Concept of a Lunar ISRU Plant

- In-situ Production of LOX / LH2 from Lunar Regolith -

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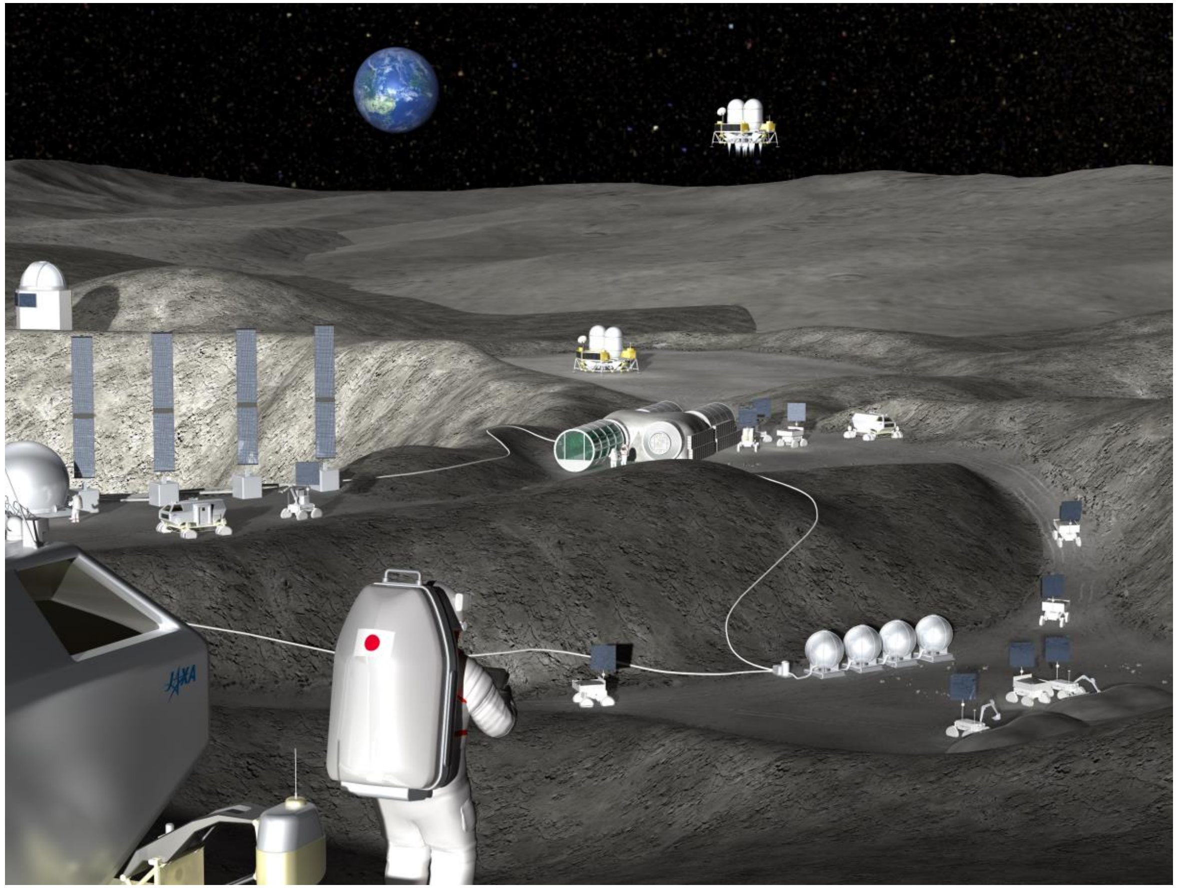
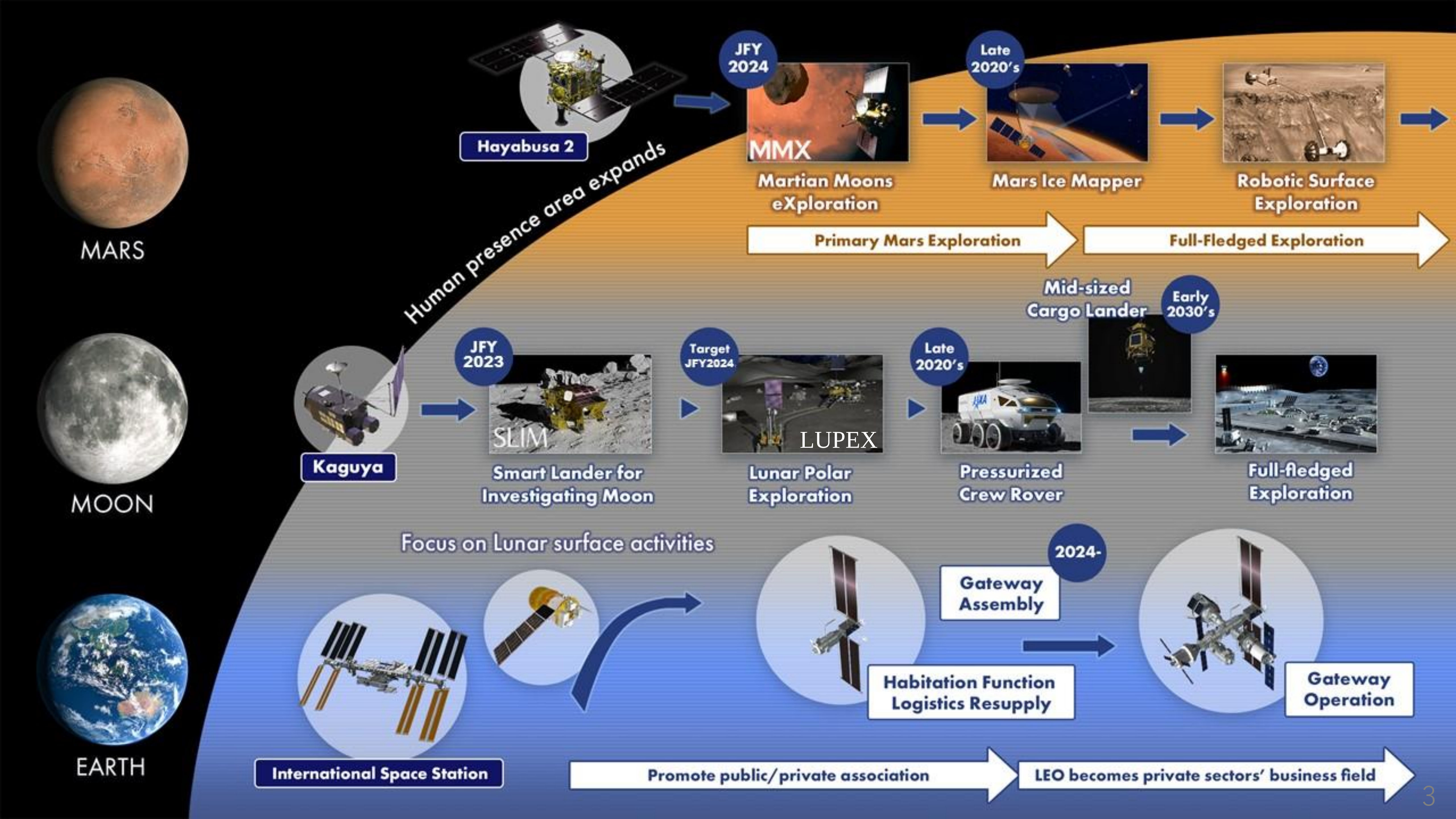
Contents



