LEVERAGING THE USE OF NOVEL LUNAR ISRP & ISRU METHODS WITH SPACE BASED SOLAR POWER

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Mr. Connor MacRobbie – MASc. Candidate, Mechanical & Mechatronics Engineering, University of Waterloo, Ontario
Mr. Kyle MacRobbie – BSc. Candidate, Physics & Astronomy, University of Waterloo, Ontario
Mr. Jack Ehling– BSc. Candidate, Physics & Astronomy, University of Waterloo, Ontario
Dr. Anqi Wang – Post Doctoral Fellow, Mechanical & Mechatronics Engineering, University of Waterloo, Ontario
Dr. Jean-Pierre Hickey – Associate Professor, Mechanical & Mechatronics Engineering, University of Waterloo, Ontario
Dr. John Wen - Professor, Department of Mechanical and Mechatronics Engineering, Ontario

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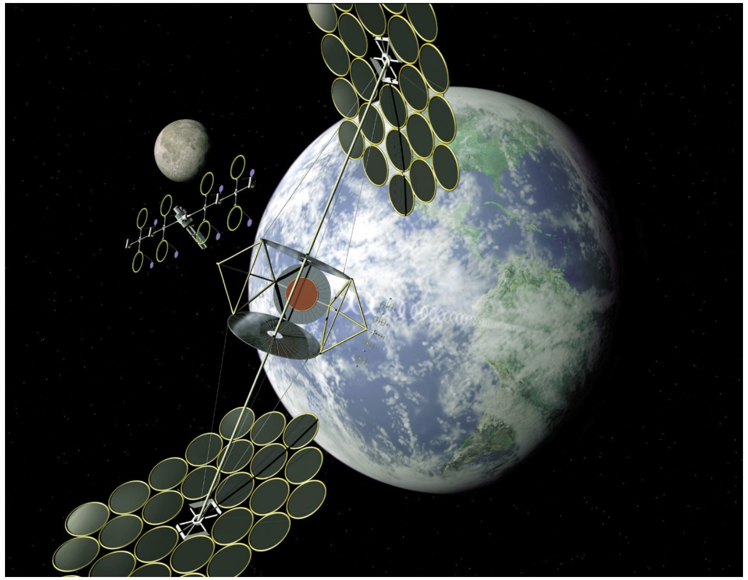
Background

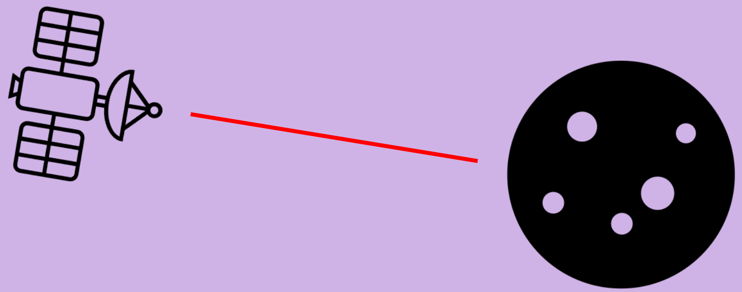
- Lunar In-Situ Resource Utilization (ISRU) and In-Situ Resource Processing (ISRP) are of high importance in today's research
  - They will be fundamental to the building blocks of lunar infrastructure
  - This infrastructure will help humans travel to the moon and beyond
- These processes often require large amounts of power
- Space based solar power (SBSP) can be gathered and transferred to the lunar surface
- This work covers a review of ISRU and ISRP processes to be enabled by SBSP, a novel method of material processing, and important links between SBSP and lunar resources



[1] NASA

Simplified Roadmap to ISRU for Lunar Infrastructure using SBSP

SBSP Generation & Distribution
- Large solar arrays in orbit around the moon
- Microwave transmission
- Laser transmission



Material Acquisition
- Mining
- Excavation
- Transport

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ISRP
- Size Filtering
- Molten Regolith Electrolysis
- Vapor Phase Pyrolysis
- Carbothermal Methods
- Ice/Water Electrolysis

