The Future of Aerospace

A technology development roadmap for
the aerospace sector over the next 30 years

PRESCOUTER

The space ecosystem will be centered around **7 technology innovation sectors** in the next 5-30 years.

In this report, we identify and forecast the evolution of technology innovation sectors integral to the aerospace ecosystem over the next 5-30 years. To do this, we categorized the innovation sectors based on their technology readiness level (TRL) and identified for each sector the underlying technologies and innovations needed to propel the sector to the commercial stage.

TRL 7-9
0-5 years from commercial availability

Imaging & Monitoring

Communications

Space Transportation

TRL 4-6
5-20 years from commercial availability

Space Exploration

Human Life Support & Habitation Systems

TRL 1-3
20-30 years from commercial availability

In-Space Manufacturing

Mining Resources in Space

The aerospace landscape within the next 5 years

Imaging & monitoring, communications and space transportation technologies are today fully present on the commercial stage and are required to unlock future innovation sectors.

Imaging & Monitoring

The imaging and monitoring sector is the most developed sector in the space ecosystem, with a wide supplier base, numerous research labs and large investments.

Communications

The communications sector is another key innovation sector that will support future developments in the aerospace ecosystem. Specific applications like telemedicine are shaping the evolution of the communication sector along with the underlying components like advanced sensor technologies.

Space Transportation

Space transportation is seeing greater interest from the private sector with the introduction of new critical technologies to support the infrastructure needed to commercialize this sector. As such, commercial space transportation is now on the mid-development to final stages.

Imaging & Monitoring

Developments

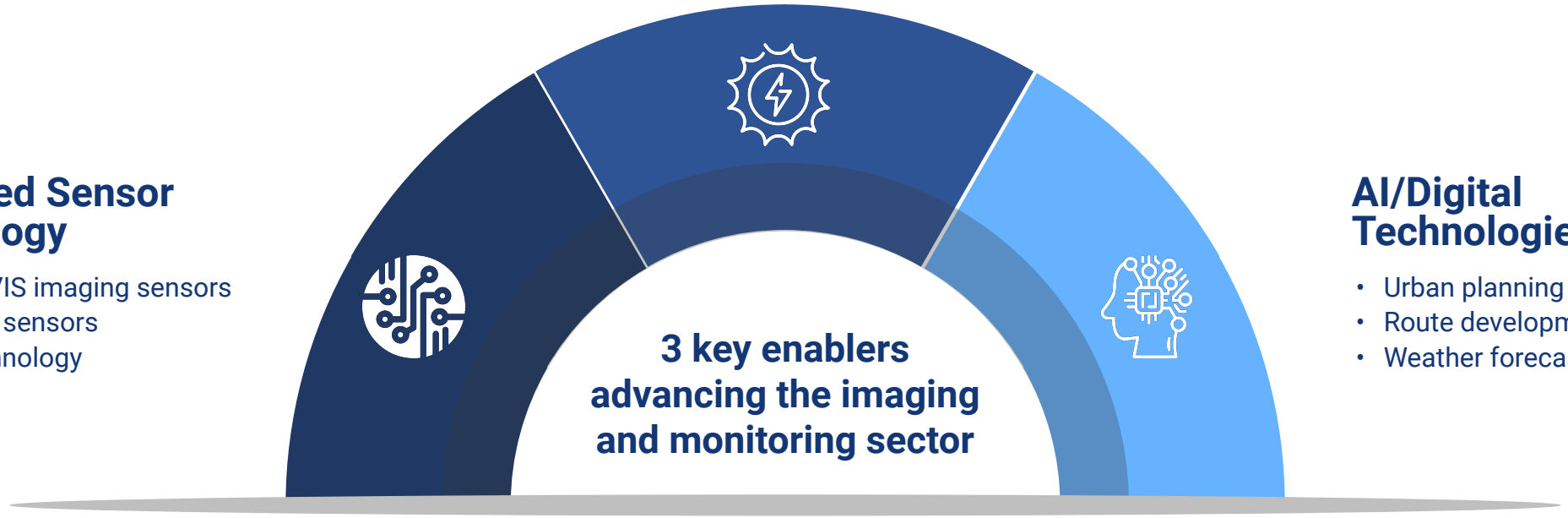
- Most developed sector in space ecosystem
- Wide supplier base and research labs
- Key enablers: Sensors, AI/Digital technologies and huge investments

Roadblocks

- Stability and adaptability
- Technology readiness for exploration
- Common cyber infrastructure

Energy Systems

- Storage systems
- Power systems
- Thermal management systems (cryogenic, thermal protection, thermal control)



