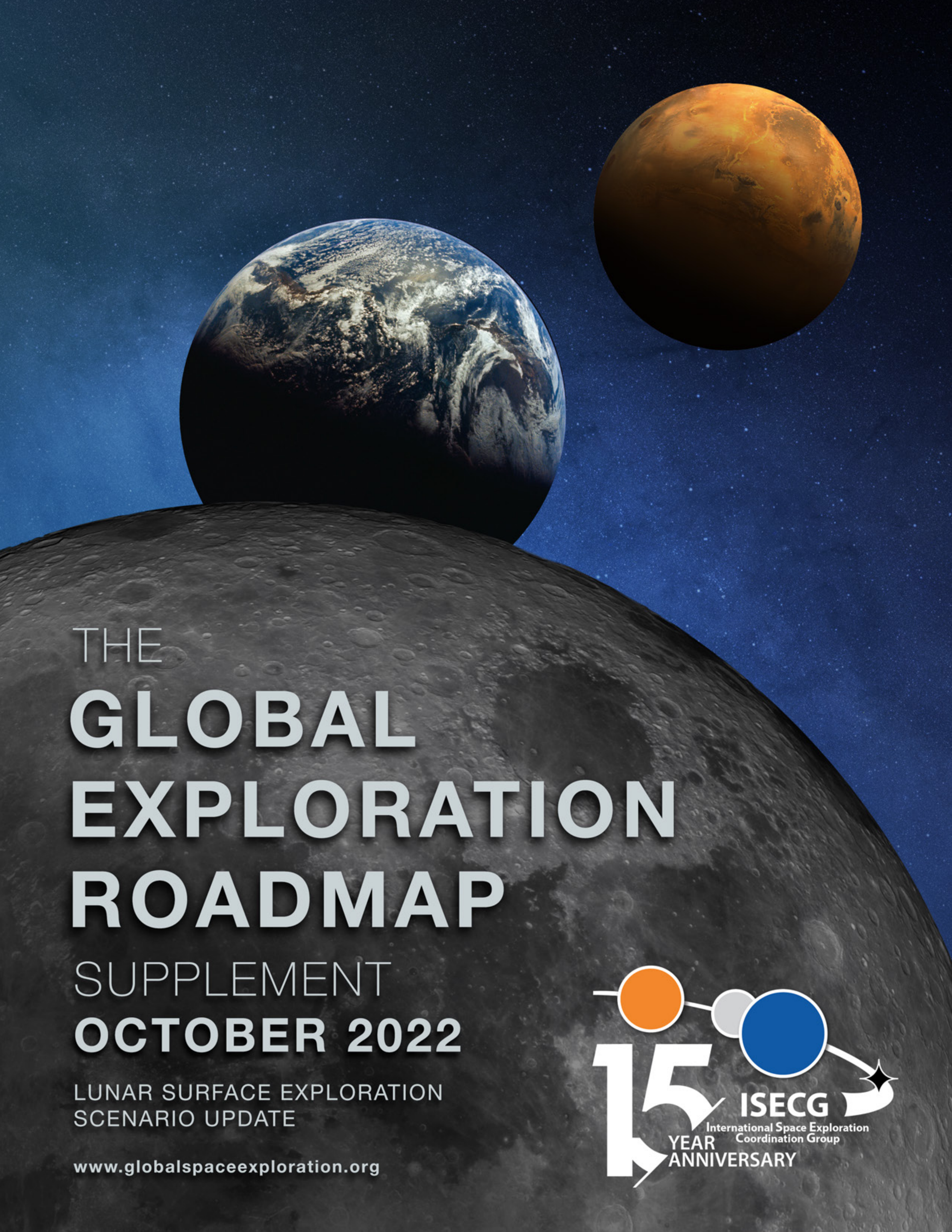

THE GLOBAL EXPLORATION ROADMAP

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.

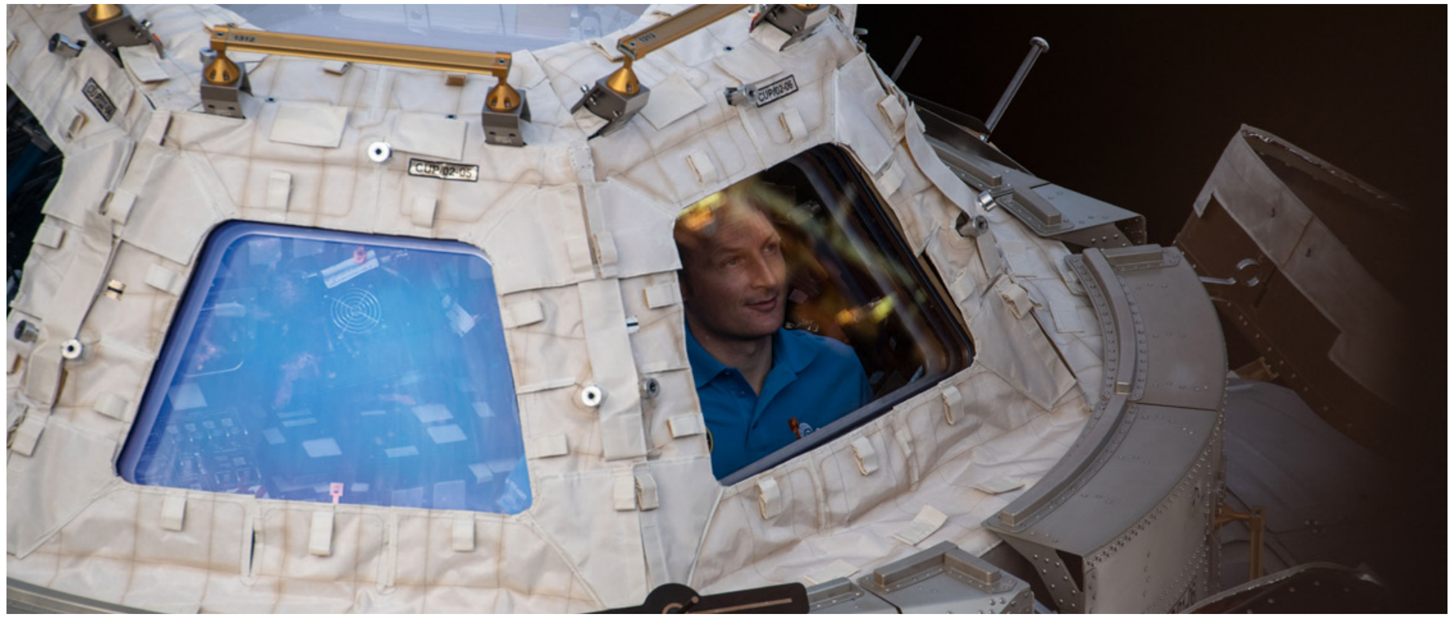

Image of ESA astronaut Matthias Maurer inside seven-windowed Cupola of the International Space Station during Expedition 67. Image Credit: ESA/DLR/NASA

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

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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.

