R&D for Construction on the Moon

Yoji Ishikawa
Obayashi Corporation

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Space-related Activities

R&D for the Moon and Mars

Current Topics

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Current Topics

Obayashi Corporation

One of the Largest Construction Companies in Japan

- ✓Establishment: 1892
- ✓Number of employees: 15,876
- ✓Overseas offices: 14 Offices
- ✓Net Sales: 20 billion USD (FY2022)

Projects in Japan

TOKYO SKYTREE®

Tokyo Central Station

Kansai International Airport

Overseas Projects

Hoover Dam Bypass Project
- Colorado River Bridge

Stadium Australia

San Francisco General Hospital

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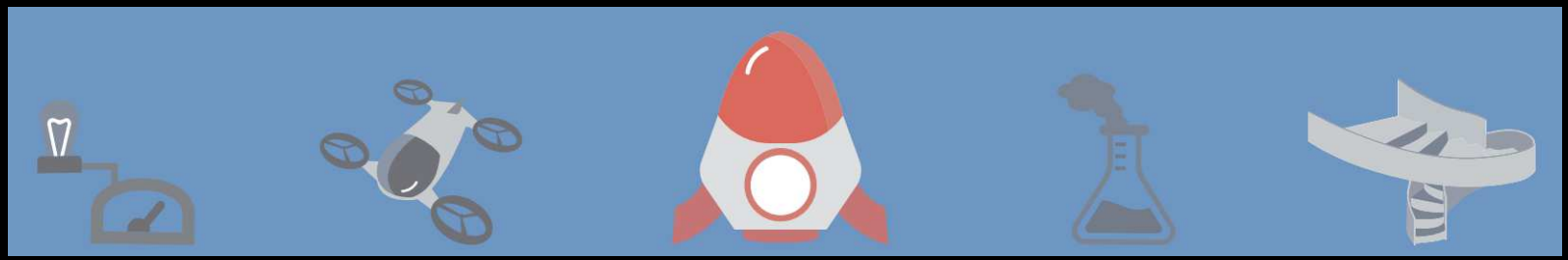
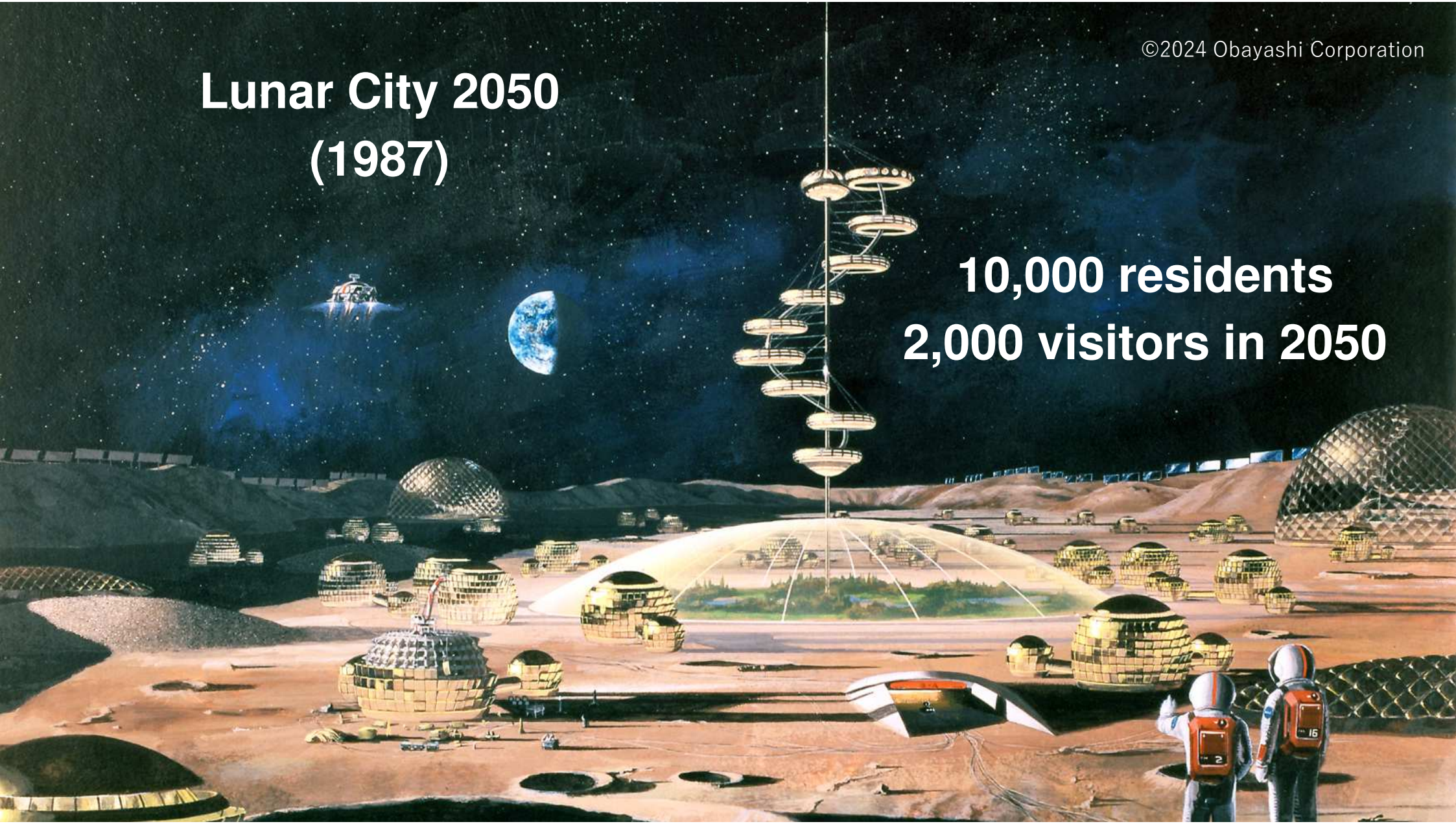
Current Topics

Obayashi Future Lab

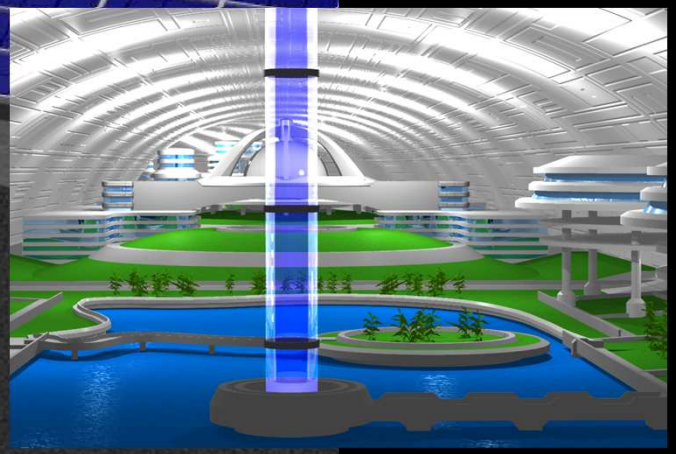
- ✓ **Space**, biotech, energy, mobility, and advanced construction
- ✓ Long-term future business seeds
- ✓ Open innovation

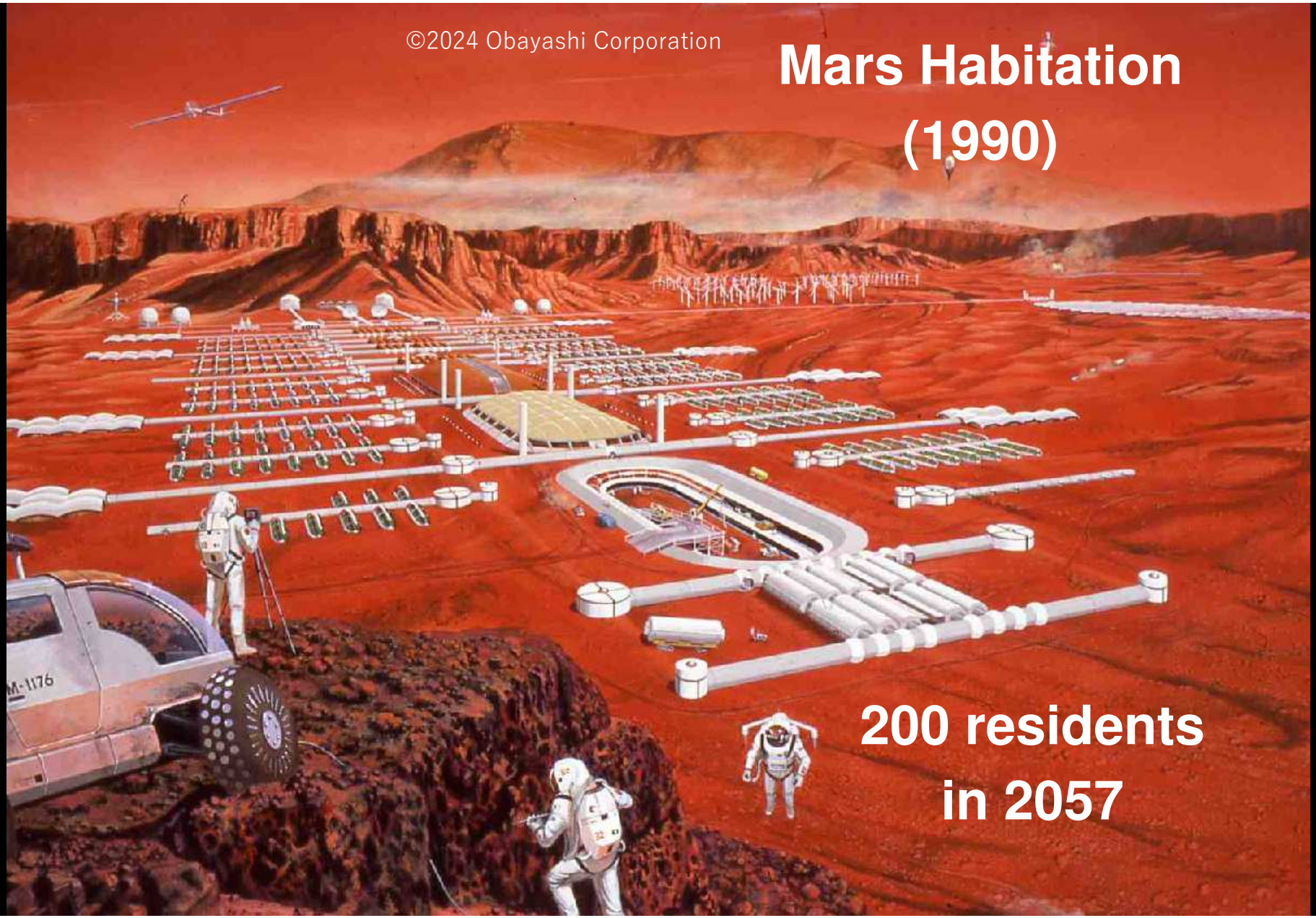


Energy　Mobility　**Space**　Biotech　Advanced construction


Lunar City 2050
(1987)
©2024 Obayashi Corporation
10,000 residents
2,000 visitors in 2050