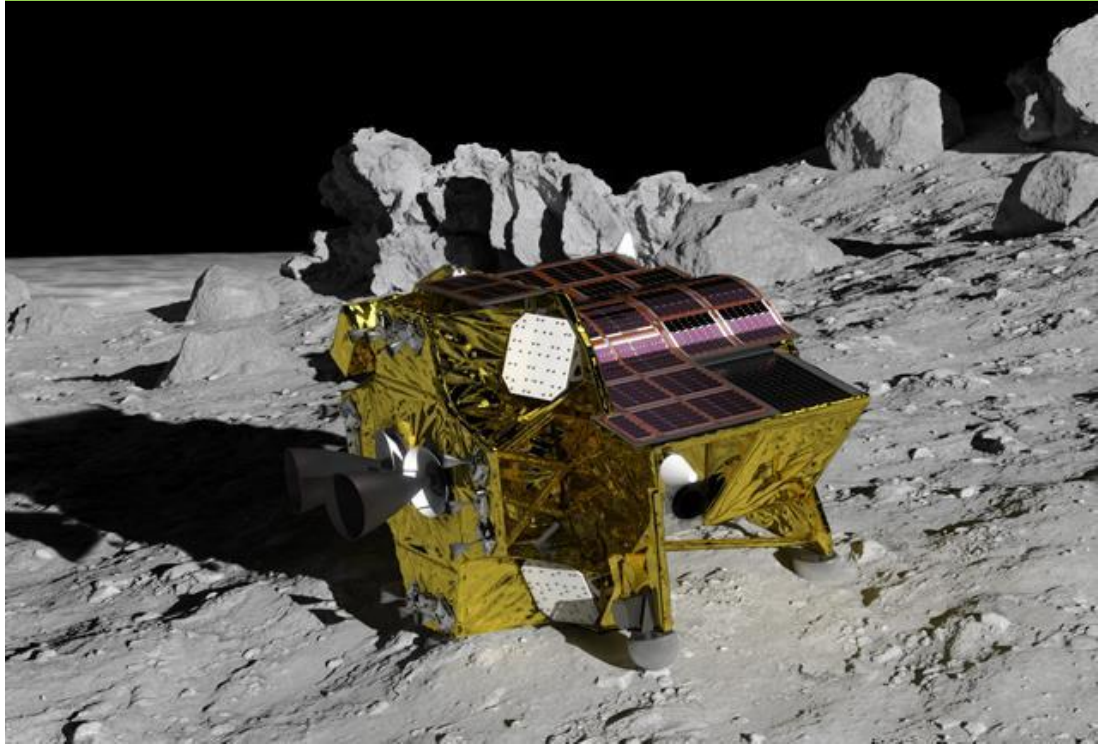


MARS
MOON
EARTH
Human presence area expands
Hayabusa 2
JFY 2024
MMX
Martian Moons eXploration
Late 2020's
Mars Ice Mapper
Robotic Surface Exploration
Primary Mars Exploration
Full-Fledged Exploration
Kaguya
JFY 2023
SLIM
Smart Lander for Investigating Moon
Target JFY2024
LUPEX
Lunar Polar Exploration
Late 2020's
Pressurized Crew Rover
Mid-sized Cargo Lander
Early 2030's
Full-fledged Exploration
Focus on Lunar surface activities
2024-
Gateway Assembly
Habitation Function Logistics Resupply
Gateway Operation
International Space Station
Promote public/private association
LEO becomes private sectors' business field

