mPower TECHNOLOGY

SPACE POWER FOR THE MOON AND BEYOND

AN MPOWER TECHNOLOGY WHITE PAPER

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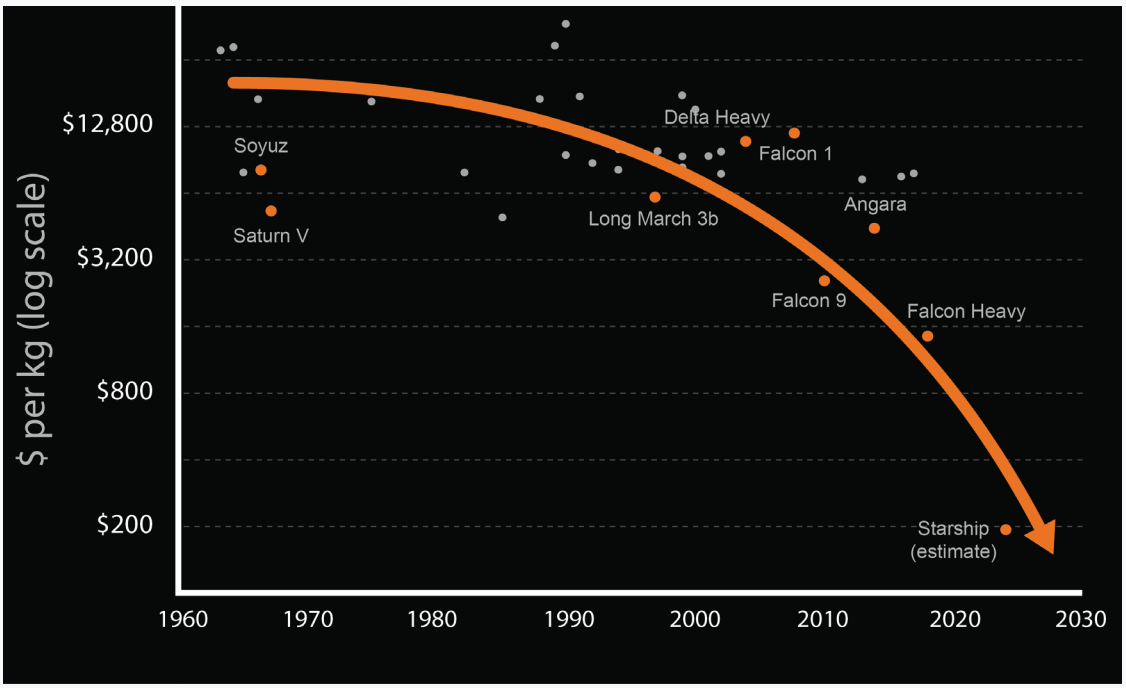
POWER FOR THE MOON AND BEYOND

Commercial and government activity in space is experiencing exponential growth, fueled by rapidly increasing levels of investment and the simultaneous decline of launch costs. Ambitious Space 2.0 programs, once deemed impossible just a few years ago, are now not only being contemplated but are being funded and built.



Space 2.0 programs are growing exponentially due to rapidly declining launch costs

Many of these programs are focused on missions in Earth's orbit, such as broadband communications and Earth observation, but there are many well-funded government and commercial programs moving beyond the cradle of Earth's orbit to focus on the Moon and eventually, by extension, Mars.

Interest in a lunar economy has skyrocketed over the past few years. The Artemis program (led by the international space agencies NASA, ESA, JAXA, and others) has been a major driver, handing out major contracts to companies like SpaceX, Blue Origin, and others for services spanning launch, payload delivery, communications, construction, and power on the lunar surface. With the goal of returning humankind to the Moon and establishing a permanent lunar presence, Artemis is comprised of several individual programs including the SLS heavy launch system, the Gateway space station (below), a Human Landing System, the Orion spacecraft, and a lunar Artemis base camp.