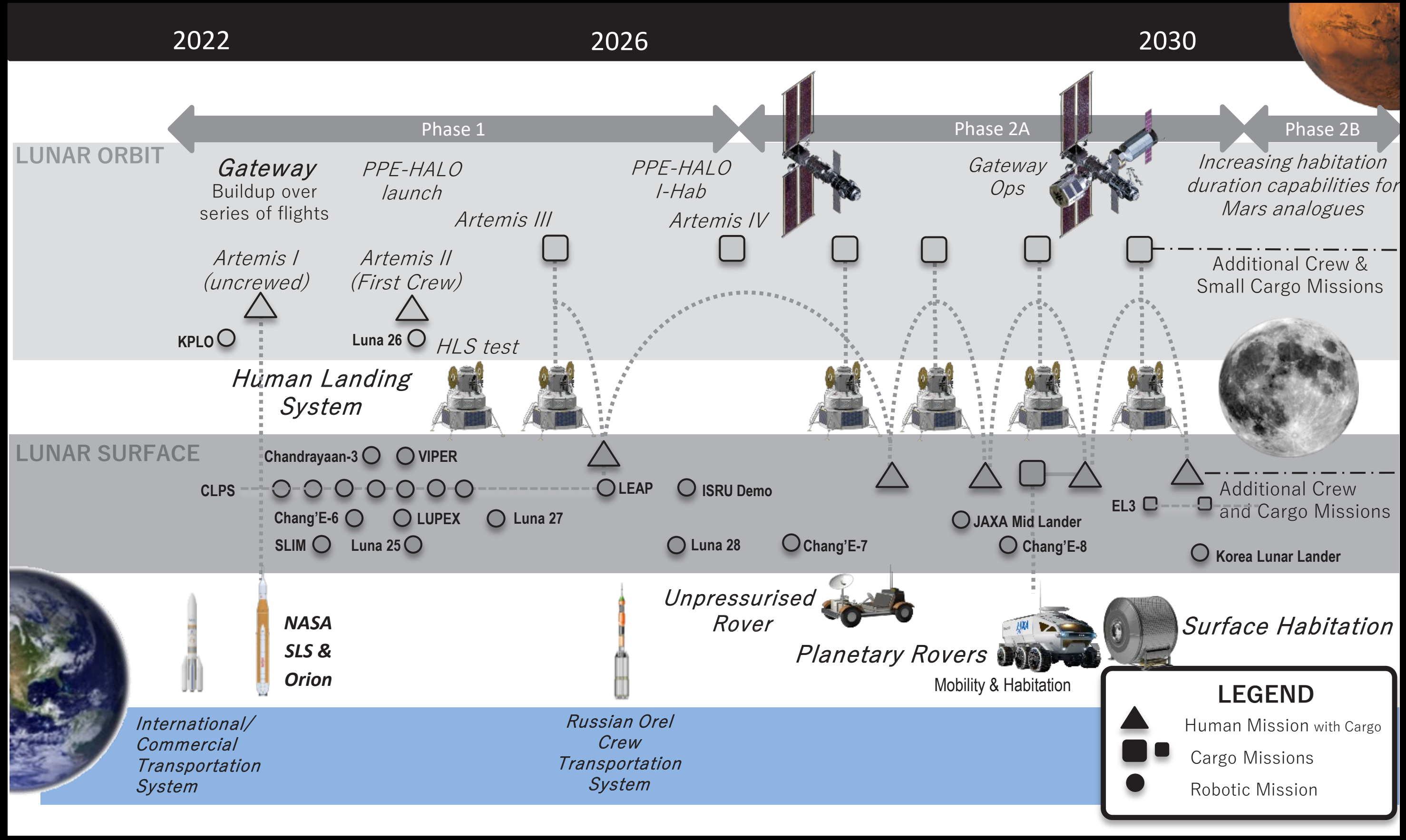


Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

ISECG AGENCIES WORLD MAP

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 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.

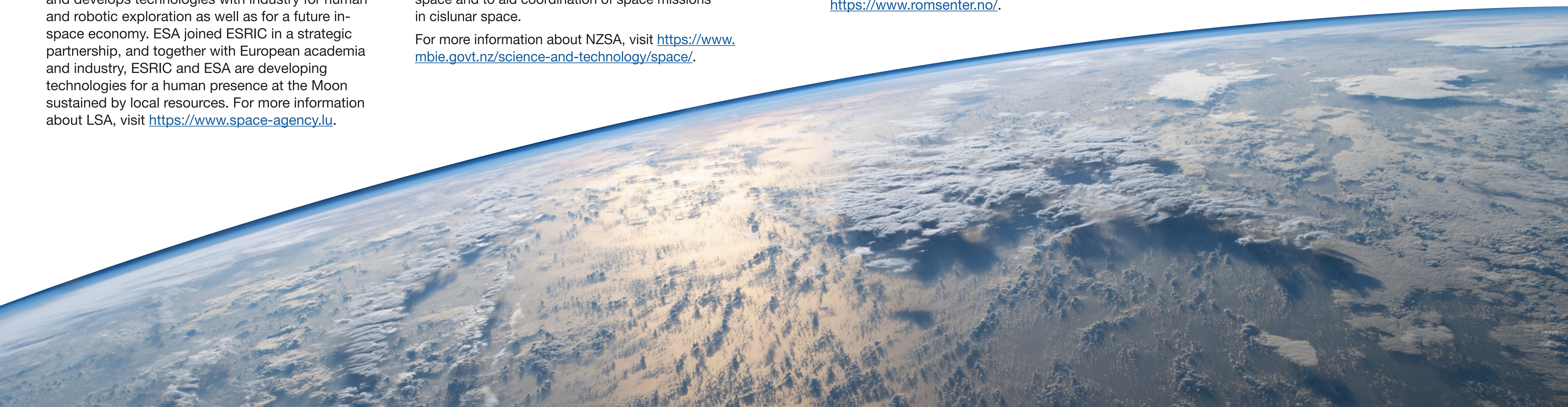
NOSA views their membership in ISECG as an opportunity to expand their perspective and work with international entities towards mutual goals for exploration. For more information NOSA, visit https://www.romsenter.no/.

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

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/.

rosa

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.

