Saudi Arabia
Centre for
Space Futures

Pioneering the Future: Space Technologies Poised to Revolutionize Exploration and Economy by 2035

FACTSHEETS

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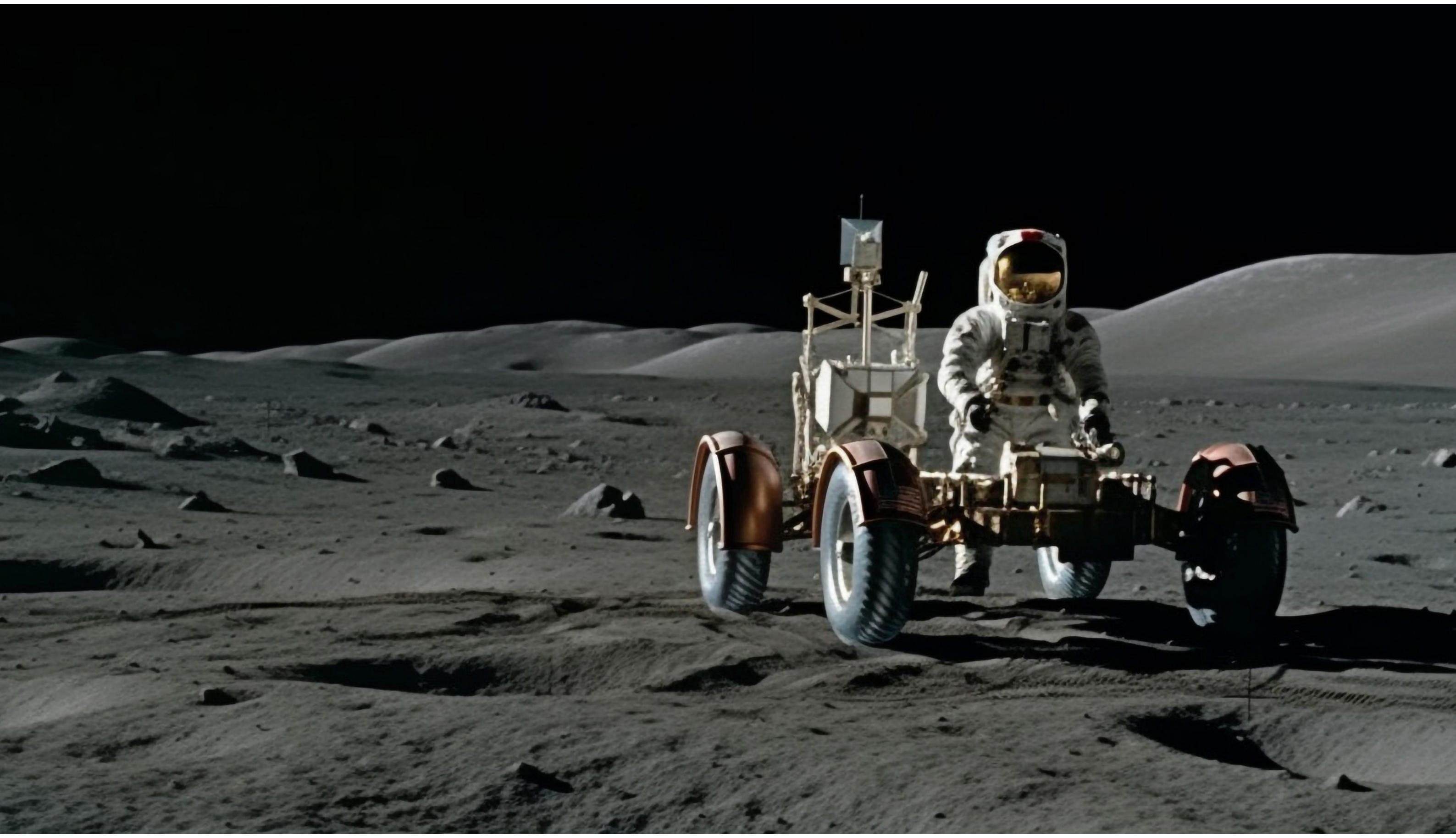
Contents

