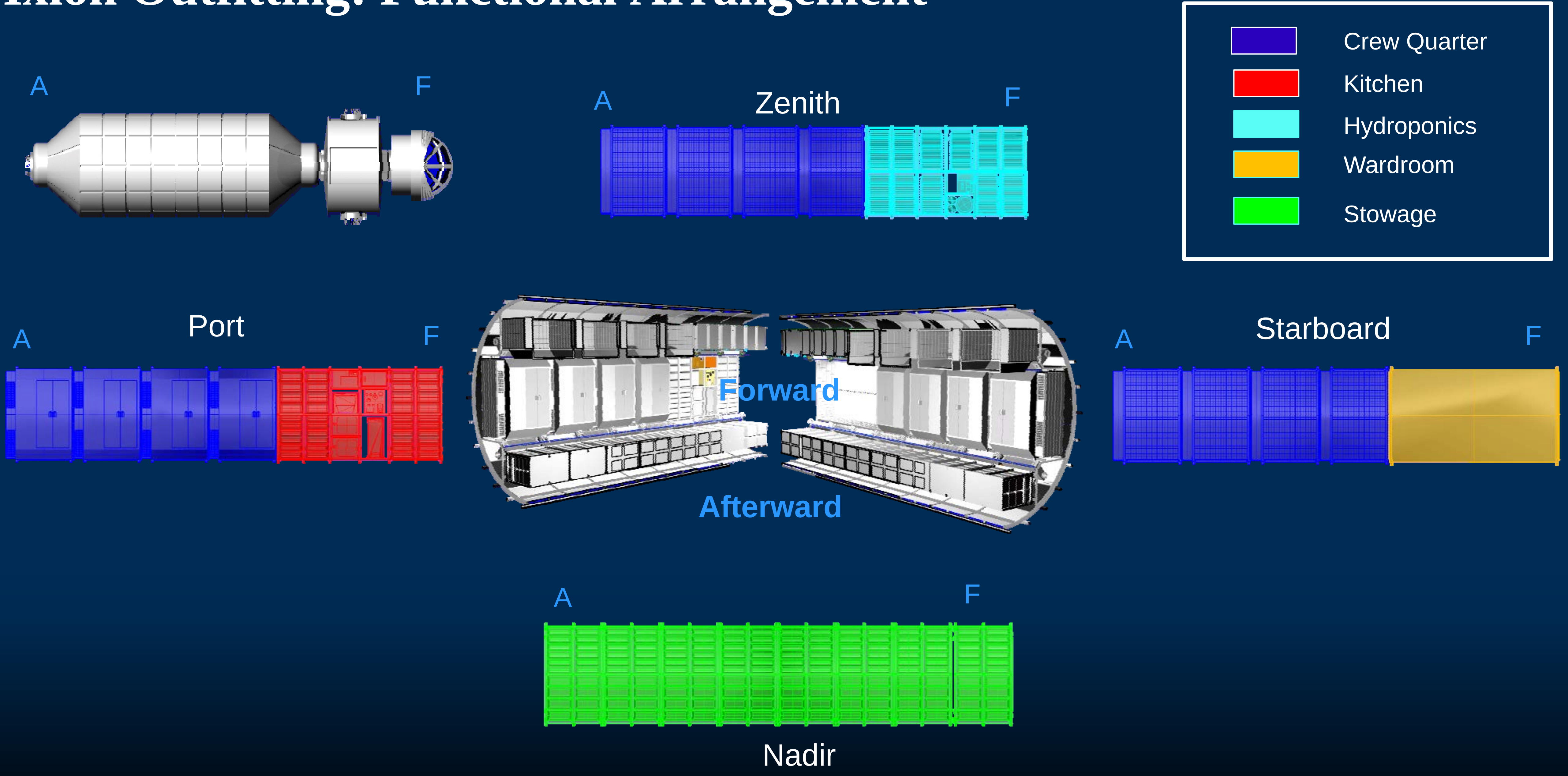
Interior System

- Air Ventilation



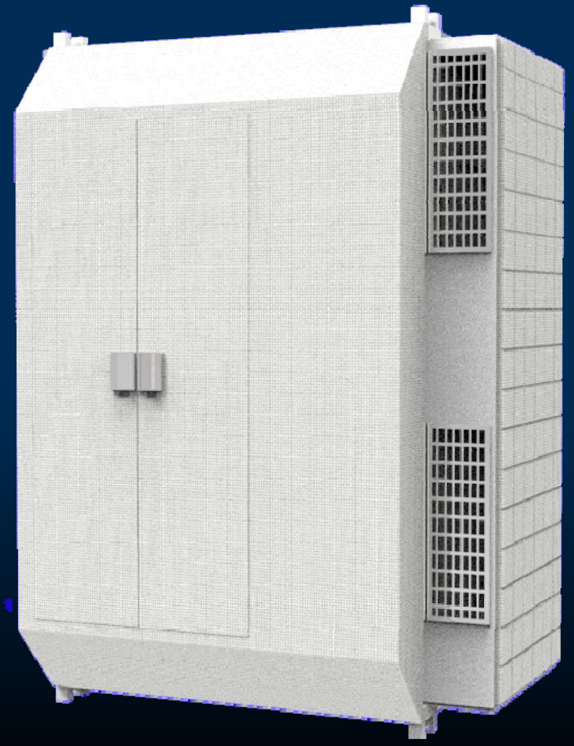


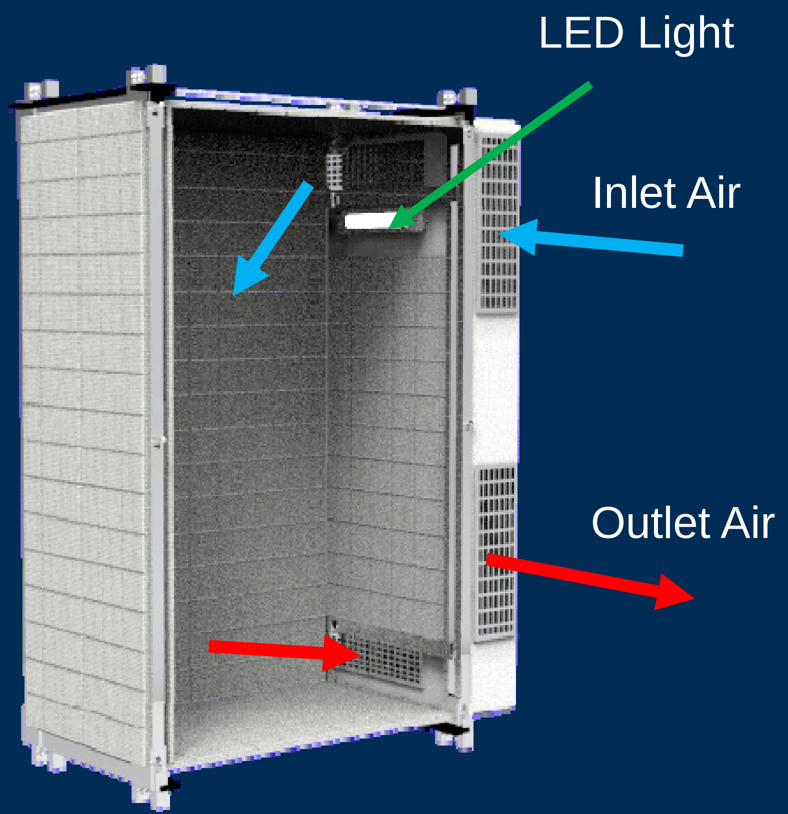
Ixion Outfitting: Functional Arrangement

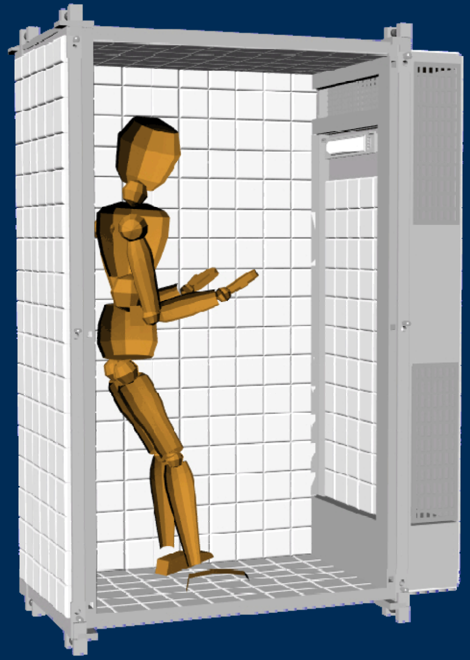


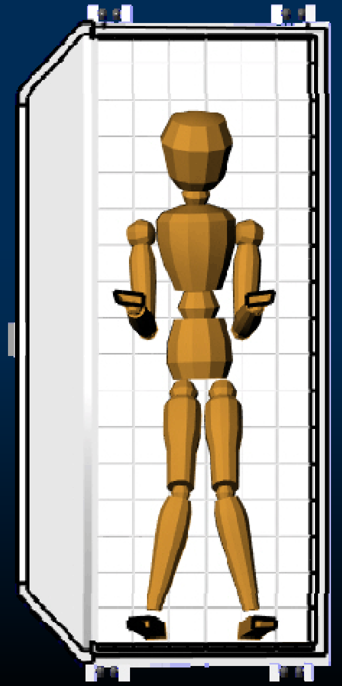
Interior System

- ❑ Craw Quarter
  - ➢ CQ Functional Requirement:
  - ▪ Air Ventilation
  - ▪ LED Light
  - ▪ Utility cable









➢ CQ Dimension:

