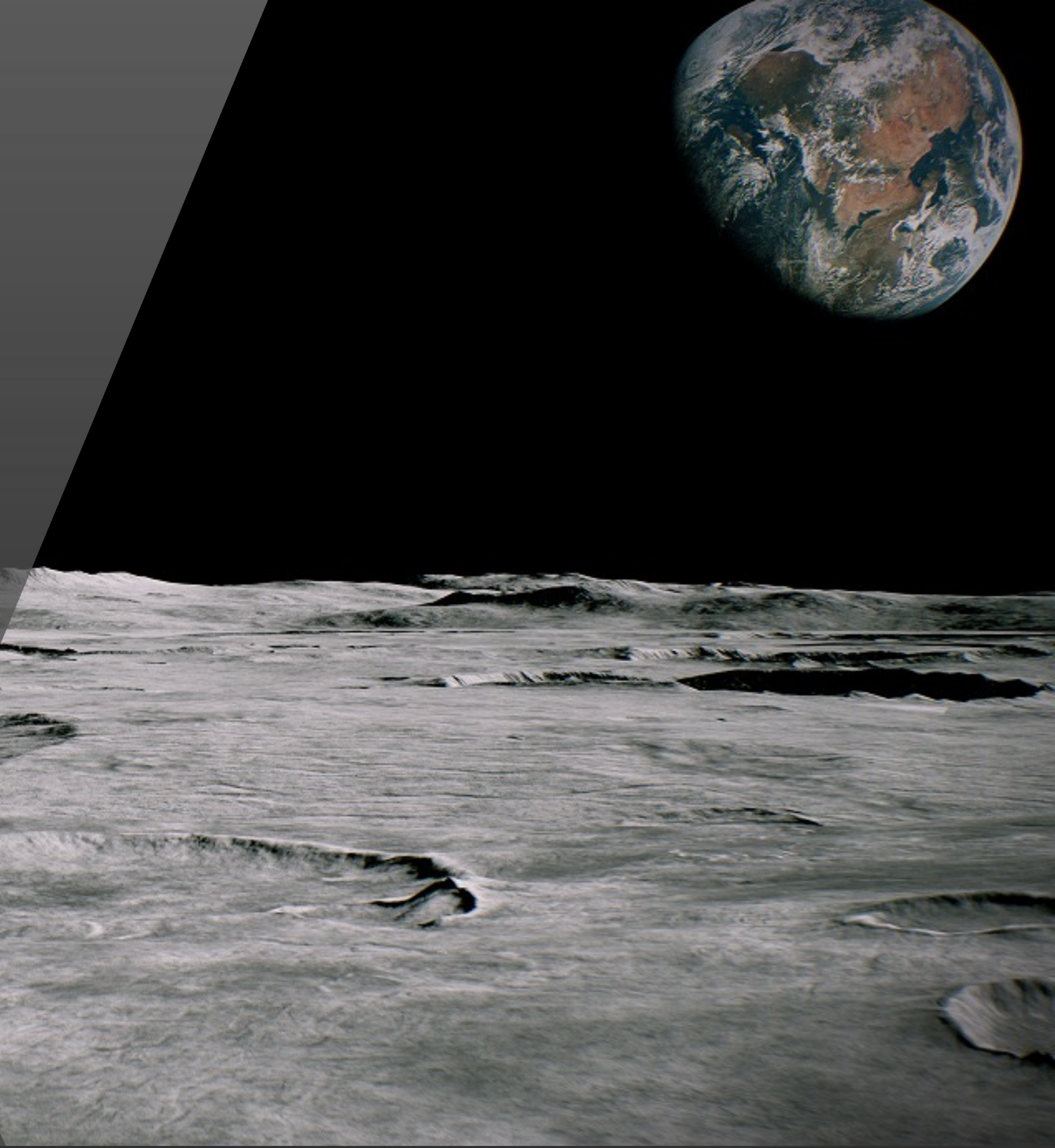

# Feasibility Study of Lunar ISRU Plants by Japanese Plant Engineering Company

**Wed. June 4, 2025, XXV SPACE RESOURCES ROUNDTABLE,**

