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Gateway Program Development Progress

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Abstract

This paper provides an overview and status of Gateway, humanity's first space station to orbit the Moon providing vital support for a sustained, long-term human return to the lunar surface and a steppingstone to Mars as part of the Artemis missions. As a lunar outpost, Gateway is a destination for deep space crew expeditions and science investigations, a port for deep space transportation, including landers transiting to the lunar surface or spacecraft embarking to deep space destinations beyond the Earth-Moon system. The National Aeronautics and Space Administration (NASA) leads the Program and is the integrator of the spaceflight capabilities and contributions of U.S. commercial partners and international partners to develop Gateway.

This paper will provide an overview of Gateway's major components in various stages of development. The entire Gateway spacecraft is at preliminary design level of maturity, with some components at or near critical design review. Gateway's major components are the Power and Propulsion Element; the Habitation and Logistics Outpost; Deep Space Logistics; the International Habitation module; Gateway External Robotics System; European System Providing Refueling, Infrastructure and Telecommunications; and an Airlock. This paper will also provide an update on the status of the integration activities necessary to fly and operate this complex, next-generation integrated spacecraft for a minimum 15-year design life, including systems engineering integrated analysis cycles, the autonomous Vehicle System Manager software, verification and validation labs, and common vehicle equipment.

Expanding on the successful partnership that has provided over 20 years of continuous crew operations in low-Earth orbit on the International Space Station, Gateway is an evolution of this extraordinary partnership leveraging the capabilities of each contributor to expand humankind's sustained exploration deeper into the cosmos. Highlighting the international program with participation from multiple space agencies, this paper will also provide a status of Gateway multilateral governance structure and international agreements.

Keywords: Gateway; Artemis; Moon; Mars; science; deep space exploration; international partnerships; commercial partnerships; lunar surface; NRHO

Acronyms/Abbreviations

Carbon Dioxide Removal System (CDRS)
Canadian Space Agency (CSA)
Co-manifested vehicle (CMV)
Deep Space Logistics (DSL)
European Radiation Sensors Array (ERSA)
European Space Agency (ESA)
European System Providing Refueling, Infrastructure, and Telecommunications (ESPRIT) known as Lunar View as of 2024
Exploration Ground Systems (EGS)
Extra Vehicular Activity (EVA)
Extra Vehicular Activity and Human Surface Mobility Program (EHP)
Gateway Logistics Services (GLS)
Glenn Research Center (GRC)
Habitation and Logistics Outpost (HALO)
Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES)
Human Landing System (HLS)
Human Surface Mobility (HSM)
Internal Dosimeter Array (IDA)
International Habitation module known as Lunar I-Hab as of 2024
International Space Station (ISS)
Japan Aerospace Exploration Agency (JAXA)
Johnson Space Center (JSC)
Memoranda of Understanding (MOU)
Near Rectilinear Halo Orbit (NRHO)
Power and Propulsion Element (PPE)
Space Launch System (SLS)

1. Introduction

Gateway is humanity's first space station to orbit the Moon. It is a central element of NASA's Artemis campaign – along with the Exploration Ground Systems (EGS), Space Launch System (SLS) rocket, Orion spacecraft, Human Landing System (HLS), and Extravehicular Activity and Human Surface Mobility (EHP) programs.

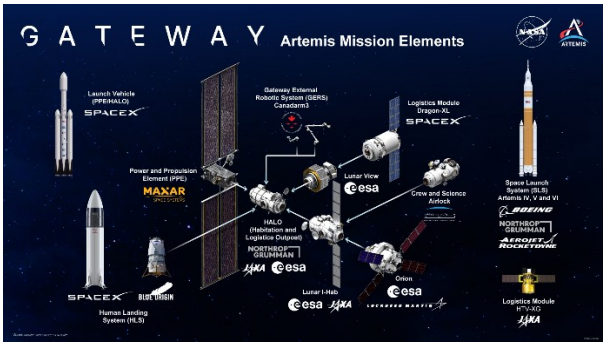

Fig. 1. Expanded view of Gateway Integrated Spacecraft, featuring Artemis mission elements