Introduction

The following factsheets complement the 'Pioneering the Future: Space Technologies Poised to Revolutionize Exploration and Economy by 2035' report developed as part of the Centre for Space Futures' initiative to identify, assess, and accelerate the development and deployment of emerging space technologies. The broader report provides the strategic context, methodology, maturity assessment, market outlook, barriers to adoption, cross-cutting applications, and acceleration measures for each technology area.

The factsheets offer a more concise, accessible snapshot of the key findings to help policymakers, investors, industry leaders, decision-makers, researchers, and technology developers quickly identify the relevance, readiness, and investment potential of each priority technology. Each factsheet summarizes the strategic value proposition, key applications, cross-sector capabilities, readiness levels, market opportunities, development barriers, adoption enablers, and investment outlook of the respective Top-5 technology clusters identified through expert consultation, survey results, and workshop discussions.

The factsheets complement the full report by providing a practical bridge between analysis and action. They translate the report's findings into a decision-support output to help stakeholders identify where space technologies are maturing, where bottlenecks remain, where investment confidence can be strengthened, and where collaboration across public, private, and research ecosystems can accelerate market deployment.



List of Acronyms

Acronym	Definition
5G	Fifth-generation mobile network
6G	Sixth-generation mobile network
AI	Artificial Intelligence
AP&SPS	Advanced Propulsion and Space Power Systems
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CLPS	Commercial Lunar Payload Services
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EO	Earth Observation
GEO	Geostationary Earth Orbit
ILRS	International Lunar Research Station
ISAM	In-Space Servicing, Assembly, and Manufacturing
ISRU	In-Situ Resource Utilization
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
Mkt-RL	Market Readiness Level
MRL	Manufacturing Readiness Level
NTN	Non-Terrestrial Network
OSAM	On-Orbit Servicing, Assembly, and Manufacturing
PNT	Positioning, Navigation, and Timing
ROI	Return on Investment
SATCOM	Satellite Communication
SC&ODI	Space Communications and On-Orbit Data Infrastructure
SNP&P	Space Nuclear Power & Propulsion
SSA	Space Situational Awareness
TRL	Technology Readiness Level
UNCTAD	United Nations Conference on Trade and Development

AI, Autonomy & Robotics

AI, Autonomy & Robotics enable space systems to sense, interpret, decide, and act with reduced ground control. They support onboard processing, autonomous operations, robotic inspection and servicing, anomaly detection, predictive maintenance, mission optimization, and space sustainability analytics.

Strategic Value Proposition

- **Enables** scalable satellite constellations, deep-space missions, ISAM/OSAM, and robotic operations.
- **Reduces** latency, downlink burden, and dependence on continuous ground control.
- **Improves** mission safety, responsiveness, and resource optimization.
- **Strengthens** mission resilience, cost-efficiency, and operational performance across the space systems.

Key Applications

01 EO analytics and onboard data triage.

02 Autonomous spacecraft operations and mission management.

03 Anomaly detection and predictive maintenance.

04 Constellation coordination and swarm autonomy.

05 Robotic inspection, servicing, assembly, and manufacturing.

06 SSA and collision-avoidance support.

07 Deep-space autonomy and surface robotics.

Cross-Cutting Capabilities

- Digital twins, simulation, and engineering support.
- Verification, validation, and mission assurance tools.
- Spillovers for logistics, mining, infrastructure monitoring, and disaster response.
- Multi-application relevance across civil, commercial, and national applications.

Readiness Assessment

TRL 7-9
System/subsystem validated in relevant environments.

MRL 4-6
Capability proven in production-relevant environments.

Mkt-RL 5-7
Early commercial adoption emerging for select applications.

