ME3302-Project: Extraterrestrial Manufacturing

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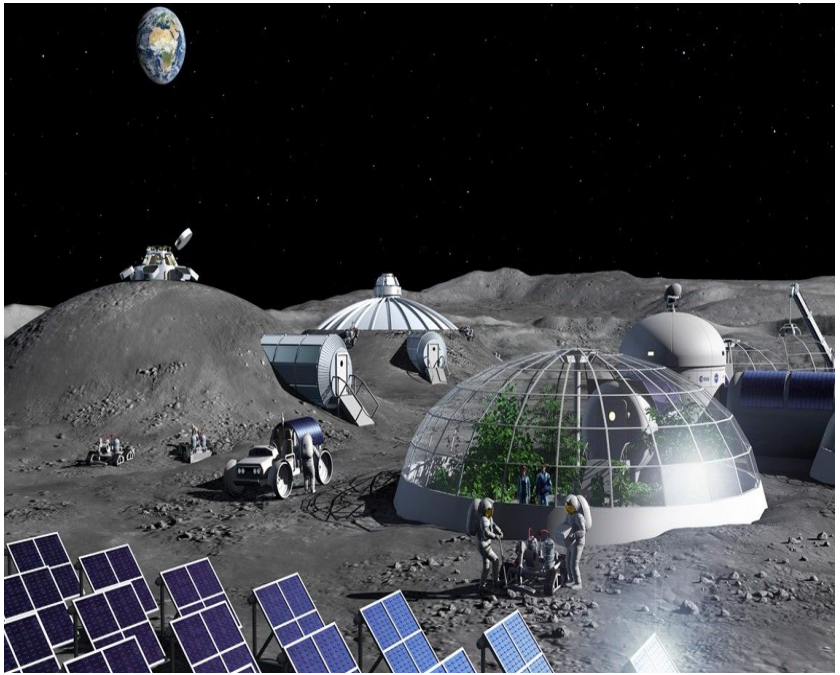
Overview

- **Product:** Oxygen
- **Raw Material:** Lunar Regolith
- **By - Products:** Metallic Powders
- **Factory Location:** Surface of Moon