W= 1.2m, L=1.0m, H= 2.0m, V= 2.28m^3

➢ Ventilation Assembly

W= 0.2m, L= 0.7m, H= 1.7m

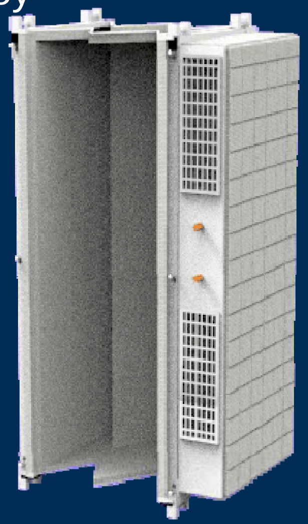
Interior System

- ❑ Craw Quarter Assembly

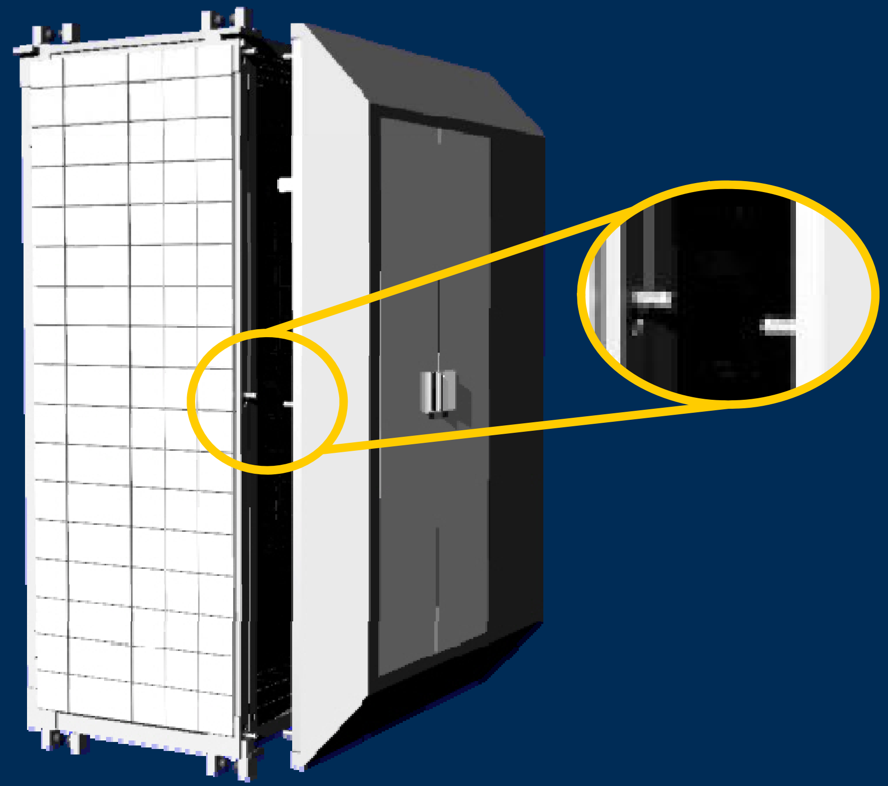
Fold

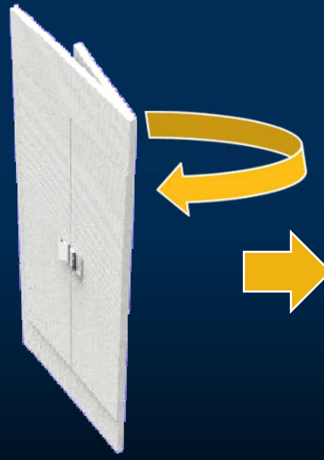
Capture pin

Deploy



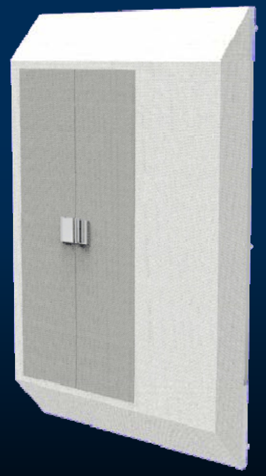
Outfit Interior



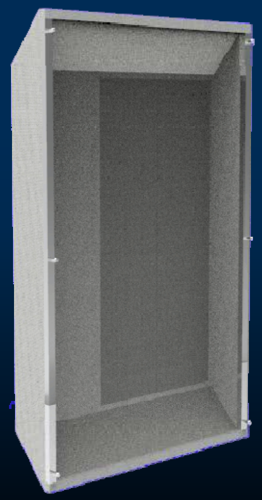


Fold Door Assembly

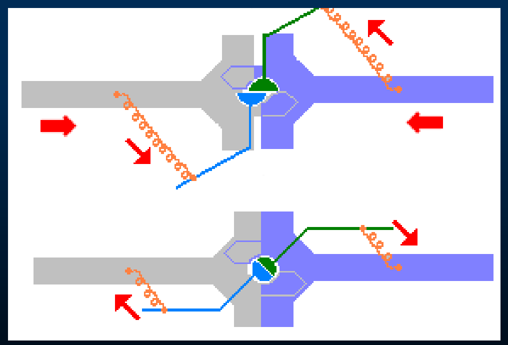
Deploy



Pop-up

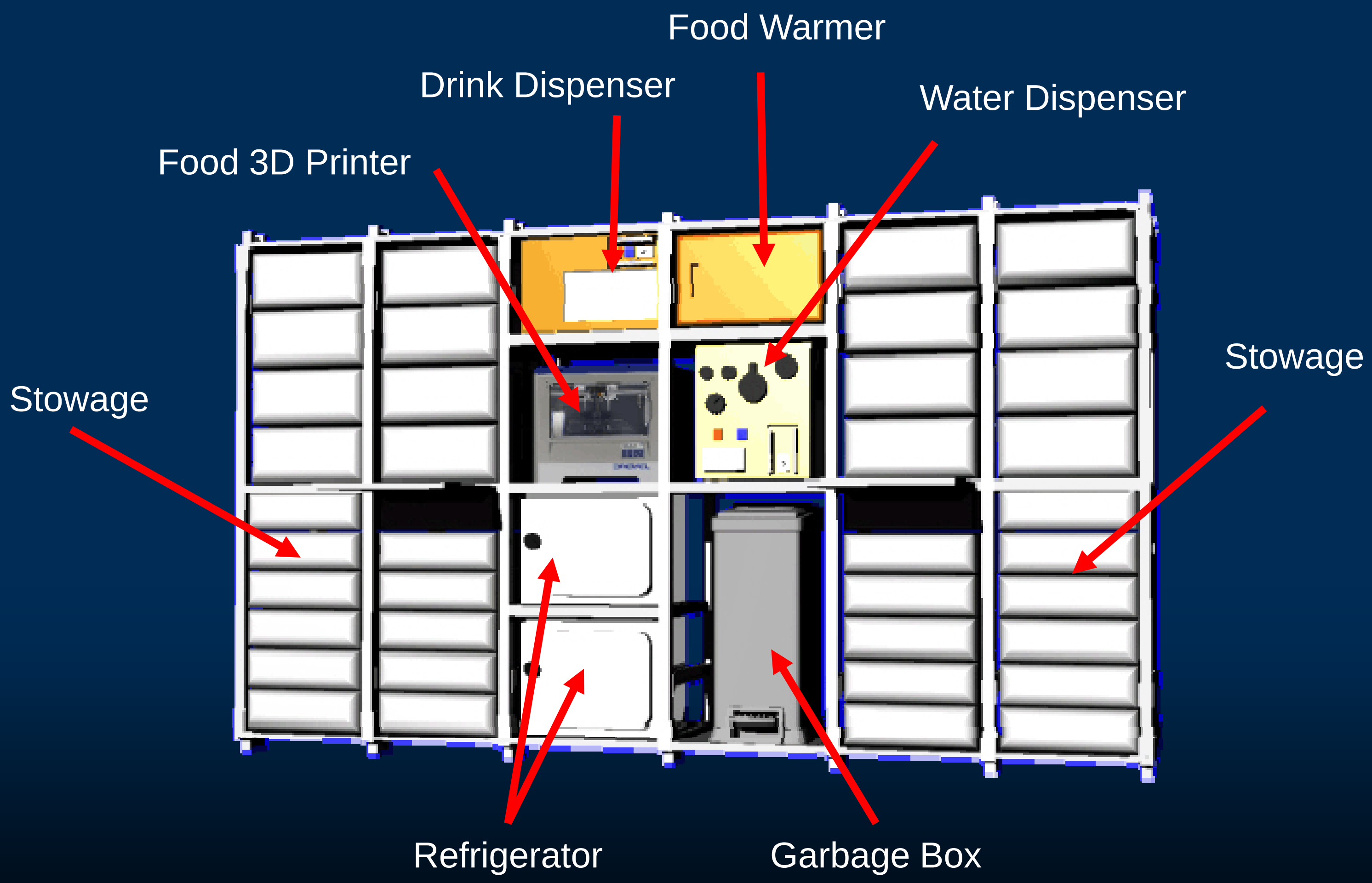


- ➢ Attachment Mechanism
  - ▪ Rotation Lock



Interior System

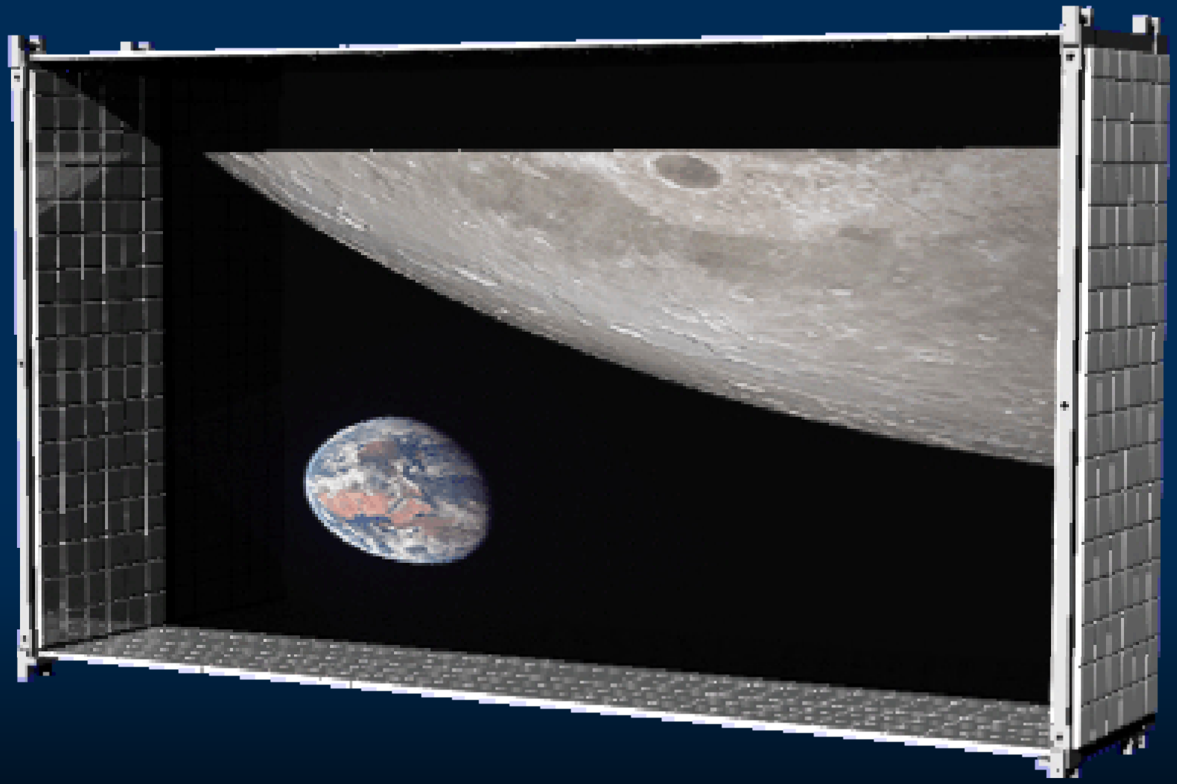
- Kitchen/ Wardroom



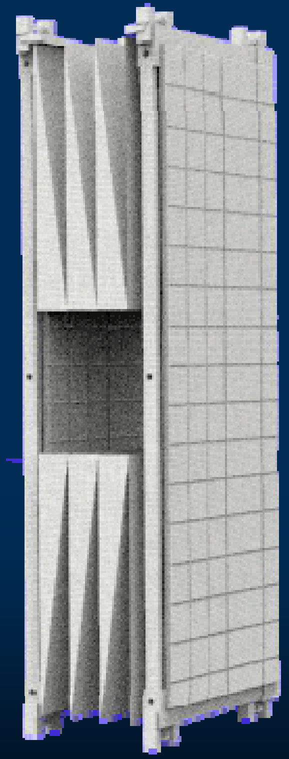
Interior System

- ❑ Virtual Window/ Projector

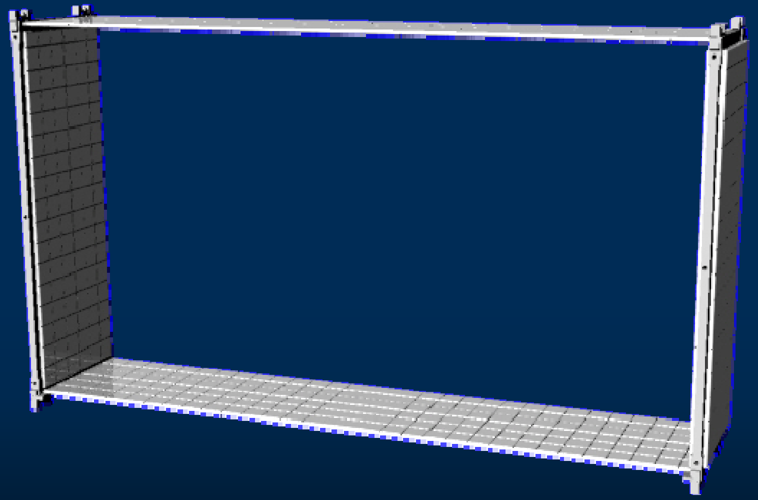
Virtual Window / Projector
