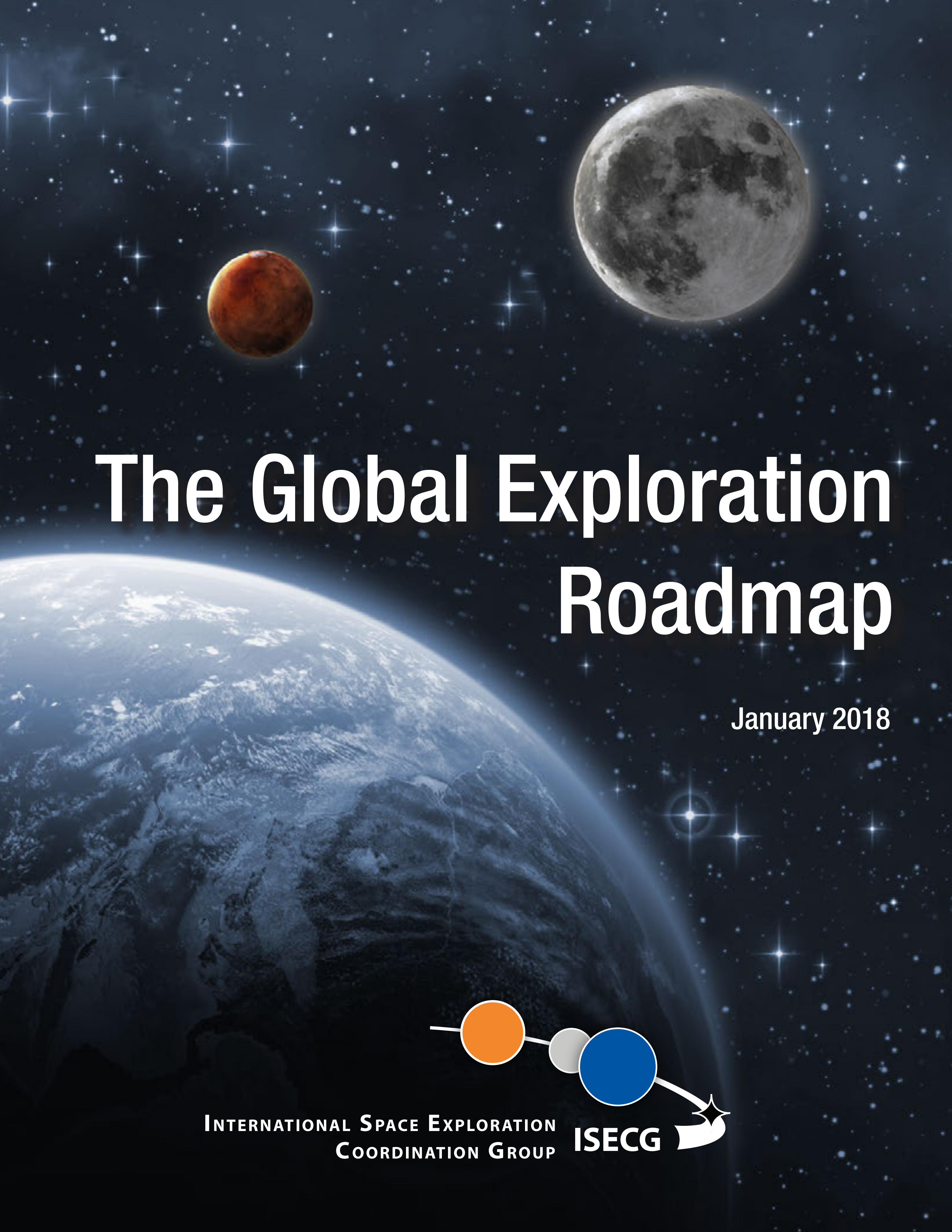


The Global Exploration Roadmap

January 2018

INTERNATIONAL SPACE EXPLORATION
COORDINATION GROUP
ISECG

What is New in The Global Exploration Roadmap?

This new edition of the Global Exploration Roadmap reaffirms the interest of 14 space agencies to expand human presence into the Solar System, with the surface of Mars as a common driving goal. It reflects a coordinated international effort to prepare for space exploration missions beginning with the International Space Station (ISS) and continuing to the lunar vicinity, the lunar surface, then on to Mars. The expanded group of agencies demonstrates the growing interest in space exploration and the importance of cooperation to realise individual and common goals and objectives.

This third edition of the Global Exploration Roadmap reflects consensus about the importance of the Moon on the pathway to Mars and adds refinements in each step along this path as agencies continue to make individual and collective progress. The roadmap demonstrates how capabilities under development or study around the world could enable a sustainable future of human and robotic space exploration. Refinements in this edition include:

- A summary of the benefits stemming from space exploration. Numerous benefits will come from this exciting endeavour. It is important that mission objectives reflect this priority when planning exploration missions.
- The important role of science and knowledge gain. Open interaction with the international science community helped identify specific scientific opportunities created by the presence of humans and their infrastructure as they explore the Solar System. Although summarised here, details of this interaction have been published in a supplemental white paper on *Scientific Opportunities Enabled by Human Exploration Beyond Low-Earth Orbit* which is available at **www.globalspaceexploration.org**.
- The introduction of an international deep space Gateway concept. The deep space Gateway is a small human-tended facility around the Moon which will play an important role in sustainable human space exploration. Initially, it supports human and robotic lunar exploration in a manner which creates opportunities for multiple sectors to advance key goals.
- The recognition of the growing private sector interest in space exploration. Interest from the private sector is already transforming the future of low Earth orbit, creating new opportunities as space agencies look to expand human presence into the Solar System. Growing capability and interest from the private sector indicate a future for collaboration not only among international space agencies, but also with private entities pursuing their own goals and objectives.

ISECG space agencies envision a future of expanding partnerships and collaboration, with an increasing number of actors, as a means to realise the ambitious shared goal of sustainably expanding human and robotic presence into the Solar System.

Australia

Canada

China

European Space Agency

France

India

Italy

Japan

Republic of Korea

Russia

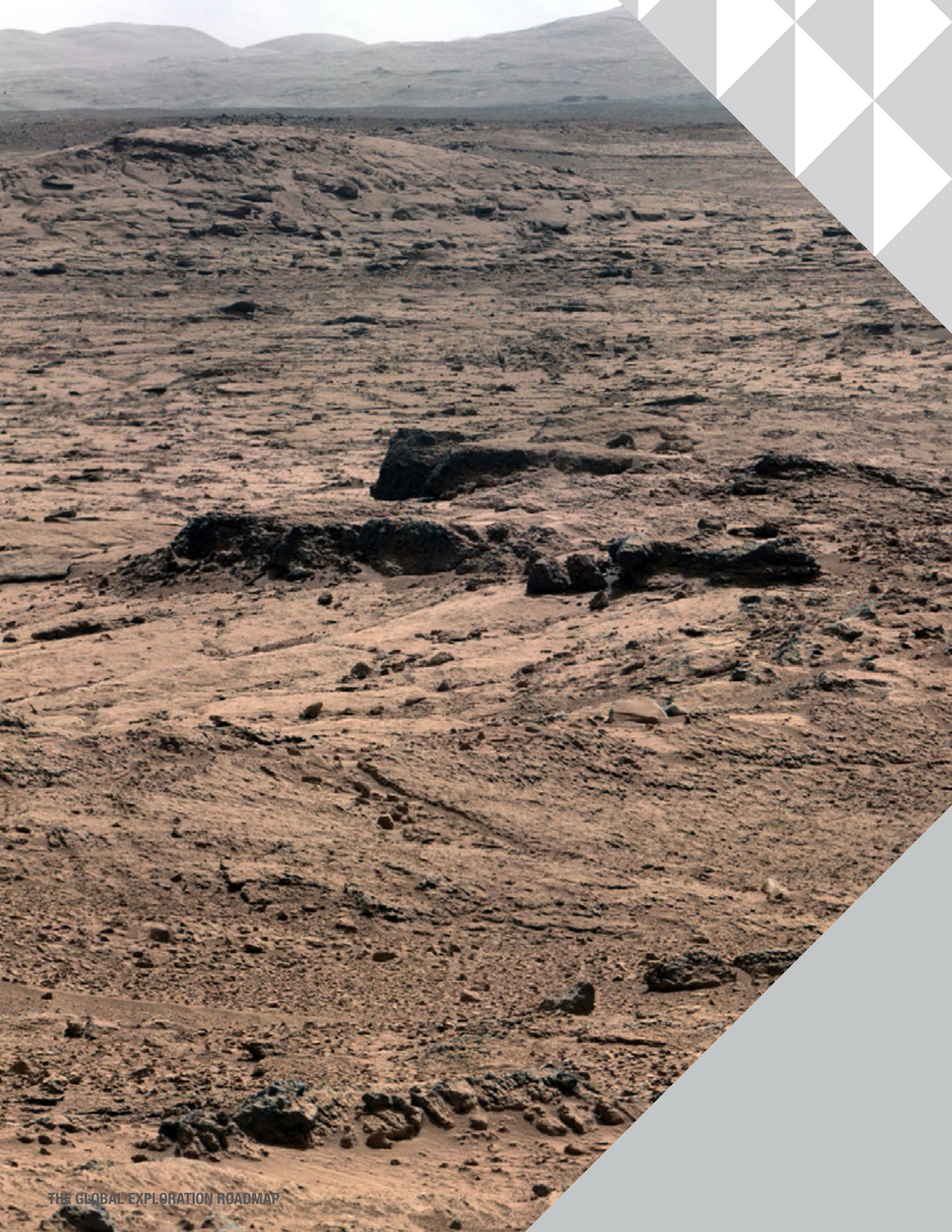
Ukraine

United Arab Emirates

United Kingdom

United States

Table of Contents



Chapter 1: Why We Explore

"The Earth is the cradle of humanity, but mankind cannot stay in the cradle forever."

~ Konstantin Tsiolkovsky

A Shared Roadmap for Expanding Human Presence into the Solar System

This shared roadmap embraces government and private sector strategies for expanding human presence in low Earth orbit, to the Moon and on to Mars. Government investments in space exploration capabilities and missions serve an important role by advancing technologies, reducing risks and identifying new markets where competition can spur innovation that generates further benefits.

The International Space Station (ISS), continuously crewed since 2000, shows the benefits and potential of human activity in low Earth orbit. The ISS hosts ongoing scientific investigations sponsored by government and non-government entities. Through international collaboration, over 2,100 such activities have been implemented with more ongoing. The ISS is an invaluable long-duration flight analogue for future human deep space missions enabling research to address human health and performance risks as well as serving as a testbed for critical technologies. It is also used for educational and outreach activities, reaching millions of students and the interested public around the world each year. Lastly, the ISS is facilitating the economic development of low Earth orbit, which will remain an important destination for human activity and research in space.

ISECG space agencies envision that by the mid 2020's a Gateway in the lunar vicinity will open the space frontier for human exploration of the Moon, Mars and asteroids as we expand human exploration and commerce into deep space. The Gateway will support activities on and around the Moon while also serving as a technology and operations testbed allowing human explorers to address the challenges and risks of deep space exploration and conduct scientific investigation of our Solar System.

Utilising the Gateway with a partially reusable lunar lander (under study by JAXA, ESA and Roscosmos), human missions to the lunar surface are envisioned. These missions will also advance some of the capabilities and technologies needed for the exploration of Mars. Astronauts can advance the preparatory work of robotic missions in assessing the potential for resources on the lunar surface and techniques for using them to make exploration sustainable.

Ambitious visions like the ones shown below have the power to unite in a common cause and inspire future generations. Human space exploration has fascinated humanity since the start of the space age in the 1950's and inspired a multitude of engaging visions, promoted by individuals, space agencies and private sector entities. The Global Exploration Roadmap is consistent with these visions and represents a common pathway which can enable their realisation.

The Global Exploration Roadmap represents a blueprint of next steps for the current and next generation of explorers. Governments, the private sector and academia will determine investments and partnerships that can translate this blueprint into tangible progress extending human presence, with the associated benefits.

The Moon Village vision entails an incrementally growing ensemble of capabilities for multiple uses and is open to multiple users.

The UAE vision of Mars 2117 will drive technologies for space exploration such as energy, water and food security that will also benefit life on Earth.

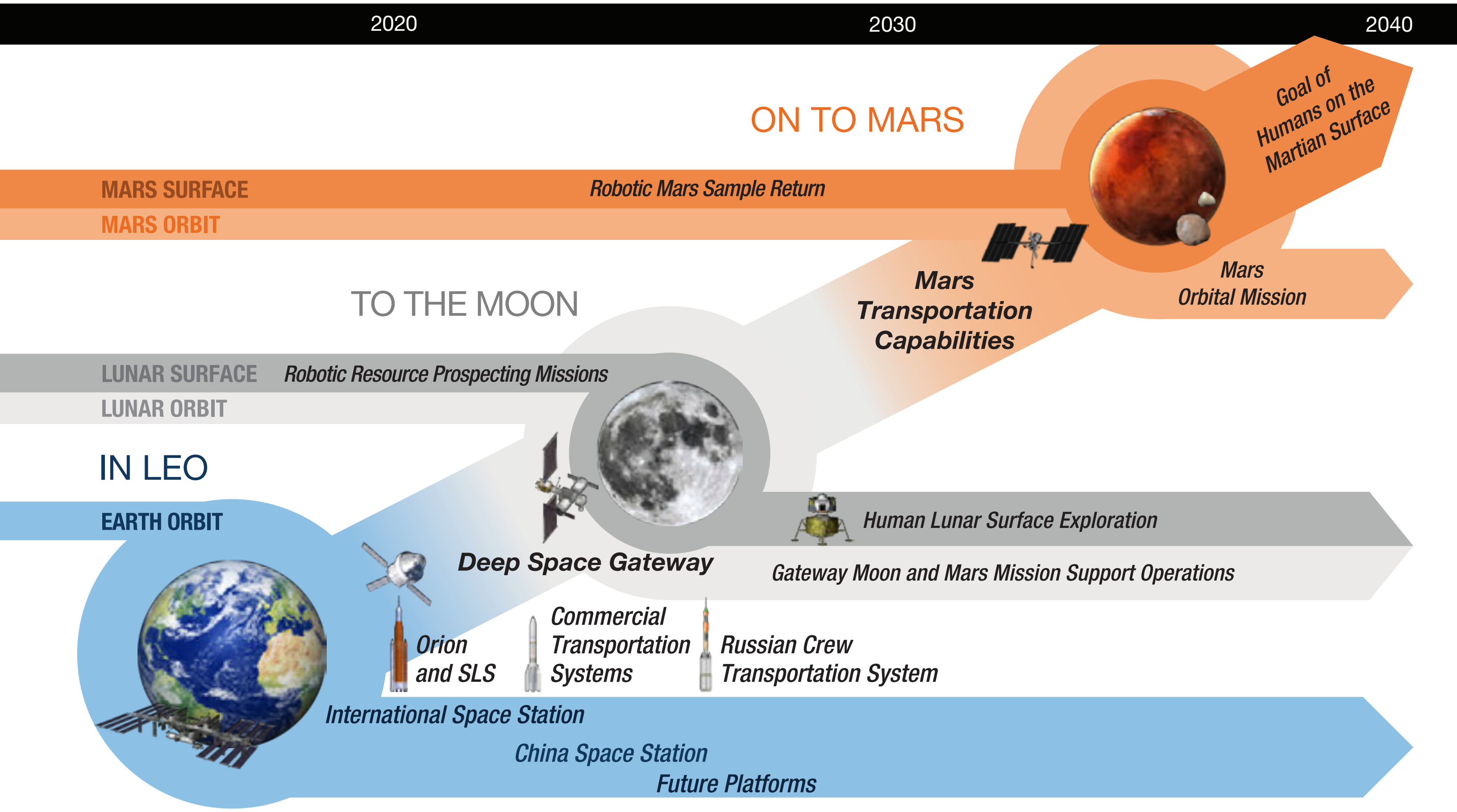
Expanding human presence into the Solar System has the unique capacity to inspire citizens around the world to create a better future.

The knowledge and technologies derived from this endeavour expand our understanding of the Universe, create economic opportunities and help address grand challenges faced here on Earth. A partnership between humans and robots is essential to the success of this venture. Robotic missions accomplish world-class science while also serving as our scouts and proxies, venturing first into hostile environments to gather critical information that makes human exploration safer. Humans will bring their flexibility, adaptability, experience, dexterity, creativity, intuition, and the ability to make real time decisions to the missions.

The Global Exploration Strategy: the Framework for Coordination, released in 2007, presents a vision for globally coordinated human and robotic space exploration focused on Solar System destinations where humans may one day live and work. In this global vision, robotic missions precede human explorers to the Moon, near-Earth asteroids, and Mars in order to unveil many of their secrets, characterise their environments, and identify risks and potential resources. Human exploration then follows in a coordinated manner that is affordable and sustainable, which both benefits and contributes to space agencies around the world achieving their goals and objectives.

The ISECG was established in response to the Global Exploration Strategy. The Global Exploration Roadmap depicted below has been developed to aid in turning this vision into reality. While not committing individual agencies to specific steps and activities, the Global Exploration Roadmap serves as a reference for generating innovative ideas and solutions to address the challenges ahead together.

The Global Exploration Roadmap



The Benefits of Space Exploration: A grand endeavour pursued by nations seeking to gain new knowledge, inspire and drive innovations.

Human and robotic space exploration responds to the deeply rooted quest of humankind for answering questions on the origins and nature of life in our Universe and extending human frontiers. Space exploration brings direct and indirect benefits to society. Benefits can be categorized into these fundamental areas:

Innovation and Economic Growth. Space exploration is a driver for innovation. It has contributed advancements in technologies touching every aspect of everyday life, from health and medicine, public safety, consumer goods, to energy and the environment, industrial productivity and transportation. Space exploration will continue to be an essential driver of technology and innovative ideas, providing opportunities for other sectors to partner with the space sector on joint research and development. For example, water recycling system innovations required to support ISS have resulted in technologies and approaches that are applied on Earth for conservation activities and in disaster relief areas. Enhancements in water recycling and environmental control needed for crew missions into deep space will improve these technologies for terrestrial use, returning these benefits to both the public and private sector. New technologies stemming from space exploration also benefit other in-space applications for terrestrial use such as satellites used for meteorology or communications.

In the last several years, job creation and economic growth have been accelerated by private investments in the space sector. Private investments and competition are stimulating the economic development of low Earth orbit, generating innovations that promise to make space exploration more affordable and sustainable.

Knowledge Gain. The benefits from space exploration are rooted in the generation of new knowledge, which is of intrinsic value to humankind. Scientific knowledge acquired from space expands humankind's understanding and frequently unlocks creative and useful Earth-based applications for society. For example, studies of the human body's response to extended periods in the microgravity environment of the ISS are improving our understanding of the aging process. Fundamental scientific studies of the Martian environment, its evolution and current state represent important benchmarks of terrestrial planetary evolution, and hence, provide a model that scientists believe will aid our growing

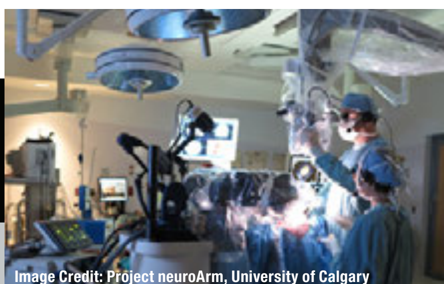


Image Credit: Project neuroArm, University of Calgary

Advanced Medical Robotics: Canadian medical robotics technology born of Canada's space robotics designed by MacDonald, Dettwiler and Associates, Ltd. (MDA) for the U.S. Space Shuttle and the ISS, neuroARM (above) is the world's first robot capable of performing surgery inside magnetic resonance imaging (MRI) machines, and helps neurosurgeons perform precise surgical techniques with real-time imagery. A Guided Autonomous Robot was also developed using this technology and is in clinical trials. It works inside an MRI machine and helps surgeons locate and identify breast tumours and perform highly dexterous, precise movements during biopsies.

Image Credit: NASA

Remote Medical Care: Provision of medical care to astronauts in space has similar challenges to that provided to patients in disaster or remote areas on Earth like northern communities in Canada. Vast distances and the lack of local access to medical specialist expertise and analytical and imaging capabilities make it a challenge to diagnose and treat an injury or illness. Exploration missions will have the additional burden of not being able to evacuate sick crewmembers back to Earth. Already today, medical care has become more accessible in remote regions by use of small ultrasound units, telemedicine and remote guidance techniques pioneered for use on the ISS.

Image Credit: NASA

Water Purification: Whether in the confines of the ISS or a tiny village in sub-Saharan Africa, drinkable water is vital for human survival. Unfortunately, many people around the world lack access to clean water. Using technology developed for the ISS, at-risk areas can gain access to advanced water filtration and purification systems, making a life-saving difference in these communities. The commercialisation of this station-related technology has provided aid and disaster relief for communities worldwide.

understanding of climate change processes on Earth. In the longer term, the knowledge accumulated over many missions and the expansion of human presence into the Solar System will help people gain perspective on the fragility and rarity of our ecosphere in the Universe and on humankind's accomplishments, potential, and destiny.

Global Cooperation: Partnership to Address Global Challenges. Sustainable space exploration is an inherently worldwide endeavour. The challenges associated with extending human presence in a sustainable manner into space are driving the creation of new partnerships at all levels of society, including governmental, industrial and academic organizations around the world. The ISS is an exceptional example of how partners from different cultures can work effectively together to advance common goals. Collaborative research on the ISS in many disciplines has significantly multiplied the global reach of results and knowledge.

Such global cooperation builds on each other's interests, strengths and capabilities, taking advantage of the opportunity to share views and leverage both complementarity and diversity. Cooperation among different stakeholders has generated synergies along the entire value chain, including exchanging know-how on space project best practices, and spin-offs of innovative technologies. Newly forged global partnerships may offer resources for addressing the global challenges facing humankind today and in the future.

Culture and Inspiration. Space exploration offers a unique and evolving perspective on humanity's place in the Universe. It stimulates curiosity and the ability to see the bigger picture. By uncovering new information about the beginnings of our Solar System, space exploration brings us closer to answering profound questions that have been asked for millennia: What is the physical nature of the Universe? Is the destiny of humankind bound to Earth? Are we and our planet unique? Is there life elsewhere in the Universe? The excitement and enthusiasm generated by space exploration attracts young people to careers in science, technology, engineering and mathematics, and increases public interest and support of science and exploration. Motivating our youth to study and achieve is a common desire shared by all nations.

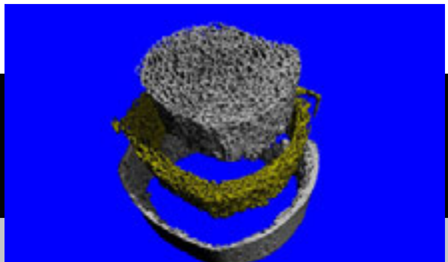


Image Credit: CNES and ESA

Measure of Bone Architecture and Bone Quality: During spaceflights, astronauts present a fast bone loss, about ten times faster than the fastest similar processes on Earth. Space research has contributed to better understand the effects of mechanical constraints on bone loss. The ERISTO project, co-founded by CNES and ESA, has enabled the development of innovative tools to measure bone architecture and bone quality that are currently used pre- and post-flights as well as for the routine practice of clinical medicine.

Earth Observation: Images from orbit can help with rapid response efforts to floods, fires, volcanic eruptions, deforestation, harmful algal blooms and other types of natural events. The ISS passes over more than 90 percent of the Earth's populated areas every 24 hours. An imaging system aboard the station, ISS SERVIR Environmental Research and Visualization System, captured this photo of Mt. Etna, Italy.

For more information on space exploration benefits:

CNES: https://cnes.fr/en/page-intermediaire/CNESMAG
CSA: http://www.asc-csa.gc.ca/eng/about/everyday-benefits-of-space-exploration/
ESA: http://youbenefit.spaceflight.esa.int/
ISECG: http://www.globalspaceexploration.org
JAXA: http://iss.jaxa.jp/kiboresults/benefits/
NASA: https://spinoff.nasa.gov/Spinoff2017/index.html
Roscosmos: https://www.roscosmos.ru/

Goals and Objectives

Recognising the importance of delivering benefits to stakeholders, space agencies have identified five common space exploration goals and associated objectives. These goals and objectives reflect the integrated nature of science and exploration and also build on the synergies that exist between human and robotic space exploration missions. The formulation of goals and objectives is an iterative process that reflects ongoing refinements as agency priorities evolve.

Expand Human Presence into the Solar System

- Ensure continuity for human spaceflight and continued utilisation of low Earth orbit
- Enable sustained living and working around and on the Moon
- Enable sustainable human missions living and working around and on Mars

Understand Our Place in the Universe

- Study the origin and evolution of the Earth and the Moon system, the Solar System and the Universe
- Search for evidence of past or present life and the origin of life on Earth
- Investigate habitability of potential human destinations

Image Credit: UAE

Culture and Inspiration: Space is inspiring young men and women to pursue careers in science, engineering and technology. In the space sector of the United Arab Emirates, over 40% of the workforce are female. Since 2000, the UAE has carried out an extensive range of space activities with ambitions set significantly higher for the future. The development and use of space technology will contribute to the diversification of the national economy.

Image Credit: NASA

Temperature-Regulating Fabrics Keep Babies Comfortable: Like ice cubes in a drink, phase change materials absorb heat as they change from solid to liquid, and, if exposed to colder temperatures, they release that heat as they refreeze. Phase change material advancements driven by spacesuit needs led to the creation of fabrics incorporating phase change materials, most recently commercialised by San Francisco-based Embrace Innovations in wraps and blankets that help keep babies at an optimal temperature.

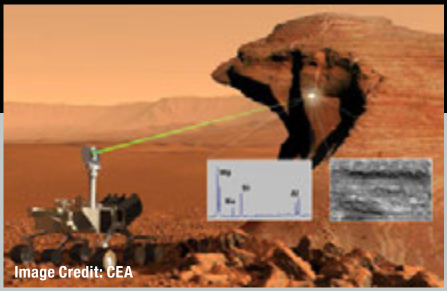


Image Credit: CEA

Mars Science: The French ChemCam instrument on the Mars Science Laboratory, Curiosity, fires a laser and analyses the elemental composition of vaporised materials on the surface of Mars. Mars has the greatest similarity to Earth in past and current planetary processes, and may have the best record of when life started in our Solar System and of catastrophic change in planetary evolution. As we learn more about Mars (surface, interior, atmosphere, hydrosphere and potential for supporting biology) our understanding of the Earth and potential risks to this amazing planet will be dramatically improved.

Engage the Public

- Inspire and educate
- Create opportunities for participation in space exploration
- Deliver benefits to society

Stimulate Economic Prosperity

- Promote industrial capability and competitiveness for space exploration
- Facilitate the development of commercial markets at exploration destinations
- Promote collaboration with the private sector

Foster International Cooperation

- Encourage and embrace the participation of nations in space exploration initiatives
- Promote interoperability to increase opportunities for international partnerships

Image Credit: ACCESS

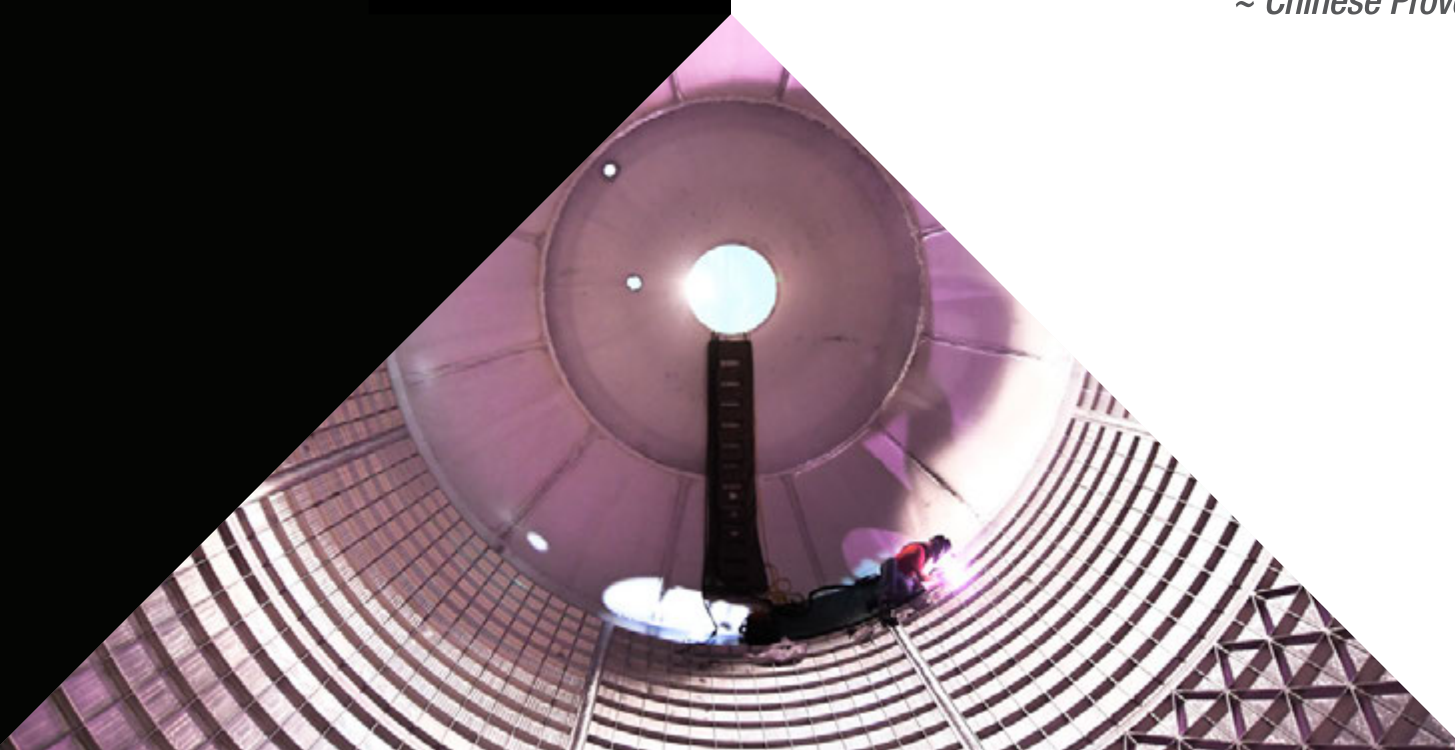
New Materials for Better Planes: The investigation of new metallic alloys such as titanium aluminide onboard the ISS as well as relevant techniques for their utilisation has contributed to the development of new turbine blades for the Airbus A320neo. These titanium aluminide blades are significantly lighter than the usual blades, while showing great strength and little corrosion. With the new material, jet engines are quieter, more fuel efficient and eco-friendly.

Plant Research: Innovation in meeting human needs by more efficient use of mineral, water, energy and food resources. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has an extensive program in plant research and works closely with industry. CSIRO is the federal government agency for scientific research in Australia. In September 2017 the Australian Government announced the formation of the Australian Space Agency heralding a new future for Australian space development.

Chapter 2:
The Mission Scenario

"The journey of a thousand miles begins with one step."

~ Chinese Proverb



In Low Earth Orbit, to the Moon, on to Mars

Several ISECG space agencies are developing human space exploration capabilities required to venture out beyond low Earth orbit in partnership. For NASA, these initial enabling capabilities consist of a heavy lift launch vehicle (the Space Launch System/SLS), an exploration crew vehicle (Orion), and updated ground launch systems. NASA's Space Launch System provides a critical heavy-lift capability powering people and cargo to the Moon and beyond. It also opens new possibilities for other payloads, including robotic scientific missions to places like Mars, Jupiter and beyond. Offering the highest-ever payload mass and volume capability and energy to dramatically reduce travel times to deep space destinations, SLS is designed to be flexible and evolvable in order to meet a variety of crew and cargo mission needs.

The Orion Spacecraft is built to take four crewmembers farther into space than ever before. Orion will serve as the exploration vehicle that carries crew beyond the Earth and provides safe reentry at the high-return velocities typically needed for deep space missions. The Orion service module is built in Europe and provides in-space propulsion capability, attitude control, power, water and oxygen needed for a habitable environment.

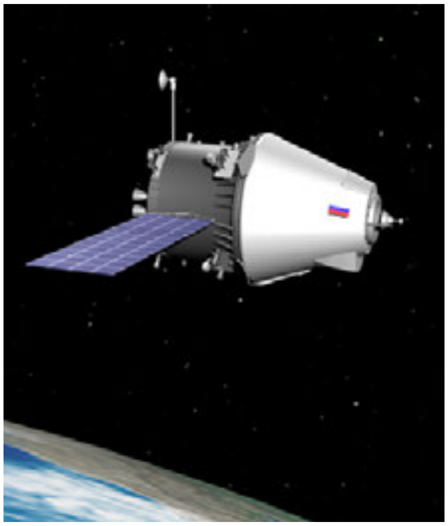
Russia will begin testing a new crew transportation system in the early 2020's. Initial flights to the ISS will demonstrate the new system that will eventually be used for missions to the Moon. By the end of the 2020's, the Russian super-heavy launch vehicle with the crew transportation system will be ready for human flights to the Moon. Prior to this, several robotic precursor missions will explore the Moon's surface and test technologies as a part of the Russian lunar program.

Sustainability Principles

The following set of principles guide development of the Global Exploration Roadmap. They represent attributes of a sustainable human space exploration endeavour.

- **Affordability – Innovative approaches to enable more with available budgets**
  Cost must be a consideration when formulating exploration programmes as well as throughout programme execution. Architectures should favour reusable and reliable in-space systems implemented in partnership to share cost.
- **Exploration Benefit – Meet exploration objectives and generate public benefits**
  Sustainable human space exploration must respond to exploration goals and objectives and provide value to the public and other stakeholder communities. Synergies between space and other domains are crucial.
- **Partnerships – Provide early and sustained opportunities for diverse partners**
  International cooperation is critical for enabling and sustaining increasingly complex exploration missions. Collaborations should consider the long-term interests of each partner, large or small. Collaborations with the private sector, where goals align, can enable new approaches and create markets for services to support space exploration.
- **Capability Evolution and Interoperability – The step-wise evolution of capabilities with standard interfaces**
  Building upon existing capabilities and increasing performance with each step. Using common interfaces and modular architectures facilitates addition of new partners, reduces mass and increases safety.
- **Human-Robotic Partnership – Maximise synergies between human and robotic missions**
  Combining the unique and complementary capabilities of humans and robotic systems enables a greater set of goals to be met effectively, cost-efficiently and safely.
- **Robustness – Provide resilience to technical and programmatic challenges**
  Plans and actions must have flexibility to cope with unplanned changes or crisis situations, whether due to catastrophic events, changes in partner priorities, adjustments in available funding or the evolution of objectives. Dissimilar redundancies of critical functions should be applied early, where practicable.

Orion Spacecraft, NASA, with service module provided by ESA.

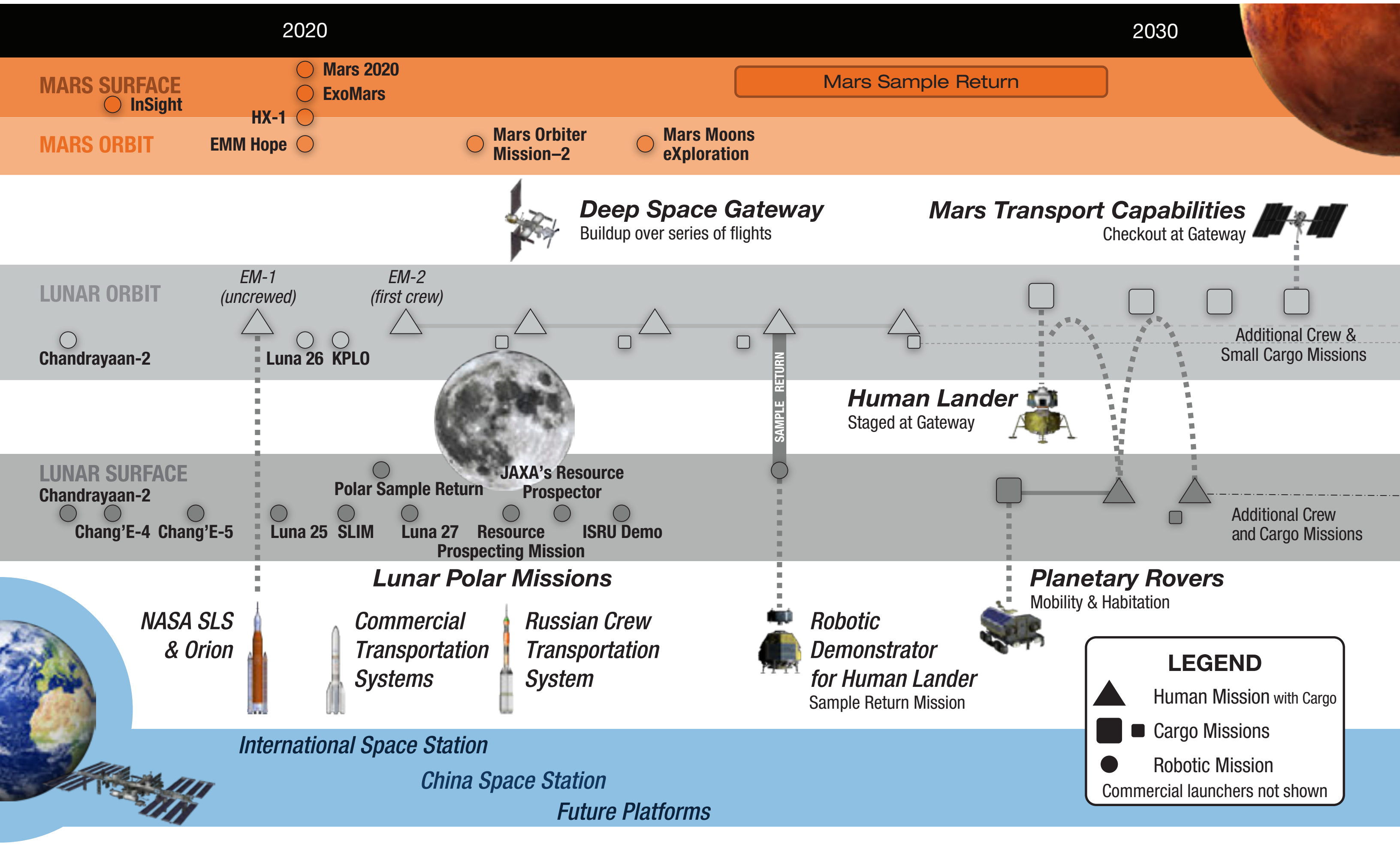


Russian Crew Transport System, Roscosmos.

The Mission Scenario

The ISECG Mission Scenario reflects planned human and robotic missions, as well as conceptual missions under study. While not all agencies will participate in all missions, this mission scenario shows an international collaborative effort and consensus on steps to achieving the common horizon goal of human missions to explore the surface of Mars. It recognizes the shared importance of low Earth orbit and lunar exploration to the sustainability of the endeavour.

ISECG Mission Scenario



The key steps for expanding human presence shown in the ISECG Mission Scenario:

- Low Earth Orbit: Validate needed deep space technologies and capabilities, provide continuity for research in low Earth orbit
- Robotic Missions
  - Demonstrate technologies for human missions
  - Perform surveys or sample returns for science as well as resource and environment assessment
- Lunar Vicinity: Establish a platform (deep space Gateway)
  - Learn more about living in deep space
  - Operate robotic missions to and on the lunar surface
  - Stage crewed missions on the lunar surface (Human Lunar Lander)
  - Enhance science of the Moon and the Solar System
  - Assemble and check-out of the transport vehicle to Mars
- Lunar Surface Missions: Establish a lunar surface capability
  - Support lunar science
  - Prepare and test mission operations for subsequent human exploration of Mars and/or long-duration human activities on the Moon
  - Understand the potential economic implications of lunar development and/or commerce
- Humans to Mars: Enable sustainable human missions to Mars
  - Missions to Mars orbit and surface

Low Earth Orbit: Human activity is here to stay.

THE INTERNATIONAL SPACE STATION

The ISS provides a variety of equipment and systems to support advanced research and development activities. There is equipment to support life sciences, physical sciences and materials science research. Examples are on-board capabilities for rodent research, protein crystal growth, DNA sequencing, cubesat and small spacecraft deployment and additive manufacturing equipment. A steady stream of logistics flights brings equipment to the ISS and returns investigation samples to support timely opportunities for research and analysis. Information on available resources and equipment can be found at **www.nasa.gov/stationfacilities** and on individual ISS partner agency websites.

New research modules on the Russian segment of the ISS will expand the opportunities for research and technology demonstration. New commercial capabilities, including European and US capabilities, are also being added. New US crew and cargo transportation systems are anticipated in the future, providing increased access and beneficial conditions for users. These new crew transportation systems will join the Russian Soyuz which has been essential to ISS operations. These are examples of the benefits of international partnership.

The ISS is a useful platform for performing Earth science, heliophysics, and astrophysics. The ISS is also an essential platform to prepare for human space exploration and much work remains to be done. Human research and exploration technology demonstrations are a significant focus of activity onboard the ISS. Maturing life support systems from the ISS state of the art to the performance and reliability requirements of exploration missions is a high priority for several space agencies.

The ISS serves as an innovation platform where governmental and non-governmental entities alike are exploring opportunities in low Earth orbit. Entrepreneurs, innovators, pharmaceutical companies and other consumer product researchers are all attracted to low Earth orbit for its potential to lead to new products, markets and services. Over 600 payloads have been delivered to the ISS for such purposes. These developments appear to indicate that private sector demand, in addition to space agency demand for humans and their infrastructure in low Earth orbit, will continue far into the future.

International Space Station partner agencies are committed to operation of ISS until at least 2024 and potentially beyond.

JAXA's water recovery system technology demonstration will be delivered to the ISS in 2018.

NASA demonstrates 3-D printing on the ISS.