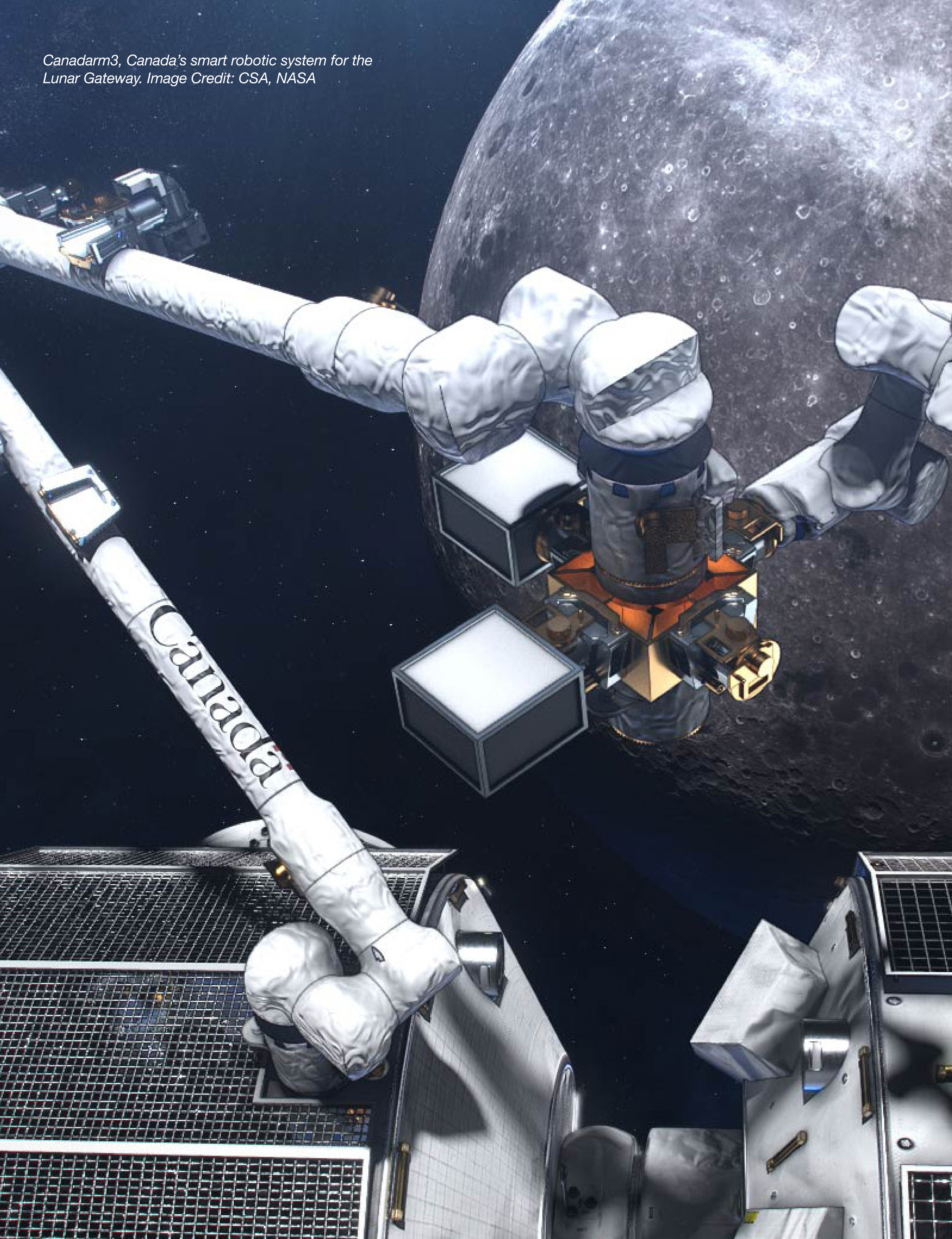
The main focus of SSO in exploration is science, the development of space technologies and international collaboration. The development and utilisation of space infrastructures to the benefit of society are a key element of the Swiss Space Policy. Space exploration enables continuous improvement in understanding 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.

VNSC
Lift-off your Dream

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)

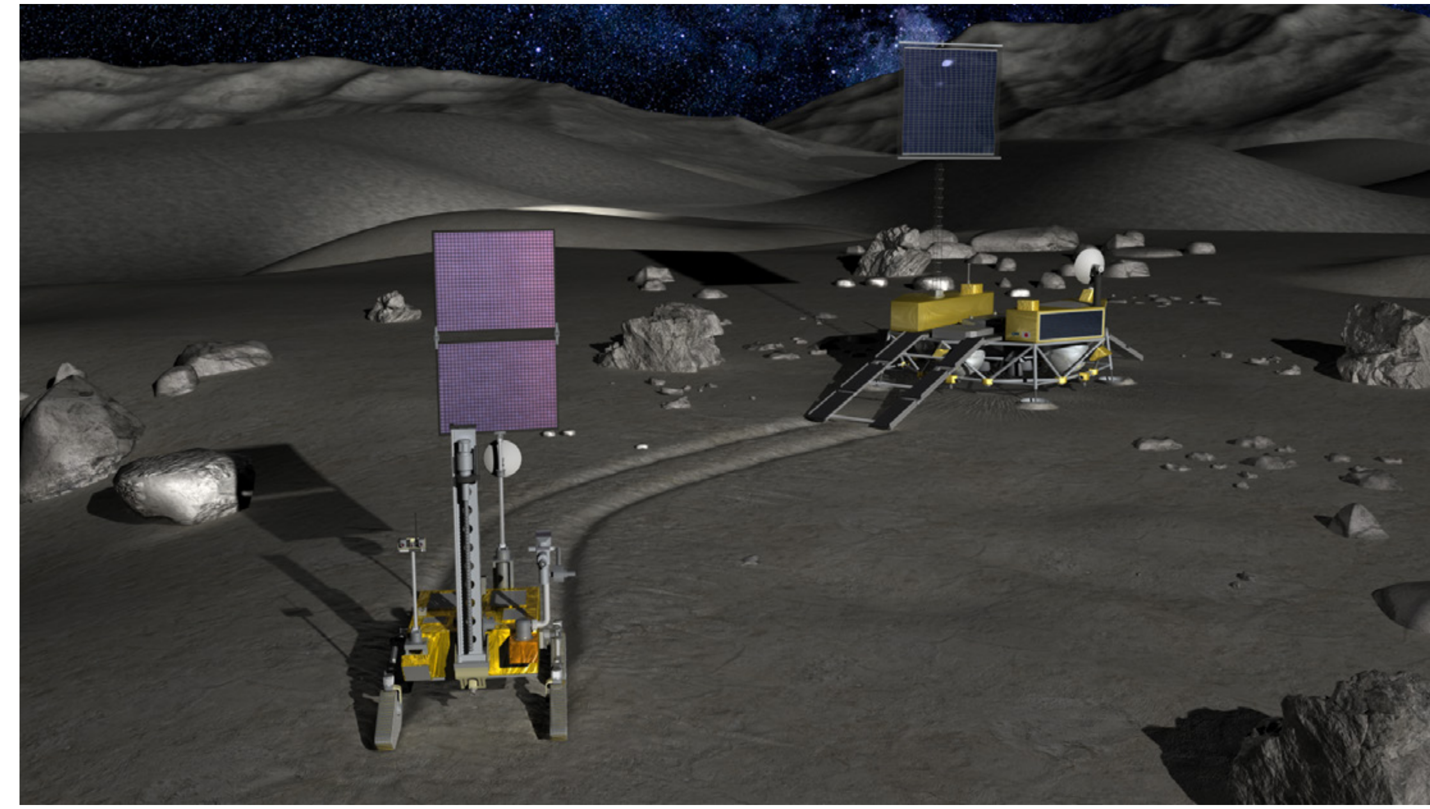
ISRO launched Chandrayaan-2 on 22 July 2019 with the goal of demonstrating an end-to-end lunar mission capability, including insertion of an orbiter in lunar orbit, and soft landing and roving on the lunar surface. The mission was originally designed to last one year. The orbiter, which was equipped 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