1. Introduction

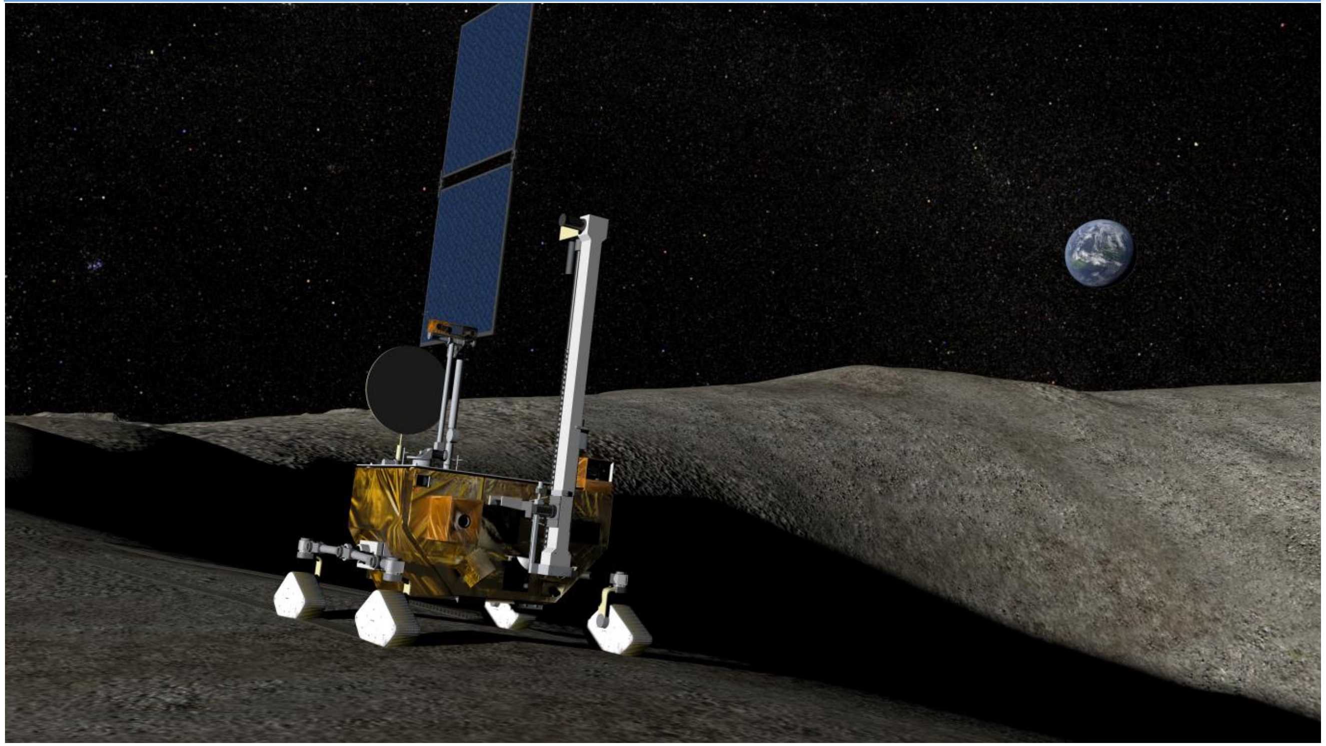
<u>Smart Lander for Investigating Moon (SLIM)</u>

- **100m precision landing tech demo**
- **Mass: 210kg (Wet) / 190kg (Dry)**
- **To be launched as early as 2023**
- **Landing Site: Vicinity of “Sea of Nectar”**