THE CHINESE SPACE STATION

In September 2010, the Chinese government approved the implementation of their space station project. China's Space Station project is organised in two phases: the first phase includes the Space Laboratory; the second phase includes construction of a Space Station. The Tiangong 2 Space Laboratory was launched in September 2016. Then, the Shenzhou-11 crewed spacecraft and cargo spacecraft docked with it. The China Space Station consists of a core module and two specialised modules. The China Space Station will have an orbital inclination of 42 degrees and an altitude of approximately 340-450 km. The station has a design life of 10 years with the ability to extend service life through maintenance. After the construction is completed, two or three astronauts will live and work continuously for long durations, with the station supporting a maximum of six people during periods of crew rotation. The station is equipped with an external robotic arm and other equipment to support station construction, maintenance and operations.

The Space Station phase is divided into three sub-phases. In the key technical verification phase, the test core module is launched and multiple pilot and cargo spacecraft launches test the core module to validate astronaut long-term presence, regenerative life support systems, flexible solar wing and drive mechanism, control of a large flexible structure, and space station assembly. Following this key technical verification phase, the two specialised modules are launched completing the construction phase. During this period, a number of Shenzhou crewed and cargo spacecraft will be launched to support the completion of construction tasks and carry out scientific and technological experiments simultaneously.

When the Space Station construction tasks are completed, the operations phase begins. The astronaut crew will conduct long-duration missions to conduct scientific and technological research and exploration activities. On the basis of the existing three-module configuration, an additional docking interface is available with the capability of docking an additional permanent element. The Space Station can accommodate other countries' spacecraft access that meets the standards of China's space station and can also be equipped with an external experimental platform and experimental equipment. Additional modules may be added to the Space Station in the future.

The main scientific research and application directions of the Space Station are: space medicine, space life science and biotechnology, microgravity fluid physics, space material science, microgravity basic physics, space astronomy and astrophysics, space environment and space physics, aerospace components, space geosciences and applications, space-based information technology, new aerospace technologies and new applications in space applications.

International cooperation can be based on module level cooperation, on other countries' spacecraft visits, on astronaut joint flights, and on cooperation in space science and space applications research.

FUTURE PLATFORMS

Several private sector companies have announced concepts for commercial platforms, which could be human-tended, to offer services to a diverse set of non-government and government users. In addition to government users, demand is expected to come from private companies conducting research or in-space manufacturing, tourism, and other commercial initiatives that benefit from access to low Earth orbit. The availability of a private sector platform or platforms in low Earth orbit where government sponsored research can be accomplished will be a consideration related to ISS lifetime decisions. Ensuring the continuity of human spaceflight is another major consideration as it is critical to maintain the industry capabilities, technologies and inspirational and aspirational momentum for future generations.

Some agencies are studying future platform designs in order to understand future possibilities, either to be realised through government investment or in partnership with private sector entities. For example, a post-ISS Russian orbital station concept, aimed to continue the success of the ISS and to provide transition to low Earth orbit utilisation with a wide range of benefits for humanity, as well as to create additional opportunities for partnership, is being studied. The goals of these studies are to understand the major characteristics of a user-driven platform, and assess possible government roles in promoting their availability.

ISECG space agencies are increasingly vocal about their need for continued access to low Earth orbit beyond the ISS lifetime. Several have announced commitments to continue research and astronaut development activities with the hopes that these will provide encouragement to private sector entities studying future platforms. ISECG space agencies acknowledge significant developments in the private sector and welcome the emerging space economy around humans and their infrastructure in low Earth orbit as several agencies expand their focus with goals and resources toward human exploration of the lunar environment, Mars and other destinations.

The Lunar Vicinity: The next step for advancing and sustaining human space exploration goals.

Both the orbit and the surface of the Moon play important roles in sustainable human space exploration. A small human-tended facility placed in the lunar vicinity enables human and robotic lunar exploration in a manner that creates opportunities for multiple users to advance key goals and foster a burgeoning presence of humans in deep space.

In particular, a human-tended facility in the lunar vicinity enables:

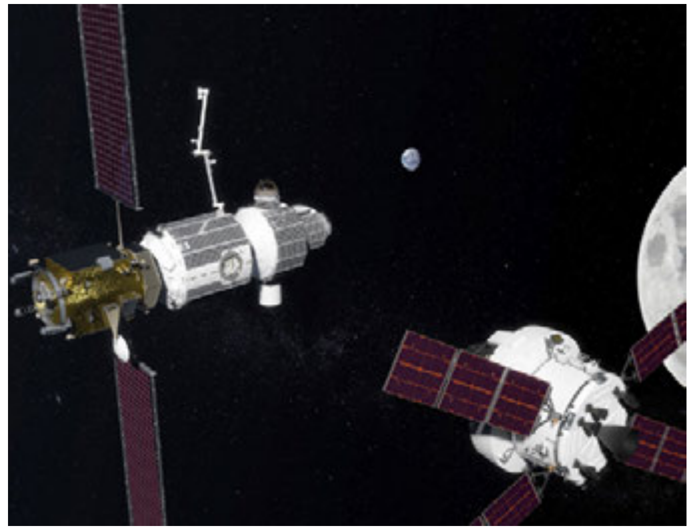
- **Reusability:** The lunar vicinity is an excellent location for staging and refurbishment of reusable elements for exploration of the Moon and Mars. The location contains stable orbits which are outside of Earth's deep gravity environment and provides a convenient jumping off point for reusable robotic and human lunar landing systems including refuelling and servicing between missions.
- **Testing:** Deep space electric propulsion systems can be tested. Also, the environment of the lunar vicinity is equivalent to what astronauts and spacecraft will experience in deep space. Technologies, procedures and risk management protocols can be tested in relative proximity to Earth in case of an emergency. Prior to departing for 2-3 year missions to Mars, in-space capabilities can be tested to assure flight readiness.
- **Accessibility:** The lunar vicinity is reachable by government and commercial launch transportation systems promoting robustness and opportunity. There are many possibilities for commercial services and collaborations between government and the private sector.

Lunar Vicinity Orbits Support a Variety of Exploration Objectives

Balancing orbital energy between the Earth and the Moon gravity wells, and maintaining favourable communications and thermal attributes, are important considerations for lunar orbit locations. The most promising locations consist of a family of halo orbits around the collinear Earth-Moon Libration points that pass within a few thousand kilometers of the lunar surface every seven days. From this home-base orbit, the Gateway will be relocated within the lunar vicinity, reaching other orbits in support of exploration and objectives while testing advanced propulsion technologies needed for space exploration.

An international deep space Gateway to the Moon and Mars

A conceptual international deep space Gateway is the next piece of the architecture that enables a sustainable and affordable future for human space exploration. The first element of the deep space Gateway will be a module that uses a high-power solar electric propulsion system and provides power, command and data services to the rest of the platform. The Gateway will include habitation capabilities to support a crew, a science airlock, a robotic arm and capability for spacewalks. The Gateway will provide communication to Earth and the surface of the Moon, opening up new opportunities for robotic exploration of the scientifically interesting lunar far side and polar regions.



A concept for the deep space Gateway.

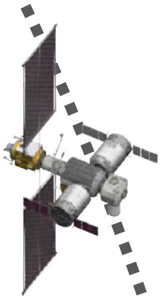
Gateway assembly and operation will be supported by Orion and the Space Launch System, as well as other space transport systems. Initially, it will be visited by a crew of four for missions of a minimum of 30 days at a time. Initial 30 day missions may increase in frequency and length of time as the Gateway evolves and additional transportation systems become available.

The conceptual Gateway includes interfaces for installation of future advanced closed loop life support systems, allowing for testing of new systems and longer crew stays at the Gateway. Gateway crews will perform science, assess habitation capabilities for future missions, and investigate exploration technologies requiring the deep space environment for testing. Private entities may also utilise the Gateway through public private partnerships. When uncrewed, the Gateway will continue to support science and other activities operated from Earth.

Lunar exploration studies by JAXA, ESA, CSA and Roscosmos make use of the Gateway for support to reusable human lunar landers and robotic exploration of the Moon. The Gateway and its crew can provide services and support for future transportation systems heading to Mars.

Science enabled at an international deep space Gateway

The lunar vicinity is a vantage point from which to conduct scientific observations of the Moon, the Earth, and the Solar System, using instruments externally mounted on the Gateway. A Gateway can be used to receive scientifically valuable samples from the lunar surface as well as other Solar System destinations. The Gateway can act as a communication relay for smallsats, cubesats and lunar surface assets. The Gateway enables human physiology experiments in a deep space environment. The lunar surface could be explored remotely using tele-robotics, including deployment of complex surface scientific instrumentation.



Contributions to Mars Mission Readiness

- Transport spacecraft assembly and checkout
- Demonstration of deep space transportation and habitation capabilities
- Autonomous crew operations protocols
- Demonstration of operations with reduced supply chain
- Radiation protection strategies
- Perfection of tele-robotics techniques
- Demonstration of vehicle servicing and refuelling

The Lunar Surface: A series of missions to the lunar surface with 4 crew to explore a cornerstone for Solar System discovery and prepare for Mars.

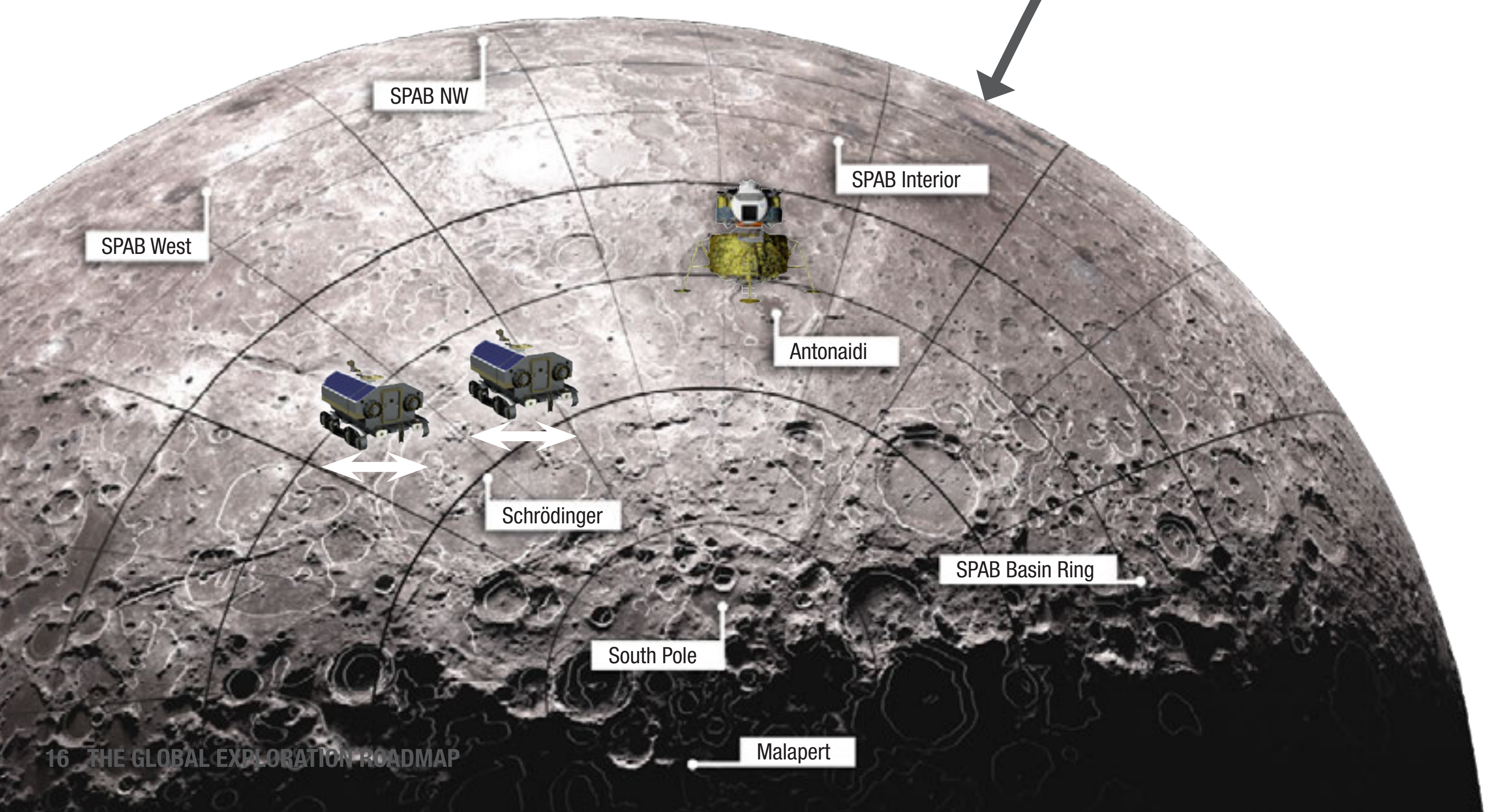
While conducting scientific study of the Moon with capabilities that can evolve for Mars exploration, space agency investments will advance technologies and buy down the risks which will enable sustained lunar surface operations led by governments or the private sector.

From the Gateway, lunar surface missions can feature:

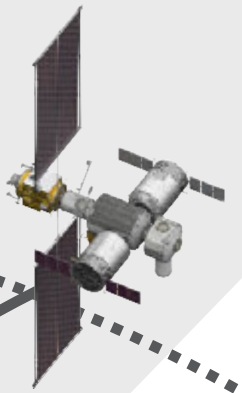
- **Reusable lunar landers:** shifting cost from developing recurring units to enabling other elements such as an in-space refuelling infrastructure.
- Decreased risk by making the Gateway available as a **crew safe haven** in a surface abort scenario.
- A crew of four to maximise exploration return and provide **flight opportunities for many partners**.
- Advancing and augmenting **in-situ resource utilisation** activities started by lunar robotic missions.

Potential Landing Sites:

The Moon is scientifically diverse with many places to explore. Interesting locations include the lunar poles (both north and south), volcanic deposits, impact craters and basins, and lava tubes or pits. The ability for pressurised rovers to move large distances on the surface between crewed missions would enable regional scientific exploration.

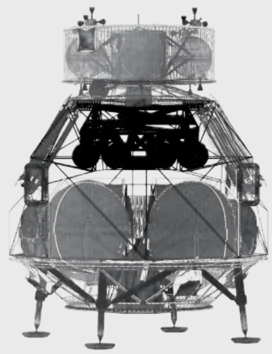


An international architecture for Human Lunar Exploration



Staged at the deep space Gateway, the ***partially reusable lunar lander*** would deliver a crew of four to locations on the lunar surface which will be chosen for high scientific and exploration value. When the crew lands on the surface, ***two relocatable rovers*** (first generation designs of the future Mars rovers) and supplies to enable an extended stay will be waiting for them. Exploring by day, analysing and planning by night, the crew will gather scientific samples and demonstrate in-situ resource utilisation techniques for the ***extended 42 day*** mission (two Moon days, one Moon night). The rovers are moved to meet the next crew, performing science along the way.

Robotic Demonstrator for Human Landing Mission



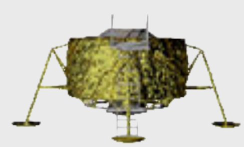
- Demonstrating critical components of crewed lander and rover
- Building confidence for operations on the surface and in transit to the Gateway
- Delivering of samples from unexplored lunar regions to the Gateway

Human Lunar Elements

4 Crew Reusable Ascent Module

3.7 t Dry
6.2 t Bi-prop
9.9 t Total

Descent Module & Cargo Lander



5.4 t Dry
19.7 t LOX/CH_4
25.1 t Total
10 t Cargo

2 Crew Pressurized Rover (x2)

5 t each

Lunar Science

The Moon preserves many of the geologic processes that occurred early in our Solar System and during the period when life formed. It preserves a record of the impact history over geologic time. Such records have been obliterated on planetary bodies that are active and have atmospheres. The Moon also preserves a record of the Sun's activity in its regolith and the early evolution of terrestrial planets. Volatile deposits at the lunar poles may contain a record of the volatiles transported to the inner Solar System. The radio-quiet lunar far side enables astrophysical investigations into the earliest stages of our universe through the deployment of radio telescopes. Human presence on the Moon would permit detailed geologic mapping, the collection of critical samples for analysis in Earth-based laboratories, and the emplacement of delicate instrumentation, including seismometers and other geophysical instrumentation.

Contributions to Mars Mission Readiness

- **Lander:** Liquid Oxygen/Methane engine demonstration, safe ascent from surface and rendezvous with return spacecraft
- **Rovers:** Long-distance and long-duration mobility, habitation capabilities in dusty environment
- **General:** Demonstration of safe sample return to Earth, in-situ resource utilisation techniques
- **Power:** Advanced nuclear power systems

Mars: Captivating people all over the world, human exploration of Mars would enable detailed in-situ scientific study of the planet and drive technologies for Earth and space exploration.

To achieve this ambition, the necessary capabilities should be developed in an order that logically fits the evolution of missions of increasing duration, complexity and distance from Earth. At minimum, six elements are required to send humans to the Mars surface and back:

1. A deep space transportation vehicle, leveraging work on ISS and investments in the deep space Gateway
2. An entry-descent lander, leveraging investments made for robotic landers and the human lunar lander
3. A Mars ascent vehicle capability, leveraging investments made for the lunar ascent vehicle and Mars sample return
4. Surface habitat and utilities, leveraging investments made for lunar vicinity and surface habitation and power generation
5. Mars surface mobility (EVA and rovers), leveraging investments made for lunar vicinity and surface EVA and rovers
6. Sufficient reconnaissance (orbital and ground) necessary to support human base selection and to inform engineering development of all Mars mission elements

Science opportunities at Mars

Mars has the greatest similarity to Earth in past and current planetary processes, and may have the best record of when life started in our Solar System and of catastrophic change in planetary evolution. Robotic missions have shown that Mars has significant amounts of buried water which is promising for the possible existence of life (past and/or present) and the support of future human explorers. Exploration of Mars will result in answers to profound scientific and philosophical questions such as: How did life start in our Solar System? Did life exist on Mars and does it exist today? What can we learn about Earth's past and future by studying Mars? Building on over 50 years of robotic-enabled science, and eventually sample return, human explorers on the surface of Mars will be critical to revealing the subtleties needed to answer these complex and fundamental questions. Humans will make possible intelligent sampling in geologic context, iterative environmental field investigations and sample preparation/analyses. Humans will advance a multi-disciplinary set of scientific objectives, such as investigations into astrobiology, atmospheric science, medicine, and geoscience.

With capabilities to travel to Mars, it will be possible to visit some asteroids in their native orbits. These remnants of early Solar System formation have scientific interest and may hold resources which will be useful in the future.

Science opportunities at Near-Earth Asteroids

Near-Earth asteroids exhibit considerable diversity within their population and have witnessed events and conditions throughout the history of the Solar System. Human exploration of asteroids will permit placement of complex instruments on the asteroid surface, as well as the ability to sample surface and subsurface sites to obtain information on the ancient history of the Solar System that larger and evolved planetary bodies have lost. Samples that are carefully chosen by a trained explorer can also help us better understand the thousands of meteorites we already have available for study by scientists, providing geologic context to meteorites that have formed much of the paradigm for the origin of the Solar System. We will also work to better understand the internal structures of Near-Earth Asteroids, a vital part of the puzzle needed in order to develop mitigation strategies for addressing threats from an Earth-bound asteroid.

Robotic Exploration Missions

Planned future robotic missions to the Moon and Mars are important for answering new science questions and closing strategic knowledge gaps related to human space exploration. The agency-led missions referenced below will be joined by numerous other robotic missions and cubesats planned by public and private organisations. ISECG space agencies have worked with relevant groups to identify strategic knowledge gaps associated with the Moon, asteroids and Mars, which can be accessed at **www.globalspaceexploration.org**.

Future Lunar Robotic Missions

Mission	Agencies/Launch Date	Objectives/Strategic Knowledge Gaps Addressed
Chandrayaan-2	ISRO/2018	Polar scientific orbiter, lander, and rover.
Chang'E-4	CNSA/2018	Far side scientific lander and rover. Communications relay satellite.
Chang'E-5	CNSA/2019	Near side sample return.
KPLO	KARI/2020	Polar scientific orbiter.
Luna 25/Luna Glob	Roscosmos/2020	Lunar volatile prospecting. Soft landing technology demonstration.
SLIM	JAXA/2020	Technology demonstration.
Polar Sample Return	CNSA/around 2020	Polar volatiles sample return.
Luna 26/Luna-Resurs Orbiter	Roscosmos/2022	Polar scientific orbiter. Polar volatiles mapping.
Resource Prospecting Mission	NASA/early 2020's	Polar science, volatile prospecting and acquisition. Drill technology demonstration.
JAXA's Resource Prospector	JAXA/early 2020's	Polar lander and rover. Polar science and volatiles prospecting.
Luna 27/Luna-Resurs Lander	Roscosmos, with ESA/2023	Polar science, volatile prospecting and acquisition. Drill technology demonstration.
ISRU Demo	ESA/2025	ISRU technology demonstration.
Korea Lunar Lander	KARI	Technology demonstration.
Luna 28/Luna Grunt	Roscosmos	Cryogenic polar volatiles sample return.

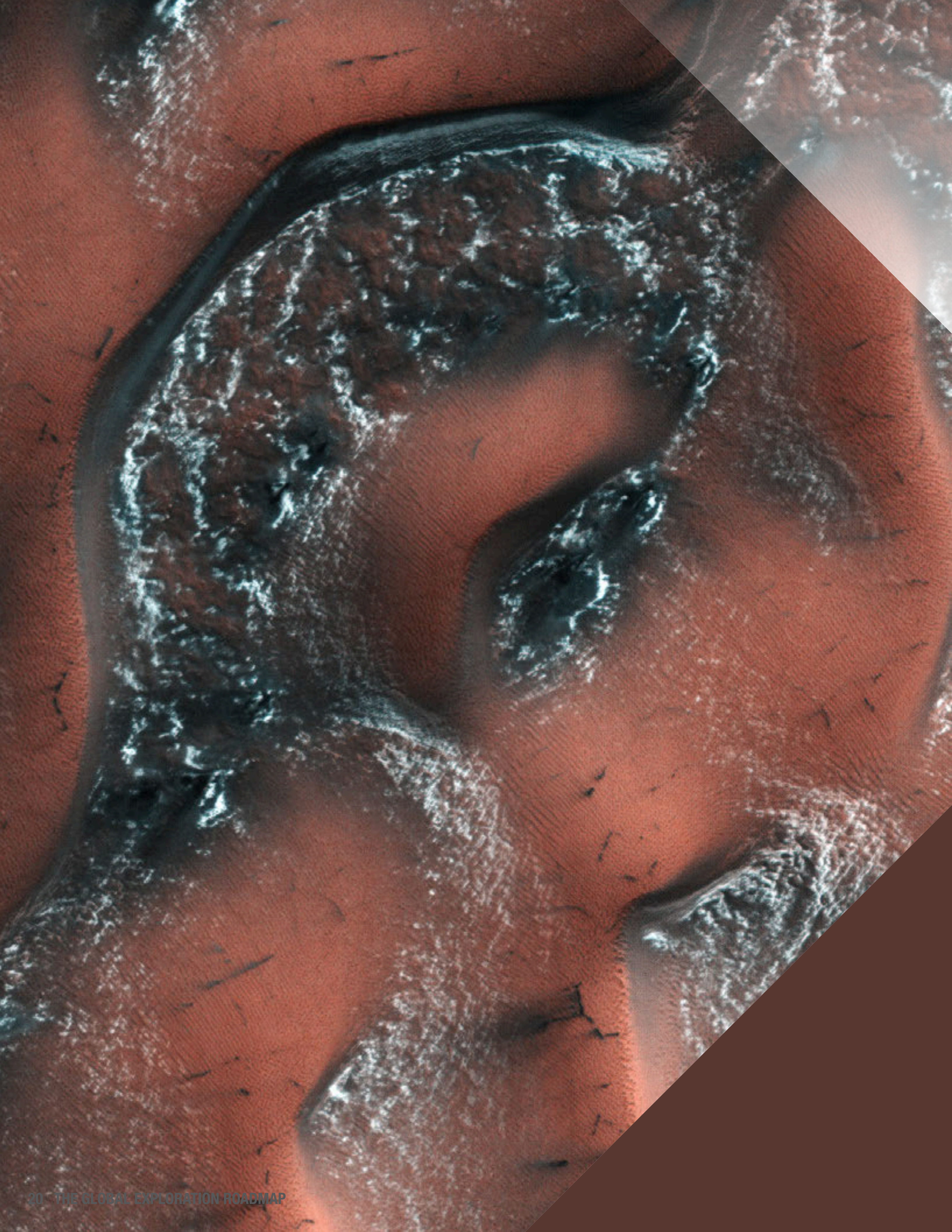
Mars Sample Return

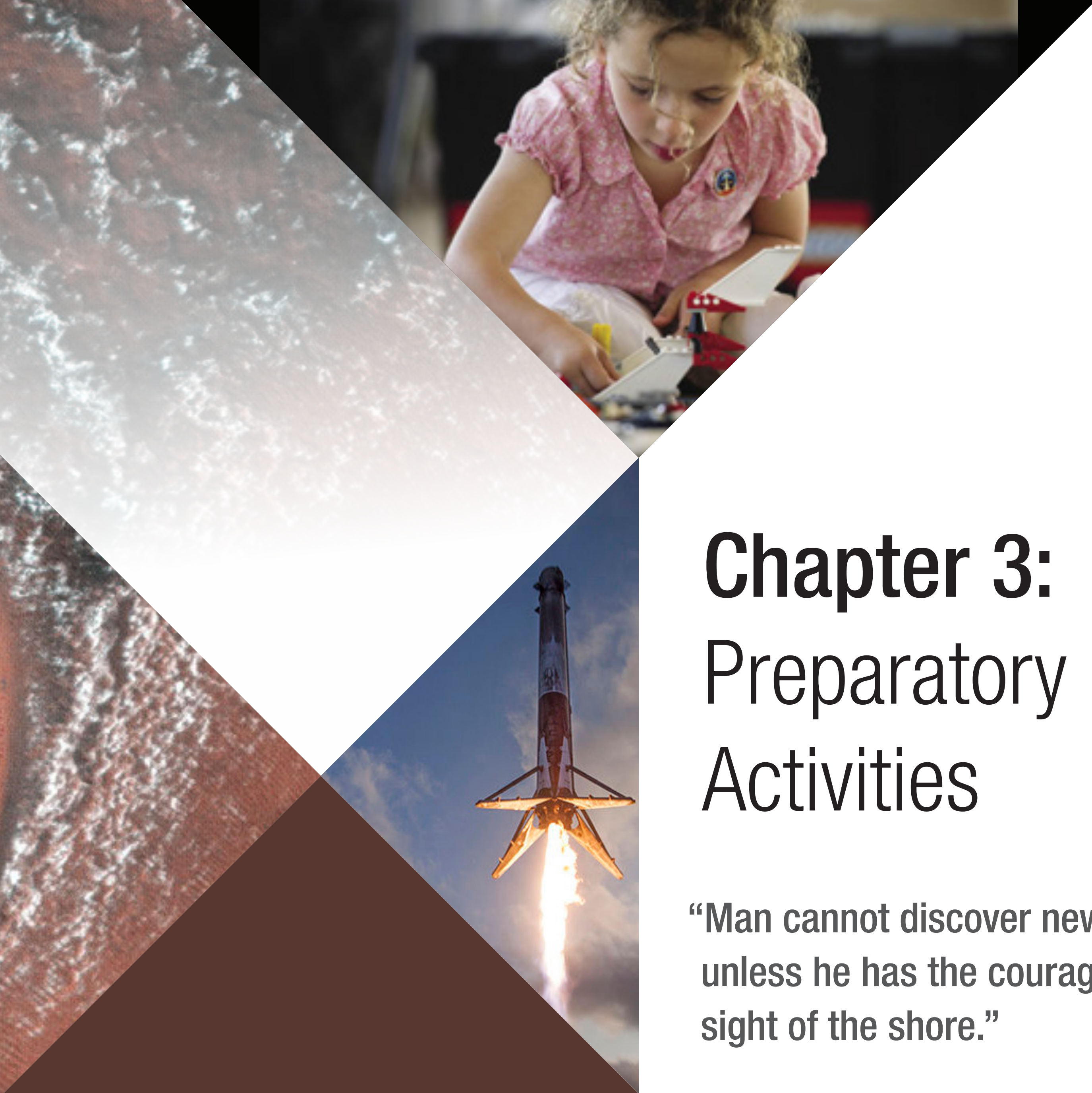
Mars sample return is a high priority for the global planetary science community. It will advance our search for life in the Solar System. The mission will also address key decadal survey priorities and allow us to understand the mechanical properties of the soil/dust and potential health hazards. It will also inform techniques for roundtrip human missions.

Under NASA leadership, mission concepts are under study. At a conceptual level, a sequence of three missions is envisioned to collect samples, place them into Mars orbit, and return them to Earth. This modular approach is robust, with each mission possessing a manageable number of engineering challenges. The approach also allows the sample return campaign to proceed at a pace determined by available funding and international involvement. The study of Mars as an integrated system is so scientifically compelling that it will continue with future missions implementing geophysical and atmospheric networks, providing in-situ studies of diverse sites and ample opportunity for additional investigations to be accomplished before the arrival of humans to the surface of Mars.

Future Mars Robotic Missions

Mission	Agencies/Launch Date	Objectives/Strategic Knowledge Gaps Addressed
InSight	NASA, with CNES, CSA, DLR/2018	Subsurface geothermal gradient/seismology and internal structure of the planet. Identification of seismic risk at the location. Weather station to monitor weather conditions.
ExoMars	ESA/Roscosmos, with ASI, CNES, DLR, NASA, UKSA and Spain/2020	Rover with 1.5m drill with instruments to search for bio-signatures, subsurface hydrated materials and very shallow ice.
Mars 2020	NASA, with CNES, ASI, Norway and Spain/2020	Oxygen processing demonstration, caching samples for later return to Earth.
EMM Hope	UAE Space Agency/2020	Synoptic weather views moving through all times of day.
HX-1	China/2020	Orbit, landing and roving mission. Investigate topographical and geological features, physical fields and internal structure, atmosphere, ionosphere, climate and environment.
Mars Orbiter Mission-2	ISRO/2022	Orbiter to study the surface and sub-surface features, mineralogy composition and upper atmospheric processes.
Mars Moons eXploration	JAXA with CNES, NASA and other agencies/2024	Sample return from one of the two moons to progress our understanding of planetary system formation and primordial material transport.





Chapter 3:
Preparatory Activities

"Man cannot discover new oceans unless he has the courage to lose sight of the shore."

~ André Gide

Private Sector Initiatives and Partnership Opportunities

The last five years have seen significant growth in private space exploration activities. Emerging commercial ventures, start-ups, small and medium enterprises, as well as large aerospace companies are aiming to benefit from increased interest and commercial potential as human presence in space is expanded. These developments are not limited to low Earth orbit. Numerous initiatives have early stage private funding to advance technologies and system concepts that will help make the exploration and economic development of the Moon, asteroids and eventually Mars, both affordable and achievable. For example, motivated by the Google LunarX Prize, several teams have developed small lunar landing and roving devices that represent capabilities which could be purchased to achieve commercial or space agency objectives. Asteroid mining concepts have illuminated the resource potential of these celestial bodies. These initiatives are a significant factor in government planning for future exploration. They present opportunities for public-private partnerships that will help achieve ambitious space exploration goals and objectives more cost effectively and contribute to affordability of the global space exploration endeavour.

Private sector innovation is a necessary component of making human space exploration sustainable and contributing to the opening of new markets and economic expansion.

Space agency planning for human exploration can already anticipate opportunities for public-private partnerships aimed at strengthening the missions defined in this roadmap. Looking one step beyond, the availability of commercial services and capabilities may influence architectures and mission approaches. For example, the ability to purchase propellant around the Moon, should it develop, will certainly impact exploration architectures. Agencies are interested in the following:

1. Space capability development partnerships that lead to the availability of capabilities or services supporting exploration missions:
   a. Cost-sharing to realise a capability or future service that would support government and other customers. Examples may include power, fuel supply, robotics assembly and servicing, lunar surface mobility, etc.
   b. Government contribution of technical expertise, facilities, hardware or software to the partnership

2. Commercial space services:
   a. Delivery of logistics to the deep space Gateway
   b. Communication services
   c. Delivery of instruments or logistics to the surface of the Moon and Mars

An international consensus exists on the value of government/private sector partnerships. Agencies welcome private sector efforts and the innovative ideas that result. Strengthening the space exploration community and promoting the development of new markets in space are keys to a sustainable human space exploration effort.

An illumination map of the resource-rich areas near the Moon's south pole. This map was created from thousands of images taken throughout a lunar year by NASA's Lunar Reconnaissance Orbiter.

In-Situ Resource Utilisation and the Lunar Poles

For several decades, the use of local resources at exploration destinations has been studied as a way to limit the cost and complexity of bringing all the needed supplies from Earth. Water is a high priority resource, as it can be used for life support consumables and the production of rocket propellant. While water exists on Mars and asteroids (as ice or in hydrated minerals), the nearness of the Moon and the presence of water ice at the lunar poles has placed the exploration for lunar polar volatiles as a high priority for ISECG agencies. Study of lunar volatiles also opens up new avenues of scientific research; such as where do the water and other volatiles come from? How did they become concentrated in the permanently shaded regions?

Other resources, including bulk regolith for construction and radiation shielding, solar-wind implanted gases, and the many chemicals and minerals that make up the surface materials on the Moon, Mars and asteroids may also be valuable for sustained long-term human presence.

Resource Prospecting

Finding useful resources and understanding their grade and tonnage is one of the important first steps in determining their potential.

ISECG agencies with lunar polar robotic missions are working on a coordinated strategy to explore multiple sites of high interest where orbital data indicates the presence of water ice. By targeting different sites on the lunar surface, the first missions to reach the lunar poles will take one or more of the measurements listed below to allow comparison of sites for their resource potential:

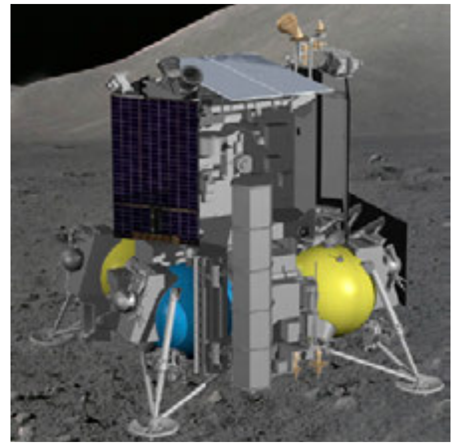
- Bulk Hydrogen within 1 m of the surface
- Volatile inventory
- Geological context
- Geotechnical and physical properties of the site

Subsequent missions could then conduct more intensive characterisation at the most promising sites, determining the grade and tonnage of water ice deposits. Space agency missions may be supplemented by targeted instrument delivery by commercially available lunar landers.

Resource Acquisition and Processing Demonstrations

Several upcoming robotic missions include capabilities to acquire and process local resources. Drills and science instruments on Roscosmos's Luna 27 and NASA's resource prospecting mission will demonstrate the thermochemical extraction of water from lunar regolith. ESA is also funding an ISRU demonstration mission with a commercial partner to produce water or oxygen on the Moon. NASA's Mars 2020 will collect the Mars atmosphere and then electrochemically split the CO_2 molecules into oxygen and carbon monoxide.

If the use of lunar volatiles and other space resources is proven to be economically advantageous, it is envisioned that commercial companies will collaborate with ISECG agencies in public-private partnerships to develop a space-based industry of in-situ resource utilisation.



Luna-27, near-term lunar polar volatiles prospecting mission.

Exploring and Using Lunar Polar Volatiles

ISECG space agencies have been working together to better understand the potential of lunar polar volatiles. International virtual workshops open to all have been held to share information and seek consensus on next steps. A website has been developed to share information on the current agency activities and a reference library. The website can be accessed at **https://lunarvolatiles.nasa.gov/**.

JAXA's Resource Prospector Mission is a mission under study.

Advanced Technologies

Each step in expanding human presence beyond low Earth orbit relies on the readiness of new capabilities and technologies. As no single agency has the resources to develop all those critical capabilities, appropriately leveraging global investments in technology development and demonstration is important. Although technology development is a competitive area, space agencies seek to inform their technology investment planning, create synergies and maximise their readiness to play a critical and visible part in the exploration endeavour.

Identification of Critical Technology Gaps: Space agencies have identified a list of critical technologies related to the missions shown in the Global Exploration Roadmap that are currently not available or need to be developed or matured. These technologies are considered technology "pulls" and can be mapped to corresponding agency technology development activities. By mapping critical technology needs to agency technology development activities, gaps can be identified. The Critical Technologies table shown on page 23 summarises many of the critical technology gaps. Technology needs for Mars vicinity/surface missions are the main driver and early availability of some of the technologies will enhance exploration of the lunar surface.

Assessing and Closing Technology Gaps: The listed critical technologies identify a large spectrum of challenges needed to close the gap between the state of the art and the technology required for the specific mission. The majority of these technologies are actively being pursued by multiple ISECG agencies with a robust level of investment and are envisioned to be sufficiently advanced by current or planned technology development activities. Several other technologies are advancing forward, but with more moderate levels of investment, meriting attention to ensure readiness. However, some critical technologies do not yet show a clear path to closure and need particular attention by the space exploration community and would benefit strongly from coordination and collaboration.

Detailed gap assessments of selected critical technologies have shown that:

- **Liquid Oxygen/Methane propulsion technologies** can make use of in-situ propellant production, lead to improved performance, and leverage fluid commonality. Technology gaps that need to be addressed include throttleable engines, thrusters with integrated cryogenic feed systems, long-duration reliable cryogenic refrigeration systems, and high performance pressurization systems that improve storage density and reduce mass.

- **Dust mitigation technologies** are a key enabling factor to perform extended duration lunar surface missions. While viable technology solutions have been identified by experts, there is a need for the maturation of related technologies to support both lunar and Mars missions. No single technology completely solves the challenges of dust, but rather a suite of technologies will be required to address them.

- **Autonomous systems** enable the crew to conduct operations under nominal and off-nominal conditions independent of assistance from Earth-based support. Advances in electronics, computing architectures and software that enable autonomous systems to interact with humans are needed and can be leveraged from commercial markets to support maturation of needed capabilities.

- **Tele-robotic operations with time delay** can make human-in-the-loop commanding and monitoring of robots at remote distances less effective. For safety and efficiency with time delays greater than five seconds, it is recommended that robots be operated as autonomously as possible. Terrestrial applications in this area are well advanced but on-orbit applications need to be matured.

Partnerships: Terrestrial commercial applications are well developed in several areas related to critical technologies. Fostering partnerships among government and commercial organisations will advance critical knowledge and accelerate the demonstration of spin-in technologies in space in order to verify the performance in a flight environment and identify unknown issues specific to operations beyond low Earth orbit. Partnerships can also lead to valuable experience and knowledge gap closures, especially in the development of standards and common interfaces.

CSIRO Autonomous Systems Research.