Gateway will be a relatively small space station orbiting the Moon to support human exploration of the lunar surface and a staging point for deep space exploration. Early missions to Gateway are expected to be approximately 30 days, with subsequently longer-duration missions up to 90 days when the space station is expanded with new elements. In its role housing international teams of astronauts in deep space and serving as a lunar science lab, Gateway will be a central hub for crew vehicles, lunar landers and cargo spacecraft transiting to and from Earth and destinations beyond the Moon, including Mars.

Gateway's unique 6.5-day polar orbit, known as near-rectilinear halo orbit (NRHO), facilitates year-round deep space scientific and technology demonstrations, with scientific experiments and contributions provided by NASA, international and commercial partners, and academia.

Gateway's orbit directly supports the long-term success of Artemis, permitting access for astronauts and their spacecraft to the entire lunar surface, including the lunar South Pole region. It enables uninterrupted communications between the Moon and Earth, unique opportunities for science within the deep space environment, and it is highly fuel efficient, translating to lower costs. [1] NASA's Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission, which launched in June 2022, is currently exploring the orbit. [2] Having spent over a year in space, CAPSTONE has accomplished its primary mission objectives and continues to demonstrate the feasibility of operations in NRHO needed by Gateway to safely function in lunar space.

This paper will provide an overview of the Gateway Program's development progress, international partnerships, and a status update for each of the spacecraft's integrated elements as of September 2024.

2. Gateway Overview

2.1 Management and Governance

Managed from NASA's Johnson Space Center in Houston, Texas, the Gateway Program consists of multiple elements (also called *projects* or *modules*) that are led by NASA Centers across the United States and international partners.

The Vision and Mission statements for the Gateway Program are:

- Mission: Creating the cislunar springboard for cooperative and sustainable human deep space exploration.
- Vision: A vibrant and lasting human presence in deep space.

The Gateway Program received approval for acquisition strategy from NASA Headquarters in 2018, authorization to proceed into Formulation in early 2019, and the Program Office was established at JSC in early calendar year 2019. Across the Program, multiple Gateway projects, systems, and components have finalized their Critical Design Reviews (CDRs) and are preparing for System Integration Reviews (SIR) in late 2024 and early 2025.

Progress continues for Gateway's Power and Propulsion Element (PPE), HALO (Habitation and Logistics Outpost), and Lunar I-Hab, formerly known as the International Habitat. After completing three Preliminary Design Review (PDR) events for Gateway's first elements (the integrated PPE and HALO, recognized as a co-manifested vehicle) in early 2023, the Program is planning to hold its first Program-wide CDR event in late 2024.

2.2 International Partnerships

Expanding on the successful partnership that has provided over 20 years of continuous crew operations in low-Earth orbit on the International Space Station (ISS), Gateway evolves the ISS framework to leverage the capabilities of partners and introduce new contributors. Gateway's international partners provide important contributions to the lunar outpost, and these partnerships mark a fundamental aspect of NASA's efforts to lead a

global coalition to the Moon. International partners are embedded members within the Gateway development team, with membership on Gateway Control Boards and technical integration embedded at all levels.

Memoranda of Understanding (MOU) and Implementing Arrangements (IAs) provide the formal commitments between the U.S. Government and partner agencies and governments to fulfill Gateway partnership obligations.

In October 2020, the European Space Agency (ESA) signed an agreement with NASA to contribute habitation and refuelling modules, enhanced lunar communications to Gateway and two more Orion service modules. The ESA-provided Lunar I-Hab will enhance Gateway capabilities for scientific research, life support systems, and crew living quarters. These capabilities enable longer duration crewed Gateway missions. The refuelling and storage module, renamed in 2024 by ESA as Lunar View, will include crew observation windows. The enhanced lunar communications module, Lunar Link, will be integrated with HALO pre-launch and provide high-rate communications relay between Gateway and elements on the lunar surface.