<u>Lunar Polar Exploration (LUPEX)</u>

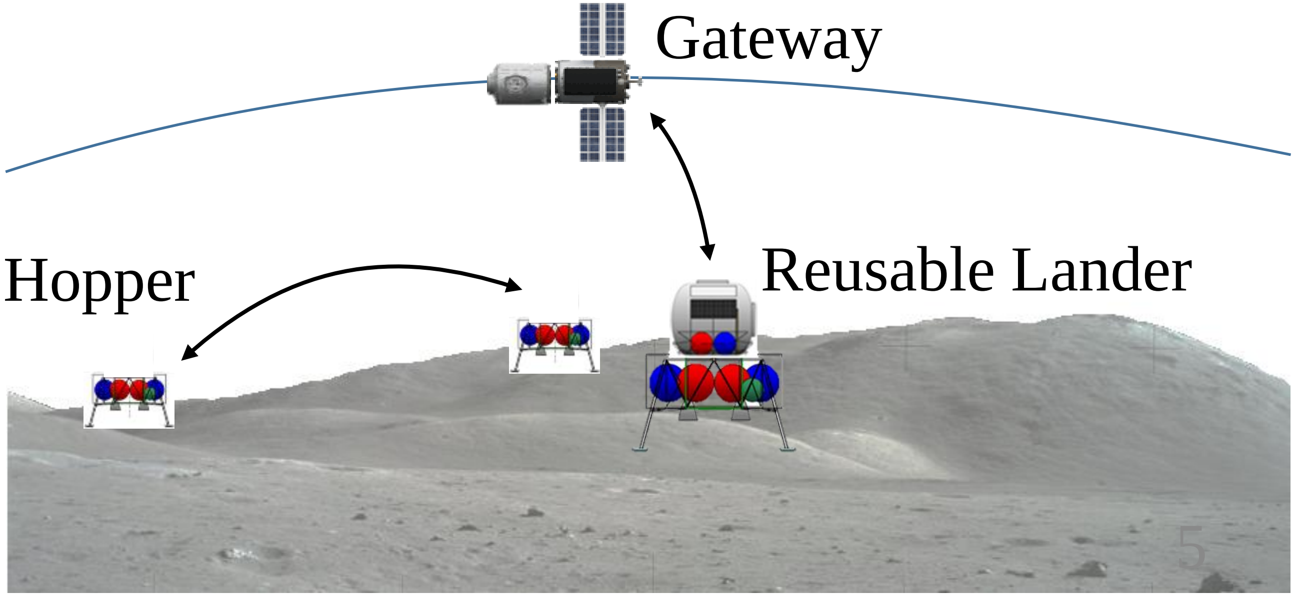
- **Explore the south pole region by 350kg class rover**
- **Investigate availability of water-ice resources**
- **Planned to be launched in 2025**
- **Collaborated w/ Indian Space Research Organisation**