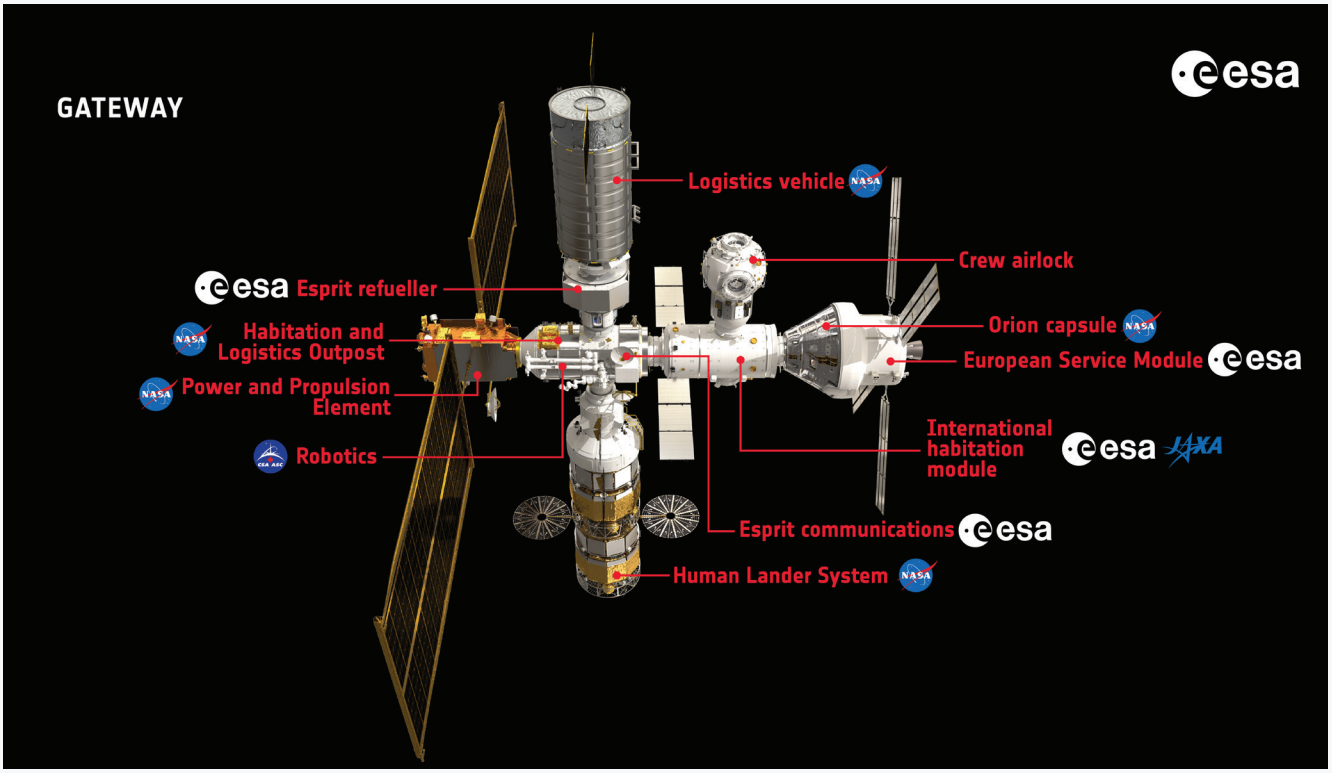


Image source: European Space Agency

But, if government initiatives are leading the charge, the private markets are not far behind. In a report published last year, McKinsey & Co. found that the share of private investment into the space economy that's focused on "lunar and beyond" initiatives has steadily risen, accounting for 10-15% of overall private investment into space-related companies.

While commerce is a significant driver, international competition and security also critically drive these programs. Being able to observe, control and secure navigation in near-Earth, cis-lunar space is critical to maintaining safe passage and a key priority for many governments.

We are at the beginning of an exciting new chapter of exploration for the Moon and beyond, and it will require significant amounts of space power.

There are two fundamental approaches to power generation in space - nuclear and solar. For deep space missions in very low-light conditions such as those beyond Jupiter, nuclear power is the only option. However, for most all other missions closer to the sun, solar is the preferable option, offering superior cost, schedule, availability, and safety and reliability.

Solar solutions for the Moon and beyond require a low-cost, lightweight, highly scalable source of power that is resilient, efficient and requires minimal maintenance.

ENTER DRAGONSCALES™

DragonSCALES from mPower Technology is ideally suited for these extraterrestrial missions, offering an unmatched set of combined advantages. Consider the following benefits of DragonSCALES:

1. **Low cost:** Power systems for lunar missions and beyond need to reach highly efficient dollar per watt targets to ensure missions remain economically viable. DragonSCALES modules combine low-cost terrestrial silicon cells at <$0.25 per watt with high-volume microelectronics assembly processes. The result is cost-effective modules that are more than five times less expensive when compared to traditional gallium arsenide (GaAs)-based solutions.

2. **Extremely high production rates and volumes:** Power requirements for target lunar and other deep-space missions (mining, manufacturing, etc.) are significant and hence power solutions must be produced rapidly at immense scale. DragonSCALES modules are based on terrestrial silicon cells that are readily available off the shelf with annual volumes exceeding 200 gigawatts per year in 2022 and increasing at >30% per year. Optimized DragonSCALES modules and structures can be built and deployed rapidly at gigawatt per year scale within 12-24 months.