New Lunar City in Lava Tube (2021)




©2024 Obayashi Corporation
Mars Habitation
(1990)
200 residents
in 2057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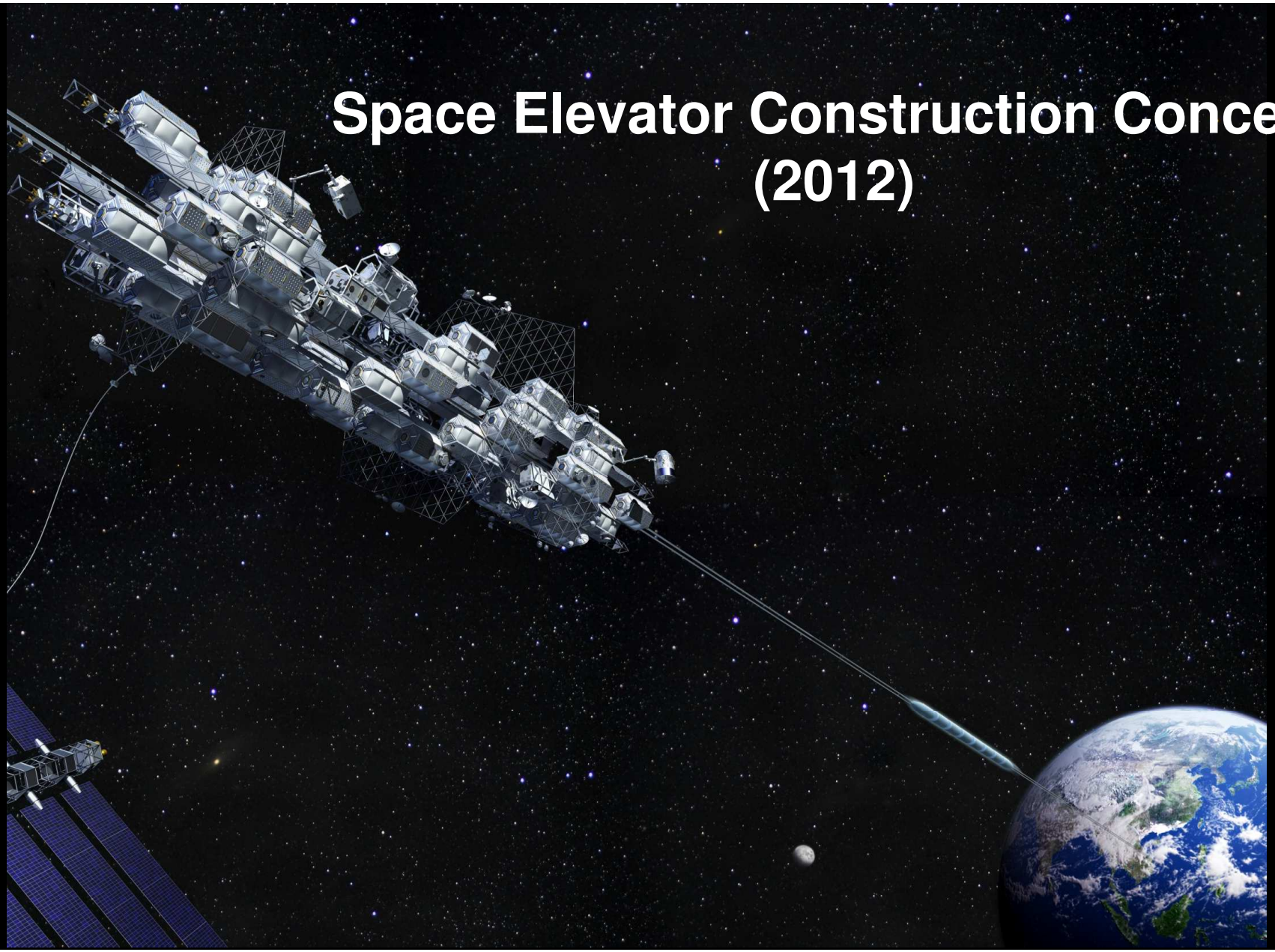
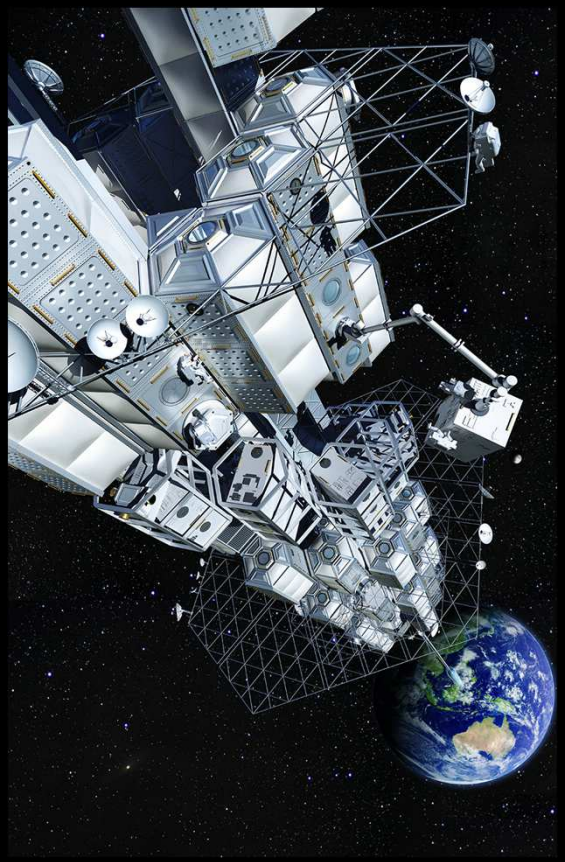
Space Station in Lagrange Point
(1996)
Located in L1 between the Earth and the Moon


Space Elevator Construction Concept
(2012)

Obayashi's Space – Main Themes

- ✓ Go to space
- ✓ Live in space
- ✓ Use the space

Go to Space



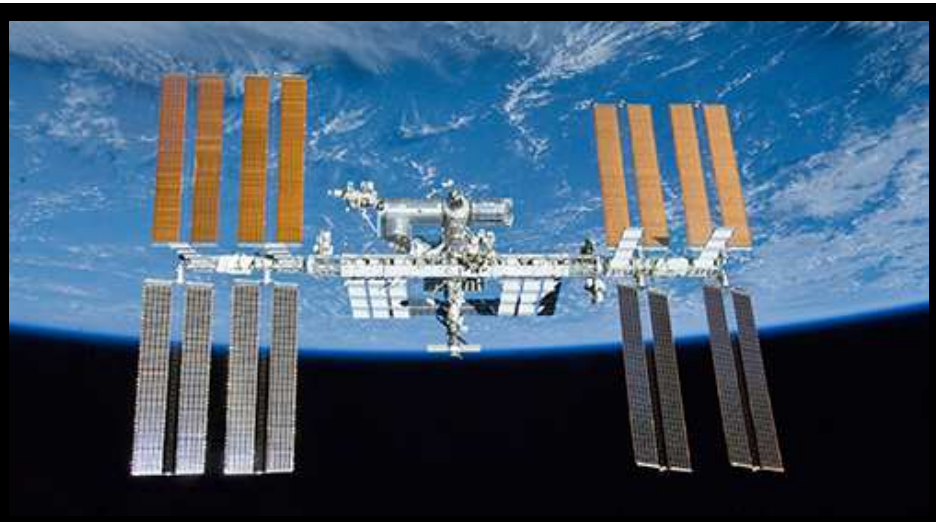
Space elevator

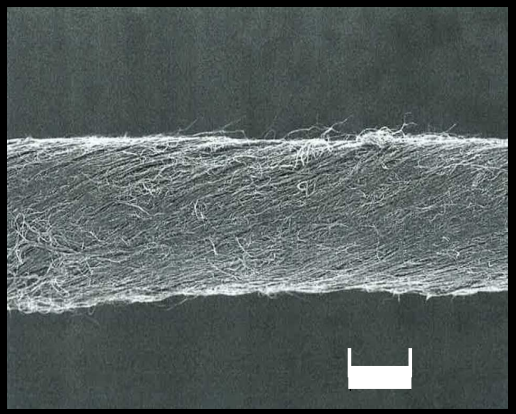
Airborne rocket launch

Sea launch

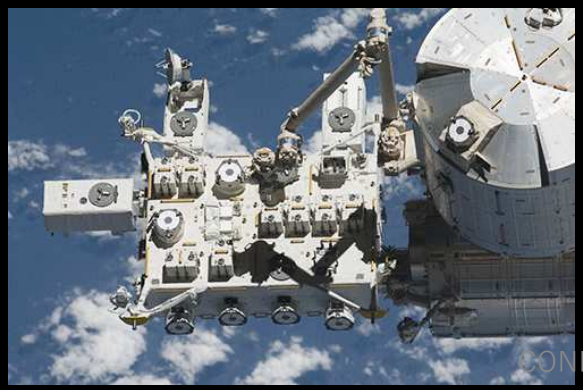
Go to Space – Space Elevator

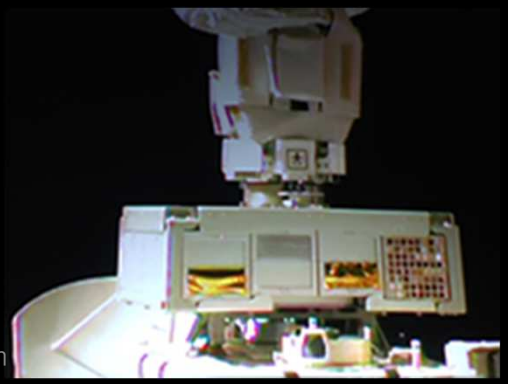
- ✓ New material space exposure test on the International Space Station
- ✓ Development of climber (vehicle)
- ✓ Effect of lightning