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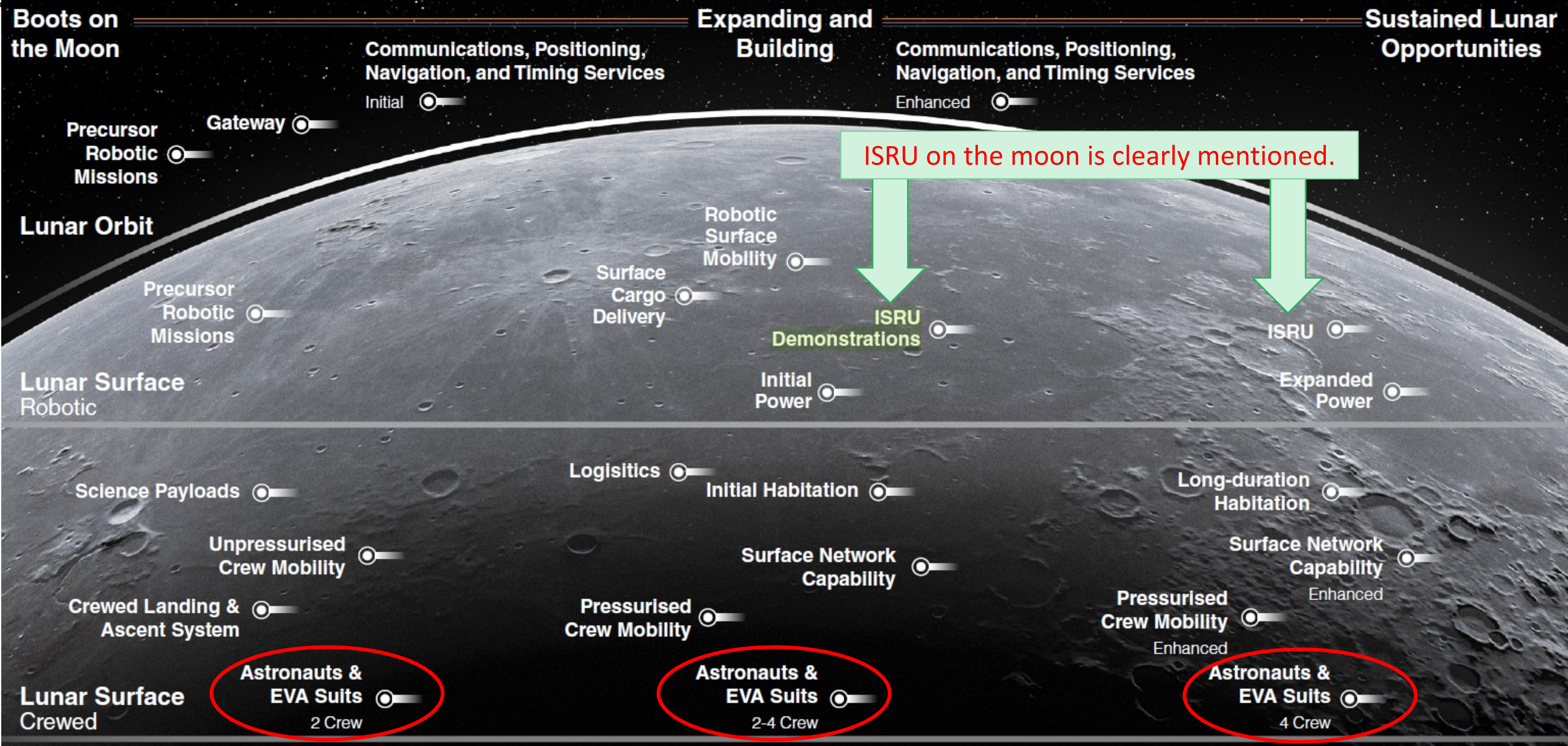
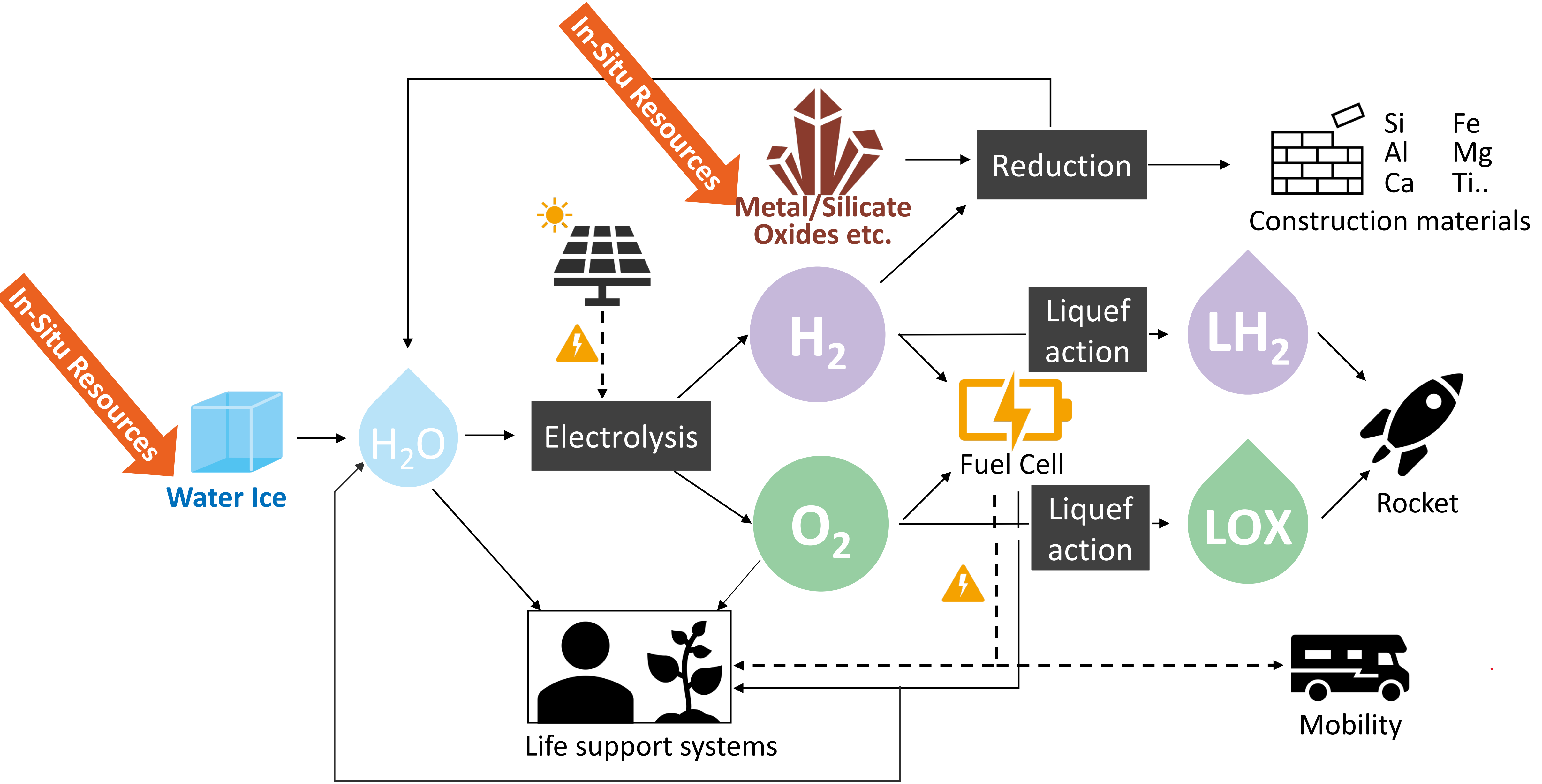
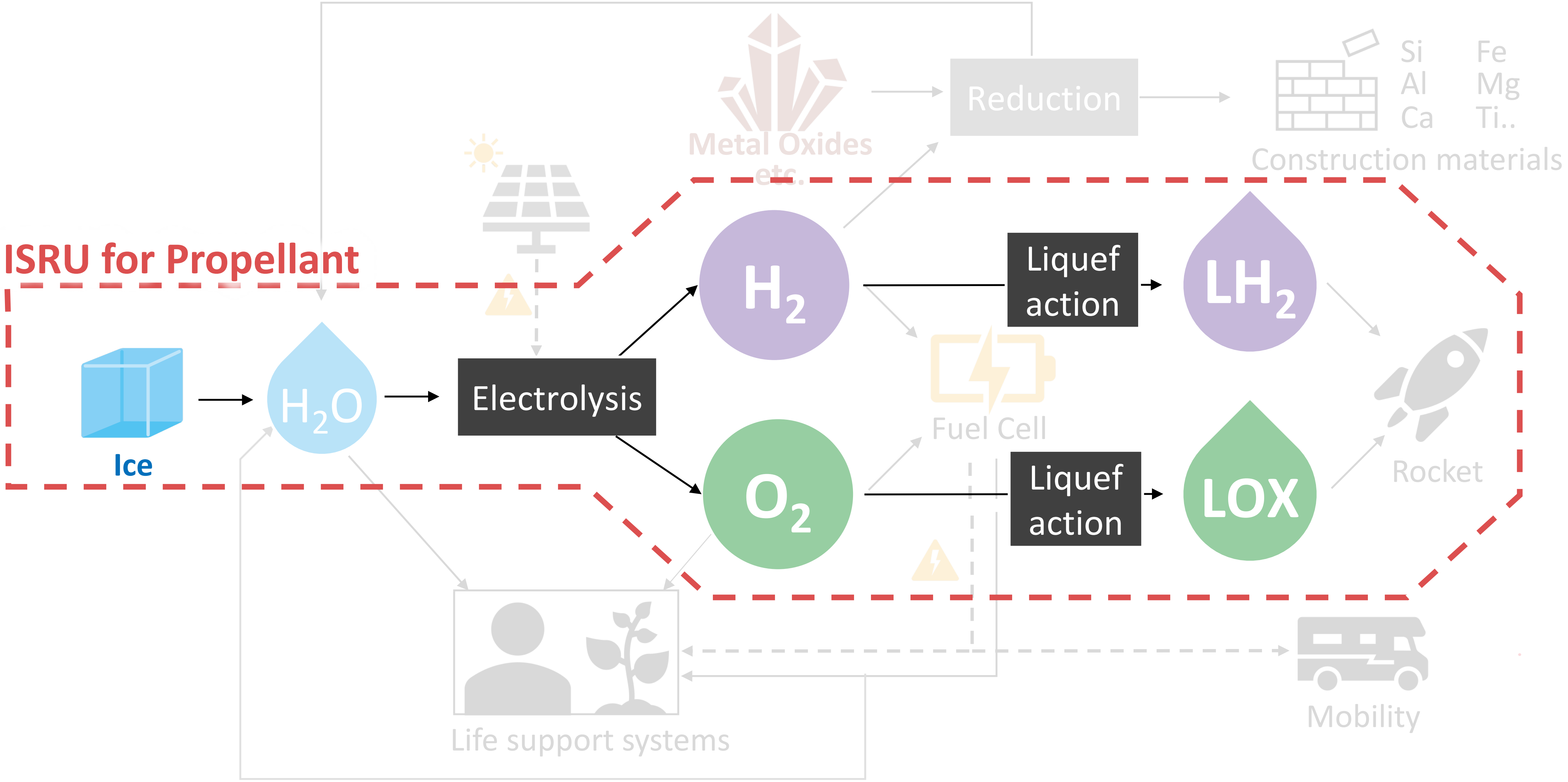
# Lunar Surface Scenario