The following table highlights technologies identified by the ISECG as critical for future exploration missions. The target performance for each technology is based on preliminary analysis for human Moon and Mars missions, and may change as the analysis is iterated further. There are technologies where the state of the art is sufficient for near-term lunar operations and opportunities exist to demonstrate advancements needed for Mars. For the full Critical Technology Portfolio: **www.globalspaceexploration.org**

Global Exploration Roadmap Critical Technologies (Summary Table)	Today ISS & Spaceflight Heritage	Near-Future Moon Vicinity/Surface	Future Mars Vicinity/Surface
Propulsion, Landing, Return			
In-Space Cryogenic Acquisition & Propellant Storage	Spacecraft: CPST/eCryo demo	u-G vapor free liquid tank to propulsion transfer, Efficient low-power LOx & H_2 storage >1 Yr (Mars)	
Liquid Oxygen/Methane Cryogenic Propulsion		Throttleable Regen Cooled Engine for Landing (Lunar Scale)	Throttleable Regen Cooled Engine for Landing (Mars Scale)
Mars Entry, Descent, and Landing (EDL)	Spacecraft: MSL class (~900 kg)	Demonstration of advanced technology in deep space environment	Large Robotics >1000 kg; Human ~40,000 kg
Precision Landing & Hazard Avoidance	Spacecraft: Lunar & Mars Landers State-of-the-Art	~100 m accuracy, 10's cm hazard recognition, Support all lighting conditions	
Robust Ablative Heat Shield Thermal Protection	Spacecraft: Orion Heatshield test flight (EFT-1)	~1000 W/cm2 under 1.0 atmospheric pressure	~2,500 W/cm2 under 0.8 atmospheric pressure
Electric Propulsion & Power Processing	Spacecraft: 2.5 kW thruster (Dawn)	~10 kW per thruster, High Isp (2000 s) (for some mission options)	~30-50 kW per thruster (for some mission options)
Mid & High Class Solar Arrays	ISS: 7.5 kW/Panel	High Strength/Stiffness Deployable, 10-100 kW Class (for some mission options)	Autonomously Deployable, 300+kW Class (for some mission options)
Autonomous Systems			
Autonomous Vehicle System Management	ISS: Limited On-Board Mgmt functions, < 5 s comm delay	On-Board Systems Mgmt functions (handles > 5 s comm delay)	On-Board Systems Mgmt functions (handles > 40 min comm delay)
AR&D, Proximity Operations, Target Relative Navigation	ISS: Autonomous docking	High-reliability, All-lighting conditions, Loiter w/ zero relative velocity	
Beyond-LEO Crew Autonomy	ISS: Limited Autonomy	Automate 90% of nominal ops Tools for crew real-time off-nom decisions	
Life Support			
Enhanced Reliability Life Support	ISS: MTBF <10 E-6, Monitored/operated by GC	More robust & reliable components (eliminate dependence on Earth supply logistics) Increased systems autonomy, failure detection capabilities, and in-flight repairability	
Closed-Loop Life Support	ISS: 42% O_2 Recovery from CO_2, 90% H_2O Recovery	Demonstration of advanced technology in deep space environment	O_2/CO_2 Loop closure; H_2O Recovery further closure; Solid Waste, reduce volume/storage
In-Flight Environmental Monitoring	ISS: Samples to Earth	On-Board Analysis for Air, Water, Contaminants	
Crew Health & Performance			
Long-Duration Spaceflight Medical Care	ISS: First Aid+, return home	Demonstration of advanced technology in deep space environment	Training (pre & in-flight) for medical aspects Continuous monitoring & decision support
Long-Duration Behavioral Health & Performance	ISS: Monitoring by Ground	Demonstration of advanced technology in deep space environment	Cognitive performance monitoring Behavioral health indicators & sensory stim.
Microgravity Counter-Measures	ISS: Large treadmills, other exercise equipment	Demonstration of advanced technology in deep space environment	Compact devices to assess/limit disorders Reduced weight/vol. aerobic & resistive eqpt.
Deep Space Mission Human Factors & Habitability	ISS: Large crew volume, food & consumables regular resupply	Demonstration of advanced technology in deep space environment	Assess human cognitive load, fatigue, health Optimized human systems factors/interfaces
Space Radiation Protection (GCR & SPE)	ISS: Partially protected by Earth Apollo: (accepted risk)	Advanced detection & shielding New biomedical countermeasures	
Infrastructure & Support Systems			
High Data Rate (Forward & Return Links)	Ground (DSN): 256 kbs Forward, 10 Mbs Return Link	Demonstration of advanced technology in deep space environment	Forward: 10's Mbps; Return: Optical > 1Gb/s
Adaptive, Internetworked Proximity Communications	ISS: Limited capabilities	Demonstration of advanced technology in deep space environment	>10's of Mbps simultaneously between users Multiple Modes; Store, Forward & Relay
In-Space Timing & Navigation	ISS: Limited to GPS range Spacecraft: DSN Ranging	Demonstration of advanced technology in deep space environment	Provide high-spec Absolute & Relative pos'n Space-Qualified clocks 10x-100x beyond SOA
Low Temperature & Long-Life Batteries	ISS: Lithium-ion (-156 C short duration), ~167 Wh/Kg	Lunar night temperatures and duration	
Comprehensive Dust Mitigation	Apollo: limited 3 day crew ops Rovers: limited mitigation	Multiple Active & Passive technologies required Significant advances in Life cycle	
Low-Temperature Mechatronics	ISS: +121 to -157 C	Operations to -230 C (cryo compatible); multi-year life	
ISRU: Mars In-Situ Resources		Potential Test-Bed for Mars Forward, and enhance lunar missions	O_2/CH_4 generation from atmosphere LOX/LH_2 generation from soil
Fission Power (Surface Missions)		Potential Test-Bed for Mars Forward, and enhance lunar missions	Fission Reactor (10's of kWe)
EVA/Mobility/Robotic			
Deep-Space Suit	ISS: EVA Ops at 0.3 Bar (4.3 Psid)	EVA Ops at 0.55 Bar (~8 Psid), extended EVA lifecycle On-Back regen CO_2 & humidity control, High Specific-Energy Batteries	
Surface Suit (Moon & Mars)	Apollo: 3 day max (Lunar)	30 day min duration, improved lower torso mobility, dust tolerant	1 year+ duration, thermal insulation (CO_2 atmosphere)
Next Generation Surface Mobility	Spacecraft: Lunar and Mars Rovers State-of-the-Art	Autonomous & Crewed capability, less Ground Control Extended range, speed, payload; navigate soft/steep varying soils	
Tele-robotic Control of Robotic Systems with Time Delay	ISS: <1-10 Sec delay for GC Ops Spacecraft: Lunar/Mars Rovers	Few seconds to 10's of seconds Dynamic environments w/variable delays & LOC	Up to 40 Minutes
Robots working side-by-side w/ crew	ISS: Limited (Robotic support to EVA)	EVA control robots w/ no reliance on Ground Control International standard & protocols	

Managing Human Health and Performance Risks for Space Exploration

Long-duration missions and planetary operations entail numerous risks that must be understood and mitigated in order to maintain the health and productivity of crew members. The five human spaceflight hazards that need to be considered for any deep space exploration mission are:

1. Radiation – in deep space, radiation exposure is a top concern.
2. Isolation – psychological stress associated with limited space and group dynamics.
3. Distance from Earth – some operations in deep space, such as medical activities and procedures, are a challenge.
4. Gravity – The different levels of gravity will affect many of the human physiological systems.
5. Environment – hostile and closed environments will affect the overall living environment (e.g., toxicology, microbiology, etc.).

To address these challenges, agencies are actively performing studies in laboratories, ground analogues and on board the ISS and other flight platforms, including the deep space Gateway.

On the Ground

Isolation facilities are used for studies on behavioural performance. The facilities being used include the Human Exploration Research Analogue in Houston, Texas, and the Institute of Biomedical Problems Ground-based Experimental Complex in Moscow, Russia.

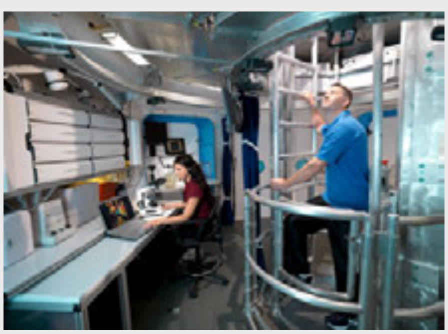
Other important ground facilities are located in Europe. These facilities host studies of musculoskeletal and cardiovascular deconditioning and psychological effects of long-term confinement. One example is the MEDES, an institute for space medicine and physiology in Toulouse, France.

In Flight

Numerous studies are ongoing onboard the ISS. Information on past and present studies can be found at **https://www.nasa.gov/mission_pages/station/research/** and **http://www.esa.int/Our_Activities/Human_Spaceflight/Research**.

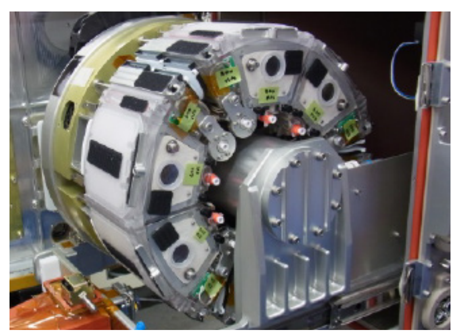
The first one-year mission has completed and preliminary results are interesting. Most notably, gene expression in space is altered, thereby opening new research possibilities aimed at mitigating health effects of long-duration spaceflight and with potential applicability to terrestrial health.

Today, bioanalytical and biomonitoring capabilities in space are limited. Canada is focusing on in-space analysis capabilities to remove these limitations. One example is a bioanalyser for space that can measure different populations of blood cells and measure diverse proteins in a single sample. This eliminates the need for storing samples and speeds the analysis. Another is a garment that can continuously collect an array of physiological data which is being developed for testing on ISS. An early version of this garment, Astroskin, has been used in isolation experiments on Earth. Canada is also developing a simple, robust technology to isolate biomolecules or cells of interest in order to enhance research capabilities on ISS and support science and medicine for future space exploration. Italy developed and positively tested on the ISS (VITA mission) a payload consisting in a garment containing water as shielding material against radiation, and a portable bioanalyzer enabling direct analysis of samples, rather than collecting and storing samples that will be analyzed upon their return to Earth.



NASA's Human Exploration Research Analogue is used several times per year to understand and test mitigation strategies for human performance risks.

Aquapad: During the ISS Proxima mission, CNES, in partnership with the bioMérieux company, tested a technology to detect microbial contamination of water. The technology, which is simple and can be stored in ambient conditions, has been used on Earth for the detection of cholera in high-risk locations.



JAXA's Multiple Artificial-gravity Research System is a rodent habitat for ISS. The system includes a centrifuge that allows studies from 0 g up to and including 1 g. This capability enables investigations comparing gravity effects on animals in the same space environment with gravity as the only variable.

Analogues to Simulate Exploration Destinations and Missions

In addition to analogues used for human health studies, other sites and facilities are in use today by space agencies around the world to simulate a variety of scientific, technical and operational activities in preparation for eventual exploration missions. Agencies are regularly sharing information related to planning of so-called "analogue" deployments and their associated lessons learned in order to maximise the usefulness of these activities.

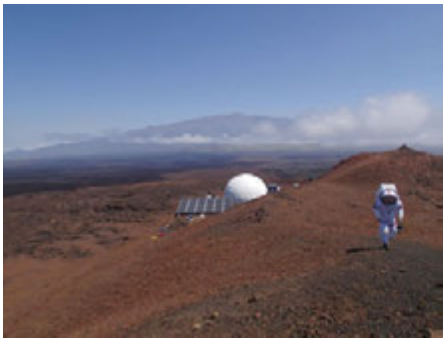
Technology Development Analogue Tests. Developing new technologies to accomplish the challenging missions in space can have the added benefit of stimulating new economic opportunities on Earth. The German Helmholtz Alliance "Robotic Exploration of Extreme Environments" (ROBEX) is one example of a collaboration between explorers from two different worlds – space and deep sea research. Sixteen research institutions, universities, and commercial companies cooperate to find solutions for autonomy, navigation, power management and communication for not only future lunar missions but also applications at the bottom of the world's oceans.

DLR's rover during the ROBEX analogue deployment on Mt. Etna, Italy.

Analogue Tests of Science Operations and Techniques. Achieving the goal of learning more about our place in the Universe will require human and robotic missions of increasing scope and complexity. In many cases, this leads to programs with significant international collaboration. One of the most complex and highly anticipated robotic missions on the horizon is the return of surface samples from Mars. The Canadian Space Agency recently completed a two-part analogue mission, the Mars Sample Return Analogue Deployment, simulating the sample caching and sample collection elements of this mission architecture. An international team of collaborators, including NASA/JPL, the UKSA, DLR, seven Canadian universities, and three American universities, participated in these deployments, involving simultaneous activities in both Canada and the United States.

Training, Public Engagement, and Outreach. Agencies carry out many of their analogue missions in a way that can be readily grasped by the general public while acquiring meaningful information for the programs they support. Analogues are also being used to draw in the next generation of scientists and engineers to add a practical facet to classroom learning. The previously described Canadian analogue relied on a large contingent of students as an integral part of the accomplishing simulation goals. NASA's Revolutionary Aerospace Systems Concepts – Academic Linkage program recently hosted a competition for engineering students to conceive and demonstrate innovative means for drilling into a simulated Martian ice deposit and withdrawing water—simulating new approaches to in-situ resource utilisation for future human missions—using approaches with a logical path to flight hardware. The two and one half days of the final competition was streamed live over the internet on a variety of platforms. This event generated over 1.5 million views on social media platforms.

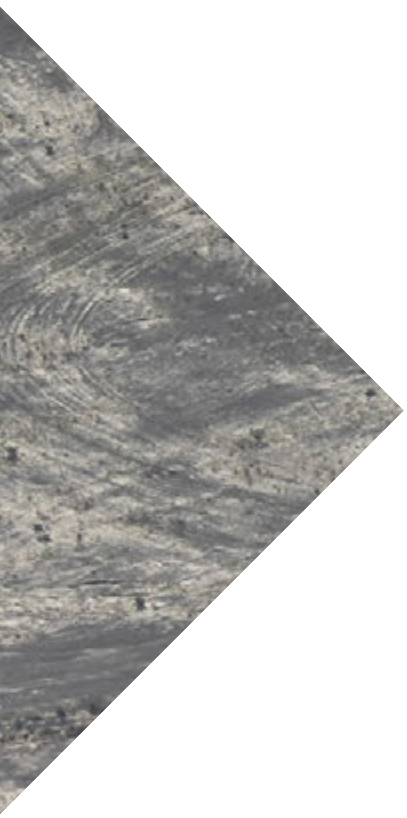
Supporting Decisions Among Options. Analogues provide a cost-effective means of providing information to support strategic decisions: from top-level architecture options to lower-level system or subsystem options. For example, ESA's Multi-Purpose End-To-End Rover Operations Network (METERON) experiment ANALOG-1 (scheduled for mid-2019) is designed to generate quantitative information supporting decisions regarding human-robotic coordinated operations, with a specific focus on the HERACLES mission.



HI-SEAS is a martian simulation on the slopes of the Mauna Loa volcano, Hawaii.

The CSA's Mars Exploration Science Rover during the Mars Sample Return Simulation.

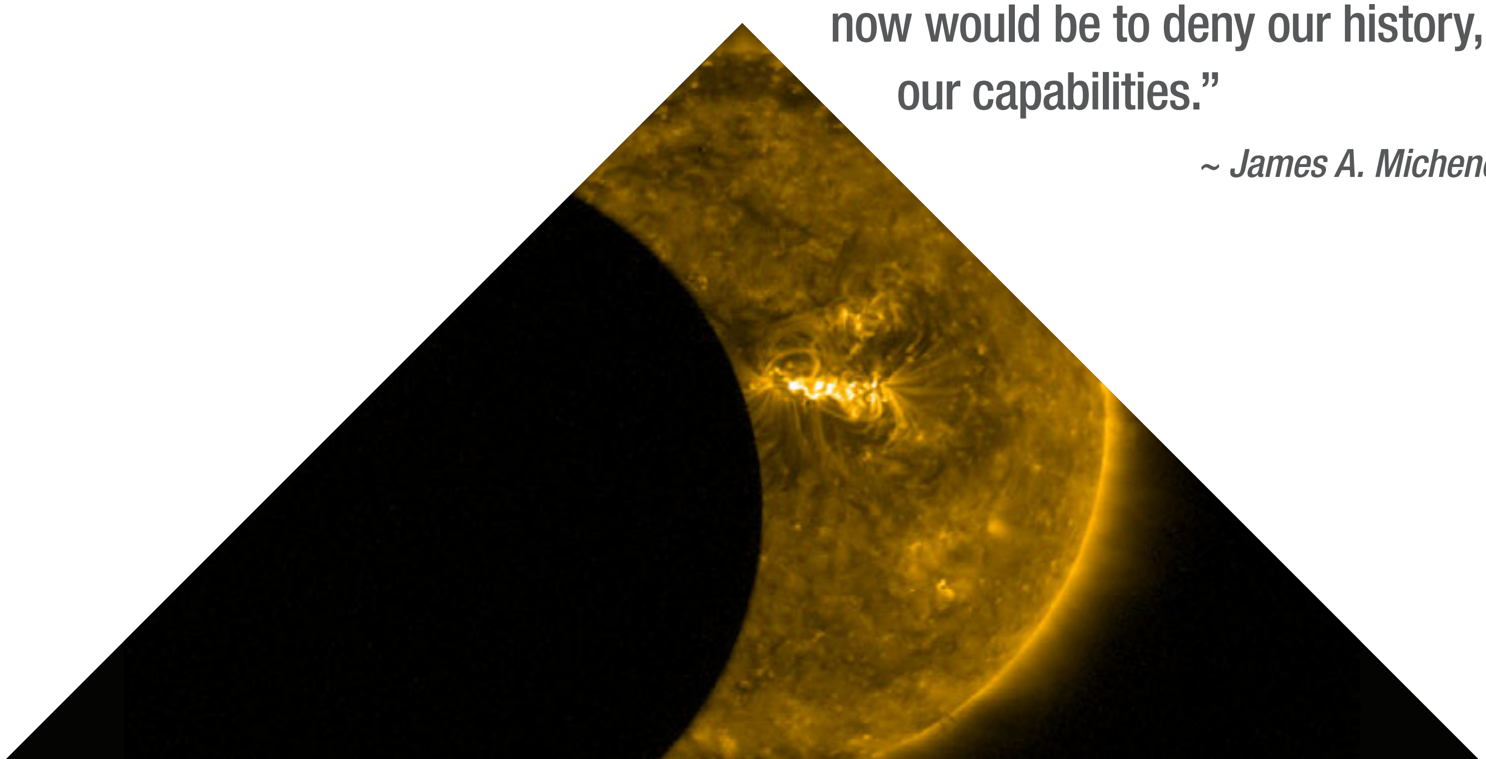
Revolutionary Aerospace Systems Concepts – Academic Linkage project engages students and the public.

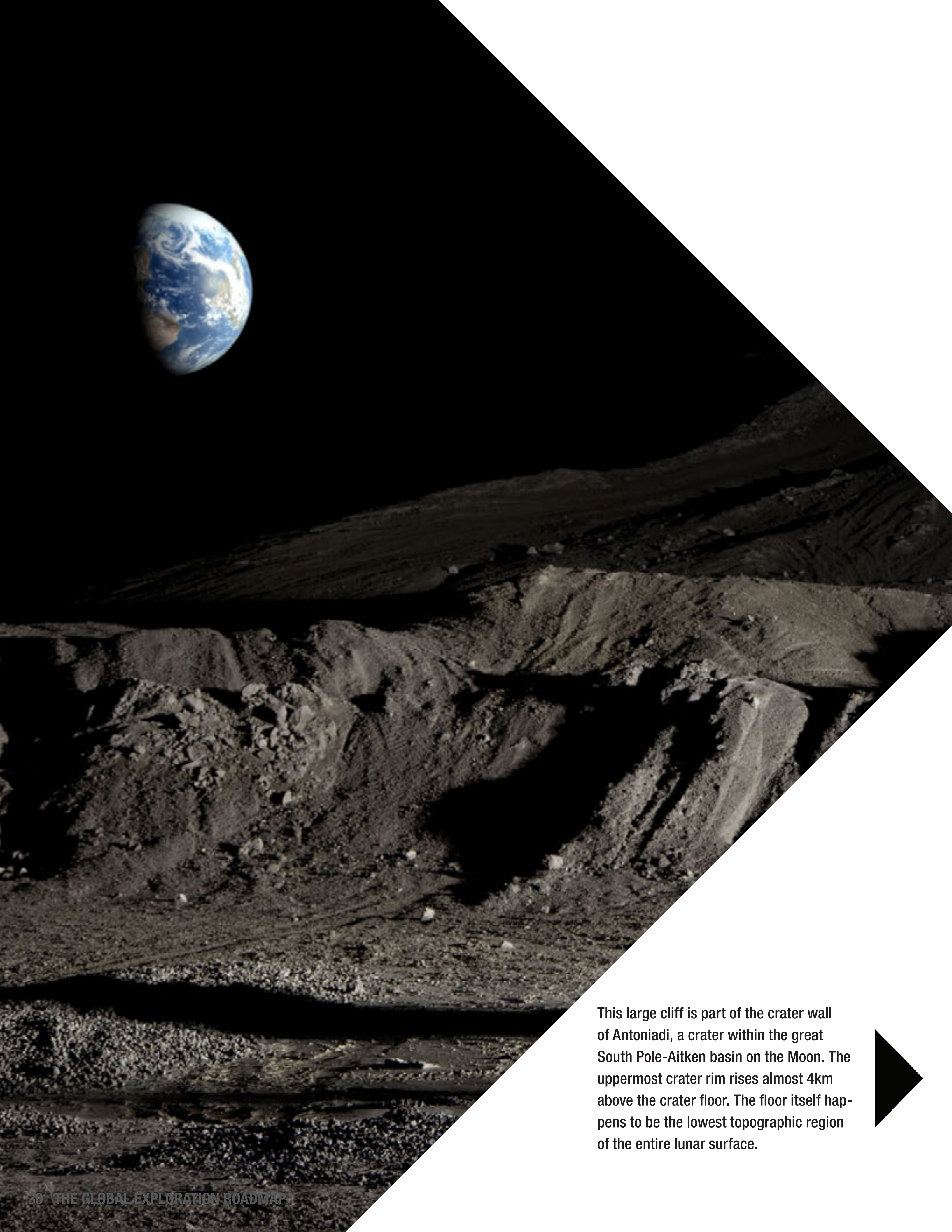


Chapter 4: Conclusion

"Space is indifferent to what we do; it has no feeling, no design, no interest in whether or not we grapple with it. But we cannot be indifferent to space, because the grand, slow march of intelligence has brought us, in our generation, to a point from which we can explore and understand and utilise it. To turn back now would be to deny our history, our capabilities."

~ James A. Michener





This large cliff is part of the crater wall of Antoniadi, a crater within the great South Pole-Aitken basin on the Moon. The uppermost crater rim rises almost 4km above the crater floor. The floor itself happens to be the lowest topographic region of the entire lunar surface.

The Global Exploration Roadmap reflects international efforts to define a sustainable pathway for human exploration of the Solar System, with Mars as the horizon goal. International cooperation will not only enable these challenging missions, but also increase the probability of their success. Over time, updates to this roadmap will continue to reflect the efforts of space agencies to collaboratively develop exploration mission scenarios and coordinate their preparation.

Since its inception, space exploration has produced numerous benefits for humanity. Innovation and economic growth have resulted from efforts to solve the challenges of space exploration. Knowledge gained has driven scientific and technological innovation that continues to contribute to new products and services for spaceflight and terrestrial application. Space exploration stimulates curiosity about our place in the Universe, impacts culture, and inspires people on Earth. Overcoming the challenges and realising the capabilities needed to explore will bring nations together with the capacity to address shared challenges and opportunities.

Decisions regarding implementation of specific mission scenarios will follow national policy decisions and international consultation, but these decisions will be more durable and effective if informed by products (architectures, mission designs, etc.) developed collectively. International standards will enable multiple partners to participate. In the coming years, many nations will continue developing domestic policy, regulatory and legal frameworks to most effectively implement sustainable human space exploration.

Increasingly, space agencies are engaged in dialogue with private sector entities that are beginning to move forward with plans to invest in projects in and beyond low Earth orbit. For such private sector efforts to succeed, they need the certainty of a long-term governmental commitment to space exploration, the continued opportunity to introduce ideas into government thinking, and supportive national business environments.

While this document does not create commitments of any kind on behalf of any of the participants, the Global Exploration Roadmap and the coordination that supports its development are important tools for achievement of a global, strategic, coordinated, and comprehensive approach to space exploration. This and subsequent editions of the Global Exploration Roadmap will provide a technical basis to inform programmatic discussions among agencies. The space agencies participating in the ISECG will continue the dialogue to coordinate and advance sustainable space exploration, extending human and robotic presence into the Solar System.

ISECG
International Space Exploration
Coordination Group

The Global Exploration Roadmap is a nonbinding product of the International Space Exploration Coordination Group (ISECG) space agencies. This third edition will be followed by periodic updates as the content evolves and matures. ISECG is committed to the development of products that enable participating agencies to take concrete steps toward partnerships that reflect a globally coordinated exploration effort.

Australia

Canada

China

European Space Agency

France

India

Italy

Japan

Republic of Korea

Russia

Ukraine

United Arab Emirates

United Kingdom

United States

Publishing services provided by:

This document is available online at **http://www.globalspaceexploration.org**

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

www.nasa.gov

NP-2018-01-2502-HQ
G-327035

GLOBAL EXPLORATION ROADMAP

SUPPLEMENT AUGUST 2020

LUNAR SURFACE EXPLORATION SCENARIO UPDATE

INTERNATIONAL SPACE EXPLORATION COORDINATION GROUP

ISECG

ABOUT THIS SUPPLEMENT

The Global Exploration Roadmap (GER) is a non-binding product of the International Space Exploration Coordination Group (ISECG). The GER presents a shared international vision for human and robotic space exploration and is based on the coordinated programmes, initiatives and goals of the ISECG agencies. This coordinated vision from the ISECG agencies around the world recognises that the difficult and long-term challenges of spaceflight are best achieved through cooperative ventures.

The GER reflects an exploration strategy that begins with the International Space Station (ISS) and extends to the Moon, asteroids, Mars and other destinations. This strategy builds on a shared set of exploration goals and objectives and reflects missions that will provide substantial benefits to the citizens of Earth.

Since the release of the GER in January 2018, many ISECG space agencies* have set new national priorities and intensified and accelerated lunar exploration plans. These ambitious exploration plans, coupled with new agency participants in the ISECG, created the opportunity to produce a Supplement to the 2018 GER that extends and refines the ISECG Lunar Surface Exploration Scenario. This scenario update supplements the 2018 GER by introducing the newly joined ISECG organisations (cf. Chapter 1) and updating agency lunar exploration plans (cf. Chapter 2). This GER Supplement also includes a newly formulated set of common objectives for a sustainable lunar surface exploration campaign (cf. Chapter 3) and the updated Lunar Surface Exploration Scenario (cf. Chapter 4) describes the architecture elements and the exploration campaign that progressively meet these lunar surface exploration objectives and serve as preparation for missions to Mars and for further activities on the Moon.

This GER Supplement will be used to support coordination efforts among space agencies by providing context for establishing solid partnerships and executing successful missions. Partnerships of all types—amongst government agencies, academia, public-private entities and within the private sector—provide the best ideas and solutions from around the globe. Space exploration is an inherently global endeavour.

In February 2020, the upgraded version of the mobile robot assistant CIMON-2—developed in Germany—successfully premiered with ESA-Astronaut Luca Parmitano on the ISS. Image Credit: ESA/DLR/NASA

"Space agencies" refers to government organisations responsible for space activities.

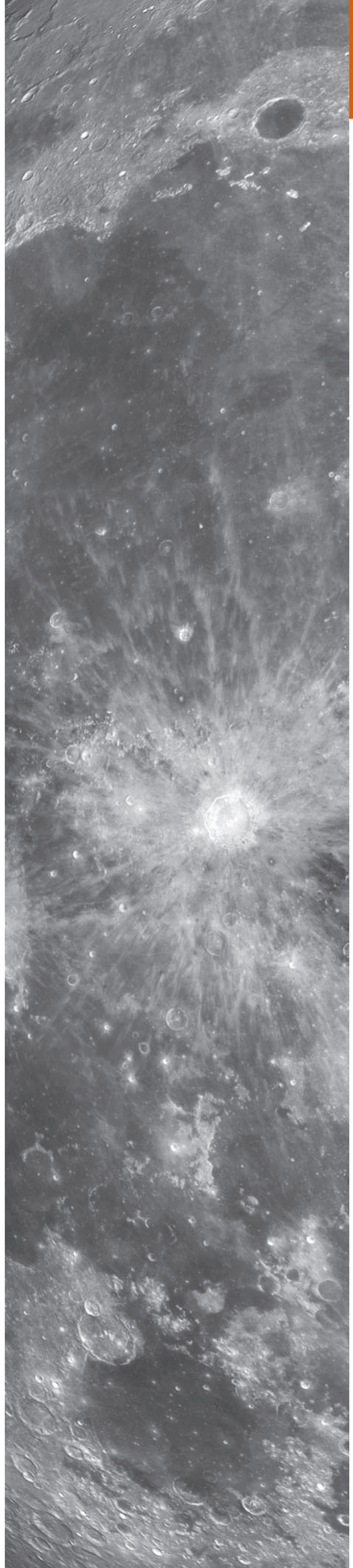


TABLE OF CONTENTS

EXECUTIVE SUMMARY

The 2018 Global Exploration Roadmap (GER) captures a shared vision from space agencies* participating in the International Space Exploration Coordination Group (ISECG) for international collaboration based upon a common set of exploration goals, objectives and identified benefits to humanity. Since then, many space agencies have renewed their focus on the Moon, both for its scientific opportunities and to demonstrate capabilities that will also prepare for human missions to Mars and for further activities on the Moon. This renewed focus has led ISECG agencies to update the Lunar Surface Exploration Scenario and capture the latest developments in lunar exploration planning from around the globe in this GER Supplement. The ISECG membership has also expanded with the addition of nine new organisations since the last GER release. This growth reflects the increasingly important role of spaceflight endeavours in providing economic and societal benefits to people on Earth while leveraging international cooperation to achieve scientific and exploration goals. In parallel, commercial space activities are achieving new capabilities for spaceflight leading to economic conditions suitable for business sustainability that have opened the spaceflight frontier to new entrants and new government strategies for science and human exploration of the solar system.

This GER Supplement describes the latest mission scenario and architecture for human and robotic lunar surface missions and preparatory activities for Mars. This Supplement integrates renewed and emerging national plans and commercial capabilities among ISECG participating countries. Leveraging the ISECG goals and sustainability principles (from the 2018 GER), a set of 12 lunar exploration objectives was formulated with rational and performance measure targets defined and then incorporated into one scenario with three phases:

- Phase 1: Boots on the Moon
- Phase 2: Expanding and Building
- Phase 3: Sustained Lunar Opportunities

ISECG SUSTAINABILITY PRINCIPLES

- ***Affordability*** Innovative approaches to enable more with available budgets.
- ***Partnerships*** Provide early and sustained opportunities for diverse partners.
- ***Human-robotic Partnerships*** Maximise synergies between human and robotic missions.
- ***Exploration Benefit*** Meet exploration objectives and generate public benefits.
- ***Capability Evolution and Interoperability*** The stepwise evolution of capabilities with standard interfaces.
- ***Robustness*** Provide resilience to technical and programmatic challenges.

"Space agencies" refers to government organisations responsible for space activities.

Additionally, this Supplement captures the increasing interest and associated mission planning in lunar in-situ resource utilisation (ISRU), communication systems, lunar transportation, surface power and dust mitigation technologies. These capabilities, combined with new commercial payload delivery services, will also benefit science and academic communities by providing more frequent and lower-cost missions to the Moon and, ultimately, Mars.

Evolved lunar surface exploration and ultilisation scenarios reflect plans for a near-term series of robotic missions followed by humans returning to the Moon in this decade. Rather than looking at individual missions, the scenario depicts a stepwise development of an increasingly capable lunar transportation system to the lunar surface, traversing systems on the lunar surface, and infrastructure supporting them that will enable cooperative science and human exploration efforts leading toward a sustained presence on the lunar poles and incorporating lunar surface activities as analogues in preparation for human missions to Mars. These efforts emphasise landed downmass to eventually support four crewmembers per mission and mobility systems that dramatically enhance science return and exploration distances around a lunar pole base camp.

Sustained exploration and presence on the lunar surface are not the only goals for future exploration; rather they are part of a collection of incremental advancements, each adding to our combined knowledge of the Moon and preparing for continued exploration across the solar system, starting with Mars. These activities are also a driver for innovation and economic growth. Advancements in technologies touching every aspect of everyday life—health and medicine, public safety, consumer goods, industrial productivity, transportation and many others are a direct result of space exploration. In the last several years, job creation and economic growth have been accelerated by private investments in the space sector.

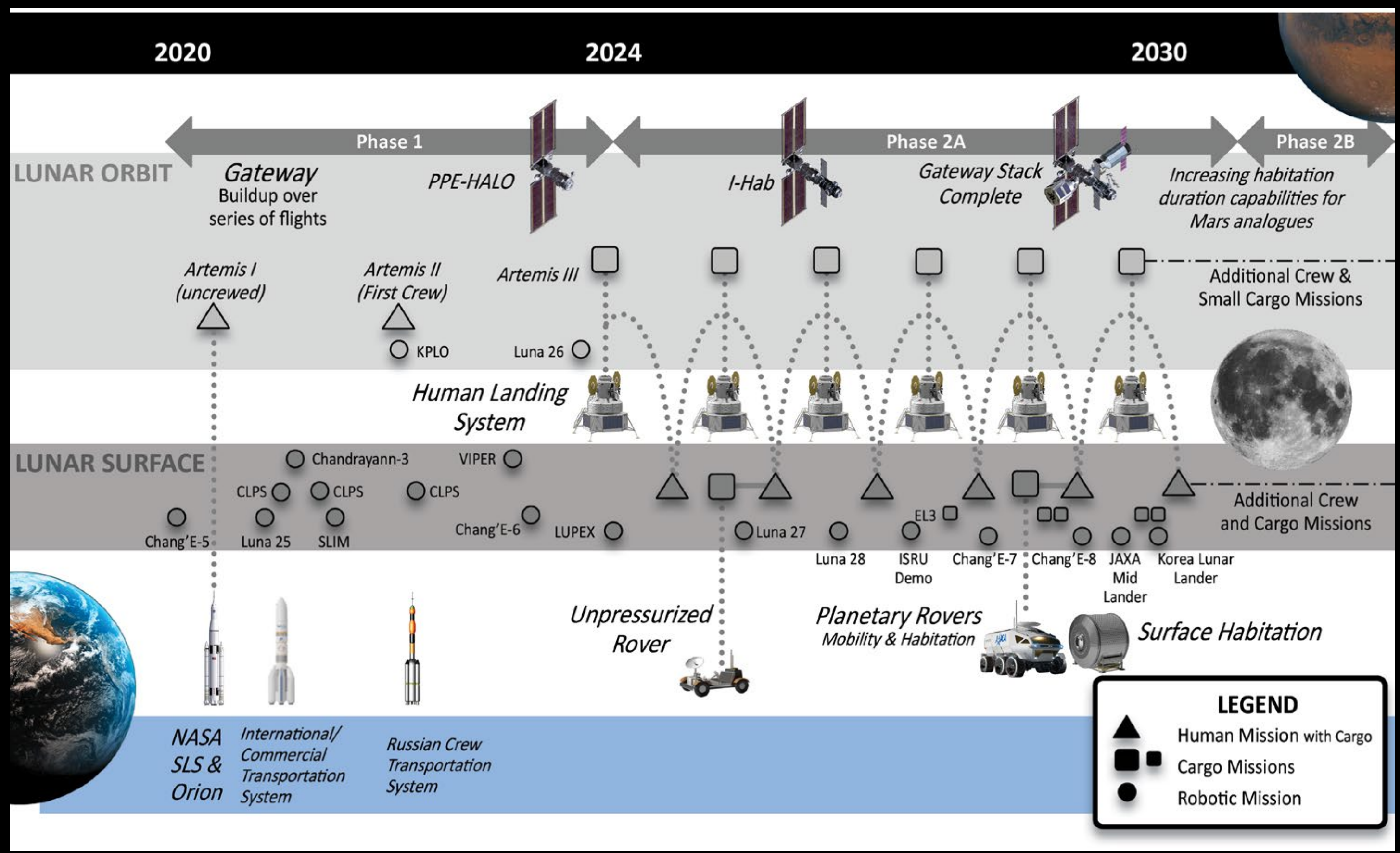
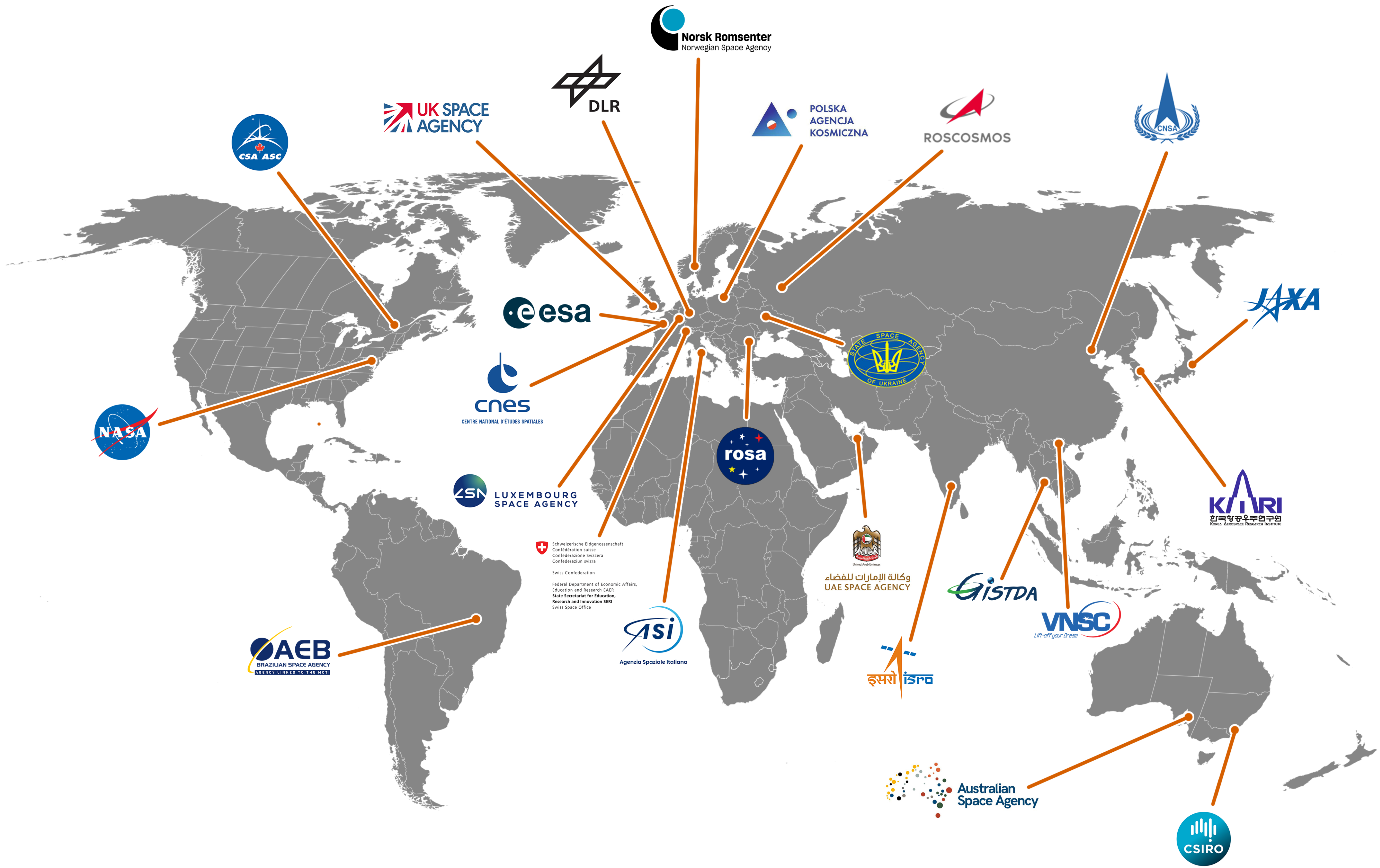


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

ISECG AGENCIES WORLD MAP



CHAPTER ONE

GROWING GLOBAL MOMENTUM

The steadily increasing number of ISECG agencies underscores the growing global interest and momentum for going forward to the Moon and Mars. Since the 2018 GER release, the number of ISECG agencies has increased from 15 to 24. Below is a summary of the of the new organisations along with the date they joined:

BRAZILIAN SPACE AGENCY (AUG 2020)

The Brazilian Space Agency (Agência Espacial Brasileira—AEB), a government agency established in February 1994 with the purpose of promoting the development of space activities of national interest, is responsible for the formulation, coordination, and implementation of the National Policy for the Development of Space Activities. AEB seeks to ensure that the downstream market for space-based products and services meets the needs of Brazilian society. Additionally, AEB´s efforts are targeted at consolidating the Brazilian space industry, increasing its competitiveness and capacity for innovation. The Agency views space cooperation as a critical tool to leverage resources and reduce risks, favoring the joint development of technological and industrial projects that generate valuable outcomes to both Brazil and its international partners.

Advances in space science and the use of space applications in everyday life inspire positive developments in the formulation of improved public policies and in the design of business-oriented space diplomacy that delivers sustained prosperity to all. As the key body of the Brazilian space ecosystem, AEB understands that becoming a full ISECG member will grant the agency the opportunity to learn from top performers, build on a widespread culture of collaboration and innovation and take a more active part in the international space agenda. Further information about AEB can be found at **https://www.aeb.gov.br**.

AUSTRALIAN SPACE AGENCY (FEB 2019)

On 1 July 2018, the Australian Government established the Australian Space Agency (ASA) with the intent of transforming and growing a globally respected space industry. Australia's long history of supporting space exploration dates back to the 1960's, with the efforts of the existing ISECG member Commonwealth Scientific and Industrial Research Organisation (CSIRO), and is now increasing its ability to participate in global efforts for the peaceful use of space. Australia has strong capabilities in robotics and remote operations, artificial intelligence, space domain awareness, advanced communications, health, and remote medicine. Australia is increasing its capacity and facilities in areas including:

- Mission and robotics command and control centres
- Ground station networks
- Space manufacturing and space data analytics
- Introducing industry programmes to collaborate internationally and support global plans to reach the Moon and continue on to Mars

ASA looks forward to sharing ideas and contributing to the international efforts to solve the challenges related to achieving ISECG goals. For more information about the Australian Civil Space Strategy, visit **https://www.industry.gov.au/strategies-for-the-future/australian-space-agency**.

GEO-INFORMATICS AND SPACE TECHNOLOGY DEVELOPMENT AGENCY (APR 2020)

The Geo-Informatics and Space Technology Development Agency was founded in 2000. GISTDA's primary objective has been the development of geo-informatics and space technology and these core functions are divided into two segments: ground and space. Since its inception nearly 20 years ago, GISTDA has focused on developing Earth observation satellite technology and applications and building the professional capacity of Thailand and Southeast Asia by investing in human capital and training. Another critical element of GISTDA's mission is building and leveraging its domestic space industry.

Recently, Thailand has broadened its focus to include space exploration. Under the umbrella of Earth Space System, they announced the Ministry of Higher Education, Science, Research and Innovation initiative, which aims to increase space exploration research and development within Thailand. GISTDA is Thailand's main space agency and has officially launched its Space Exploration Program which has the following focus areas:

- Scientific research in low-Earth orbit, the Moon and beyond
- Increasing space technology capacities of exploration, scientific payload and instrument, robotic rover, spaceflight and spaceport
- Building awareness in the space exploration sector
- Supports Thailand to New Space Economy

GISTDA joined ISECG to help Thailand become a contributing member of the global space exploration community and to assist in expanding the global space economy. For more information about GISTDA, visit **https://www.gistda.or.th**.

LUXEMBOURG SPACE AGENCY (SEP 2019)

The Luxembourg Space Agency was founded in 2018. LSA's primary focus is to develop the space sector in Luxembourg by creating new and supporting existing companies, developing human resources, facilitating access to funding and supporting academic research. The agency executes the National Space Economic Development Strategy, manages national space research and development programmes and leads the *SpaceResources.lu* initiative. LSA also represents Luxembourg within the European Space Agency (ESA), which the country has been a member of since 2005, and participates in space-related programmes of the European Union (EU) and the United Nations (UN).