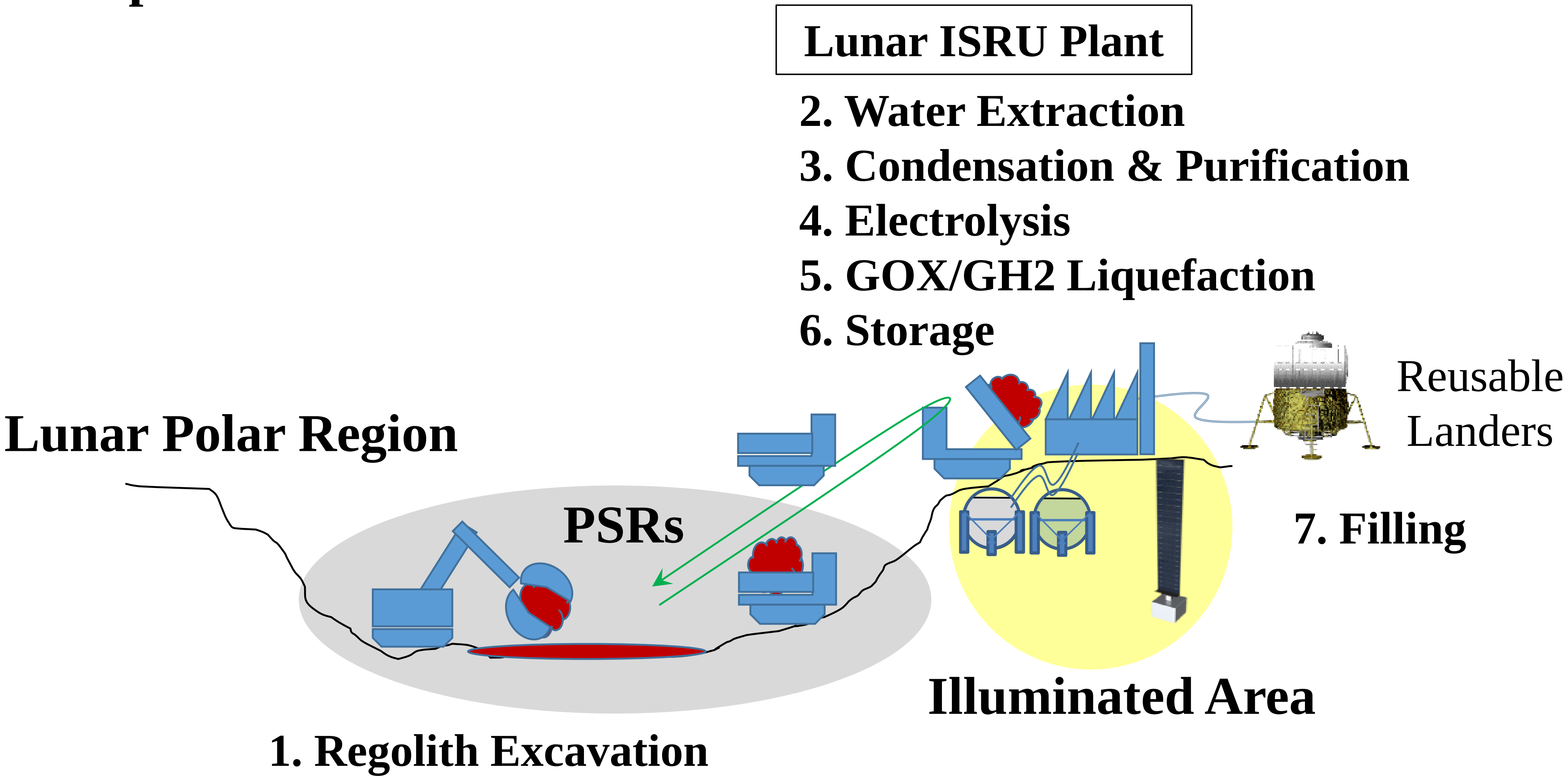
1. Introduction

<u>JAXA's vision for ISRU on the Moon</u>

Ensure long-term sustainability of lunar surface exploration by in-situ production of O_2 and H_2 from regolith with water contents to refill reusable landers and hoppers.



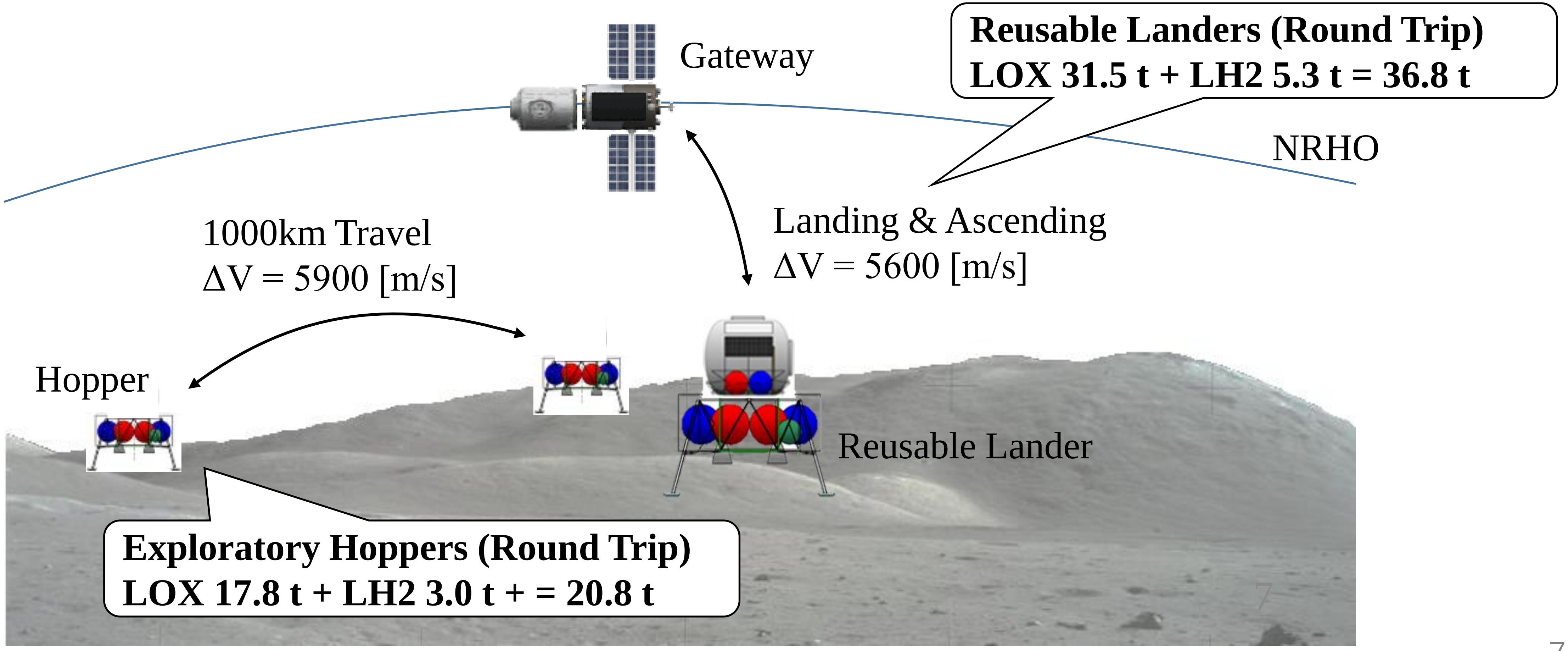
2.1 Concept


Lunar ISRU Plant
2. Water Extraction
3. Condensation & Purification
4. Electrolysis
5. GOX/GH2 Liquefaction
6. Storage
Reusable
Landers
Lunar Polar Region
PSRs
7. Filling
Illuminated Area
1. Regolith Excavation

2. Baseline requirements for a lunar ISRU plant

2.2 Production Rate

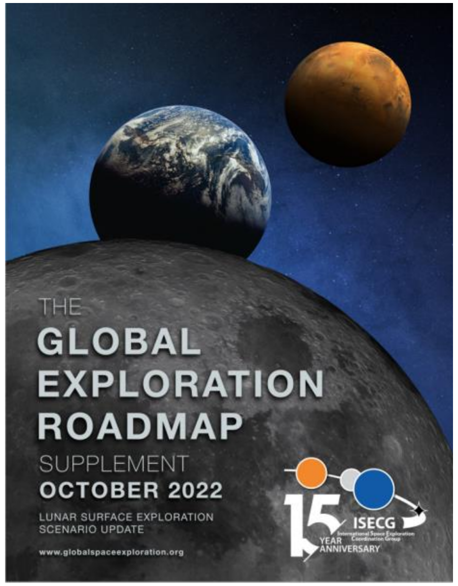
Production rate of propellant：57.6 ton/year
（LOX 49.3 ton/year, LH2 8.3 ton/year）



