



Energy + SPACE

Turning to space – Dawn
of a new age of energy



**ENERGY AND UTILITIES COMPANIES
HAVE SIGNIFICANT OPPORTUNITY TO
LEVERAGE SPACE CAPABILITIES IN THE
MANAGEMENT AND OPTIMIZATION OF
THEIR ASSETS.**

—JACOB HACKER, HEAD OF STRATEGY AND ENABLEMENT, AUSTRALIA

SETTING THE STAGE

Why is the Energy +Space intersection important?

The energy sector is undergoing a long-term transformation toward diversification. At the same time, the pace of innovation is driving a relentless demand for energy. This tension creates a perfect environment for innovation with precision, where even incremental change can have significant impact. Within this context, energy leaders don't need to look far to find a wealth of opportunity; they just need to look up.

The intersection of Energy +Space is not new, but it is nascent. The growing momentum of the commercial space sector is opening up new possibilities. This synergy is critical for leveraging mutual advancements, boosting efficiency, enhancing sustainability, and achieving technological breakthroughs.

For energy organizations, the intersection with the space sector offers a pathway to revolutionary advancements in operations, digitalization, and hardware. Space companies, with their expertise in areas such as advanced manufacturing, robotics, and material science, are well positioned to address some of the most pressing challenges in the energy sector. Earth observation (EO) reveals insights previously unavailable through continuous monitoring and evolving imaging capabilities. By integrating space technologies, energy organizations can enhance their operational efficiency, reduce costs, and develop more sustainable practices.

From an executive-level perspective, the Energy +Space intersection presents a strategic opportunity to drive long-term growth and resilience. Executives in the energy sector can harness the innovative spirit of the space industry to foster a culture of continuous improvement and technological agility. This collaboration can also open new revenue streams and market opportunities, as energy companies diversify their portfolios by adopting cutting-edge space technologies. Moreover, the alignment with the space sector can enhance the company's reputation as a forward-thinking leader in sustainability and innovation, attracting investors and stakeholders who value long-term, impactful solutions.

By embracing this convergence, energy executives can ensure their companies remain competitive, resilient, and at the forefront of technological advancements. The potential benefits are vast, from operational efficiencies to new business models, making this intersection a key strategic priority for the future of the energy sector.

NOW: PRESENT-2 YEARS

Developments to be aware of

The space industry is experiencing rapid advancements, driven by both private and public sector initiatives. Key trends include the resurgence of lunar exploration, with multiple uncrewed landings planned by private companies and national agencies. The development of reusable rockets continues to reduce the cost of access to space. Additionally, advancements in satellite technology are enhancing EO capabilities, providing critical data for climate monitoring and disaster management to mitigate disruption to energy operations and service.

Another significant trend is the investment in space-based infrastructure, which aims to support long-term operations and markets beyond Earth. Energy solutions are a critical part of this off-planet infrastructure. For example, the use of 3D printing for energy infrastructure components can lead to significant cost savings and increased reliability, while advanced materials developed for space applications can improve energy storage and transmission capabilities.

Moreover, the collaboration between space and energy sectors is fostering innovative technologies that benefit both fields. Coupled with cutting-edge advancements in quantum technologies and robotics, these initiatives are set to revolutionize how we generate, store, and utilize energy, contributing to a more sustainable and resilient future.

Relevant space technologies impacting the energy sector



Solar cell technology: Space has historically been on the leading edge of solar power—driven by the constraints of weight, form factor, and extremely harsh environmental conditions—which has significantly accelerated the viability of an Earth-based solar energy market.



Advanced EO systems: These systems provide real-time data for monitoring energy infrastructure, detecting leaks, and optimizing resource management.¹



Thermal control systems: Managing temperature control and reducing heat loss through space-derived insulation solutions is driving energy efficiency.

Manufacturing advancements bridging energy and space



Additive manufacturing: Space companies are utilizing 3D printing to produce complex components for spacecraft and energy infrastructure, reducing costs and increasing efficiency.^{2,3}



Advanced materials: Development of lightweight, durable materials for use in both space and energy applications.²



Robotics and automation: Implementing robotic systems for self-assembly, maintenance, and monitoring in space and energy facilities.²

NEAR: 3-5 YEARS

Early-mover opportunities

In the near term, early movers will start to notice more opportunities for technology transfer, partnerships, and value-add services among other strategies. Space technology is evolving in both hardware—from sensor and chip advancements to miniaturization—and software such as modeling and predictive analytics. The energy sector will see EO services evolving and becoming more customized to the industry’s changing needs.