In December 2020, the Canadian Space Agency (CSA) signed an agreement with NASA to participate in Gateway and provide advanced external robotics. The CSA-provided external robotics system includes a next-generation robotic arm, Canadarm3, for Gateway. Canadarm3 will move end-over-end to reach many parts of Gateway's exterior, where its anchoring "hand" will plug into specially designed interfaces. CSA will provide robotic interfaces for Gateway modules, which will enable payload installation including the first two scientific instruments launching on Gateway.

In December 2020, the Japanese Aerospace Exploration Agency (JAXA) finalized an agreement with NASA to provide several capabilities for Gateway's Lunar I-Hab, which will provide the heart of Gateway life support capabilities and additional space where crew will live, work, and conduct research during Artemis missions. JAXA's planned contributions include Lunar I-Hab's environmental control and life support system, batteries, thermal control, and imagery components integrated by ESA prior to launch. These capabilities are critical for sustained Gateway operations during crewed and uncrewed time periods. JAXA will provide logistics resupply via the High Transfer Vehicle-XG (HTV-XG) spacecraft, an evolution from the HTV and HTV-X logistics carriers that resupply ISS. NASA and JAXA have reached agreement on the first HTV-XG resupply vehicle, providing 4mT of pressurized logistics.

In January 2024, the Mohammed bin Rashid Space Centre (MBRSC) of the United Arab Emirates (UAE) signed an arrangement with NASA to provide Gateway's airlock for crew and science research transfers to and from the habitable environment of Gateway's pressurized crew modules to the vacuum of space. These transfers will support broader science in the deep space environment and Gateway maintenance.

Canadian, European, Japanese and Emirati astronauts will fly on Artemis missions to Gateway.

3. Status of Gateway Elements

3.1 Gateway Initial Capability

The integrated PPE and HALO are Gateway's first elements to launch to the Moon.

PPE is a high-power, 60-kilowatt solar electric propulsion spacecraft that will provide power, high-rate communications, attitude control, orbit maintenance, and orbital transfer capabilities for Gateway. PPE is being developed and built by Maxar Space Systems headquartered in Palo Alto, California, and is managed out of NASA's Glenn Research Center in Ohio. Maxar Space Systems was awarded the contract for PPE in 2019 and [3] successfully conducted a first PDR in July 2021. [4]

In Spring 2022, the PPE engineering team started an extensive end-to-end testing campaign of PPE's advanced electric propulsion system thrusters. Based on the success of the work to date, the team successfully completed the next phase of the testing campaign with Aerojet Rocketdyne, an L3 Harris Technologies company, in the summer of 2023 which provided the project with greater insight into the thrusters' capabilities as an integrated system. [5]

Completion of PPE's CDR was held in March 2024 and structural assembly and integration of various components are underway. In June 2024, Gateway Program leadership coordinated vendor visits with Maxar Space Systems and its subcontractors, Aerojet Rocketdyne and Redwire to observe hardware development progress. As of July 2024, both Xenon and Bi-Propellant (Bi-Prop) tanks have been installed into the PPE primary structure.

HALO is where Artemis astronauts will live and conduct research while visiting Gateway. The pressurized living quarters will provide command and control systems for the lunar outpost and docking ports for visiting spacecraft, such as NASA's Orion spacecraft, lunar landers, and logistics resupply craft. HALO will serve as the backbone for command and control and power distribution across Gateway and will perform other core functions, including hosting science investigations via internal and external payload accommodations and communicating with lunar surface expeditions. HALO also will enable the aggregation of additional habitable elements to expand Gateway capabilities. HALO leverages contributions from

Gateway international partners for robust capabilities. Batteries provided by JAXA will power HALO until PPE solar arrays can be deployed and during eclipse periods. Robotic interfaces provided by CSA will host payloads and provide base points for Canadarm3 robotic operations. ESA will provide a lunar communications system to enable high-data-rate communications between the lunar surface and Gateway.