The Luxembourg Space Agency is excited to partner with ISECG and is dedicated to aiding efforts to advance global coordination in space exploration. In the coming years, the exploration and utilisation of space resources are set to generate attractive opportunities. LSA is committed to supporting and nurturing the growing commercial space industry and contributing to the peaceful exploration and sustainable utilisation of resources from celestial bodies, including the Moon and near-Earth objects such as asteroids. For more information about LSA, visit **https://www.space-agency.lu**.

NORWEGIAN SPACE AGENCY (JAN 2020)

The Norwegian Space Agency is a government agency under the Ministry of Trade, Industry and Fisheries. The Agency was established in 1987, when Norway became a member of ESA. NOSA is responsible for organizing Norwegian space activities, particularly with respect to ESA and the EU, and for coordinating national space activities. Space activities have a large strategic value for Norway, with its vast ocean areas and as one of the world's northernmost areas.

Norwegians have always been pioneers when it comes to exploring the unknown and have a long tradition for operating in harsh and remote environments. With increased international focus on space exploration comes new challenges, leading to increased scientific and technological knowledge. NOSA sees this as a great opportunity for innovation that could be useful both in space and on Earth, widening the scope for Norwegian activities.

NOSA views their membership in ISECG as an opportunity to expand their perspective and work with international entities towards mutual goals for exploration. For more information about NOSA, visit **https://www.romsenter.no/**.

POLISH SPACE AGENCY (NOV 2018)

The Polish Space Agency (POLSA) was founded in 2014 and joined the ISECG in 2018. POLSA is deeply committed to the ISECG's principles and primary objective of shared cooperative international space exploration. Poland has a rich history of space discovery and exploration that has benefitted humankind for centuries. POLSA's priorities include:

- National space sector enhancement
- Robotic, sensor and lander mission
- Advancing the use of space technology for everyday life
- Space professional development

For more information about POLSA, visit **https://polsa.gov.pl/**.

ROMANIAN SPACE AGENCY (MAR 2019)

Created in 1995, the Romanian Space Agency (ROSA) was born out of the Romanian Commission for Space Activities (CRAS), which was established in 1968. ROSA is a self-funded public institution and is coordinated by the Ministry of Education and Research—National Authority for Scientific Research and Innovation. ROSA acts as the financing agency for the national research programmes on Space, Aeronautics and Security; chairs the inter-agency Security Research working group; serves as the national coordinator for the Space Situational Awareness (SSA) Programme; and is the Competent Authority for the Galileo Public Regulated Service (PRS). ROSA is also the Romania representative in all international space organisations and coordinates all of the nation's space-related activities. Joining the ISECG provides ROSA a new framework and broader opportunities for cooperating and collaborating with space agencies worldwide. For more information about ROSA, visit **http://www2.rosa.ro/index.php/en/**.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI
Swiss Space Office

SWISS SPACE OFFICE (MAR 2019)

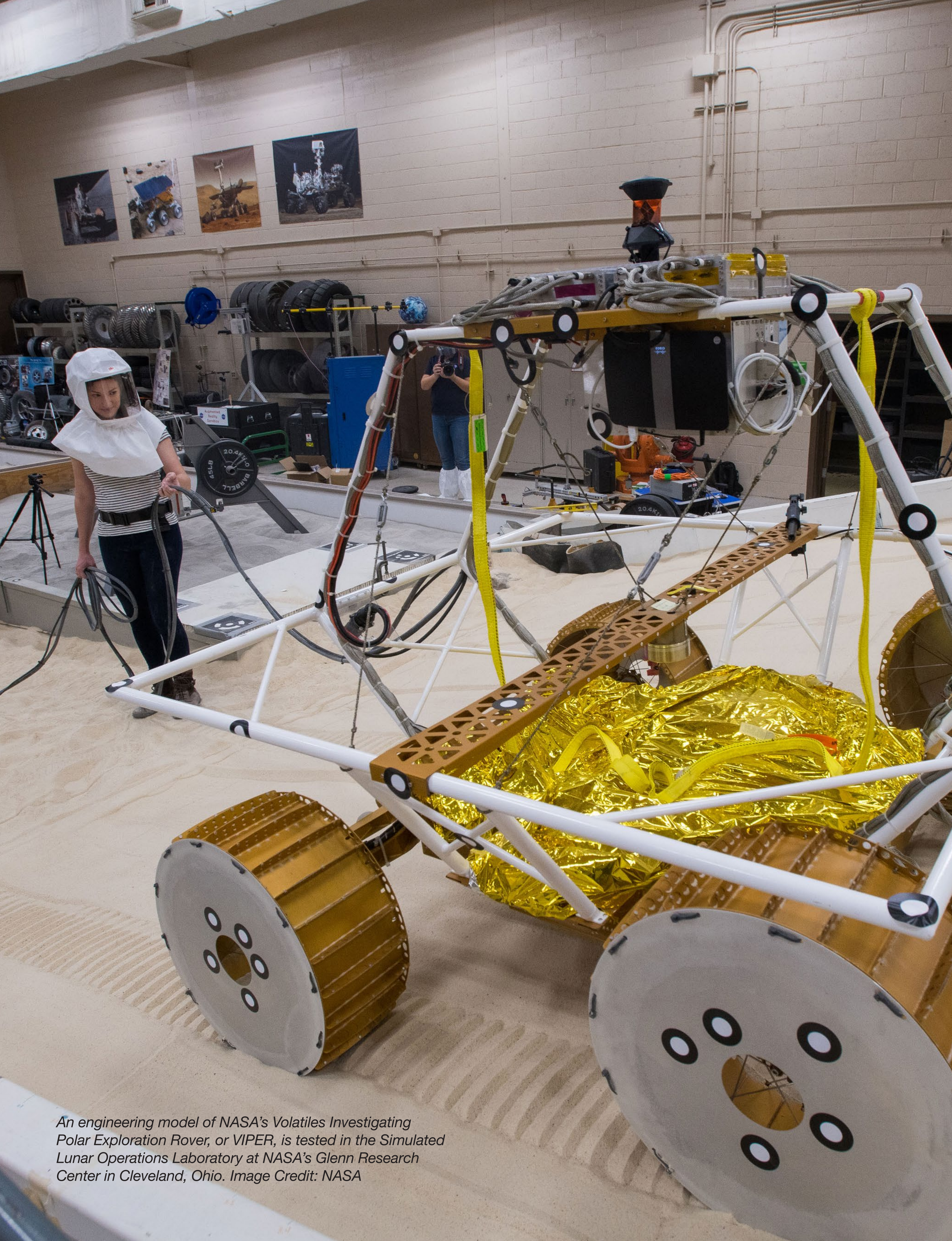
The Swiss Space Office is an integral part of the State Secretariat for Education, Research and Innovation (SERI) in the Federal Department of Economic Affairs, Education and Research (EAER). Its main responsibility is to prepare and implement the Swiss Space Policy, primarily through participation in ESA programmes.

The main focus of SSO in exploration is science, the development of space technologies and international collaboration. The development and utilisation of space infrastructures to the benefit of society are a key element of the Swiss Space Policy. Space exploration enables continuous improvement in understanding humanity's place in the universe. These endeavours simultaneously deliver tangible results in science and technology, which are directly applicable on Earth. For more information about SSO, visit **https://www.sbfi.admin.ch/sbfi/en/home/research-and-innovation/space.html**.

VIETNAM NATIONAL SPACE CENTER (JAN 2020)

Established in 2011, the Vietnam National Space Center is governed by the Vietnam Academy of Science and Technology (VAST), which administers and advances research and development and technology applications. VAST is working with VNSC to increase Vietnam's space science and technology capabilities with additional investments in national training and infrastructure. The VNSC is proud to be one of ISECG's newest agencies and is poised to cooperate, partner and contribute as needed in order to serve the common peaceful purpose of the ISECG.

VNSC's primary focus is to facilitate international cooperation and the agency has become an active member of several international organisations including the International Astronautical Federation (2012), Committee on Earth Observations (2013) and Group on Earth Observations (2014). VNSC also oversees the management and implementation of the Vietnam Space Center Project—one of Vietnam's largest science and technology investments. For more information about VNSC, visit **https://vnsc.org.vn/en/**.



An engineering model of NASA's Volatiles Investigating Polar Exploration Rover, or VIPER, is tested in the Simulated Lunar Operations Laboratory at NASA's Glenn Research Center in Cleveland, Ohio. Image Credit: NASA

CHAPTER TWO

MAJOR UPDATES IN LUNAR EXPLORATION PLANS

Since 2018, ISECG agencies have made significant updates to explorations plans, with a special emphasis on lunar missions and polar volatiles. Most agencies have become increasingly interested and committed to exploring the Moon's polar regions and in implementing long-term sustainable exploration missions based on international cooperation and commercial participation. These exploration plans include strategies that follow the established spaceflight practice where robotic missions come first and are primarily driven by scientific and technology demonstration objectives. Then more complex and capable robotics systems will be developed and become extensions of human lunar explorers. As these human and robotic capabilities merge, they are incorporated into the overarching mission strategies, which will significantly enhance exploration capabilities.

CREWED LUNAR EXPLORATION AND SUPPORTING MISSIONS

The United States has announced a new lunar exploration programme—Artemis—that soon will enable human missions to the Moon and in a manner that is sustainable long-term and tests the systems and operations necessary to prepare for future human Mars missions. The National Aeronautics and Space Administration's (NASA's) Artemis missions will enable human missions to the lunar surface beginning in 2024 and target sustainable lunar exploration by 2028. The first Artemis mission will launch in 2021 (uncrewed full system test), followed by Artemis II in 2023 (crewed mission in cislunar space) and will culminate with Artemis III in 2024 with a crewed mission to the lunar surface.

Following Artemis III, crewed missions with two crewmembers will fly to the lunar surface annually and then increase to four crewmember missions in 2028. The European Space Agency (ESA) has provided the European Service Module (ESM) for the Orion spacecraft, which has been integrated with the Orion capsule for the Artemis I mission. ESM2 is under development and procurements for ESM3 through ESM6 were approved in 2019 by the European ministers to support this sequence of Artemis missions. ESA is also studying options for providing science and logistic capabilities with an implementation decision planned for 2022. The study includes plans for a cislunar transfer vehicle (CLTV) or a European Large Logistics Lander (EL3) with a capability to deliver large (1.5-2 tonnes) in-situ science and technology payloads or cargo for human lunar surface activities.

Since the GER's release in 2018, the concept of the cislunar Gateway has matured to include a high-solar electric power and propulsion element (PPE) and a pressurised Habitation and Logistics Outpost (HALO) that will be integrated for launch in 2023.

NASA also recently awarded the first Gateway Logistics Services (GLS) contract to SpaceX to deliver cargo, experiments and other supplies to the outpost. Echoing the success of the Commercial Resupply Services programme, GLS will leverage commercial partners to deliver logistics to the Gateway, supporting lunar operations while building experience and technologies that can support the first human mission to Mars.

In early 2019, Canada announced its plan to develop and contribute an advanced, next-generation, artificial intelligence-enabled robotic system for Gateway. The smart robotic system will perform critical operations and support the deployment of science and technology experiments at Gateway.

In June 2020, Japan renewed the Basic Plan on Space Policy, which states that Japan will support the Artemis programme by contributing to the Gateway through habitation technologies and logistic capability, and aim to contribute to human lunar surface missions by transportation vehicles on the lunar surface, so that Japanese astronauts can actively participate in the Artemis mission. A Japan Aerospace Exploration Agency (JAXA) crew mobility capability could also provide an opportunity to leverage lunar surface activities to simulate and refine plans for the first human Mars surface mission.

Following decisions taken at the ESA Council meeting at ministerial level end of 2019 (Space19+), in addition to contributing to Gateway transportation with ESMs, ESA will:

1. Supplement the Gateway's PPE/HALO communication system with an enhanced communication string before 2024.
2. Contribute the International Habitation Module (I-HAB), which will increase habitation capability and the number of docking ports in 2025.
3. Develop a refuelling system and viewing capability (ESPRIT) to contribute to the sustainability of the Gateway.
4. Provide external radiation sensors to the PPE.

The Gateway will provide a next-generation deep space platform from which to conduct science investigations outside the protection of the Earth's Van Allen radiation belts. The international science community has identified heliophysics, radiation, and space weather as high-priority investigations to conduct on the Gateway. The Gateway is a vital part of the international community's deep space exploration plans, along with NASA's Space Launch System (SLS) rocket, Orion spacecraft, and the human landing system that will carry astronauts to the surface of the Moon in preparation for sending humans on a historic first journey to Mars.

The State Space Agency of Ukraine (SSAU) recently announced a new addition to its Ukrainian Space Programme for 2021-2025, which includes opportunities for contributing to the Artemis missions as well as the European Moon Village Association initiative. SSAU is working on three major lunar activities:

1. Creating a power plant for the lunar base—once established—that will be powered by solar energy. The technology for the power plant is based on innovative electrolysis technology and can be used to produce rocket fuel within the lunar base environment.
2. Developing a 6U CubeSat that will be in a selenocentric orbit and provide images of the Moon from several vantage points allowing terrain imaging and measuring spectral changes on the lunar surface.
3. Manufacturing a solar-thermoelectric generator designed to produce renewable energy. The generator would retain its functionality absent solar radiation by absorbing heat from the lunar surface.

ROBOTIC LUNAR EXPLORATION MISSIONS

Many individual robotic missions aim to understand the science and exploration value of the lunar poles. This portfolio of missions form a de-facto international Polar Exploration Campaign beginning with regional surveys (i.e., ground truth for ice, resources and local chemistry at diverse locations), followed by site exploration and preparation of locations identified as high priority. This campaign will ultimately support international sustained lunar surface activity. Robotic lunar missions that have either flown or have been formally approved for further study and/or funded by space agencies through 2030 (since publication of the 2018 GER) are outlined in Table 2 of this Supplement. The growing list of institutional missions (complemented by private-sector initiatives that are not shown in Table 2) underscores that there remains continued scientific interest and highlights both the scale of this cooperative effort globally and the human-robotic partnership required for sustainable lunar surface exploration.

China National Space Administration (CNSA)
On 3 January 2019, the Chang'e-4 mission achieved the first ever soft landing on the far side of the Moon and the Yutu-2 rover was deployed. CNSA is also implementing phase three of the Chinese Lunar Exploration Programme, which will entail collecting samples from the near side of the Moon, returning them to Earth—all to be accomplished by Chang'e-5 in 2020. Chang'e-6 is the backup mission to Chang'e-5, and its implementation is dependent on the status of the Chang'e-5 mission. Along with the implementation of all three phases of the Chinese Lunar Exploration Programme, CNSA plans to initiate both the Chang'e-7 and Change'e-8 missions from 2023 to 2030. The objective of these missions is to establish a prototype of the International Lunar Research Station (ILRS) at the lunar South Pole and construct and operate a platform supporting large-scale scientific exploration, demonstrate technologies and develop and utilise lunar resources.

Canadian Space Agency (CSA)
The CSA has the on-going Lunar Exploration Accelerator Program (LEAP), which supports lunar technology development, in-space demonstration and science missions. LEAP, in conjunction with international partners, plans to send payloads to the lunar surface by 2024. These payloads may include mobility and other science or technology demonstrations.

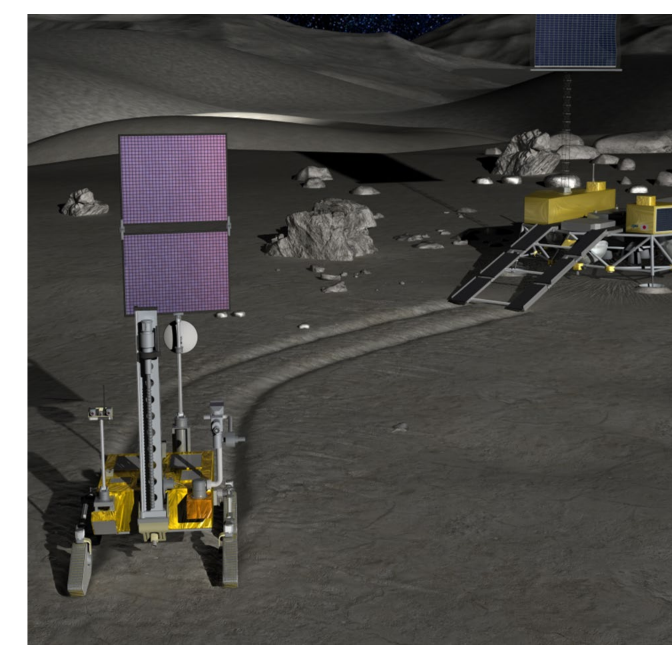
European Space Agency (ESA)
ESA is developing payloads—which build on prior investments—on partner-led missions including contributing to Roscosmos' missions Luna 25 and Luna 27 and the NASA Commercial Lunar Payload Services (CLPS) programme.

ESA has partnered with industry and is working on defining a high-data-rate lunar communication commercial service starting with the Lunar Pathfinder mission. Lunar Pathfinder is a relay satellite scheduled to be in lunar orbit by 2023. It should be followed by the development of a more capable high-performance lunar communication and navigation services (LCNS) constellation that will support sustained robotic and human exploration and is expected to be operational by late 2025.

ESA also recently approved system studies to demonstrate the technical and programmatic feasibility of a Cislunar Transfer Vehicle (CLTV) or a European Large Logistic Lander (EL3). The EL3 is a key capability designed to deliver scientific or logistic payloads to any location on the lunar surface. Its missions can include cargo delivery, sample return or scientific and/or technology demonstrations (e.g., extraction of oxygen from lunar regolith). The implementation planning decision will be concluded in late 2022 and launch is tentatively scheduled for 2027/2028.

Indian Space Research Organisation (ISRO)
ISRO launched Chandrayaan-2 on 22 July 2019 with the goal of demonstrating an end-to-end lunar mission capability, including insertion of an orbiter in lunar orbit, and soft landing and roving on the lunar surface. The mission was originally designed to last one year. The orbiter, which was equipped with eight advanced payload instruments, was successfully inserted into a 100 km orbit. The orbiter experiments are performing very well and are expected to contribute much to lunar science at the end of the now-extended mission of nearly 7 years. However, the mission was unable to soft land the lander and rover. The Indian government approved a follow-on mission, Chandrayaan-3, which is expected to launch in 2021, and has a lander and rover carrying the same set of payloads as Chandrayaan-2. ISRO is also working with JAXA to conduct a feasibility study for a joint lunar exploration mission.

Japan Aerospace Exploration Agency (JAXA)
JAXA continues to focus on developing lunar surface capabilities using the Smart Lander for Investigating Moon (SLIM) mission. SLIM will demonstrate pinpoint landing technology and is planned for launch in 2021/2022. JAXA, in cooperation with ISRO, is also planning a Lunar Polar Exploration (LUPEX) mission slated for launch in the 2023/2024 timeframe. The aim of this mission is to obtain knowledge of lunar water resources and to explore the suitability of the lunar polar region for the establishment of a lunar base. JAXA is working towards sending small missions to lunar orbit in the early 2020s in order to increase industry's capability and maintain the science community's interests. JAXA is also working to develop a medium-sized lander by the late 2020s that is capable of providing logistics support for human lunar surface missions and/or conducting science missions.

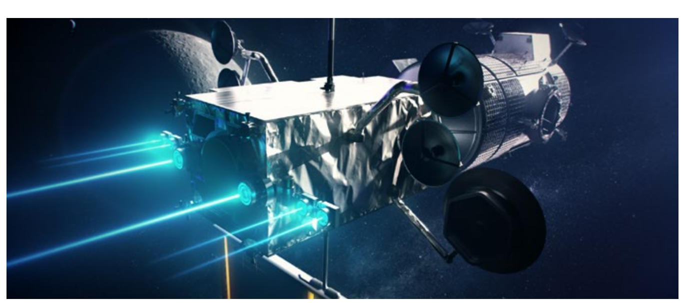


Lunar Polar Exploration (LUPEX). Image Credit: JAXA

Korea Aerospace Research Institute (KARI)
KARI has plans to launch the Korea Pathfinder Lunar Orbiter (KPLO) in 2022. The main objectives of the KPLO mission are 1) developing the critical technologies for lunar exploration; 2) performing scientific investigations on the lunar environment including topographic map for future lunar landing mission; and 3) realising and validating new space technology. The second lunar mission is a robotic lunar lander planned for launch by 2030.

National Aeronautics and Space Administration (NASA)
The Commercial Lunar Payload Services (CLPS) project was developed by NASA to procure delivery of payloads to the lunar surface from commercial providers. There are currently 14 companies on the CLPS contract, all of whom can compete when NASA releases a request for a lunar surface delivery. Early commercial delivery manifests will conduct science experiments, test technologies, and demonstrate capabilities to help NASA explore the Moon and prepare for crewed missions. Typically, these CLPS deliveries have additional payloads from entities other than NASA, e.g., universities, companies, other US government agencies, and/or international space agencies.

NASA has currently awarded contracts for four surface deliveries to both polar and non-polar lunar locations beginning in 2021 (see Table 1). The expected cadence for deliveries is approximately one every six months. NASA is utilising the CLPS capability for one of these deliveries to land the Volatiles Investigating Polar Exploration Rover (VIPER) on the South Pole to investigate the location and concentration of water ice in the region and takes samples to inform future science and human missions to the South Pole. VIPER is scheduled to land in the South Pole region of the Moon in late 2023.



The Gateway. Image Credit: NASA

TABLE 1

NASA's currently awarded contracts for surface deliveries to both polar and non-polar lunar locations beginning in 2021

YEAR	CLPS PROVIDER	MANIFEST	LOCATION
2021	Astrobotic	Science/ Technology	Lacus Mortis
2021	Intuitive Machines	Science/ Technology	Oceanus Procellarum
2022	Masten	Science/ Technology	Polar Region
2023	Astrobotic	VIPER rover	Polar Region

Roscosmos
Roscosmos adjusted the timeline of its Luna series of missions to explore the lunar poles. These updates are as follows:

- Luna-25 Lander Mission (Luna-Glob-Lander) scheduled for launch in 2021.
- Luna-26 Orbital Mission (Luna-Resurs-Orbiter) scheduled for launch in 2024. This mission will study the lunar surface from low polar orbit (approximately 50–100 km).
- Luna-27 Landing Mission (or Luna-Resurs-Lander) scheduled for launch in 2025. These missions are being developed in conjunction with ESA. ESA will provide communications, precision landing, hazard avoidance, drilling, sampling, sample analysis and ground support to these missions.
- Luna 28 (Luna Resource 2 or Luna-Grunt Rover) scheduled for launch in 2027. This is a cryogenic polar volatiles sample return mission and is a follow-up mission for Luna 27 (also proposed by Roscosmos).

Russian manufacturers and research institutes are conducting R&D activities on advanced methods and system design to provide navigation and communication services for lunar exploration users.

TABLE 2

Robotic lunar missions performed since the 2018 GER and planned by ISECG agencies

MISSION	AGENCY/LAUNCH DATE	DESCRIPTION/OBJECTIVES
Queqiao	CNSA 2018	Communication relay satellite.
Chang'e-4	CNSA 2018	Far side scientific lander and rover.
Chandrayaan-2	ISRO 2019	Polar scientific orbiter, lander, and rover.
Chang'e-5	CNSA 2020	Near side sample return.
Luna 25	Roscosmos 2021	Lunar volatile prospecting. Soft landing technology demonstration.
Chandrayaan-3	ISRO 2021	Lunar polar lander and rover.
Artemis I	NASA/ESA 2021	Uncrewed Orion/ESM flight with science and technology payloads. Deployment of cubesats in lunar orbit.
SLIM	JAXA 2021/22	Pinpoint landing technology demonstration.
KPLO	KARI 2022	Polar scientific and technology demonstration orbiter.
Chang'e-6	CNSA 2022-2024	Polar volatiles sample return.
VIPER	NASA 2023	Lunar polar rover. Polar science and volatiles.
LUPEX	JAXA/ISRO 2023/24	Polar lander and rover. Polar science and understanding the distribution and characterization of volatiles.
Luna 26	Roscosmos 2024	Polar scientific orbiter. Polar volatiles mapping.
Luna 27	Roscosmos with ESA 2025	Polar science, volatile prospecting and acquisition. Drill technology demonstration.
EL3 (TBC)	ESA 2027/2028	Science and/or logistic capabilities.
Luna 28	Roscosmos 2027	Cryogenic polar volatiles sample return.
ISRU demo	ESA 2027	In-situ end-to-end extraction of oxygen from lunar regolith.
Chang'e-7	2023-2030	Prototype of International Lunar Research Station (ILRS).
Chang'e-8	2023-2030	Prototype of International Lunar Research Station (ILRS).
Mid Lander	JAXA Late 2020's	Transport logistics and/or science.
Korea lunar lander	KARI 2030	Technology demonstration.

CHAPTER THREE

LUNAR SURFACE EXPLORATION OBJECTIVES

Based on the ISECG Goals and Objectives and Sustainability Principles, published in the 2018 GER, a set of dedicated Lunar Surface Exploration Scenario Objectives was developed (see Table 3). This set of objectives is based on the principle that human lunar surface exploration should focus on preparation for human Mars missions and for sustainable activities on the Moon leveraging ISRU.

The Lunar Surface Exploration Scenario Objectives in Table 3 are the drivers for the updated ISECG Lunar Exploration Scenario. For each lunar surface objective, there is a rationale that maps to one or more higher-level ISECG goals and corresponding performance measure targets. These performance targets can be achieved in a single mission or over a series of missions. These targets provide a guidepost for long-term goals but are flexible and will evolve over time to support agency priorities. The objectives in Table 3 are prioritised according to how they are executed in the ISECG scenario. The final five objectives will be executed throughout the scenario.

Several of the objectives necessitate a fixed location to support completion, such as long-duration habitation and ISRU, whereas other objectives require diverse locations on the Moon and long-range mobility. These competing objectives led ISECG members to adopt an approach where initial capabilities are continually leveraged while additional capabilities are added.

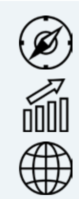
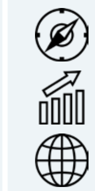
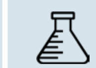
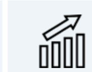
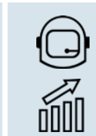
Concept design of a pressurised rover. Image Credit: Toyota

ESA astronaut Matthias Maurer and spacewalk instructor Hervé Stevenin collecting rock samples using new tool prototypes and documenting them with the Electronic Field Book during the PANGAEA-X test campaign in Lanzarote, Spain. Image Credit: ESA–A. Romeo.

TABLE 3

Lunar Surface Exploration Scenario Objectives

				
Expand Human Presence into the Solar System	**Understand Our Place in the Universe**	**Engage the Public**	**Stimulate Economic Prosperity**	**Foster International Cooperation**

OBJECTIVE	RATIONALE	ISECG GOAL	PERFORMANCE MEASURE TARGET*
Demonstrate human landing/ascent capability to and from the lunar surface.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on the lunar surface. Number of crew should be as many as possible considering the nature of international programme, but within the realistic constraints of crew transportation capability planned by governments and envisioned commercial missions.		4 crew
Demonstrate a range of cargo delivery capabilities on the lunar surface for large surface elements and logistics.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on lunar surface. As much cargo capability as possible is desired. Cargo capacity performance measure range is driven by: 1) Mass of crew consumables necessary for sortie mission will be around 1-2 tons; and 2) current human ascent module is estimated to be 9 tons.		>9 t for large surface elements, >1 t for logistics, x cubic meters of cargo delivered.
Demonstrate Extra Vehicular Activity (EVA) capabilities on the lunar surface.	To mitigate the risk for future human Mars missions and sustainable lunar exploration and for commercial activities on the lunar surface.		Reusable EVA systems with reasonably minimal maintenance including onsite dust management/mitigation and science sampling/ curation techniques.
Demonstrate human long-range traversing capability on the lunar surface.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on the lunar surface. Mobility capability design life of 10,000 km is the total round-trip distance to explore and traverse the five crew sites indicated in the 2018 GER.		10,000 km (cumulative)
Demonstrate reliability of human long-duration habitation capability and operational procedures on the lunar surface.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on the lunar surface. Systems need to be capable of environmental extremes (e.g., temperature, radiation, pressure). Demonstration of human long-duration habitation and reliability can be achieved over a series of crewed and uncrewed missions, yielding the confidence for long-duration missions on the Moon and Mars. Astronaut operations need to be implemented and checked in different operative scenarios.		500 days (cumulative)
Demonstrate crew health and performance sustainability to live and work on the lunar surface for a sufficient duration to validate Mars surface missions.	To understand the human health effects of low gravity and deep space environment for long-duration missions on the Moon and notional Mars crewed surface mission. A number of medium-duration missions are expected to address the ability to understand how crew health and performance are affected by long duration exposure in the deep space environment.		TBD days (continuative) Comprehensive evaluation needed to determine the minimum duration and number of missions.
Demonstrate in-situ resource production and utilisation capability sufficient for crew transportation between lunar surface and Gateway and lunar surface utilisation needs.	To expedite sustainability for future human Moon and Mars exploration and to identify future commercial markets on the lunar surface.		Produce 50 tons of propellant per year.
Conduct effective global human/robotic cooperative science exploration to perform groundbreaking science.	To accomplish lunar objectives specified in the ISECG Science White Paper, "Scientific Opportunities Enabled By Human Exploration Beyond Low-Earth Orbit" as well as lunar objectives identified by ISECG agencies.		Comprehensive evaluation needed to determine value of science.
Develop infrastructure (e.g., power and communication systems) necessary to achieve the objectives for sustained exploration.	To demonstrate and establish infrastructure capabilities including a certain level of power and communication systems for achieving objectives such as long-duration habitation, ISRU, diverse science and public engagement. Commercial activities rely on infrastructure to stimulate economic growth.		300 kW of power generation and 1 Gbps for data rates, availability of TBD systems.
Engage the public in general and the youth in particular with human/robotic lunar surface exploration by bringing the action to large audiences, making full use of the state-of-the-art technology and through new ways of communication.	To inspire new generations, increase awareness of the relevance of space, and recognise the importance of different perspectives and domains of knowledge present in different scientific endeavours. Also, public participation is necessary in the long run to ensure sustainability of such plans (civic engagement/empowerment). If space exploration is a topic of interest to the public, the public has increased its potential to participate in policy making or at least influence it. Show the relevance of STEM and inspire young people to follow in those footsteps.		On national level as feasible, measuring positive public attitude towards lunar surface exploration (e.g., > 30% agreement) through surveys, website hits, social media impact, etc.
Implement new commercial arrangements that stimulate economic prosperity and foster commercial opportunities.	To achieve commercially led sustainable (i.e., market-driven economy with diminishing reliance on governments) economic activities on the Moon, new commercial arrangements are essential.		Increasing number of commercial partners or stakeholders providing critical lunar services year after year.
Provide a large number of collaboration opportunities for international partners to contribute to the lunar surface scenario.	To encourage global participation in the lunar surface scenario, inclusive of a range of contributions from science to hardware.		More than 100 nations' participation to lunar surface scenario.

*Performance measure targets reflect long-term objectives and can be achieved in a single mission or over a series of missions across several decades.

CHAPTER FOUR

UPDATED LUNAR SURFACE EXPLORATION SCENARIO

The Lunar Surface Exploration Scenario integrates recent key updates to the GER's lunar exploration plans with the lunar surface exploration objectives. The mission scenario is divided into three phases (Boots on the Moon, Expanding and Building and Sustained Lunar Opportunities) to more clearly describe and focus the activities that achieve both lunar objectives for Mars and further lunar activities.

The update includes lunar orbit and lunar surface activities and reflects more detail on the buildup of Gateway in lunar orbit along with Artemis missions and the timing of upcoming robotic missions. On an annual basis, planned utilisation for the human lunar lander is primarily crewed missions along with options to pre-emplace infrastructure such as rovers and habitation elements.

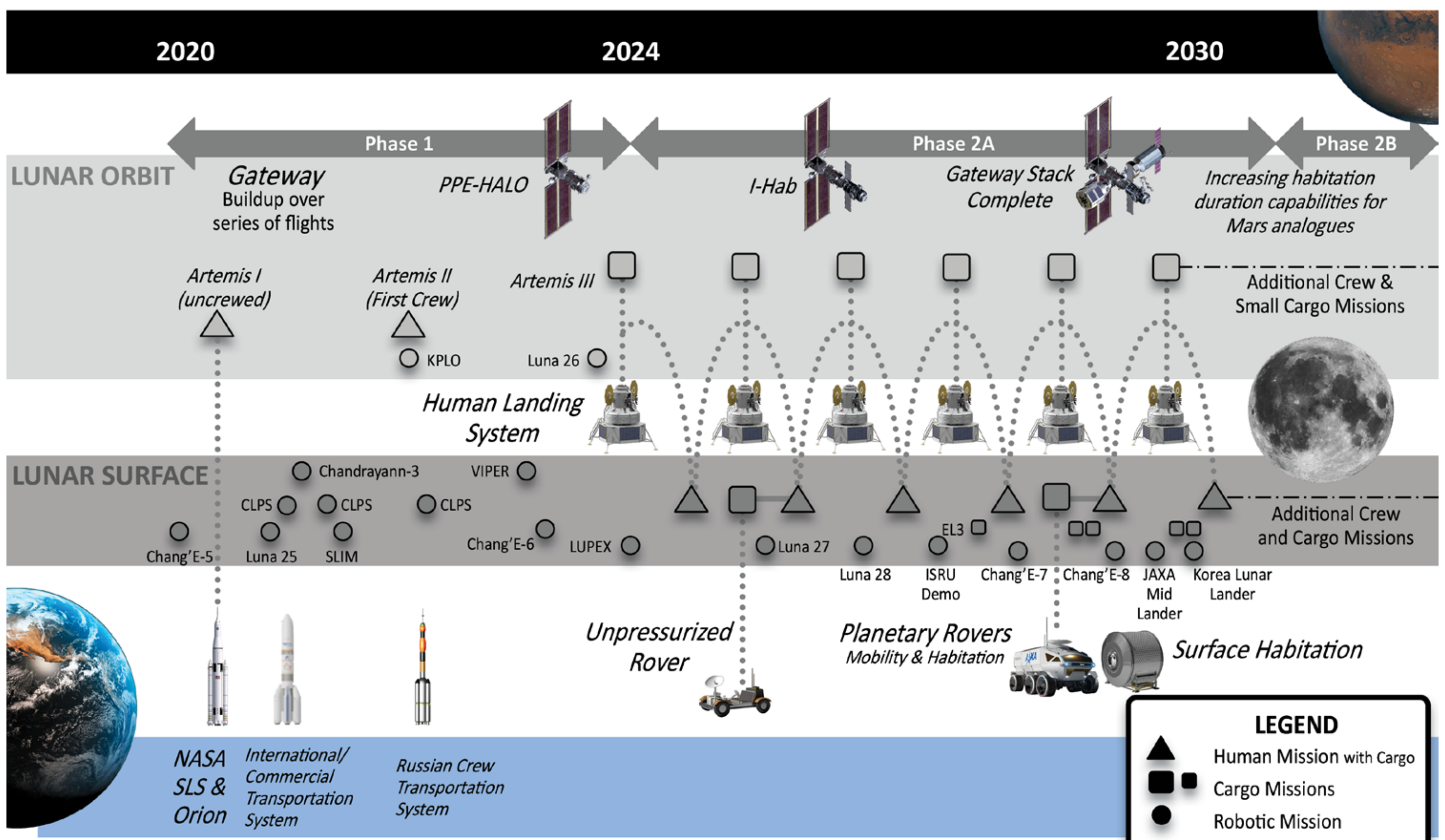
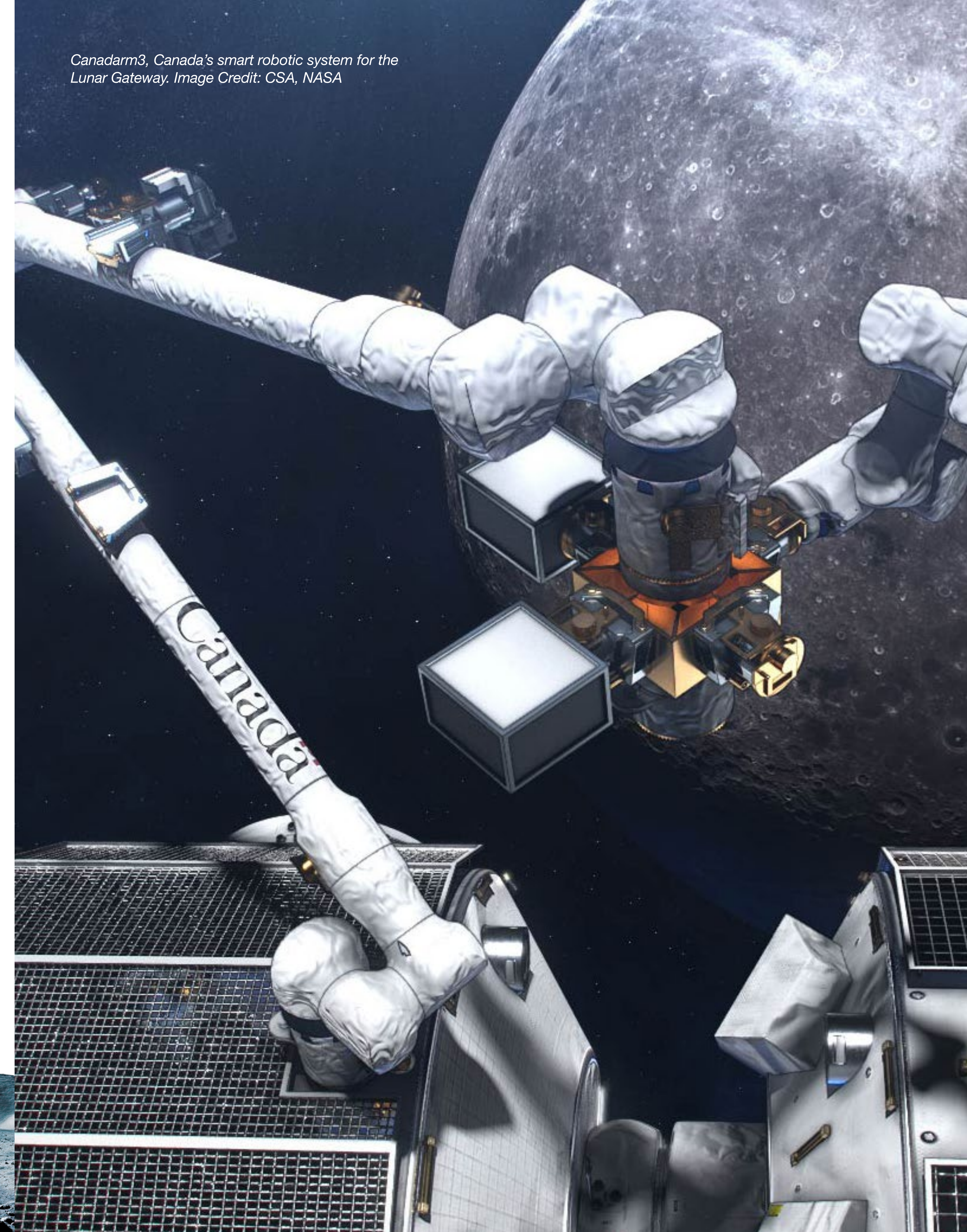


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.



Canadarm3, Canada's smart robotic system for the Lunar Gateway. Image Credit: CSA, NASA

NOTIONAL ELEMENT CONCEPTS

Table 4 shows several key notional elements needed to support the lunar surface scenario. These elements are sequenced from initial or early capabilities to later capabilities and support the phased approach.

TABLE 4

Key Elements of Lunar Surface Exploration Scenario

PHASE	ELEMENT	FUNCTION
1	Crew Vehicle	Vehicle provides transportation for a crew of four between Earth and the lunar vicinity, including sustainment of the crew during space travel and providing safe reentry from deep space. As an example, NASA's Orion spacecraft has a four-crew, 21-day capability.
	Unpressurised Rover	Provides transportation on the lunar surface for two extra-vehicular activity (EVA)-suited crew with payload. The range of the unpressurised rover is targeted to be greater than 2 km for each excursion. The rover may be used during uncrewed periods through tele-operations.
	Human Lander	Initial capability will provide transportation for two crew between the lunar vicinity and the lunar surface, with an evolutionary goal of four crew, for up to an 8-day mission.
	EVA Suits	Dedicated suit system for use in deep space in microgravity locations or on the lunar surface to allow crewmembers to perform extra-vehicular activities (EVA) for up to 8 hours. EVA suits are planned to be used through a conventional airlock system and evolve to support suitport capability.
	Small Landers / Robotic Precursors	Delivery of cargo to the lunar surface. Target range of cargo is 10s-100s of kg. Robotic precursors for science, utilisation and potential pathfinder for technology demonstrations.
2A	Small Pressurised Rover	Provides mobility of up to 600 km per mission and habitation for two crew on the lunar surface for up to 42 days. Assumed reuse over multiple crew missions and ability to locate to new landing sites between crew missions.
	Logistics Capability	Delivery of logistics and cargo to the lunar vicinity. Depending on launch vehicle, a range of cargo between ~2000 to 3400 kg can be accommodated to Gateway.
	Medium-Class Cargo Landers	Delivery of cargo to the lunar surface. Target range of cargo is ~1000-2000 kg. Cargo can include science payloads, logistics and equipment.
	Communications Relay	Uplink and downlink of data between lunar surface and Gateway or Earth. Communication bands under consideration include S-band, X-band, Ka-band and optical comm. Gateway elements can fill this need.
	Power	Provides supplemental power generation and storage to localized assets (such as ISRU demonstrations, rover recharge, habitat) on the lunar surface. Target of ~17 kW to support Phase 2A operations.
	Utility Rovers	Provides mobility options to support science and ISRU. Payload accommodations of 25-250 kg. Capable of traveling up to 2000 km.
	ISRU Pilot Plant	Subscale version of the Phase 3 operational plant that demonstrates ~1/100 of the oxygen needed from the Phase 3 operational plant. Will prove safety of operations and reliability needed for the operational plant.
2B	Long-Duration Habitation	Lunar surface habitation to support four crew for up to 60 days. Assumes provisions are delivered separately or with the crew and sufficient volume is available, which may be provided by several pressurised surface elements.
	Reusable Human Lander	Provides crew transportation between lunar vicinity and the lunar surface. Reusable ascent element for a crew of four for a multiple stage lunar lander. Propellant for ascent element can be supplied on orbit or on the surface.
	Nuclear Power	Modular power system sized to provide ~10 kW for the lunar day or night. Multiple units can provide power to meet infrastructure demands.
	ISRU Plant	Operational ISRU plant capable of producing ~50 tonnes of propellant per year. Electrolysis is used to create hydrogen and oxygen for propellant for a reusable lander. Excavation, collection and storage would be part of the plant system.
3	Crewed Hopper	Provides unpressurised two-way crew transportation within a 1000 km range of the landing site for a crew of four EVA-suited astronauts. Hopper is assumed to be refueled on the lunar surface between uses.