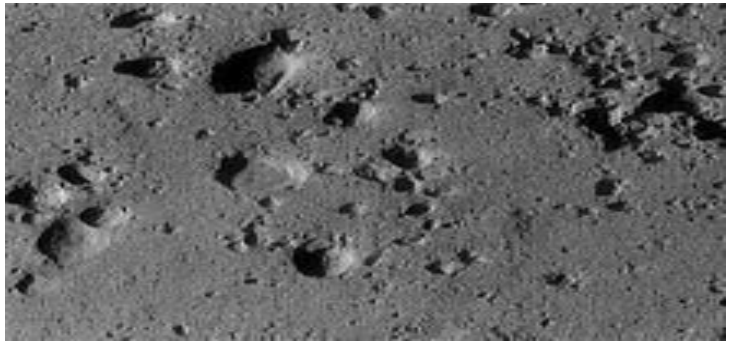


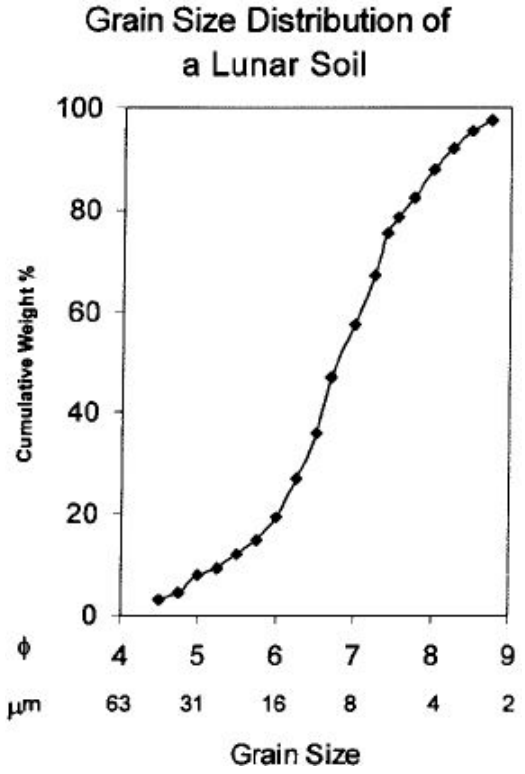
Overview

- Raw Material
- Mining the Lunar Soil
- Transportation of Raw Material to Processing Plant
- Processing Plant
  - Beneficiation
  - Material Handling between Steps
  - Energy Systems for Processing
  - Production of Oxygen Using Molten Regolith Electrolysis
  - Automation in the Plant
- Design of Factory and Factory Layout
- Teleoperation Methods to Control Manufacturing Process
- Safety Measures
- Manufacturing Metrics and Economics

Raw Material

- Lunar Regolith
- It comprises several different oxides of elements such as Silicon, Aluminium, Magnesium, Calcium and so on
- Thickness of the regolith layer varies from approximately 4 to 15 m on the lunar surface



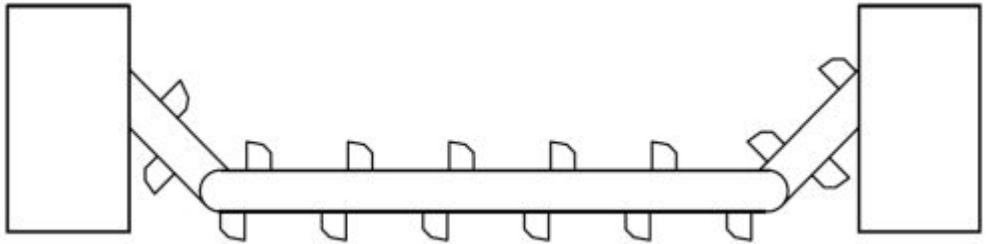


Mining the Lunar Soil - Factors to Consider

- Lower Gravitational Force
- Soft Soil Surface
- Presence of Sharp and Large Grains
- Eruption of Dust during the Digging Process

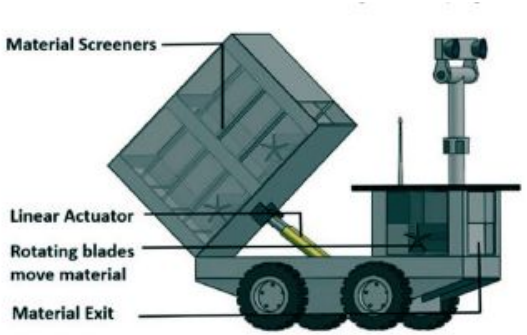
Mining the Lunar Soil - Bucket Chain Excavator

- The long horizontal bar with multiple buckets scrapes the soil from the surface
- The two side beams help in varying the depth of excavation.
- One major advantage is that it can be positioned in one place with one side of the bridge being fixed and the other moving in a semicircular motion to dig the soil.



Transportation of Raw Material to Processing Plant

- **Wheeled rovers with bucket chain excavators**
- They offer advantages such as ease of movement, high flexibility and easy teleoperation.
- The rover shall have the capacity of excavating and collecting 100 kgs of regolith in 5 minutes.



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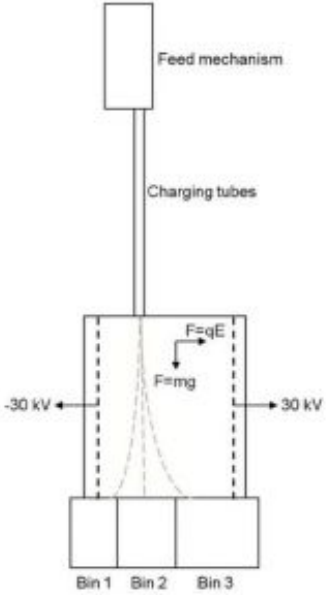
Beneficiation

- Beneficiation is the process by which the collected raw material is enriched for suitable minerals and classified by size