Note: Software-heavy applications are closer to adoption, while robotics, onboard edge AI, ISAM/OSAM, and deep-space autonomy require more flight heritage and validation.

Market Opportunity

- Macro AI tailwind: **approximately 38% CAGR, (2023–2033).**
- Distributed across multiple market segments.
- Priority segments include:
  - EO and geospatial intelligence.
  - Mission operations software.
  - SSA and collision-avoidance analytics.
  - Onboard edge AI and autonomy stacks.
  - Robotics, ISAM, and swarm systems.

Development Barriers

- Limited availability of space-grade computing and onboard power.
- Fragmented datasets and insufficient validation environments.
- High costs for qualification, certification, and flight demonstration.
- Cybersecurity exposure and export-control constraints.
- Challenges in explainability, liability, accountability, and operational trust for mission-critical decisions.

Adoption Enablers

- In-orbit testbeds and demonstration missions.
- Shared datasets, digital twins, and simulation platforms.
- Verification, validation, explainability, cybersecurity, and mission assurance frameworks.
- Anchor procurement, public-sector co-funding, and regulatory clarity.
- Partnerships with AI, robotics, semiconductor, and advanced manufacturing actors.

Investment Outlook

- **Near-term investability:** Data fusion, EO analytics, SSA, mission operations, anomaly detection, and predictive maintenance.
- **Medium-term opportunities:** Onboard edge AI, autonomy stacks, and predictive maintenance.
- **Long-term strategic bets:** Robotics, ISAM/OSAM, swarm systems, and deep-space autonomy.

Note: Software-heavy models may offer shorter payback cycles, while hardware-intensive systems require stronger de-risking through demonstrations, procurement, and flight heritage.

In-Space and On-Orbit Servicing and Manufacturing (ISAM/OSAM)

ISAM/OSAM enable the assembly, integration, servicing, upgrading, and manufacturing of space systems after launch. It shifts space operations from a launch-and-replace model toward serviceable, modular, and reusable orbital infrastructure, while laying the foundation for larger platforms, cislunar logistics, and future in-space industrial activity.

Strategic Value Proposition

- **Extends** the life, resilience, and utility of satellites and orbital infrastructure.
- **Reduces** replacement launches through in-orbit inspection, servicing, repair, repositioning, and upgrades.
- **Supports** space sustainability through servicing, disposal, and debris-removal capabilities.
- **Establishes** the foundation for future deep-space and large-scale in-space infrastructure.

Key Applications

01 Satellite life extension.

02 Inspection and anomaly assessment.

03 Rendezvous, proximity operations, and docking.

04 Refueling, tugging, and repositioning.

05 Robotic capture and active debris removal.

06 Logistics and disposal services.

Cross-Cutting Capabilities

- Space sustainability and debris mitigation.
- Satcom and infrastructure resilience.
- Exploration, cislunar platforms & deep-space logistics.
- Spillovers in remote maintenance, offshore energy, aviation, mining automation, and robotics.
- Applications across the other priority emerging space technologies.

Readiness Assessment — Overall low-to-moderate and highly uneven across subsegments

TRL 6-8

Selected capabilities demonstrated.

MRL 5-7

Varied production maturity across subsystems and missions.

Mkt-RL 3-6

Early commercial adoption; strongest for life extension, inspection, and logistics support.

Note: Life-extension and inspection services are the most mature near-term applications, while refueling, modular upgrades, large-scale assembly, and in-space manufacturing require further validation, standardization, and repeated demonstrations.

Market Opportunity

- Estimated growth: **$2.7B (2024) to $5.0-8.0B (2030-2034).**
- Long-term upside linked to reusable space infrastructure, satellite servicing, in-space logistics, refueling, and in-space manufacturing.
- Priority segments include:
  - Life extension
  - Inspection
  - Refueling
  - Relocation
  - Anomaly recovery
  - Manufacturing
  - Disposal support
  - In-space logistics

Market estimates are directional due to the wide scope of and variations across services and utilities of ISAM/OSAM.