CAMPAIGN APPROACH

The updated Lunar Surface Exploration Scenario implements a phased approach and follows the sustainability principles established in the 2018 GER. It begins with human lunar return, then transitions to expanding and building up capabilities on the lunar surface and enabling sustained lunar opportunities. These phases build upon each other and will eventually lead to achieving Mars mission capability. Throughout the scenario, there is an emphasis on the advancement of knowledge and sustainable expansion of utilisation and commercial opportunities.

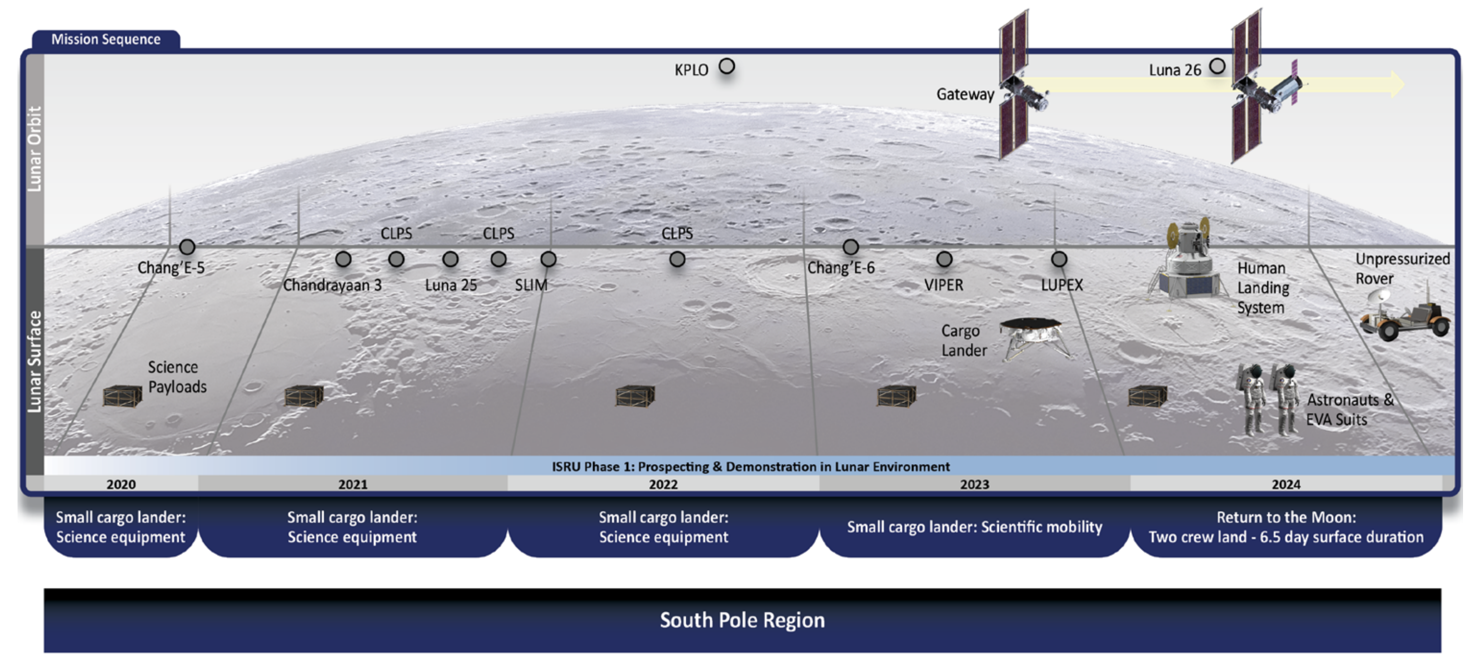


Figure 2. Phase 1: Boots on the Moon—South Pole.

Phase 1: Boots on the Moon
The updated mission scenario focuses on human missions to the surface of the Moon. NASA has announced bold plans to send humans to the Moon beginning in 2024, and other agencies, such as Roscosmos, CSA, and JAXA, are considering plans to enable human exploration of the Moon with several prospecting missions to support the 2024 goal. ESA is providing the ESM element of Orion and is planning lunar surface exploration activities after 2024. The ESA-DLR LUNA analogue facility provides a realistic environment for technology testing, procedures development, crew and ground personnel training, and end-to-end integrated simulations of EVA and robotic surface operations. Given the time frame for sending humans to the Moon, it is unlikely that there will be large infrastructure on the Moon to support initial missions. It is anticipated that initial capabilities will include small (cargo) landers—to support science and resource characterisation— as well as Gateway, a human lander, EVA hardware and an unpressurised rover.

Phase 2: Lunar Exploration—Expanding and Building
Following the initial human missions to the Moon, the updated mission scenario moves toward a sustained lunar presence that includes a focus on mobility, exploration and science, with demonstration of pressurised rover capabilities and resource utilisation. To support these missions, periodic cargo transportation will be needed. After mobility and exploration activities have been fully demonstrated, a shift to surface sustainability and Mars-focused demonstrations will occur, including enhanced pressurised rovers, longer-duration habitation, power systems and ISRU. The progression of capability then moves from local to regional exploration using at least one pressurised rover and is performed early on at the South Pole. The areas of exploration will be limited to locations that receive no more than eight consecutive days of continuous darkness. With the delivery of the first pressurised rover, Mars surface mission analogues become possible, while a second pressurised rover will greatly increase science and human exploration capabilities within a lunar region.

After the first several crewed missions, additional capabilities will be delivered to the lunar surface (i.e., upgrades to the pressurised rovers or new pressurised rovers enabling survival through a full lunar night of 14 days). This will allow crewmembers (and tele-operated science roving missions) to visit new sites outside of the South Pole region and explore the various sites outlined in the 2018 GER—with the rovers traversing to the new sites between crewed missions.

After completing several missions of expanding exploration capability and building infrastructure (Phase 2A), the focus will return to the South Pole for longer-duration habitation and ISRU.

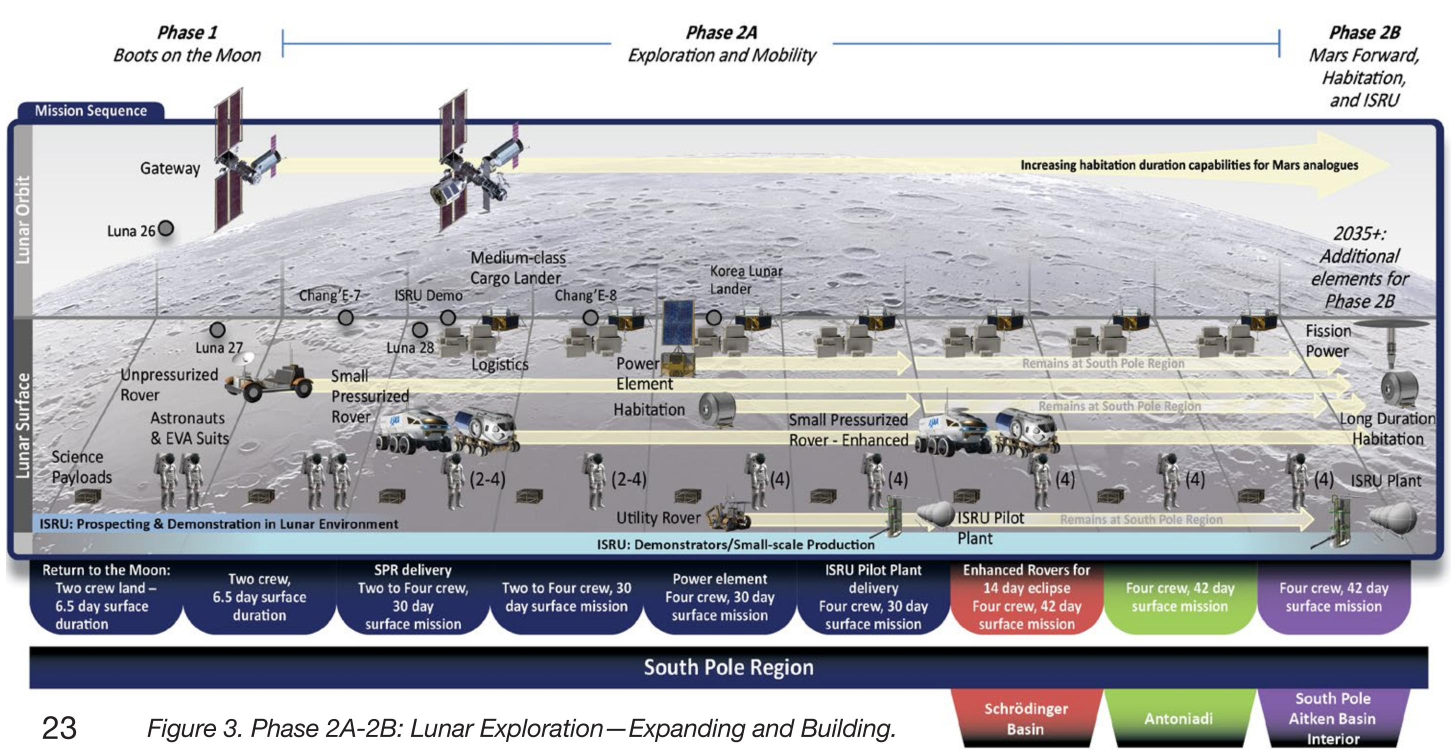


Figure 3. Phase 2A-2B: Lunar Exploration—Expanding and Building.

Additional habitation capabilities will be required to meet longer durations on the surface (e.g., closed-loop life support, crew health and performance, in-situ food/plant production, etc.). ISRU pilot and demonstration plants, and power to support the infrastructure and ISRU will also be needed. Figure 4. shows a potential end state for Phase 2B, focusing on the objectives related to longer durations on the lunar surface. Another key aspect for architecture capabilities includes looking at dissimilar redundancies for several of the key elements. These experiences and enhanced capabilities will prepare agencies for the first human mission to Mars.

Phase 3: Sustained Lunar Opportunities
The updated mission scenario envisages laying the foundation for a sustained and vibrant lunar presence in the coming decades. This sustainable vision includes stimulating opportunity through technology testing, investing in infrastructure and creating opportunities accessible through partnerships with international governments, academia and industry. The potential capabilities that aid a sustainable lunar surface economy may include long-duration habitation operations, associated commercial developments, mobility systems (providing global access), and ISRU production and operation. These would be built upon the basic infrastructure (power, communications, etc.) provided during the first two phases, which will occur within the next two decades.

As access to and from the lunar surface becomes more commonplace and affordable, the viability of lunar economies will improve over time and open Earth's nearest celestial body for ongoing human discovery and development. Governments would shift their investment focus to support exploring other frontiers, including Mars exploration missions. While the more detailed assessment of sustained lunar opportunities is not within the scope of this Supplement, ISECG agencies envision a future lunar surface with robust economic activity that lay the foundation for exploration across the solar system with robotic and human missions.

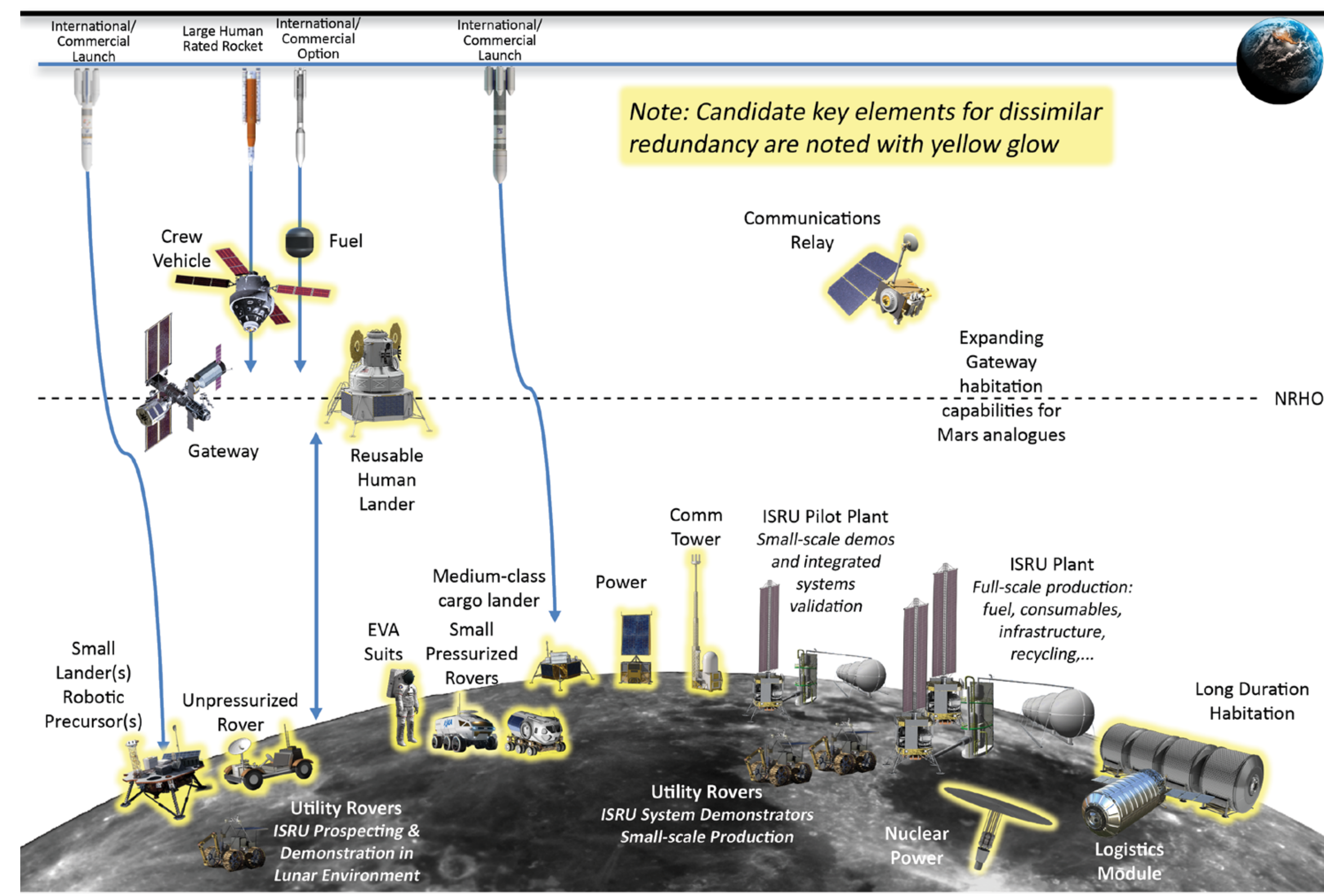
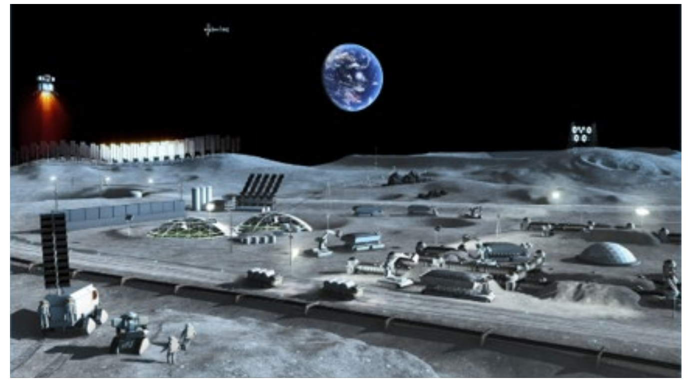


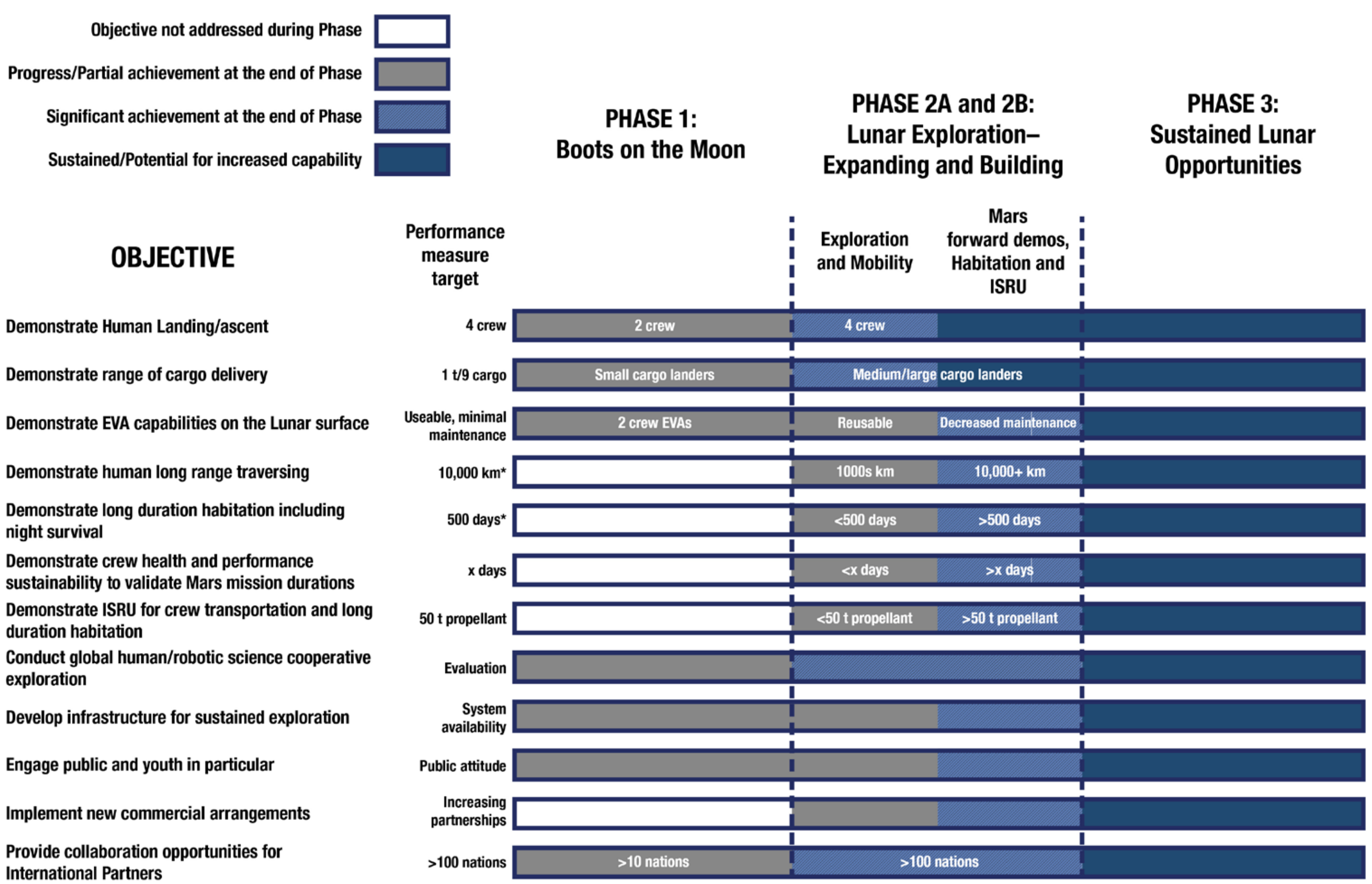
Figure 4. Expanding and Building—Longer Duration and Increased Utilisation (Phase 2B End State).

PROGRESSION ON OBJECTIVES

Given the implementation of the updated Lunar Surface Exploration Scenario, Figure 5 shows the progression of achieving the lunar surface exploration objectives over time. Objectives such as science, engaging the public, collaborative partnerships, preparing for Mars and enabling commercial endeavours are front and centre throughout the entire Lunar Surface Exploration Scenario. Other segments of the scenario, such as Phase 1: Boots on the Moon, focus on demonstrating specific objectives. In this case, the first phase is to demonstrate landing and ascent and delivery of cargo to the lunar surface.



A Future Vision of a Fully Developed Lunar Economy. Image Credit: JAXA



Note: Assumes reuse of capabilities into following phases
**** Cumulative over one to several missions***

Figure 5. Objectives Progression across Phases.

CHAPTER FIVE

INCREASING INDUSTRY CAPABILITIES

Over the past decade, ambitions and capabilities to explore space and transport humans, robots and cargo to low-Earth orbit and beyond have increased significantly. In the past, these capabilities were only achievable through the resources and support of governments. Now missions are rapidly transitioning from being the exclusive purview of large agency development programmes to include more non-government actors using a services-based model or having entire missions executed by private companies around the world. While governments will continue to invest in key space technologies, projects and missions to explore LEO and beyond, ISECG agencies expect to leverage emerging capabilities for use in planning future spaceflight science and exploration activities. Leveraging these new capabilities will lower overall costs and benefit their countries by providing them access to new economies and technologies.

Some space agencies have responded to these increasingly successful private-sector capabilities with novel spaceflight acquisition approaches that both achieve the agency goals and provide private companies with opportunities to reduce risk while refining their economic operations systems and broadening their customer range. ISECG agencies welcome and support these new partnerships for both the benefits provided to the domestic economies as well as their contributions to achieving international space exploration goals.

CSA's Juno rover operating at night and simulating soil sampling in lunar permanently shadowed regions. Image Credit: CSA

APPENDIX

LIST OF ACRONYMS

AEB	Brazilian Space Agency
ASA	Australian Space Agency
ASI	Italian Space Agency
CLPS	Commercial Lunar Payload Services
CLTV	Cislunar Transfer Vehicle
CNES	National Centre for Space Studies
CNSA	China National Space Administration
CRAS	Commission for Space Activities
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DLR	German Aerospace Center
EAER	Federal Department of Economic Affairs, Education and Research
EL3	European Large Logistics Lander
ESA	European Space Agency
ESM	European Service Module
EU	European Union
EVA	Extra-Vehicular Activity
GER	Global Exploration Roadmap
GISTDA	Geo-Informatics and Space Technology Development Agency
GNSS	Global Navigation Satellite System
HALO	Habitation and Logistics Outpost
HTV-X	Next-Generation H-2 Transfer Vehicle
I-HAB	International Habitation Module
ILRS	International Lunar Research Station
ISRO	Indian Space Research Organisation
ISRU	In-Situ Resource Utilisation
ISECG	International Space Exploration Coordination Group
JAXA	Japan Aerospace Exploration Agency

KARI	Korea Aerospace Research Institute
KPLO	Korea Pathfinder Lunar Orbiter
LCNS	Lunar Communication and Navigation Services
LEAP	Lunar Exploration Accelerator Program
LEO	Low-Earth Orbit
LSA	Luxembourg Space Agency
LUPEX	Lunar Polar Exploration
NASA	National Aeronautics and Space Administration
NOSA	Norwegian Space Agency
NRHO	Near Rectilinear Halo Orbit
POLSA	Polish Space Agency
PPE	Power and Propulsion Element
PRS	Public Regulated Service
ROSA	Romanian Space Agency
Roscosmos	Roscosmos State Corporation for Space Activities
SERI	State Secretariat for Education, Research and Innovation
SLS	Space Launch System
SSA	Space Situational Awareness
SSAU	State Space Agency of Ukraine
SSO	Swiss Space Office
UAESA	United Arab Emirates Space Agency
UK Space Agency	United Kingdom Space Agency
VAST	Vietnam Academy of Science and Technology
VIPER	Volatiles Investigating Polar Exploration Rover
VNSC	Vietnam National Space Center

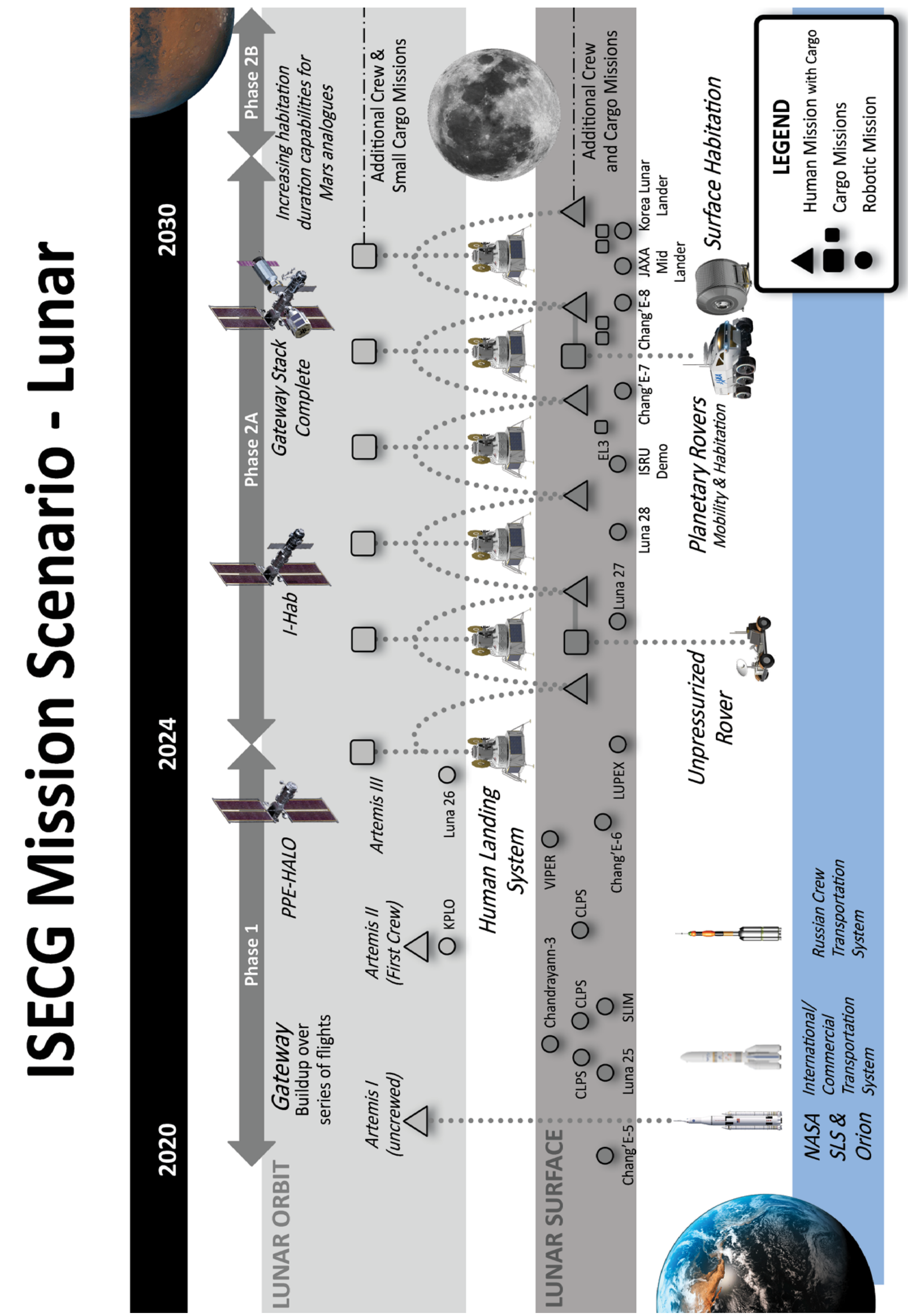


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

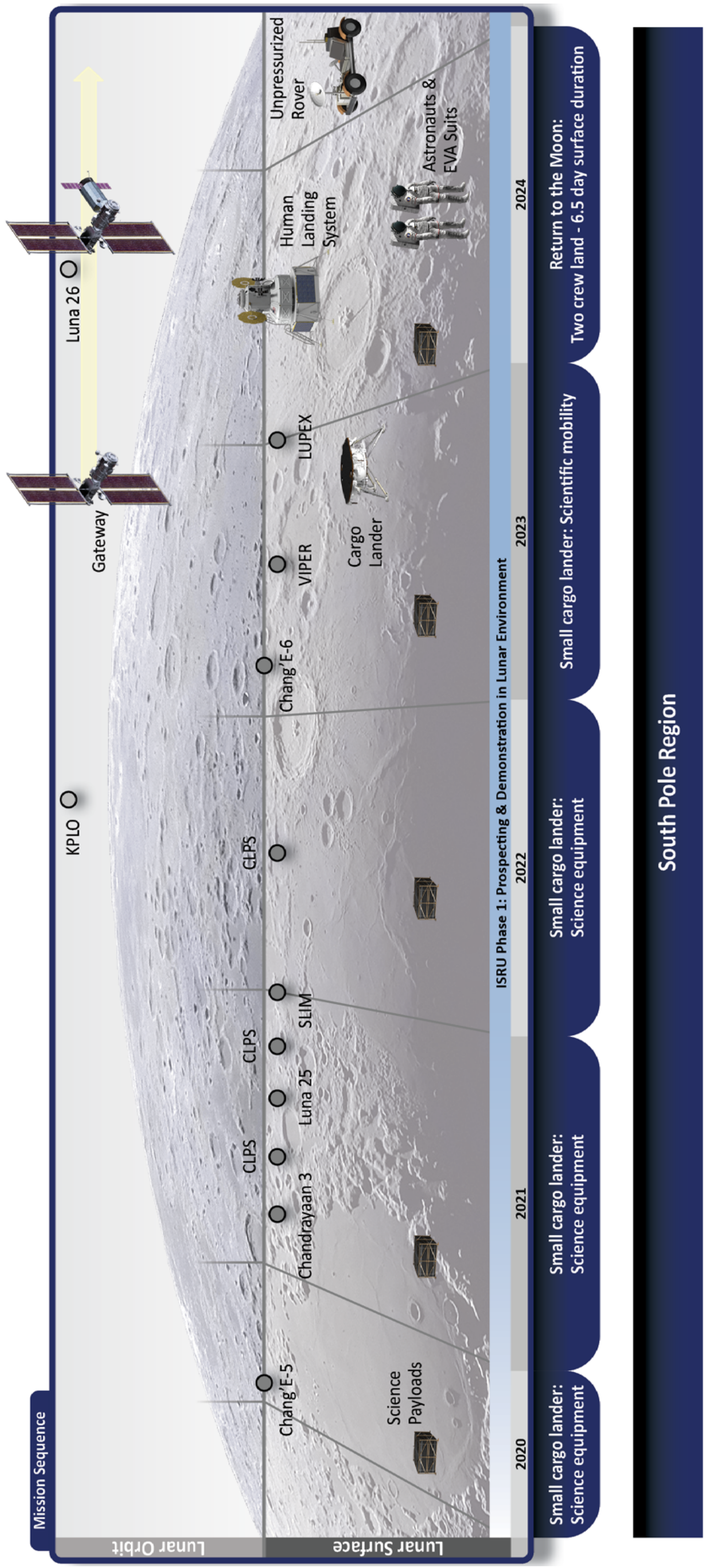


Figure 2. Phase 1: Boots on the Moon—South Pole.

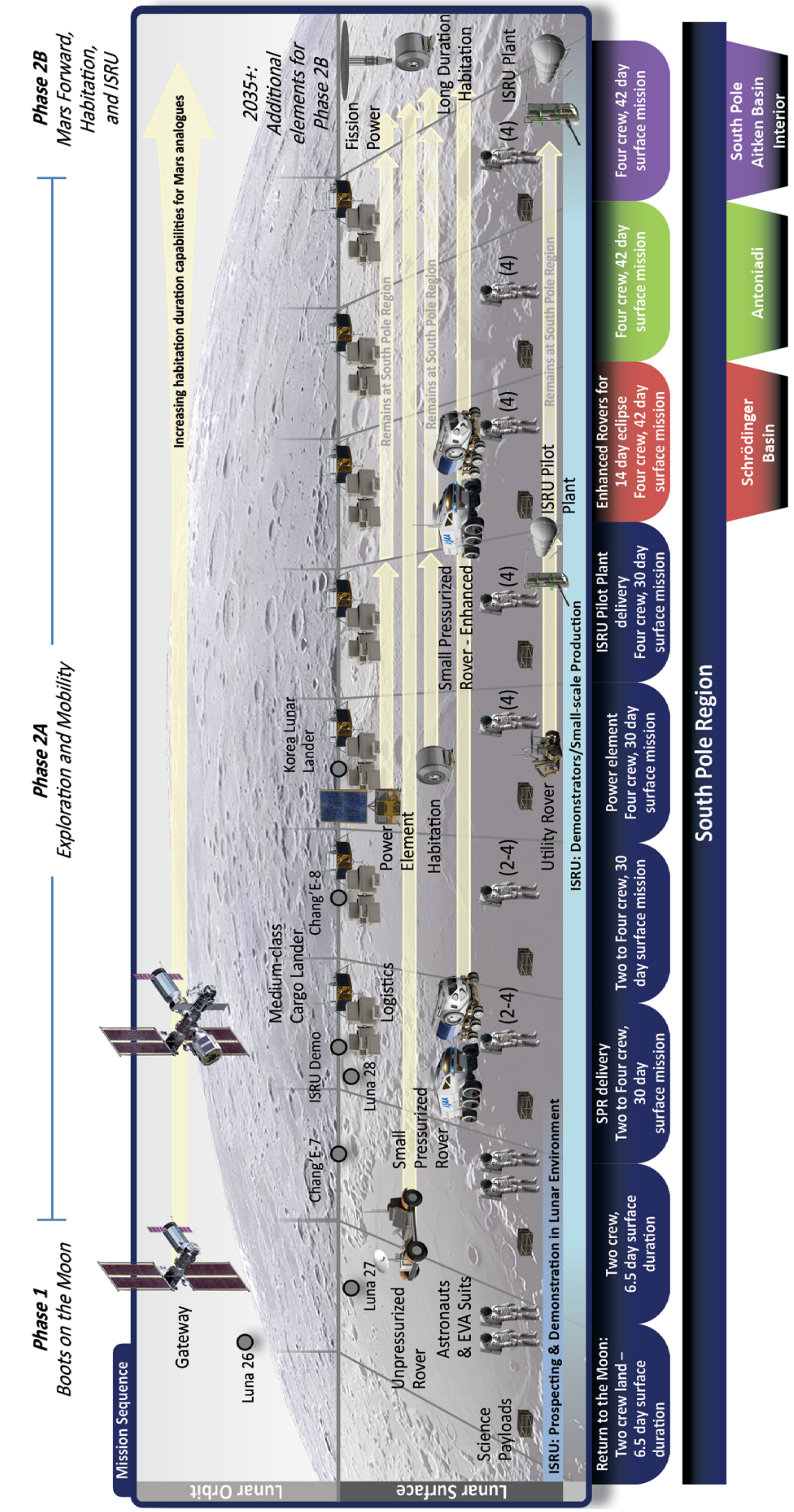


Figure 3. Phase 2A-2B: Lunar Exploration—Expanding and Building.

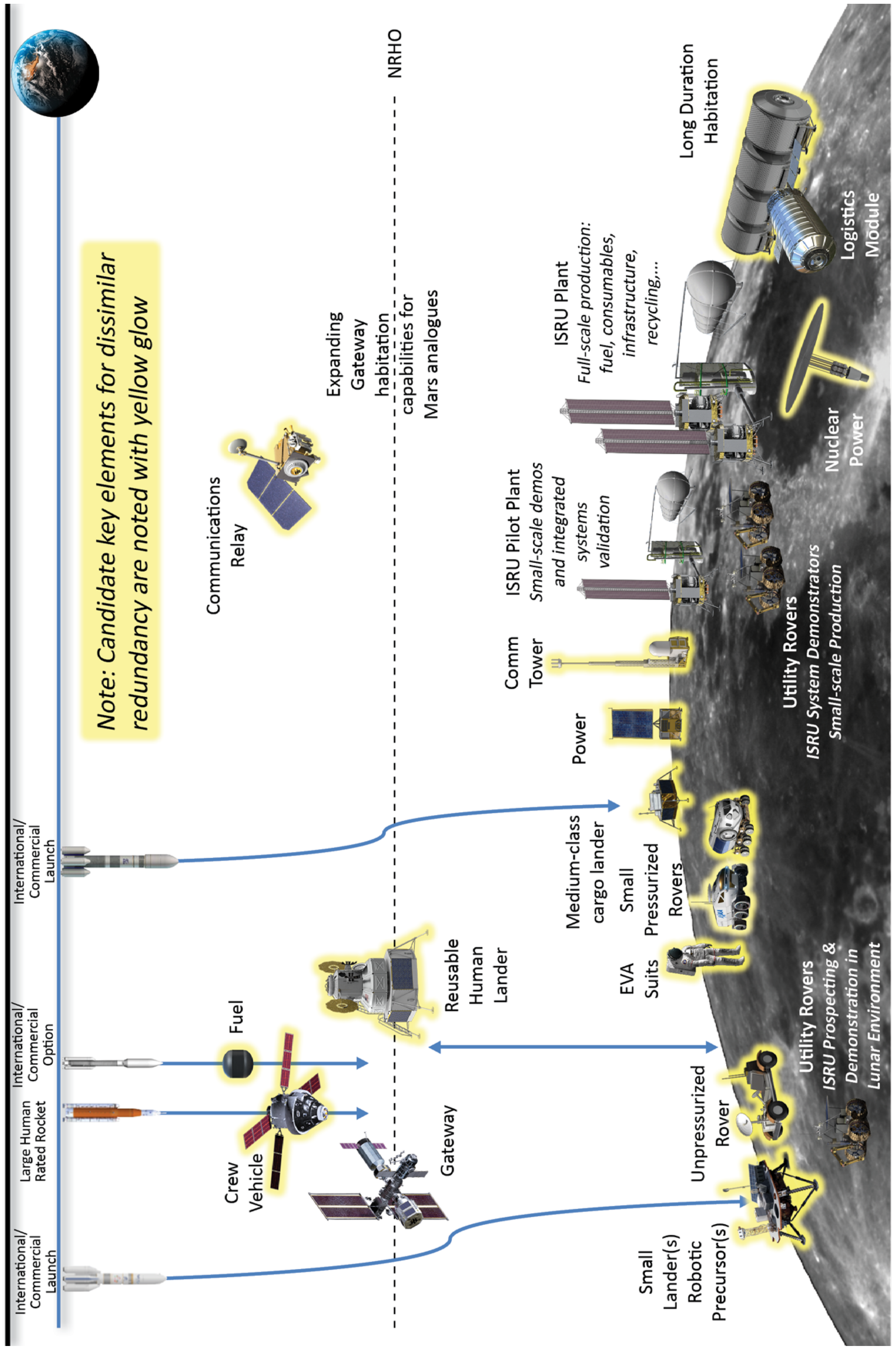


Figure 4. Expanding and Building—Longer Duration and Increased Utilisation (Phase 2B End State).

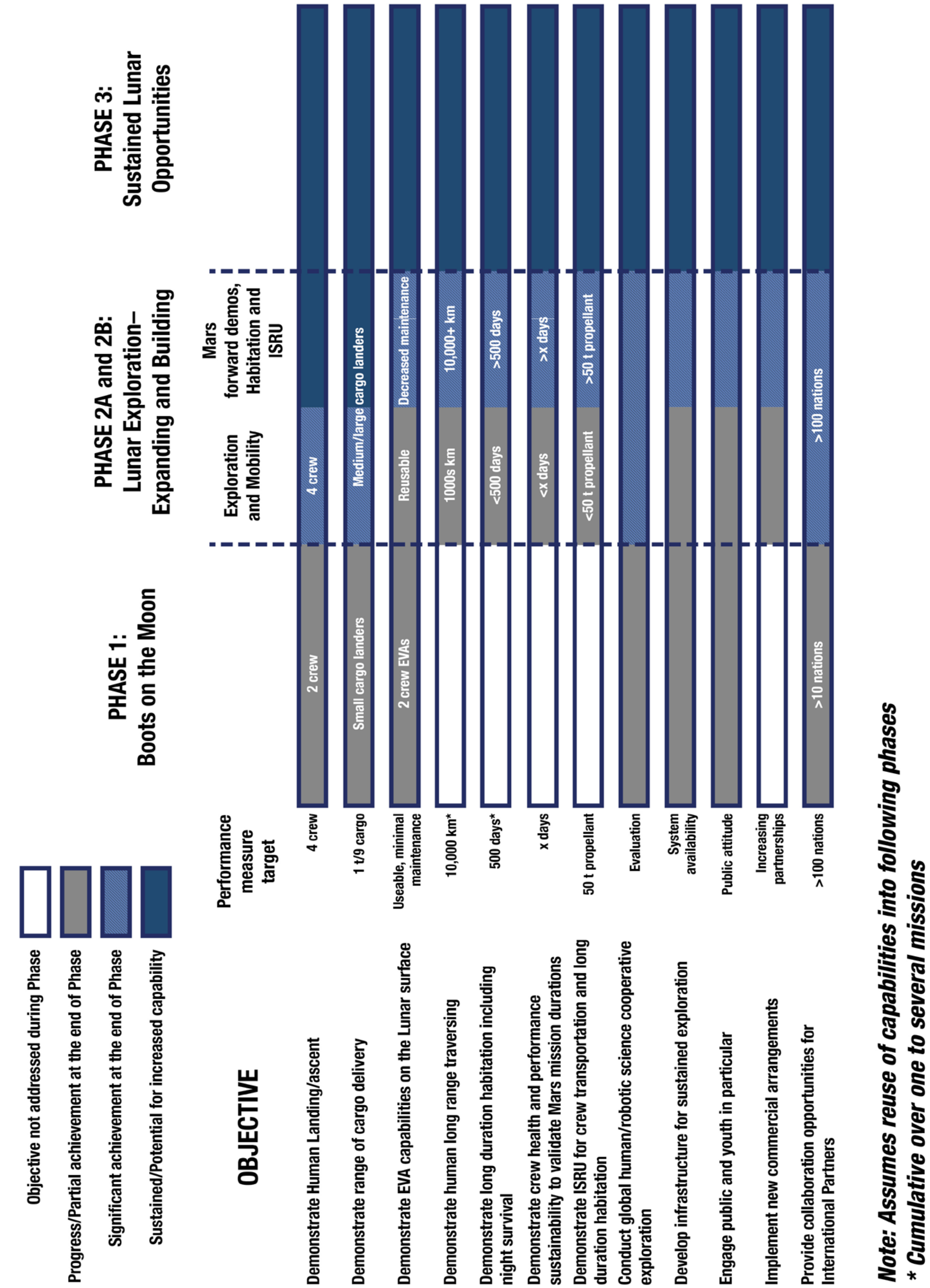


Figure 5. Objectives Progression across Phases.