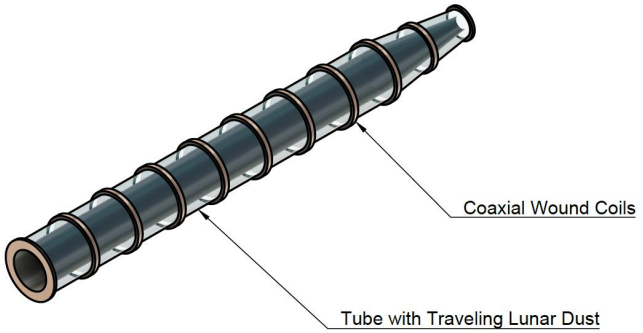
- Few Techniques:
  - Electrostatic separation
  - Coulombic separation techniques
  - Tribocharging and free fall separation



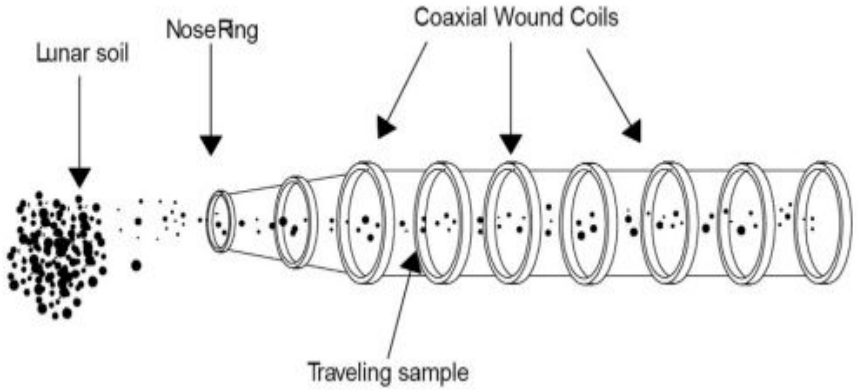
Tribocharging and Free Fall Separation

Material Handling - Electromagnetic Conveyors

- A unique system for conveyance on the Moon is proposed
- Electronic impulses are passed through coils at regular intervals resulting in a force that causes the regolith to move from one coil section to the next one.