(W: 3m × L: 0.8m × H: 2m)



Folded
(Thickness: 0.14m × L: 0.8m × H: 2m)

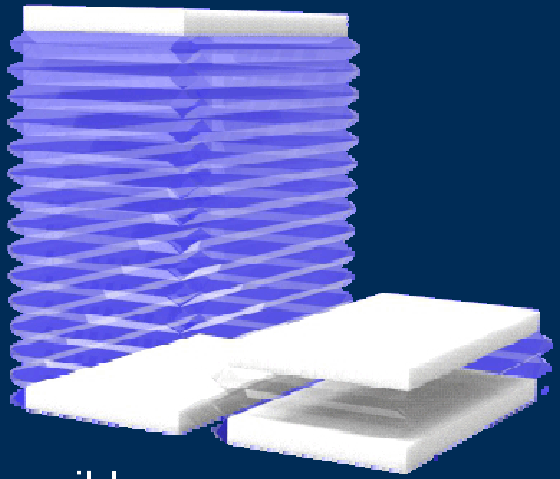


Deploy

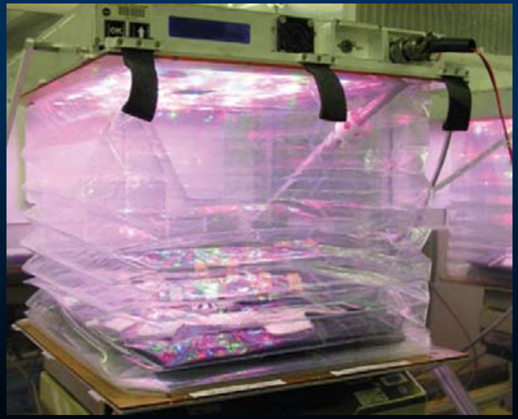


Interior System

- ❑ Hydroponics



Collapsible
Hydroponics

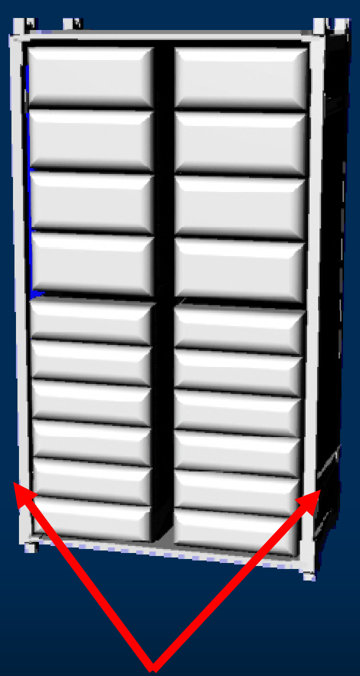


Fertilizer, CO2 tank,
Control Assembly

Fluidic& gas Line

Interior System

- Cargo
  - Ixion has capability to store **18m^3** (2m^3 each stowage)
  - Cloth, food, spent items, spare parts,



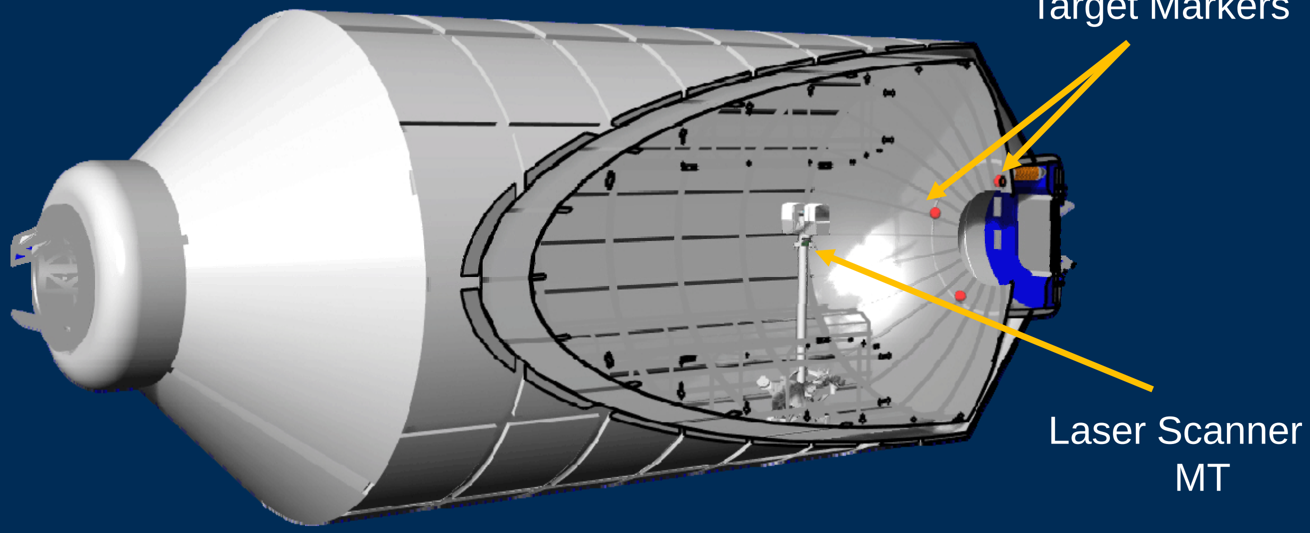
RAF Frame

Folded Cargo Space

Deploy

Ixion Outfitting: Hardware Requirement

- FARO 3D Laser Scanner

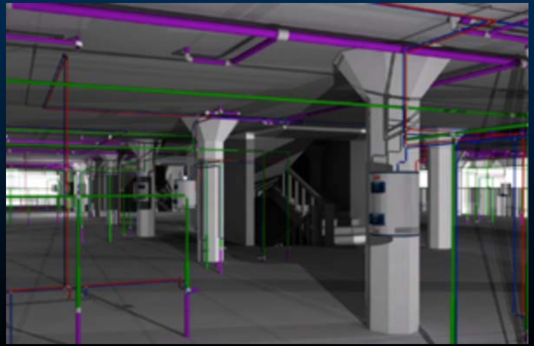


Scan Image

Coordinate Alignment

CAD DATA

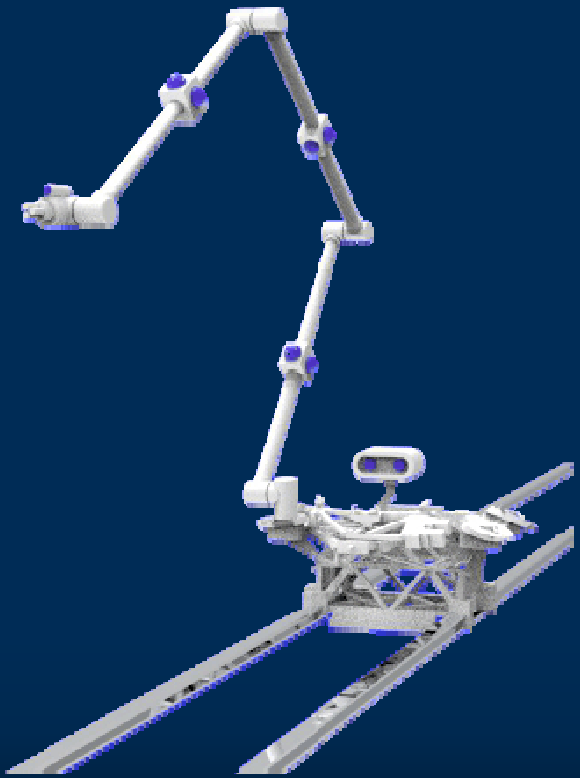
Justify to assembly objects at appropriate position