*GER 2024 by ISECGより抜粋

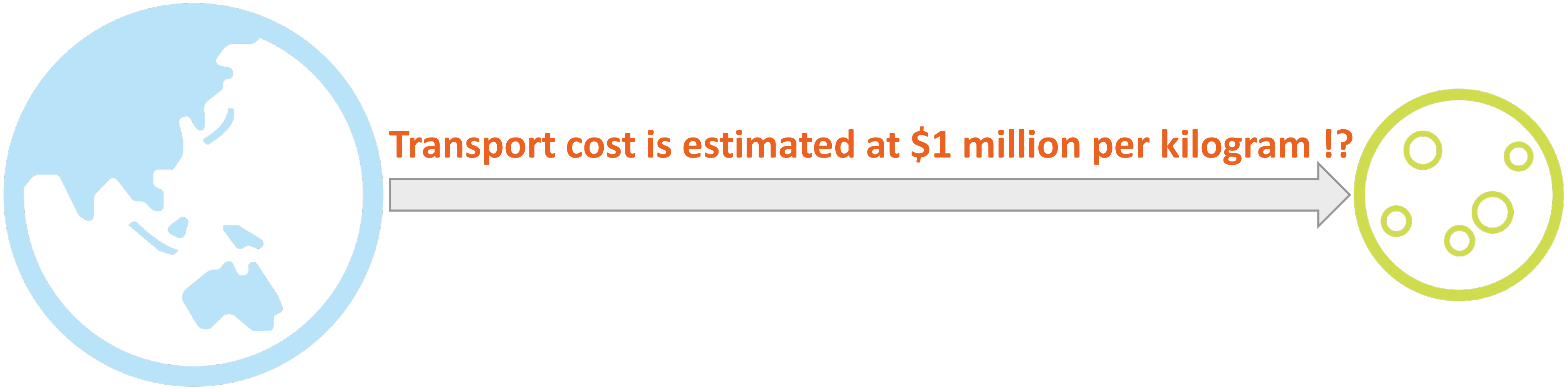

In-Situ Resources
In-Situ Resources
Metal/Silicate Oxides etc.
Reduction
Si Fe
Al Mg
Ca Ti..
Construction materials
Water Ice
H2O
Electrolysis
H2
O2
Liquefaction
LH2
Liquefaction
LOX
Fuel Cell
Rocket
Life support systems
Mobility


Metal Oxides etc.
Reduction
Si
Al
Ca
Fe
Mg
Ti..
Construction materials
ISRU for Propellant
Ice
$H_2O$
Electrolysis
$H_2$
$O_2$
Liquefaction
Liquefaction
$LH_2$
LOX
Fuel Cell
Rocket
Mobility
Life support systems

# Q. What are the Advantages of Producing Propellant on the Moon?

## Q. What are the Advantages of Producing Propellant on the Moon?

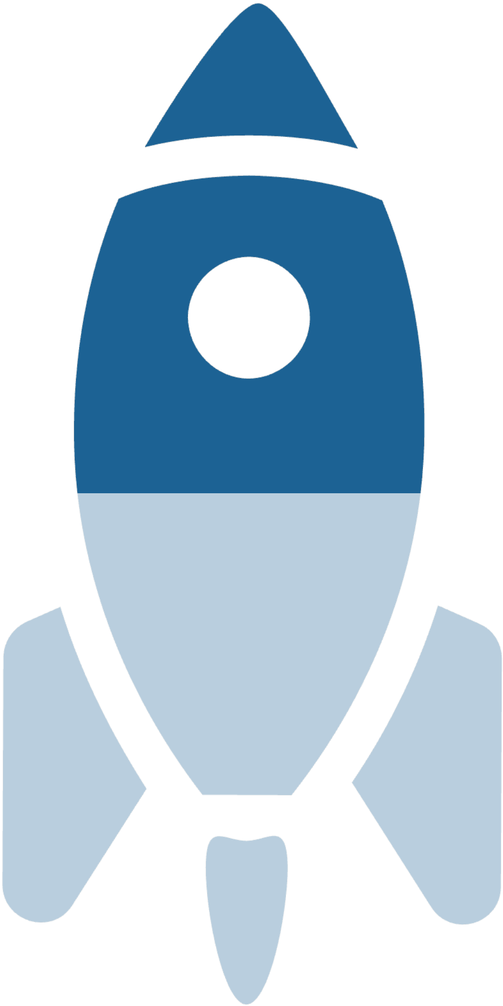
## A. Minimizing Payload Mass (Of Course!)



## What's Inside a Rocket Headed to the Moon...?

- **Astronauts**
- **Various equipment** (e.g., life support systems, scientific instruments for local exploration)
- **Food and oxygen**, among other essentials
- **Fuel, propulsion systems, and cargo space required to transport the above** (astronauts, equipment, food/oxygen)
- **Fuel for local surface operations** (=*1)
- **Fuel required for return** (i.e., to escape the Moon's gravity) (=*2)
- Includes **additional fuel to compensate for boil-off and losses of above *1 and *2, or re-liquefaction (cooling) systems** for vaporized propellants
- **Fuel, propulsion systems, and cargo space required to transport the above *1 and *2.**

## ISRU plant can reduce payload mass by more than the amount of propellant it produces.



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- ~~**Fuel, propulsion systems, and cargo space required to transport the above *1 and *2.**~~

# Q. What are the Advantages of Producing Propellant on the Moon?

## A. Is “Minimizing Payload Mass” the only benefit?

## Q. What are the Advantages of Producing Propellant on the Moon?

A1. Minimizing Payload Mass

A2. Technology Demonstration in preparation for Deep Space Exploration

## End-to-End Technology Demonstration for deep space exploration : From Launch to Operation

Launching → transporting through space → Landing and deploying → Extracting local resource → Operating

**The most accessible extraterrestrial object**

➕

**Ultra-high vacuum and extreme thermal conditions (Difficult on Earth)**
**Low gravity and high levels of cosmic radiation (Difficult on even though LEO)**