CAD Model of an Electromagnetic Conveyor Tube

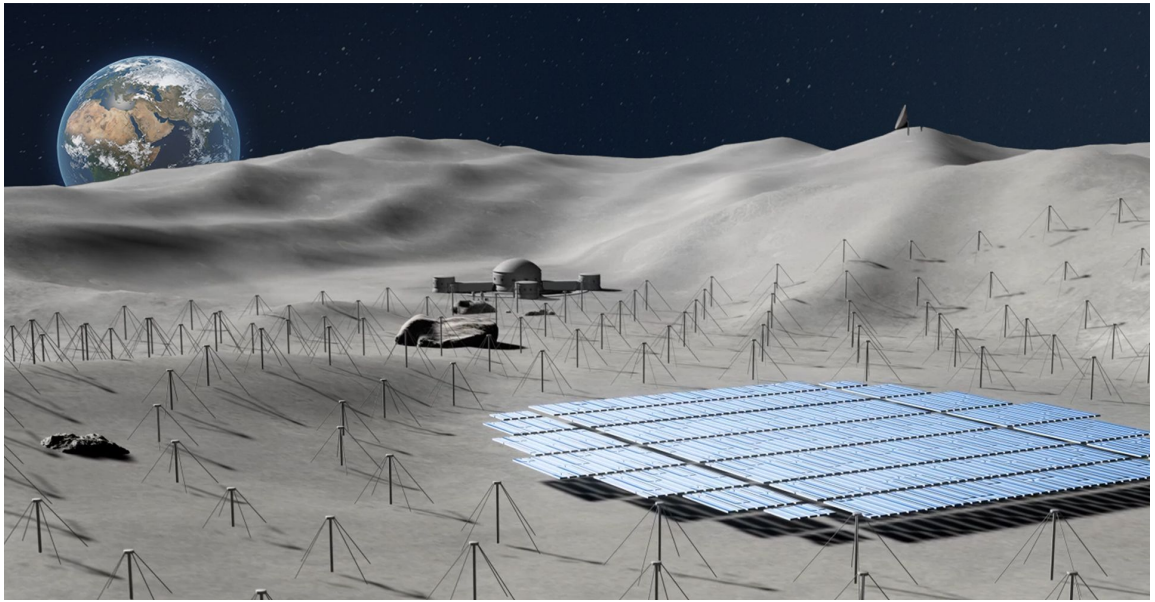


Material Handling - Other Systems

- Individual Rovers within Factory
- Scrapers Conveyors
- Screw Conveyors
- Railways System
- Ropeway System

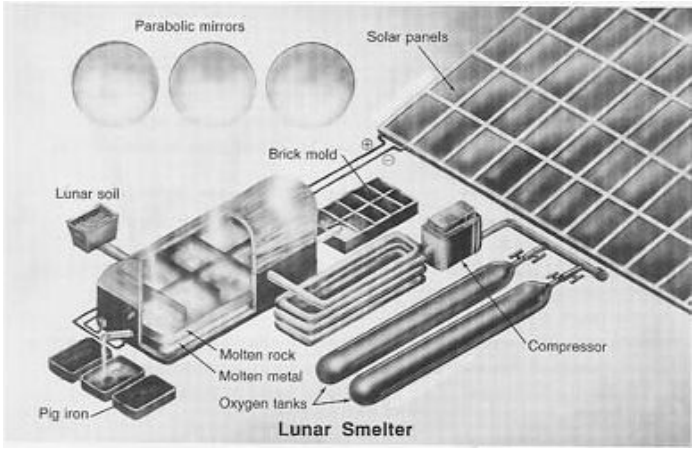
Energy Systems for Processing - Solar Panels

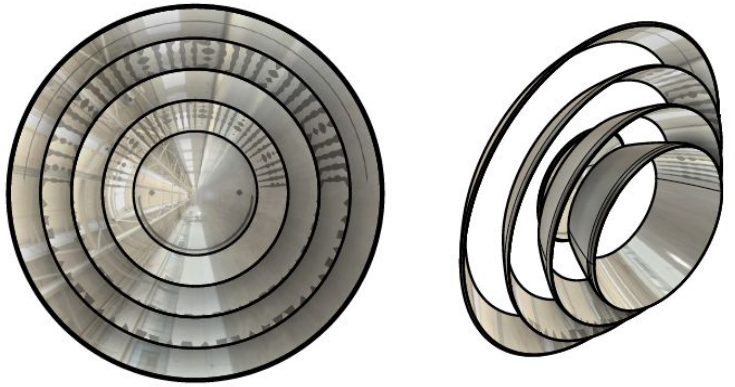
- Large Solar Arrays are setup to generate electricity which is used to power rovers and processes in production plants.



Energy Systems for Processing - Solar Concentrators

- Tracking based solar concentrators, adjustable mirrors and fibre optics will be used to track the sun and concentrate sunlight on regolith to melt or heat it.

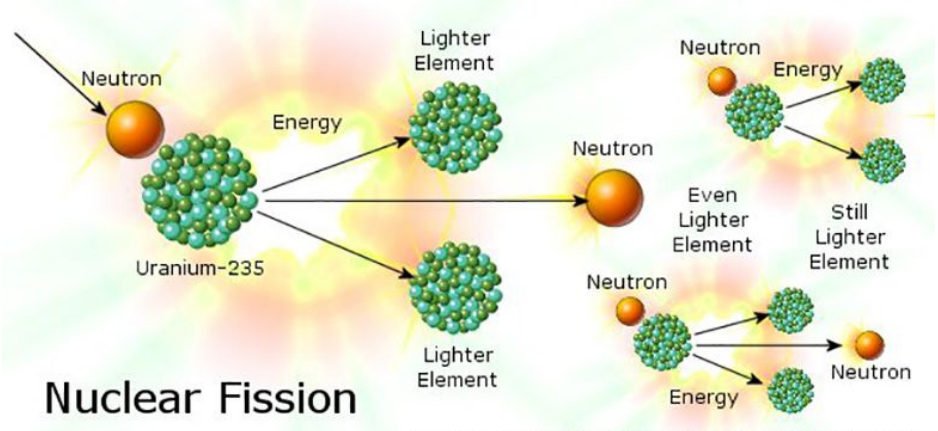




Adjustable Ring Array Solar Concentrator (CAD Model)