Development Barriers

- Complex proximity operations and docking risks.
- Unprepared targets for servicing.
- Lack of standardized interfaces and modular spacecraft design.
- High CAPEX, qualification costs, and limited in-space testing.
- Regulatory ambiguity, liability allocation, insurance uncertainty, cybersecurity, and multi-application concerns.
- Limited repeatable demand and uncertain revenue models for services.

Adoption Enablers

- Anchor procurement, service contracts, and public-private co-funding.
- Standardized interfaces and modular spacecraft architectures.
- Shared testbeds, in-space sandboxes, and pilot missions.
- Transparent safety standards, regulatory pathways, and insurance.
- Frameworks for proximity operations, authorization, liability, and responsible behavior in orbit.

Investment Outlook

Near-term investability:
Life extension, inspection, relocation, anomaly recovery, and disposal support.

Medium-term opportunities:
Refueling, modular upgrades, and prepared-satellite servicing.

Long-term strategic bets:
Large-scale assembly, in-space manufacturing, and cislunar infrastructure.

Note: National demads can act as early anchor markets; bankability depends on revenue-linked use cases, repeated demonstrations, and clearer regulatory pathways.

Advanced Propulsion and Space Power Systems (AP&SPS)

AP&SPS enable spacecraft mobility, endurance, maneuverability, long-duration operations, and future cislunar and deep-space infrastructure. The cluster includes electric, chemical, and green propulsion, high-power propulsion concepts, power generation, energy storage, power management, and SNP&P.

Strategic Value Proposition

- **Improves** mission mobility, endurance, and flexibility.
- **Supports** orbit-raising, station-keeping, collision avoidance, and deorbiting.
- **Enables** high-power payloads, long-duration operations, cislunar logistics, and deep-space missions.
- **Enhances** resilience, energy availability, maneuverability, and mission lifetime.

Key Applications

01 Orbit-raising, station-keeping, collision avoidance, and deorbiting.

02 Cislunar logistics, deep-space transfer, and high-energy mobility.

03 Surface power, high-power payloads, and long-duration operations.

04 Servicing, tugging, and responsive-space missions.

05 SNP&P for long-duration, high-energy, and surface applications.

Cross-Cutting Capabilities

- AI/autonomy, ISAM, space logistics, and lunar/Martian infrastructure.
- Communications, exploration, and deep-space missions.
- Energy systems, hydrogen, semiconductors, and advanced manufacturing.
- Spillovers in microgrids, electric mobility, mining automation, and power safety governance.

Readiness Assessment — Overall uneven maturity across propulsion and power

TRL 5-9

Mature for chemical/electric propulsion, solar arrays, batteries, and power management; lower for high-power propulsion, advanced storage, in-orbit refueling, and SNP&P.

MRL 5-8

Strong for established propulsion and power systems; lower for high-power, SNP&P, and long-duration technologies.

Mkt-RL 5-8

Strongest demand for electric propulsion, satellite power systems, and select green propulsion applications.

Note: Electric propulsion and core power systems are nearing operational maturity, while high-power, refueling, and SNP&P require further demonstration, qualification, and regulatory acceptance.

Market Opportunity

- **$10.2B (2024) to $20.0B (2030) at 11.9% CAGR.**
- Demand is driven by larger constellations, high-power payloads, maneuverable spacecraft, cislunar activity, deep-space missions, and surface infrastructure.
- Priority segments include:
  - Electric and green propulsion
  - High-power propulsion
  - Power generation
  - Energy storage
  - Power management
  - SNP&P

Note: Market definitions vary; figures are indicative.

Development Barriers

- High testing costs and lengthy qualification timelines.
- Complex mass, efficiency, power, & thermal trade-offs.
- Limited demonstration opportunities for high-power and SNP&P.
- Degradation due to harsh environments.
- Supply-chain constraints for specialized components and advanced materials.
- Regulatory, safety, licensing, and public-acceptance challenges for SNP&P technologies.