- Carbon Nanotube Space Environment Exposure Experiment
- International Space Station Japanese Module “Kibo” Exposed Facility
- Starting May 2015 (Duration 1 and 2 yrs)





Space Elevator Challenge, Japan Space Elevator Association

Cable Dynamics of Space Elevator

$$m_i \frac{d^2 \boldsymbol{r}_i}{dt^2} = -2 m_i \boldsymbol{\Omega} \times \frac{d \boldsymbol{r}_i}{dt} + m_i (\boldsymbol{\Omega} \cdot \boldsymbol{\Omega}) \boldsymbol{r}_i - m_i (\boldsymbol{\Omega} \cdot \boldsymbol{r}_i) \boldsymbol{\Omega}$$

Coriolis Force　　Centrifugal Force

$$- GM_e m_i \frac{\boldsymbol{r}_i}{|\boldsymbol{r}_i|^3} - GM_{moon} m_i \frac{\boldsymbol{r}_i - \boldsymbol{r}_{moon}}{|\boldsymbol{r}_i - \boldsymbol{r}_{moon}|^3} - GM_{sun} m_i \frac{\boldsymbol{r}_i - \boldsymbol{r}_{sun}}{|\boldsymbol{r}_i - \boldsymbol{r}_{sun}|^3}$$

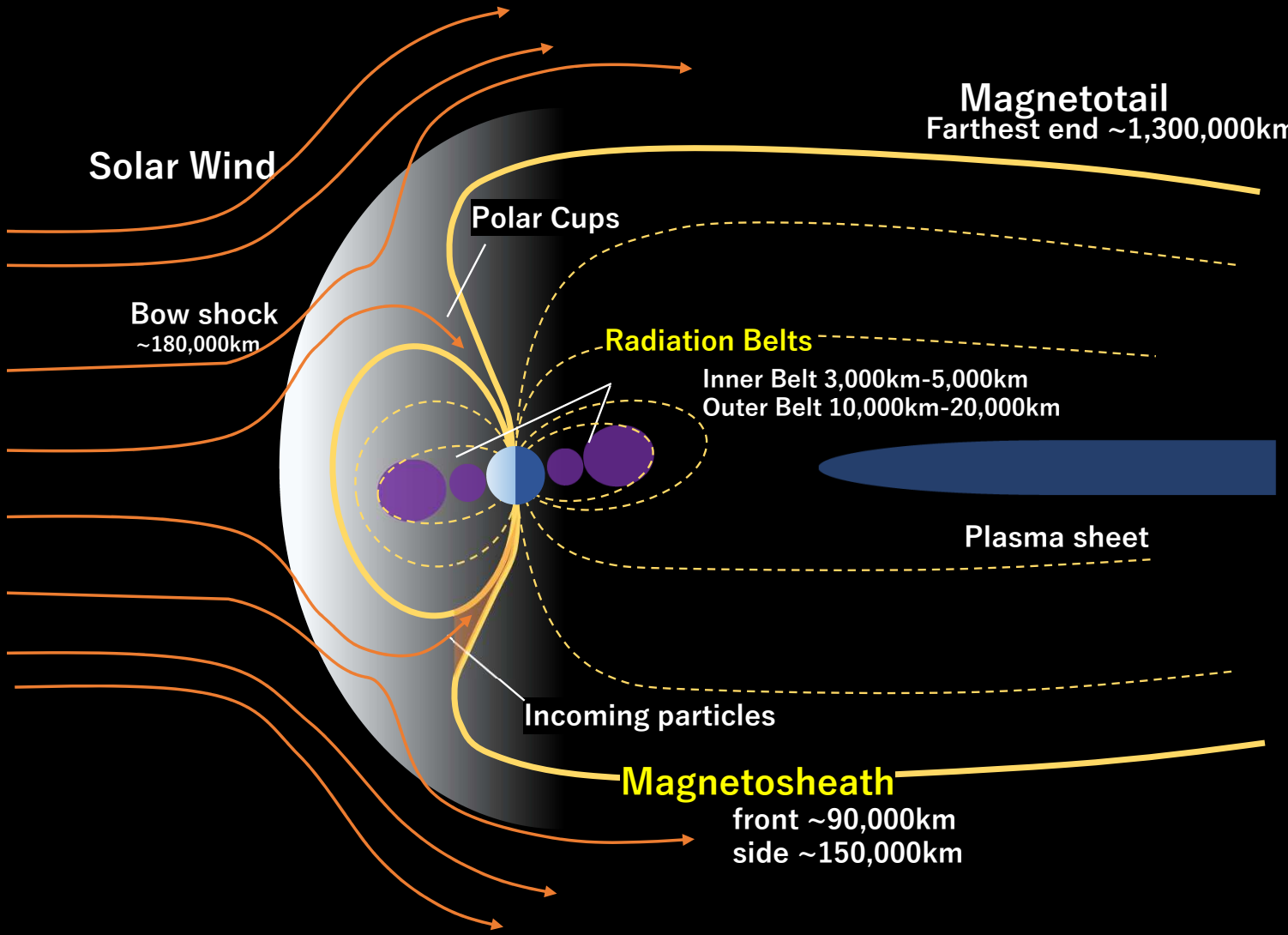
Earth Gravity　　Moon Gravity　　Sun Gravity

$$- k_{i,i+1} \frac{\boldsymbol{r}_{i+1} - \boldsymbol{r}_i}{|\boldsymbol{r}_{i+1} - \boldsymbol{r}_i|} \Delta |\boldsymbol{r}_{i+1} - \boldsymbol{r}_i| + k_{i,i-1} \frac{\boldsymbol{r}_i - \boldsymbol{r}_{i-1}}{|\boldsymbol{r}_i - \boldsymbol{r}_{i-1}|} \Delta |\boldsymbol{r}_i - \boldsymbol{r}_{i-1}|$$ Elasticity

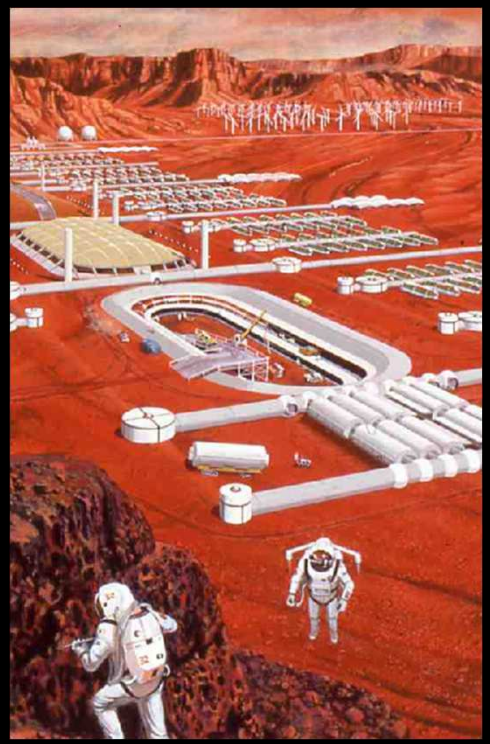
$$- \rho_{air} C_D A \left| \frac{d \boldsymbol{r}_i}{dt} - \boldsymbol{U}_{air} \right| \left(\frac{d \boldsymbol{r}_i}{dt} - \boldsymbol{U}_{air} \right)$$ Air Resistance of Wind

$$+ \boldsymbol{F}_{other}$$ Load of Climbers

■Space Environments



Live in Space

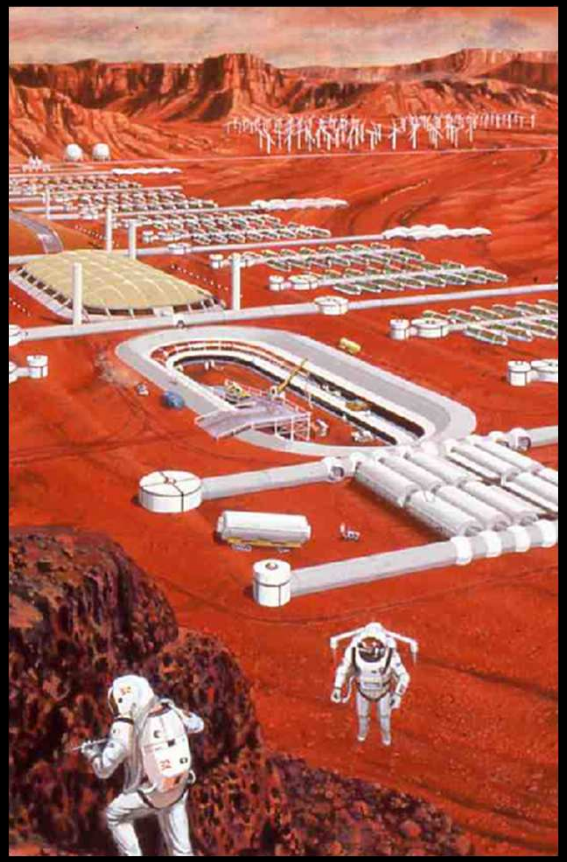


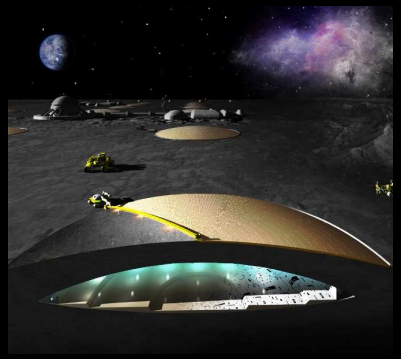
Lunar & Martian bases

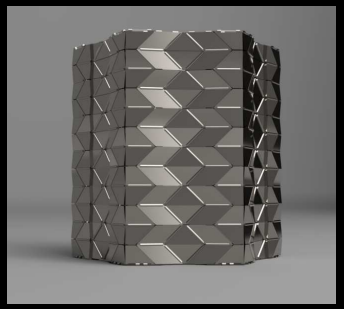
Compact agriculture

Robotic construction

Live in Space – Material and structure







- ✓ **Construction material manufacturing from local regolith simulant**
- ✓ **Inflatable structure**
- ✓ **Unfolding “Origami” structure**