3. **Resilience and reliability:** As a critical mission enabler, power systems for landed and deep-space missions need to be highly reliable and resilient. They must be able to tolerate multiple deploy/stow/redeploy cycles, environmental damage (e.g., micrometeorites), shading, and other faults and continue to function with graceful degradation. They must also operate in dust-filled environments and support various dust mitigation approaches. Using massively parallel and redundant interconnects, DragonSCALES are built with a highly redundant, resilient architecture that compartmentalizes faults and damage to minimize system impact, resulting in highly resilient and reliable power delivery.

4. **Low mass:** While launch costs have been significantly reduced, the ability to provide maximum power at lowest mass is critical, particularly for distant destinations such as the Moon and Mars. DragonSCALES provides lower mass/higher power output by using highly efficient silicon solar cells in an architecture that reduces the use of metal traces in the stack and minimizes back side wiring.

5. **Modularity:** System components need to be readily serviceable and replaceable to allow rapid expansion and replacement as needed. DragonSCALES is inherently suited for this, enabling highly modular power systems that can be constructed with self-contained, high-voltage solar arrays and rapidly coupled with other sections to form large-scale power systems.

6. **Cold performance:** Many of the lunar and Martian operating environments are extremely cold and will require power systems that can operate efficiently in these conditions. Silicon-based power systems using DragonSCALES will inherently operate at higher efficiencies in cold environments such as in shadowed lunar craters.

LOOKING TO THE FUTURE

In Situ Power System Manufacturing - While early exploration missions can be carried out with small, energy-efficient systems, later stage missions will require large power systems capable of multi-megawatt to gigawatt output for activities as manufacturing, mining, material processing, fuel production, infrastructure construction and prolonged habitation. A long-term, sustained presence on the Moon (and eventually Mars) will require a robust power infrastructure that can leverage local materials to reduce launch costs and logistics. A recent experimental demonstration of solar cell fabrication from lunar regolith demonstrates what may be possible.

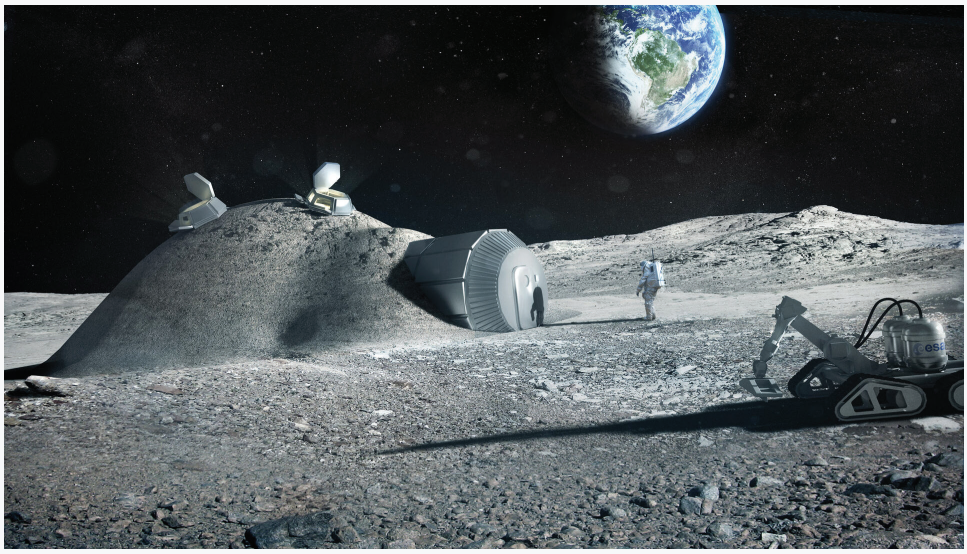


Image source: European Space Agency

Image source: Blue Origin

The eventual large-scale production of solar cells using materials sourced beyond Earth (in orbit or in landed bases) will dramatically increase the scale of potential power production in space and enable the broad range of power-demanding activities mentioned above.

Power Distribution through Power Beaming - Power beaming will enable centralized generation and distribution of power much as it is on Earth. With power beaming, power can be transmitted to the desired location, rather than having to build power systems at each location and/or having to lay down wire-based connectivity across large distances and very challenging environments. Even though some energy is lost due to transmission, power beaming more than compensates by removing the costs for heavy, expensive cables and the costs of launching and landing massive structures. What's more, the power receivers for power beaming systems can harvest solar energy when available and can provide thermal energy in colder locations as needed. The following document captures more on how DragonSCALES is ideally suited for power beaming systems: Space-based Solar Power White Paper.