National Aeronautics and Space Administration

NASA Hydrogen Development Efforts and Opportunities

Ohio Aerospace Institute (OAI)
Hydrogen Development Efforts & Opportunities
Mentor High School Paradigm Center

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15 February 2024

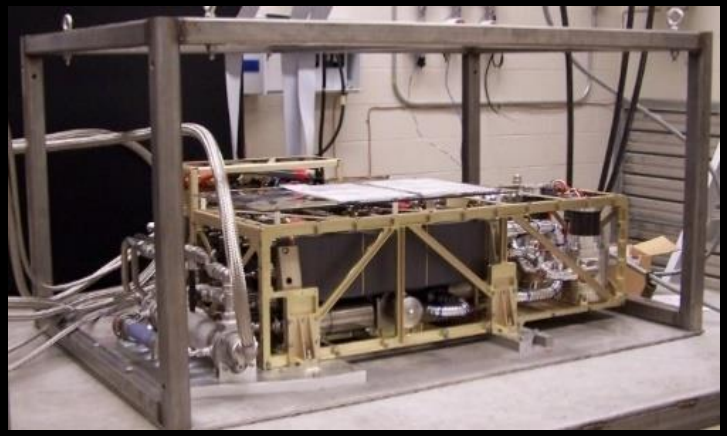


Presentation Overview

- NASA Glenn Research Center (GRC)
- GRC Hydrogen History
  - Fundamental Research
  - Hydrogen Fueled Aircraft
  - Hydrogen-Oxygen Rockets
- GRC Power History
  - Alternative Energy
  - Electric Cars
  - Fuel Cells
- Current GRC Activities
  - Fuel Cells and Water Electrolysis
  - Cryogenic Hydrogen Management
  - US National Clean Hydrogen Strategy



High-Energy Propellant Rocket Firing at the Rocket Lab



Space Shuttle Replacement Fuel Cell

NASA in Ohio?

- Two Sites
  - Lewis Field adjacent to Cleveland Hopkins Airport
  - Armstrong Test Facility in Sandusky, Ohio
- Established in 1941
- ~3,300 employees
  - ~18% have PhDs
  - ~40% have Masters Degrees
  - ~73% Scientists or Engineers
- Output of >$1.9 billion to Northeast Ohio annually
- Every U.S. aircraft has NASA Glenn technology on board.
- World-renowned test facilities bring NASA, military, and private industry customers to Ohio
  - NASA's Neil Armstrong Test Facility is home to the world's largest and most powerful space environment simulation chambers
- Glenn helped make NASA's most famous missions possible



NASA Glenn Research Center Lewis Field Campus

Numbers from "THE NASA JOHN H. GLENN RESEARCH CENTER: AN ECONOMIC IMPACT STUDY FISCAL YEAR 2022" assembled by Cleveland State University (https://www.nasa.gov/wp-content/uploads/2023/09/csu-nasa-glenn-economic-impact-fy-2022-20230813-final.pdf?emrc=9bbd01)

GRC Hydrogen History

Historical Hydrogen Research

- Fundamental work started in 1950
  - Hydrogen characterization
  - Hydrogen safety
  - Hydrogen liquefaction and storage
- Hydrogen Research for Aviation
  - Piston-based engines
  - Turbojets
  - Ramjets
  - Turbines
  - Fuel management systems: tanks, pumps, heat exchangers, and controls
  - Materials for high temperature combustion



Martin B–57B Canberra with wing tip fuel tanks used for an experimental liquid hydrogen fuel system, referred to as Project Bee

- Project Bee: Hydrogen-fueled jet
  - 1955: Lewis engineers began converting one Curtiss Wright J-65 engines of a B-57B Canberra to a dual-fuel engine (hydrogen or jet fuel (JP-4))
    - Hydrogen enabled a shorter, lighter engine that could operate at ~ 4500 meters (14,700 ft) higher altitude
  - 1956: Air Products LH2 production plant came on-line in Painesville Ohio (680 kg/day)
  - 1957: First successful flights
  - 1959: Project ended after completing all objectives

