Continuous empowering with laser power transmission technologies for ISRU moon assets: CIRA approach

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Abstract. Due to the potential possibility of changing the dynamics of the New Space Economy, In-Situ Resource Utilization (ISRU) is acquiring more and more importance within the Space Exploration scenario. Indeed, the closest space missions will return humans to the Moon, while planning the long-term stay. This aspect opens the way to the need for employment and processing of local resources, with the aim of reducing the dependence on Earth-based resources, also ensuring the financial sustainability of the space exploration programs. ISRU technologies will demand for energy values likely to be in the Megawatt range and, eventually, at Gigawatt levels, to be ensured in the harsh hazardous environmental conditions of the celestial bodies (e.g. Moon, Mars, Near Earth Asteroids). This work, performed by the CIRA TEES Laboratory, provides the CIRA approach to the feasibility study concerning the Laser Power Transmission (LPT) technologies for Moon assets empowering. The aim is to evaluate whether LPT can be a potentially efficient solution for continuous power delivery from an orbiting source device, considering long-distance wireless employments and severe environmental conditions, to drive ISRU Moon assets (habitats, rovers, local industrial plants, conveyance facilities, et cetera). For the purpose of this study, starting from the space mission identification, an increasing complexity multi-step approach was properly conceived by CIRA to design the dedicated LPT system responding to the evaluated mission requirements.

ISRU: CIRA LPT Model & Approach

The term ISRU (In-Situ Resource Utilization) refers to the use and processing of local resources directly found on the Moon, or other planetary bodies, to obtain raw materials supporting robotic and/or human space exploration missions. ISRU technologies aim at creating products or services fundamental for lunar and Mars long-term stays, also reducing the need for continuous resupply from the Earth, [1], with an unavoidable huge impact on the dynamics of the New Space Economy.

In general terms, the ISRU domain relies on three key concepts: identification (prospecting for recoverability), processing (mining, extraction, beneficiation) and use of local (natural and artificial) resources. Each concept will imply dedicated technologies, systems and capability development involving various technical disciplines, [2]. More in detail, local resources account for the ones recoverable on extra-terrestrial bodies.

This paper deals with the problem of the Moon ISRU assets' continuous power delivery. Indeed, for the lunar case, the severe environmental conditions of the surface, combined with the long periods of darkness due to its day-night cycle, make the energy supply a pivotal issue. Several approaches have recently been considered to store and provide energy to the surface of the Moon by means of ISRU (In-Situ Resource Utilization) technology, [3]. Among the various potential solutions identified in literature, the CIRA TEES laboratory is deepening the one based on the solar power caught by dedicated satellites (Solar Power Satellites, SPS) in proper orbits, equipped with a laser system, capable of generating a power laser beam driven for long distances to activate

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Moon assets (rovers, habitats, infrastructures, etc.). From now on, the overall system this work refers to will be designated as LPT (Laser Power Transmission) system, portrayed in Figure 1.

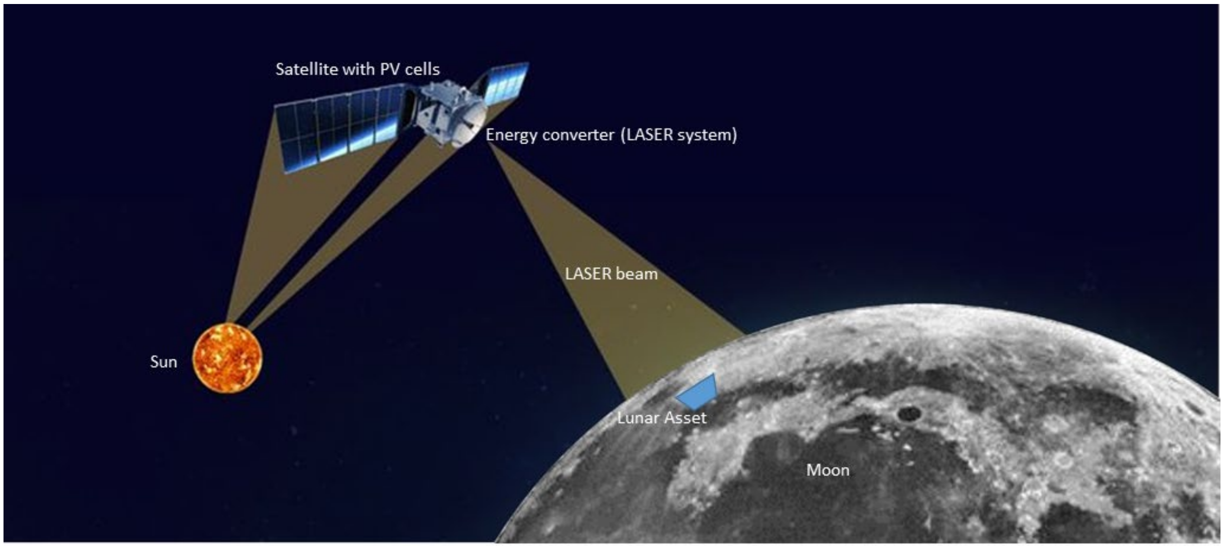

Figure 1 - Space Laser Power Transmission System Overview for Moon Assets Empowering