Solar power, energy storage, and materials science innovations have been trickling in steadily from space into the energy sector. Additionally, advancements in in-space manufacturing and assembly, energy storage, and quantum technologies are expected to enhance the efficiency and sustainability of energy infrastructure on Earth.

As these technologies mature, the world’s largest energy companies are beginning to recognize the strategic importance of integrating space-based solutions into their operations. By leveraging advancements in space technology, these companies can achieve greater efficiency, resilience, and sustainability, positioning themselves as leaders in the transition to a more sustainable energy future.



Anticipated developments

Projected advancements in space technology

The next few years will bring several milestones in demonstrating new energy systems and the establishment of a sustainable infrastructure in space to support new markets. Key developments include:

- **SBSP:** Advancements in wireless power transmission and solar panel efficiency will make SBSP a viable energy source.⁶
- **In-space assembly and manufacturing (ISAM):** Enhanced capabilities for robotic assembly and manufacture of components in microgravity, leading to superior material properties, and breakthroughs in form factor and performance.⁷
- **Energy storage:** Improved energy storage is enabling the development of microgrids, more efficient electric powered vehicles, and broader adoption of renewable energy.

- **Quantum technologies:** Development of quantum communication and sensing technologies for enhanced energy security and efficiency.⁸

Influence on the Energy sector

These advancements will enable the energy sector to achieve greater efficiency, sustainability, and resilience. For example, SBSP can provide a continuous and abundant energy source, reducing reliance on terrestrial energy production. In-space manufacturing can lead to the creation of more efficient energy components, while advanced EO systems can optimize resource management and infrastructure maintenance.

Projected advancements in space technology and anticipated impacts:

Technology	Anticipated advancements	Anticipated impacts
In-space assembly and manufacturing	Enhanced robotic assembly and autonomous operations	Superior material properties, and more efficient form factors
Energy storage	Microgrid proliferation	Failsafe backup power that can integrate different power sources and adapt output to demand
Quantum technologies	Development of quantum communication and sensing	Enhanced energy security and efficiency



Playbooks for companies
in the energy sector

EARLY-STAGE COMPANIES

- Focus on niche markets:**
Identify specific areas where space technology can provide a competitive advantage, such as advanced materials or additive manufacturing.
- Leverage government grants:**
Apply for grants and funding opportunities to support R&D efforts in space-related technologies.
- Build strategic partnerships:**
Collaborate with established space companies to gain access to technology and expertise.

MID-STAGE COMPANIES

- Expand R&D capabilities:**
Invest in in-house R&D to develop proprietary space-based manufacturing technologies.
- Adopt advanced manufacturing techniques:** Implement additive manufacturing and digital twins to enhance production efficiency and product quality.
- Explore new markets:** Identify and enter new markets where space technology can provide a competitive edge.

MATURE COMPANIES

- Diversify product offerings:**
Develop new products and services that leverage space technology, such as space-grade materials or energy components.
- Invest in infrastructure:**
Upgrade manufacturing facilities to accommodate advanced space-based manufacturing techniques.
- Form industry consortia:** Lead or join industry consortia to drive the adoption of space technology across the sector.



NEXT: 5-10 YEARS

Transformative technologies in a dynamic environment

The integration of space-based innovations into the energy sector will become increasingly critical over the next decade. These technologies promise to enhance efficiency, sustainability, and resilience, positioning the energy sector to meet the growing demands of a rapidly changing world.

Other external factors such as geopolitics and major infrastructure directives will continue to incentivize optionality of energy sources and backup systems to minimize economic disruptions and increase national security.

Diversification of energy sources being explored for different space-based applications will likely start to develop terrestrial markets and be adopted by leading energy companies and governments seeking affordable and reliable energy for their citizens. New entrants focused on energy solutions for space will identify adjacent markets that allow them to scale and further mature their technology. What will this look like in practice, and how can today's energy leaders plan to be ahead in the next ten years?