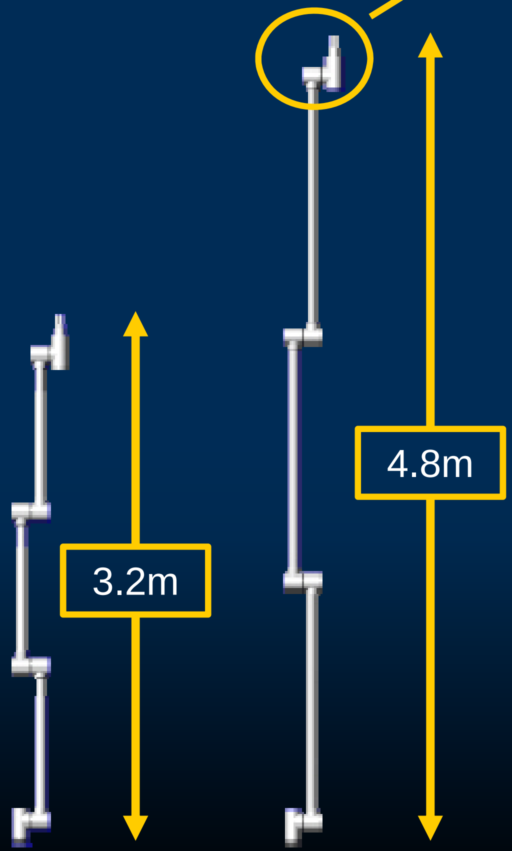
- Distance accuracy up to ±1mm
- Range from 0.6m up to 70m

Ixion Outfitting: Assembly Hardware Requirement

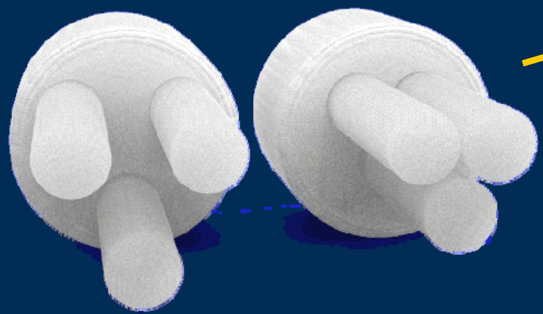
- Autonomous Assembly Robot (A2R)