HALO is managed out of NASA's Johnson Space Center in Houston. Northrop Grumman of Dulles, Virginia was awarded a contract for the preliminary design of HALO in 2020, and the remaining content for HALO was finalized between NASA and Northrop Grumman through a contract signed in July 2021. [6] HALO successfully completed PDR in summer of 2021 and completed a CDR in summer 2022. As of July 2024, construction of HALO's outer shell, including structural welding in Italy, is complete and teams at Thales Alenia Space are completing final load testing and certification. The HALO structure is slated for delivery to Northrop Grumman's facilities in Gilbert, Arizona, in 2025 where it will begin the process of being outfitted with various components to support future Artemis missions. [7]

In February 2021, NASA selected SpaceX to provide launch services for the PPE and HALO modules. The modules integrate on Earth and launch as a co-manifested vehicle (CMV) ahead of the Artemis IV mission on a Falcon Heavy rocket from Launch Complex 39A at Kennedy Space Center. [8]

Some of the scientific payloads that will fly on Gateway's initial capabilities have already been selected. [9, 10, 11] They include:

- The European Radiation Sensors Array (ERSA) will help provide an understanding of how to keep astronauts safe by monitoring the radiation exposure in Gateway's unique orbit.
- The Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) is NASA's space weather instrument suite that will observe solar particles and solar wind created by the Sun.
- The ESA Internal Dosimeter Array (IDA) will include instruments provided by JAXA. Radiation measurements and data provided by the IDA will allow for the study of radiation shielding effects and improve radiation physics models for cancer, cardiovascular, and central nervous system effects, helping assess crew risk on exploration missions.

3.2 Deep Space Logistics and Gateway Logistics Services

As astronauts prepare for missions to the lunar surface, they will need deliveries of pressurized and unpressurized cargo, science experiments, and supplies. The Kennedy Space Center manages the Deep Space Logistics (DSL) project office, which includes management of Gateway Logistics Services (GLS) contracts.

In March 2020, NASA selected SpaceX of Hawthorne, California, as the first U.S. commercial provider under the GLS contract. [12] SpaceX and the DSL team are currently completing several special studies while simultaneously working towards a Systems Requirements Review (SRR) in 2025 after receiving authority to proceed (ATP) for the first GLS mission in December of 2023.

In the past, these studies included detailed analysis on required capabilities, logistics mission planning, and providing astronauts with additional stowage and waste management solutions. Current efforts are focused on requirement maturation, ensuring the results from these studies are incorporated into the final hardware and mission design.

Working in conjunction with Gateway's international partners, DSL has partnered with JAXA to share lessons learned and inform their development of the HTV-XG logistics resupply vehicle. DSL also remains engaged, in conjunction with SpaceX, with CSA as they develop the GERS system to ensure full compatibility of Canadarm3 with future logistics efforts.

3.3 Lunar I-Hab, Lunar View, and Lunar Link

ESA will contribute habitation and refueling to Gateway. The Lunar I-Hab, or I-Hab for short, will enhance Gateway capabilities for scientific research, life support systems and crew living quarters, which will enable longer duration crewed Gateway missions. JAXA will provide several capabilities for I-Hab, including its environmental control and life support systems, batteries, thermal control, and imagery components, which will be integrated into the module by ESA prior to launch. Lunar I-Hab will utilize similar life support systems to those currently on the ISS. As a technology risk mitigation, a scaled version of the JAXA developed Gateway CO2 removal system (CDRS) will be flown and demonstrated on ISS in 2025. This tech demo will help validate the CDRS design and identify any issues prior to launching the CDRS in I-Hab where crews will depend on it for longer duration stays at Gateway.