## Q. What are the Advantages of Producing Propellant on the Moon?

A1. Minimizing Payload Mass

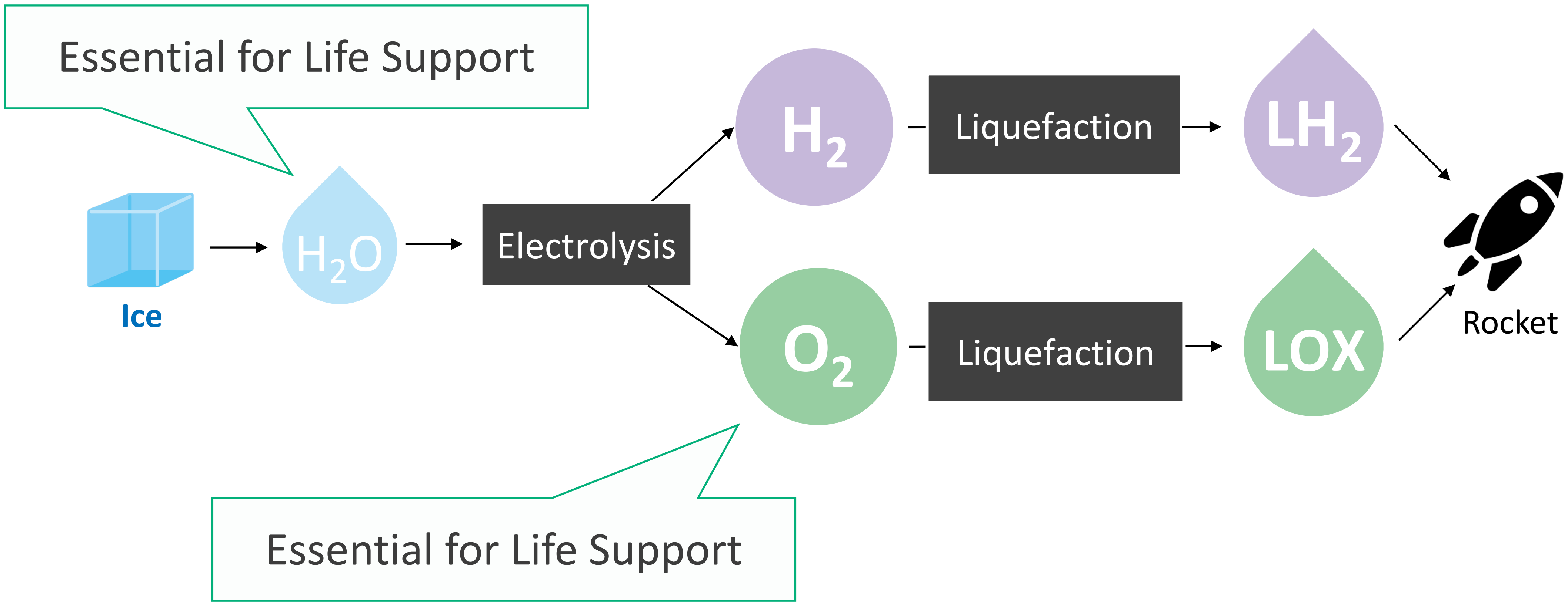
A2. Technology Demonstration in preparation for Deep Space Exploration

# Q. What are the Advantages of Producing Propellant on the Moon?

A1. Minimizing Payload Mass

A2. Technology Demonstration in preparation for Deep Space Exploration

A3. Risk Mitigation and Psychological Safety in Crewed Lunar Operations




A propellant production plant on the Moon **can enhance the psychological safety** of lunar explorers.

It also **increases the number of viable options** in the event of unexpected mission scenarios.

**This is a significant advantage that cannot be easily quantified in terms of cost.**

## Q. What are the Advantages of Producing Propellant on the Moon?

A1. Minimizing Payload Mass

A2. Technology Testbed for Deep Space Exploration

A3. Risk Mitigation and Psychological Safety in Crewed Lunar Operations

# Q. What are the Advantages of Producing Propellant on the Moon?

A1. Minimizing Payload Mass ← Today's Topic

A2. Technology Demonstration in preparation for Deep Space Exploration

A3. Risk Mitigation and Psychological Safety in Crewed Lunar Operations

## 2. Outline and preconditions for the study

Table. Major requirement of ISRU Plant

| Requirements | Setting | Note |
|---|---|---|
| Resource (Feed of plant) | Extracted ice from PSR | Note 1 |
| Water content | 1wt% | Note 2 |
| Product 1 (Production rate) | LH2 (8.3 ton/year) | Note 1 |
| Product 2 (Production rate) | LOX (49.3 ton/year) | Note 1 |
| Location of production facility | illuminated area at the edge of a PSR | Note 1 |

Note1. From the "JAXA(2022), *Japanese International Space Exploration Scenario 2021*".
Note2. : Assumptions made by the authors.
The range of 0.1wt% ~ 20wt% is considered in the Japanese International Space Exploration Scenario 2021.

## 2. Outline and preconditions for the study

- The term "**propellant production plant**" refers to the equipment responsible for extraction, purification, electrolysis, liquefaction, and storage—**in other words, the systems involved in production and storage.**
- Resource excavation and transportation are not considered part of the plant itself but rather fall under construction machinery.
- The assumed technical configuration for the production equipment is as follows.

Table. Assumed technical configuration for today.

| STEP | Assumption | Detail |
| --- | --- | --- |
| Extraction | Microwave | Enables efficient internal heating. |
| Electrolysis | PEM | Wide operating range, product purity, and no need for electrolyte or high-temperature heat sources. |
| $O_2$ Liquefaction | Radiator | It can be liquefied only with a radiator by taking advantage of the lunar environment. |
| $H_2$ Liquefaction | Radiator + Gas Refrigeration | The workload (equipment mass and power) of liquefied nitrogen in the ground equipment is replaced by that of the radiator. |
| Storage | CFRP Tank | On the ground, a two-layer (vacuum layer) type using stainless steel is commonly used, but for installation in the shade of the Moon, a one-layer + MRI type should be sufficient. The results are based on the "assumption" that CFRP or a similarly light material can be used for the material. |

## 3. Results 3.1 Estimation of mass and power consumption of production equipment

**Assumptions**

- The table below shows the approximate mass and power consumption of the device.
- The values are calculated based on the assumption that the system is operated continuously day and night for one year without a break.
- In subsequent studies, the number of operating days and operating hours will be changed.
  In such cases, a simplified approximation that mass and power are proportional to the required production capacity is performed.
  Example) If the annual operating rate is 80%, the required production capacity is 10/8 = 1.25 times. Accordingly, the equipment mass and power consumption are also 1.25 times those shown in Table 4.

Table . Equipment mass and power consumption for each step

| STEP | Mass [kg] | Power Consumption [kW] |
|---|---|---|
| Extraction | 210 | 75 |
| Electrolysis | 1,000 | 55 |
| $O_2$ Liquefaction | 1,000 | - |
| $H_2$ Liquefaction | 850 | 8 |
| Storage | 700 | - |
| Extraction | **3,760** | **138** |

The “total mass of the propellant is about 4 tons << annual supply of 57.6 tons of propellant”. On the other hand, what should be noted here is the power consumption. If we consider a power supply facility capable of stably supplying 138 kW of electricity throughout the year, it would be larger and heavier than the production facility.