Identification of key technologies

SBSP

SBSP involves harvesting solar energy in space and transmitting it to Earth. This technology has the potential to provide a continuous and abundant energy source, independent of weather conditions and daylight hours. Recent advancements in wireless power transmission and solar panel efficiency are bringing SBSP closer to practical implementation.⁹

IMPACT ON THE ENERGY SECTOR

Continuous energy supply: SBSP can provide a reliable and uninterrupted energy source, reducing reliance on terrestrial energy production and enhancing energy security.

Decarbonization: By harnessing solar energy in space, SBSP can significantly reduce greenhouse gas emissions, contributing to global decarbonization efforts.

Cost efficiency: Over time, the cost of SBSP is expected to decrease, making it a competitive alternative to traditional energy sources.

Nuclear power

Nuclear power is experiencing a renaissance, driven by the need for clean, reliable energy and advancements in reactor technology. Space-specific nuclear developments, including small fission reactors and radioisotope power systems, are pushing the boundaries of exploration and enabling long-duration missions. These innovations are also influencing terrestrial applications, promising more efficient and versatile nuclear energy solutions.¹⁰

IMPACT ON THE ENERGY SECTOR

Expanding applications: Nuclear technology is finding new uses beyond traditional power generation, including in agriculture and water desalination.

Powering data centers: With the growing demand for data centers, Small Modular Reactors are being adopted as a potential continuous, carbon-free solution for our growing demand for computer processing power.

Hybrid energy networks: Nuclear is increasingly integrated with renewables and storage for grid stability.



Reimagined energy infrastructure

Space-derived innovations will fundamentally transform energy infrastructure, enabling decentralized, adaptive, and ultra-resilient systems. Drawing from spacecraft design principles, material science breakthroughs, and orbital data integration, future energy grids will prioritize modularity, self-repair, and seamless fusion of terrestrial and space-based resources.¹¹

IMPACT ON THE ENERGY SECTOR

Modular, portable power systems: Inspired by spacecraft design, energy infrastructure will shift to hybrid, plug-and-play microgrids and portable reactors.

AI optimized grid: Satellite-derived hyperspectral imaging and quantum communication networks will feed AI models to predict and balance energy flows. Autonomous systems will reroute power during outages.

Infrastructure resilience: Space-hardened technology will fortify critical energy infrastructure assets against extreme weather and even electromagnetic pulses.

HARNESSING ENERGY FROM SPACE IS NOT SCIENCE FICTION, IT'S A REALITY WE ARE ACCELERATING TOWARD. MOMENTUM IN COMMERCIAL SPACE IS USHERING IN NEW TECHNOLOGIES AND A NEW ERA OF ENERGY RESILIENCE AND DIVERSIFICATION, MAKING HARNESSING POWER BEYOND EARTH NOT JUST POSSIBLE BUT ESSENTIAL TO REMAINING COMPETITIVE.

—ANGELA GILDEA, US ENERGY SECTOR LEAD

Projected advancements in space technology and anticipated impacts:

Technology	Anticipated advancements	Anticipated impacts
SBSP	Improved wireless power transmission and solar panel efficiency	Continuous and abundant energy source, reduced reliance on terrestrial energy
Nuclear power	Carbon-free energy solutions	Development of adjacent markets
Reimagined energy infrastructure	Hybrid, modular energy grids	Resilient energy systems in the face of extreme weather and threats from bad actors



Starting ahead of the curve

The next five to ten years will be a period of significant transformation for the energy sector. Many advancements in energy production, storage, and distribution will be driven by innovations in space technology. Materials science, space-derived renewable solutions, ISAM, and advanced EO systems are poised to reconfigure the energy economy. These technologies offer unique benefits, from providing continuous and abundant energy sources to optimizing resource management and infrastructure maintenance.

Scenario planning

Future scenarios incorporating space-derived tech

SCENARIO 1: SBSP

In 2030, a major energy company successfully deploys a fleet of satellites equipped with advanced solar panels to harvest solar energy in space. The energy is transmitted wirelessly to Earth, providing a continuous and abundant power supply to millions of homes. This breakthrough reduces the company's reliance on fossil fuels and significantly lowers greenhouse gas emissions.