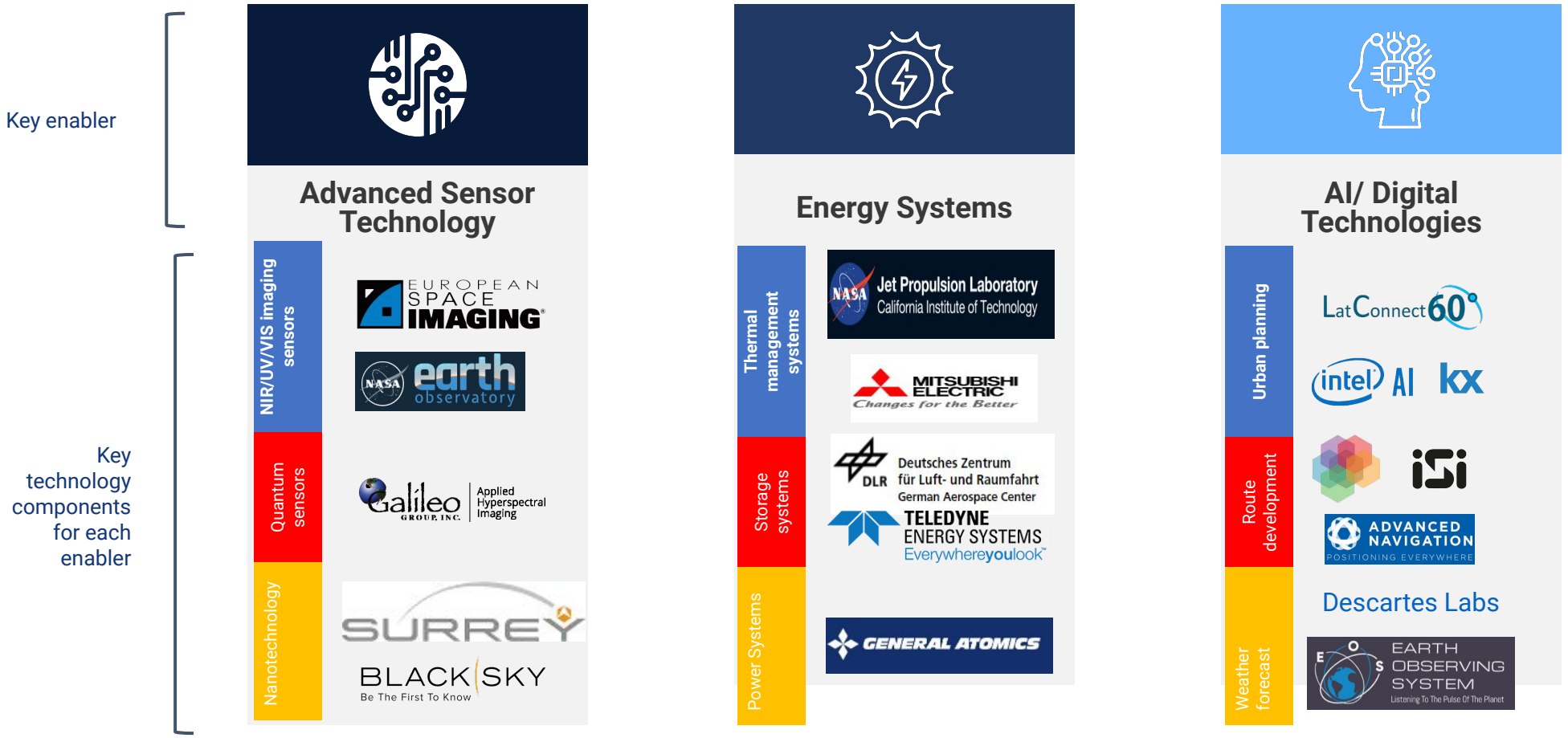
Advanced Sensor Technology

- NIR/UV/VIS imaging sensors
- Quantum sensors
- Nanotechnology

AI/Digital Technologies

- Urban planning
- Route development
- Weather forecasts

Imaging & Monitoring



**List shared here is not exhaustive but representative of key players working in respective areas*

Communications

Developments

- Satellite and navigation systems has seen major developments with stronger alliances and tech sharing with market leaders

Roadblocks

- Lack of long-range planning and resources

Navigation and Timing

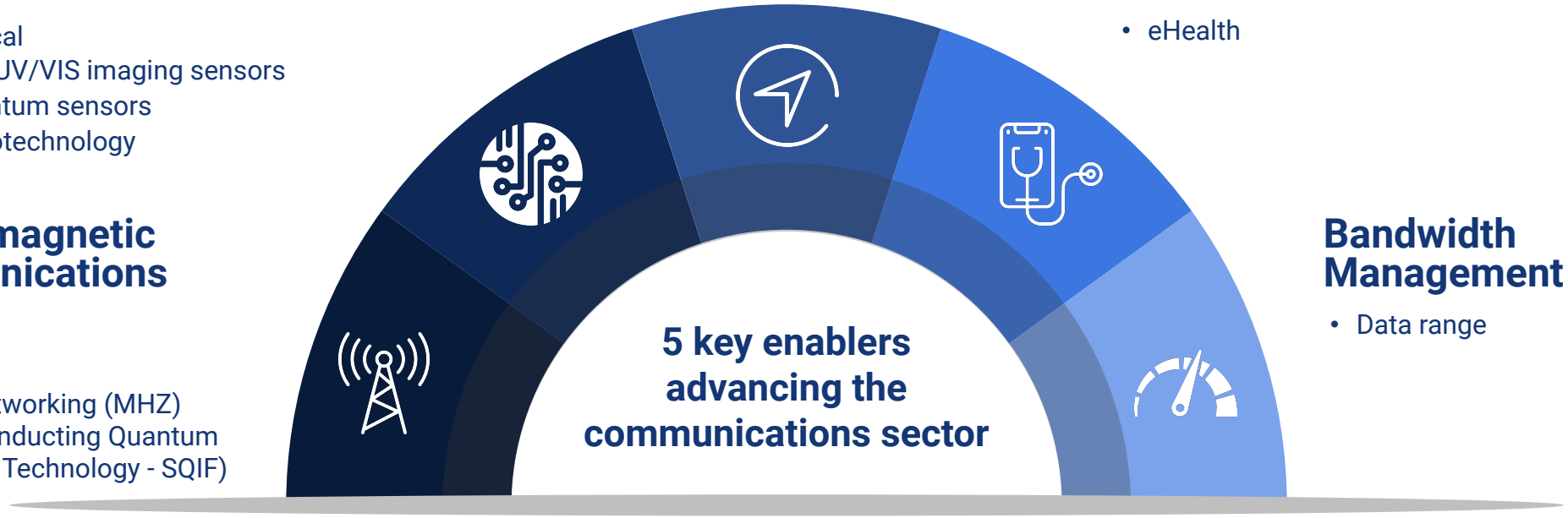
- Quantum sensors/technologies
- Satellite-based (GPS, GNSS, GIS)
- X-ray navigation