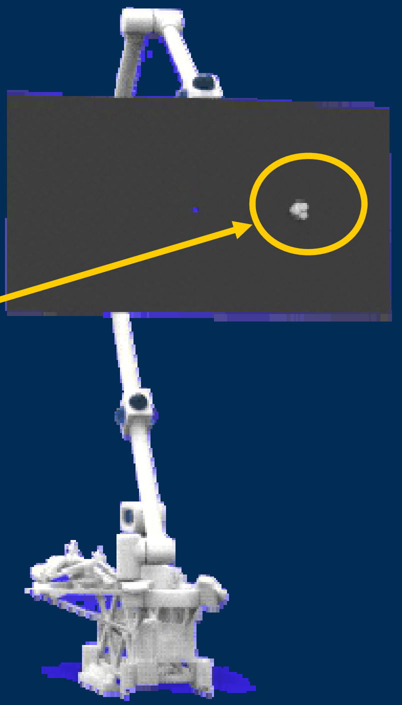


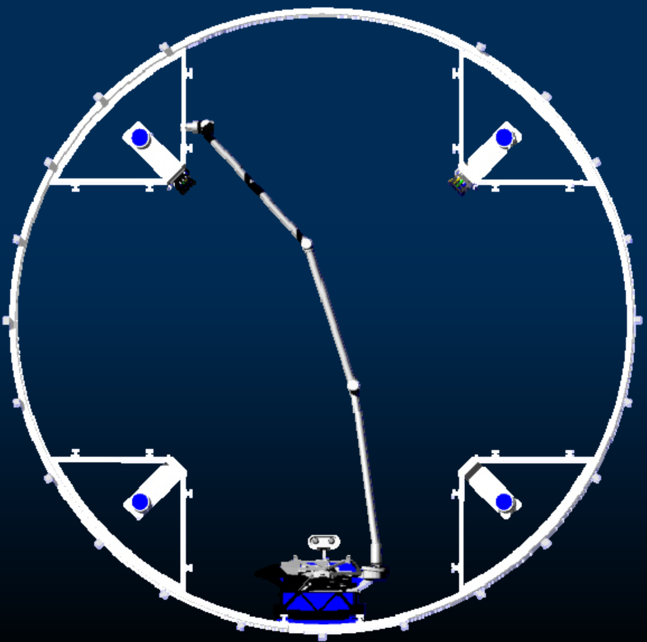
Robotic Arm



Capture mechanism



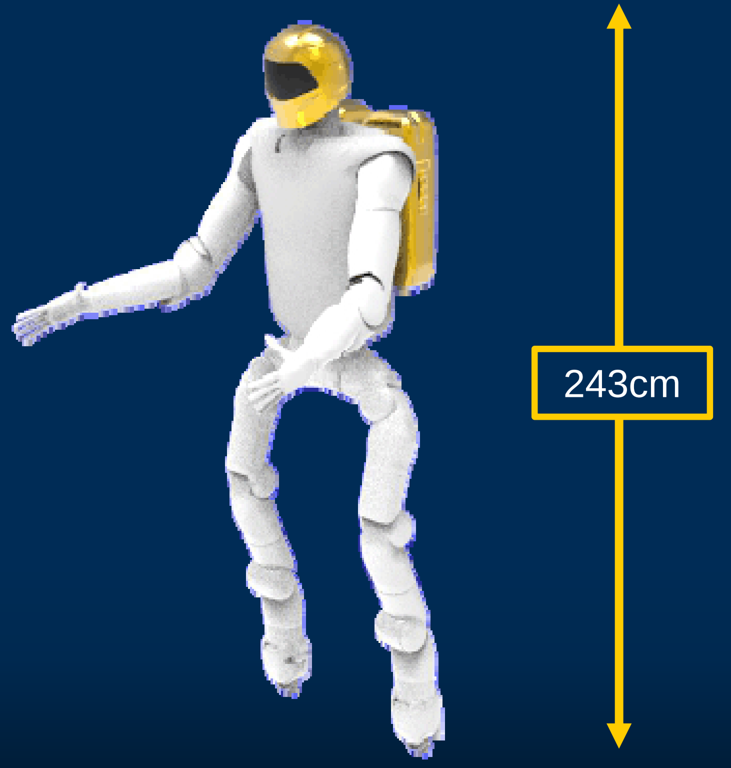


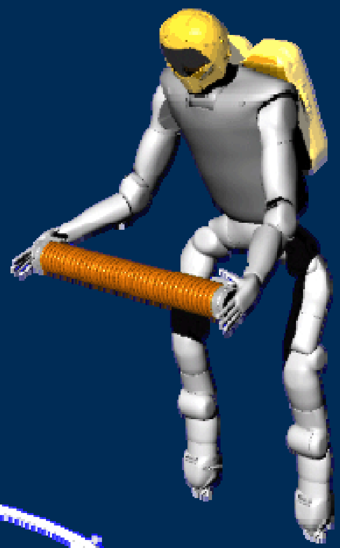


Power: Li-ion Battery
Wireless Communication

Ixion Outfitting: Hardware Requirement

- Robonaut 2

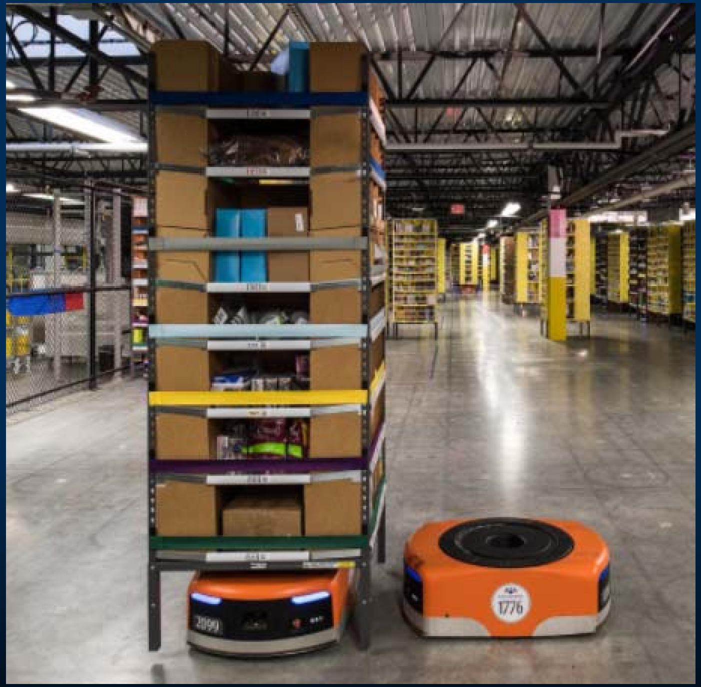




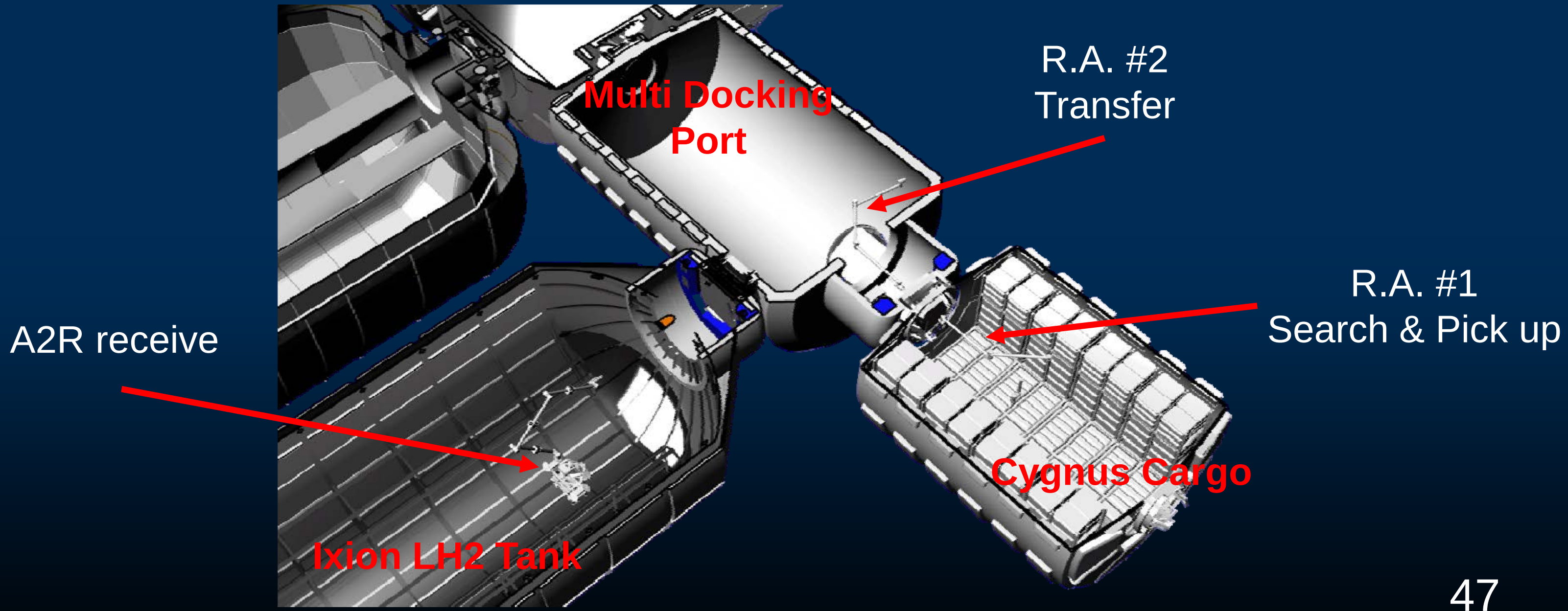
Ixion Outfitting: Hardware Requirement

- RFID: Radio Frequency Identification
  - Identify the location of the Cargo
  - “ Just-In-Time” system