Use the Space

- ✓ **Automatic & remote-control operation of construction machine using GNSS (global navigation satellite system)**
- ✓ **Automatic transportation of concrete at a dam site**
- ✓ **Survey and ground deformation monitoring**

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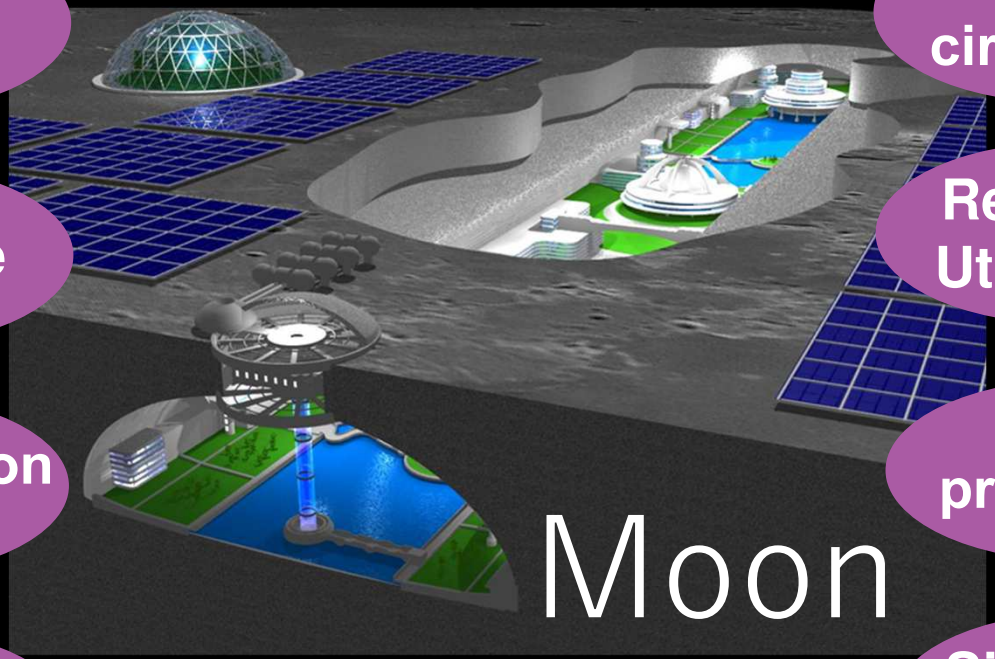
R&D Subjects for the Moon

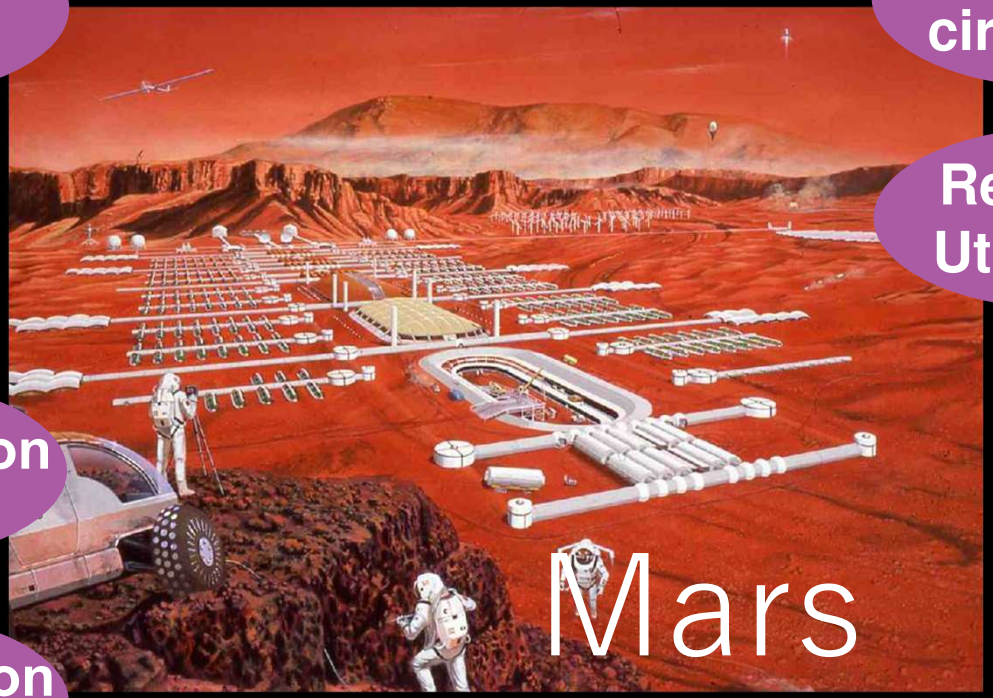


- Concept
- Structure
- Construction material
- Construction method
- Resource circulation
- Resource Utilization
- Food production
- Simulated facility

R&D Subjects for Mars

Concept

Resource circulation



Resource Utilization

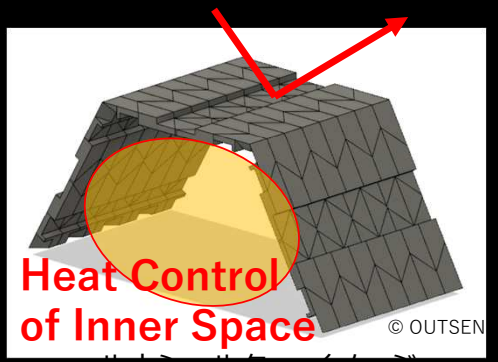
Construction material

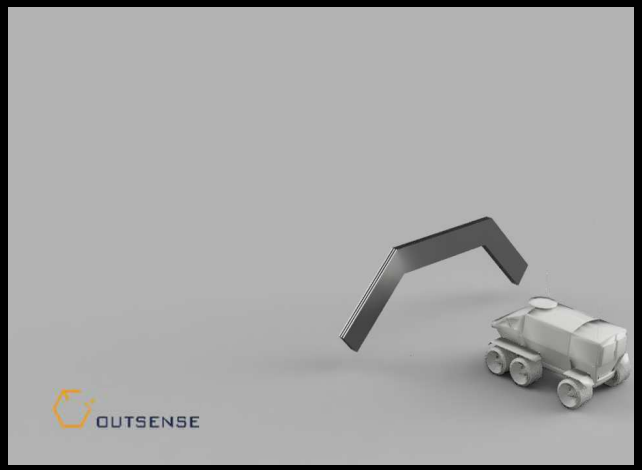
Construction method

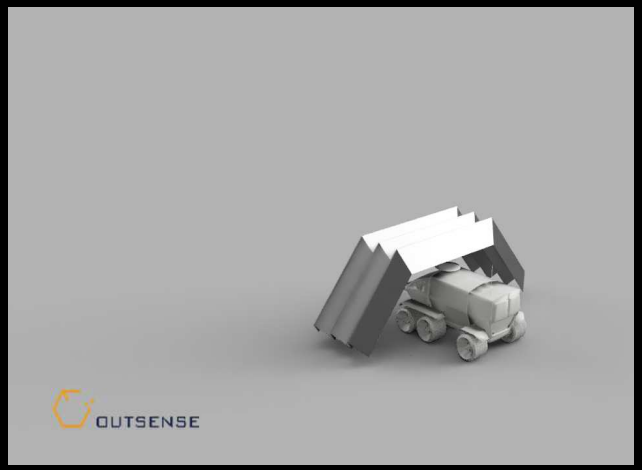
Structure for the Moon

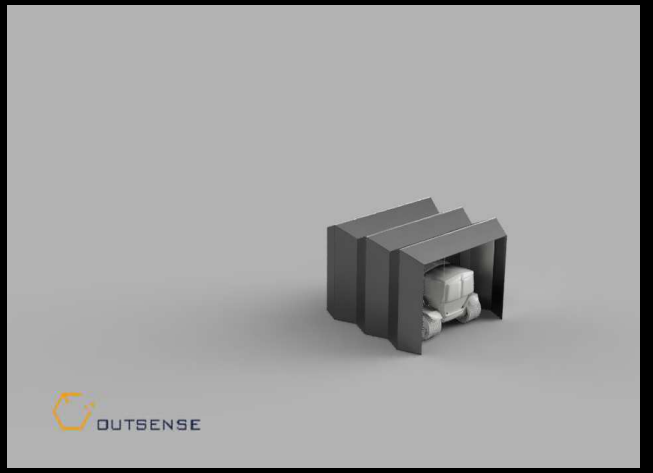
Lunar Shelter (expandable structure)