**1. Power generation** **2. Overnight device** **3. Power transmission**

### 1st Choice : Power generation

| | |
|---|---|
| Solar | A realistic solution in the early stages of development. |
| Nuclear | Essential for large-scale development. |

### 2nd Choice : Overnight device (Only if solar is selected as power generation device)

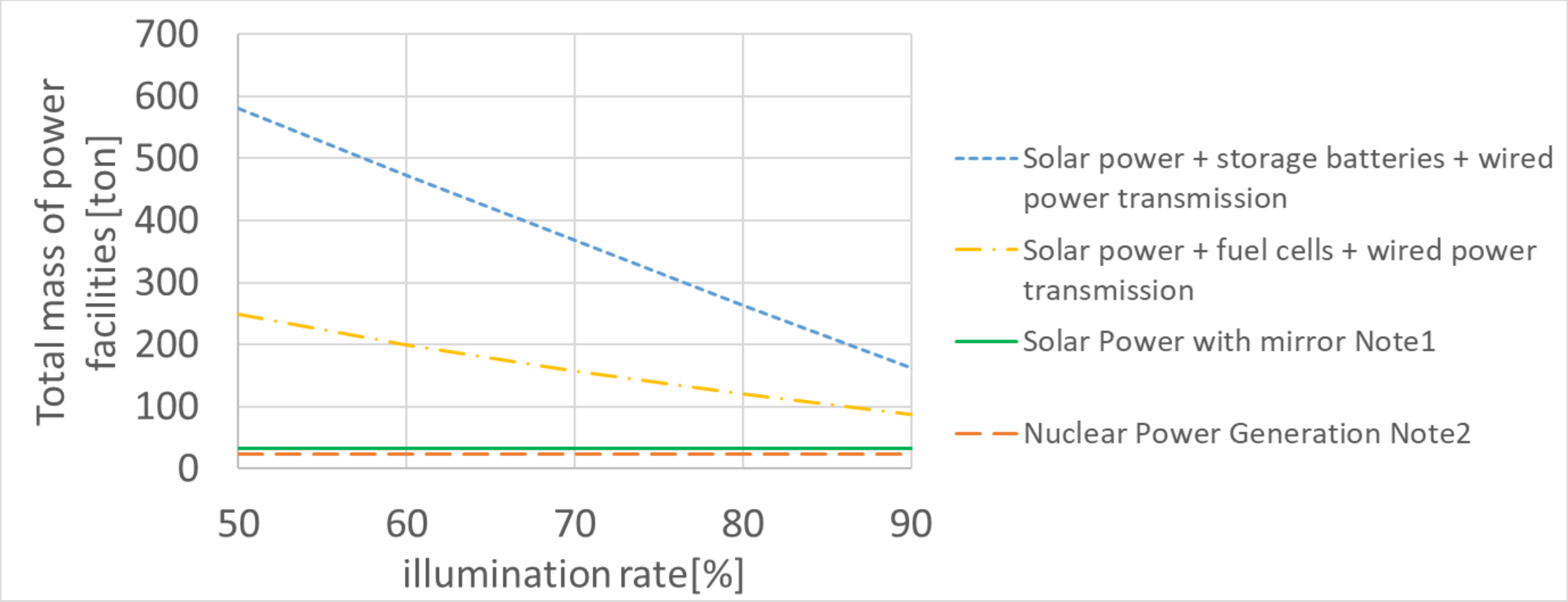
| | |
|---|---|
| Storage battery | Too heavy for mission completion especially for large scale development. |
| Fuel cells with electrolysis | Too heavy for mission completion especially for large scale development. |
| Light transmission by mirror | Can be a realistic solution in limited terrain conditions and distances. |

**1. Power generation** **2. Overnight device** **3. Power transmission**

### 3rd Choice : power transmission methods(Pros/Cons)

| | |
|---|---|
| Wireless transmission | Hope for the future. |
| Wire transmission | Practical in transmitting power between fixed locations. |
| Battery transport | As a means of supplying power to the mobile unit. |
| H2/O2 transport (by cartridge) | As a means of supplying power to the mobile unit. |
| H2/O2 transport (by Pipeline) | It's not realistic. (No advantage over wired power transmission found.) |
| Light transmission by mirror | Can be a realistic solution in limited terrain conditions and distances. |

# 3. Results 3.2 Estimation of mass of power supply facilities.




Note.1 This technology can be used only when mirrors are placed at two (or three or more) locations where day and night are reversed, and the panels can be placed in the line of sight from both locations. There are some locations in the vicinity of the poles in the Antarctic and Arctic regions that satisfy this condition.
Note.2 Installed in the vicinity of the user. The distance of 500m is tentatively set as the separation distance.

Fig. Total mass of power facilities (Continuous operation / 138 kW / Sum of power generation, overnight device and power transmission)

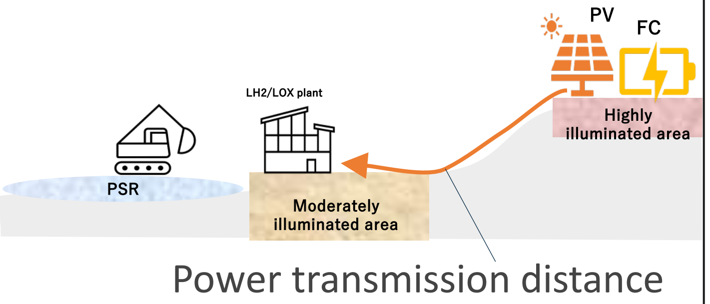
- When using photovoltaic power generation, we estimated 30 tons for a 138 kW power source when nighttime power is provided by mirrors, but 260 tons would be required when using storage batteries, even under favorable sunlight conditions of 80%. If fuel cells are used, it would be about 120 tons.
- If a nuclear power is available, it is estimated that a 138 kW power supply can be provided in about 23 tons (from NASA's Kilopower* project).
  *https://www.nasa.gov/wp-content/uploads/2017/12/kilopower_media_event_charts_16x9_final.pdf?emrc=e7cbc5

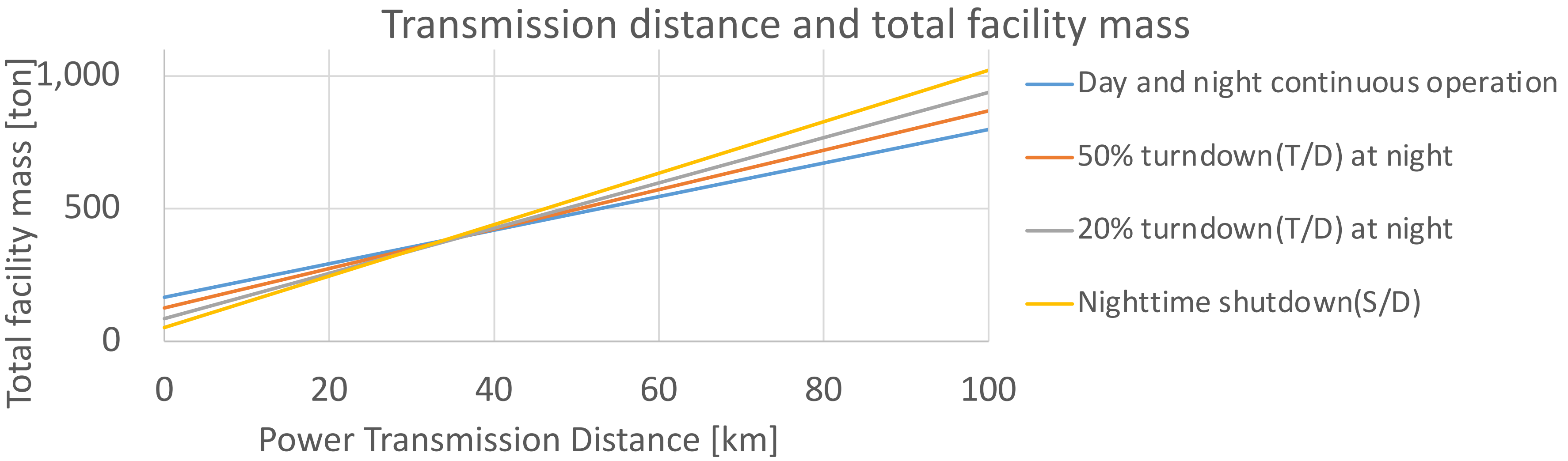
- **The cost-saving effect from reduced transport is : 540[ton] x 1,000 [kg/ton] x 1,000,000 USD/kg = $ 540 billion !!**
  - ✓ Total production over the facilities' lifespan : 57.6 ton/year x 10 years = 576 ton
  - ✓ Total mass of facility ≒ 30 ton(*).