Assembly → Detect Location → Pick up → Transport → Assembly



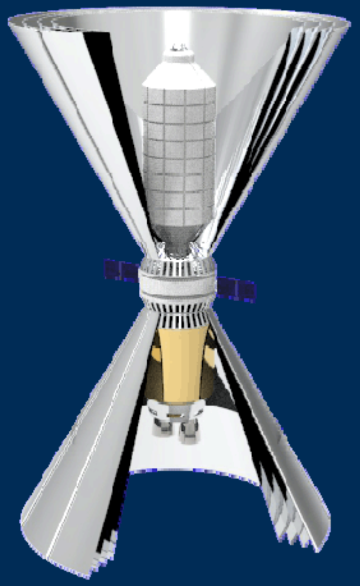
- Cargo Transfer Scenario



Assembly Process

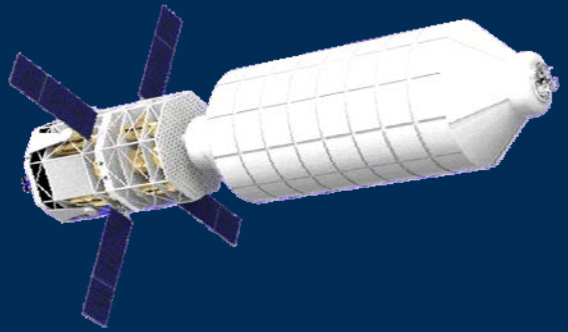
A: A2R, R: R2, H: Human

1. Vent all residual
Propellant and gas

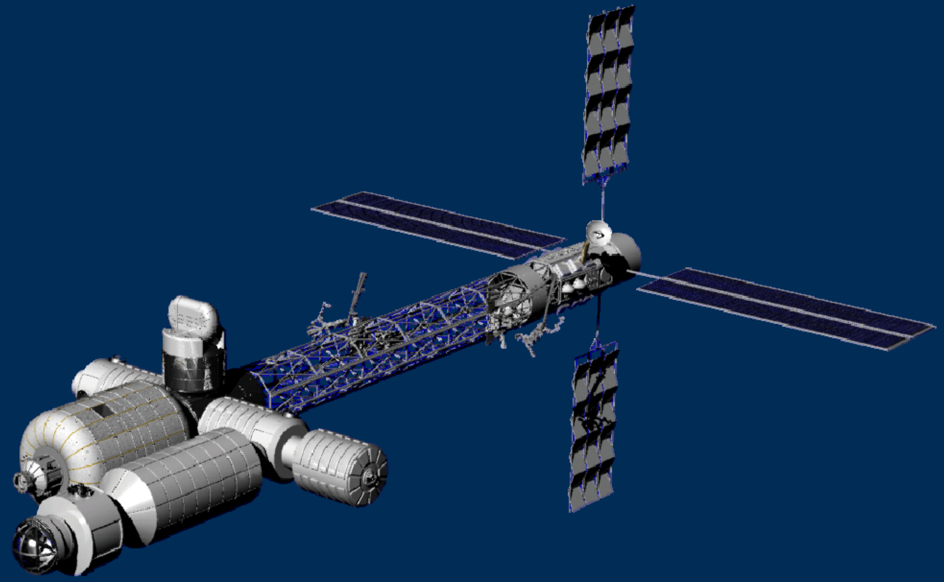


2. Transfer to AXIS

Space Tug



3. Docking



4. Bleed O_2 and N_2,
Stabilize inner temperature

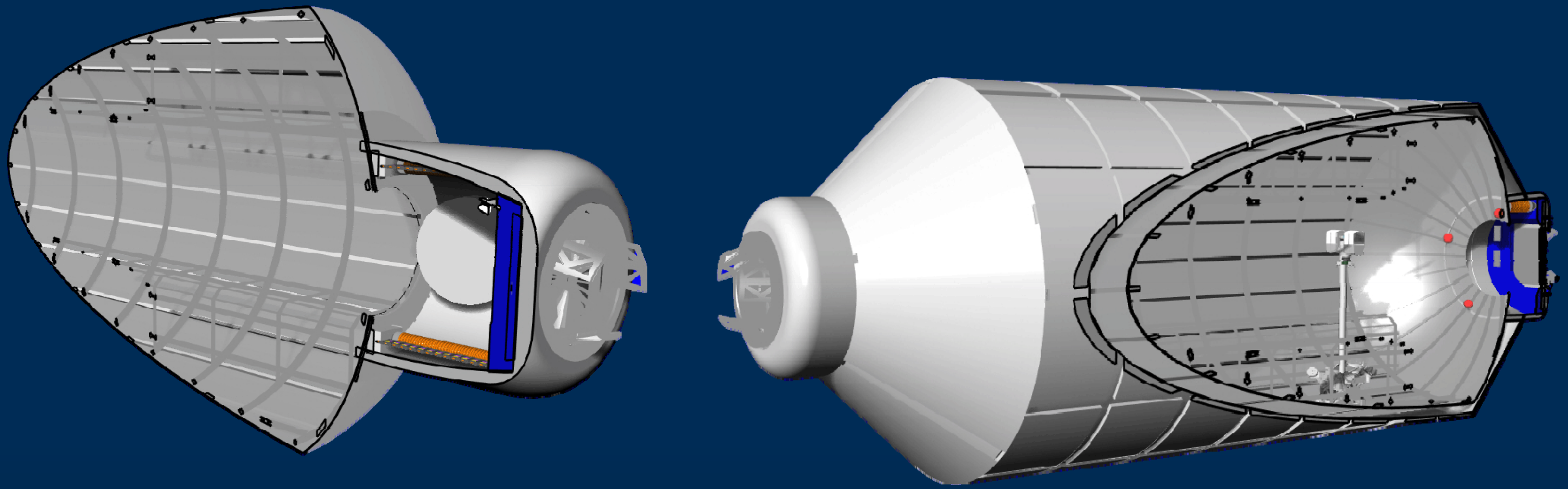
Assembly Process

A: A2R, R: R2, H: Human

H
5. Crew open the Hatch

H
6. Install Target Marker

H
7. Install MT and Scanner



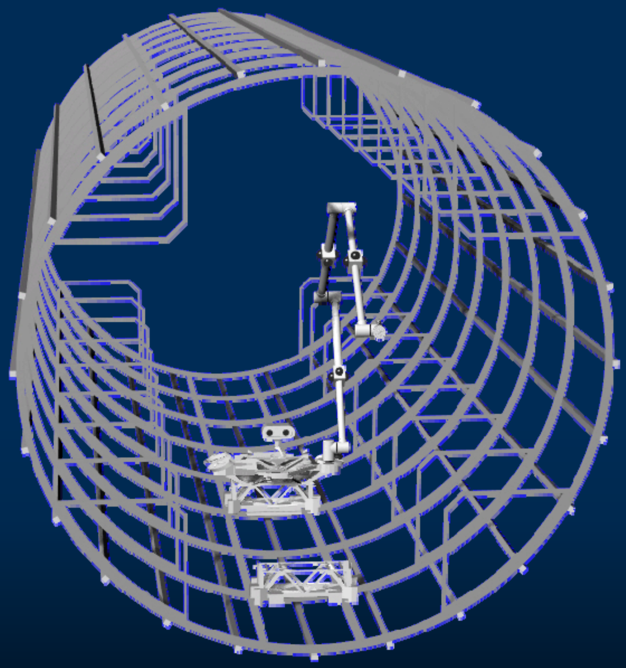
8. Scan Internal Tank

Assembly Process

A: A2R, R: R2, H: Human

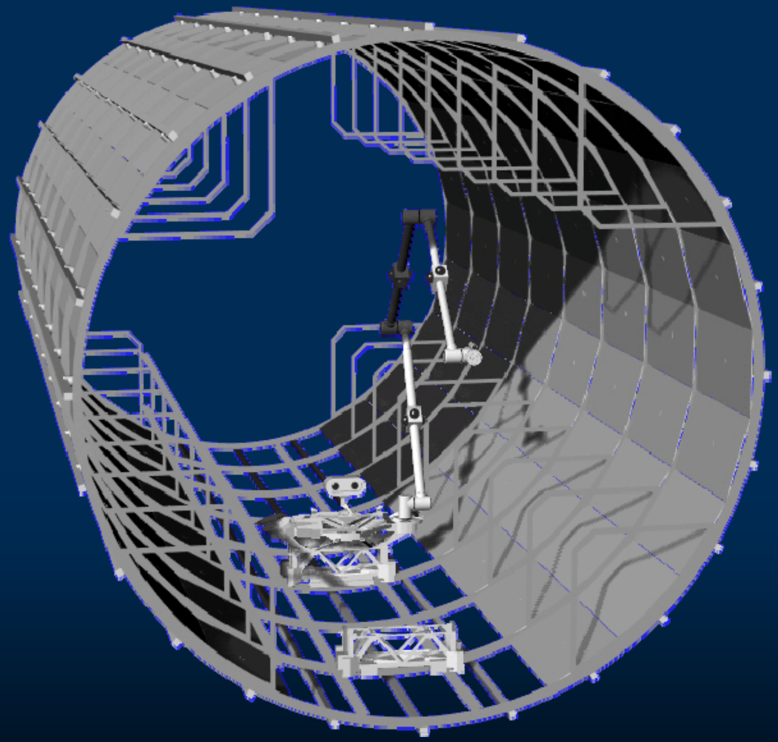