- ✓ Garage for rover
- ✓ Multi-purpose
- ✓ Passive heat control





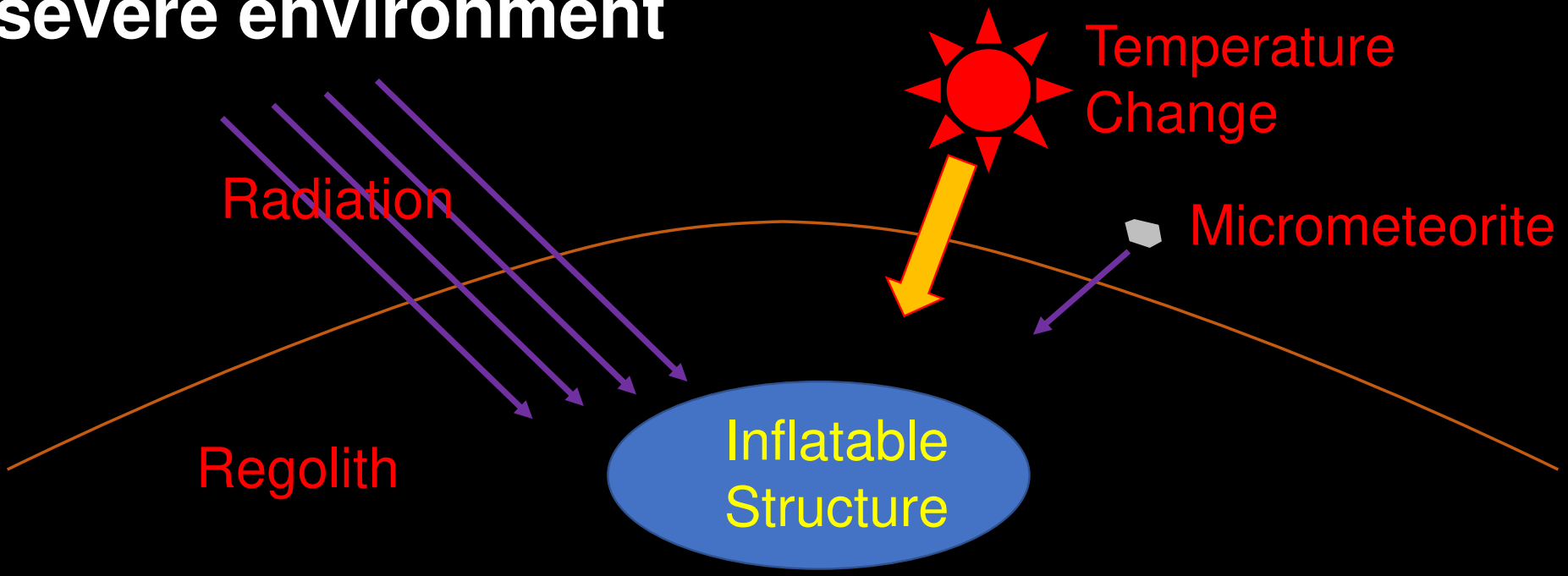




Structure for the Moon

Inflatable Structure (expandable structure)

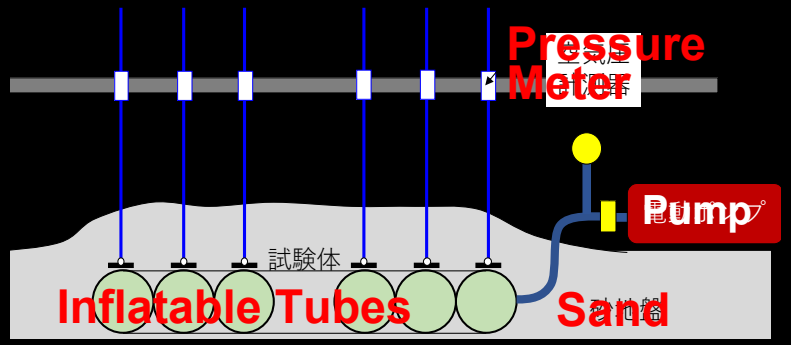
- ✓ **Protection of people and devices from severe environment**



Structure for the Moon

Inflatable Structure (expandable structure)

- ✓ Mini-scale test of inflation
- ✓ **Multi-torus shape** is most stable

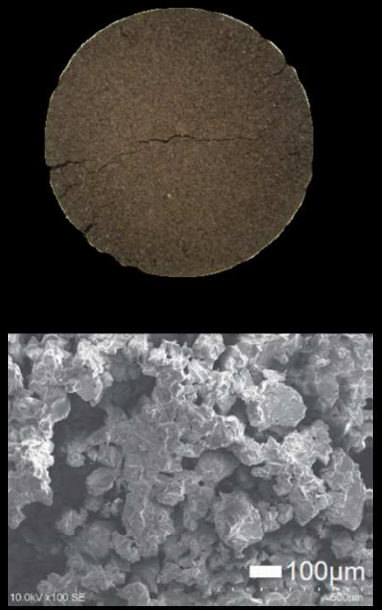


Construction Material for the Moon

Local manufacturing for local use

- ✓ Microwave sintering

Lunar Soil Simulant



Sintered Product

Fused Product

Construction for the Moon

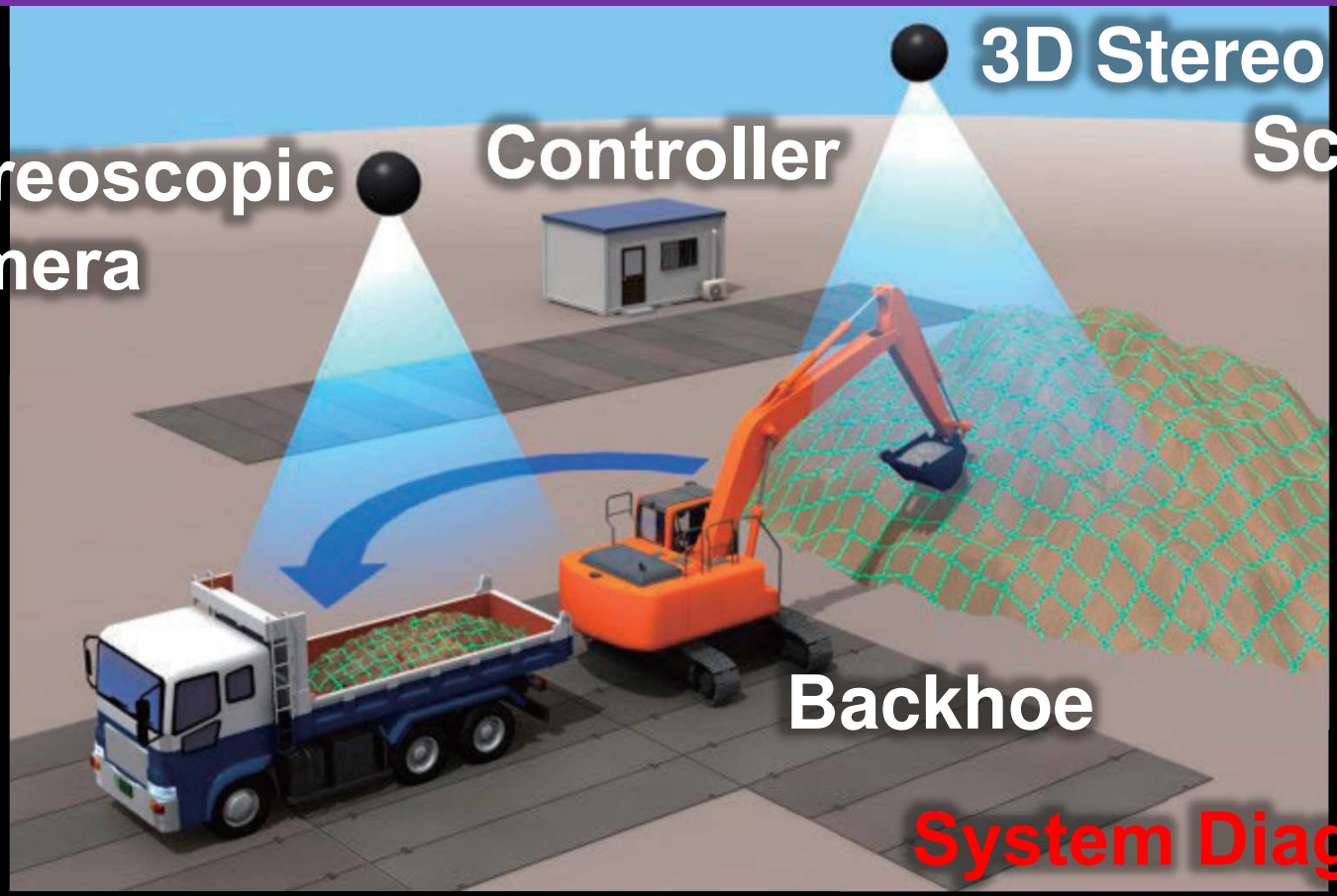
3D printers to make composite cement structure