2. Baseline requirements for a lunar ISRU plant

- Objective not addressed during Phase
- Progress/Partial achievement at the end of Phase
- Significant achievement at the end of Phase
- Sustained/Potential for increased capability

OBJECTIVE	Performance measure target	PHASE 1: Boots on the Moon	PHASE 2A and 2B: Lunar Exploration– Expanding and Building — Exploration and Mobility	PHASE 2A and 2B: Lunar Exploration– Expanding and Building — Mars forward demos, Habitation and ISRU	PHASE 3: Sustained Lunar Opportunities
Demonstrate Human Landing/ascent	4 crew	2 crew	4 crew		
Demonstrate range of cargo delivery	1 t/9 cargo	Small cargo landers	Medium/large cargo landers		
Demonstrate EVA capabilities on the Lunar surface	Useable, minimal maintenance	2 crew EVAs	Reusable	Decreased maintenance	
Demonstrate human long range traversing	10,000 km*		1000s km	10,000+ km	
Demonstrate long duration habitation including night survival	500 days*		<500 days	>500 days	
Demonstrate crew health and performance sustainability to validate Mars mission durations	x days		<x days	>x days	
Demonstrate ISRU for crew transportation and long duration habitation	50 t propellant		<50 t propellant	>50 t propellant	
Conduct global human/robotic science cooperative exploration	Evaluation				
Develop infrastructure for sustained exploration	System availability				
Engage public and youth in particular	Public attitude				
Implement new commercial arrangements	Increasing partnerships				
Provide collaboration opportunities for International Partners	>100 nations	>10 nations	>100 nations		



3. Results of conceptual study

3.1. Overview

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JAXA carried out conceptual study of a lunar ISRU Plant with JGC Corporation.

- ◆ One of the largest total engineering companies in the world.
- ◆ Headquartered in Yokohama, Japan.

3.1. Overview

Qualitative & quantitative studies of a plant system to meet baseline requirements.

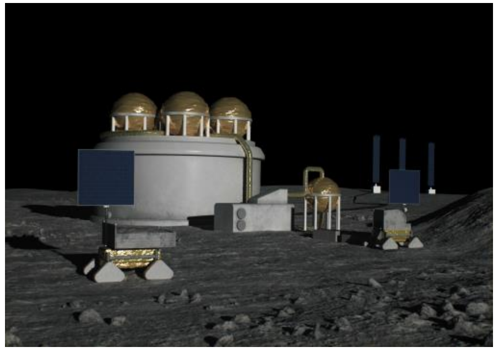
- ◇ Block Flow Diagram
- ◇ Material Balance
- ◇ Key Technical Elements
- ◇ Mass & Size Estimation
- ◇ Site Selection

Discussions on technical & managemental issues.

- ◇ Plant System
- ◇ Subsystem
- ◇ Construction & Infrastructure
- ◇ Operation
- ◇ Project Management

Formulation of R&D strategy and project plans.

- ◇ Pilot Plant
- ◇ Full-scale Plant



Overview of conceptual study of a lunar ISRU plant

3.2. Key Technical Elements

Process	Key Technical Elements on Processing (Examples)
Regolith Excavation	・Low-power regolith excavation ・Remote control and automatic operation of construction machinery ・Decentralized control of multiple construction machinery
Water Extraction	・Low-power water extraction (extraction at a plant vs on-site) ・Efficient heating (magnetron vs electric heating vs solar power) ・Thermal insulation of heating container ・Dust mitigation & Effect analysis of regolith contamination ・Treatment of residue after water extraction ・Water vapor adsorption on inner walls of pipelines
Condensation & Purification	・Efficient condensation after water extraction ・Design of water tank in consideration of 1/6G