Impact: Continuous energy supply, reduced carbon footprint, enhanced energy security

SCENARIO 2: IN-SPACE MANUFACTURING

By 2028, an energy company partners with a space manufacturing firm to produce advanced energy components in microgravity. These components, with superior material properties, are used to upgrade the company's energy infrastructure, resulting in increased efficiency and reduced maintenance costs.

Impact: Enhanced material properties, cost reduction, improved infrastructure performance

SCENARIO 3: ADVANCED EO SYSTEMS

In 2027, an energy company implements a network of advanced EO satellites to monitor its infrastructure in real time. The data collected helps the company optimize resource management, detect leaks early, and improve maintenance schedules, leading to significant cost savings and increased operational efficiency.

Impact: Optimized resource management, early issue detection, cost savings

SCENARIO 4: QUANTUM TECHNOLOGIES

By 2030, an energy company adopts quantum communication and sensing technologies to enhance its energy security and efficiency. These technologies enable secure data transmission and precise monitoring of energy systems, reducing the risk of cyberattacks and improving overall system reliability.

Impact: Enhanced energy security, improved system reliability, reduced cyber risks

SCENARIO 5: SPACE-BASED ENERGY STORAGE

In 2029, an energy company develops a space-based energy storage system using advanced materials produced in microgravity. This system provides a reliable backup power source, ensuring uninterrupted energy supply during peak demand periods and emergencies.

Impact: Reliable backup power, uninterrupted energy supply, enhanced grid stability

Future scenarios of changes to daily life

SCENARIO 1: CLEAN ENERGY FOR ALL

By 2030, households across the globe benefit from SBSP, enjoying a continuous and clean energy supply. This reduces electricity costs and contributes to a significant decrease in air pollution, improving public health and quality of life.

Impact: Lower electricity costs, improved air quality, better public health.

SCENARIO 2: SMART HOMES AND CITIES

In 2028, advanced EO systems enable the development of smart homes and cities. Real-time data on energy usage and environmental conditions helps optimize energy consumption, reduce waste, and enhance urban planning.

Impact: Optimized energy consumption, reduced waste, improved urban planning

SCENARIO 3: ENHANCED DISASTER RESPONSE

By 2027, real-time monitoring of energy infrastructure using advanced EO systems allows for quicker and more effective disaster response. This minimizes the impact of natural disasters on energy supply and ensures rapid recovery.

Impact: Quicker disaster response, minimized impact on energy supply, rapid recovery

SCENARIO 4: SECURE AND EFFICIENT ENERGY SYSTEMS

In 2030, quantum technologies provide households with secure and efficient energy systems. These technologies ensure that energy data is transmitted securely, reducing the risk of cyberattacks and enhancing system reliability.

Impact: Secure energy systems, reduced cyber risks, improved reliability

SCENARIO 5: SUSTAINABLE LIVING

By 2029, space-based energy storage systems enable households to store excess energy generated from renewable sources. This promotes sustainable living by reducing reliance on nonrenewable energy and ensuring a stable energy supply.

Impact: Sustainable living, reduced reliance on nonrenewable energy, stable energy supply

Potential consumer impacts and societal benefits



Lower energy costs: Space-based energy solutions can reduce energy costs for consumers by providing a continuous and abundant energy supply.



Improved air quality: Reduced reliance on fossil fuels can lead to improved air quality and better public health.



Enhanced energy security: Advanced technologies such as quantum communication can enhance energy security and reduce the risk of cyberattacks.



Sustainable living: Space-based energy storage systems can promote sustainable living by reducing reliance on nonrenewable energy sources.



Disaster resilience: Real-time monitoring of energy infrastructure can improve disaster response and recovery, minimizing the impact of natural disasters.

THE FUTURE OF ENERGY IS INTERCONNECTED WITH SPACE EXPLORATION: THE PAPER OUTLINES A TIMELINE OF POTENTIAL ADVANCEMENTS IN SPACE-BASED ENERGY TECHNOLOGIES, HIGHLIGHTING THE SIGNIFICANT IMPACT THESE INNOVATIONS WILL HAVE ON THE ENERGY SECTOR AND SOCIETY AS A WHOLE.