ISECG is a voluntary, non-binding coordination forum of 24 space agencies. ISECG operates in accordance with the key principles set forth in the Global Exploration Strategy—which are open and inclusive, flexible and evolutionary—and is meant to foster mutually beneficial partnerships.

ISECG is committed to fostering the discussions in non-binding forums and to develop products that enable its members to take concrete steps towards establishing partnerships that reflect a globally coordinated exploration effort and enhance the benefits of space exploration for all.

For more information on ISECG activities and how to join, visit the ISECG public website,
https://www.globalspaceexploration.org

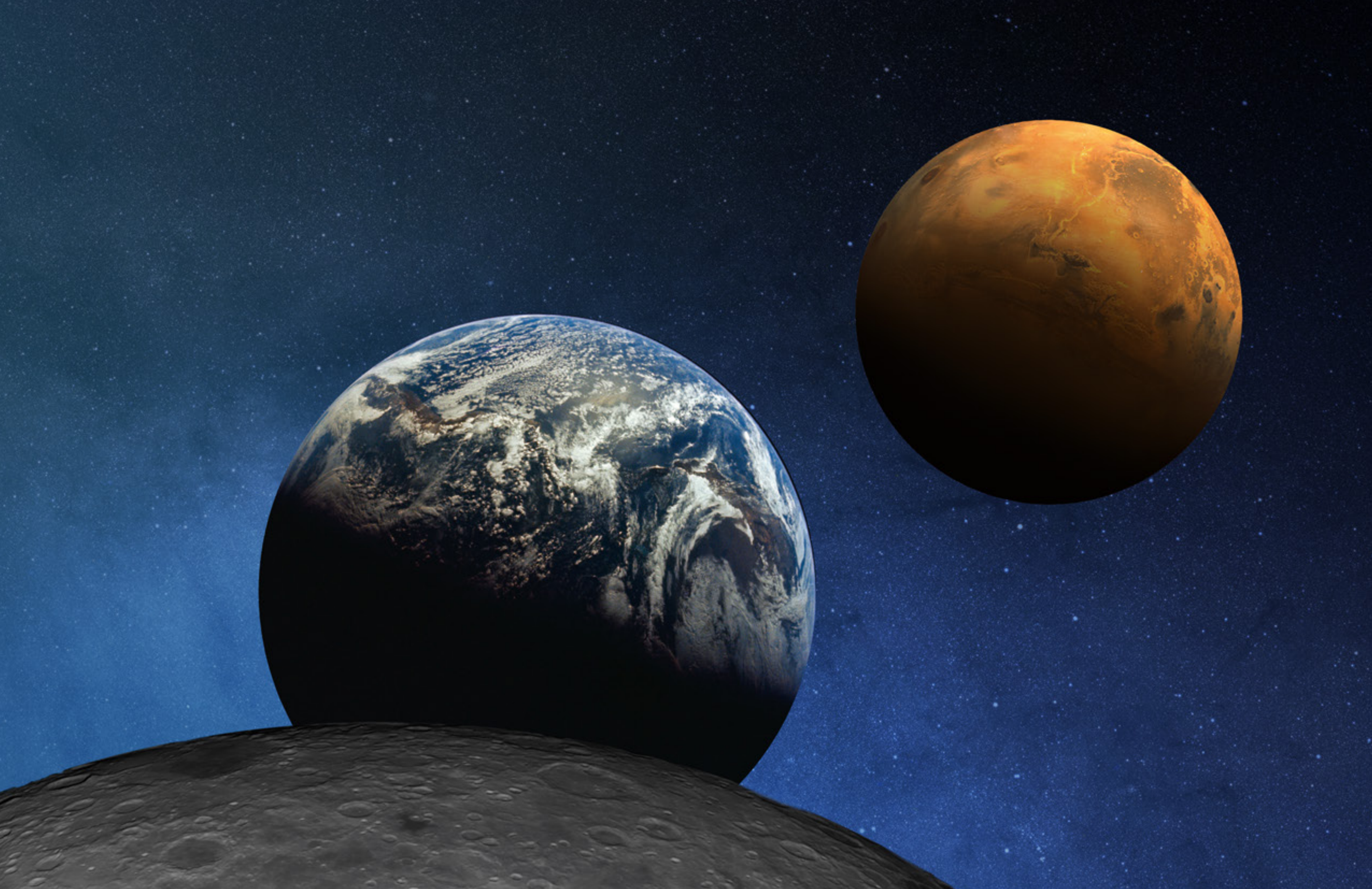
Publishing services provided by:

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

www.nasa.gov

NP-2020-07-2888-HQ
Rev 0

This document is available online at
http://www.globalspaceexploration.org



THE

GLOBAL EXPLORATION ROADMAP

SUPPLEMENT

OCTOBER 2022

LUNAR SURFACE EXPLORATION
SCENARIO UPDATE

www.globalspaceexploration.org

15 YEAR ANNIVERSARY
ISECG
International Space Exploration Coordination Group

ABOUT THIS SUPPLEMENT

The Global Exploration Roadmap (GER) is a non-binding product of the participating agencies in the International Space Exploration Coordination Group (ISECG). The GER presents a shared international vision for human and robotic space exploration and is based on the coordinated programmes, initiatives and goals of the ISECG space agencies. This coordinated vision from the ISECG agencies around the world recognises that the difficult and long-term challenges of exploration, coupled with common objectives and goals, are best addressed through cooperative ventures.

The GER reflects an exploration strategy that begins with the International Space Station (ISS) and extends to the Moon, asteroids, Mars and other destinations. This strategy builds on a shared set of exploration goals and objectives and reflects missions that will provide substantial benefits to the citizens of Earth.

Since the release of the GER in January 2018 and subsequent release of the 2020 Lunar Surface Exploration Scenario Update ('GER Supplement'), many ISECG space agencies* have intensified and accelerated lunar exploration plans. These rapidly evolving exploration plans, coupled with several new agency participants in the ISECG, necessitated an update to the 2020 Lunar Supplement. This new 2022 GER Supplement refines lunar objectives, updates mission plans and includes the newly joined ISECG organisations (cf. Chapter 1) and updates to agency lunar exploration plans (cf. Chapter 2).

This 2022 GER Supplement also includes a refined set of common objectives for a sustainable lunar surface exploration campaign (cf. Chapter 3) and the updated Lunar Surface Exploration Scenario (cf. Chapter 4) describes the architecture elements and the exploration campaign that progressively meet these lunar surface exploration objectives. This Supplement also includes a new chapter (cf. Chapter 6) which characterises lunar scientific priorities enabled by exploration initiatives. This updated 2022 GER supplement and agency specific objectives will be used to support coordination efforts amongst space agencies by providing context for establishing solid partnerships and executing successful missions. As space exploration is an inherently global endeavour, partnerships of all types—amongst government agencies, academia, public-private entities and within the private sector—are crucial and provide the best ideas and solutions from around the globe.

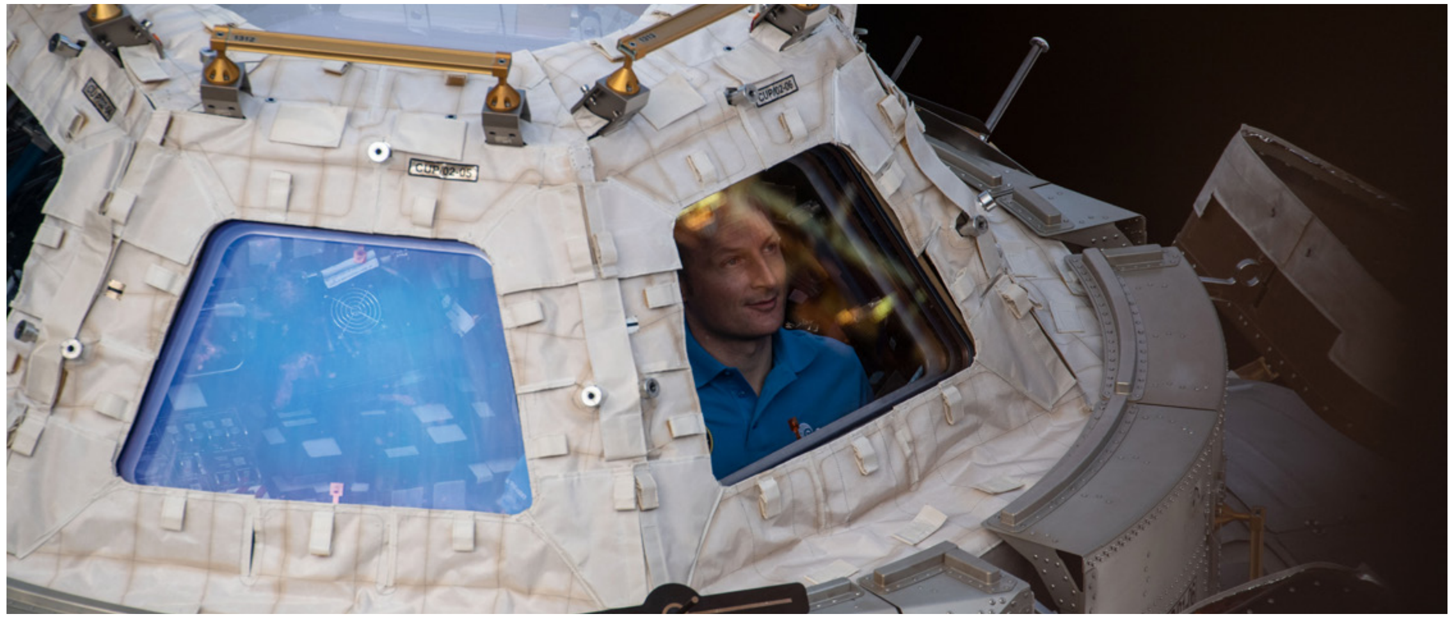


Image of ESA astronaut Matthias Maurer inside seven-windowed Cupola of the International Space Station during Expedition 67. Image Credit: ESA/DLR/NASA

"Space agencies" refers to government organisations responsible for space activities.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The 2018 Global Exploration Roadmap (GER) reflects an exploration strategy that captured a shared vision from space agencies* participating in the International Space Exploration Coordination Group (ISECG) for international collaboration based upon a common set of exploration goals, objectives and identified benefits to humanity. Since then, many space agencies have renewed their focus on the Moon, for its scientific opportunities and prospects for sustained human presence and to demonstrate capabilities that will prepare for human missions to Mars. This renewed focus led ISECG agencies to update the Lunar Surface Exploration Scenario and capture the latest developments in lunar exploration planning from around the globe in the 2020 GER Supplement. The ISECG membership has subsequently expanded while agency plans have continued to advance since the 2020 GER Supplement release. This growth in ISECG members and continued advancement of agencies' exploration plans reflects the increasingly important role of spaceflight endeavours in providing economic and societal benefits to people on Earth through increased lunar investments and expanded scientific and exploration goals.

In parallel, commercial space activities are achieving new capabilities for spaceflight leading to economic conditions suitable for business sustainability that have opened the spaceflight frontier to new entrants and new government strategies for science and human exploration of the solar system.

This 2022 updated GER Supplement describes the latest mission scenario and architecture for human and robotic lunar surface missions, preparatory activities for Mars and scientific priorities for the Moon. This Supplement also integrates renewed and emerging national plans and commercial capabilities among ISECG participating countries, including international efforts to agree on a lunar navigation and communication architecture. Leveraging the ISECG goals and sustainability principles (from the 2018 GER), a set of 12 lunar exploration objectives was formulated with rationale and performance measure targets defined and then incorporated into one scenario with three phases:

- Phase 1: Boots on the Moon
- Phase 2: Expanding and Building
- Phase 3: Sustained Lunar Opportunities

ISECG SUSTAINABILITY PRINCIPLES

- ***Affordability***
  Innovative approaches to enable more with available budgets.
- ***Partnerships***
  Provide early and sustained opportunities for diverse partners.
- ***Human-robotic Partnerships***
  Maximise synergies between human and robotic missions.
- ***Exploration Benefit***
  Meet exploration objectives and generate public benefits.
- ***Capability Evolution and Interoperability***
  The stepwise evolution of capabilities with standard interfaces.
- ***Robustness***
  Provide resilience to technical and programmatic challenges.

"Space agencies" refers to government organisations responsible for space activities.

Additionally, this Supplement captures the increasing interest and associated mission planning in lunar in-situ resource utilisation (ISRU), communication and navigation systems, lunar transportation, surface power and dust mitigation technologies. These capabilities, combined with new commercial payload delivery services, will also benefit science and academic communities by providing more frequent and lower-cost missions to the Moon and, ultimately, Mars.

Evolved lunar surface exploration and utilisation scenarios reflect plans for a near-term series of robotic missions followed by humans returning to the Moon in this decade. Rather than looking at individual missions, the scenario depicts a stepwise development of an increasingly capable lunar transportation system to the lunar surface, traversing systems on the lunar surface, and infrastructure supporting them that will enable cooperative science and human exploration efforts leading toward a sustained presence on the lunar poles and incorporating lunar surface activities as analogues in preparation for human missions to Mars. These efforts emphasise landed downmass to eventually support four crewmembers per mission and mobility systems that dramatically enhance science return and exploration distances around a lunar pole base camp.

Sustained exploration and presence on the lunar surface are not the only goals for future planning; rather they are part of a collection of incremental advancements, each adding to our combined knowledge of the Moon and preparing for continued exploration across the solar system, starting with Mars. These activities are also a driver for innovation and economic growth. Advancements in technologies touching every aspect of everyday life—health and medicine, public safety, consumer goods, industrial productivity, transportation and many others—are a direct result of space exploration. In the last several years, job creation and economic growth have been accelerated by private investments in the space sector.

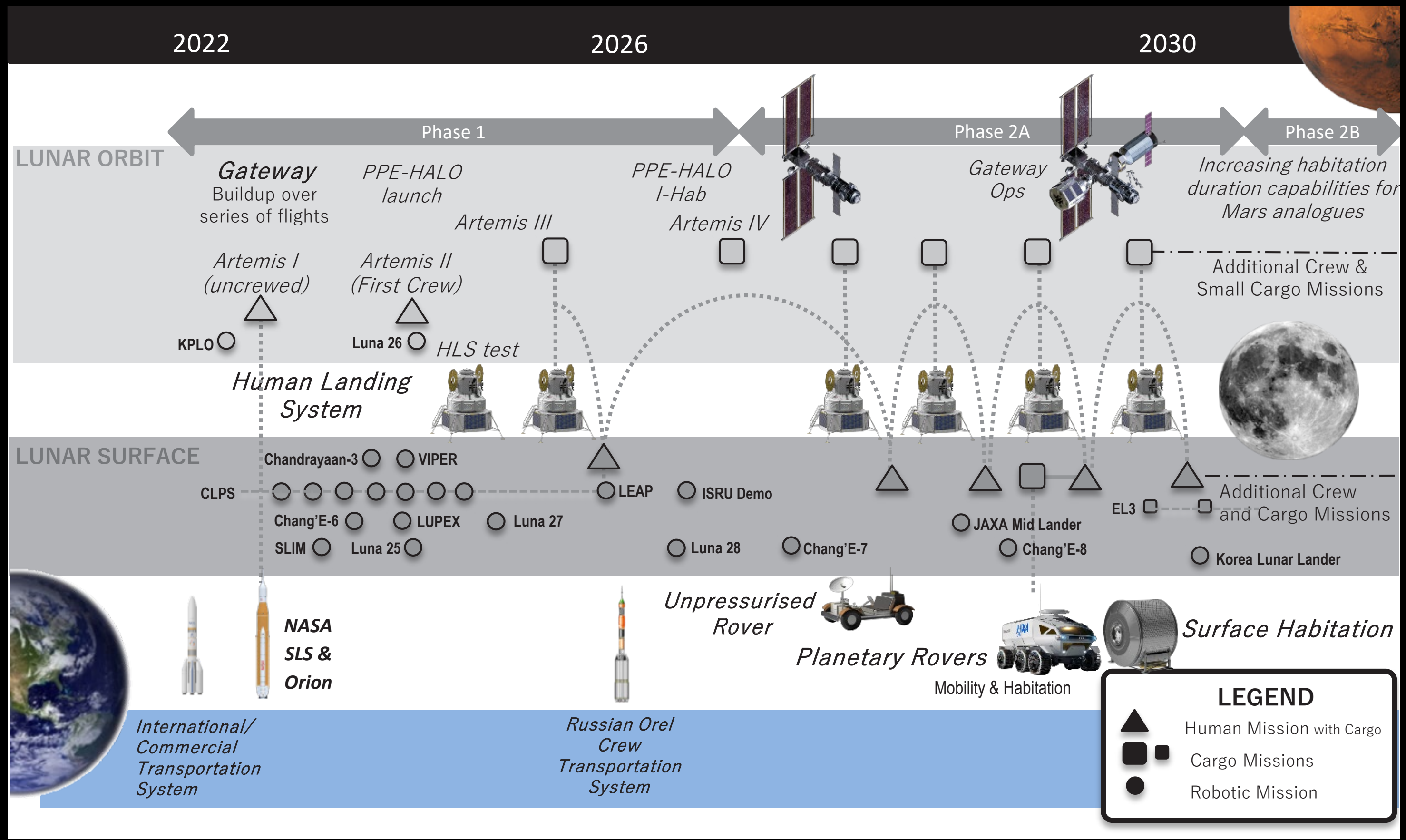
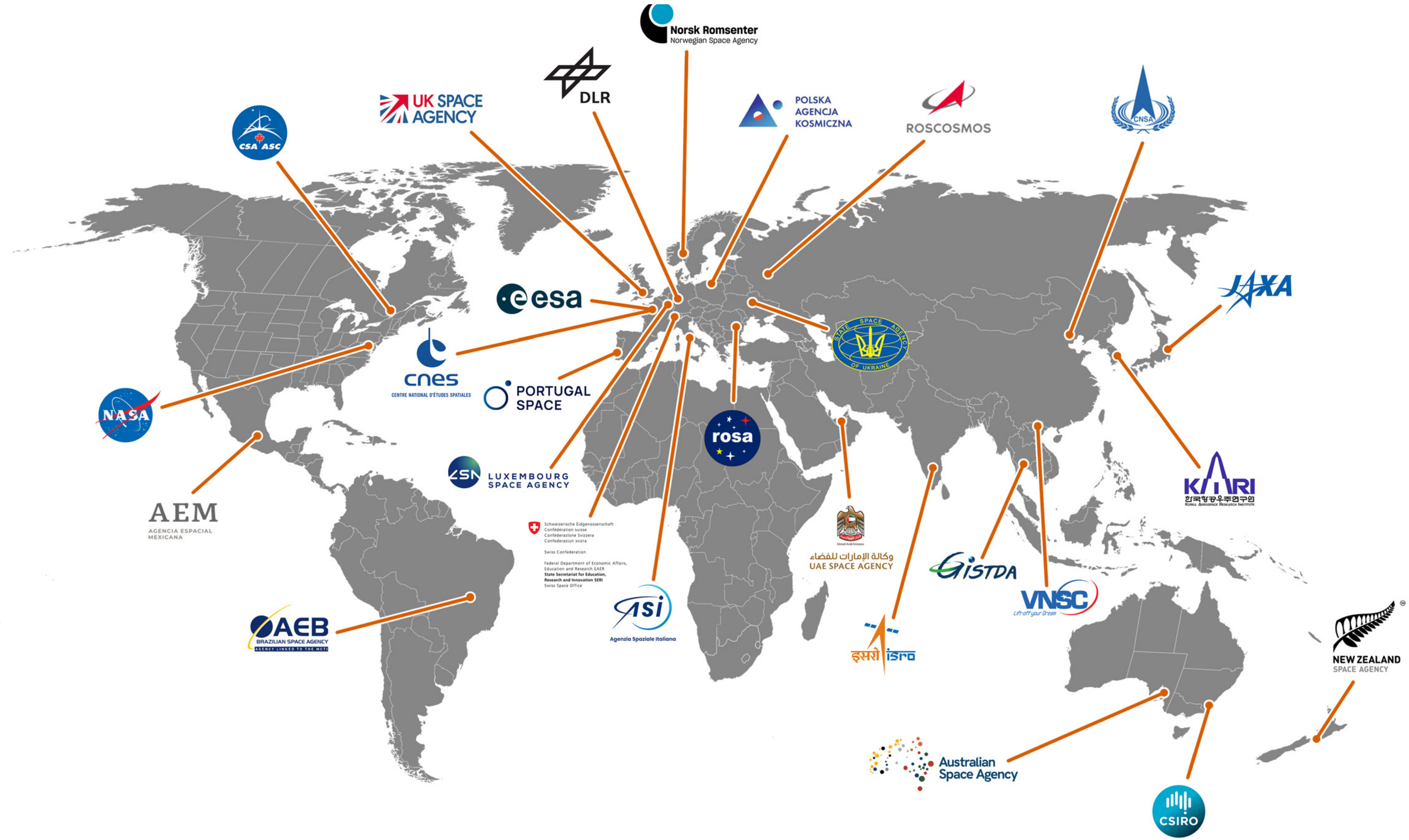


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

ISECG AGENCIES WORLD MAP



GROWING GLOBAL MOMENTUM

The steadily increasing number of ISECG agencies underscores the growing global interest and momentum for going forward to the Moon and Mars. Since the 2018 GER release, the number of ISECG agencies has increased from 15 to 27. Below is a summary of the new organisations along with the date they joined:

BRAZILIAN SPACE AGENCY (AUG. 2020)

The Brazilian Space Agency (Agência Espacial Brasileira—AEB), a government agency established in February 1994 with the purpose of promoting the development of space activities of national interest, is responsible for the formulation, coordination, and implementation of the National Policy for the Development of Space Activities. AEB seeks to ensure that the downstream market for space-based products and services meets the needs of Brazilian society. Additionally, AEB´s efforts are targeted at consolidating the Brazilian space industry, increasing its competitiveness and capacity for innovation. The Agency views space cooperation as a critical tool to leverage resources and reduce risks, favoring the joint development of technological and industrial projects that generate valuable outcomes to both Brazil and its international partners.

Advances in space science and the use of space applications in everyday life inspire positive developments in the formulation of improved public policies and in the design of business-oriented space diplomacy that delivers sustained prosperity to all. As the key body of the Brazilian space ecosystem, AEB understands that becoming a full ISECG member will grant the agency the opportunity to learn from top performers, build on a widespread culture of collaboration and innovation and take a more active part in the international space agenda. For more information about AEB, visit https://www.aeb.gov.br.

AUSTRALIAN SPACE AGENCY (FEB. 2019)

On 1 July 2018, the Australian Government established the Australian Space Agency (ASA) with the intent of transforming and growing a globally respected space industry. Australia's long history of supporting space exploration dates back to the 1960's, with the efforts of the existing ISECG member Commonwealth Scientific and Industrial Research Organisation (CSIRO), and is now increasing its ability to participate in global efforts for the peaceful use of space. Australia has strong capabilities in robotics and remote operations, artificial intelligence, space domain awareness, advanced communications, health, and remote medicine. Australia is increasing its capacity and facilities in areas including:

- Mission and robotics command and control centres
- Ground station networks
- Space manufacturing and space data analytics
- Introducing industry programmes to collaborate internationally and support global plans to reach the Moon and continue on to Mars

ASA looks forward to sharing ideas and contributing to the international efforts to solve the challenges related to achieving ISECG goals. For more information about the Australian Civil Space Strategy, visit https://www.industry.gov.au/strategies-for-the-future/australian-space-agency.

MEXICAN SPACE AGENCY (OCT. 2020)

The Mexican Space Agency (AEM), a government agency established in July 2010 by Congress Decree with the purpose to use space and technology to meet the needs of the Mexican population, promoting innovation and development of the space sector, contributing to the competitiveness and positioning Mexico in the international community within the peaceful, effective, and responsible use of outer space.

The AEM has a National Space Activities Program 2020-2024 (PNAE) focused on contributing to the solution of the public problems and for this, the AEM promotes the Penta helix model: government, society; academia, industry, and the environment, constituting the propellers around sustainable development. The priority objectives of the AEM contained in the PNAE are the following:

1. Identify the perspectives and promote the development of space infrastructure for navigation, global positioning, and its applications.
2. Promote the development of a comprehensive program of national scope for Earth observation for the benefit of the population.
3. Increase capacities and promote cooperation in science and technology in the country, in space exploration for the scientific and technological strengthening of Mexico.

As transversal: Development of human capital; industrial, commercial and competitiveness in the space sector; and international cooperation and space security.

The Mexican Space Agency, in accordance with its mission and work program, shares the principles that support ISECG, and is interested in advancing in full coordination and cooperation. Everything indicates that space activity will be an important driver of economic activity in the remainder of the 21st century. Visit: https://www.gob.mx/cms/uploads/attachment/file/585644/Programa_Nacional_de_Actividades_Espaciales_2020-2024.pdf.

GEO-INFORMATICS AND SPACE TECHNOLOGY DEVELOPMENT AGENCY (THAILAND) (APR. 2020)

The Geo-Informatics and Space Technology Development Agency (GISTDA) was founded in 2000. GISTDA's primary objective has been the development of geo-informatics and space technology and these core functions are divided into two segments: ground and space. Since its inception nearly 20 years ago, GISTDA has focused on developing Earth observation satellite technology and applications and building the professional capacity of Thailand and Southeast Asia by investing in human capital and training. Another critical element of GISTDA's mission is building and leveraging its domestic space industry.

Recently, Thailand has broadened its focus to include space exploration. Under the umbrella of Earth Space System, they announced the Ministry of Higher Education, Science, Research and Innovation initiative, which aims to increase space exploration research and development within Thailand. GISTDA is Thailand's main space agency and has officially launched its Space Exploration Program which has the following focus areas:

- Scientific research in low-Earth orbit, the Moon and beyond
- Increasing space technology capacities of exploration, scientific payload and instrument, robotic rover, spaceflight and spaceport
- Building awareness in the space exploration sector
- Supports Thailand to New Space Economy

GISTDA joined ISECG to help Thailand become a contributing member of the global space exploration community and to assist in expanding the global space economy. For more information about GISTDA, visit https://www.gistda.or.th.

LUXEMBOURG SPACE AGENCY (SEPT. 2019)

The Luxembourg Space Agency (LSA) was founded in 2018. LSA's primary focus is to develop the space sector in Luxembourg by creating new and supporting existing companies, developing human resources, facilitating access to funding and supporting academic research. The agency executes the National Space Economic Development Strategy, manages national space research and development programmes and leads the SpaceResources.lu initiative. LSA also represents Luxembourg within the European Space Agency (ESA), which the country has been a member of since 2005, and participates in space-related programmes of the European Union (EU) and the United Nations (UN).

The Luxembourg Space Agency is excited to partner with ISECG and is dedicated to aiding efforts to advance global coordination in space exploration. In 2020, LSA established the European Space Resources Innovation Centre (ESRIC) in Luxembourg to contribute to the peaceful exploration and sustainable utilisation of resources for the benefit of human kind. ESRIC is conducting research in the field of space resources, hosts an open research infrastructure and develops technologies with industry for human and robotic exploration as well as for a future in-space economy. ESA joined ESRIC in a strategic partnership, and together with European academia and industry, ESRIC and ESA are developing technologies for a human presence at the Moon sustained by local resources. For more information about LSA, visit https://www.space-agency.lu.

NEW ZEALAND SPACE AGENCY (SEPT. 2021)

Established in 2016, the New Zealand Space Agency (NZSA), part of the Ministry of Business, Innovation and Employment, is the front door for space activity in New Zealand – the lead government agency for space policy, regulation and sector development. NZSA's role is to enable the continued growth of New Zealand's space sector, while ensuring all space activities are conducted safely, sustainably and securely. NZSA achieves this through supporting the development of innovative space technology and a future-focused and flexible policy and regulatory regime.

New Zealand has a broad space sector with strengths in a number of areas including launch, manufacturing, and operations. Through enabling collaborations between New Zealand's space sector and international space partners, NZSA seeks to promote the development of space technologies and solutions that will benefit life on Earth, including those that will contribute to our understanding of the solar system. Recent collaborations between the New Zealand space sector and international partners including space agencies and commercial space operators, will see innovations developed to both support a sustained human presence in space and to aid coordination of space missions in cislunar space.

For more information about NZSA, visit https://www.mbie.govt.nz/science-and-technology/space/.

NORWEGIAN SPACE AGENCY (JAN. 2020)

The Norwegian Space Agency (NOSA) is a government agency under the Ministry of Trade, Industry and Fisheries. The Agency was established in 1987, when Norway became a member of ESA. NOSA is responsible for organizing Norwegian space activities, particularly with respect to ESA and the EU, and for coordinating national space activities. Space activities have a large strategic value for Norway, with its vast ocean areas and as one of the world's northernmost areas.

Norwegians have always been pioneers when it comes to exploring the unknown and have a long tradition for operating in harsh and remote environments. With increased international focus on space exploration comes new challenges, leading to increased scientific and technological knowledge. NOSA sees this as a great opportunity for innovation that could be useful both in space and on Earth, widening the scope for Norwegian activities.

NOSA views their membership in ISECG as an opportunity to expand their perspective and work with international entities towards mutual goals for exploration. For more information NOSA, visit https://www.romsenter.no/.

POLISH SPACE AGENCY (NOV. 2018)

The Polish Space Agency (POLSA) was founded in 2014 and joined the ISECG in 2018. POLSA is deeply committed to the ISECG's principles and primary objective of shared cooperative international space exploration. Poland has a rich history of space discovery and exploration that has benefitted humankind for centuries. POLSA's priorities include:

- National space sector enhancement
- Robotic, sensor and lander mission
- Advancing the use of space technology for everyday life

For more information about POLSA, visit https://polsa.gov.pl/.

PORTUGAL SPACE (DEC. 2020)

The Portuguese Space Agency, Portugal Space, is an organization created in 2019 by the Portuguese government to implement the National Space Strategy. The Agency's primary purpose is to promote and strengthen the Space ecosystem and value chain, for the benefit of society and economy in the Portugal and worldwide.

Portugal Space coordinates the Portuguese participation in several international organisations such the European Space Agency (ESA) and advises the Portuguese government on the contributions and subscriptions made to ESA. Portugal Space also coordinates the Portuguese participation in the European Southern Observatory (ESO), in the European Solar Telescope (EST) and in the recent SKAO (Square Kilometer Array Organization) as a founding member. Portugal Space is also the national representative for Portugal to the European Commission for matters related to Space, namely the European Union Space Program and Horizon Europe.

Concerning space exploration activities, Portuguese entities participate in ESA missions such as ExoMars and Mars Sample Return, the International Habitation Module (I-HAB) part of the Lunar Gateway, the future European Large Logistic Lander (EL3), the planetary defense mission HERA, in the Columbus module at the ISS amongst others. Furthermore, Portugal is participating in the development, utilization and landing of Space Rider, the future European orbital and reentry platform to perform microgravity research in space. Moreover, in the research field Portugal is in the process of commissioning ESTHER, the European Shock-Tube for High Enthalpy Research, a world-class facility to study reentry plasma physics. Finally, Portugal is also home to space analogue sites, such as some caves in Selvagens Islands, which have been used to perform microbial life research.

For more information about Portugal Space, visit https://ptspace.pt/.

ROMANIAN SPACE AGENCY (MAR. 2019)

Created in 1995, the Romanian Space Agency (ROSA) was born out of the Romanian Commission for Space Activities (CRAS), which was established in 1968. ROSA is a self-funded public institution and is coordinated by the Ministry of Education and Research—National Authority for Scientific Research and Innovation. ROSA acts as the financing agency for the national research programmes on Space, Aeronautics and Security; chairs the inter-agency Security Research working group; serves as the national coordinator for the Space Situational Awareness (SSA) Programme; and is the Competent Authority for the Galileo Public Regulated Service (PRS). ROSA is also the Romania representative in all international space organisations and coordinates all of the nation's space-related activities. Joining the ISECG provides ROSA a new framework and broader opportunities for cooperating and collaborating with space agencies worldwide. For more information about ROSA, visit http://www2.rosa.ro/index.php/en/.

SWISS SPACE OFFICE (MAR. 2019)

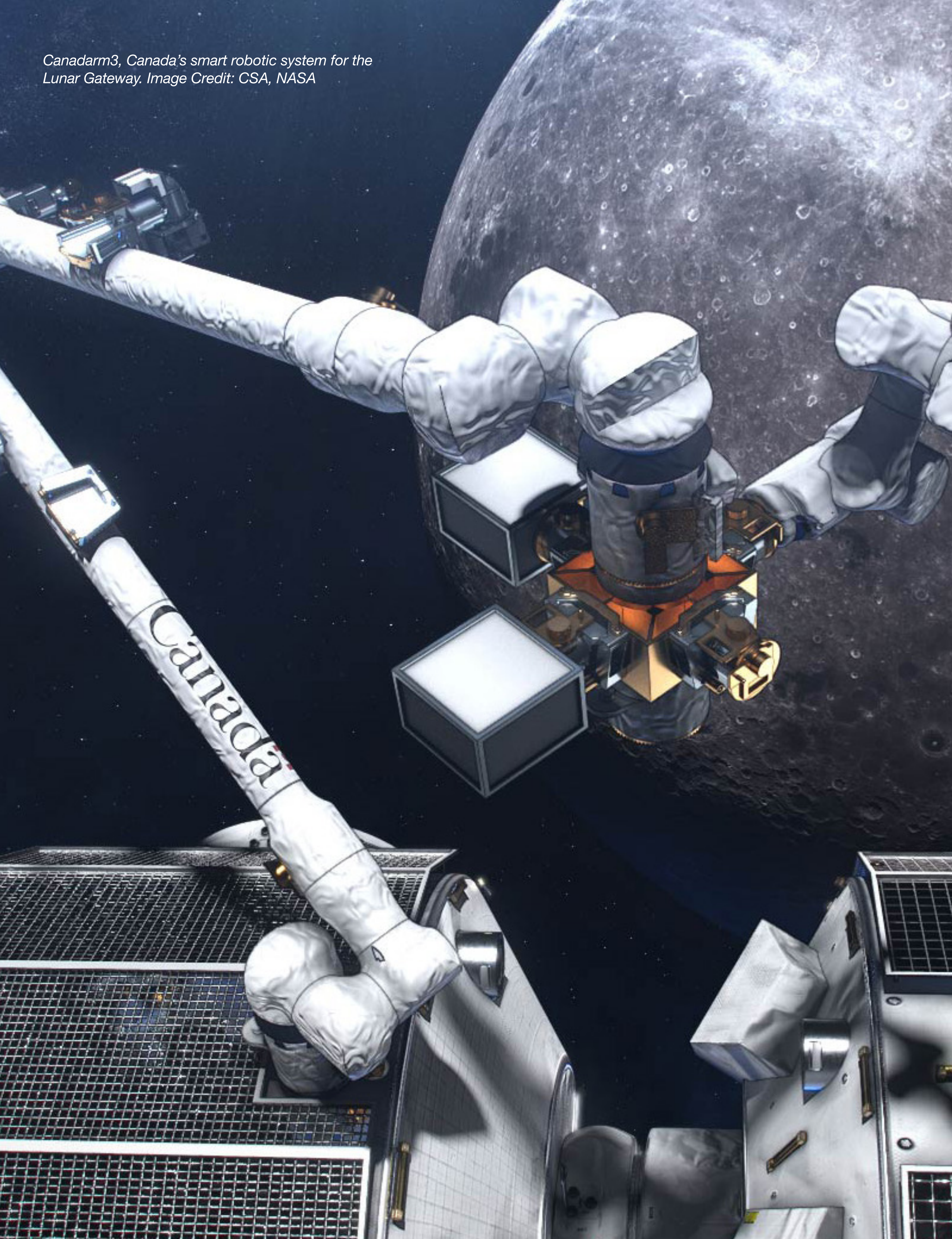
The Swiss Space Office is an integral part of the State Secretariat for Education, Research and Innovation (SERI) in the Federal Department of Economic Affairs, Education and Research (EAER). Its main responsibility is to prepare and implement the Swiss Space Policy, primarily through participation in ESA programmes.

The main focus of SSO in exploration is science, the development of space technologies and international collaboration. The development and utilisation of space infrastructures to the benefit of society are a key element of the Swiss Space Policy. Space exploration enables continuous improvement in understanding humanity's place in the universe. These endeavours simultaneously deliver tangible results in science and technology, which are directly applicable on Earth. For more information about SSO, visit https://www.sbfi.admin.ch/sbfi/en/ home/research-and-innovation/space.html.

VIETNAM NATIONAL SPACE CENTER (JAN. 2020)

Established in 2011, the Vietnam National Space Center (VNSC) is governed by the Vietnam Academy of Science and Technology (VAST), which administers and advances research and development and technology applications. VAST is working with VNSC to increase Vietnam's space science and technology capabilities with additional investments in national training and infrastructure. The VNSC is proud to be one of ISECG's newest agencies and is poised to cooperate, partner and contribute as needed in order to serve the common peaceful purpose of the ISECG.

VNSC's primary focus is to facilitate international cooperation and the agency has become an active member of several international organisations including the International Astronautical Federation (2012), Committee on Earth Observations (2013) and Group on Earth Observations (2014). VNSC also oversees the management and implementation of the Vietnam Space Center Project—one of Vietnam's largest science and technology investments. For more information about VNSC, visit https://vnsc.org.vn/en/.



Canadarm3, Canada's smart robotic system for the Lunar Gateway. Image Credit: CSA, NASA

CHAPTER TWO

MAJOR UPDATES IN LUNAR EXPLORATION PLANS

Over the past several years, ISECG agencies have made significant updates to explorations plans, with a special emphasis on lunar missions and polar volatiles. Most agencies have become increasingly interested and committed to exploring the Moon's polar regions and in implementing long-term sustainable exploration missions based on international cooperation and commercial participation. These exploration plans include strategies that follow the established spaceflight practice where robotic missions come first and are primarily driven by scientific and technology demonstration objectives. These are followed by more complex and capable robotics systems that become extensions of human explorers. As these human and robotic capabilities merge, they are incorporated into the overarching mission strategies, which will significantly enhance exploration capabilities.

CREWED LUNAR EXPLORATION AND SUPPORTING MISSIONS

The United States is undertaking a new lunar exploration programme—Artemis—that soon will enable human missions to the Moon and in a manner that is sustainable long-term and tests the systems and operations necessary to prepare for future human Mars missions. The National Aeronautics and Space Administration's (NASA's) Artemis missions have a goal of enabling human missions to the lunar surface as early as 2025 and target sustainable lunar exploration near the end of the decade. The first Artemis mission will launch in 2022 (uncrewed full system test), followed by Artemis II in 2024 (crewed mission in cislunar space) and will culminate with Artemis III as early as 2025 with a crewed mission to the lunar surface.

Following Artemis III, crewed missions with two crewmembers will fly to the lunar surface annually and then increase to four crewmember missions before the end of the decade. The Artemis missions are enabled by international cooperation with the European Space Agency (ESA), which is providing the European Service Module (ESM) that powers the Orion spacecraft. ESM1 has been integrated with the Orion capsule for the Artemis I mission, ESM2 has been delivered for Artemis II, and the developments of ESM3 through ESM6 have started. ESA and NASA expect to soon reach agreement on ESA's provision of ESMs 7 through 9, contingent upon approval by ESA ministers.

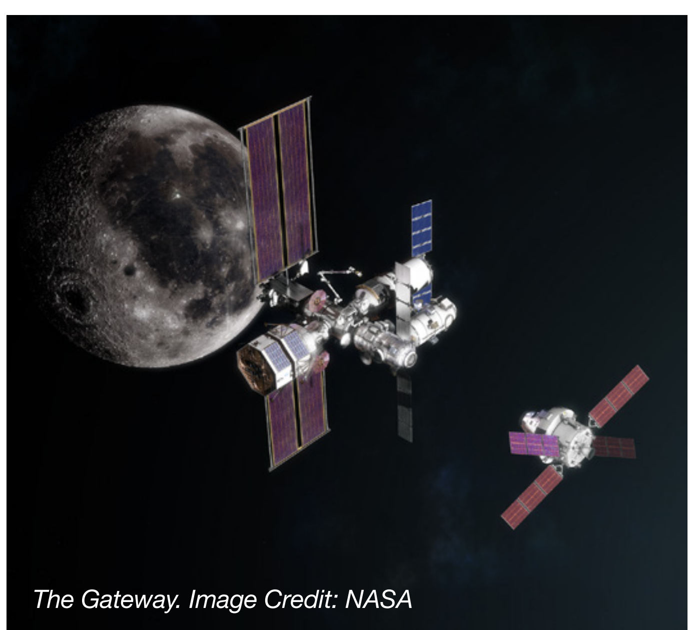
The Gateway is a vital element of international deep space exploration plans. With key investments from NASA, ESA, the Canadian Space Agency (CSA), and the Japan Aerospace Exploration Agency (JAXA), the Gateway will provide a next-generation deep space platform from which to conduct not only operations but also science investigations outside the protection of the Earth's Van Allen radiation belts. The international science community has identified heliophysics, radiation, and space weather as high-priority investigations to conduct on the Gateway.