- ✓ Robotic
- ✓ Automatic
- ✓ Remote-Control
- ✓ Autonomous

Obayashi's 3D Printed Structure

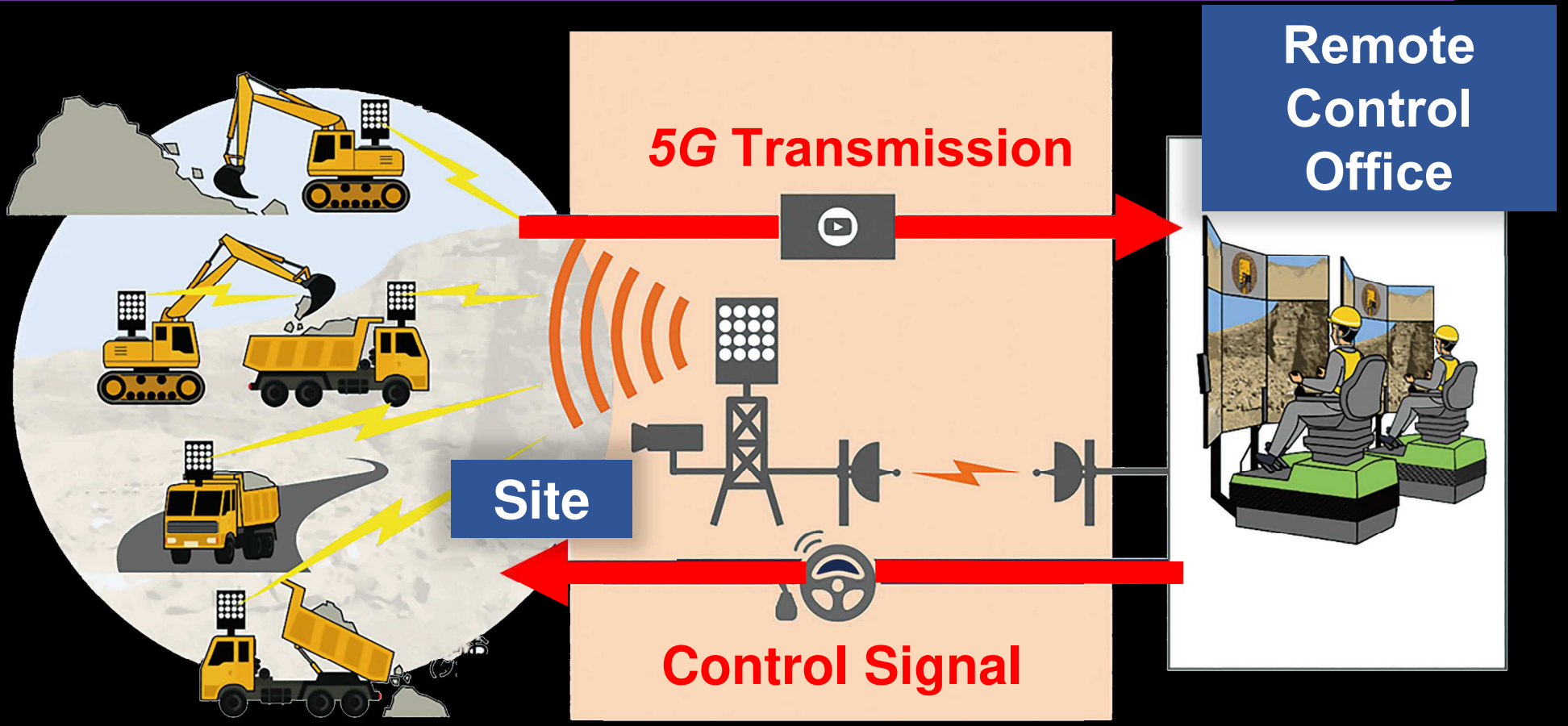
Construction for the Moon

Autonomous backhoe system with AI-aided operation



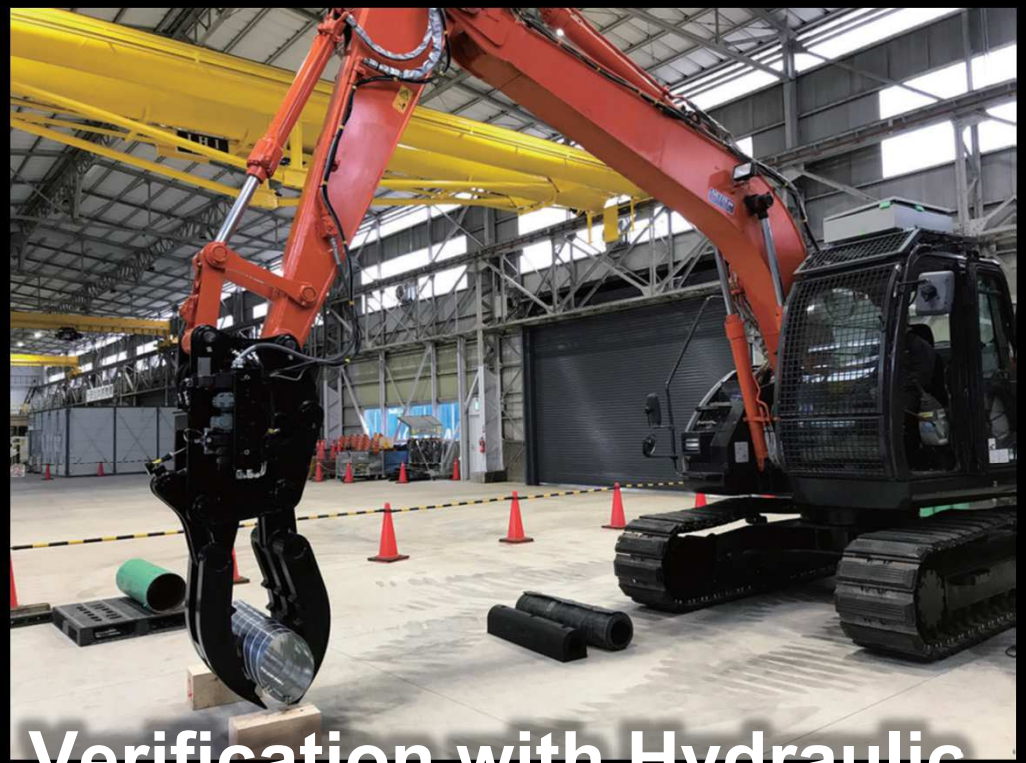
Construction for the Moon

Remote control of construction machine using *5G*

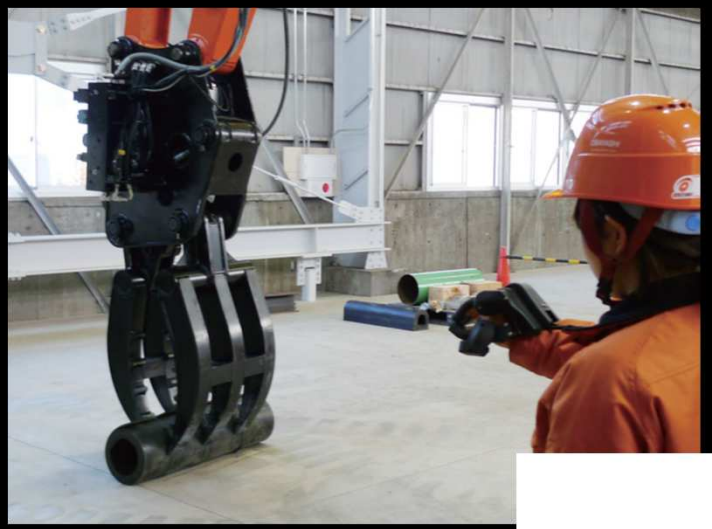


Construction for the Moon

Haptic technology to manipulate construction machine



Verification with Hydraulic Construction Machine

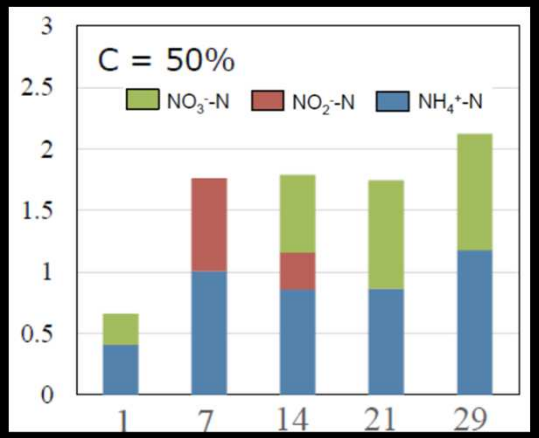


Glove-type Controller

Agriculture for the Moon

Plant cultivation using lunar simulant

- ✓ Soil made from microorganism and lunar simulant porous material
- ✓ Mustard spinach grows healthily.

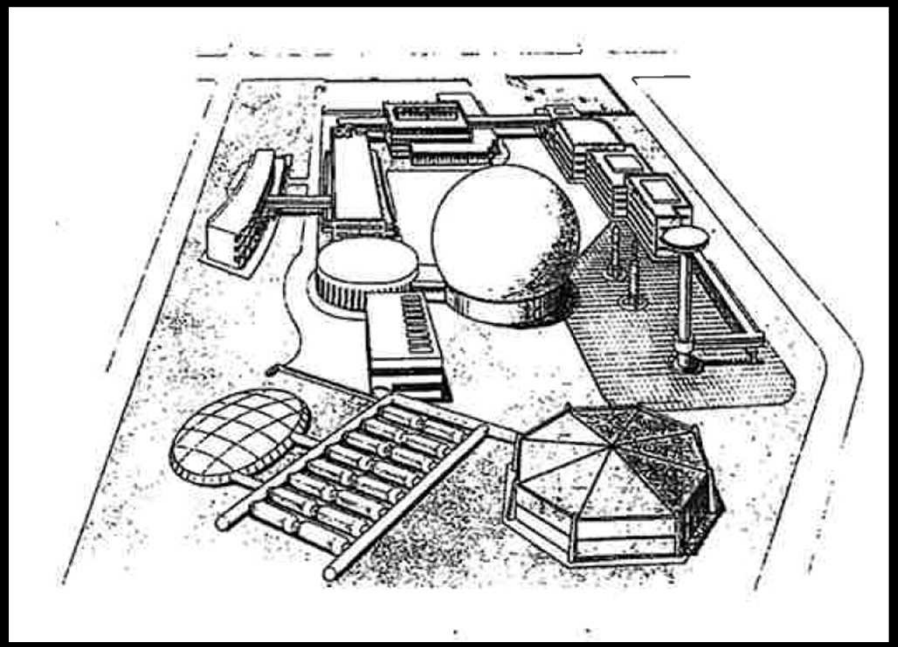


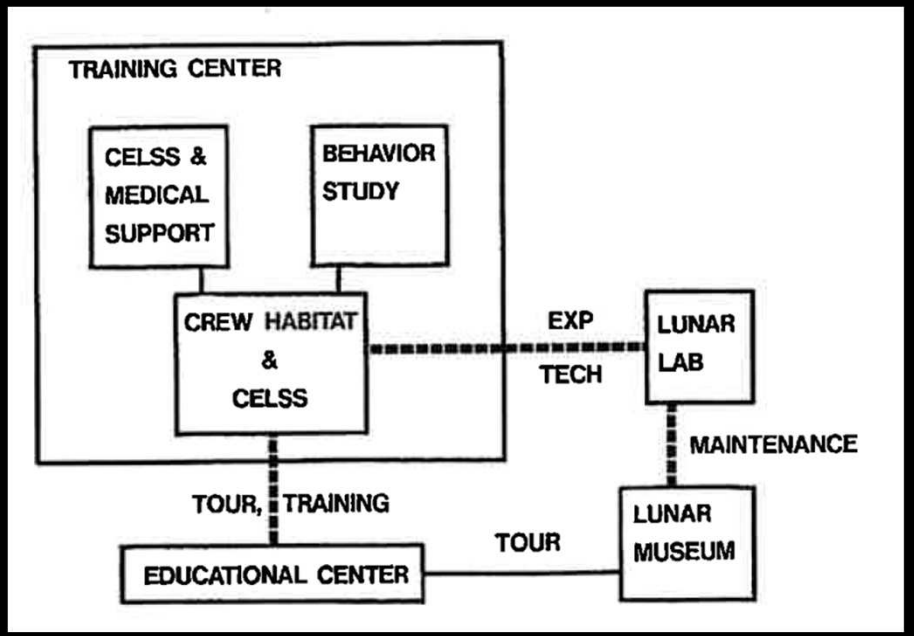
Increase of nitrate nitrogen

Simulated facility for the Moon

Moon park concept

- ✓ Facility for research, training, and education
- ✓ Jointly proposed with Prof. Kuriki (ISAS)