H

9. Install A2R



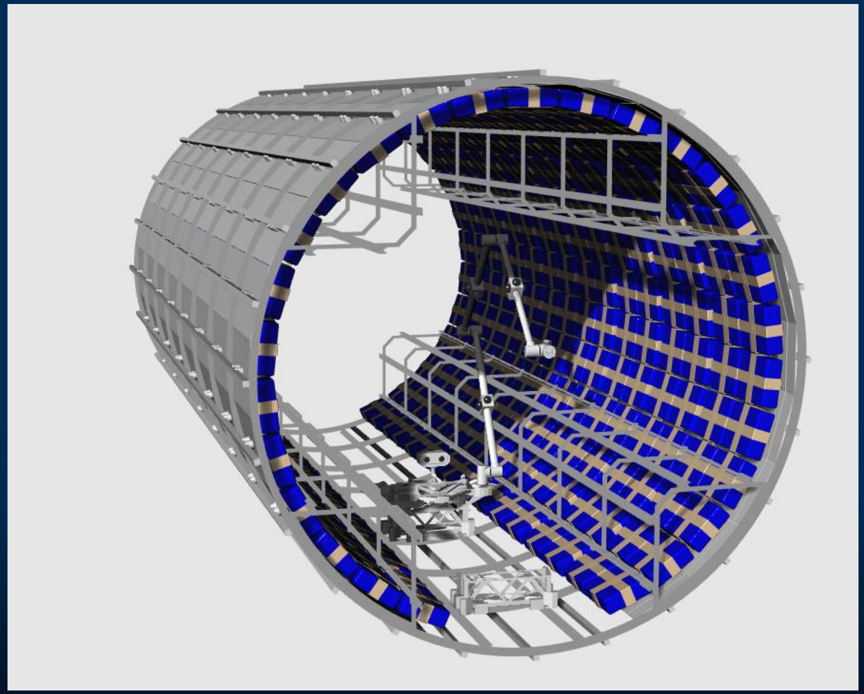
A

10. Attach CFR plate



A

11. Attach HMC



Assembly Process

A: A2R, R: R2, H: Human

R

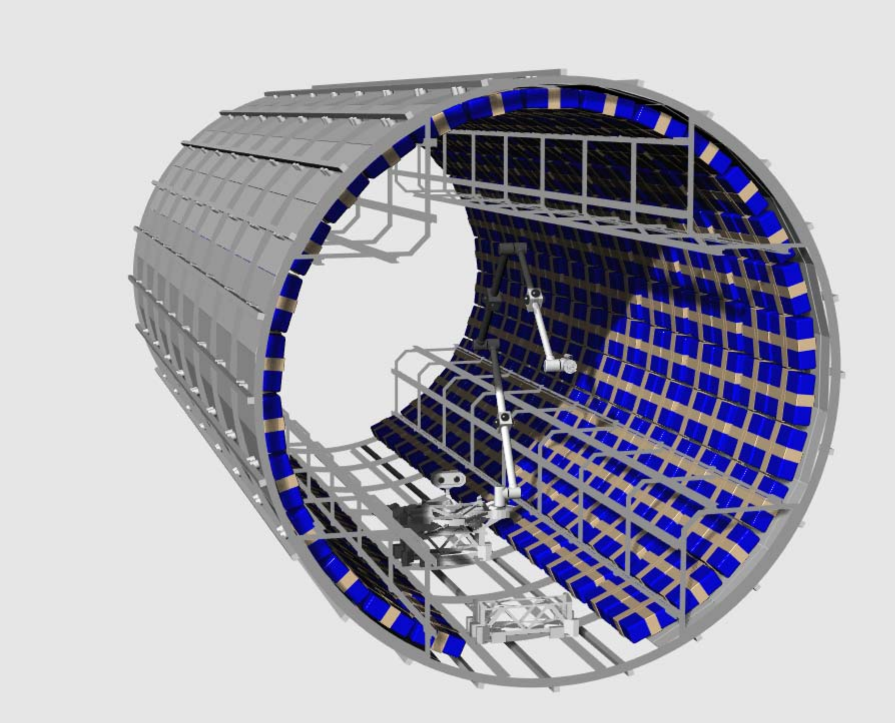
12. Attach Secondary Structure

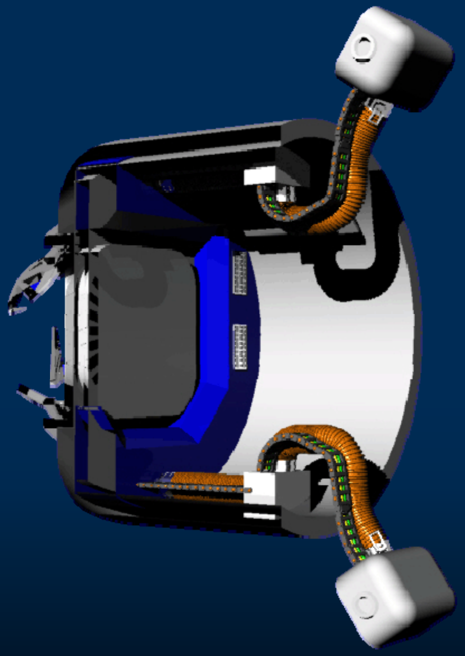
A

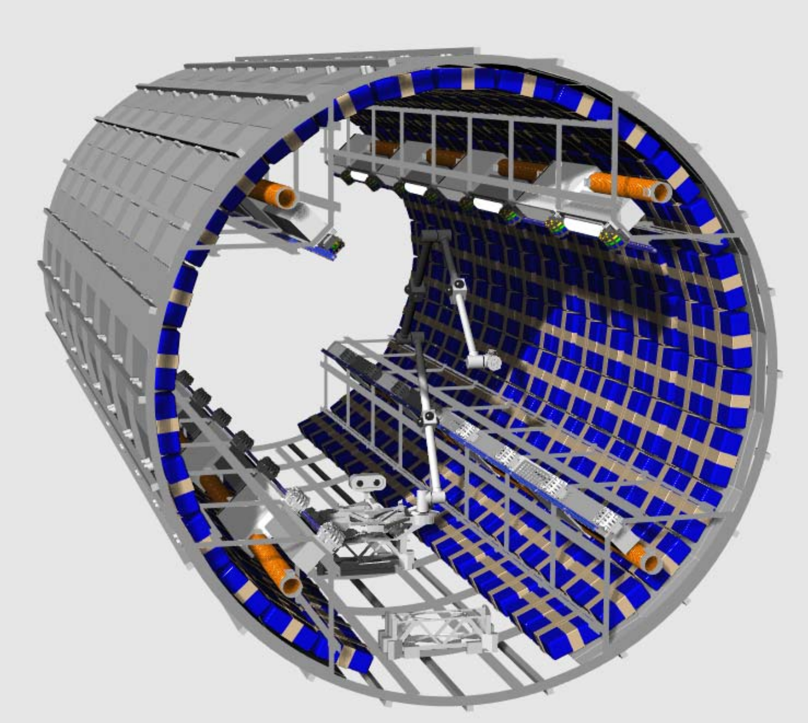
13. Attach Manifold

A

14. Install Diffuser & Return Air Fan Assembly





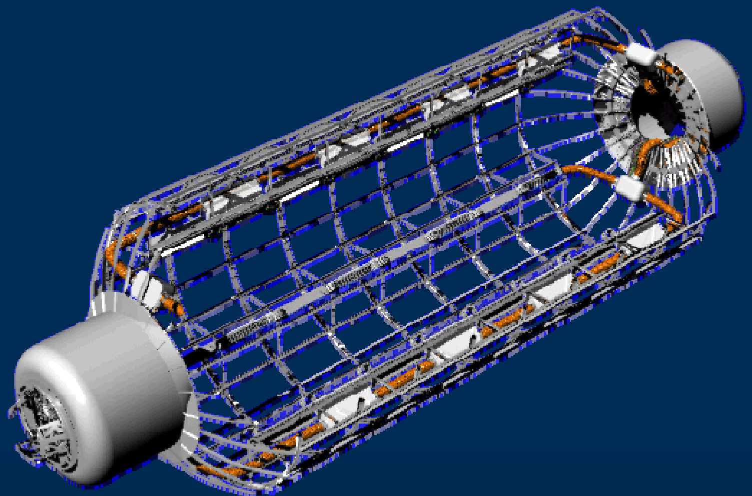


Assembly Process

A: A2R, R: R2, H: Human

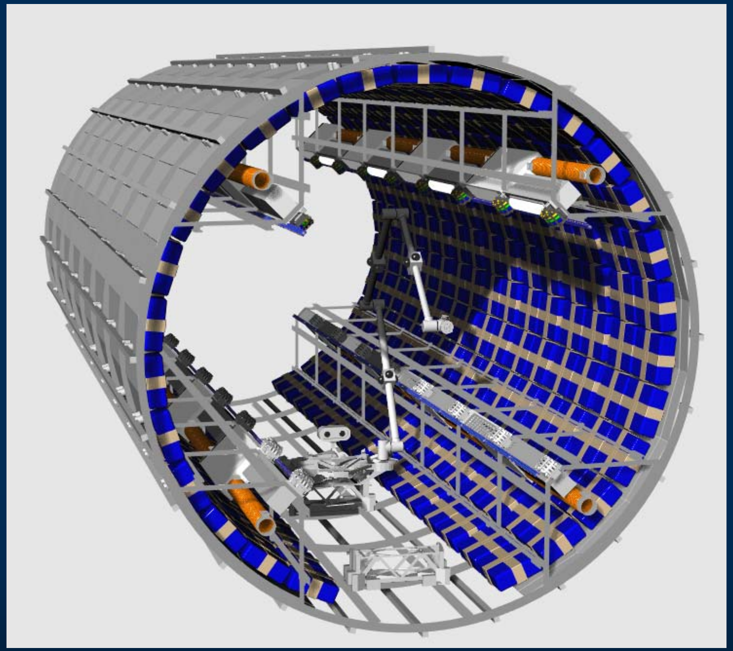
R

15. Connect Duct Hose



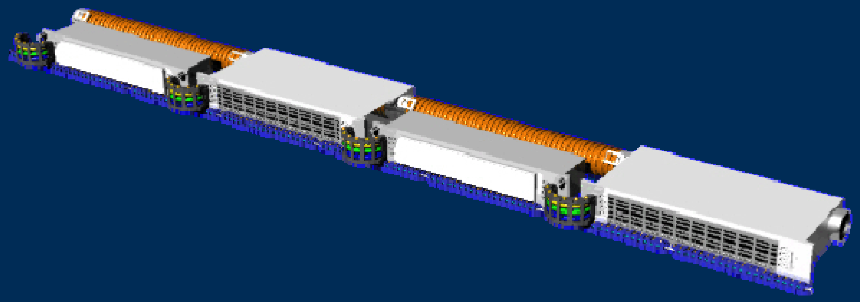
A

16. Install LED and Utility Board



R

17. Cable Connection



Assembly Process

A: A2R, R: R2, H: Human

A H