Since the GER's release in 2018, the concept of the cislunar Gateway has matured to include a high output solar electric power and propulsion element (PPE) and a pressurised Habitation and Logistics Outpost (HALO) that will be integrated for launch as early as 2024.

In addition to contributing to Gateway transportation with ESMs, ESA is developing an enhanced communication string to supplement the Gateway's lunar communication system (ESPRIT HALO-Lunar Communication System), the International Habitation Module (I-HAB), which will increase the Gateway's habitation capability and the number of docking ports, and a refueling system and viewing capability (ESPRIT European Refueling Module) to contribute to the sustainability of the Gateway.

In early 2019, Canada announced its plan to develop and contribute an advanced, next-generation, artificial intelligence-enabled robotic system for Gateway. The smart robotic system will perform critical operations and support the deployment of science and technology experiments at Gateway. The Canadian Space Agency (CSA) has also initiated preparatory activities associated with Gateway science and technology utilisation and, more recently, commenced the Lunar Surface Exploration Initiative (LSEI) that focuses on identifying major infrastructure investments Canada could make to support sustainable human presence on the lunar surface , and have Canadian astronauts engaged in the exploration of the Moon. LSEI contribution studies include capability areas of argriculture and food, rovers and robotics, nuclear power, communication and mining (remote sensing, surface prospecting and ISRU). Deep space healthcare technologies are also under study under a CSA initiative called Health Beyond.

In June 2020, Japan renewed the Basic Plan on Space Policy, which states that Japan will support the Artemis programme by contributing to the Gateway through habitation technologies and logistic capability, and aim to contribute to human lunar surface missions by providing transportation vehicles on the lunar surface, so that Japanese astronauts can actively participate in Artemis missions. The roadmap for the Basic Plan on Space Policy renewed again in December 2021 clarifies the start of a full-fledged study on the provision of a pressurised rover by the Japan Aerospace Exploration Agency (JAXA), which could provide an opportunity to leverage lunar surface activities to simulate and refine plans for the first human Mars surface mission.


The Gateway. Image Credit: NASA

In early 2021, the Japanese government initiated several technology development projects related to lunar exploration such as communication and navigation, construction, energy, food and robotics within the framework of the "Stardust Program" which is meant to accelerate research, development and utilisation of space technology. Out of these technologies identified as areas of development by the Stardust Program, JAXA is developing key technologies for lunar communication and navigation.

In June 2022 ESA released its new exploration roadmap called Terrae Novae 2030+ (Latin for new worlds) with a vision covering low-Earth orbit, the Moon and Mars. The roadmap prepares Europe to implement strategic autonomy in its lunar exploration activities, at the same time strengthening international partnership with the objective to have the first European on the Moon surface by 2030. In particular, the ESA focus is to contribute capabilities in support of Moon exploration initiatives, including:

1. Lunar transportation for science, logistics and infrastructure (European Large Logistics Lander (EL3)),
2. Communications and navigation (Lunar Pathfinder and Moonlight),
3. Lunar surface science and technology demonstration (including e.g. space resources and energy systems), and
4. Operations support for astronauts (such as medical systems).

The development of EL3, a European autonomous, multi-mission capability to deliver large (1.5-2 tonnes) science payloads, technology packages, infrastructure and cargo for robotic and human lunar surface activities, is the first step. The decision for its implementation is expected late 2022, for a launch of the first mission in 2030. In parallel, ESA has partnered with industry on a high-data-rate lunar communication commercial service starting with the Lunar Pathfinder mission. Lunar Pathfinder is a relay satellite planned to be operational in 2025, also including a navigation in orbit demonstration (IOD) payload. It should be followed by the development of a more capable high-performance lunar communication and navigation services constellation (Moonlight) that will support sustained robotic and human activities on the surface.

Within the next five-year Ukrainian Space Programme, which is under the consideration of the Ukrainian Parliament, the State Space Agency of Ukraine (SSAU) will provide contributions to the Artemis missions, as well as to the European Moon Village Association (MVA) initiative. SSAU is working on four major lunar activities:

1. Creating a power plant for the lunar base, which will be powered by solar energy. The technology for the power plant is based on innovative electrolysis technology and can be used to produce rocket fuel in the lunar base environment.
2. Developing a 6U CubeSat that will be in a selenocentric orbit and provide images of the Moon from several vantage points, allowing terrain imaging and measuring spectral changes on the lunar surface.
3. Manufacturing a solar-thermoelectric generator designed to produce renewable energy. The generator will retain its functionality in the absence of solar radiation due to absorbing heat from the lunar surface.
4. Developing a lunar lander-hopper, which will provide transportation to the lunar surface of scientific equipment with the capability to relocate to a new site or multi-site delivery of equipment.

ROBOTIC LUNAR EXPLORATION MISSIONS

Many individual robotic missions aim to understand the science and exploration value of the lunar poles. This portfolio of missions forms a de-facto international Polar Exploration Campaign beginning with regional surveys (i.e., ground truth for ice, resources and local chemistry at diverse locations), followed by site exploration and preparation of locations identified as high priority. This campaign will ultimately support international sustained lunar surface activity. Robotic lunar missions that have either flown or have been formally approved for further study and/or funded by space agencies through 2031 (since publication of the 2018 GER) are outlined in Table 2 of this updated Supplement. The growing list of institutional missions (complemented by private-sector initiatives that are not shown in Table 2) underscores that there remains continued scientific interest and highlights both the scale of this cooperative effort globally and the human-robotic partnership required for sustainable lunar surface exploration.

China National Space Administration (CNSA)

On December 17, 2020, the Chang'E-5 mission successfully returned 1731g of lunar samples, marking the successful implementation of "Orbiting, Landing and Return" three-step goals of China's lunar exploration. At present, the phase four of the China Lunar Exploration Program is being carried out, including Chang'E-4, Chang'E-6, Chang'E-7 and Chang'E-8 missions. The Chang'E-4 mission achieved the first soft landing on the far side of the Moon on January 3, 2019, and deployed the Yutu-2 rover. The Chang'E-6 mission is scheduled to launch around 2024, which aims to collect samples from the far side of the Moon. The Chang'E-7 mission, scheduled to launch around 2025, will focus on investigation of water distribution in the Moon's polar region. The Chang'E-8 mission is scheduled to launch around 2028, carrying out scientific exploration of the polar region and verifying key technologies for the construction of the lunar research station. In the future, it is planned to complete the construction of International Lunar Research Station (ILRS) around 2035, in order to carry out normalised scientific exploration, technological verification and utilisation of lunar resources.

Canadian Space Agency (CSA)

The CSA has the on-going Lunar Exploration Accelerator Program (LEAP), which supports lunar technology development, in-space demonstration, and science missions. LEAP, in conjunction with international partners, plans to send payloads to the lunar surface by 2026. These payloads will include a lunar rover and other science or technology demonstrations.

European Space Agency (ESA)

ESA is developing several surface science and technology demonstration payloads, including:

- The PROSPECT instrument package for volatiles investigations and a first ISRU experiment, including a cryogenic drill and a sample analysis system for ice and other polar volatile chemistry, to be flown with the NASA CLPS programme in the mid-decade.
- The Exosphere Mass Spectrometer (EMS)), derived from an instrument in the PROSPECTchemical laboratory, will fly on the NASA CLPS first Astrobotic Peregrine lander end

2022 to measure the lunar exosphere. It is also planned to fly the instrument on the ISRO/JAXA LUPEX mission.

- Autonomous technologies for precise navigation and hazard detection are needed for future planetary access, in particular for the European Large Logistics Lander. A qualified navigation camera will fly in the frame of the first ESA commercially procured lunar landing service. The data collected during flight will be used for ground validation.
- A laser retroreflector allowing ranging from the Earth to test relativity and measure the lunar interior is planned for delivery by Intuitive Machines through NASA's CLPS programme in 2024.
- The Negative Ions at the Lunar Surface (NILS) Payload on the Chinese Chang'E 6 mission will measure an important unknown spect of the environment at the lunar surface in 2024 (TBC).

Italian Space Agency (ASI)

ASI strongly supports Lunar exploration, in particular the crewed initiatives through ESA, with several national companies working on ESMs and the Gateway modules and having a deep interest in surface elements like ESA European Lunar Lander EL3. Key technologies like communication and navigation, as well as landing capability are promoted for development. Also, ASI is currently working in the design of a future Lunar Surface Multi-Purpose Habitation (MPH) Module(s) to support lunar surface exploration plans.

Concerning the robotic initiatives, on the occasion of the Artemis I mission Italy will launch and operate the ArgoMoon 6U cubesat, the first national spacecraft in Near Deep Space with the aim to collect unique pictures of the SLS ICPS stage and, furthermore, of the Moon surface.

In addition, the Lunar Global Navigation Satellite System Receiver Experiment (LuGRE) will be deployed and operated late 2023 on board of the Firefly Blue Ghost Mission 1 (BGM1), landing in Moon's Mare Crisium as part of the NASA CLPS program.

Among the ESA contributions, Italy is a key player in the PROSPECT instrument development, for the in-situ surface sample analyses.

At national level, ASI promotes Lunar Surface Science, ISRU as well as in the study and development of innovative surface architectures.

Indian Space Research Organisation (ISRO)

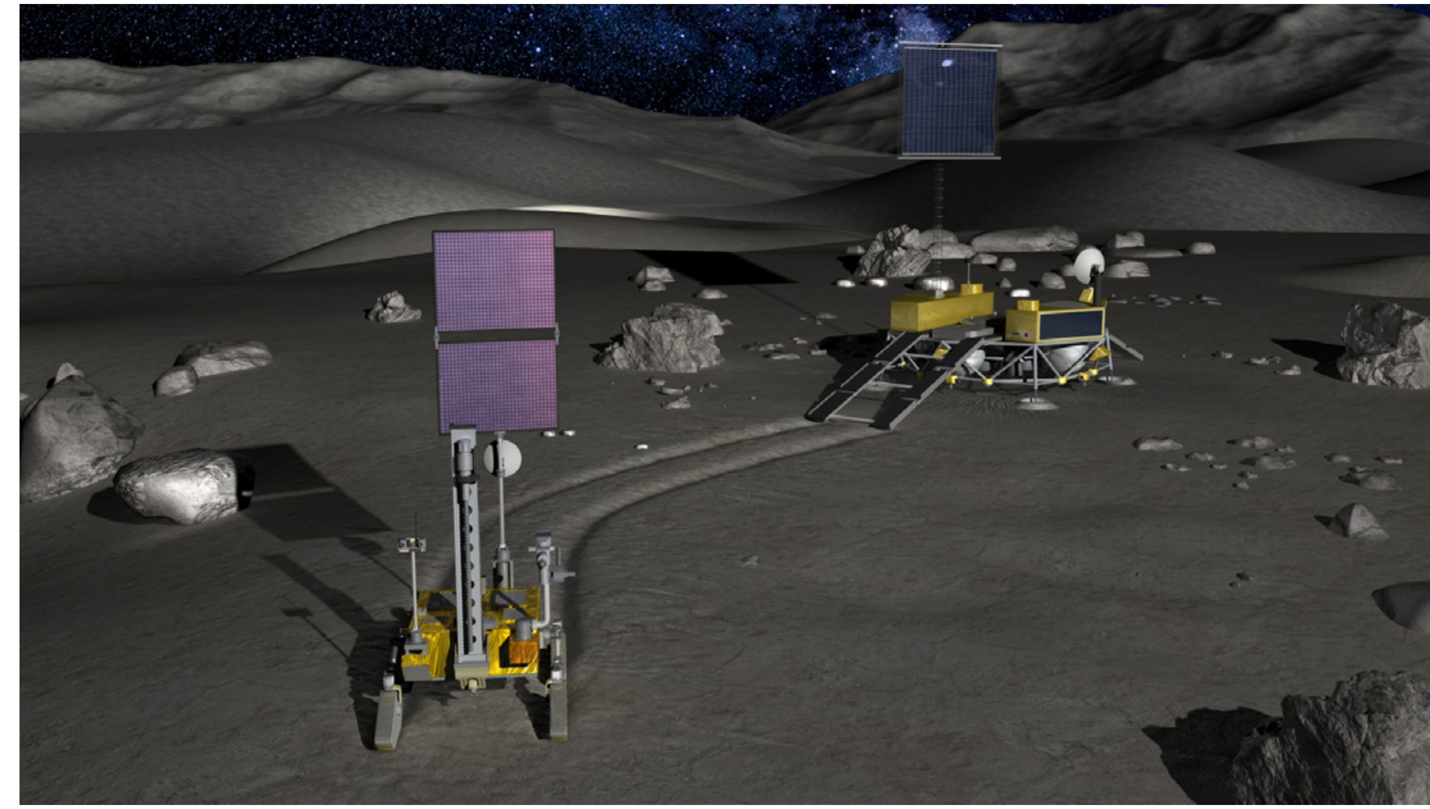
ISRO launched Chandrayaan-2 on 22 July 2019 with the goal of demonstrating an end-to-end lunar mission capability, including insertion of an orbiter in lunar orbit, and soft landing and roving on the lunar surface. The mission was originally designed to last one year. The orbiter, which was equipped with eight advanced payload instruments, was successfully inserted into a 100 km orbit. The orbiter experiments are continuing to perform very well and are expected to contribute much to lunar science at the end of the now-extended mission of nearly seven years. However, the mission was unable to soft land the lander and rover.

Chandrayaan-3 is a follow-on mission to the Moon for demonstrating landing and roving on the lunar surface and is expected to be launched in 2023. It consists of a lander and rover carrying payloads to study thermo-physical properties, plasma environment, seismicity and conduct in-situ elemental composition measurements in the vicinity of the landing site. The lander is expected to land in the 'unexplored' southern high latitudes on the Moon and the mission life is around 14 Earth days.

In addition, ISRO is now conducting a feasibility study for a joint lunar polar exploration mission with JAXA launching later this decade.

Japan Aerospace Exploration Agency (JAXA)

JAXA continues to focus on developing lunar surface capabilities using the Smart Lander for Investigating Moon (SLIM) mission. SLIM will demonstrate pinpoint landing technology and is planned for launch in 2022/2023. JAXA has formulated a formal project team for the Lunar Polar Exploration (LUPEX) mission in cooperation with ISRO, slated for launch in the 2024/2025 timeframe. The aim of this mission is to obtain knowledge of lunar water resources and to explore the suitability of the lunar polar region for the establishment of a lunar base. JAXA is working towards sending small missions to lunar orbit in the early 2020s in order to increase industry's capability

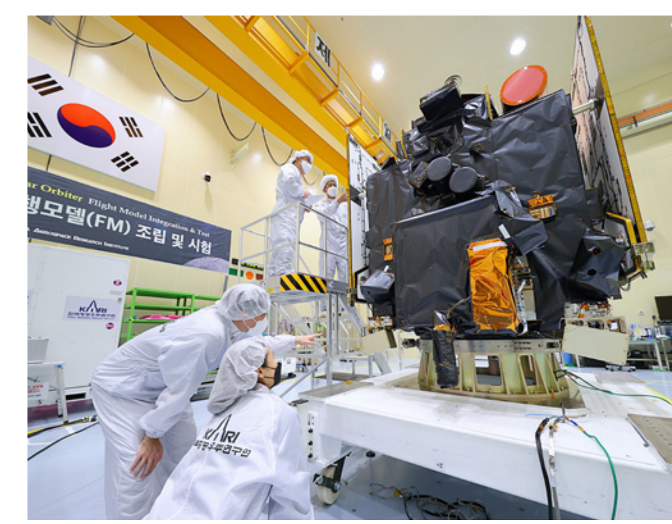


Lunar Polar Exploration (LUPEX). Image Credit: JAXA

and maintain the science community's interests. JAXA is also working to develop small-sized and medium-sized landers in the late 2020s and no earlier than 2030 respectively, for technology development and science missions, and also for providing logistics support for human lunar surface missions.

Korea Aerospace Research Institute (KARI)

KARI launched the Korea Pathfinder Lunar Orbiter (KPLO) – officially named 'Danuri' – in August 2022. KPLO will make South Korea's first step into lunar exploration. After reaching the Moon, KPLO will orbit the Moon at about 100km altitude for one year carrying an array of instruments, including one U.S.-built instrument called 'Shawdowcam', which will acquire high-resolution images of PSRs. KPLO's main objectives are to develop and validate critical technologies for lunar exploration, and to perform scientific investigations and topographic mapping of the Moon for a future landing mission. KARI's second lunar mission is a robotic lander and rover planned for launch in 2031. The lander will be developed to demonstrate the safe, precise, and soft landing capability, and to deploy a rover that will carry instruments to observe the lunar dust and the surrounding terrain. In addition, early-stage development and verification of other surface technologies (e.g. ISRU and RTG) will also be carried out. Prior to the landing mission, a lunar orbit insertion demonstrator will be launched by the inaugural flight of the next generation of the Korean Space Launch Vehicle (KSLV-III).



Danuri - Korea Pathfinder Lunar Orbiter (KPLO). Credit: KARI.

National Aeronautics and Space Administration (NASA)

In September 2022, NASA released its Moon to Mars Objectives as part of its effort is to develop and document an objectives-based approach to its human deep space exploration efforts. These objectives incorporate inputs gathered from U.S. industry and academia as well as international partner space agencies. The Commercial Lunar Payload Services (CLPS) project was developed by NASA to procure delivery of payloads to the lunar surface from commercial providers. There are currently 14 companies on the CLPS contract, all of whom can compete when NASA releases a request for a lunar surface delivery. Early commercial delivery manifests will conduct science experiments, test technologies, and demonstrate capabilities to help NASA explore the Moon and prepare for crewed missions. Typically, these CLPS deliveries have additional payloads from entities other than NASA, e.g., universities, companies, other US government agencies, and/or international space agencies.

As of Q2 2022, NASA has awarded seven contracts for surface deliveries to both polar and non-polar lunar locations beginning in 2022 (see Table 1). The expected cadence for deliveries is approximately two per year. NASA is utilising the CLPS capability for one of these deliveries to land the Volatiles Investigating Polar Exploration Rover (VIPER) on the lunar South Pole to investigate the location and concentration of water ice in the region and takes samples to inform future science and human missions to the South Pole. VIPER is scheduled to land in the South Pole region of the Moon in late 2023. NASA is also preparing to initiate acquisition of commercial lunar communication and navigation services in 2022.

NASA is making significant investments to mature technologies that support sustained science and exploration on the lunar surface across a range of Technology Readiness Levels (TRL), including CLPS payloads. These technology areas include advanced power; ISRU; materials, structures, excavation and construction; advanced thermal; dust mitigation; and autonomous systems and robotics. NASA also supports the Lunar Surface Innovation Consortium which fosters communication and collaboration among US industry, academia and government.

TABLE 1

NASA's contracts for surface deliveries to both polar and non-polar lunar locations beginning in 2022

YEAR	CLPS PROVIDER	MANIFEST	LOCATION
2022	TO2: Intuitive Machines	Science/ Technology	Oceanus Procellarum
2022	TO2: Astrobotic	Science/ Technology	Lacus Mortis
2023	19C: Masten	Science/ Technology	Haworth Crater/ S. Pole
2023	PRIME-1: Intuitive Machines	Science/ Technology	S. Pole
2023	20A: Astrobotic	VIPER	Nobile Crater/ S. Pole
2024	19D: Firefly Aerospace	Science/ Technology	Mare Crisium
2024	CP-11: Intuitive Machines	Science/ Technology	Reiner Gamma

Roscosmos

As of 2020, Roscosmos adjusted the timeline of its Luna series of missions to explore the lunar poles. These 2020 updates are as follows:

- Luna-25 Lander Mission (Luna-Glob-Lander) scheduled for launch in the early 2020s.
- Luna-26 Orbital Mission (Luna-Resurs-Orbiter) scheduled for launch in 2024. This mission will study the lunar surface from low polar orbit (approximately 50–100 km).
- Luna-27 Landing Mission (or Luna-Resurs-Lander) scheduled for launch in 2025.
- Luna 28 (Luna Resource 2 or Luna-Grunt Rover) scheduled for launch in 2027. This is a cryogenic polar volatiles sample return mission and is a follow-up mission for Luna 27 (also proposed by Roscosmos).

Russian manufacturers and research institutes are conducting Research and Development activities on advanced methods and system design to provide navigation and communication services for lunar exploration users.

TABLE 2

Robotic lunar missions performed since the 2018 GER and future plans by ISECG agencies

MISSION	AGENCY/LAUNCH DATE	DESCRIPTION/OBJECTIVES
Queqiao	CNSA 2018	Communication relay satellite.
Chang'E-4	CNSA 2018	Far side scientific lander and rover.
Chandrayaan-2	ISRO 2019	Polar scientific orbiter, lander, and rover.
Chang'E-5	CNSA 2020	Near side sample return.
Luna 25	Roscosmos TBD	Lunar volatile prospecting. Soft landing technology demonstration.
Artemis I	NASA/ESA 2022	Uncrewed Orion/ESM flight with science and technology payloads. Deployment of cubesats in lunar orbit.
KPLO (Danuri)	KARI 2022	Polar scientific and technology demonstration orbiter.
SLIM	JAXA 2022/2023	Pinpoint landing technology demonstration.
Chang'E-6	CNSA 2022-2024	Polar volatiles sample return.
Chandrayaan-3	ISRO 2023	Lunar polar lander and rover.
VIPER	NASA 2023	Lunar polar rover. Polar science and volatiles.
LUPEX	JAXA/ISRO 2024/2025	Polar lander and rover. Polar science and understanding the distribution and characterization of volatiles.
Luna 26	Roscosmos 2024	Polar scientific orbiter. Polar volatiles mapping.
Luna 27	Roscosmos 2025	Polar science, volatile prospecting and acquisition. Drill technology demonstration.
LEAP Lunar Rover Mission	CSA with NASA 2026	Polar rover incorporating Canadian and U.S. instruments via a CLPS lander.
Luna 28	Roscosmos 2027	Cryogenic polar volatiles sample return.
ISRU demo	ESA 2027	In-situ end-to-end extraction of oxygen from lunar regolith.
Chang'E-7	CNSA 2023-2030	Prototype of International Lunar Research Station (ILRS).
Chang'E-8	CNSA 2023-2030	Prototype of International Lunar Research Station (ILRS).
Small Lander	JAXA Late 2020s	Science and technology development.
EL3	ESA 2030	Multi-mission science and logistic capability.
Mid Lander	JAXA NET 2030	Transport logistics and/or science.
Lunar Lander Orbit Insertion Demo	KARI 2030	Launch vehicle capability demonstration.
Korea Lunar Lander	KARI 2031	Lunar lander and rover for scientific research and technology demonstration.

CHAPTER THREE

LUNAR SURFACE EXPLORATION OBJECTIVES

Based on the ISECG Goals and Objectives and Sustainability Principles, published in the 2018 GER, ISECG participating agencies developed a set of dedicated Lunar Surface Exploration Scenario Objectives (see Table 3). This set of objectives is based on the principle that human lunar surface exploration should focus on preparing for human Mars missions and for sustainable activities on the Moon leveraging ISRU.

The Lunar Surface Exploration Scenario Objectives in Table 3 are the drivers for the updated ISECG Lunar Exploration Scenario. For each lunar surface objective, there is a rationale that maps to one or more higher-level ISECG goal(s) and corresponding performance measure targets. These performance targets can be achieved in a single mission or over a series of missions. These target(s) provide a guidepost for long-term goals but are flexible and will evolve over time to support agency priorities. The objectives in Table 3 are prioritised according to how they are executed in the ISECG scenario. The final five objectives will be executed throughout the scenario. In addition, it is assumed each agency will set their own priority objectives for their own missions.

Several of the objectives necessitate a fixed location to support completion, such as long-duration habitation and ISRU, whereas other objectives require diverse locations on the Moon and long-range mobility. These competing objectives led ISECG members to adopt an approach where initial capabilities are continually leveraged while additional capabilities are added.

Concept design of a pressurised rover. Image Credit: JAXA/Toyota

NASA's Volatiles Investigating Polar Exploration Rover, or VIPER, undergoes mobility testing using simulated lunar regolith at the NASA Glenn Research Center. Image Credit: NASA

TABLE 3

Lunar Surface Exploration Scenario Objectives

Expand Human Presence into the Solar System | Understand Our Place in the Universe | Engage the Public | Stimulate Economic Prosperity | Foster International Cooperation

OBJECTIVE	RATIONALE	ISECG GOAL	PERFORMANCE MEASURE TARGET
Demonstrate human landing/ascent capability and establish regular access to and from the lunar surface.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on lunar surface, global lunar access is desired. Number of crew should be as many as possible considering the nature of international programme, but within the realistic constraints of crew transportation capability planned by governments and envisioned commercial missions.	Expand Human Presence; Stimulate Economic Prosperity; Foster International Cooperation	Establish a cadence of at least 3 4-crew missions in a 5-year period
Demonstrate a range of cargo delivery capabilities on the lunar surface for large surface elements and logistics.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on lunar surface, global lunar access and as much cargo capability as possible is desired. Cargo capacity performance measure range is driven by: 1) Mass of crew consumables necessary for 4 crew for 30 days will be around 2 tons; and 2) current human ascent module is estimated to be at least 9 ton.	Expand Human Presence; Stimulate Economic Prosperity; Foster International Cooperation	>9 t for large surface elements >1 t for logistics
Demonstrate Extra Vehicular Activity (EVA) capabilities on the lunar surface.	To mitigate the risk for future human Mars missions and sustainable lunar exploration and for commercial activities on the lunar surface.	Expand Human Presence; Stimulate Economic Prosperity; Foster International Cooperation	Reusable EVA systems with minimal maintenance including on-site dust management/ mitigation and science sampling/curation techniques.
Demonstrate human long range traversing capability on the lunar surface.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on lunar surface. Mobility capability design life of 10,000 km is the total round trip distance to explore and traverse the five crew sites indicated in the 2018 GER. Traverses to anywhere on the lunar surface are dependent on lunar night survival (up to 14 days).	Expand Human Presence; Stimulate Economic Prosperity; Foster International Cooperation	10,000 km (cumulative)
Demonstrate reliability of human long duration habitation capability and operational procedures on the lunar surface.	To mitigate the risk for future human Mars exploration and for future government activities and commercial markets on lunar surface. Systems need to be capable of environmental extremes (e.g. temperature, radiation, pressure). Demonstration of human long duration habitation and reliability can be achieved over a series of crewed and uncrewed missions, yielding the confidence for long-duration missions on the Moon and Mars. Astronaut operations need to be implemented and checked in different operative scenarios.	Expand Human Presence; Stimulate Economic Prosperity; Foster International Cooperation	500 days (cumulative)
Demonstrate crew health and performance sustainability to live and work on the lunar surface for a sufficient duration to validate Mars surface missions.	To understand the human health effects of low gravity and deep space environment for long duration missions on the Moon and notional Mars crewed surface mission. A number of integrated missions of increasing durations are expected to address the ability to understand crew health and performance of long duration exposure in the deep space environment.	Expand Human Presence; Understand Our Place	Missions with 30-60 days of lunar surface time, increasing microgravity durations, and approximately 10 subjects for each mission duration: Research Missions with ≈ 90 days pre-surface microgravity; Risk Reduction Missions with ≈ 180 days pre-surface microgravity; and Mars Validation with 360 days pre-surface in microgravity and 270 days post-surface in microgravity.
Demonstrate in-situ resource production and utilisation capability sufficient for crew transportation between lunar surface and Gateway and lunar surface utilisation needs.	To expedite sustainability for future human Moon and Mars exploration and to identify future commercial markets on lunar surface.	Expand Human Presence; Stimulate Economic Prosperity; Foster International Cooperation	Produce 50 t propellant per year.
Conduct effective global human/robotic cooperative exploration to perform ground breaking science.	To accomplish lunar objectives specified in the ISECG Science White Paper, "Scientific Opportunities Enabled By Human Exploration Beyond Low-Earth Orbit" as well as lunar objectives identified by ISECG agencies.	Understand Our Place	Comprehensive evaluation needed to determine value of science.
Develop infrastructure (e.g. power and communication systems) with high availability necessary to achieve the objectives for sustained exploration and continuous human presence.	To demonstrate and establish infrastructure capabilities including a certain level of power and navigation and communication systems for achieving objectives such as long duration habitation, ISRU, diverse science and public engagement. Commercial activities rely on infrastructure to stimulate economic growth. Availability will be determined for each system, where availability is the probability that a system will be functional when required, including the necessary spares and associated crew time for maintenance to support those systems.	Stimulate Economic Prosperity	Power: 300 kW of power Generation, Communications: 1 Gbps for global lunar coverage with Earth-Moon data rates. Additional Systems TBD.
Engage the public in general and the youth in particular with human/robotic lunar surface exploration by bringing the action to large audiences, making full use of the state-of-the-art technology and through new ways of communication.	To inspire new generations, increase awareness of the relevance of space, recognise the importance of different perspectives and domains of knowledge present in different scientific endeavours. Also public participation is necessary in the long run to ensure sustainability of such plans (civic engagement/empowerment).	Engage the Public; Stimulate Economic Prosperity	On national level as feasible, measuring positive public attitude towards lunar surface exploration through surveys, website hits, social media impact, etc.
Implement new commercial arrangements that stimulate economic prosperity, foster commercial opportunities, and increase resiliency with dissimilar redundancy.	To achieve commercially-led sustainable (i.e. market-driven economy with diminishing reliance on governments) economic activities on the Moon, new commercial arrangements are essential. ISS and other exploration endeavours have demonstrated an increased economic robustness with dissimilar redundancy.	Expand Human Presence; Stimulate Economic Prosperity	Increasing number of commercial partners or stakeholders providing lunar services year-after-year.
Provide a large number of collaboration opportunities for international partners to contribute to the lunar surface scenario.	To encourage global participation in the lunar surface scenario, inclusive of a range of contributions from science to hardware.	Foster International Cooperation	More than 100 nations' participation to lunar surface scenario.

**Performance measure targets reflect long-term objectives and can be achieved in a single mission or over a series of missions across several decades.*

CHAPTER FOUR

LUNAR SURFACE EXPLORATION OPERATION CONCEPT

Since the publication of the lunar surface exploration scenario in the 2020 GER supplement, ISECG's lunar surface exploration operation concept has been further studied and documented. The objectives of this exercise were to identify necessary elements and additional elements if needed to realise the operation scenario in the GER and also to derive the functional allocation to each element by going through the operational steps of the operation concept. Additionally, by investigating major operational contingency cases, several additional functions were found for further consideration (e.g. unpressurised rover roles during pressurized rover exploration).

The updated Lunar Surface Exploration Scenario describes a phased approach to implementing infrastructure and exploration on the lunar surface to meet the goals and objectives defined by ISECG. The updated scenario starts with Phase 1, Boots on the Moon, where space agencies focus on sending humans to the Moon along with robotic exploration missions to support this goal and the later phases. Phase 2 follows, Lunar Exploration—Expanding and Building, emphasises the completion of the proposed lunar surface objectives by diversly exploring the lunar surface diversely and ultimately identifying the most beneficial site for longer durations. The initial focus is on achieving lunar surface exploration objectives pertaining to human landing and ascent, logistic cargo landers, and long-range traverses. The later focus is toward lunar surface exploration objectives pertaining to long duration habitation, crew health and performance, and in-situ resource utilisation (ISRU). Phase 3, Sustained Lunar Opportunities, envisages laying the foundation for a sustained and vibrant lunar presence in the coming decades through partnerships with international governments, academia and industry. During this phase, governments would shift their investment focus to further expand the exploration frontier, including Mars exploration missions.

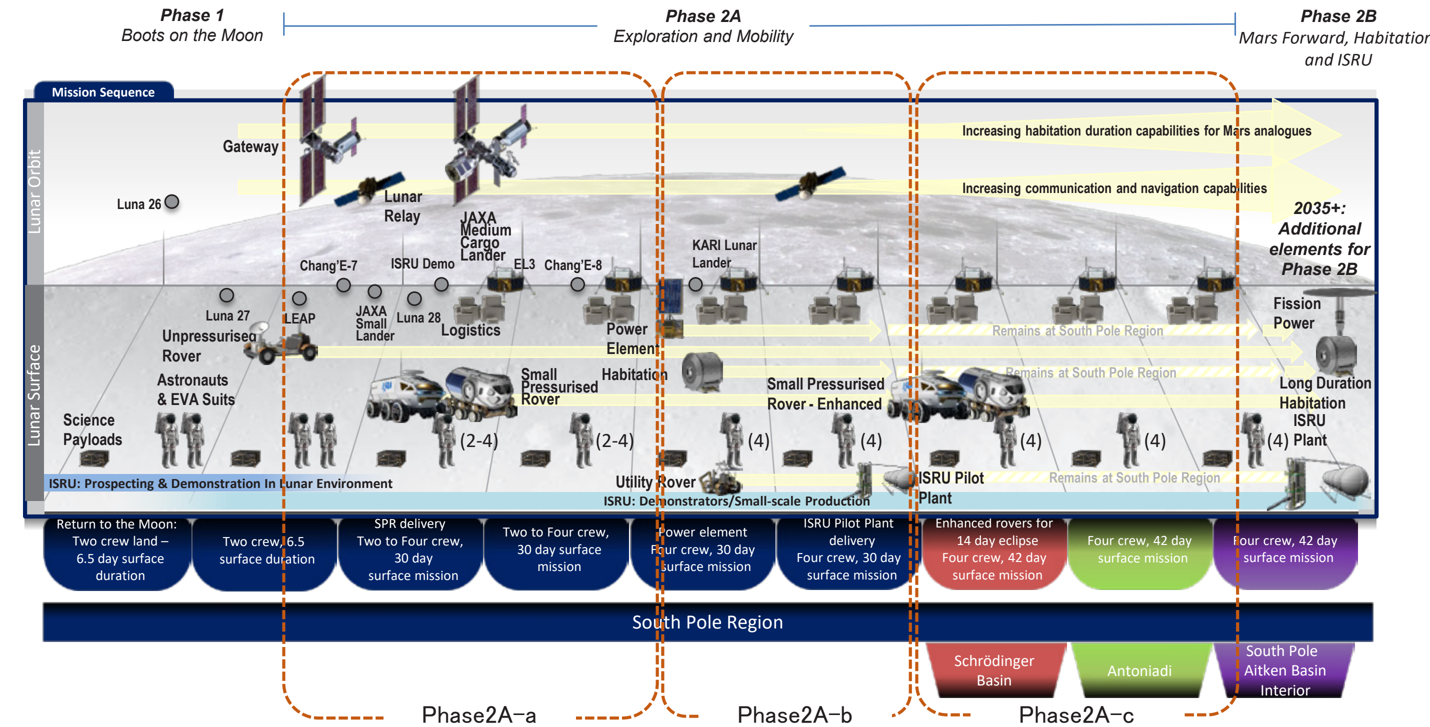
Because scenarios for Phase 2B and Phase 3 are not yet well defined in the GER and given that the human return to the Moon (Phase 1) is being led by NASA, ISECG focused the studies of the operation concept on Phase 2A. The Phase 2A is further divided into sub-phases such as phase 2A-a to 2A-d as below and as shown in the figure on page 25 to facilitate the operation concept study.

- Mission 2A-a: One Pressurised Rover (PR) at the South Pole
- Mission 2A-b: One PR & Fixed Surface Habitat (FSH) at the South Pole
- Mission 2A-c: Two PRs at the South Pole for the first mission and off the pole for the following missions
- Mission 2A-d: Uncrewed Mission (not shown in the chart)

The current operational concept is reliant on several choices available in the operational approach. Since the surface architecture elements are in an early phase of definition, many of these choices are driven by uncertainties in the element design. Major trade themes, options, current approach assumptions, and the pros and cons associated with each option were examined and identified for further discussion. Trade themes and selected approaches are summarized in Table 4.

To illustrate a typical operation concept in Phase 2, additional details in the operation concepts for the Phase 2A-b are described below:

During the Phase 2A-b, one PR with one Lunar Terrain Vehicle (LTV) and FSH are present for the lunar surface exploration. The LTV will be used for contingency return if the PR has failed or is immobile. Two of the crew will stay in the PR and the other two crewmembers will stay in the FSH. In the middle of the mission duration, the crew will switch the habitation locations. The HLS will not be used for primary habitation while the crew are on the surface.



Mission Phases Summary

TABLE 4

Operational Trades for ISECG Concept Scenarios

TRADE THEME	SELECTED APPROACH
Level of cooperation between the human exploration architecture and robotic precursors	Coordination
EVA support mode of the crewed surface elements (HLS, PR, FSH)	HLS: Cabin Depress or Airlock FSH: Airlock PR: Ingress/Egress systems
Mode of unloading of the medium cargo lander	Mechanical Aid
Crew interaction with medium cargo lander	Crew Access to deck
Communication relay service coverage	All locations
Habitation function distribution	HLS: Only for transfer FSH: Yes PR: Yes
Dedicated Power Plant	Not required
Operational interface between ISRU Pilot Plant and Power plant	Only power plant to ISRU pilot plant
Envisioned EVA frequency	FSH: Few & Long PR: Many & Short

Artistic impression of the European Lunar Logistics Landers (EL3) integrated in a Artemis human surface exploration scenario. The EL3 lander has delivered a combination of cargo items, scientific payloads and small robotic assets (rovers). An Artemis crew is unloading the lander assisted by a robotic arm and preparing lunar surface exploration activities. Image credit: ESA

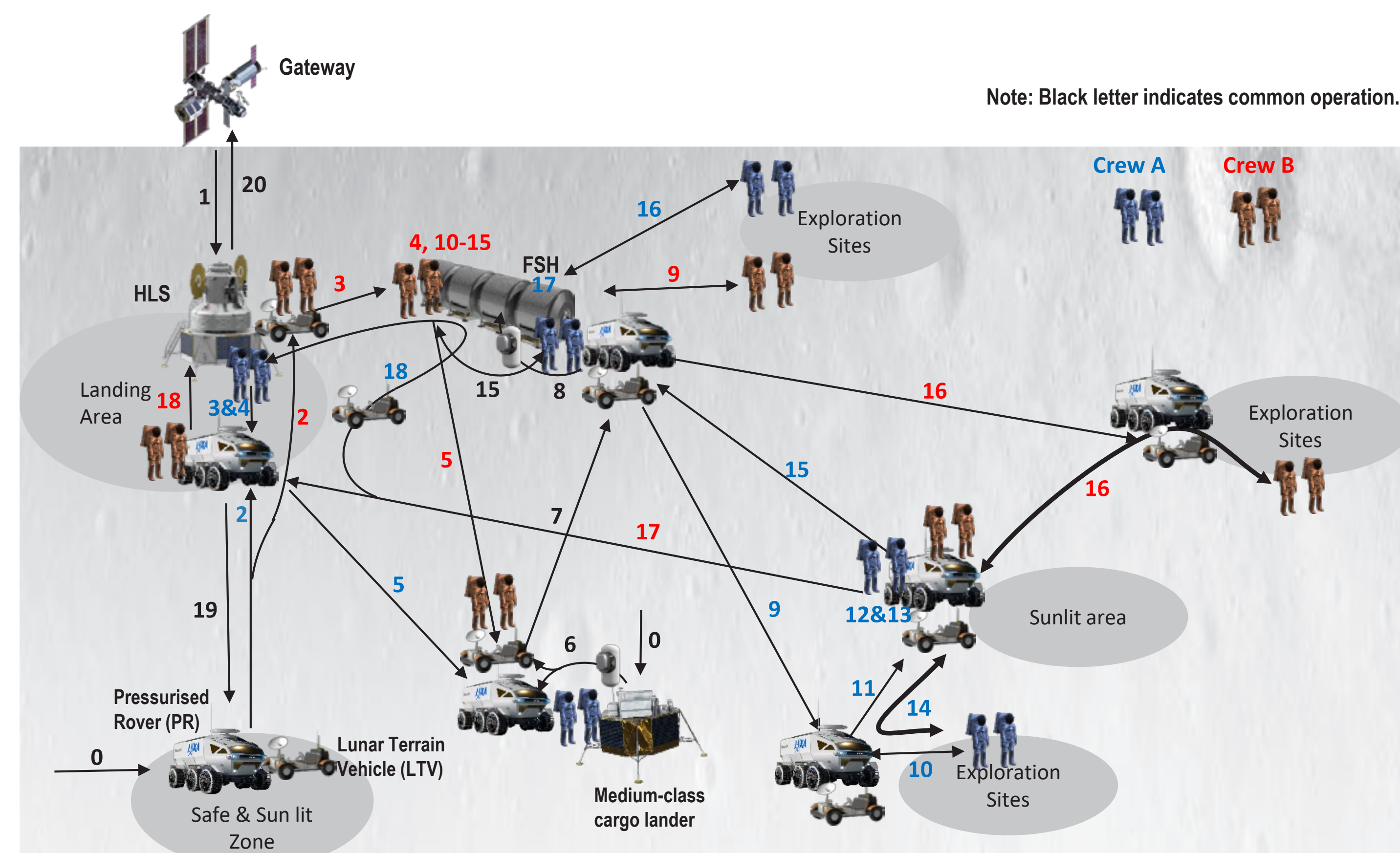
The crew will be launched on SLS/Orion from the Kennedy Space Center in Florida, USA. Upon the arrival to the Gateway, the crew will transfer to the HLS. After the completion of the checkout of the HLS, the HLS will depart the Gateway and descend to lunar surface. The operation concepts following the HLS landing are illustrated in the figure below with the itemized steps described in Table 5.

In addition, ISECG's international architecture working group identified numerous lunar surface contingency cases which drive architectural design, element functionality and operational implementation. Examples include loss of PR power or life support capabilities, crew incapacitation during EVA and mechanical failures in mobility systems leading to immobile rovers. Other considerations in addressing contingency cases include element capabilities for remote operations (i.e. local control by crew or off-surface control of surface assets). All of these considerations will undergo further analysis of element designs and concept development[1].