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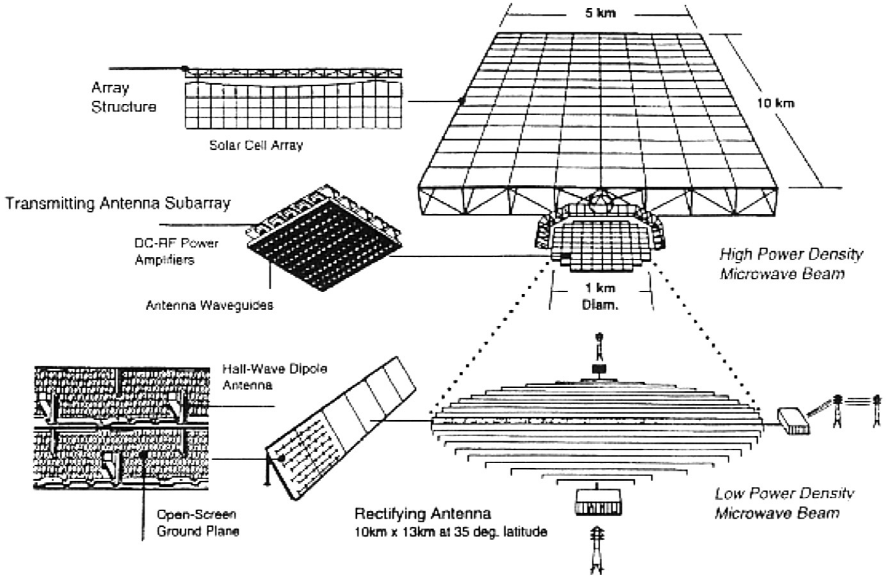
ISRU
- Life Systems
- Construction
- Power
- Propellant
- Manufacturing

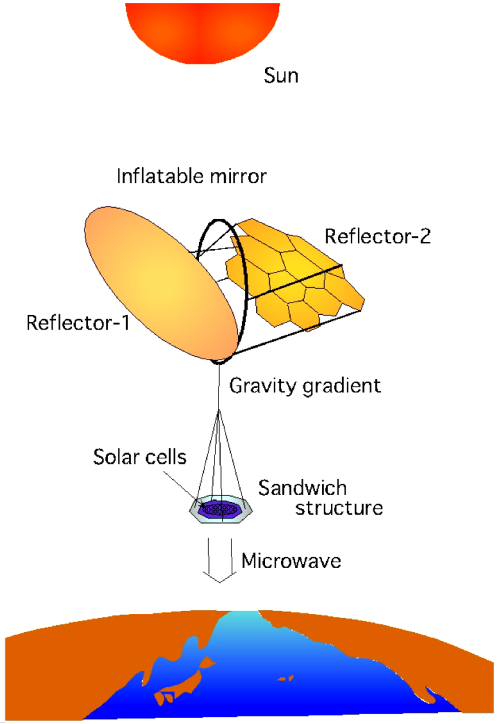
Require Significant Power (ISRP and ISRU)

Power Generation and Distribution Methods

- Power requirement for ISRU and ISRP depends on scale.
  - It takes 1.5 MJ to melt 1kg of regolith
- Space based arrays could capture large amounts of power
  - Most concepts on the order of GW
  - Kilometers in size. High cost & environmental impact
- Wireless Power Transmission (Microwave or laser) to lunar surface
- A receiver will convert the microwave/laser energy into useable electrical energy



[2] NASA



[3] Kaya

Why Not Alternative Power?

Nuclear Sources	• Controlled goods • Not as easily accessible to private entities
Batteries	• Size and weight requirements for such high power • Need for continuous power through the lunar night
Fuel	• Require extra fuel to be bought from Earth • Using local water as fuel is not yet viable

ISRP Methods

- Physical processing of the lunar material will be important (refining, filtering, etc.)