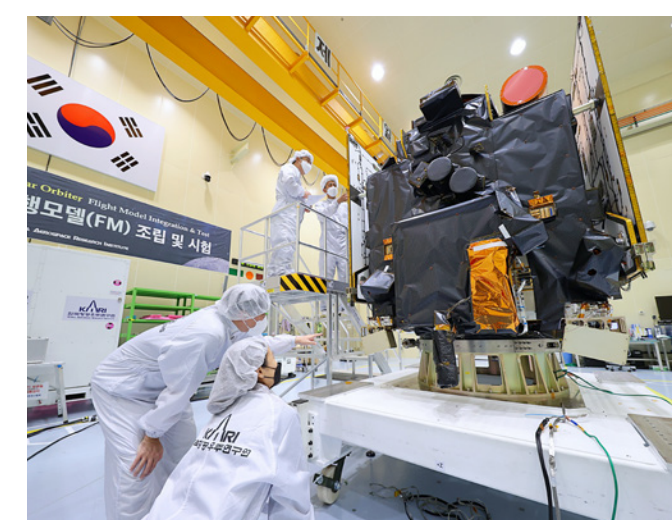


Lunar Polar Exploration (LUPEX). Image Credit: JAXA

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.

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	T02: Intuitive Machines	Science/ Technology	Oceanus Procellarum
2022	T02: 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

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.

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.		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.		>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.		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).		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.		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.		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.		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.		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.		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).		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.		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.		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.

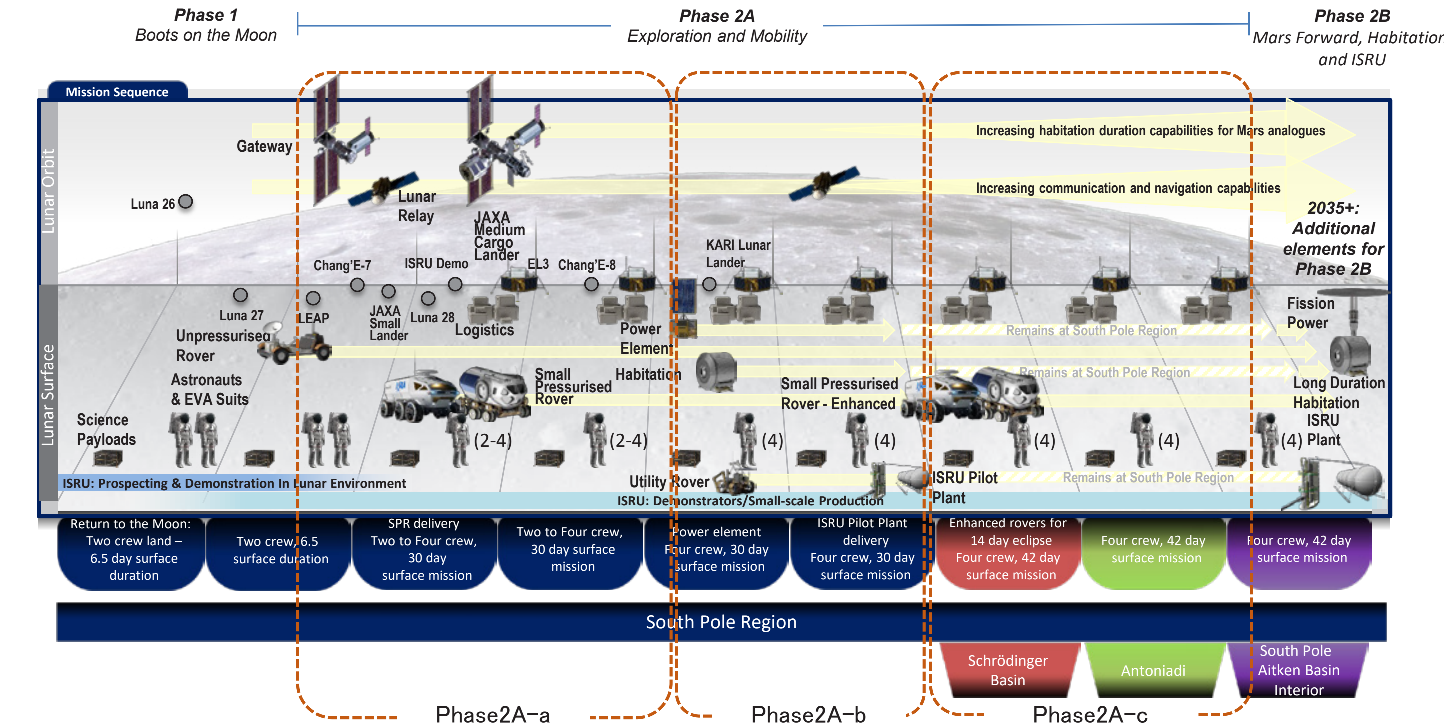
Because scenarios for Phase 2B and Phase 3 are not yet well defined in the GER and given that the human return to the Moon (Phase 1) is being led by NASA, ISECG focused the studies of the operation concept on Phase 2A. The Phase 2A is further divided into sub-phases such as phase 2A-a to 2A-d as below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