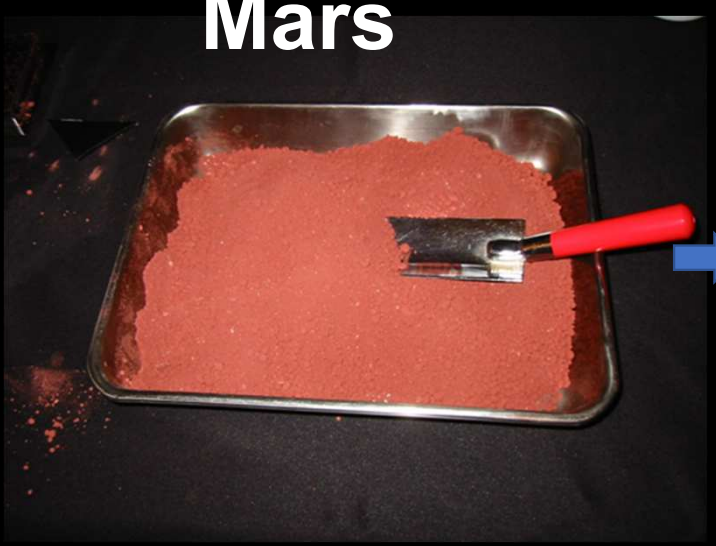




Construction Material for Mars

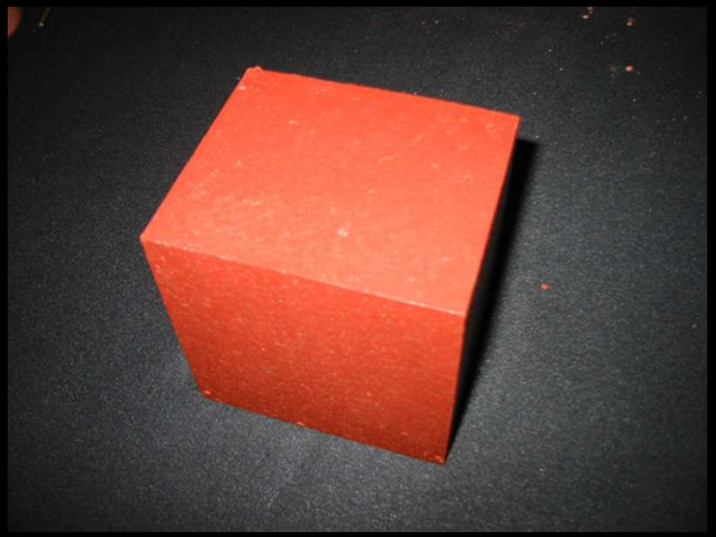
Local manufacturing for local use

- ✓ Cold press method using igneous rock, clay mineral, and water which are supposed to exist on Mars



Martian simulant

Simulant in mold



Molded block

Construction for Mars

Construction of initial Mars base

- ✓ Excavation, leveling, and pipe laying
- ✓ Joint research with NASA and Stanford University

Facility	Work
Common Facilities	- Prepare roads
Rigid Habitat Module	- Prepare the emplacement location - Move the module - Install the module - Cover the module with soil
Inflatable Habitat Module	- Prepare the emplacement location - Install supports (anchors) - Raise a center post - Install exterior and interior - Inflate - Cover with bagged soil
Greenhouse	- Prepare the emplacement location - Move equipment to site - Instal and inflate
Nuclear Power Source	- Prepare the emplacement location - Move equipment to site - Instal equipment - Construct soil shield wall
Solar Panel	- Prepare the emplacement location - Move the arrays - Instal the arrays

Equipment name and picture	Tasks
 Dragline	• suitable for working in a broad area • possible to excavate underwater • good for excavating at a level lower than the machine level • not good for excavating firm soil • not good for accurate work
 Clamshell	• suitable for working in a broad area, especially suitable for excavating in a deep narrow hole
 Backhoe	• suitable for excavating at a level lower than the machine level • good for excavating firm soil • good for accurate work
 Shovel	• suitable for excavating at a level higher than the machine level • good for excavating firm soil • good for accurate work

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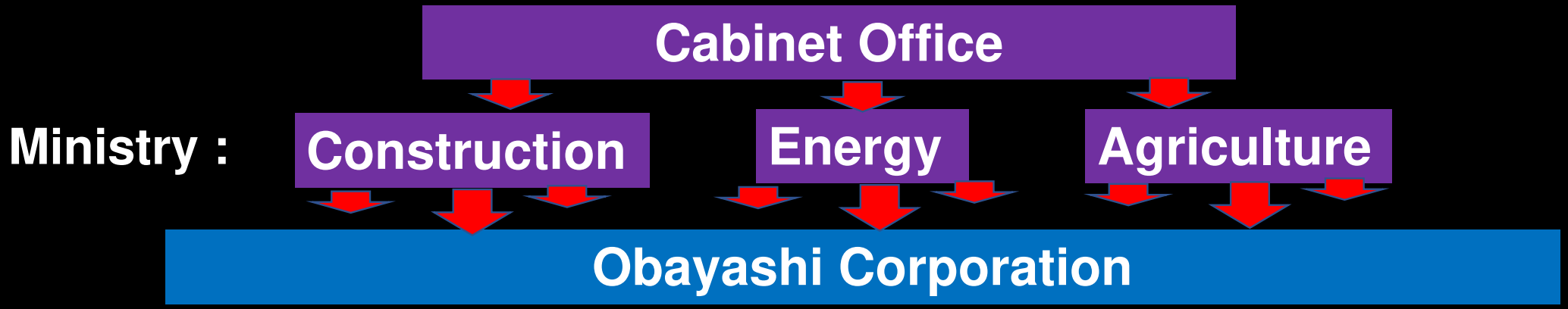
Current Topics

- ✓ Strategic Program for Accelerating Research, Development and Utilization of Space Technology (Stardust Program) (from 2021)
- Government research fund to develop technologies for Lunar development



- Construction material
- Lunar structure
- Solar on surface
- Construction of H_2 Fac.
- Vegetable growing

Construction Material (Stardust Program)

Method

- ✓ **Microwave heating of regolith**
- ✓ **Laser heating of regolith**
  - No material to be imported from the Earth

Application

- ✓ Pavement material for transportation road
- ✓ Pavement material for takeoff/landing area of rockets
- ✓ Protection material of residential facilities

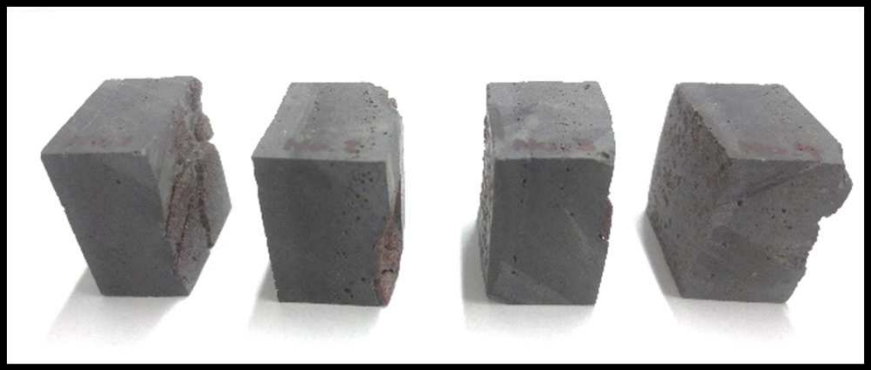
Construction Material (Stardust Program)

Microwave heating

- ✓ Sintering successful both in air and vacuum
- ✓ Both compressive and flexural strengths strong enough for the applications


Simulant in mold


Sintered body

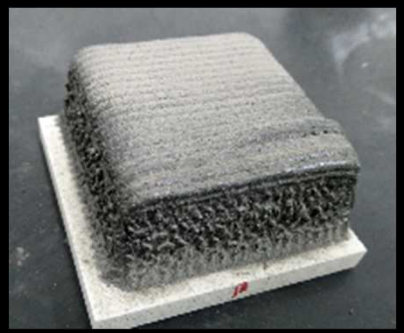

Specimens for test

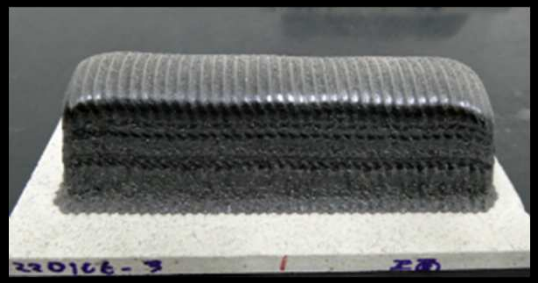

Strength test

Construction Material (Stardust Program)

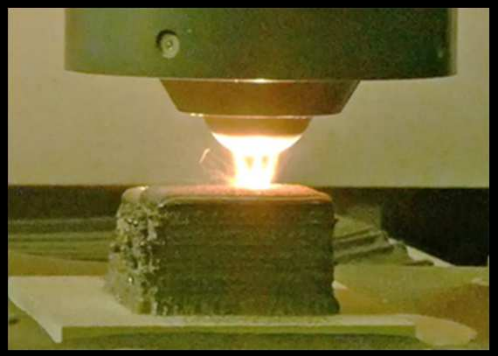
Laser heating

- ✓ Direct Energy Deposition (DED) Method
  - 3D printer
  - 6-axis driven robot arm
- ✓ Both compressive and flexural strengths strong enough for the protection of residential facilities