Molten Regolith Electrolysis

- Separates the species into glass silicate and metal alloy while harvesting the oxygen
- Melts the regolith and applies a voltage
- Proven on 20 kW scale [4]

Vapor Phase Pyrolysis

- Used to separate and gather specific species from the gasified regolith
- Controlled temperature environment allows for species collection

Carbothermal Methods

- Uses additives to reduce the metal oxides in regolith
- Oxygen is produced as well as iron and silicon which can be removed from the molten metal

Water Electrolysis

- Used to separate hydrogen and oxygen from lunar ice
- Requires much pre-processing to move ice from extraction to plant location

Novel ISRP Concept

- We are proposing an expanded Molten Regolith Electrolysis (MRE) method
  - Decomposition of metal oxides is dependent on electrolysis voltage
  - Use voltage steps to control the species dissociation and removal from the molten solution
  - This will decrease post processing costs of residual materials
  - Mechanical system concepts to be created
  - Small batch analysis to be tested in lab. Supported by the Laboratory for Emerging Energy Research (LEER) University of Waterloo
- Similarly, in VPP a stepped temperature model will allow certain species to gasify and be collected in succession

Oxide	$-E°$ (V)	JSC–1 Conc. (wt. %)	Lunar Soil Conc. (wt. %)
K_2O	0.748	0.82	0.6
Fe_2O_3	0.842	3.44	0.0
FeO	0.986	7.35	10.5
Na_2O	1.117	2.7	0.7
Cr_2O_3	1.363	0.04	0.2
MnO	1.486	0.18	0.1
SiO_2	1.757	47.7	47.3
TiO_2	1.822	1.59	1.6
Al_2O_3	2.179	15.02	17.8
MgO	2.376	0.18	0.1
CaO	2.59	0.04	0.2

[5] Sadoway

ISRU Applications

- Space based solar power can directly support energy intensive ISRU systems
  - Additive manufacturing or casting manufacturing methods for parts or bulk material
- Once processing has occurred the materials serve many purposes
  - Oxygen: Life support, fuel, plants, water storage, propellant, etc.
  - Metals: Construction, infrastructure, and propellant
  - Silicon: Solar cells for future energy production
- All these materials can be used to economically scale SBSP
- Production cycle that make lunar infrastructure more independent of earth

[6] ESA

MORPHEUS

- The MORPHEUS (The Multi-domain Operations using Rapidly-responsive PHased Energy Universally Synchronized) is a new sandwich type SBSP concept, designed with a focus on sustainability and lifecycle analysis of SBSP
- Developed by Metasat
- The concept has been developed with an eco-design approach using lunar materials, to reduce the environmental footprint, while meeting technical goals
- This is the first large scale SBSP concept looking at predominantly lunar based resources. This will require the processing methods discussed here
- A life cycle sustainability assessment was done on the reference design in 2020 [7] and showed that that design had potential to be ‘green’ and cost effective. This novel concept improves on the reference design

Technological Gaps & Next Steps

- Technological gaps include:
  - High TRLs for desired technology in each aspect of the ISRU pipeline
  - A high-level system design that utilizes all aspects of the process such that ISRU is of reasonable cost, scale and safety
  - Potential methods of combining ISRP and ISRU methods to reduce overall power requirement
- Next steps include:
  - Study for solar array size requirements of a ISRP / ISRU plant using select methods
  - Development of a detailed voltage stepped molten regolith electrolysis concept
  - Laboratory feasibility studies of voltage stepped MRE with LEER at the University of Waterloo

Conclusions

- Space based solar power will be critical for future missions and settlements on the moon and beyond
- ISRU and ISRP methods that require large amounts of power will utilize SBSP
- A novel high energy ISRP method for oxygen and metal extraction is presented
- The importance of ISRU and ISRP to scaling sustainable SBSP is demonstrated
- Technology gaps and next steps are outlined

[8] ESA

THANK YOU

QUESTIONS?

Email: cjmacrob@uwaterloo.ca

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