The space system, this work refers to, has been intended as promising in order to empower Moon assets in a continuous manner. Figure 2 reports a block schematization of the previous Figure 1, helpful to understand the here described work.

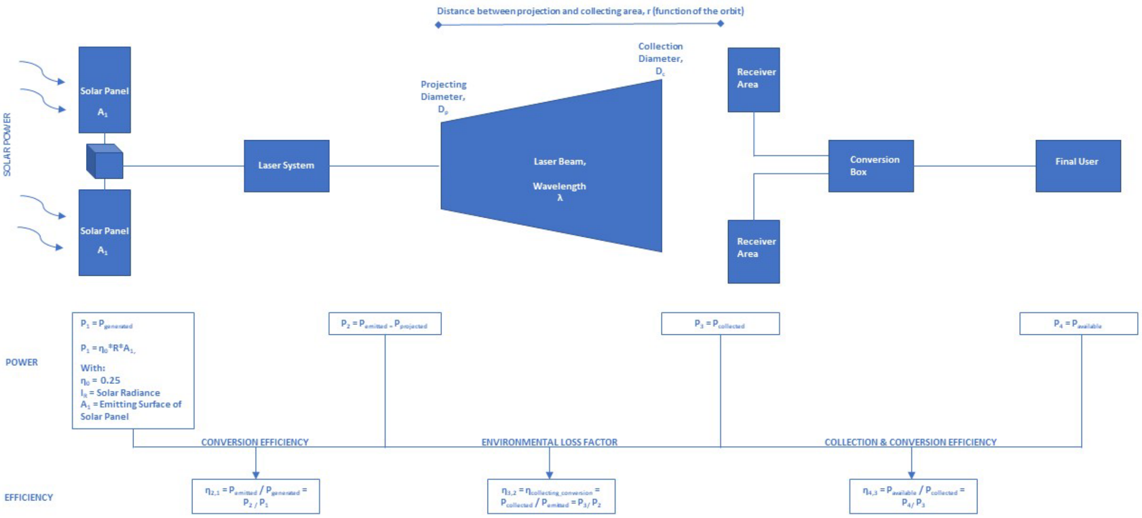

Figure 2 - CIRA LPT Preliminary Model Block Schematization

In particular, the overall system is composed by:

- One/more satellite/s, equipped with photovoltaic solar panels to catch the Sun power (the choice of the orbit is not the actual objective of this study);
- A laser system, using solar energy to generate a laser power beam;
- A laser power collecting station, with a proper receiving area;
- A conversion box, capable of converting the laser power beam into electrical energy to activate:
- A final user, which functioning needs to be guaranteed by the overall system.

Precisely, CIRA is now performing an accurate study to assess such a complex topic in terms of feasibility of the conceived system process. Thus, a multi-step dedicated approach has been developed: the main phases are depicted in Figure 3, with a focus on the Step 2.