    * Assuming continuous day-and-night operation, and power configuration is "Nuclear power" or "Solar panels + mirrors to provide sunlight during nighttime".
  - ✓ Payload Mass reduction > 576 ton – 30 ton = 540 tons (Considering boil-off gas during transport and the fuel and vehicle mass required to carry the above propellant, the actual reduction effect would be even greater.)
- While reducing the unit cost of transport should also be a goal, **even if transport costs are reduced to 1/100, the savings would still amount to $ 5.4 billion.**
- In practice, the mass and power consumption of rovers responsible for excavation and transporting regolith ice must also be considered. However, as long as their total does not exceed 540 tons, transport cost reduction can still be achieved.
- As a more "conservative" configuration that does not rely on mirrors or semi-permanent power sources, consider the following: solar power, wired power transmission, fuel cells, 60% sunlight availability, and a 10 km transmission distance. Even under continuous day-and-night operation, the total mass of the power supply system would be 240 tons. This still results in a transport volume reduction of nearly 300 tons.

**Assumption of this example**

- illumination Rate = 50%
- PV x wired transmission x Fuel Cell




Total facility mass includes:

- ISRU plant except excavation step **
- Solar Power Generation*
- Fuel Cell Systems for Overnight Use*
- Power transmission line (approximated by aluminum conductors)*, **

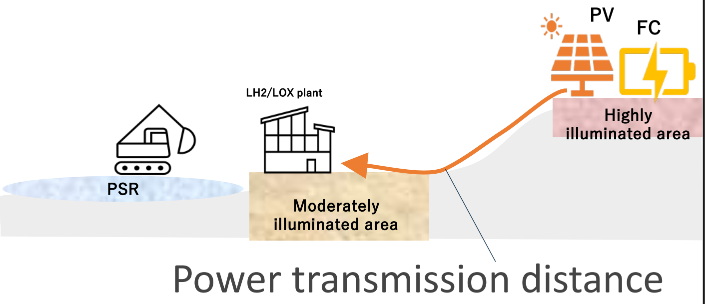
* Mass depends on transmission distance and amount of transmission loss. (Heavier as transmission distance increases.)
** Mass and Rated electric power increases due to nighttime shutdowns. (Heavier as nighttime S/D, T/D.)

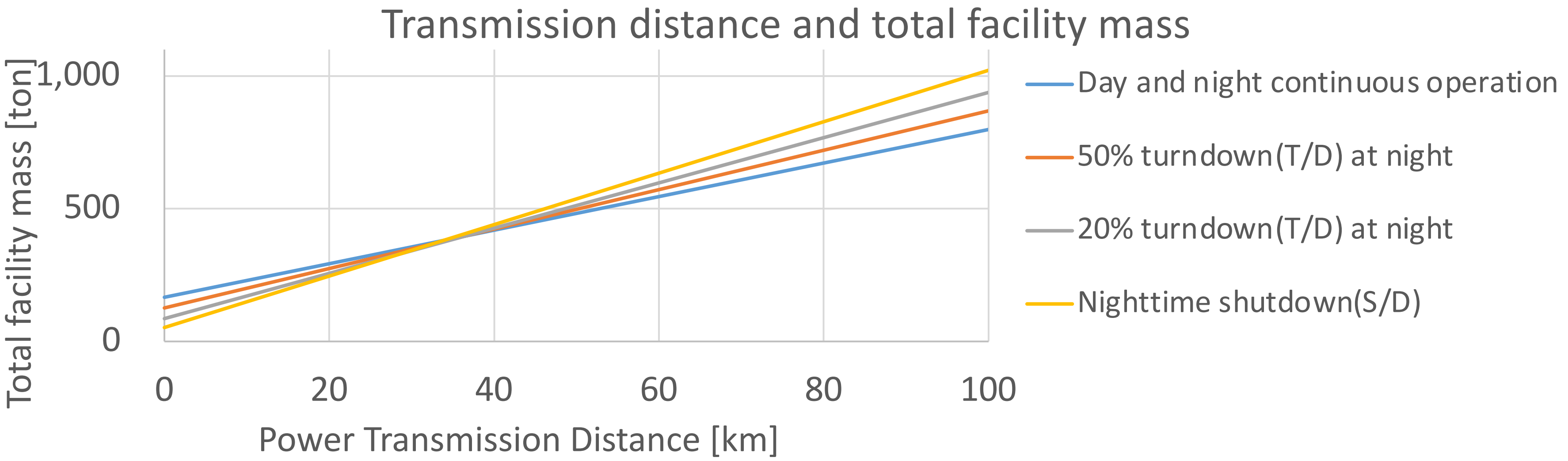
Interpretation of Results

- When transmission distance is SMALL： Mass of fuel cell system is dominant.
  → Nighttime S/D with tiny fuel cell system is optimum option.
- When transmission distance is LARGE : Mass of power transmission line will be dominant.
  → Continuous day/night operation with smaller wiring(=small rated power of ISRU plant) is optimum.

**Assumption of this study**

- illumination Rate = 50%
- PV x wired transmission x Fuel Cell




The above results will differ under the following conditions：

- Increasing or decreasing the illumination rate.
- Nuclear power is used.
- PV panels are installed beside the ISRU plant and sunlight is mirrored from daylight area.

<u>Not only the optimization of operation scenarios, but also the technology selection of each steps will differ under different assumption. Therefore, to enable an apples-to-apples comparison of ISRU facilities, it is essential to establish a common set of assumptions regarding the energy plan and land use plan.</u>

# 4. Conclusion

- Power systems are the main contributor to the plant’s total equipment mass.
- ISRU plant can reduce transport costs by $540B.
- Even after development and manufacturing costs, the investment may still be profitable.
- Benefits go beyond cost： supports deep space tech validation and crew psychological safety.
- Accurate cost-benefit analysis requires：
  - ✓ Evaluation of mining equipment (mass, power, operations)
  - ✓ Detailed resource data by sample analysis.
  - ✓ Internationally coordinated architecture of power generation and land use plan.

# Reference

# 2. Conceptual Study of the Lunar ISRU Plant

Feasibility study of a ISRU plant based on the “total mass” of production and power supply equipment.