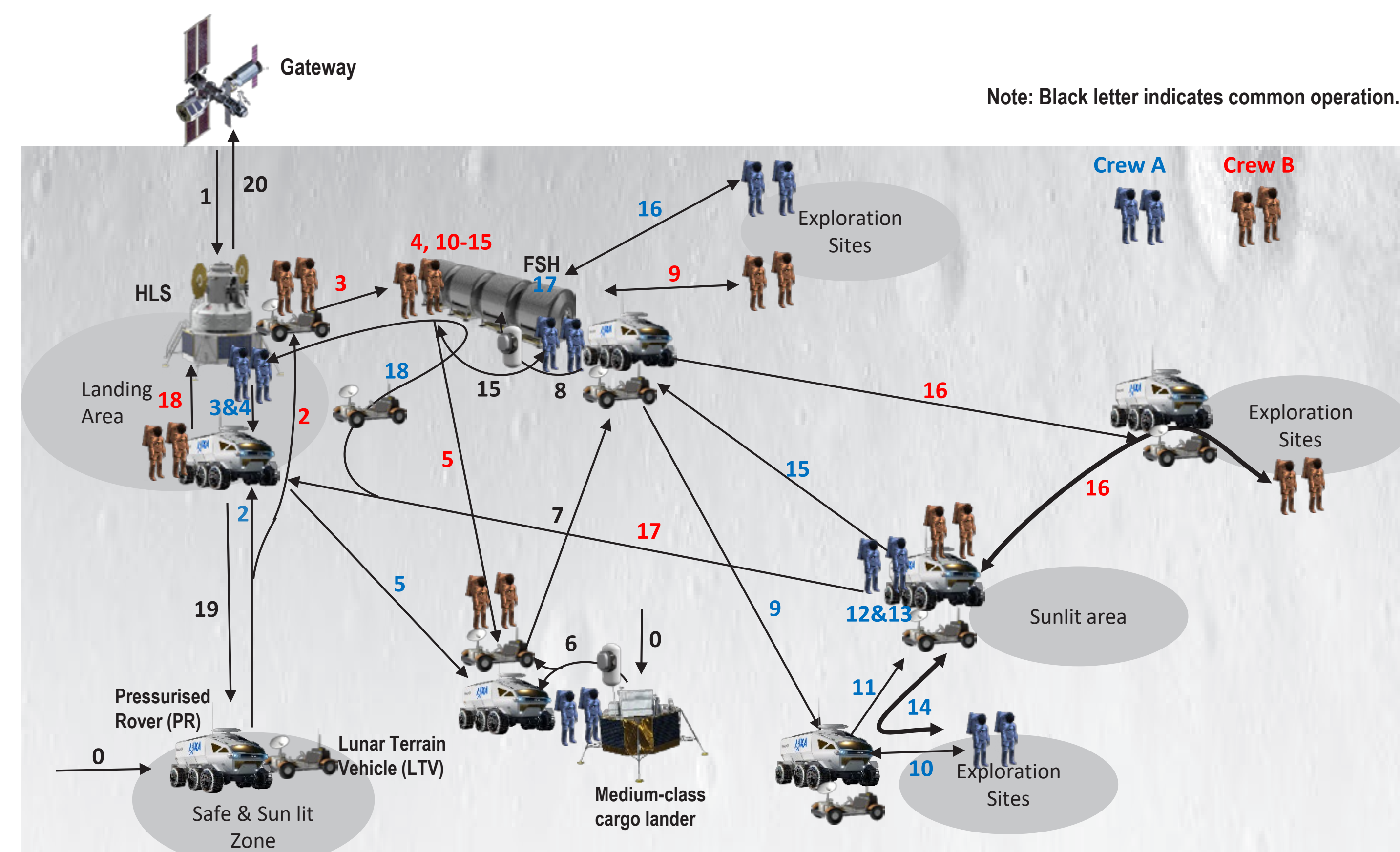
Artistic impression of the European Lunar Logistics Landers (EL3) integrated in a Artemis human surface exploration scenario. The EL3 lander has delivered a combination of cargo items, scientific payloads and small robotic assets (rovers). An Artemis crew is unloading the lander assisted by a robotic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

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[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

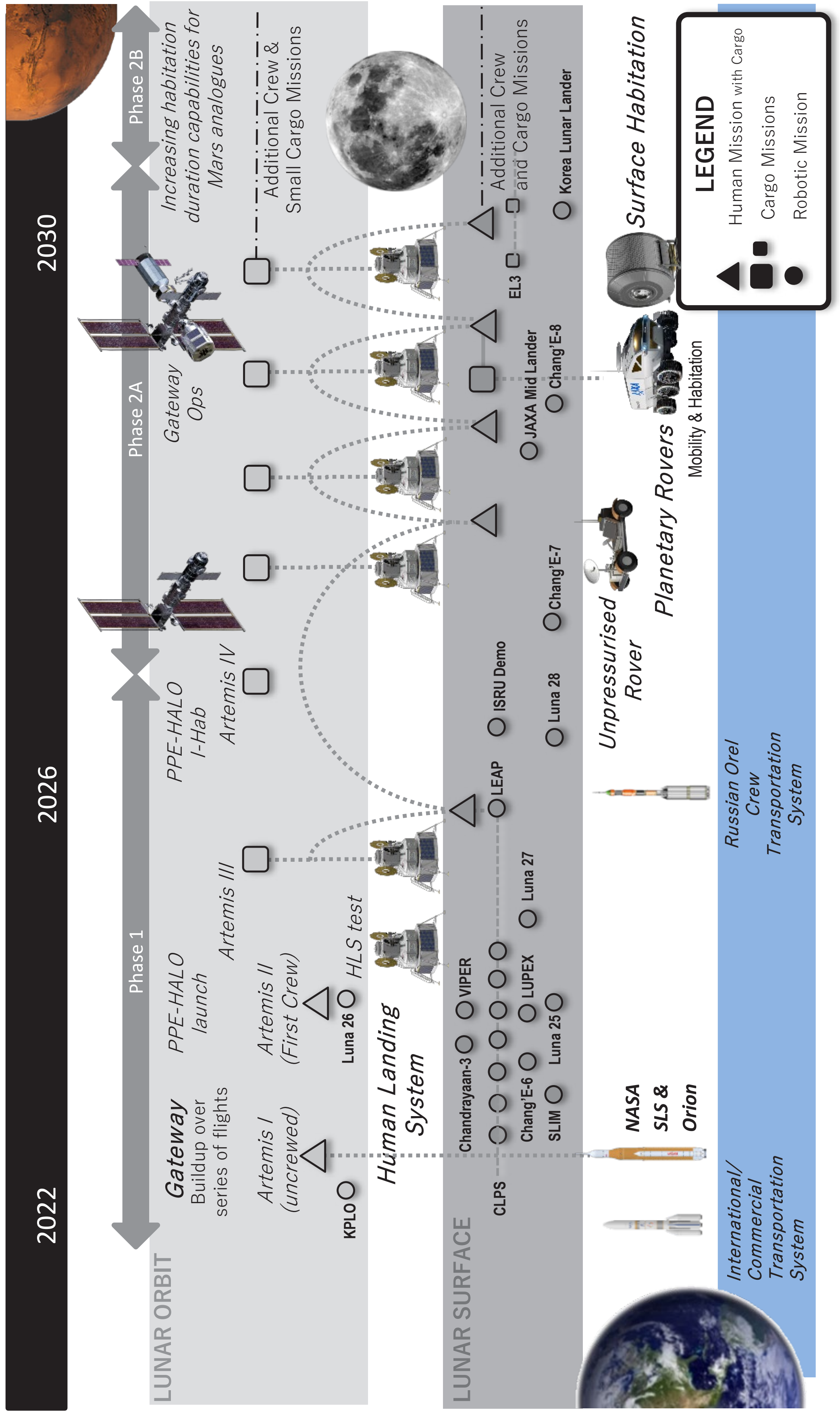

Figure 1. Updated ISECG Lunar Surface Exploration Scenario.