Adoption Enablers

- Shared qualification frameworks, test infrastructure, and in-space demonstrations.
- Standardized interfaces, modular architectures, and scalable propulsion platforms.
- Clearer regulatory pathways for high-power and SNP&P.
- Cross-sector partnerships across energy, nuclear, hydrogen, aviation, automotive, semiconductors, materials, and advanced manufacturing.

Investment Outlook

- **Strongest near-term cases:**
  Electric and smallsat propulsion, deployable solar arrays, batteries, power management, and select green propulsion systems.
- **Longer-term strategic bets:**
  SNP&P, cislunar logistics, deep-space transportation, and surface power infrastructure.

Note: Government anchors and flight heritage will reduce risk.

In-Situ Resource Utilization (ISRU) & Space Resources

ISRU refers to the prospecting, extraction, processing, storage, and use of materials found beyond Earth to support space operations through propellant production, life support, shielding, construction, and industrial feedstocks. ISRU reduces dependence on Earth-launched supplies enabling sustainable operations.

Strategic Value Proposition

- **Reduces** dependence on Earth-launched supplies by enabling local resource use.
- **Supports** sustained lunar, cislunar, and future Martian operations.
- **Provides** propellant, life-support resources, construction materials, and radiation shielding.
- **Establishes** the foundation for future off-Earth industries and space economies.

Key Applications

01 Lunar resource prospecting & mapping, drilling, excavation, and regolith handling.

02 Long-duration lunar, cislunar, and Mars missions.

03 Volatile detection, water-ice mapping, and water and oxygen extraction.

04 Propellant production and fuel depots.

05 Resource assessment for asteroids and other non-terrestrial bodies.

06 Radiation shielding and surface infrastructure.

07 Life-support resources and habitat consumables.

08 Construction materials and in-situ manufacturing.

Cross-Cutting Capabilities

- Mining, robotics, autonomy, energy systems, hydrogen, cryogenics, advanced materials, construction, digital twins, insurance, and science diplomacy.
- Spillovers in autonomous mining, off-grid power, hydrogen systems, water recovery, low-carbon construction, hazardous-environment robotics, and frontier-infrastructure finance.

Readiness Assessment — Overall low-to-moderate and highly uneven across subsegments

TRL 2-5

Some subsystem demonstrations, but end-to-end systems are still early-stage.

MRL 3-5

Limited production and operational maturity.

Mkt-RL 3-5

Demand signals exist, but commercial markets are not yet established.

Note: Resource prospecting, laboratory extraction, simulant testing and robotics are advancing, but end-to-end ISRU production at operational scale in still emerging.

Market Opportunity

- Pre-commercial with widely varying estimates.
- Space mining: **$1.90B (2024) to $5.02B (2030) at 17.9% CAGR.**
- ISRU-specific: **$2.80B (2025) to $9.40B (2034) at 14.4% CAGR.**

Figures are directional and dependent on market definitions, mission cadence, anchor demand, and the pace of lunar and cislunar infrastructure development.

Development Barriers

- Early-stage extraction and processing technologies.
- Limited lunar surface access and constrained in-situ testing opportunities.
- End-to-end demonstrations remain limited.
- High infrastructure costs and long development timelines.
- Evolving regulatory frameworks for resourcing rights, access, safety, liability, and benefit-sharing.
- Uncertain revenue models and limited near-term anchor demand.

Adoption Enablers

- Government anchor demand and procurement.
- Artemis and ILRS are driving sustained demonstrations and interoperability.
- Shared lunar analogue facilities and testbeds.
- Standards for regolith simulants and resource characterization.
- End-to-end pilot missions for excavation, processing, storage, and utilization.
- Anchor customers for key logistics services.