—ANISH DE, KPMG GLOBAL HEAD OF ENRC

CALL TO ACTION – LEADERSHIP CONSIDERATIONS

The integration of space-derived technologies into the energy sector is not just a futuristic vision but a present-day reality with transformative potential. As the global space economy continues to expand, reaching an estimated \$1.8 trillion by 2035,¹ the energy sector stands at the cusp of a new era of innovation and sustainability. From SBSP to advanced EO systems, these technologies promise to enhance efficiency, resilience, and sustainability, positioning the Energy sector to meet the growing demands of a rapidly changing world.

Leadership in the energy sector must recognize the strategic importance of these advancements and take proactive steps to integrate space-based solutions into their operations. By investing in research and development, forming strategic partnerships, and adopting new business models, energy companies can leverage space-based technologies to drive innovation and sustainability.

This call to action outlines actionable insights and strategic considerations for business executives in the energy industry, providing a roadmap for navigating the evolving landscape of the space economy.

The following are detailed insights into the anticipated developments, early-adoption strategies, and practical implications of integrating space-derived technologies into the energy sector. Each horizon includes actionable recommendations for leaders to prepare and adapt, ensuring that their organizations are well positioned to capitalize on the opportunities presented by the space economy.



Now (0–3 years)

Actionable insights

Implement pilot projects: Test the feasibility of spacebased energy solutions through pilot projects.

Upgrade infrastructure: Invest in infrastructure upgrades to integrate space-derived technologies.

Train workforce: Ensure that employees are trained to operate and maintain new technologies.

Adopt advanced monitoring systems: Implement advanced EO systems for real-time monitoring of energy infrastructure.

Collaborate with space industry leaders: Form partnerships with leading space companies to gain access to cutting-edge technologies and expertise.

Explore quantum technologies: Invest in quantum communication and sensing technologies to improve energy security and efficiency.



Near (3–5 years)

Actionable insights

Scale up successful projects: Expand successful pilot projects to full-scale operations.

Develop cost management strategies: Create strategies to manage the costs associated with new technologies.

Implement advanced EO systems: Use satellite-based monitoring systems to optimize resource management and infrastructure maintenance.

Invest in R&D: Continue to allocate resources to research and development of space-based energy solutions.

Form industry consortia: Lead or join industry consortia to drive the adoption of space technology across the sector.

Adopt new business models: Develop new business models to capitalize on the benefits of space-derived technologies.



Next (5–10 years)

Actionable insights

Fully integrate space-based solutions: Ensure that space-based energy solutions are fully integrated into existing operations.

Continuously innovate: Stay ahead of technological advancements by continuously innovating and adopting new technologies.

Develop new revenue streams: Identify and develop new revenue streams based on space-derived technologies.

Focus on sustainability: Promote sustainable living by reducing reliance on nonrenewable energy sources.

Enhance energy security: Use advanced technologies such as quantum communication to enhance energy security and reduce the risk of cyberattacks.

Improve disaster resilience: Implement real-time monitoring of energy infrastructure to improve disaster response and recovery.

TIMELINE OF POTENTIAL ADVANCEMENTS

ENERGY +SPACE (2025-2035)

2025

Sbsp demonstrations: Initial demonstrations of space-based solar power systems, capturing solar energy in space and transmitting it to Earth.

Advanced energy storage in space: Development of high-capacity energy storage systems designed for space applications, improving energy availability for space missions.

Microgrid technologies for space stations: Implementation of microgrid technologies to manage energy distribution efficiently on space stations.

Space-based hydrogen production: Utilizing solar energy in space to produce hydrogen, a clean fuel, through electrolysis.

Satellite-assisted renewable energy forecasting: Using satellite data to improve the accuracy of renewable energy production forecasts on Earth.

2026

Nuclear fusion reactors in space: Testing small-scale nuclear fusion reactors in space to provide a reliable and powerful energy source for long-duration missions.⁶

Space-based energy harvesting: Developing technologies to harvest energy from cosmic rays and other space phenomena.

Enhanced solar panel efficiency: Creating ultra-efficient solar panels using materials and technologies developed in space.

Space-based energy transmission: Advancing wireless energy transmission technologies to send power from space to remote areas on Earth.

Energy-efficient space habitats: Designing space habitats with integrated energy-efficient systems to support long-term human presence.

2027

Space-based geothermal energy exploration: Using space-based sensors to identify geothermal energy sources on Earth.

Advanced battery technologies: Developing next-generation batteries in space with higher energy densities and longer lifespans.