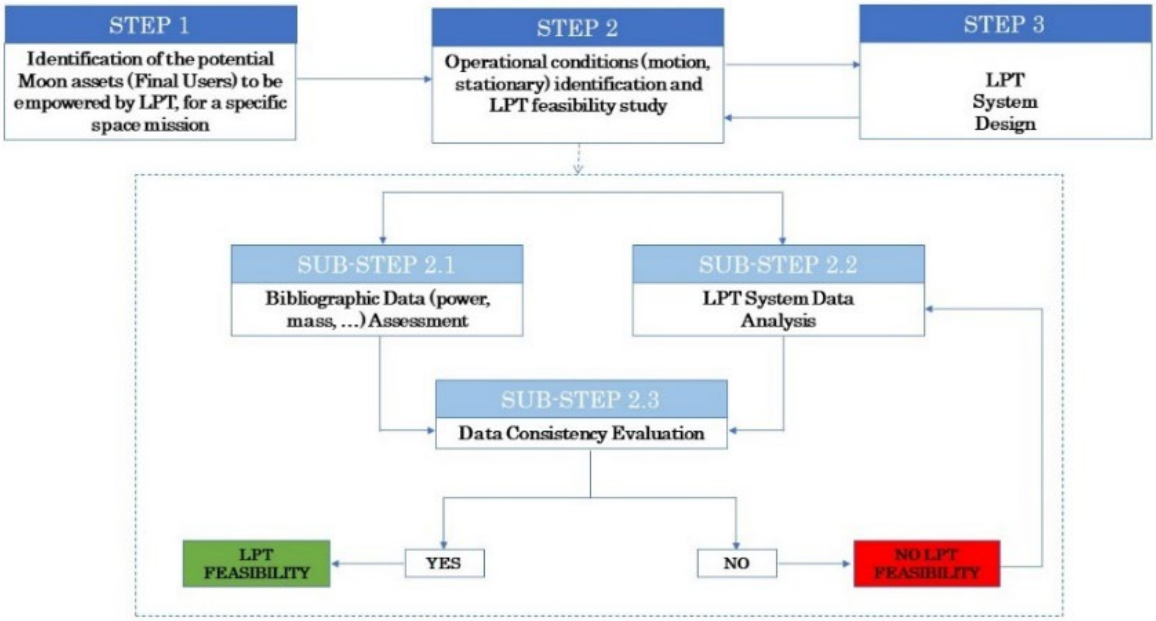

Figure 3 - LPT feasibility study for IRSU applications: the CIRA Approach

A first brief description of the conceived three steps is herein provided, while the Section 2 contains a more detailed characterization of the STEP 2, core of this work:

- STEP 1: dealing with the identification of the potential ISRU Moon assets to be empowered by means of an LPT system, for a given space mission. The Global Exploration Roadmap (GER, [6]) has been used in support of this stage to screen the possible final users of the LPT system, mentioning rovers, (for mobility, transportation, image acquisition, data measurement), landers (crew, cargo, robotic), habitats (pressurized, mono- or multi-module), industrial plants (for production and processing of materials), extraction instruments/equipment (bucket-wheel, auger/drill, scoop, pneumatic excavator), comminution instruments/equipment (size crushing, sorting), et cetera.
- STEP 2: among the final users, deriving from the Step 1, the rover has been chosen as the model to develop the preliminary LPT feasibility study in this stage. In particular, the Step 2 has been further exploded into three sub-steps:
  - ✓ SUB-STEP 2.1: after schematizing the possible operative conditions for the chosen systems (rovers), this sub-step collects literature power and mass data of (already dismissed/currently working) rovers for Moon and Mars exploration, also accounting instruments (magnetometers, spectrometers, etc.), cameras and actuators. An example of some collected data is reported in Table 1, for the Intrepid lunar rover, [4].

Table 1 - Collected mass and power data for Intrepid rover at system and sub-system level

		Operational Condition	Mass [Kg]	Power [W]	Reference
System	Intrepid Rover (Moon)	Driving Mode	371,00	239,00	Table 3-3, [4]
Sub-System	Instruments	Stationary Mode	11,50	16,00	Table 1-3, [4]
	Cameras		8,50	14,00	
	Actuators		48,31	60,00	Mass, Appendix D, [4]; Power, Table 3-2, [4]

  - ✓ SUB-STEP 2.2: LPT system data analysis, by means of the implementation of analysis loops to process data resulting from the sub-step 2.1, [5], to be confronted with into the:
  - ✓ SUB-STEP 2.3: dealing with the consistency assessment of the values deriving from the previous sub-steps.
- STEP 3: not object of the present work, regarding the LPT system design and optimization of design parameters, [7].

Operational Conditions Identification and LPT Feasibility Study: Focus on The Step 2

As before mentioned, the real core of this work is the Step 2, herein described more in detail.
At first, a collection of data from literature was indispensable to have an overview of the power and mass values related to still working/already dismissed Moon rover systems. Those values have been then used as key elements to drive the following two approaches, namely the direct and the reverse ones. In particular, referring to the preliminary model block scheme reported in Figure 2, the Table 2 summarizes the input and output parameters considered in both cases.