Advanced Sensor Technology

- Optical
- NIR/UV/VIS imaging sensors
- Quantum sensors
- Nanotechnology

Telemedicine

- eHealth



Electromagnetic Communications

- GHZ
- KHZ
- Radio networking (MHZ) (Superconducting Quantum Interface Technology - SQIF)

Bandwidth Management

- Data range

Communications

Key enabler

Key technology components for each enabler

Electromagnetic Communications

- GHZ: OneWeb
- KHZ: ITU
- MHZ: TELESPAZIO a LEONARDO and THALES company

Advanced Sensor Technology

- NIR/UV/VIS imaging sensors: NASA earth observatory
- Quantum sensors: x^{∞}
- Nanotech
- Optical: EUROPEAN SPACE IMAGING

Navigation and Timing

- Quantum sensors/Techs: ACSER Australian Centre for Space Engineering Research
- Satellite based: JPSS Joint Polar Satellite System Program NOAA NASA; Station Explorer for X-Ray Timing and Navigation (SEXTANT)
- X-ray navigation: LEO LABS

Telemedicine

- eHealth: JSC

Bandwidth Management

- Data range: ITU — Handled by ITU

**List shared here is not exhaustive but representative of key players working in respective areas*

Space Transportation

Developments

- Commercial transportation to space is on the mid-development to final stages
- Private organizations are showing more interest towards commercializing the sector
- Upgraded launch vehicles with heavy lift capabilities are being developed

Roadblocks

- Overall cost including the launch stage and the final propulsive stage used in orbital transfer is exorbitantly high
- Maintenance, monitoring, and perpetual improvements during travel pose a constraint

Robotics

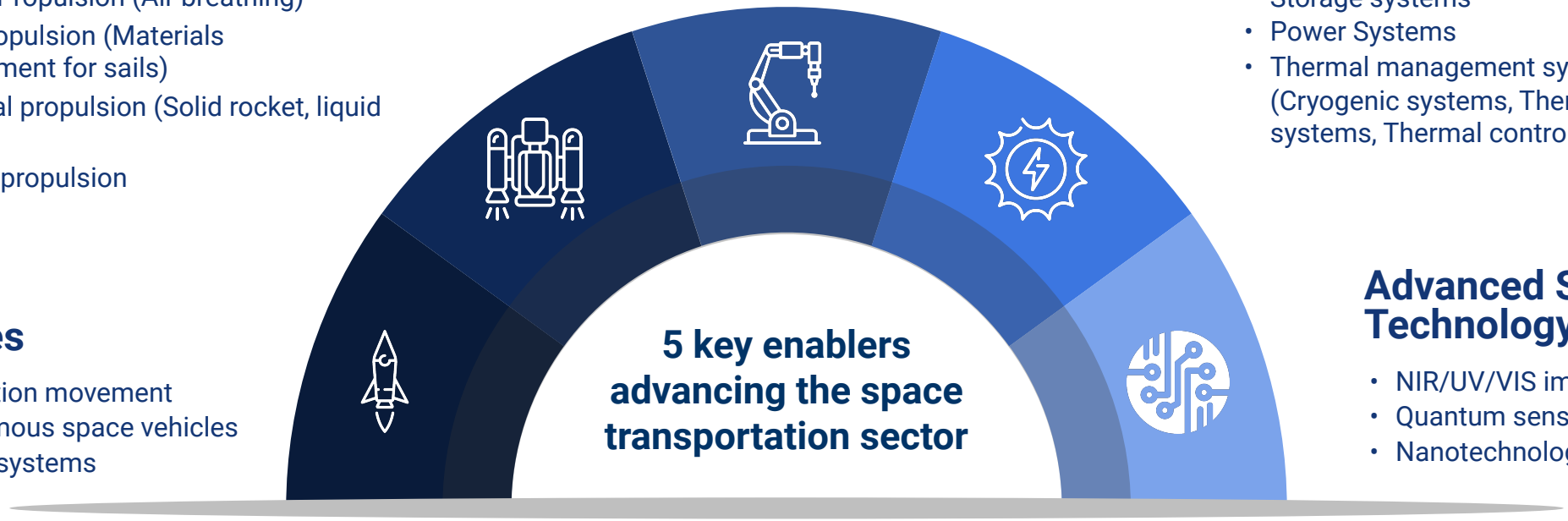
- Robotics and sub systems (Rovers, RSV, etc.,)
- Sensors and autonomous systems
- Software
- Services segment