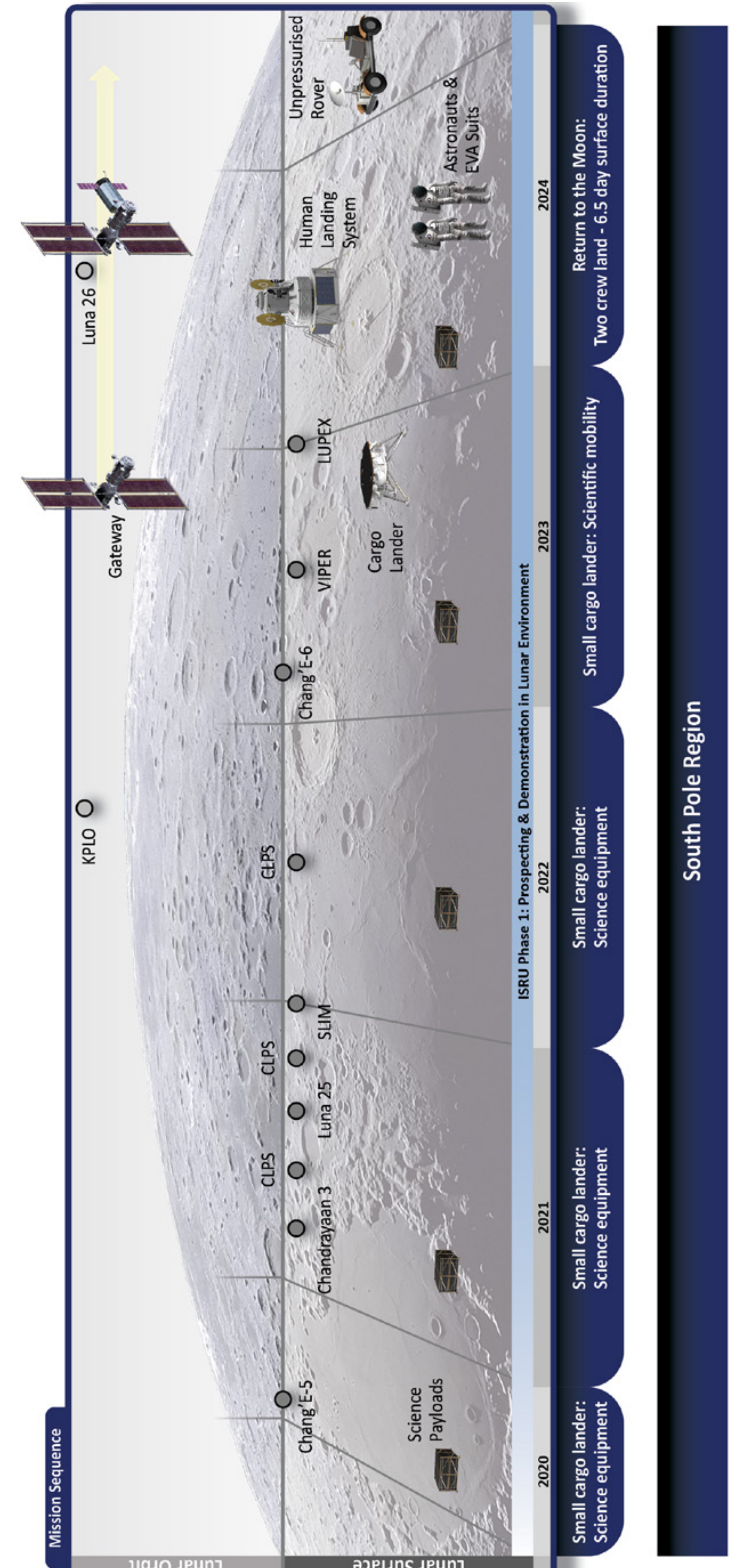

Figure 2. Phase 1: Boots on the Moon—South Pole.