Space-enhanced wind energy: Utilizing satellite data to optimize the placement and operation of wind turbines on Earth.

Space-based carbon capture: Implementing carbon capture technologies in space to reduce greenhouse gas emissions.

Energy harvesting from space debris: Exploring methods to convert space debris into usable energy.

2028

Space-based bioenergy production: Investigating the potential of producing bioenergy in space using algae and other microorganisms.

Advanced thermal management systems: Developing thermal management systems in space to improve energy efficiency in both space and terrestrial applications.

Space-driven smart grid technologies: Enhancing smart grid technologies using data and innovations from space research.

Space-based energy storage solutions: Creating advanced energy storage solutions tailored for space environments.

Space-enhanced hydropower: Using satellite data to optimize hydropower generation and management on Earth.

2032

Space-based energy storage innovations: Developing innovative energy storage solutions tailored for the harsh conditions of space.

Advanced energy harvesting from space environments: Creating technologies to harvest energy from various space environments, including the solar wind.

Space-driven energy efficiency solutions: Implementing energy efficiency solutions developed in space for use in terrestrial applications.

Space-based renewable energy systems: Establishing renewable energy systems in space to support long-term space missions.

Energy harvesting from asteroids: Exploring the potential of harvesting energy from asteroids and other celestial bodies.

2031

Space-based energy distribution networks: Developing networks to distribute energy generated in space to various locations on Earth.

Advanced energy conversion technologies: Creating technologies to convert energy from space-based sources into usable forms on Earth.

Space-enhanced energy security: Using space-based technologies to enhance energy security and resilience on Earth.

Space-based energy research facilities: Establishing research facilities in space dedicated to energy innovation.

Energy harvesting from martian resources: Exploring the potential of harvesting energy from resources on Mars.

2030

Space-based energy storage networks: Establishing networks of energy storage systems in space to support large-scale energy needs.

Advanced energy harvesting technologies: Developing technologies to harvest energy from various space environments, including asteroids and other celestial bodies.

Space-enhanced energy management systems: Creating advanced energy management systems using insights from space missions.

Space-based energy production facilities: Building energy production facilities in space to support long-term space missions and provide energy to Earth.

Space-driven renewable energy innovations: Implementing renewable energy innovations developed in space for use on Earth.

2029

Space-based energy beaming: Demonstrating large-scale energy beaming from space to Earth, providing a new method of energy transmission.

Advanced photovoltaic materials: Developing new photovoltaic materials in space to increase solar energy conversion efficiency.

Space-driven energy efficiency innovations: Implementing energy efficiency innovations in space habitats and transferring these technologies to Earth.

Space-based renewable energy integration: Integrating multiple renewable energy sources in space to create a sustainable energy ecosystem.

Energy harvesting from lunar resources: Exploring the potential of harvesting energy from lunar resources, such as helium-3.

2033

Space-based energy production innovations: Developing innovative energy production methods in space to support human exploration.

Advanced energy storage networks in space: Establishing advanced networks of energy storage systems in space to support large-scale energy needs.

Space-enhanced energy management solutions: Creating advanced energy management solutions using insights from space missions.

Space-based energy research and development: Establishing research and development facilities in space dedicated to energy innovation.

Energy harvesting from lunar and martian resources: Exploring the potential of harvesting energy from resources on the Moon and Mars.

2034

Space-based energy distribution innovations: Developing innovative methods to distribute energy generated in space to various locations on Earth.

Advanced energy conversion technologies in space: Creating technologies to convert energy from space-based sources into usable forms on Earth.

Space-enhanced energy security solutions: Using space-based technologies to enhance energy security and resilience on Earth.

Space-based energy research facilities expansion: Expanding research facilities in space dedicated to energy innovation.

Energy harvesting from celestial bodies: Exploring the potential of harvesting energy from various celestial bodies, including asteroids and comets.

2035

Space-based energy production facilities expansion: Expanding energy production facilities in space to support long-term space missions and provide energy to Earth.

Advanced energy harvesting technologies in space: Developing technologies to harvest energy from various space environments, including the solar wind and cosmic rays.

Space-enhanced energy management systems expansion: Creating advanced energy management systems using insights from space missions.

Space-based renewable energy systems expansion: Establishing renewable energy systems in space to support long-term space missions.

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