Propulsion

- Electric Propulsion (Air breathing)
- Light Propulsion (Materials development for sails)
- Chemical propulsion (Solid rocket, liquid rocket)
- Nuclear propulsion

Energy Systems

- Storage systems
- Power Systems
- Thermal management systems (Cryogenic systems, Thermal protection systems, Thermal control systems)



Vehicles

- Interstation movement
- Autonomous space vehicles
- Launch systems

Advanced Sensor Technology

- NIR/UV/VIS imaging sensors
- Quantum sensors
- Nanotechnology

Space Transportation

Key enabler

Key technology components for each enabler

Vehicles

- Interstation movement
- Autonomous space vehicles
- Launch systems

Propulsion

- Electric
- Light
- Chemical
- Nuclear

Robotics

- Subsyst-ems
- Sensors and Autonomous systems
- Software
- Services

Energy Systems

- Thermal management systems
- Storage systems
- Power systems

Advanced Sensor Technology

- NIR/UV/VIS imaging sensors
- Quantum Sensors
- Nanotech

*List shared here is not exhaustive but representative of key players working in respective areas

The aerospace landscape within the next 5-20 years

Space exploration and **human life support and habitation systems** will be the next sectors to mature.

Space Exploration

Space Exploration (including deep space and near earth objects exploration) to rely on key advancements in technologies that supported the previously explored innovation sectors. Robotics are contributing to the development of an enhanced propulsion system that can support not only space missions to the ISS but also the planetary missions and other deep space explorations. Navigation and guidance systems are also an integral part of deep space exploration, as it requires high-precision tracking and guidance.

Human Life Support & Habitation Systems

Partnerships and contributions from many different stakeholders will be required to drive the space transportation sector forward

Robotics, AI, and Energy systems and their evolution will be key to unlocking the next generation of innovation sectors

Space Exploration

Developments

- Robotics are contributing to the development of an enhanced propulsion system

Roadblocks

- Deep space exploration missions require enhanced subsystems, which aid in propelling the system into space

Advanced Sensor Technology

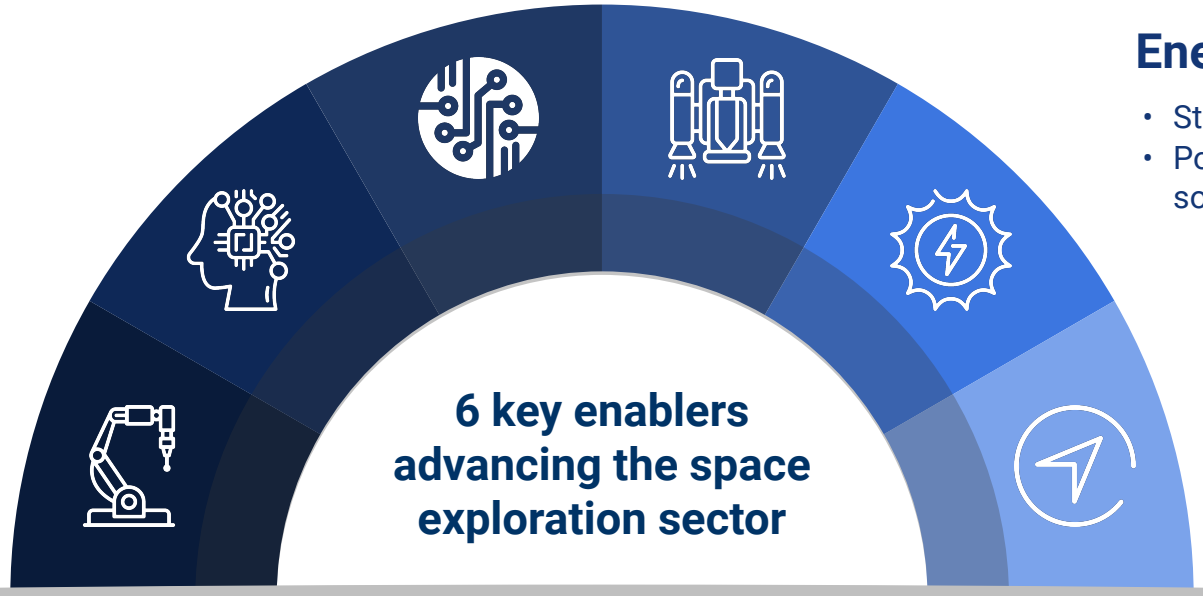
- NIR/UV/VIS imaging sensors
- Quantum sensors
- Nanotechnology

Propulsion

- Electric propulsion (Air breathing)
- Light propulsion (Materials development for sails…)
- Chemical propulsion (Solid rocket, liquid rocket)
- Nuclear propulsion

AI / Digital Technologies

- Urban planning
- Route development
- Weather forecasts



Energy Systems

- Storage systems (LIB, Fuel cells)
- Power generation (nuclear fission/fusion, solar, chemical such as biofuel)

Robotics

- Robotics and sub systems (Rovers, RSV, etc.)
- Sensors and autonomous systems
- Software
- Services segment

Navigation and Timing

- Quantum sensors/technologies
- GPS, GNSS, GIS (JMARS)
- X-ray navigation

Space Exploration

Key enabler

Key technology components for each enabler

Robotics

- Subsystems
- Sensors and Autonomous systems
- Software
- Services

No company started research

AI/Digital Technologies

- Urban Planning
- Route Developmnt
- Weather Forecast

Deep Space-1 (DS1) collaborative mission with NASA.