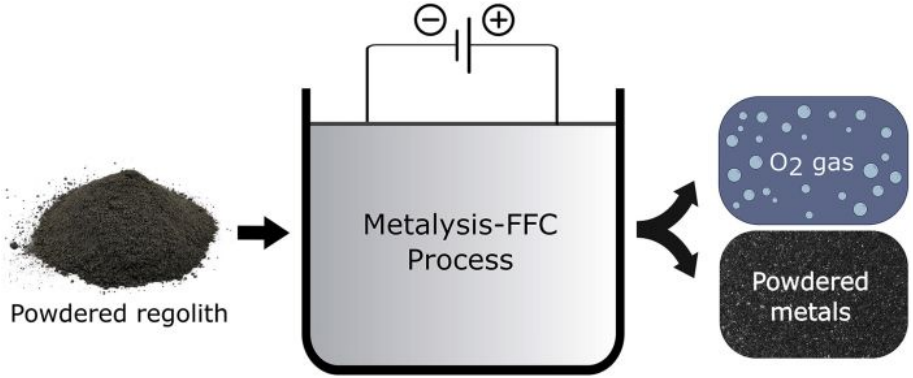
Energy Systems for Processing - Nuclear Fission

- Another alternate source of energy is nuclear fission energy.
- The raw materials (radioactive substances, materials for plants) can be carried to the moon and plants can be set up on the lunar surface.



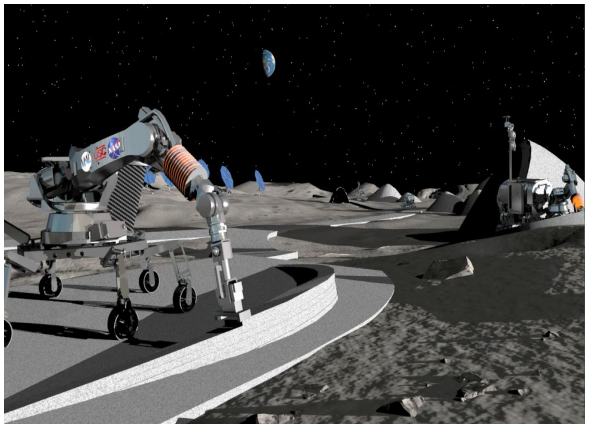
Molten Regolith Electrolysis

- After obtaining beneficiated lunar regolith, an electrochemical process takes place in a specially designed chamber.
- The raw material is submerged in molten salt ($CaCl_2$) and heated to 950°C. A current is then passed through it, causing the oxygen to migrate and collect at an anode, along with the formation of a mixture of metal powders.

