FEASIBILITY STUDY OF LUNAR ISRU PLANTS BY JAPANESE PLANT ENGINEERING COMPANY.

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Introduction: The JGC Group is an EPC (engineering, procurement and construction) contractor that has carried out 20,000 projects in more than 80 countries around the world, including extremely harsh environments such as deserts, permafrost, jungles and so on. JGC is currently challenging that expands its activities to the moon and aims to develop a lunar In-Situ Resource Utilization (ISRU) plant. In this paper, we will discuss the feasibility and values of a lunar ISRU plant based on the experience gained through many plant EPC projects. In this paper, we report the result of feasibility study for lunar ISRU plant based on transportation mass including power supply facility. This work was performed in cooperation with Japan Aerospace Exploration Agency (JAXA).

Background: The GER (Global Exploration Roadmap) [1] of the ISECG suggests an annual lunar exploration program from the end of the 2020s to the 2030s. On the other hand, the transportation fee to the Moon is generally estimated to be around $1M/kg, and the compaction of transport mass is an important issue for realizing frequent manned traffic between the Moon and the Earth. A typical solution is ISRU (In-Situ Resource Utilization), i.e. the utilization of local resources, and the letters ISRU can be seen in the aforementioned GER. Typical examples of resources available on the Moon are metal oxide (regolith) and ice, but this paper focuses on the economic feasibility study of 'propellant (liquid hydrogen and liquid oxygen) production from ice resources', which is mentioned in the GER and Japanese International Space Exploration Scenario 2021 [2].

Target facility and capacity: Lunar ISRU plant that we targeted in our research is the production facility of liquefied hydrogen and oxygen as rocket fuel using the ice resources of the lunar Permanently Shadowed Region (PSR). Referring to the Japanese International Space Exploration Scenario 2021 [2], the annual production capacity is set at 49.3 tons/year for LOX and 8.3 tons/year for LH2. Throughout the study, the water content of the ice resource was assumed to be 1 wt%.

Evaluation basis and scope: Our feasibility study began with the premise that transportation costs determine the economics of a mission. Next, we divided the facilities into two main categories. The first is production facilities, which are a group of devices that cover the entire process of resource mining, extraction, water purification, electrolysis, liquefaction and storage. The second is power supply facilities, which are a group of devices that cover power generation, device for overnight demand (overnight device) and power transmission. Overnight device includes not only power storage devices such as batteries and fuel cells, but also methods such as transporting sunlight from sunny areas. Of course, if the power generation method is nuclear power, overnight device will not be necessary.

Study procedure: First, coefficients are set for each device in the production equipment that shows the relationship between production capacity and equipment mass and power consumption. This coefficient was determined by referring to commercial facility in the industrial field, NASA's Life Support Baseline Values and Assumptions Document [3] and so on. Based on this coefficient, we calculated the total mass of the production equipment and the power consumption. Next, we calculated the mass of the power supply equipment needed to cover the relevant power consumption.

Variables for case study: The following parameters were set as variables for case studies. A: Solar radiation rate. B: Power generation method. C: Transmission distance when using solar power. D: Type of overnight device. E: Whether or not there is nighttime operation.

Results: Table 1 shows the approximate values for the device mass and power consumption. The values were calculated on the assumption that the device would operate continuously day and night for a year without any breaks. In subsequent investigations, the number of operating days and hours will be changed, but in that case, a simple approximation will be used, in which the mass and power consumption will be proportional to the required production capacity. For example, if the annual operating hours are 80%, the required production capacity will be 10/8 = 1.25 times, so the device mass and power consumption will also be 1.25 times the values in Table 1.

Table 1. Device mass and power consumption

STEP	Mass [kg]	Power consumption [kW]
Extraction	210	75
Electrolysis	1,000	55
Liquefaction(O_2)	1,000	-
Liquefaction(H_2)	850	8
Storage	700	-
Total	**3,760**	**138**

Basically, values are set to be similar to the mass and power of the ground equipment, but the values for liquefaction are set to be significantly different from the ground equipment. For the oxygen liquefaction, we assumed that it would be liquefied in a radiator, and estimated the necessary area, and then estimated the mass using the mass coefficient described in the Life Support Baseline Values and Assumptions Document (2022, NASA)[3]. For the hydrogen liquefaction device, while we referred to the nominal gas refrigeration device on the ground, the design was to replace the liquid nitrogen system with a radiator, so the power consumption is small compared to that on the ground.