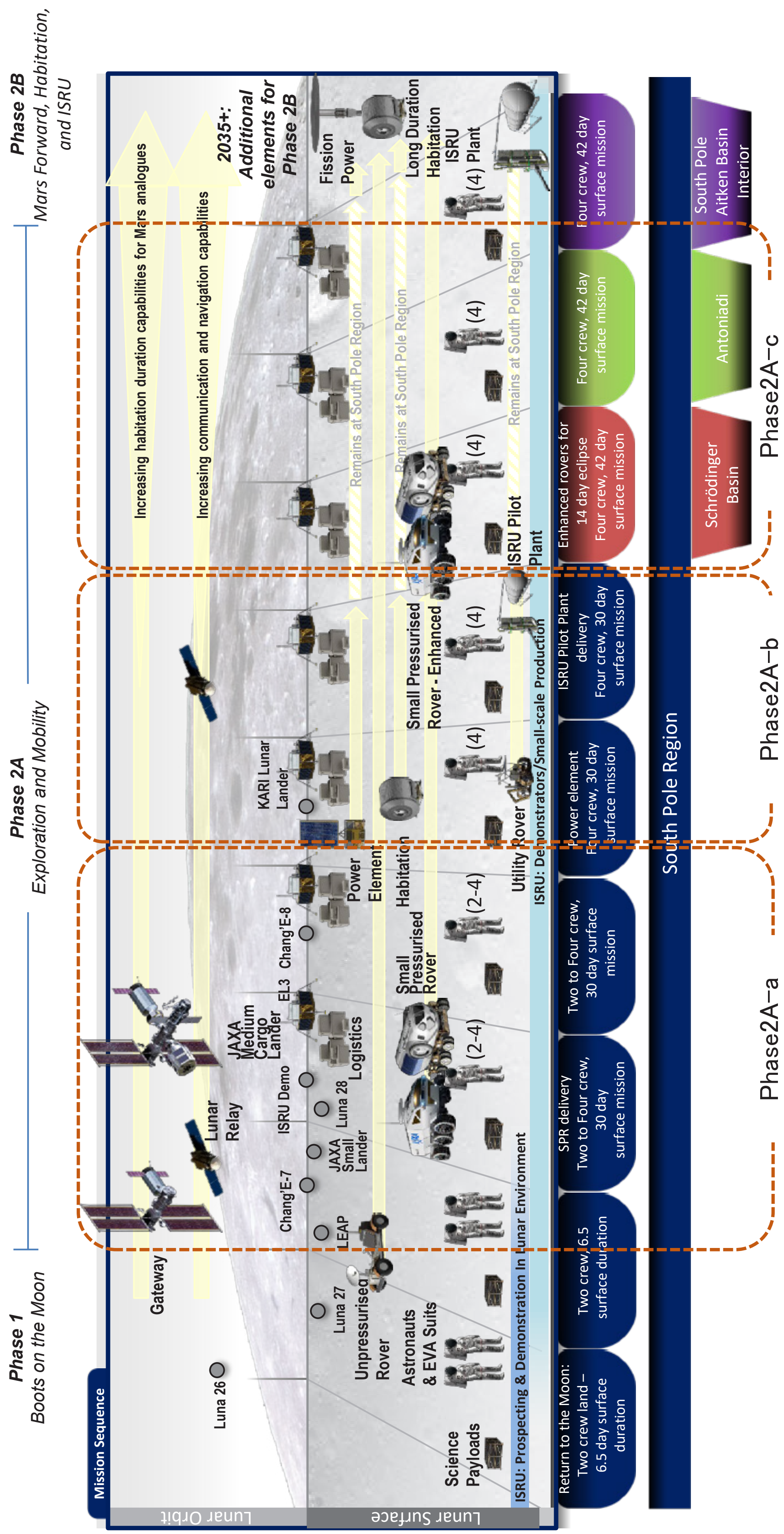

Figure 3. Phase 2A-2B: Lunar Exploration—Expanding and Building.

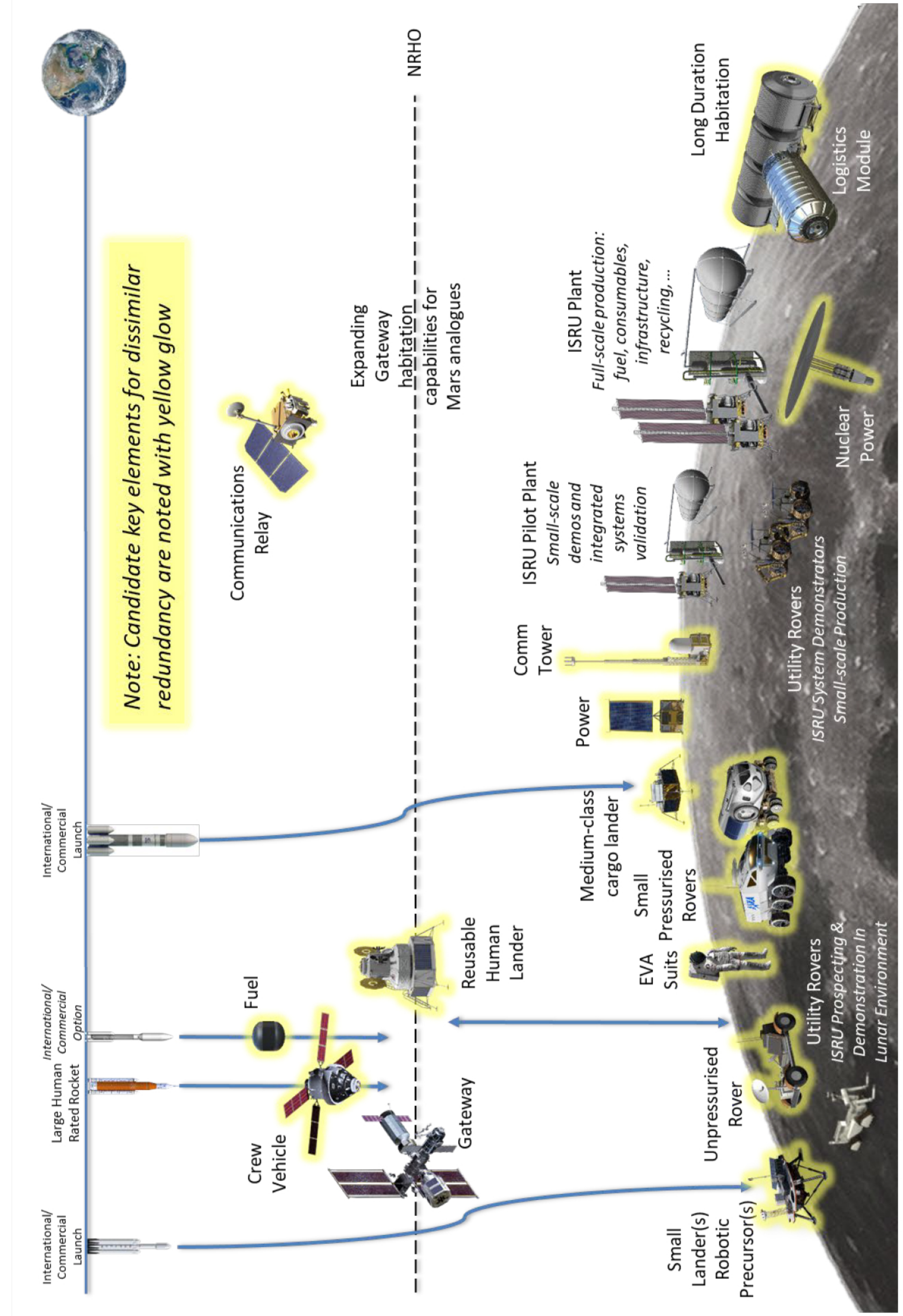

Figure 4. Expanding and Building—Longer Duration and Increased Utilisation (Phase 2B End State).