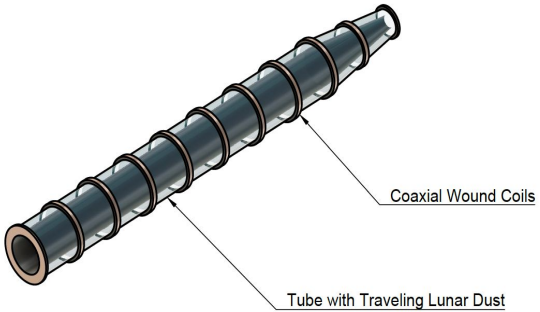


Automation in the Plant

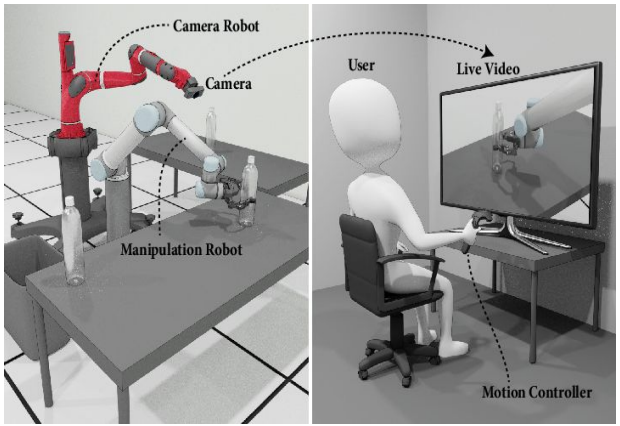
- The processing plant is a **fully automated manufacturing system**, as it requires very little human intervention once set up.
  - Rovers for transportation and collection of regolith
  - Automated electromagnetic conveyance system
  - Teleoperation techniques



Rovers



Automated Electromagnetic Conveyor



Teleoperation Techniques

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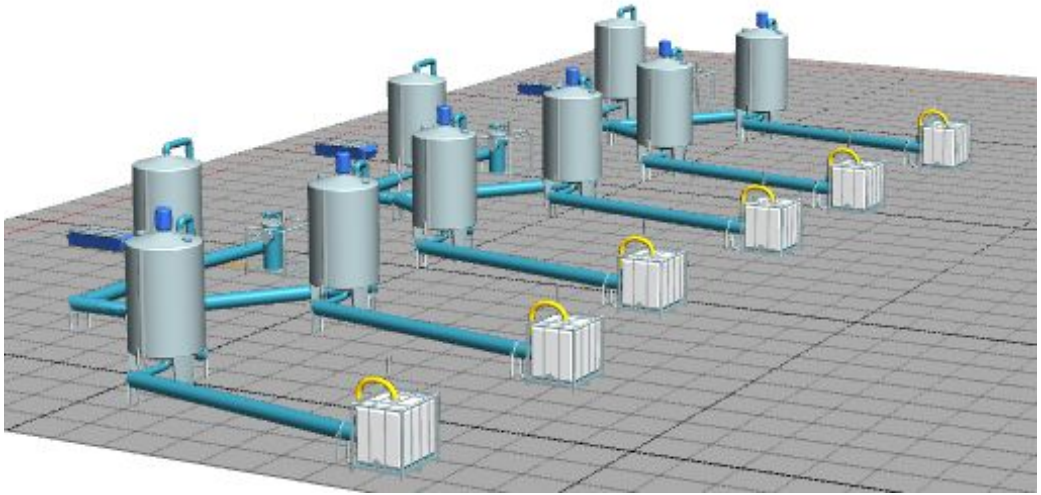
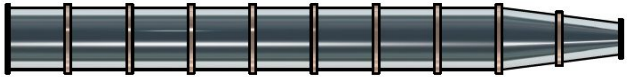
Factory Design and Factory Layout

- **Process layout** is found to be most appropriate for the product we intend to manufacture
- A representative image of the factory is shown below.

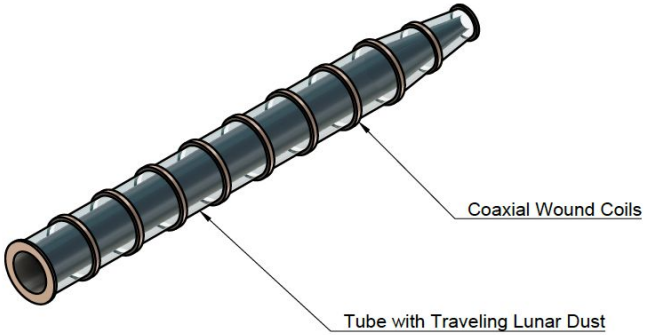


Factory Design - Electromagnetic Conveyor (CAD Model)



Front View

Cross Sectional View



Factory Design - Solar Concentrator (CAD Model)

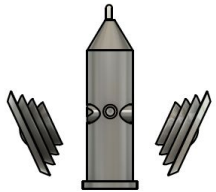
Front View
(Mirrored Surface facing the Sun)