Products



3D printer

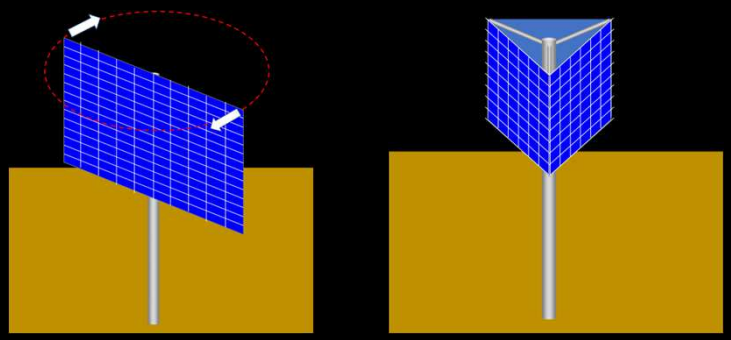
Robot arm

Energy (Stardust Program)

Solar power generation in the polar region

✓ **Recommendation** based on the study

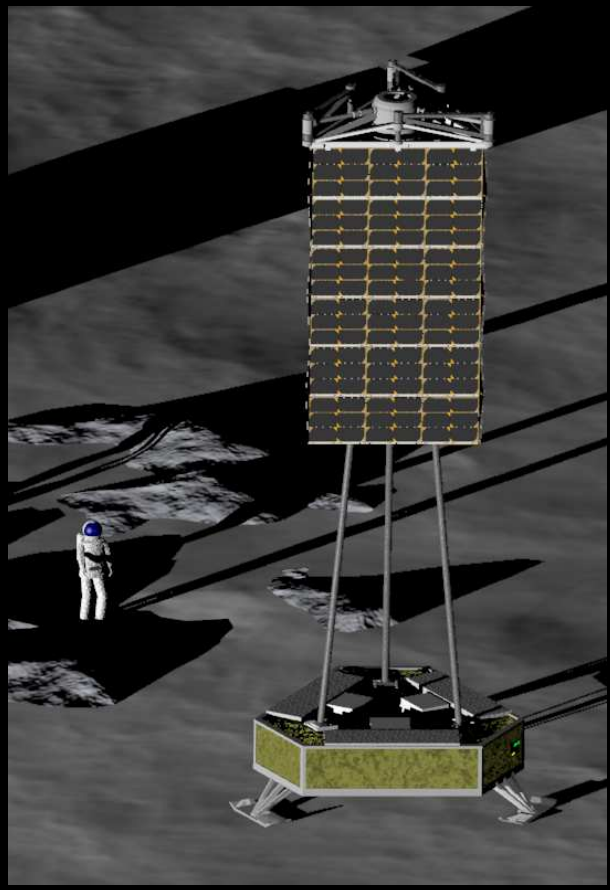
- **Tower**-type solar power generator
- **Single-axis** or **polyhedral shape** Sun-tracking system
- Limit the **operation and activities** only to the **sunshine period** to reduce the total system mass, since the storage battery mass is dominant in the total mass.



Energy and Structure (Stardust Program)

Lunar expandable power generation tower in the polar region

- ✓ **It was found that:**
  - In the lunar south polar region (85 to 90 degree), a tower of **more than 10 meters** high is required.
  - An **expandable structure** is preferred.
  - On average, **80 % of the time**, solar energy can be acquired.



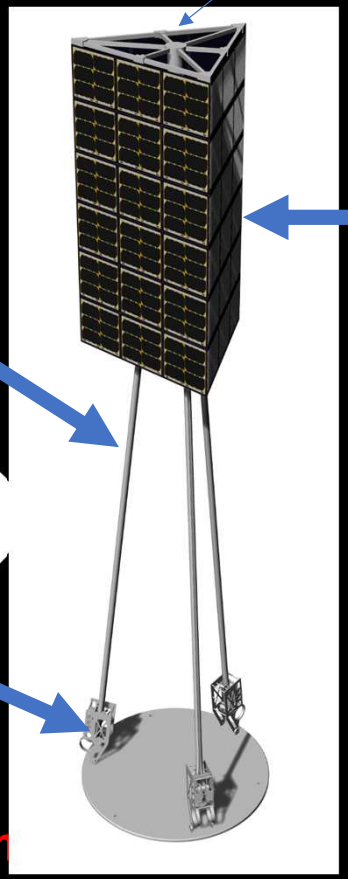
Lunar tower (12 m high)

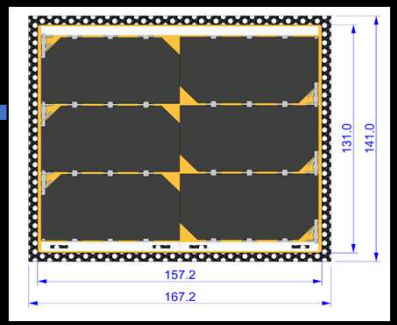
Energy and Structure (Stardust Program)

1/6 Breadboard Model (BBM) of Expandable Lunar Tower

CFRP bistable boom

Support and boom rolling system





Thin-film solar cell

Breadboard model
2 m high (1/6 size)

Acknowledgements

Sea launch
Astrocean
Chiba Institute of Technology
Space exposure of carbon nanotube
Shizuoka University
Japan Manned Space Systems Corporation
Space elevator climber
Shonan Institute of Technology
Effect of lightning on space elevator
University of Shizuoka
Otowa Electric CO., LTD.
Cable dynamics of space elevator
Shizuoka University
Lunar Shelter
Outsense Inc.
Construction
KDDI
Keio University
Lunar Agriculture
Towing
Space foodsphere
Ministry of Agriculture, Forestry and Fisheries
Moon Park
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Construction for Mars

NASA

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Construction Material

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Lunar expandable tower

JAXA

Sakase Adtec CO., LTD.

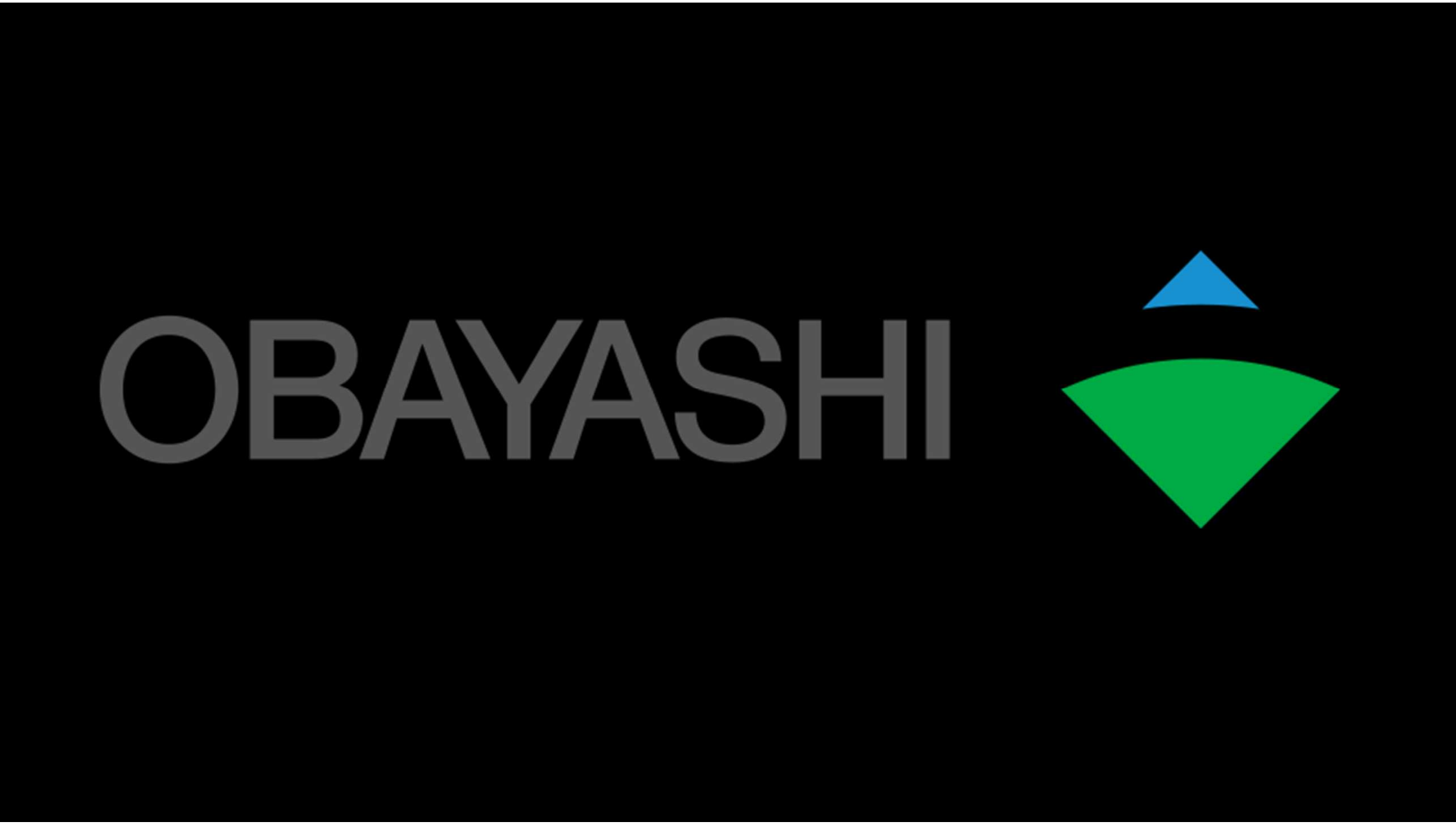
Muroran Institute of Technology

Ministry of Land, Infrastructure, Transport and Tourism

Power generation on the Moon

Sharp Corporation

Ministry of Economy, Trade and Industry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