Advanced Sensor Technology

- NIR/UV/VIS imaging sensors
- Qunatum Sensors
- Nano Technology
- Optical

No company started research

Propulsion

- Electric
- Light
- Electric
- Nuclear

No company started research

Energy Systems

- Thermal management systems
- Storage systems
- Power Systesms

Space Solar Power Systems (SSPS)

Navigation and Timing

- Quantum Sensors/Technologies
- Satellite based
- X-ray navigation

No company started research

*List shared here is not exhaustive but representative of key players working in respective areas

Human Life Support and Habitation Systems

Developments

- Robotics, AI, and Energy systems and their evolution will be key to unlocking the next generation of innovation sectors

Roadblocks

- Testing capabilities still remain a challenge
- Limited players in the sector mostly in the early stage startups or government entities

AI / Digital Technologies

- Digital twin simulation
- Modelling
- Analytics / optimization

Protection Technologies

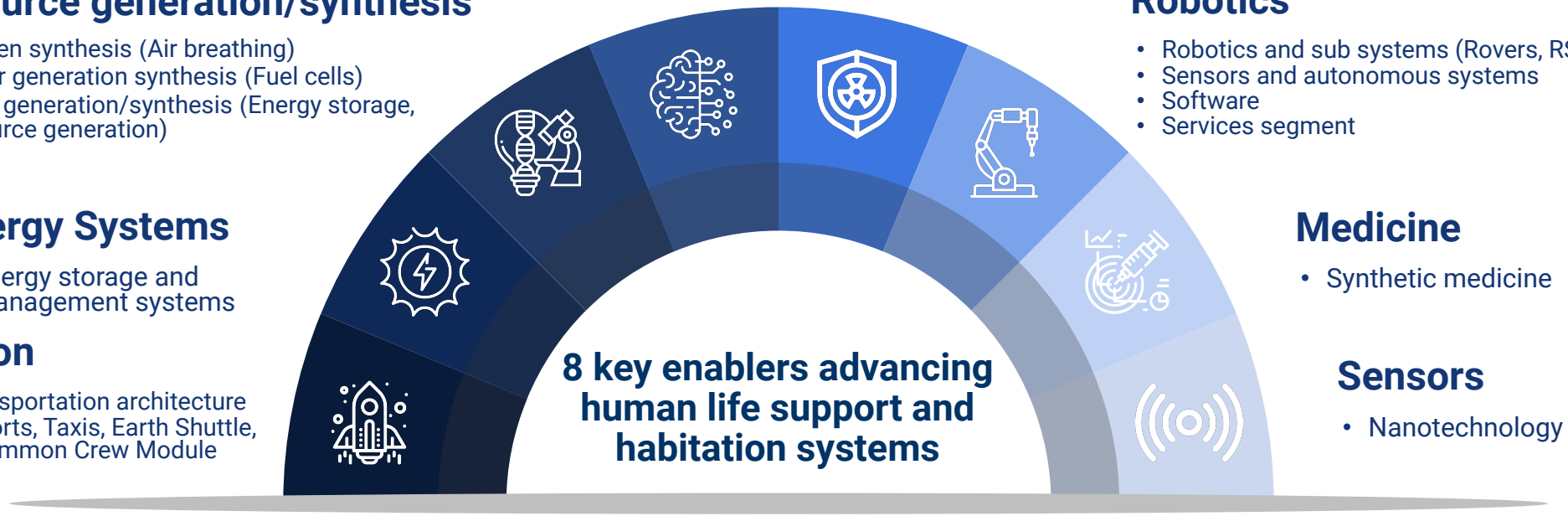
- Radiation
- Dust

Resource generation/synthesis

- Oxygen synthesis (Air breathing)
- Water generation synthesis (Fuel cells)
- Food generation/synthesis (Energy storage, resource generation)

Robotics

- Robotics and sub systems (Rovers, RSV, etc.)
- Sensors and autonomous systems
- Software
- Services segment



Energy Systems

- Energy storage and management systems

Medicine

- Synthetic medicine

Transportation

- Interplanetary transportation architecture
- Astrotels, Spaceports, Taxis, Earth Shuttle, Mars Shuttle, a Common Crew Module
- LEO travel

Sensors

- Nanotechnology

Human Life Support and Habitation Systems

Transportation

- Interdisciplinary transportation
- Common crew module
- LEO Travel

Energy Systems

- Thermal management systems
- Storage systems
- Power Systems

Resource Generation/ Synthesis

- Oxygen Synthesis
- Water Generation
- Food Geneation

AI/ Digital technologies

- Digital Twin Simulation
- Modelling
- Analytics/ Optimization

Protection Technologies

- Radiation
- Dust

Robotics

- Subsystems
- Sensors and Autonomous systems
- Software
- Services

Medicine

- Synthetic Medicine

Sensors

- Nanotechnology

**List shared here is not exhaustive but representative of key players working in respective areas*

The aerospace landscape within the next 5-20 years

In-space manufacturing and **mining** are the furthest innovation sectors on the commercialization timeline.