Side View

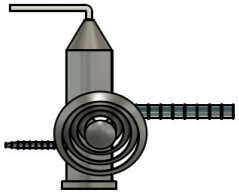
Back View
(Opaque Surface)

Isometric View

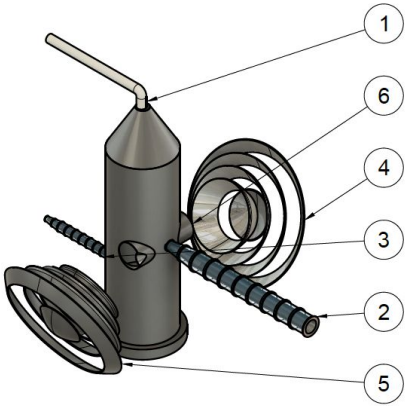
Factory Design - Electrolysis Chamber (CAD Model)

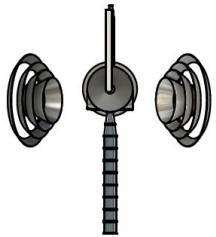


Front View



Side View



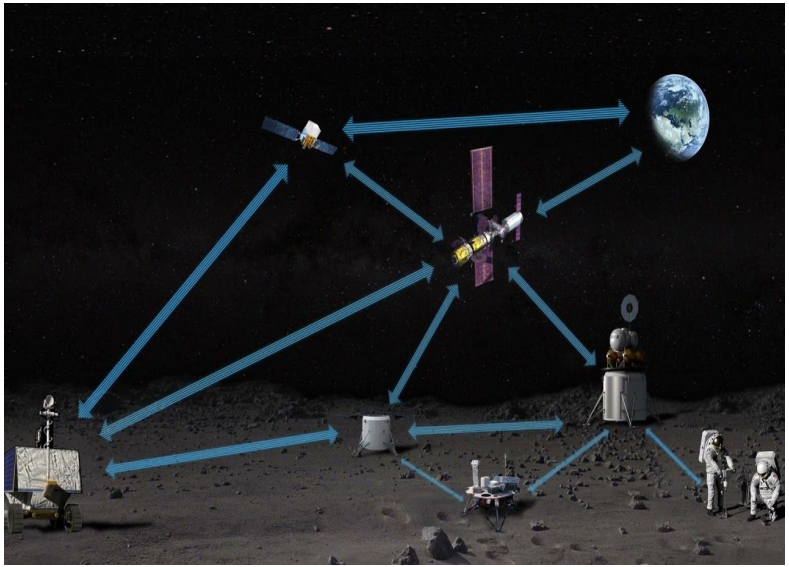


Top View

Parts List	
Item	Part Number
1	Oxygen Exit Pipe
2	Lunar Regolith Input Electromagnetic Conveyor
3	Metallic Powders Output Electromagnetic Conveyor
4	Adjustable Solar Concentrator 1
5	Adjustable Solar Concentrator 2
6	Electrolysis Chamber

Teleoperation Methods

- A human-rover teaming strategy using artificial intelligence (AI) aboard the rover and human operator can be designed.
- The human operator would bring in advantages of human cognition. The data connection between the rover and mission controller must be continuous and reliable.



Safety Measures

- The wheels and motors should be covered with protective covers and seals, to prevent glass pieces & agglutinates or harder rocks and dust respectively from damaging the rovers.

- The process plants must be equipped with interlocks and sensors like float and limit switches for electrolysis.

- Process plants like beneficiation chambers and electrolysis cells will be equipped to respond to take corrective action against a safety hazard.

Manufacturing Metrics and Economics

- The **break even time** for the factory based on assumptions on the oxygen demand is found to be **3.1833 years**
- The regolith **throughput rate** is given by the following relation as explained in the report:

$$\eta_{O_2} \equiv \frac{m_{O_2}}{m_{regolith}} = \sum_i (w_i) \left(\frac{MW_{O_2}}{MW_{oxide,i}} \right) (r_{mol,i})(e_{frac,i})$$

- The cycle time to generate one batch of oxygen cylinders is **8 hours** based on the bottleneck model in process layout

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Thank You