Investment Outlook

- **Near-term investability:** Mapping, drilling, delivery, integration, ISRU subsystems.
- **Medium-term opportunities:** Oxygen extraction, water-ice validation, autonomous excavation, regolith processing, and pilot-scale production.
- **Long-term strategic bets:** Propellant production, fuel depots, large-scale manufacturing, construction materials, and resource markets.

Note: Strong programmatic relevance and high cross-cutting potential, but public exploration programs are likely to be the first anchor customers. Commercial bankability will depend on repeated demonstrations, clear demand, infrastructure build-out and greater legal certainty.

Space Communications and On-Orbit Data Infrastructure (SC&ODI)

SC&ODI refers to the connectivity, networking, processing, storage, and security layers that enable information exchange across space and ground end users. It includes satellite and optical communications, inter-satellite links, multi-orbit networking, onboard processing, edge computing, secure data relay, and space data infrastructures.

Strategic Value Proposition

- **Enables** resilient, secure, low-latency connectivity across space, terrestrial, and ground networks networks.
- **Supports** broadband, encrypted communications, EO data relay, and autonomous operations.
- **Serves** as the digital backbone of the future space economy.
- **Unlocks** inter-satellite routing, multi-orbit networks and distributed data pathways.

Key Applications

01 Satellite broadband and direct-to-device connectivity.

02 Secure government and encrypted communications.

03 Real-time EO data relay and cloud-integrated ground services.

04 Multi-orbital optical intersatellite networks.

05 Autonomous spacecraft coordination and edge AI.

06 Cislunar communications, secure data relay, and quantum-ready networks.

Cross-Cutting Capabilities

- Telecom, 5G/6G, cloud, and edge AI.
- Photonics, cybersecurity, and secure digital infrastructure.
- EO, autonomous systems, and encrypted networks.
- Spillover in rural connectivity, disaster response, smart infrastructure, and digital resilience.

Readiness Assessment — Overall medium-high

TRL 7-9
Mature satcom, ground services, and data relay; lower for optical networking, autonomous mesh routing, and orbital computing.

MRL 6-8
Strong for satcom hardware and ground systems; improving for optical terminals, software-defined payloads, and advanced networking.

Mkt-RL 6-8
Strong commercial demand for secure optical satcom, data relay, and cloud-integrated ground services.

Note: Satcom and ground-services are commercially mature, while large-scale optical mesh networks, cislunar comms and orbital data centers remain earlier-stage.

Market Opportunity

- Global satcom: **$90.3B (2024) to $159.6B (2030) at 10% CAGR.**
- Small satcom: **$5.95B (2025) to $18.34B (2030).**
- Additional growth from optical communications and orbital data infrastructure.

Note: Estimates are indicative and vary by market scope (e.g., satcom, data relay, optical communications, ground services, edge processing, and orbital computing).

Development Barriers

- Spectrum constraints and regulatory delays.
- Developing economic viability for orbital data centers
- Optical-link weather sensitivity and infrastructure needs.
- Contested-space threats such as jamming and cyberattacks.
- Interoperability gaps and fragmented standards.
- Orbital congestion, debris, and collision exposure.
- Security, encryption, data-sovereignty, and resilience requirements for government and critical-infrastructure users.

Adoption Enablers

- Streamlining spectrum and licensing pathways.
- Developing interoperability standards.
- Integrating orbital sustainability by design.
- Standardized Multi-orbit optical networks
- Cybersecurity by design and resilience standards.
- Ground-to-cloud integration driven by anchor demand.

Investment Outlook

Near-term investability:

- Satcom, secure communications, optical networking, software-defined payloads, cloud-integrated ground systems, and data-relay services.
- Strong interest in secure communications, software-defined payloads, and edge processing.

Medium-term opportunities:

Inter-satellite networking, multi-orbit routing, edge processing, cislunar communications, and autonomous network management.

Risk outlook:

Regulation, market concentration, cybersecurity, and speculative orbital computing models.

Note: National demands, disaster response, and connectivity provide anchor demand.

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