ESA has selected Thales Alenia Space in Italy as the main contractor to develop the Lunar I-Hab. [13] Fabrication of Lunar I-Hab is currently underway at their facilities in Torino, Italy. A mock-up of the module has

been constructed to test human factors elements and provide astronaut training, and the primary structure continues to be assembled and is still in the welding process.

Lunar View will provide additional fuel capacity to resupply PPE, windows, and enhanced lunar communications. Lunar Link, formally called the HALO Lunar Communications System (HLCS), will be integrated and launched with HALO.

Lunar I-Hab completed its PDR in Fall 2021 with primary structure fabrication underway. Design of the JAXA ECLSS system is progressing with PDR completed in the summer of 2023 and key component testing within the carbon dioxide removal system is on-going.

ESA recently provided a design modification to Lunar View adding capability to launch with 1.5MT of cargo and volume for 6.5m3 of on-orbit stowage. The module size grew to 3m in diameter with a refueling ring located around the pressurized habitable compartment. In the summer of 2022, ESA conducted a delta SRR to review these changes.

Gateway refueling of Xenon and bipropellant from Lunar View storage tanks to the PPE tanks will be utilizing new technologies. Development of the refueling system has advanced with breadboard testing of the integrated ERM-HALO-PPE fueling system occurring in the summer of 2022.

3.4 Gateway External Robotics System

CSA will provide an advanced Gateway external robotics system (GERS), which includes a next-generation robotic arm, or Canadarm3. Canadarm3 will move end-over-end to reach many parts of Gateway's exterior. Canadarm3 will be used to conduct maintenance, to berth and inspect vehicles, and install science payloads. CSA will provide Gateway external robotic interfaces (GERI) across the Gateway modules. Robotic interfaces on PPE and HALO host the ERSA and HERMES payloads enabling early utilization. The GERI PDR was complete summer of 2022. MacDonald, Dettwiler and Associates Ltd. (MDA) was selected by CSA for both the Canadarm3 and external robotic interfaces. [14,15] Canadarm3 completed System Requirements Review in January 2022 and is progressing toward a PDR in late 2024.

In June 2024, MDA was awarded an additional contract for the final design and construction of Canadarm3 and CSA has now transitioned into the construction and testing phase of development. Upcoming activities include system assembly, integration, and testing of the full robotics system including both the large arm, smaller dexterous arm, specialized tools, and a ground segment for command and control. Canadarm3 will be delivered to Gateway via a Gateway logistics flight.

3.5 Crew and Science Airlock

The Gateway integrated spacecraft will also need an Airlock. The Gateway Airlock Module (ALM) will be a multi-purpose element which provides the capability for crewed spacewalks, also called Extravehicular Activities (EVAs), while supporting scientific research and day-to-day Gateway operations with a specialized science airlock. By leveraging the capabilities provided by Canadarm3, the airlock will allow scientific experiments and Gateway hardware to move between the pressurized cabin and unpressurized destinations outside of Gateway. The ALM is also planned to provide an additional docking port for visiting vehicles, supplementary storage, and the capability for un-attended robotic maintenance of the Gateway.

As of September 2024, NASA is assisting MBRSC as they begin integration into the Gateway Program as a new NASA partner. Using updated Gateway requirements for the Crew and Science Airlock, MBRSC is in discussions with potential industry partners.

4. Summary

In summary, Gateway will provide unprecedented access to the Moon and enable sustainable exploration to the lunar surface and beyond, ushering in a new era of science for the benefit of all.

Hardware fabrication of Gateway's first elements is actively taking place in facilitates throughout the world. The year ahead will be busy with continued assembly, integration and testing of the initial Gateway elements, along with construction and design of later elements.

Gateway symbolizes the expansion of NASA's international and commercial partnerships into deep space. Significant progress is underway to establish humanity's first space station in orbit around the Moon.

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