Table 2 - Direct and Reverse Approaches Input and Output Parameters for preliminary LPT Data System Analysis

Direct Approach		**Reverse Approach**	
Input Parameters	**Ordered Output Parameters**	**Input Parameters**	**Ordered Output Parameters**
η_0, Solar Panel Efficiency	P_1, Generated Power	P_4, Final User Available Power	$\eta_{3,2}$, Collecting Conversion Efficiency
I_R, Solar Radiance	P_2, Emitted Power	D_p, Projecting Beam Diameter	P_3, Collected Power
A_1, Emitting Surface of Solar Panels	$\eta_{3,2}$, Collecting Conversion Efficiency	D_c, Collected Beam Diameter	P_2, Emitted Power
$\eta_{2,1}$, Laser system Conversion Efficiency	P_3, Collected Power	r, Relative Distance Emitter - Receiver	P_1, Generated Power
D_p, Projecting Beam Diameter	P_4, Final User Available Power	λ, Power Beam Wavelength	A_1, Emitting Surface of Solar Panels
D_c, Collected Beam Diameter		η_0, Solar Panel Efficiency	
r, Relative Distance Emitter - Receiver		I_R, Solar Radiance	
λ, Power Beam Wavelength		$\eta_{2,1}$, Laser system Conversion Efficiency	
$\eta_{4,3}$, Final User Conversion Efficiency		$\eta_{4,3}$, Final User Conversion Efficiency	

Thanks to the direct approach, a sensitivity analysis of P_4 (Power Available for systems) as a function of A_1 (Solar Panel Area) has been carried out. Figure 4 reports the linear trend (based on the preliminary LPT system model) of $P_4 = P_4(A_1)$, by using Nd:YAG laser for Moon applications ($\eta_{3,2}$ resulted equal to 1, according with the lack of a consistent atmosphere).

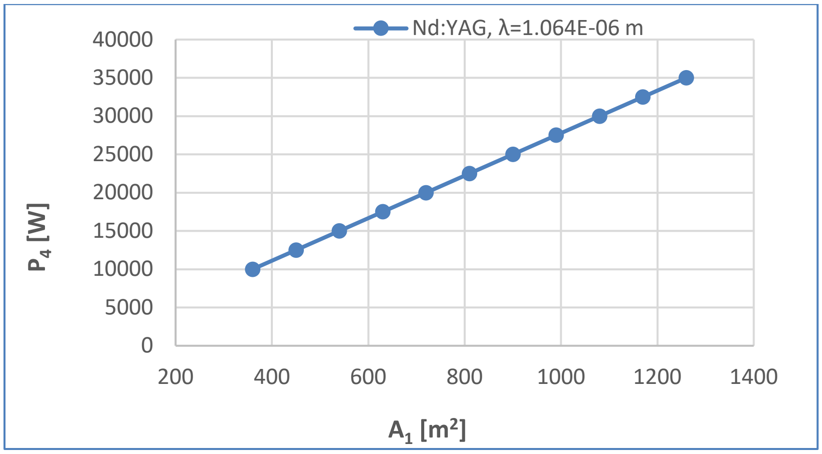

Figure 4 - Lunar Final User Power as a function of Satellite Solar Panel Area, $P_4=P_4(A_1)$

Conclusions

Referring to the challenge of the continuous empowering of Moon ISRU assets, the CIRA TEES laboratory developed a multi-step approach to conduct a preliminary feasibility study of a Solar Laser Power Transmission System for the power delivery across long distances, starting from an orbiting satellite.

At the current state, interesting results have been achieved in terms of the trend of the identified final user (rover system) available power as a function of the solar photovoltaic panels emitting area (/s, if more satellites will be considered in a more advanced system). The next step of this work will account the optimization of design parameters, such as the satellite orbit selection.

References

[1] M. Baldry, N. Gurieff, D. F. Keogh, “Imagining Sustainable Human Ecosystems with Power-to-x in-situ Resource Utilisation Technology”, 4 November 2022. https://doi.org/10.20944/preprints202111.0508.v1

[2] In-Situ Resource Utilization Gap Assessment Report, International Space Exploration Coordination Group (ISECG), NASA, 2021

[3] M. F. Palos, P. Serra, S. Fereres, K. Stephenson, R. Gonzales-Cinca, “Lunar ISRU energy storage and electricity generation”, Acta Astronautica Journal, Volume 170, May 2020, Pages 412-420. https://doi.org/10.1016/j.actaastro.2020.02.005

[4] NASA Intrepid Planetary Mission Concept Study Report, 2020

[5] C. Cougnet, E. Sein, A. Celeste, L. Summerer, “Solar Power Satellites For Space Exploration And Applications”. November 2004

[6] Global Exploration Roadmap, GER, ISECG (globalspaceexploration.org), Posted on 23 May, 2023

[7] N. Favaloro et al., “Enabling Technologies for Space Exploration Missions: the CIRA-TEDS Program Roadmap Perspective”, Aerotecnica Missili & Spazio, Springer Nature, June 2023. https://doi.org/10.1007/s42496-023-00159-4