FY25 CIF/IRAD Project End of Fiscal Year Closeout: Summary Overview of Accomplishments and Highlights to Date

Orbital Power Beaming to Provide Increased Mobility, Flexibility, and Science Measurements on the Lunar Surface

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Executive Summary: One of the biggest challenges facing the expansion of lunar surface exploration is access to a reliable and flexible power source for purposes of surviving lunar night and exploring permanently shadowed regions. The **Orbital Power Beaming Assets for Lunar Applications (OPAL)** project is a concept development effort led by engineers at NASA's Langley Research Center (LaRC) that seeks to tackle this challenge by advancing optical power-beaming technologies to enable the transmission of energy via lasers as an alternative to the power needs of lunar surface missions. In FY25, the OPAL team focused on developing a preliminary concept of operations and top-level requirements for a fully operational focusable, power-tunable, and fine-pointing capable optical power beaming system. To accomplish this, the team developed a framework to analyze complex power beaming trade spaces through an Integrated Optical Power Beaming Analysis Methodology that comprises different fields, including mission design, optical physical beam propagation modeling & simulation, parametric vehicle sizing, systems-of-systems analysis, and architecture impact analysis. The insights gained during this activity revealed technology gaps and challenges that act as next steps for power beaming research and development. Now, the OPAL team is moving forward with a technology development proposal to further mature the concept and increase its technology readiness level (TRL) towards a future in-space demonstration.

Background: Optical power beaming has been in development for years, with investments in studies and technology developments made by NASA, other government agencies (OGAs), and private and academic institutions in the United States and abroad. Subsystem developments have included design and test activities including high-power laser architectures, optical/laser power converters (receivers), short-range, low-power terrestrial demonstrations, and one publicly known short-range, low-power in-space demonstration. In increasing the end-to-end efficiency of optical power beaming systems, an emphasis has been made in the DC-to-optical power conversion (at the laser) and optical-to-DC power conversion (at the receiver). However, an important parameter known as the Power-in-the-Bucket (PIB) – a measure of how much of the propagated beam enters the receiver – has been typically overlooked. The ability to focus the optical beam and maintain fine-pointing can increase the PIB and the pointing efficiency. Furthermore, the ability to tune the power of the beam can enable a multi-client power servicing capability – i.e., a single spacecraft capable of delivering a range of optical power levels to various clients on the lunar surface. This technology improvement can be accomplished by developing a focusable, power-tunable, and fine-pointing optical power beaming payload.

Plan & Objectives: The original objectives in the OPAL FY25 effort were to develop top-level requirements for a future operational system and to develop a preliminary Concept of Operations (ConOps) for said system. The OPAL team accomplished these objectives by refining their existing analysis methodology and integrating new capabilities, namely optical physical propagation simulations, optical system design, and cost analysis. Now known as the Integrated Optical Power Beaming Analysis Methodology, the OPAL team has also established a unique capability in the agency for optical power beaming analysis.

Partnerships: Early in FY25, OPAL leveraged the optical and power beaming expertise from Subject Matter Experts in LaRC's Remote Sensing Branch. Later in FY25, the team joined the Space Technology Mission Directorate Broadcast Energy Transmission (BET) study through which the team has established a working partnership with other power beaming groups at Glenn Research Center, Marshall Space Flight Center, and the Jet Propulsion Laboratory.

Impact & Knowledge Gained:

- Developed top-level requirements for a future optical power beaming system.