In-Space Manufacturing

In-space manufacturing will allow for greater flexibility in strategy, and can be supported by many existing technologies like additive manufacturing, with many new entrants in the arena. Universities and research organizations, in particular, are working towards in-space manufacturing with special focus on 3D printing. One of the major advancements in this sector focuses around developing reusable launch vehicles which both major space agencies as well as private space companies are actively researching.

Mining of Resources in Space

Research for mining in space has increased over the years. Innovation in this sector depends greatly on advances in different non-overlapping (exclusive) technology sectors. Mining of resources will require development of warehousing and extraction technologies that are not critical to the other innovation sectors.

In-Space Manufacturing

Developments

- Major space agencies, as well as private space companies, are focused on developing reusable launch vehicles
- 3D printing capabilities have increased in the past with new entrants

Roadblocks

- Dependent on other sectors such as space transportation, robotic developments etc

Digital Technologies/ Modelling

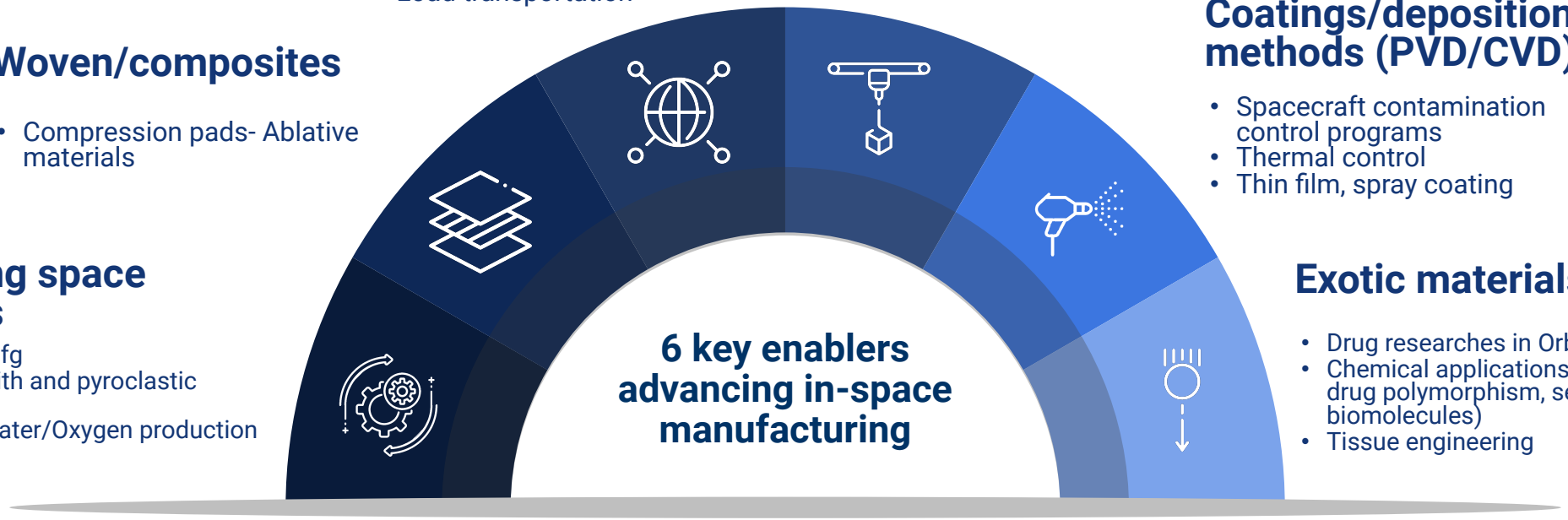
- Materials, Structures
- Mechanical systems and sensors
- Load transportation

3D Printing

- Polymers / plastics
- Metal printing capabilities
- Sensor printing
- Bio printing

Woven/composites

- Compression pads- Ablative materials



Coatings/deposition methods (PVD/CVD)

- Spacecraft contamination control programs
- Thermal control
- Thin film, spray coating

Processing space resources

- Low waste mfg
- Focus -regolith and pyroclastic deposits
- Propellant/Water/Oxygen production

Exotic materials (microgravity)

- Drug researches in Orbit
- Chemical applications (protein crystallization, drug polymorphism, self-assembly of biomolecules)
- Tissue engineering

In-Space Manufacturing

Key enabler

Key technology components for each enabler

Processing Space Resources

- Low waste mfg
- Regolith and Pyroclastic deposits
- Propellant/Water/Oxygen production

No company started research

Woven/Composites

- Compression pads

NANORACKS

Digital Technologies/ Modelling

- Load transportation
- Mechanical systems and sensors
- Materials structures

ALTEN

3D Printing

- Polymers/ Plastics
- Meta Printing capabilities
- Sensor Printing
- Bio Printing

No company started research

MADE IN SPACE

No company started research

Coatings/deposition methods (PVD/CVD)

- Spacecraft contamination programs
- Thermal Control
- Thin film, Spray coating

No company started research

AIRBUS DEFENCE & SPACE

No company started research

Exotic Materials (microgravity)

- Orbit drug researches
- Chemical applications
- Tissue Engineering

No company started research

MADE IN SPACE

*List shared here is not exhaustive but representative of key players working in respective areas