Historical Hydrogen-Oxygen Rockets

- Small-scale Hydrogen-based rocket research began in 1944 with 4 test cells
- Large-scale rocket research began after on-site Hydrogen production and liquification facility became operational in 1956
  - After initial successes, testing was delayed over a year to address major operational and design challenges
- Centaur upper stage rocket program transferred to Lewis in 1962
- Significant research invested in measuring LH2 quantities on the ground and in microgravity



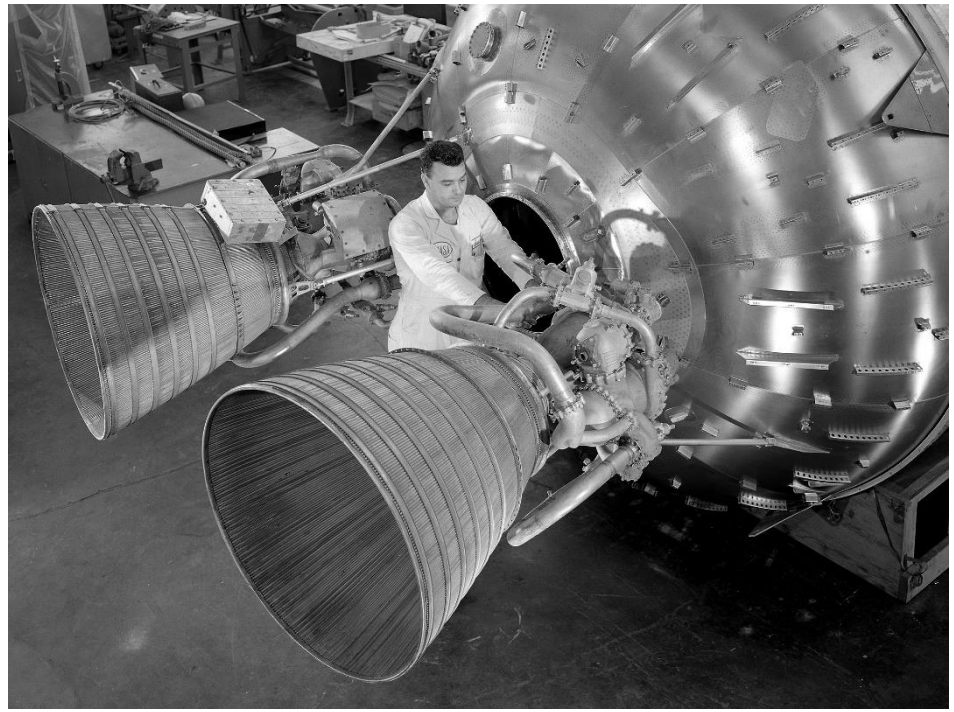
Damage at Lewis' Rocket Engine Test Facility following an test of high-energy fuels (4/27/1955)



NASA Engineers developing instrumentation to measure LH_2 aboard spacecraft

Historical Hydrogen-Oxygen Rockets

- Centaur upper stage rocket program transferred to GRC in 1962
  - Commercial vendors experienced similar challenges solved by GRC in 1957
  - GRC manages first successful Centaur rocket launch (AC-2)
  - Agena upper stage rocket program transferred to Lewis 1963
- GRC Expendable Launch Vehicles: 119 Launches (1963 to 1998)
  - THOR/Agena (11), 1964-1970
  - Atlas/Agena (19), 1964-1978
  - Atlas/Antares (2), 1964-1965
  - Atlas F&H (6), 1978-1987
  - Atlas/Centaur (72), 1963-1998
  - Titan/Centaur (8), 1974-1997
  - Titan III/TOS (1), 1992



A researcher prepares a Centaur 6A second-stage rocket for a series of tests in the Space Power Chambers' vacuum tank

For more information:
NASA SP-2004-4230
" Taming Liquid Hydrogen:
The Centaur Upper Stage Rocket 1958-2002 "
V. Dawson and M. Bowles



Rocket engines displayed in the Propulsion Systems Laboratory (1966) From left to right: two scale models of the Aerojet M-1, a Rocketdyne J-2, a Pratt and Whitney RL-10, and a Rocketdyne throttleable engine.