- Refined ConOps for a future optical power beaming system.
  - Traded different orbital regimes and assessed downstream mission impacts.
- Developed the Integrated Optical Power Beaming Analysis Methodology
  - Created a Client-Constellation Analysis Framework to study dedicated or multi-client servicing formats and impacts to vehicle sizing, laser power requirements, and ConOps.
  - Obtained insight into end-to-end system efficiency improvement opportunities (namely PIB and pointing efficiency), optical physical beam propagation, optical system design, and spacecraft-level design considerations.
  - Performed a preliminary cost estimate of optical power beaming system.
- Supporting the STMD Broadcast Energy Transmission (BET) Study.
- Developing a NASA Early Career Initiative (ECI) FY27 Project Proposal to advance optical power beaming technologies.
- Recent Publications:
  - Orbital Power Beaming to Provide Increased Mobility, Flexibility, and Science Measurements on the Lunar Surface - NASA Technical Reports Server (NTRS)
  - Orbital Power-Beaming Assets for Lunar Applications (OPAL) - NASA Technical Reports Server (NTRS)
  - Orbital Power-Beaming: An Alternative for Power-Restricted Regions on the Lunar Surface - NASA Technical Reports Server (NTRS)
  - Orbital Power Beaming Assets for Lunar Applications 2025 Concept Video - NASA Technical Reports Server (NTRS)

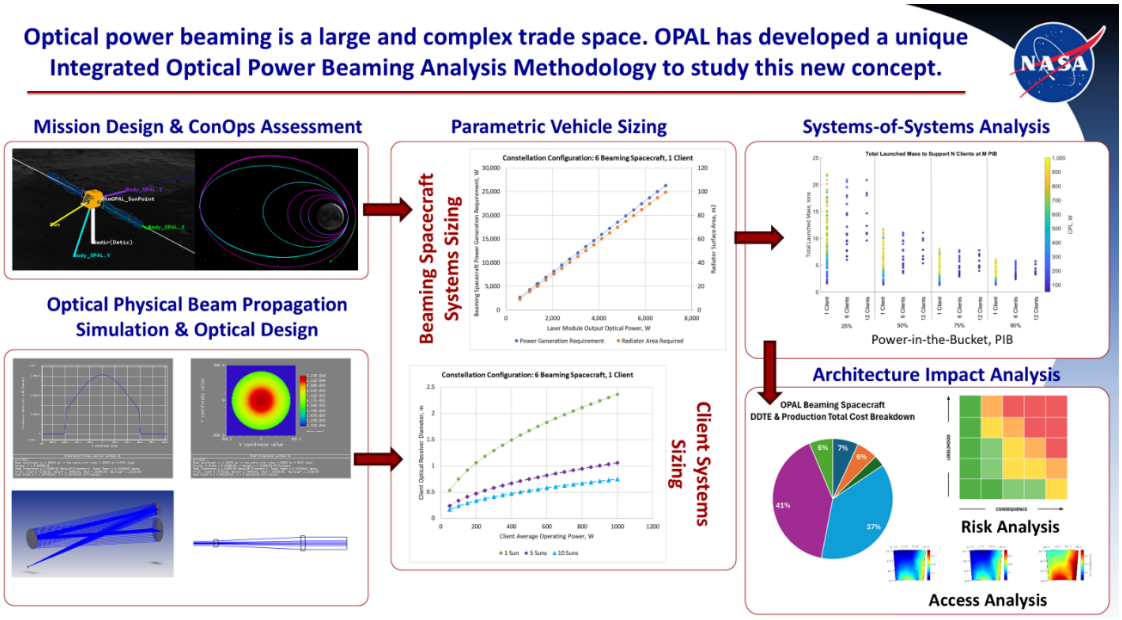


Figure 1. Integrated Optical Power Beaming Analysis Methodology developed by the OPAL team.

Technology Maturation Opportunities: The OPAL team is now seeking a NASA ECI project for FY27 to continue maturing the technology. The goal of this proposed effort is to design a preliminary **optical power beaming payload** at the **technology demonstration scale** that can achieve increased beam focusability, power-tuning, and fine-pointing at long ranges to increase end-to-end optical power beaming system efficiency. With combined investments from LaRC and STMD, OPAL has matured the concept to TRL 2. Through the proposed ECI project, the OPAL team plans to increase the concept to TRL 3. For this ECI effort, the team will partner with other NASA centers and industry partners specializing in other areas of the optical power beaming system such as the laser, optical receivers, power system designs, and telescope design.

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