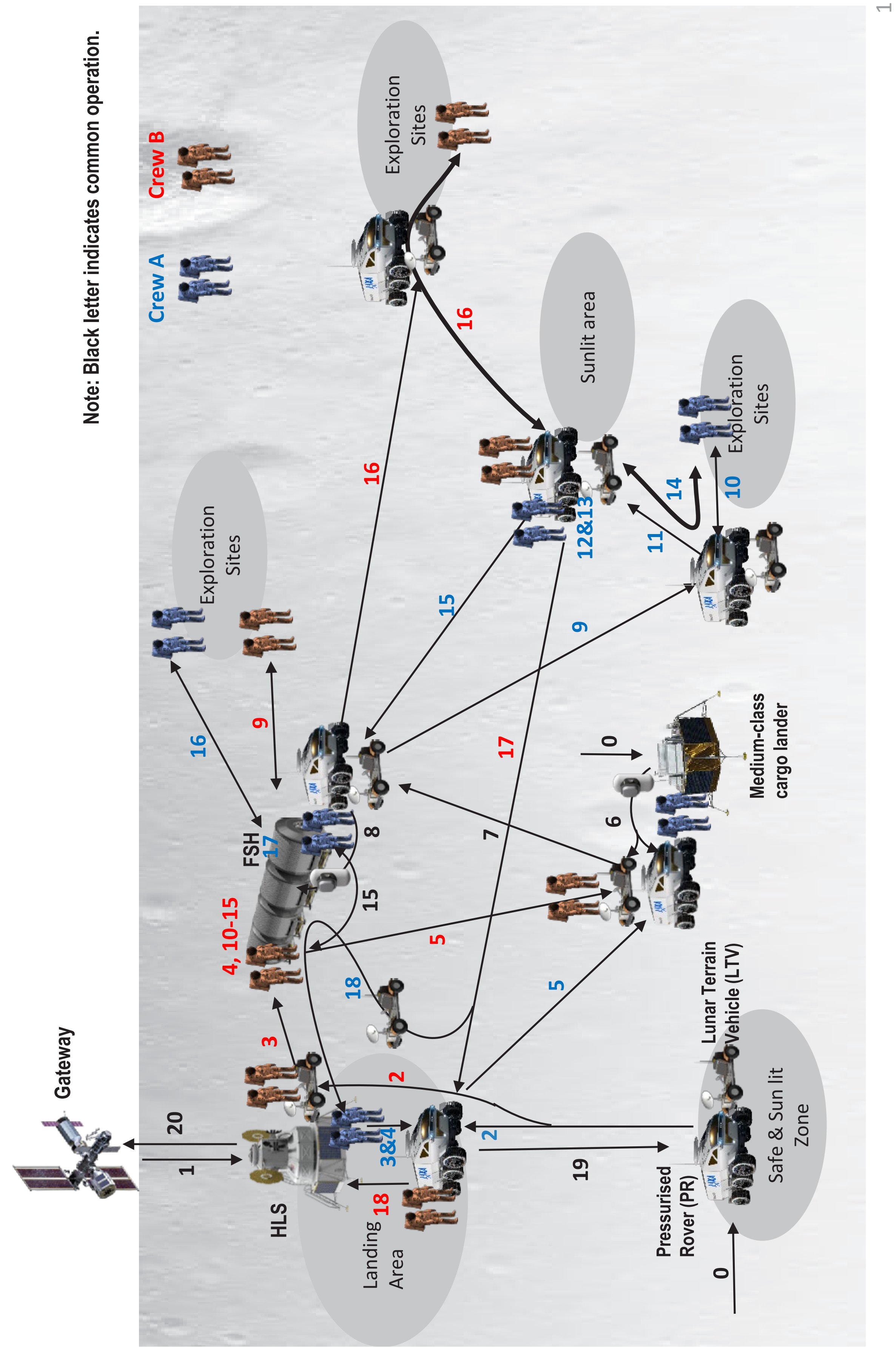

Figure 5. Overview of Operation Concept of Phase 2A-b.

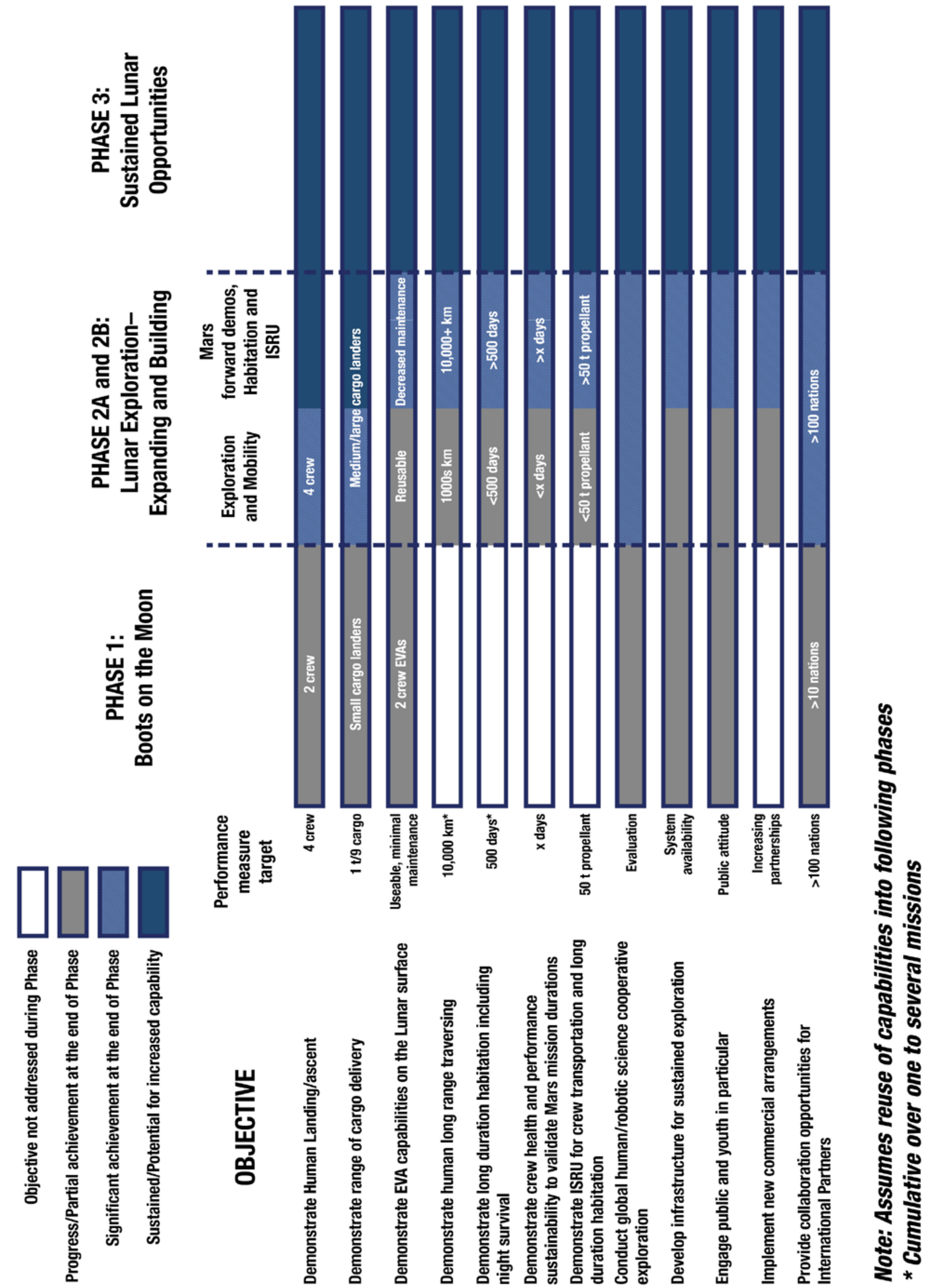

Figure 5. Objectives Progression across Phases.

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**

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