- Essentially, everything is converted to mass information, and we assess it based on mass.
  - ✓ Our modeling is Excel-based estimation.
  - ✓ Set performance values(≒ Production Rate, PR) for each device.
    Ex) Extraction and electrolysis have a performance value of ‘kg-water/hour’.
  - ✓ Set mass coefficients[kg/PR] and power consumption coefficients[kW/PR] for each device.
  - ✓ Regarding power facilities, we only set the mass coefficient.
    (PR of power generation is kW, overnight facilities is kWh, and Power transmission is kW x km*.
    * only for the case of Wired Power Transmission.)
  - ✓ The power consumption coefficient for each device is converted to mass using the mass coefficient of the power facilities.
  - ✓ Calculate the total device mass based on the required performance.

**Valuation Basis = Total Mass of Mission = Device mass of LH2/LOX plant + Facility mass of power facility**

Performance(Production rate) x mass coefficients of plant → (Device mass of LH2/LOX plant)

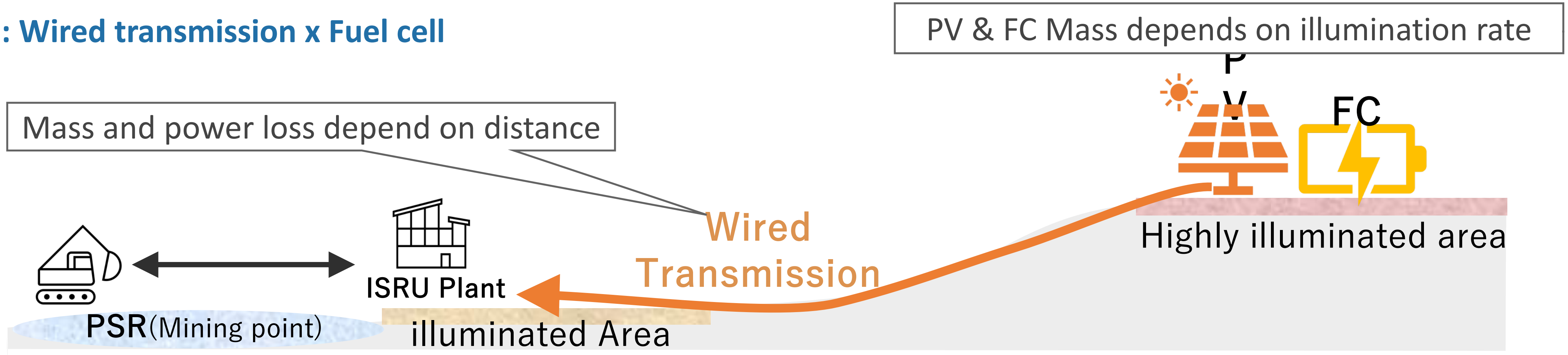
Performance(Production rate) x power consumption coefficients of plant x mass coefficients of power facilities → (Facility mass of power facility)

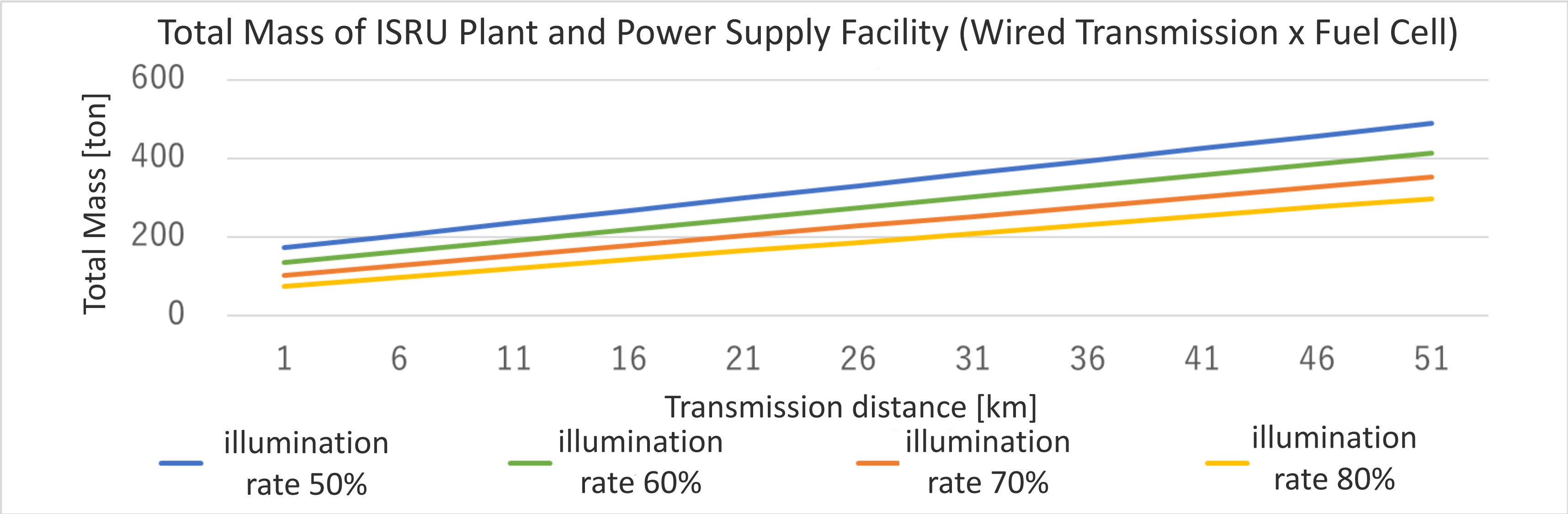
# 2. Conceptual Study of the Lunar ISRU Plant

Feasibility study of a ISRU plant based on the “total mass” of production and power supply equipment.

Ex) Total mass study based on power supply plan (transmission method x overnight method)