The total mass is around 4 tons, which is much smaller than the annual supply of propellant, which is 57.6 tons. However, what is important here is the power consumption. If we consider a power supply facility that can stably supply 138 kW of power throughout the year, it will be larger and heavier than the production facility.

The options for power generation are solar power or nuclear power sources. In the case of solar power, power can only be generated during the day, so the issue is how to secure power at night. The main candidates are storage batteries such as lithium-ion batteries and solid-state batteries, fuel cells that store power in the form of hydrogen and oxygen, and light transport, which uses mirrors to transport sunlight from distant sunny areas. This paper introduces the results of quantitative evaluations of storage batteries and sunlight transport by mirror. Next, we will explain the means of transporting energy. Wired power transmission is currently the most reliable and feasible technology. Wireless power transmission is a method that is attracting a lot of attention for use on the moon, but its TRL is low and the accuracy of the estimation of the mass of the equipment is also very low (and so it is excluded from the quantitative evaluation results introduced in this paper). Sunlight transmission by mirror cannot be used on the earth because of the attenuation, scattering and refraction of sunlight by the atmosphere, but it is a convenient method to use on the moon, where there is almost no atmosphere. However, since its availability depends on topographical conditions, it is also a method that is limited in terms of the locations where it can be used.

Figure 1 shows the mass of power generation facilities according to the illumination rate. The mass of facilities here refers to the mass of power generation facilities, overnight device, and energy transport facilities (assuming 5 km for wired power transmission in the case of solar power generation and 0.5 km for nuclear power sources) that supply the power consumption of production facilities (138 kW) 24 hours a day, 365 days a year. The Capacity of the power generation equipment also takes into account the charging of storage batteries and transmission losses. The mass of the nuclear power source is based on NASA's Kilopower project [4], and assumes that the required number of 10 kW-class nuclear power sources are lined up.

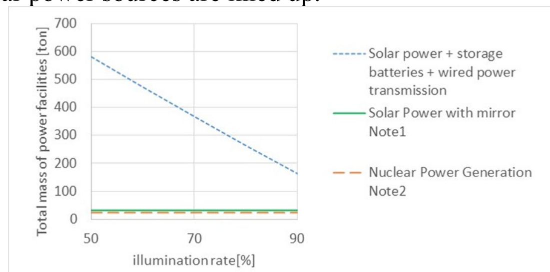

Figure 1. Total mass of power facilities

Note 1: This technology can only be used if a mirror is installed at two locations (or three or more locations) where day and night are reversed, and a panel can be installed in a position where the line of sight passes through from both sides. There are locations that meet the conditions only near the South Pole and North Pole. Note 2: Installed near the user. A separation distance of 500 m is assumed.

In power supply facilities based on solar power generation, majority of the mass is accounted for by storage batteries for overnight device. In the case of using mirrors to supply night-time power, 138 kW power supply was estimated to require 33 tons, but in the case of using storage batteries, even under favorable conditions with a sunshine rate of 80%, 263 tons would be required. Furthermore, in the case of being able to use a nuclear power supply, the calculation is that 138 kW power supply can be prepared for around 23 tons. At the presentation, we also show the result of case study for transmission distance, whether or not there is nighttime operation and so on. It was found that in order to economically operate an ISRU plant in a practical scale, it is necessary to use “nuclear power” or “solar power generation with unconventional devices such as mirrors”. In addition, the necessity of nighttime operation during solar power generation is determined by the length of the transmission distance.

References: [1] ISECG (2024) *Global Exploration Roadmap (GER) 2024*. [2] JAXA (2022) *Japanese International Space Exploration Scenario 2021*. [3] NASA (2022) *Life Support Baseline Values and Assumptions Docu-ment*. [4] NASA (2018) *Welcome to the Kilopwer Press Conference*.