Finally, ISECG understands that a successful, long-term space exploration initiative on and around the Moon is heavily dependent on a lunar communications and navigation capability capable of providing orbiting and surface assets with a robust and reliable method of exchanging command and science data as well as providing position, navigation and timing (PNT) capabilities around the lunar surface. Fortunately, the Interagency Operations Advisory Group (IOAG) is studying an appropriate interoperable lunar communications and navigation architecture standards based on today's identified lunar PNT requirements as well as integrating anticipated future capabilities by telecommunications operators around the world. The IOAG has assembled a Lunar Communications and Navigation Working Group to address the diversity of planned lunar exploration

---

[1]More details of the contingency case study results can be found in the IAC paper, "IAC-21-A5-1-5 Lunar Surface Concept Of Operations for the Global Exploration Roadmap Lunar Surface Exploration Scenario."



Overview of Operation Concept of Phase 2A-b; see Table 5.

TABLE 5

Operation Steps and Description

SCENE	DAY	OPERATION DESCRIPTION	
0	-	Medium class cargo lander lands with logistic cargo. PR/LTV traverse to safe and sun lit zone near the HLS landing point and recharge batteries. (ground operation)	
1	-	HLS lands to the landing site. Crew acclimate to 1/6G for three days.	
2	1	PR/LTV approaches to HLS. (ground operation)	
3	1	Crew A with EVA suit egress the HLS and ingress PR	Crew B with EVA suit egress HLS, and drive on LTV to and ingress FSH.
4	1	Crew A recharge PR/LTV power system by their solar array.	Crew B check out the FSH.
5	2	Crew A drive the PR to Cargo Lander.	Crew B with EVA suit drive on LTV to Cargo Lander.
6	2	Crew A with EVA suit retrieve logistic cargo from the Cargo Lander into PR.	Crew B with EVA suit retrieve logistic cargo from the Cargo Lander onto LTV.
7	2	Crew A drive PR to FSH.	Crew B with EVA suit drive LTV to FSH.
8	2	Crew A transfer the logistics cargo into FSH.	Crew B transfer the logistics cargo into FSH.
9	3	Crew A drive the PR(LTV operated from ground) to exploration area#1.	Crew B with EVA suit explore the site by walk around FSH
10	3	Crew A with EVA suit egress, explore area#1, and ingress PR.	Crew B with EVA suit explore the site by walk around FSH
11	3	Crew A drive PR (LTV operated from ground)to sun lit area.	Crew B with EVA suit explore the site by walk around FSH
12	3	Crew A recharge PR/LTV power system by their solar array.	Crew B ingress into FSH.
13	4	Crew A conduct science investigation, public engagement and exercise in PR.	Crew B conduct science investigation, public engagement and exercise in FSH.
14	5-14	Repeat operations 9 to 13 at different exploration area, having rest days.	Repeat operations 9 to 13 having rest days.
15	15-16	Joint Handover between Crew A and Crew B.	
16	17-30	Crew A perform operation 9 to 13 repeatedly at FSH.	Crew B perform operation 9 to 13 repeatedly on PR.
17	31	Crew A prepare for departure including trash packing into PLC and disposal.	Crew B drive PR to near the HLS and prepare for departure including trash packing into PLC and disposal.
18	32	Crew A with EVA suit egress FSH, drive on LTV, and ingress HLS.	Crew B with EVA suit egress PR and ingress HLS.
19	32	PR/LTV drive back to safe zone. (ground operation)	
20	32	HLS ascends and docks to the Gateway.	
21	-	PR/LTV explore other sites.	

Additional Figures reflecting further details in the concepts for Phases 1, 2A, 2B and the 2B end state, along with expectations for achieving objectives across the Phases, can be found in the supplement Appendix.

missions needs. The goal is to ensure an interoperable capability as well as cross–support from the 12 international members and observers of the IOAG[2].

As lunar communication and navigation standards mature and become accepted and as plans for launching these capabilities across the international space exploration agencies and commercial entities advance, future ISECG exploration concepts will incorporate communications and PNT information to further enhance opportunities for partnerships and cooperative endeavors.

[2]Additional information on the IOAG and the current state of LCNWG efforts can be found at www.ioag.org.

CHAPTER FIVE

INCREASING INDUSTRY CAPABILITIES

Over the past decade, ambitions and capabilities to explore space and transport humans, robots and cargo to low-Earth orbit and beyond, and providing communication and navigation capabilities for the Moon, Mars and beyond have increased significantly. In the past, these capabilities were only achievable through the resources and support of governments. Now missions are rapidly transitioning from being the exclusive purview of large agency development programmes to include more non-government actors using a services-based model or having entire missions executed by private companies around the world. While governments will continue to invest in key space technologies, projects and missions to explore Low Earth Orbit and beyond, ISECG agencies expect to leverage emerging capabilities for use in planning future spaceflight science and exploration activities. Leveraging these new capabilities will lower overall costs, share risks, foster innovation and benefit their countries by providing them access to new economies and technologies.

Some space agencies have responded to these increasingly successful private-sector capabilities with novel spaceflight acquisition approaches that both achieve the agency goals and provide private companies with opportunities to reduce risk while refining their economic operations systems and broadening their customer range. ISECG agencies welcome and support these new partnerships for both the benefits provided to the domestic economies as well as their contributions to achieving international space exploration goals. To this purpose, a new working group was recently created with a focus on commercialisation experiences within ISECG community.

CSA's Juno rover operating at night and simulating soil sampling in lunar permanently shadowed regions. Image Credit: CSA

CHAPTER SIX

SCIENTIFIC PRIORITIES ENABLED BY EXPLORATION INITIATIVES

WHY WE EXPLORE (FROM A SCIENCE PERSPECTIVE)

Robotic and human crewed missions have opened new horizons and advanced our understanding of who we are, where we come from, and where we are going. From examining planetary origins and processes to searching for signs of life, we continue to unravel the fundamental mysteries that surround us.

Scientific investigations characterising the space environment and discovering how the physical and life sciences react in that environment are crucial to establishing a sustained human presence on other planetary bodies and in deep space. These investigations stem from major scientific questions such as: What new materials and technologies will we need for us to go where we've never gone? What local resources can we identify and utilise? What can we learn once we get there? And perhaps most importantly, how can these adventures help us advance our greater well-being as a species back here on Earth? Ultimately, learning about our planetary neighbours allows us to learn more about our own home; by exploring other planets, we are really exploring the Earth.

HOW DOES LUNAR EXPLORATION HELP OUR UNDERSTANDING OF THE EARTH, MOON, SOLAR SYSTEM, AND UNIVERSE?

Past exploration of the Moon by robotic and human missions has revealed that the lunar surface is ancient, due to a lack of tectonic activity and aeolian/fluvial processes that occur on Earth erasing the history of the earliest epoch after its formation. In that sense, the Moon serves as an unaltered record of the history of Earth and, by extension, the entire solar system. The lunar terrains are geologically and geochemically very diverse, mainly due to intense impact gardening throughout its existence. Remote sensing of the lunar surface indicates that previously unsampled unique rock types exist only on the Moon, and a dedicated global sampling campaign would expand our understanding of the volcanic, magmatic and thermal history of the Moon and other differentiated planetary bodies. It is, therefore, of great scientific value to visit and characterize not only areas on the equatorial near side of the Moon, as sampled during the Apollo and Luna era, but also on the far side and at the polar regions.

One of the most important investigations is the determination of the absolute ages of lunar samples retrieved from the different regions of the Moon. Returning and ageing such samples from a broader range of global sites will also contribute to a better understanding of the ages of areas on other solar system bodies. Similarly, the detailed in-situ analysis of structural and morphological properties over the entire range of crater sizes will better characterize the impact processes and their effects, allowing us to apply such constraints to other bodies of the solar system that are currently not accessible by robotic or human exploration missions.

The Moon's regolith could also harbour information of the materials that comprised the early Earth, in the form of comets and asteroids that impacted the Moon at the same time as the Earth, as well as meteorites that were transferred between the Earth and Moon during their earliest period of formation. Such meteorites could reveal information about the conditions on the early Earth at the time of the origin of life. In that sense, lunar exploration is additionally of astrobiological significance. Furthermore, palaeoregoliths (ancient regolith) have potentially preserved other records including solar activity, galactic cosmic ray flux etc. to expand our understanding of the Sun and solar system history during its evolution.

Volatiles, and particularly water, have been delivered to the lunar surface with cometary and asteroidal impactors, and these volatiles have likely become entrained within the extremely cold, Permanently Shadowed Regions (PSR) at the lunar poles.

The cresent Earth rises above the lunar horizon in this photograph taken from the Apollo 17 spacecraft in lunar orbit during NASA's final lunar landing mission in the Apollo program. Image Credit: NASA

Samples gathered from these regions would allow for compositional characterization of volatiles, resulting in provision of clues to the compositions of the earliest volatiles in the solar system and allowing for the assessment of their usefulness as resources for future human exploration missions, including permanent bases and mobile assets, as indicated in the GER.

BROAD SCIENCE GOALS FOR THE MOON

The science goals achievable on the Moon will not only yield new and valuable information about our closest celestial neighbor but it will also provide broader context to aid in defining goals for further exploration of our solar system with both robotic and human systems. Thus, while the following set

The CSIRO ISRU Facility provides dedicated enclosures and instrumentation for investigating properties of high-quality lunar simulant and exploring dust interaction. © CSIRO

of science goals are defined by the near-term global goals of lunar exploration, they are also extensible to nearly every other planetary body. There are five areas within the lunar community's science goals (Table 6).

SCIENCE ENABLING SUSTAINABILITY

To achieve the goals of sustainable exploration, fundamental knowledge of the Moon gained through dedicated science investigations will assist in decision making, planning, mass allocations, and surface operations.

Remote sensing, mapping, characterisation of lunar surface and subsurface composition, texture and geotechnical conditions across varied terrains and illumination settings including PSRs are critical areas of knowledge that will inform architecture design and will lead to utilization of various resource reservoirs. Surface and shallow sub-surface processes including regolith processing, electrostatic environment variation, and volatile (ice) accumulation and compaction will define the reservoir concentration and accessibility of resources. Passive seismic data collection, analysis and interpretation will determine the Moon's geological profile and structure in greater detail, enabling mineral targeting and hazard awareness and providing fundamental information on the Moon's interior. Crater slope rock-mass characterisation and seismic monitoring will better define the potential slope hazards in and around craters. Sample selection, capture, and return capability must be developed for detailed laboratory analyses. In situ excavation processes under low gravity are vital to performing collection as well as validating and improving modelling capabilities. Volatile extraction, mineral beneficiation and the reduction of minerals with thermochemical or electrochemical processes to extract gases (such as oxygen) and metals is required for a better understanding of the available resources and thus to enable a future extraction and use. Understanding regolith behaviour and its potential to become nuisance dust during human and robotic interaction is important for planning and hazard mitigation.

Iterative experiments for understanding and planning for human health and performance research equipment is needed. This will build upon understanding of exposure and measurement of biological sensitivity to the integrated lunar environment to define exposure limits and inform mitigation developments.

COOPERATIVE SCIENCE MISSIONS

Efforts within the international science communities to investigate opportunities for cooperative lunar science would aid and enhance the development of sustained collaborative and synergistic activities

Using advanced augmented reality technologies to provide real-time ConOps for ISRU mission simulation and demonstration – all in a safe and collaborative environment. © CSIRO

TABLE 6

Lunar Community Science Goals

AREA	DETAILS
1. Explore the origin and evolution of the solar system.	a. The Moon retains the bombardment history of the inner solar system and informs early solar system formation and dynamics. b. Volcanic processes over billions of years preserved on the Moon can inform planetary evolution and interior composition of a differentiated planetary body. c. The lunar poles host cold traps, or PSRs, that entrain lunar volatiles sourced from the lunar interior, implanted by the solar wind, or delivered to the surface via primitive material left over from the solar system's formation. d. Sample return may yield new insights into how the Moon and the Earth are chemically linked, helping to constrain Earth-Moon formation models and test formation hypotheses. e. Geophysical investigations of the deep and shallow structure and composition of the interior will lead to data and new theories on planetary formation, evolution and the current state of the Moon.
2. Define processes that shape planetary bodies.	a. Lunar crustal rocks and regolith are preserved and inform impact processes on both a macro and micro scale. b. Space weathering effects on airless, anhydrous bodies are investigated at the lunar surface due to the lack of atmosphere. c. Investigations into space plasma physics and electrodynamical interactions with regolith/dust.
3. Use the Moon as a platform for novel and unique measurements.	a. Unique solar observations and measurements can be acquired on and around the Moon, including solar coronal imaging, solar x-ray and gamma-ray spectroscopy, radio imaging of physical processes in the inner heliosphere, magnetospheric imaging, and in-situ plasma and solar wind measurements. b. Dark Ages observations and other cosmological studies of the early Universe are enabled by utilising the radio-quiet far side of the Moon. c. Observations of climate change and Earth as a life-bearing exoplanet are enabled from the lunar surface through full-disk Earth viewing.
4. Characterisation of the Moon's environment and resources to enable more efficient and sustainable exploration of our solar system.	a. Scientific knowledge of lunar resource reservoirs and their associated sinks/sources will allow for a more complete understanding of the Moon's evolution and environment as well as the quantity and accessibility of those resources for ISRU considerations. b. Additional resources available for sustainable exploration include illumination/lighting at the poles, lava tubes that may be a resource for habitation or protection, etc. c. Research into the physical and chemical processes underlying ISRU
5. Utilise the Moon as a testbed for life sciences investigations that enable human exploration.	a. Exposure and measurement of biological (varied complexity of non-metabolic and metabolic samples) sensitivity and responses to the integrated lunar surface environment, optimized by combination of in situ and return sample analyses. b. Optimisation of countermeasures against the debilitating effects of deep space and reduced gravity environments. c. The Moon retains the impact history of the Earth-Moon system as well as reservoirs of primordial organic material delivered by comets/asteroids that may inform important astrobiological questions such as: Where did the Earth get the building blocks of life? What was the role of impacts and mass extinctions in the evolution of life?

with agency plans, broader science communities and other interested parties and stakeholders.

Potential cooperative science activities could include:

- A distributed global geophysical (and geodesy) network (e.g., seismometers, heat flow probes, magnetometers, laser ranging retroreflectors)
- A global network of lunar weather and environment monitoring stations
- An astronomical lunar observatory on the lunar farside (e.g., radio interferometric array)
- Research station for in-situ biological and geological sample analyses and fundamental physics experiments
- Polar volatile prospecting and mapping campaign (e.g., extensive mobile exploration and characterization)
- Data transfer infrastructure

Such activities are optimised through human-robotic partnerships, with an integrated system of technologies and operational capabilities supporting crew scientific operations. Initial implementation could be through modular contributions from different agencies, which could be responsibly expanded upon over time for sustained research.

RESPONSIBLE EXPLORATION

Mission activities shall be carried out with extreme care to assure long term preservation and sustainability of the lunar environment (e.g. disturbance of the lunar exosphere, light pollution and interference of the radio-quiet farside, volatile contamination and other compositional/ bio-contamination) which can disrupt future science investigations. Thus, characterization, and ultimately protection, of these tenuous environments prior to irreversible modification attributed to exploration activities should be prioritised and factored as part of responsible exploration.

Planetary protection is interwoven throughout space mission research and development activities. The impacts and activities of space missions both on Earth and in space are the subject of community scrutiny. In response to crucial environmental and community concerns, science and technologies that will minimise environmental impacts prior to, during and post-space missions will help support a sustainable future for the industry and its scientific findings.

Mutual trust between community and space research and delivery industry partners will help space-based automation and remote operations that reduce physical environmental footprints, and could improve the same on Earth. Circular economy thinking and zero waste/waste avoidance through whole-of-mission and life-cycle analysis assessments will inform value chain integration, as well as low impact enrichment and excavation technologies.

Not only will exploration of our Moon enhance our understanding of the Universe and our place within it, but it provides a source of inspiration, outreach and education for the next generation of scientists, engineers, and explorers through the achievements and advances that can be made at our nearest celestial neighbour.

The science community looks forward to the resurgence of planned agency and commercial lunar missions and remains optimistic about the expanding research opportunities described here and the exciting discoveries that await future robotic and human explorers.

CSIRO ISRU team demonstrating its autonomous rover capabilities in a sealed lunar dust testbed environment with an intern student to inspire the next generation of space researchers. © CSIRO

APPENDIX

LIST OF ACRONYMS

AEB	Brazilian Space Agency
AEM	Mexican Space Agency
ASA	Australian Space Agency
ASI	Italian Space Agency
CLPS	Commercial Lunar Payload Services
CLTV	Cislunar Transfer Vehicle
CNES	National Centre for Space Studies
CNSA	China National Space Administration
CRAS	Commission for Space Activities
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DLR	German Aerospace Center
EAER	Federal Department of Economic Affairs, Education and Research
EL3	European Large Logistics Lander
ESA	European Space Agency
ESM	European Service Module
EU	European Union
EVA	Extra-Vehicular Activity
GER	Global Exploration Roadmap
GISTDA	Geo-Informatics and Space Technology Development Agency
GNSS	Global Navigation Satellite System
HALO	Habitation and Logistics Outpost
HTV-X	Next-Generation H-2 Transfer Vehicle
I-HAB	International Habitation Module
ILRS	International Lunar Research Station
ISRO	Indian Space Research Organisation
ISRU	In-Situ Resource Utilisation
ISECG	International Space Exploration Coordination Group
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
KPLO	Korea Pathfinder Lunar Orbiter
LCNS	Lunar Communication and Navigation Services
LEAP	Lunar Exploration Accelerator Program
LEO	Low-Earth Orbit
LSA	Luxembourg Space Agency
LUPEX	Lunar Polar Exploration
NASA	National Aeronautics and Space Administration
NOSA	Norwegian Space Agency
NRHO	Near Rectilinear Halo Orbit
NZSA	New Zealand Space Agency
POLSA	Polish Space Agency
PPE	Power and Propulsion Element
PRS	Public Regulated Service
PTS	Portugal Space
ROSA	Romanian Space Agency
Roscosmos	Roscosmos State Corporation for Space Activities
SERI	State Secretariat for Education, Research and Innovation
SLS	Space Launch System
SSA	Space Situational Awareness
SSAU	State Space Agency of Ukraine
SSO	Swiss Space Office
TRL	Technology Readiness Level
UAESA	United Arab Emirates Space Agency
UK Space Agency	United Kingdom Space Agency
VAST	Vietnam Academy of Science and Technology
VIPER	Volatiles Investigating Polar Exploration Rover
VNSC	Vietnam National Space Center

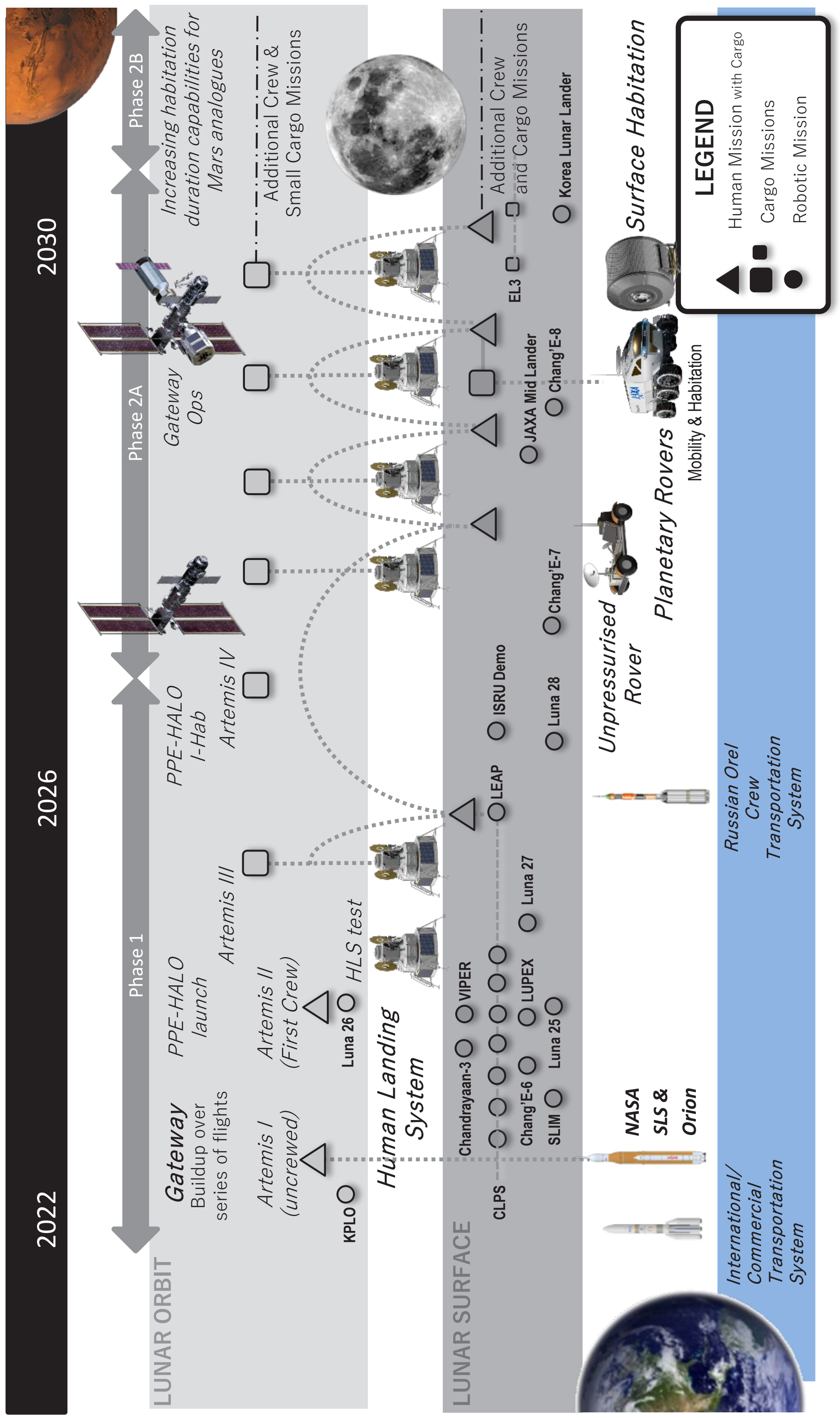


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

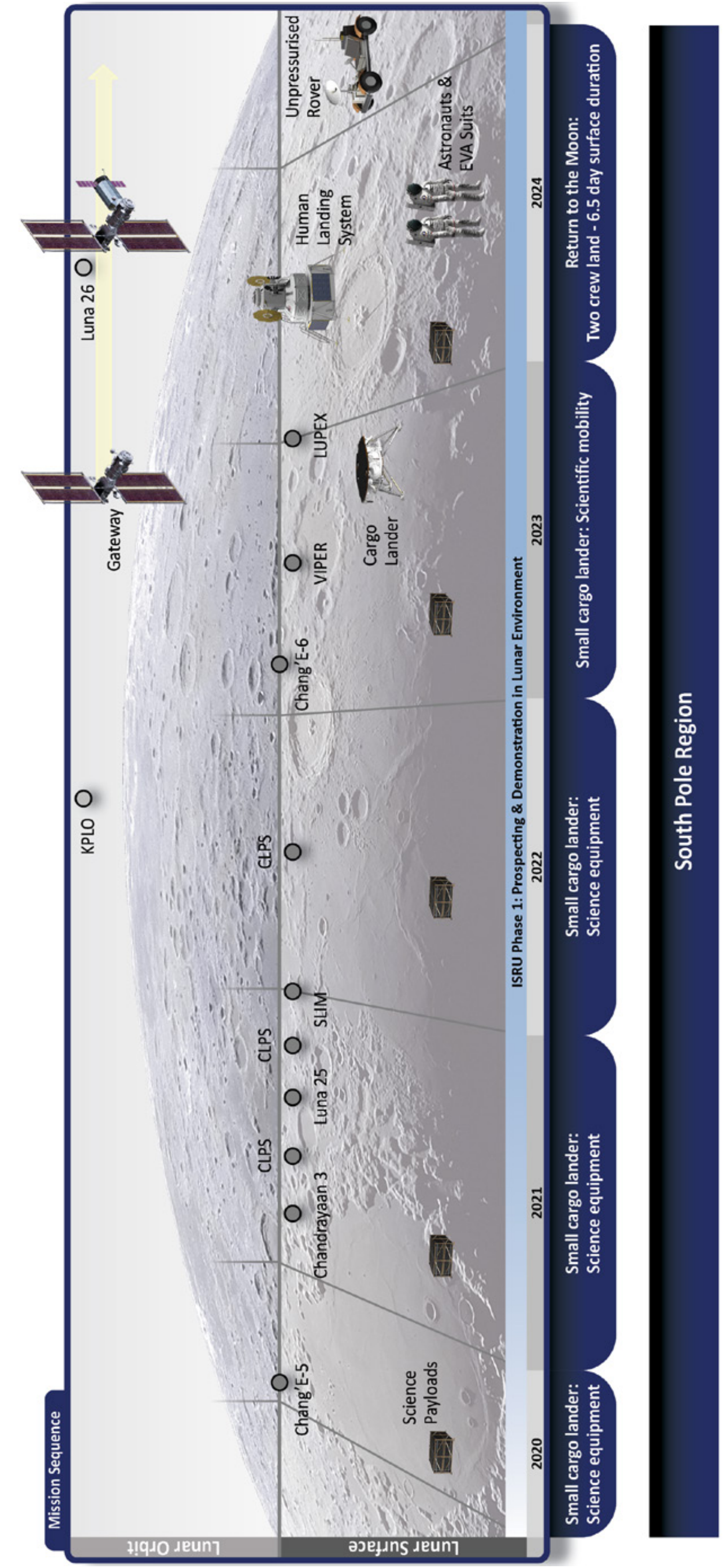


Figure 2. Phase 1: Boots on the Moon—South Pole.

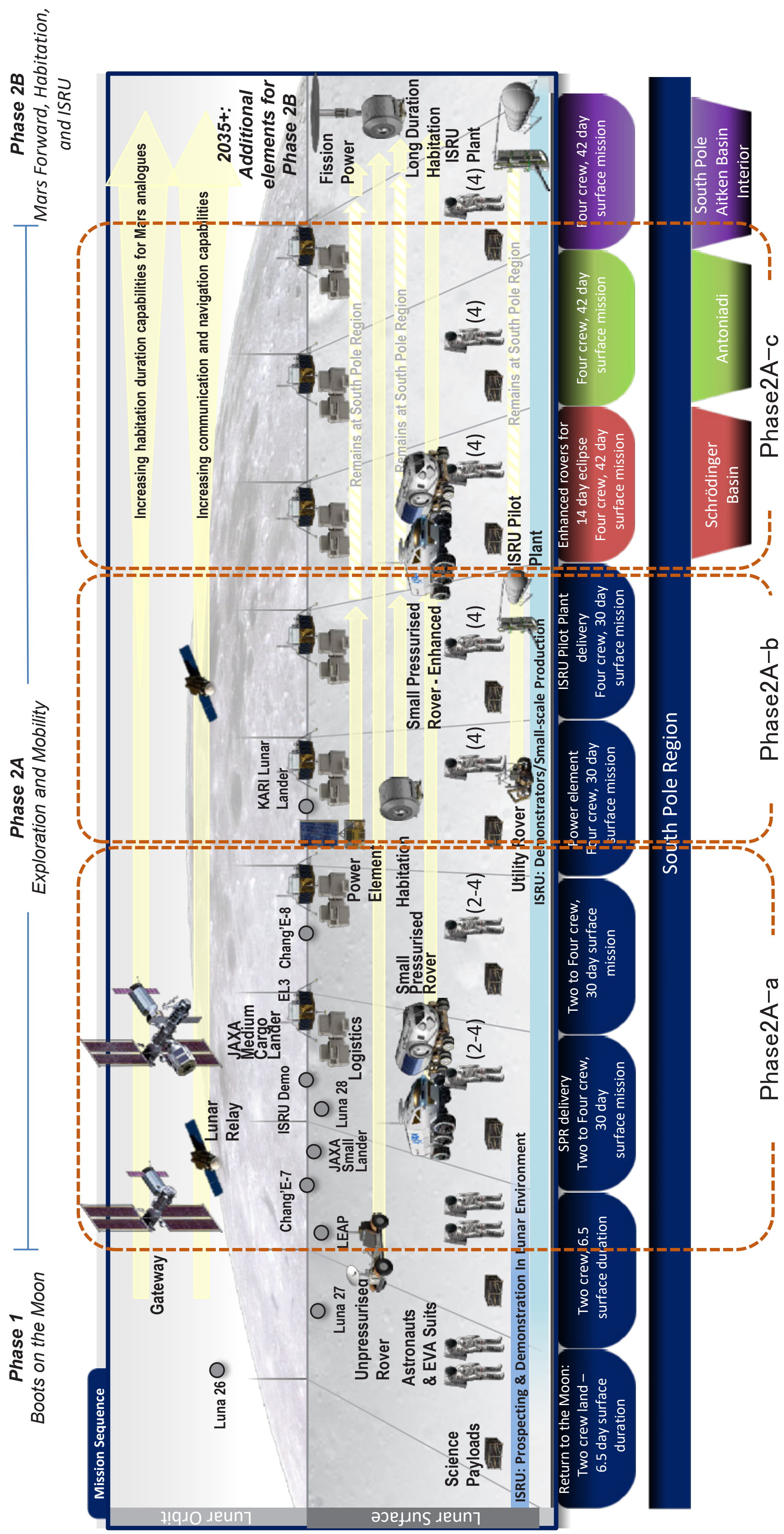


Figure 3. Phase 2A-2B: Lunar Exploration—Expanding and Building.

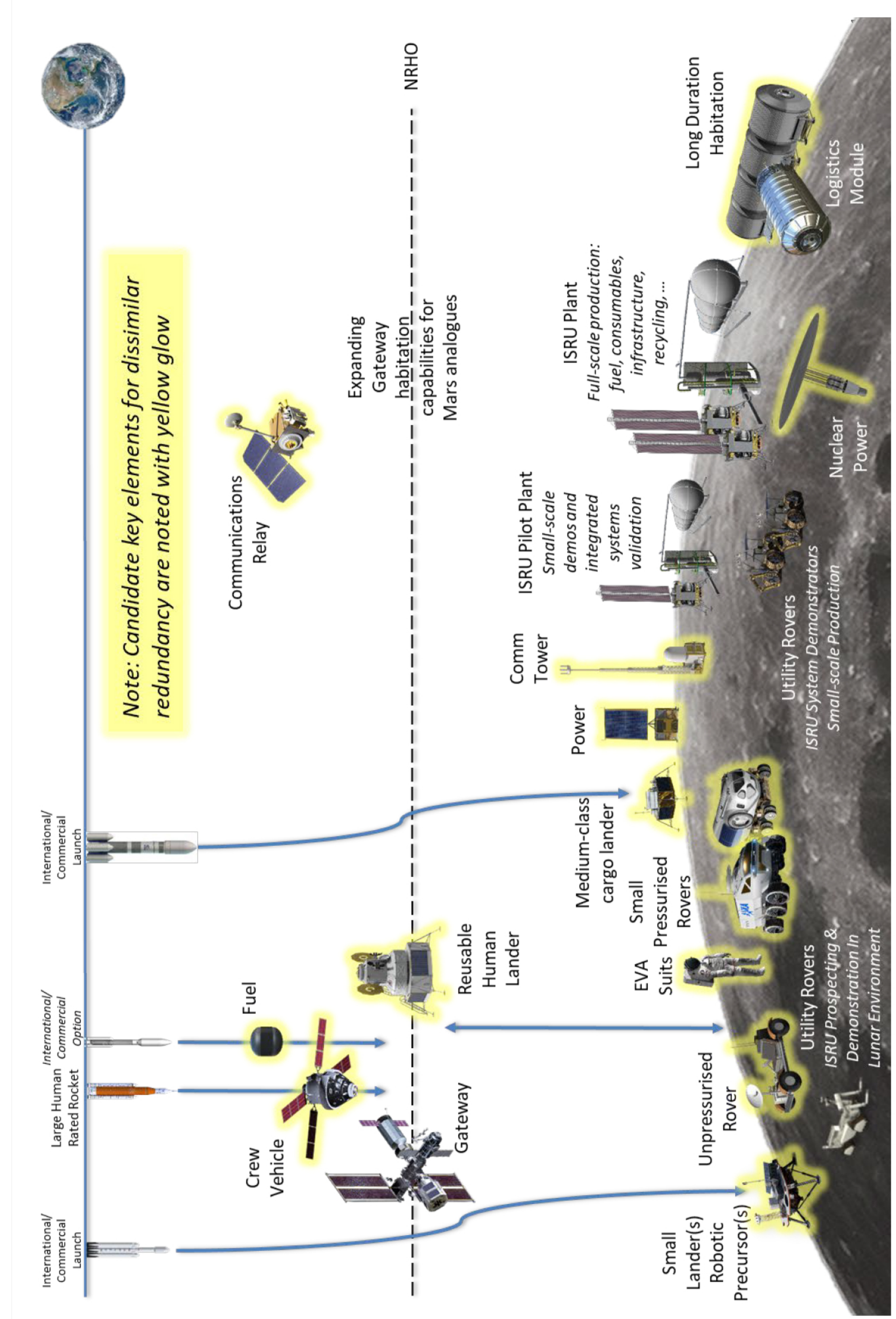


Figure 4. Expanding and Building—Longer Duration and Increased Utilisation (Phase 2B End State).

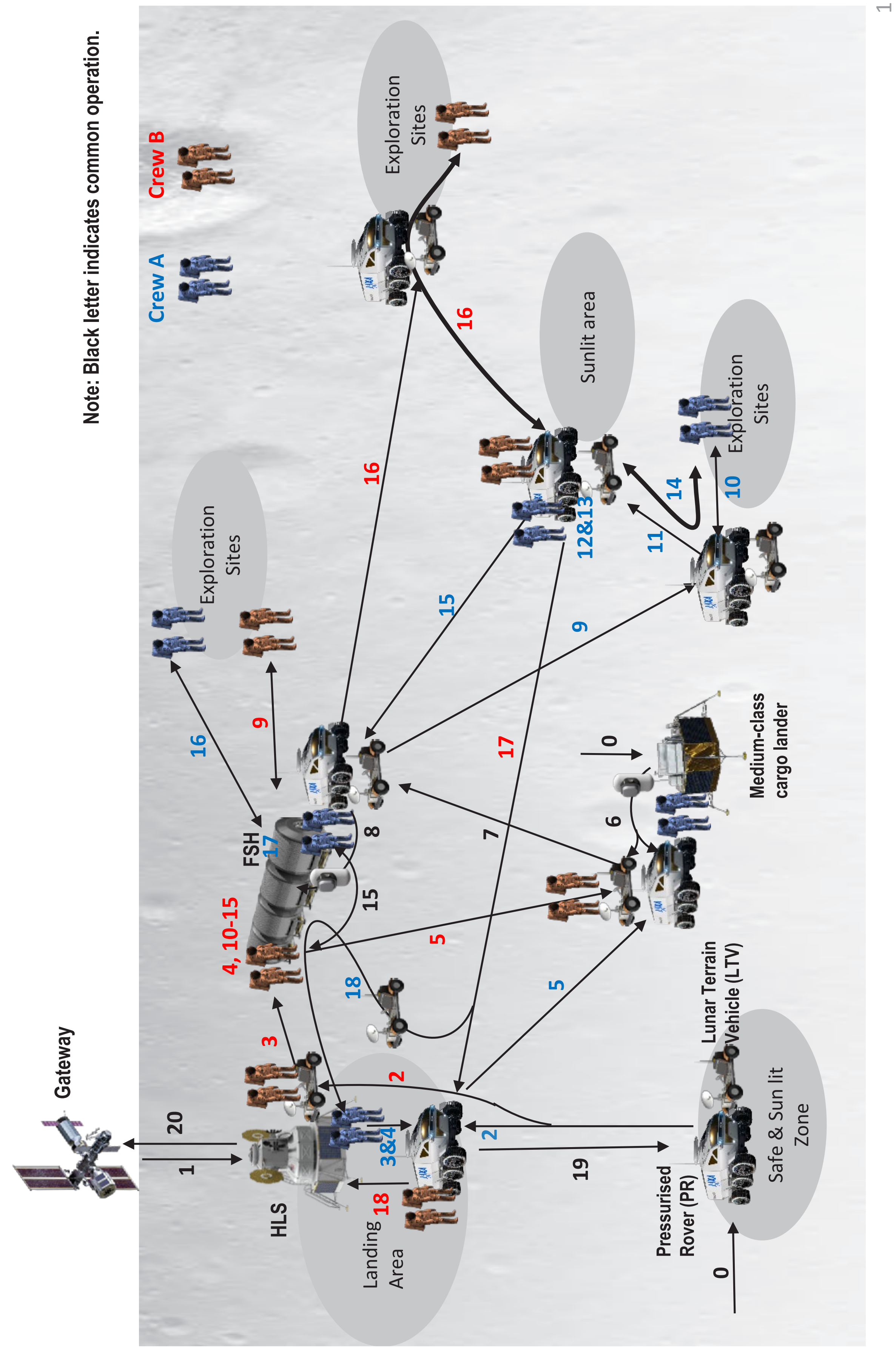


Figure 5. Overview of Operation Concept of Phase 2A-b.

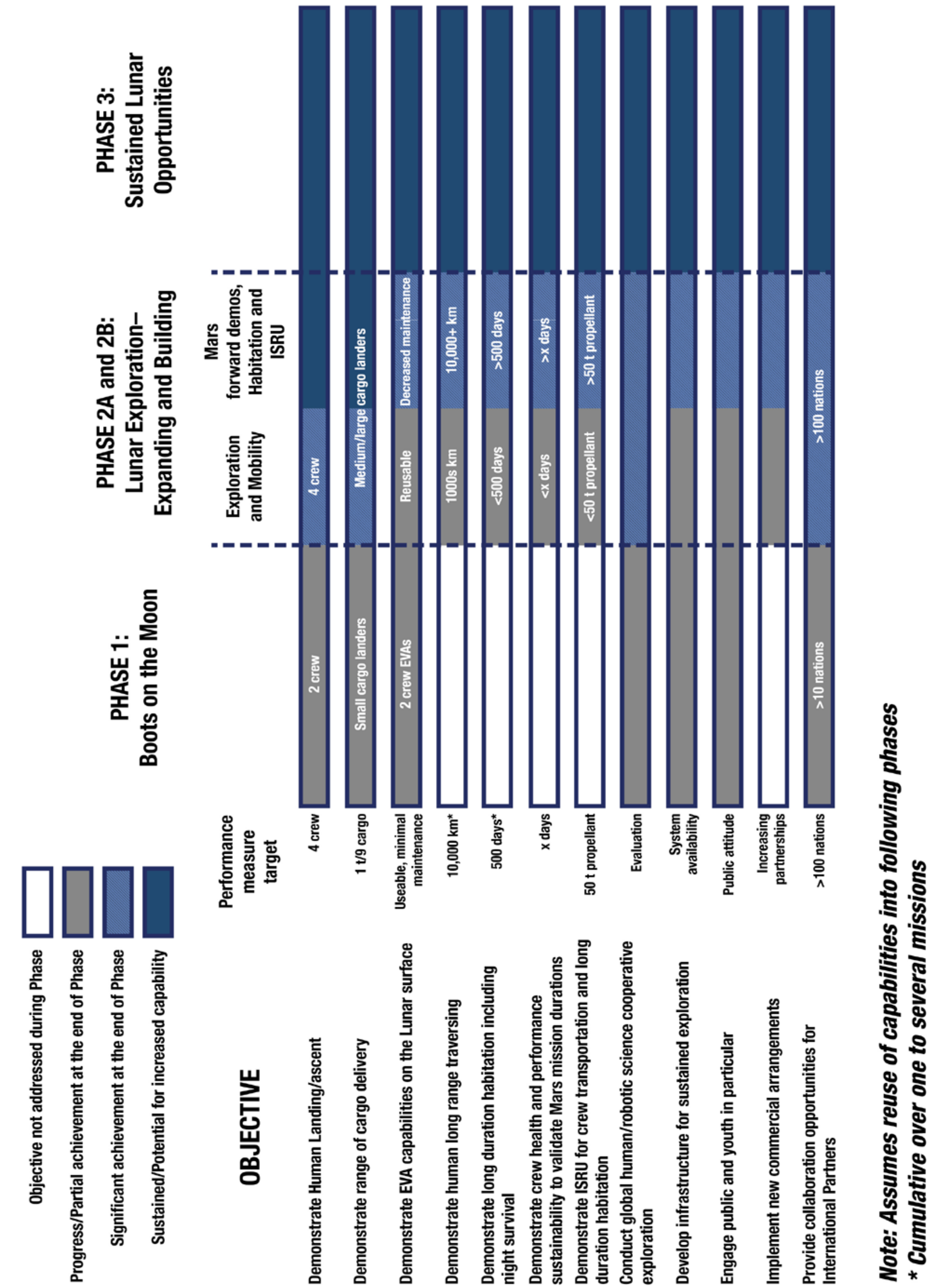


Figure 5. Objectives Progression across Phases.

ISECG is a voluntary, non-binding coordination forum of 27 space agencies. ISECG participating agencies operate in accordance with the key principles set forth in the Global Exploration Strategy—which are open and inclusive, flexible and evolutionary—and is meant to foster mutually beneficial partnerships.

ISECG is committed to fostering the discussions in non-binding forums and to develop products that enable its members to take concrete steps towards establishing partnerships that reflect a globally coordinated exploration effort and enhance the benefits of space exploration for all.

For more information on ISECG activities and how to join, visit the ISECG public website, **https://www.globalspaceexploration.org**

Publishing services provided by:

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

www.nasa.gov

NP-2022-09-3075-HQ

This document is available online at
http://www.globalspaceexploration.org