Mining of Resources in Space

Developments

- These innovation sectors all depend on advances in different non-overlapping (exclusive) technology sectors
- Research for mining in space has increased over the years

Roadblocks

- Mining of resources in space are high risk with long lead times and heavy capital investment
- Delay in signals (communication with drones)

Power Management and Distribution

- NASA's nuclear space program
- Spaceborne and space research instruments
- Ion and plasma propulsion

Advanced Sensor Technology

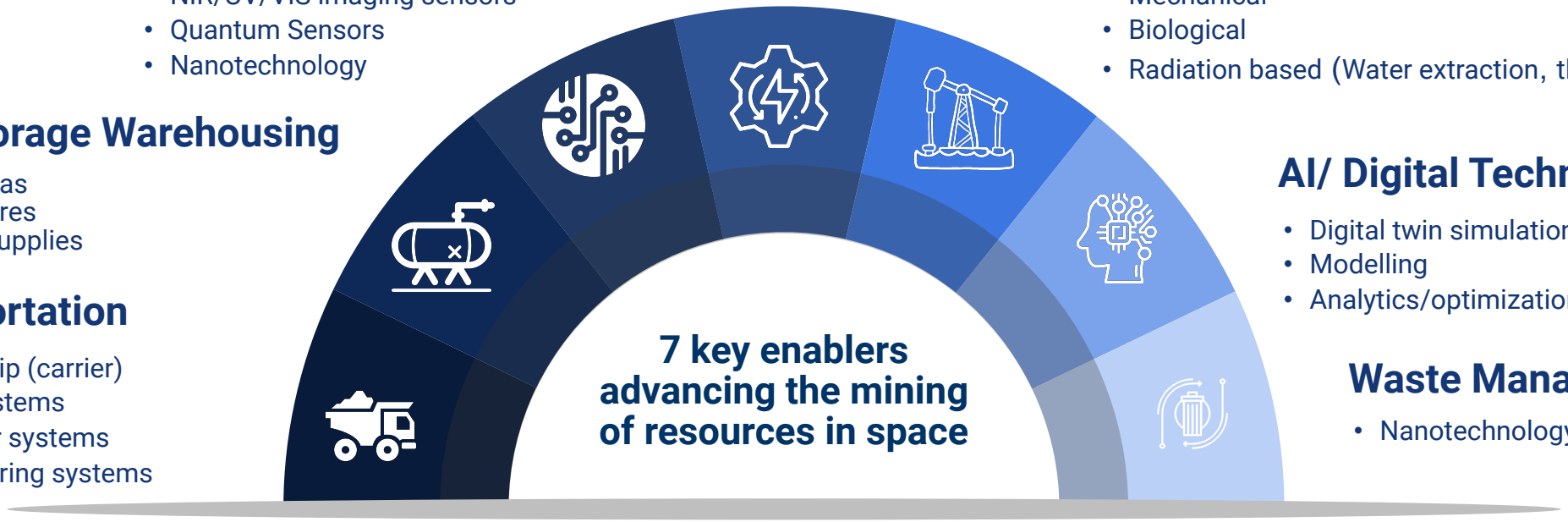
- NIR/UV/VIS imaging sensors
- Quantum Sensors
- Nanotechnology

Extraction Technologies

- Mechanical
- Biological
- Radiation based (Water extraction, thermal Mining)

Storage Warehousing

- Gas
- Ores
- Supplies



AI/ Digital Technologies

- Digital twin simulation
- Modelling
- Analytics/optimization

Transportation

- Cargo Ship (carrier)
- Utility systems
- Conveyor systems
- Maneuvering systems

Waste Management

- Nanotechnology

Mining of Resources in Space

Transportation

- Cargo Ship
- Utility Systems
- Conveyor systems
- Maintenance

Effective Space

No company started research

Storage Warehousing

- Supplies
- Orabaes
- Gas

No company started research

Advanced Sensor Technology

- NIR/UV/VIS imaging sensors
- Quantum sensors
- Nanotech-nology
- Optical

COLORADO SCHOOL OF MINES

No company started research

Power Management and Distribution

- Thermal management systems
- Storage systems
- Power Systesms

NASA RADIOISOTOPE POWER SYSTEMS

To be handled mostly by Space agencies

No company started research

Extraction Technologies

- Mechanicl
- Biological
- Radiation
- Water Extraction

No company started research

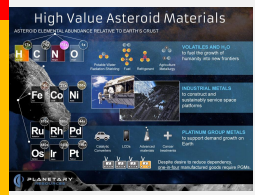
No company started research

AI/ Digital Technologies

- Digital Twin Simulation
- Modelling
- Analytics/ Optimization

intel AI

No company started research



Waste Management

- Nano Technology

ARCS AUTONOMY RESEARCH CENTER FOR STEAHM

Astroscale

*List shared here is not exhaustive but representative of key players working in respective areas

About the Authors

Sofiane Boukhalfa

Technical Director, PreScouter

Sofiane leads the high-tech, aerospace and defense, automotive & logistics practices at PreScouter. For nearly a decade, he has worked with hundreds of F500 and G1000 clients across multiple industries, through which he has developed an expertise in key emerging technologies (such as 5G, IoT, AI/ML, blockchain, energy storage and generation, quantum sensing, and others) and a strong understanding of the associated business ecosystem and drivers pushing these sectors forward (for e.g. key players and trends, roadblocks to commercialization, etc). Sofiane's strategic insights have ranged from technical due diligence for acquisition targets to identifying relevant markets for newly developed products based on emerging technologies and assessing market penetration strategies. Sofiane holds a Ph.D. in Materials Science and Engineering from the Georgia Institute of Technology, where his research focused on nanotechnology and energy storage.