## Case A : Wired transmission x Fuel cell



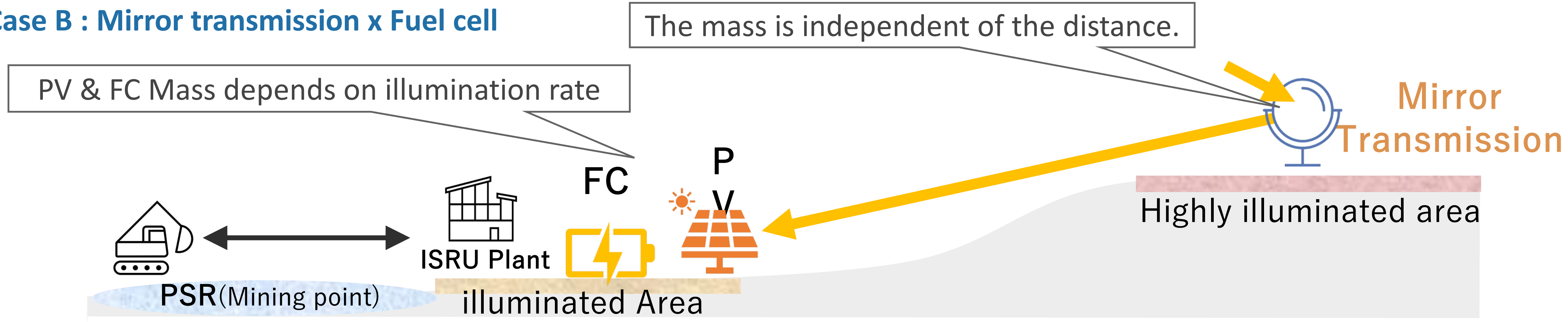



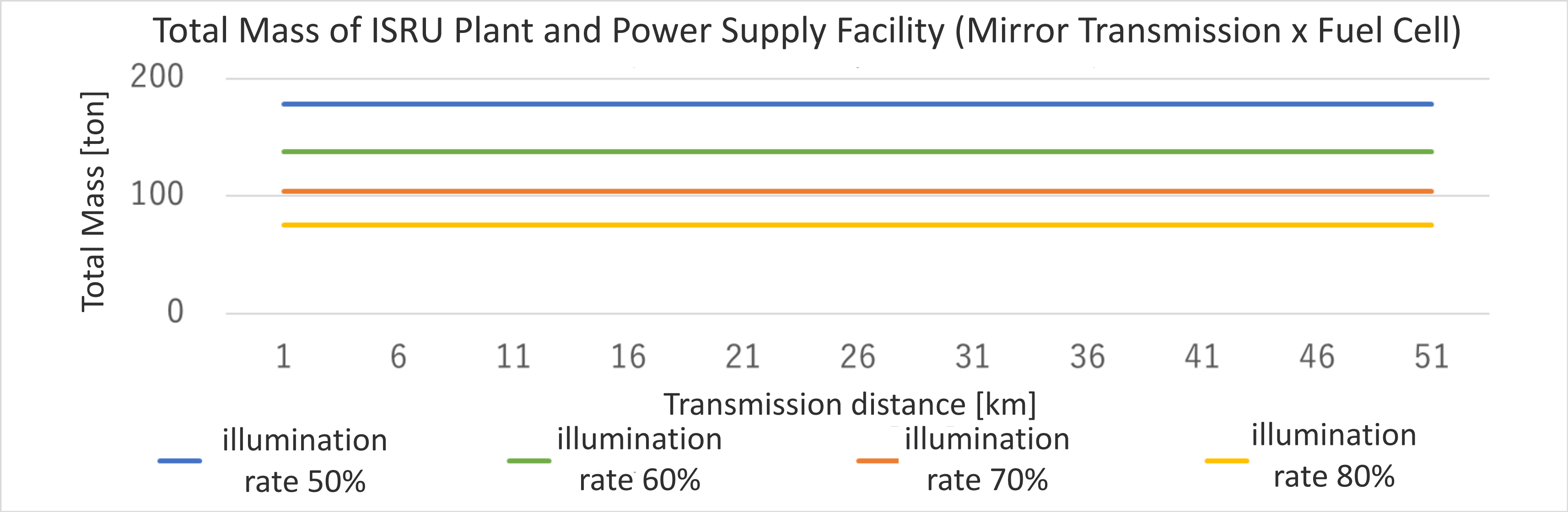
# 2. Conceptual Study of the Lunar ISRU Plant

Feasibility study of a ISRU plant based on the “total mass” of production and power supply equipment.

Ex) Total mass study based on power supply plan (transmission method x overnight method)

### Case B : Mirror transmission x Fuel cell



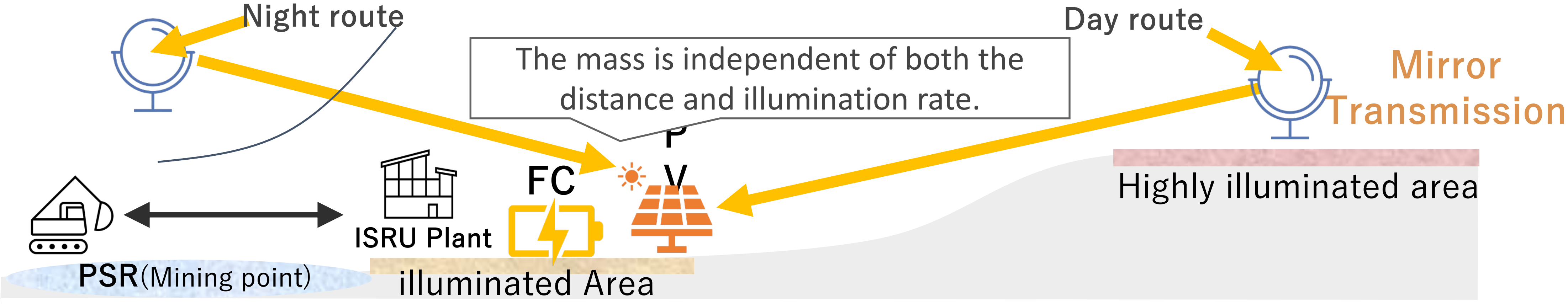



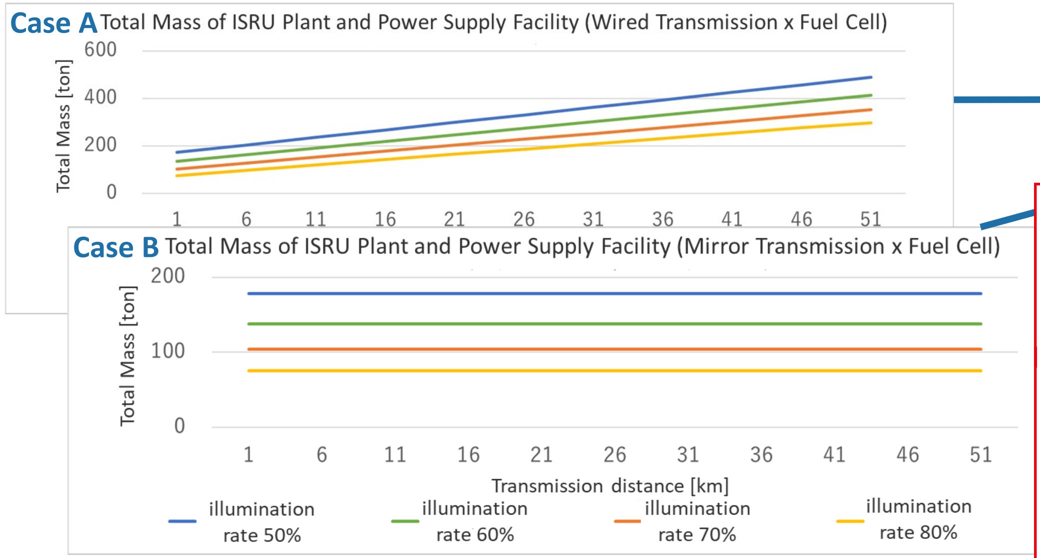
# Conceptual Study of the Lunar ISRU Plant

Feasibility study of a ISRU plant based on the “total mass” of production and power supply equipment.

Ex) Total mass study based on power supply plan (transmission method x overnight method)

## Case C : Mirror transmission x Mirror transmission




29 tons regardless of distance or sunlight ratio.

- If we can't set a high illumination area near the resource excavation point, mirrors are an effective card. They also contribute greatly to weight reduction.
- However, the use of mirrors is greatly limited by the terrain, and the range of materials that can be transported is greatly increased.
- Selection of the land is the key, whichever wired transmission and mirror.
- Only with PV, Unless we use a unique idea like a mirror, it's difficult to reduce the mass of the equipment to a realistic level.