3. Results of conceptual study

3.2. Key Technical Elements

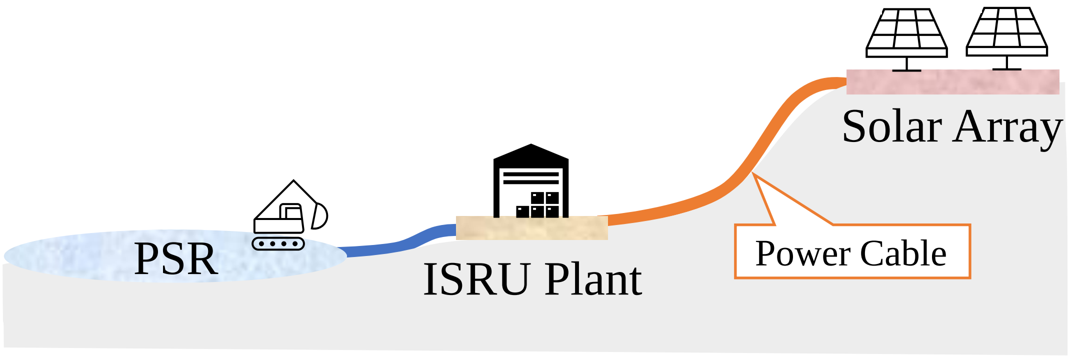
Process	Key Technical Elements on Processing (Examples)
Electrolysis	・Efficient electrolyzing methods in 1/6 gravity ・Reduction in weight of electrolysis ・Dehumidification of GOX/GH2 prior to liquefaction
Liquefaction	・Energy-efficient cooling mechanism (Vapor-compression refrigeration vs Magnetic refrigeration) e.g. Active Magnetic Regenerative Refrigeration: AMRR
Storage	・Lightweight cryogenic storage tanks with material compatibility ・Boil-off reduction ・Energy-efficient recondensation method
Propellant Filling	・Boil-off reduction during propellant filling operation ・Remote control and automatic refueling

3.3. Mass & Size Estimation

- Mass of a whole plant system: 293 ton

  (*) Preconditions
  - Production rate : 57.6 ton/year
  - Site: Prospective construction site in south pole region
  - Distance between power facility to a ISRU plant: 20 km
  - Solar illumination: Ave. 50 %
  - Power Generation: Solar Photovoltaics (PV)
  - Power Transmission: Power Cables (Al conductor cables)
  - Power Storage: Fuel Cell

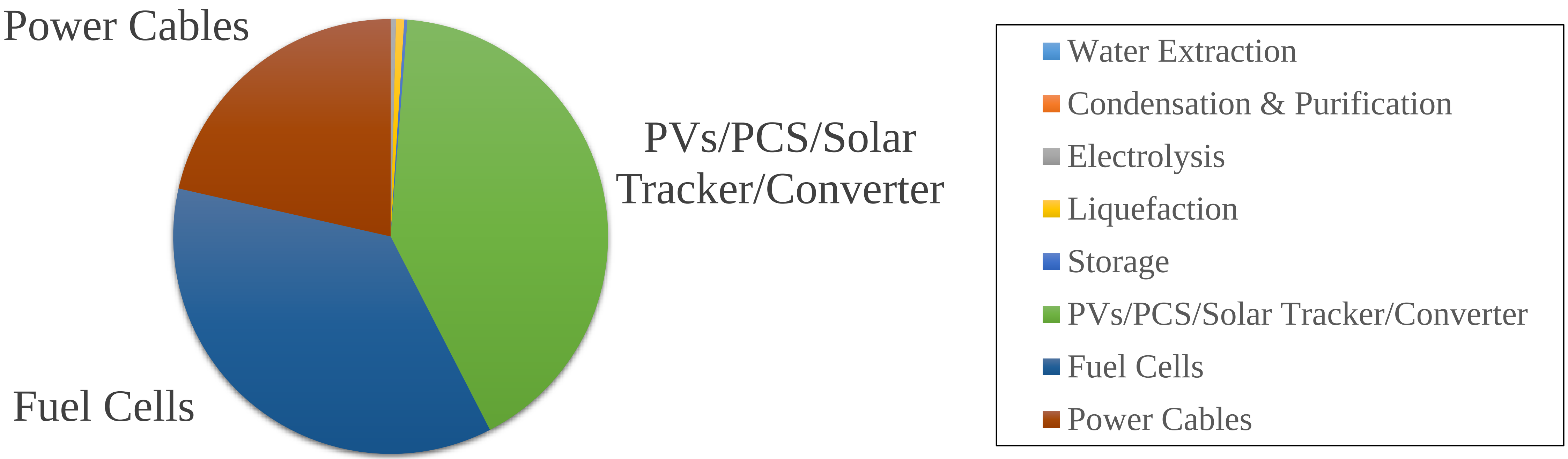
- Total area of Photovoltaics: approx. 2,000 m^2
- Target volume of a ISRU plant: < 33.1m^3 (= 1,169 cu ft.)
  ≒ Inside cubic capacity of 20ft. ISO Container
- Total area of heat rejection radiators: approx. 300 m^2



Configuration of a lunar ISRU Plant

20ft. ISO Container

3.3. Mass & Size Estimation



Drastic weight reduction of power elements (PVs / power conditioning system (PCS) / solar tracker / converter, fuel cells, power cables) and heat rejection radiators is essential given that over 95% of the total mass comes from those elements according to our estimation.