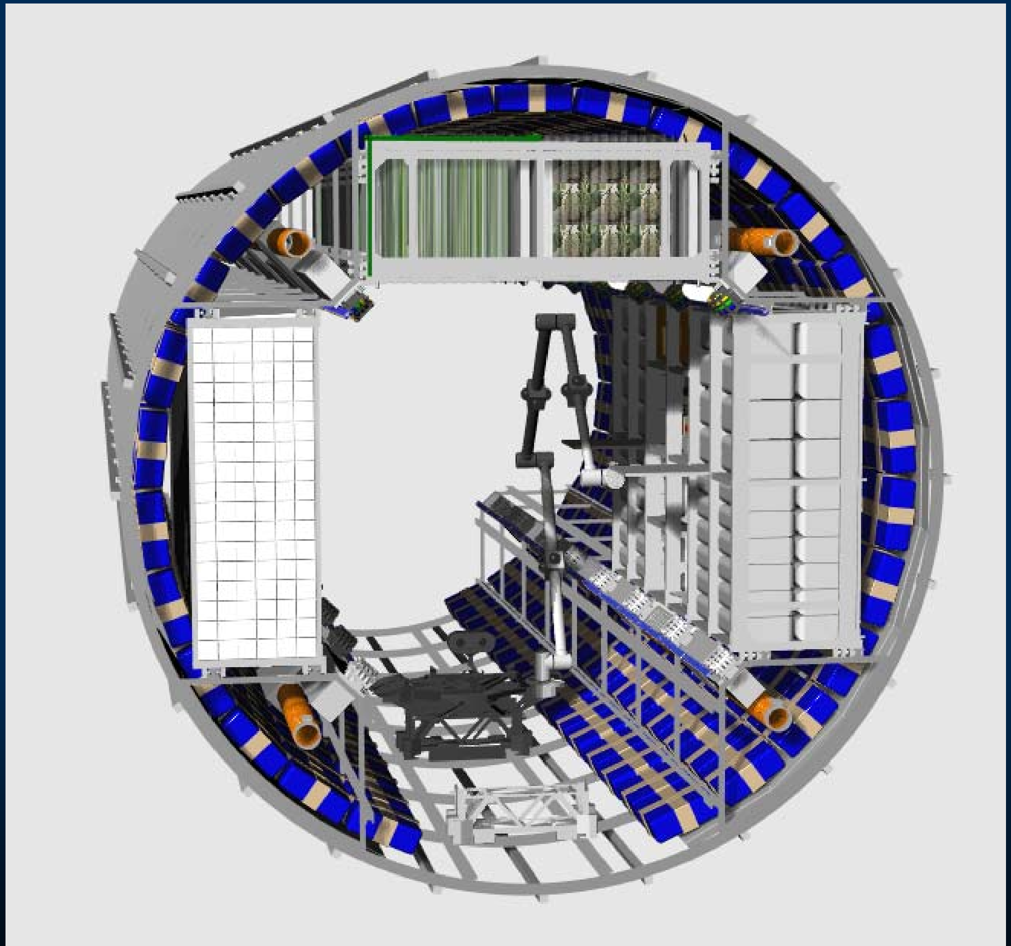
18. Kitchen

A

19. Install Projector

A H

20. Install Hydroponics

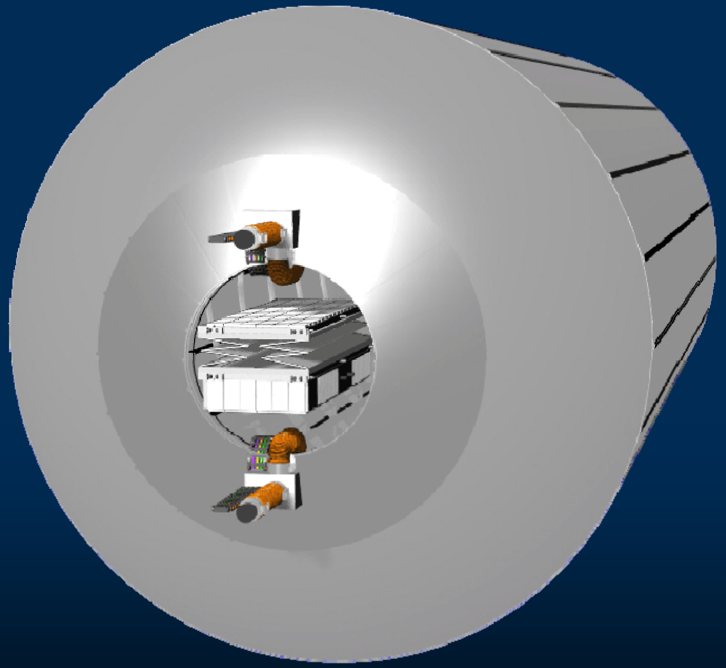


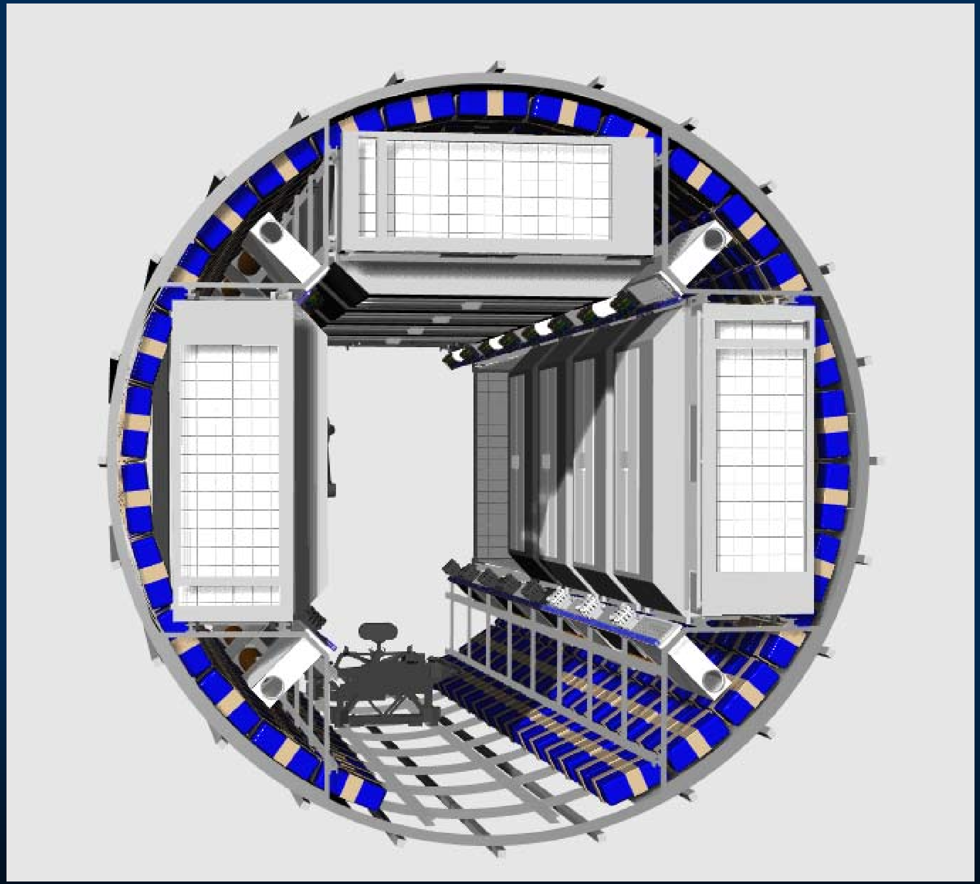
Assembly Process

A: A2R, R: R2, H: Human

A H

21. Install Crew Quarters

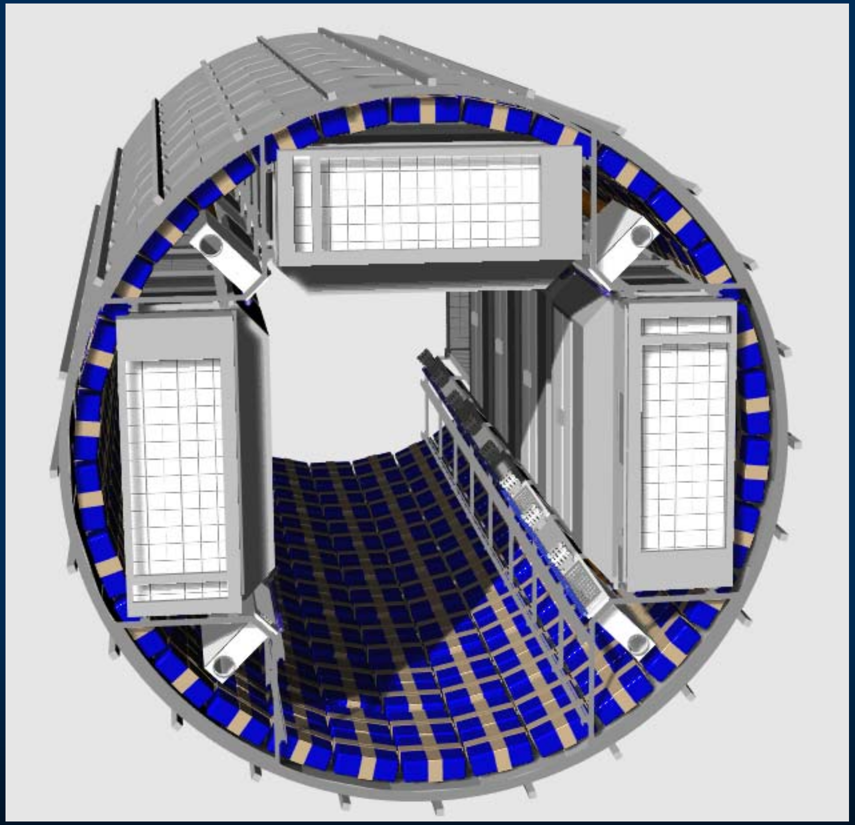




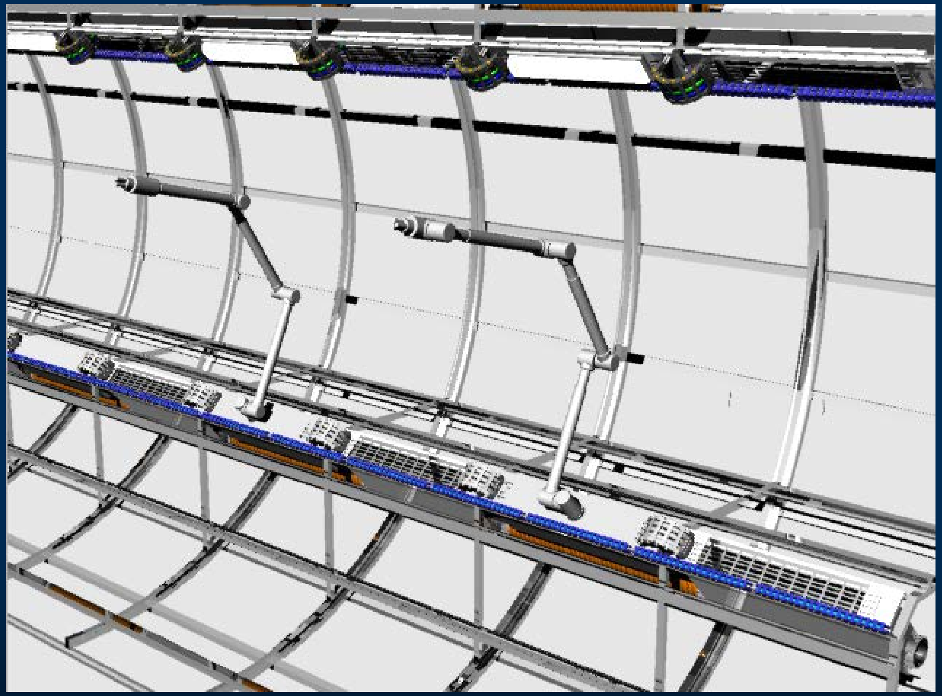
Assembly Process

A: A2R, R: R2, H: Human

A H
22. Remove rail



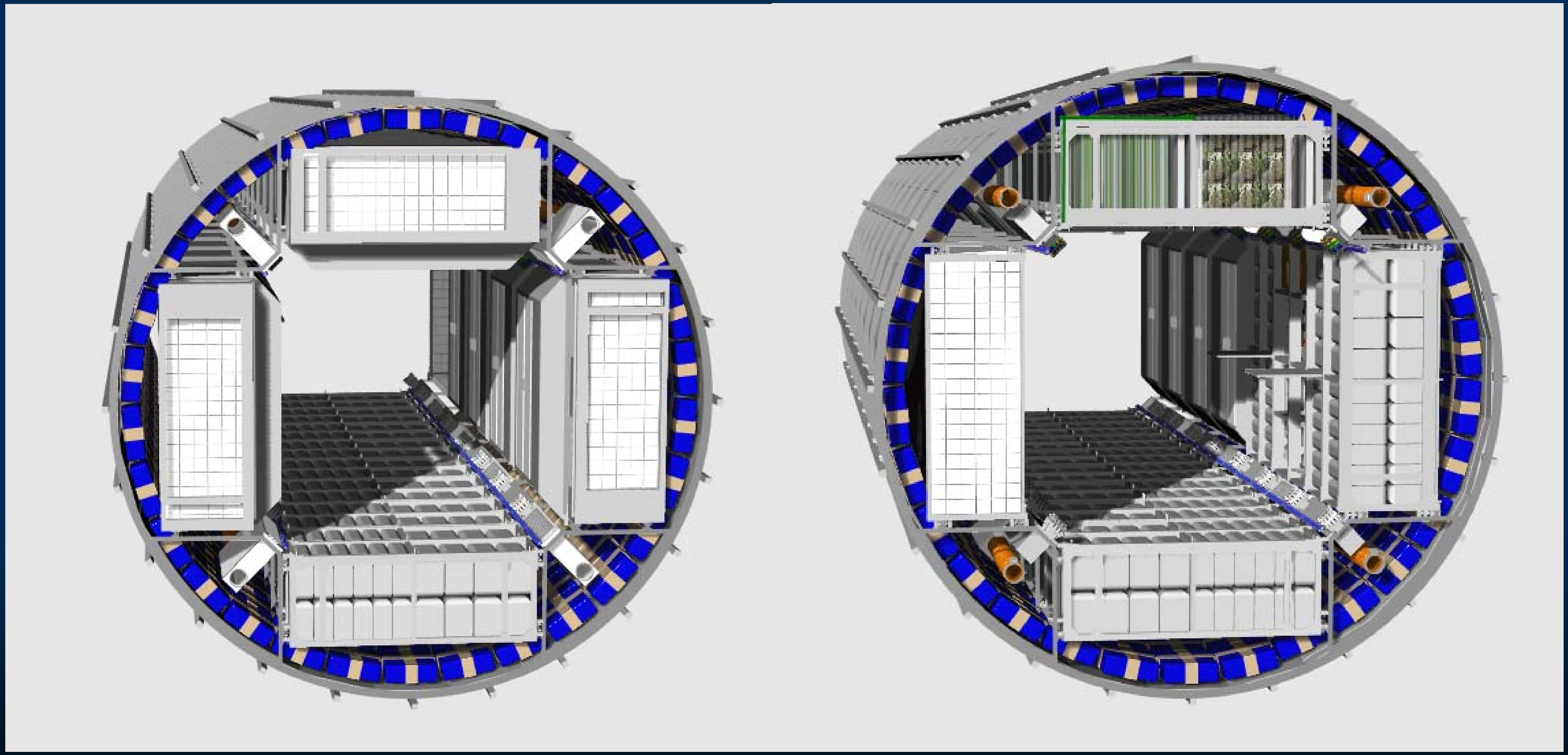
A
23. Install CFR plate and HMC wall



Assembly Process

A: A2R, R: R2, H: Human

A H
24. Install Cargo



Future Consideration

- ❑ How to convert a spent stage rocket into hab.
- ❑ Application for lunar base or deep space exploration habitatation