Kishore Ravichandran

PreScouter

Kishore has background in industrial engineering and supply chain management and has worked on 100+ projects spanning across multiple verticals.. As a business analyst in the IoT (SCM) space, he studies customer requirements to come up with new solutions and develop collaterals based on the research. Apart from that, Kishore holds a Master'. Degree s in Industrial Engineering and Management in Finland with focus towards International sales and sourcing. His key areas of specialization includes project management, supply chain solutions and market research. He has also done an exchange program in TU Darmstadt focusing on logistics.

TRL Rating Scale

The Technology Readiness Level (TRL) Scale is an industry standardized metric by which PreScouter evaluates technologies for each client. Based on the constraints on the innovation challenge, PreScouter assigns a TRL number to each identified academic, company or patent.

This process allows each solution to be easily identified for commercialization potential.

Higher number TRL's do not always equate to the best technology – for example, most late stage academic technology is best suited for optimization and integration, but would have a TRL between 2-4.

TRL 9 **Systems operation -** Actual system operated over full range of expected conditions

TRL 8 **System commissioning -** Actual system completed and qualified through demonstrate tests

TRL 7 **System commissioning -** Full-scale, similar prototype demonstration in relevant environment

TRL 6 **Technology demonstration -** Engineering / pilot scale prototype testing in relevant environment

TRL 5 **Technology development -** Lab-scale validation in relevant environment

TRL 4 **Technology development -** Component or system validation in lab environment

TRL 3 **Research to prove feasibility -** Analytical/experimental test of critical function - proof of concept

TRL 2 **Basic technology research -** Technology concept and/or application formulated

TRL 1 **Basic technology research -** Basic principles observed and reported

About PreScouter

PRESCOUTER PROVIDES CUSTOMIZED RESEARCH AND ANALYSIS

PreScouter helps clients gain competitive advantage by providing customized global research. We act as an extension to your in-house research and business data teams in order to provide you with a holistic view of trends, technologies, and markets.

Our model leverages a network of 3,000+ advanced degree researchers at tier 1 institutions across the globe to tap into information from small businesses, national labs, markets, universities, patents, startups, and entrepreneurs.

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Privileged Information: PreScouter interviews innovators to uncover emerging trends and non-public information.

Customized Insights: PreScouter finds and makes sense of technology and market information in order to help you make informed decisions.

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CLIENTS WORLDWIDE

4,000+
RESEARCH REPORTS CREATED

150,000+
HOURS OF RESEARCH COMPLETED FOR CLIENTS

References

1. https://www.nasa.gov/pdf/501627main_TASR-TABS_Foldouts-A.pdf
2. https://www.comparethecloud.net/articles/the-importance-of-artificial-intelligence-in-space-technology/#:~:text=Earth%20Observation,around%20more%20quickly%20and%20efficiently.
3. https://scienceandtechnology.jpl.nasa.gov/research/research-topics-list/spacecraft-technologies/advanced-propulsion-and-power
4. https://www.marketsandmarkets.com/Market-Reports/space-robotic-solution-market-61497036.htmlhttps://www.marketsandmarkets.com/Market-Reports/space-robotic-solution-market-61497036.html
5. https://www.nap.edu/read/6293/chapter/7#84
6. https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Robots_in_space2
7. https://www.nasa.gov/pdf/501329main_TA02-InSpaceProp-DRAFT-Nov2010-A.pdf
8. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/public-sector/space-perspective-on-tech-trends-2019.pdf
9. http://www.iste.co.uk/book.php?id=1589
10. https://www.industry.gov.au/sites/default/files/2019-03/global_space_industry_dynamics_-_research_paper.pdf
11. https://www.nap.edu/read/13354/chapter/13
12. https://www.mining-technology.com/features/history-of-space-mining/
13. http://www.geology.wisc.edu/~pbrown/spacemine/spacemine.html
14. https://phys.org/news/2019-10-space-war-zone.html
15. https://www.techbriefs.com/component/content/article/tb/stories/blog/35871
16. https://www.3dnatives.com/en/top-10-3d-printing-space/
17. https://www.nasa.gov/feature/first-3d-woven-composite-for-nasa-thermal-protection-systems
18. http://www.ae.iitkgp.ac.in/ebooks/chapter1.html
19. https://link.springer.com/chapter/10.1007/978-3-030-30881-0_4
20. https://sci.esa.int/documents/34161/35992/1567260390250-ESA_Space_Resources_Strategy.pdf
21. https://link.springer.com/article/10.1007/s11095-019-2703-7?shared-article-renderer
22. https://cosmosmagazine.com/space/the-future-of-in-space-manufacturing/
23. https://www.techbriefs.com/component/content/article/tb/features/articles/24887
24. https://web.stanford.edu/group/arl/links
25. https://spaceindividuals.com/space-companies
26. https://www.energy.gov/ne/nuclear-reactor-technologies/space-power-systems
27. https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Power_Systems
28. https://www.kinaxis.com/en/blog/space-final-logistics-supply-chain-management-frontier