3.4. Construction Method

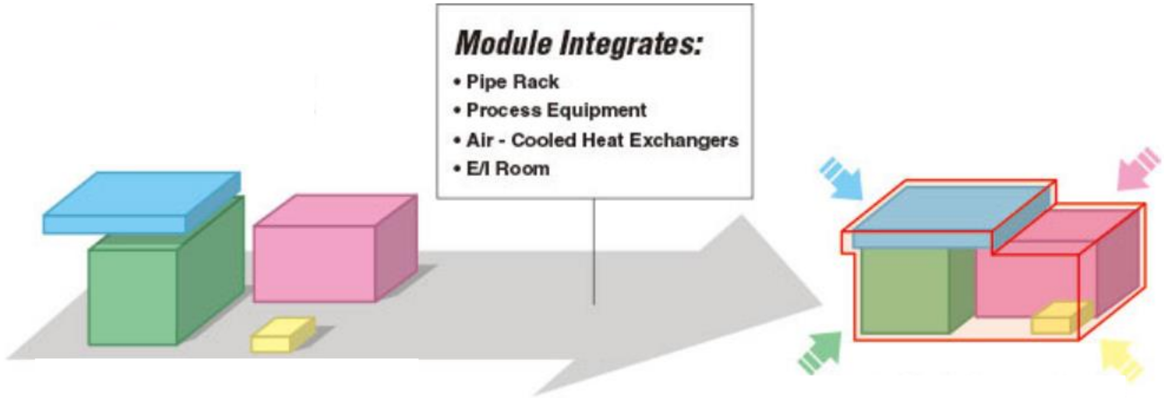
- Modular construction method, which is developed method of LNG plant construction with the aim of speedy construction, is applicable to a lunar ISRU plant.


Module Rifting


Maritime Transportation


Delivery to Construction Site


Land Transportation



SPMT (Self-Propelled Modular Transporter) / Mammoet

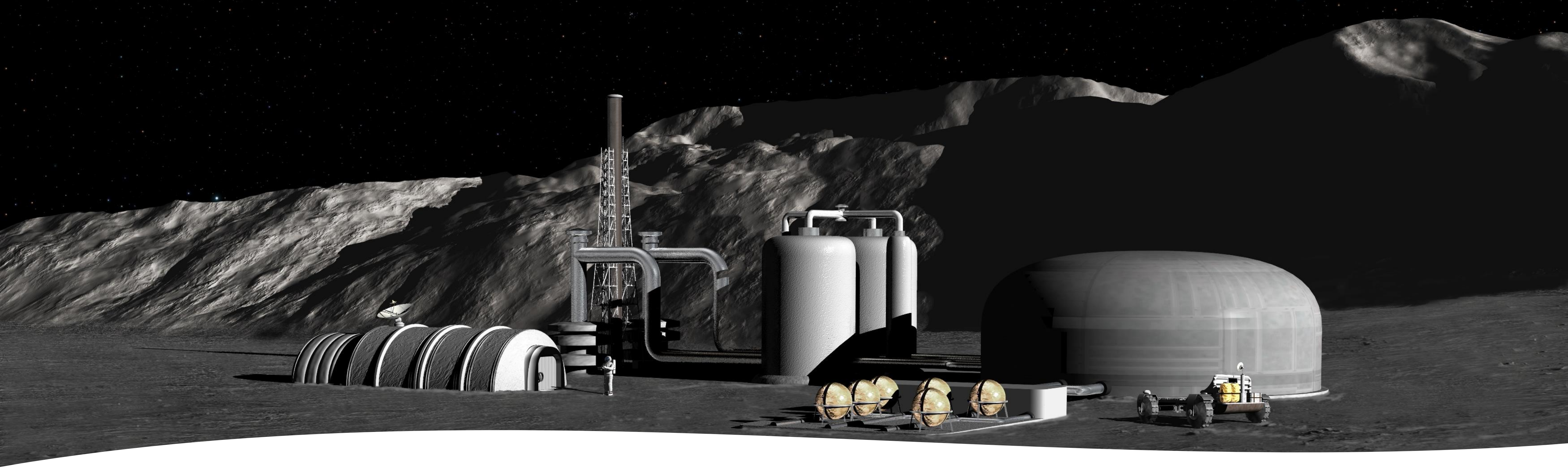
4. Future Work

4.1. Requirements Definition & Flowdown

- Define system requirements of a lunar ISRU plant taking account of stakeholders' expectations and constraints
- Flow down system requirements from a plant system level to a subsystem level.

4.2. Building an R&D Strategy and Project Plans

- Concept and technology development from a system integration standpoint.
- Deepen fundamental research for key technical elements based on requirements.
- Research on construction & infrastructure technology on a lunar surface in cooperation with general contractors and construction machinery manufacturers.
- Demonstrate LOX/LH2 production technologies from regolith simulant with water contents on the ground through development of an integrated ISRU system in the early 2020s.
- Develop a pilot plant for a sub-scale tech demo and construct a large-scale plant on the Moon.



Pilot Plant

- **Perform a sub-scale tech demo on the Moon in the late 2020s - early 2030s.**
- **Produce potable water (340 kg/year TBD) and/or breathable O2 (150 kg/year TBD) from regolith.**

Large-scale Plant

- **Commence to build a lunar ISRU plant in the late 2030s and start full-scale operation by 2040.**
- **Produce LOX (49.3 ton/year TBD) and LH2 (8.3 ton/year TBD) from regolith to refill spacecrafts.**

NOTICE: Above-mentioned plans and requirements stem from the conceptual study of a lunar ISRU plant by JAXA and JGC Cooperation. Target production rate may change. Not budgeted by the Government of Japan at this moment.

“The future is not a gift: it is an achievement.
Every generation helps make its own future.
This is the essential challenge of the present.”

— Robert Kennedy —