GRC Power History

Historical Energy Research



In 1976, NASA GRC and the Energy Research and Development Administration (ERDA) engaged in several energy-related programs in the mid-1970s, including the Electric Vehicle Project which tested 16 commercially-manufactured electric vehicles, including these.

From left to right: RIPP-Electric, EVA Contactor, Otis P-500, C.H. Waterman DAF, Zagato Elcar, unknown, Sebring-Vanguard Citicar, and Hattronic Minivan



During the 1970's, the Wind Turbine program was a joint program between NASA and the Energy Research and Development Administration (ERDA) to develop less expensive forms of energy including a series of increasingly powerful wind turbines: Mod-0A, Mod-1, WTS-4, and Mod-5. NASA Lewis was assigned the responsibility of developing large horizontal-axis wind turbines. The first device was a Mod-0 100-kilowatt wind turbine test bed at NASA's Plum Brook Station. A 2 MW Mod 1 is shown installed in Boone, NC (1979).

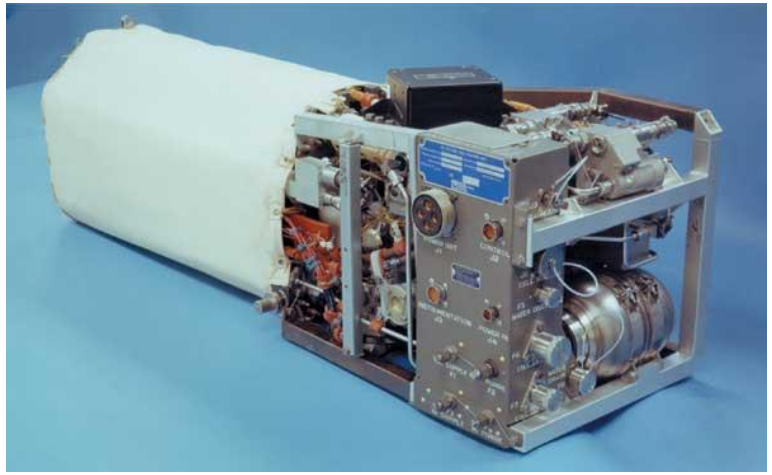
Historical Fuel Cell Activities



Gemini Fuel Cell Power Plants



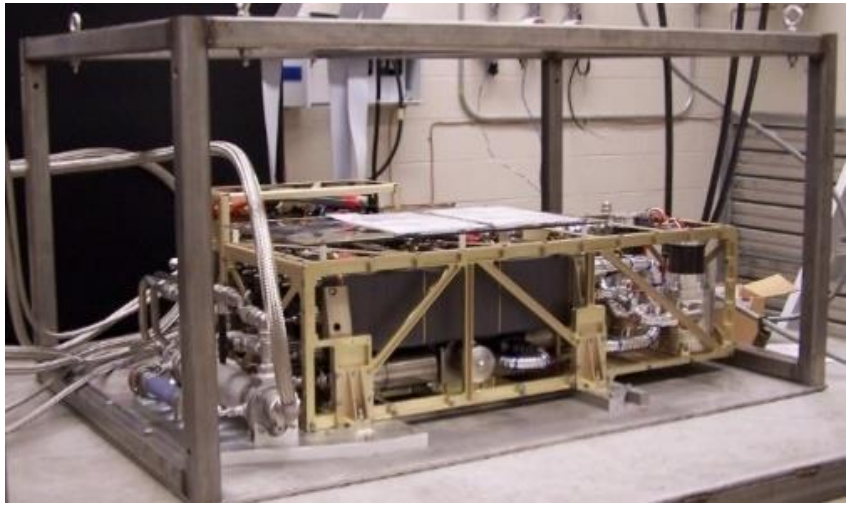
Apollo Fuel Cell Power Plants



Space Shuttle Orbiter Fuel Cell Power Plant



HELIOS Electric Aircraft

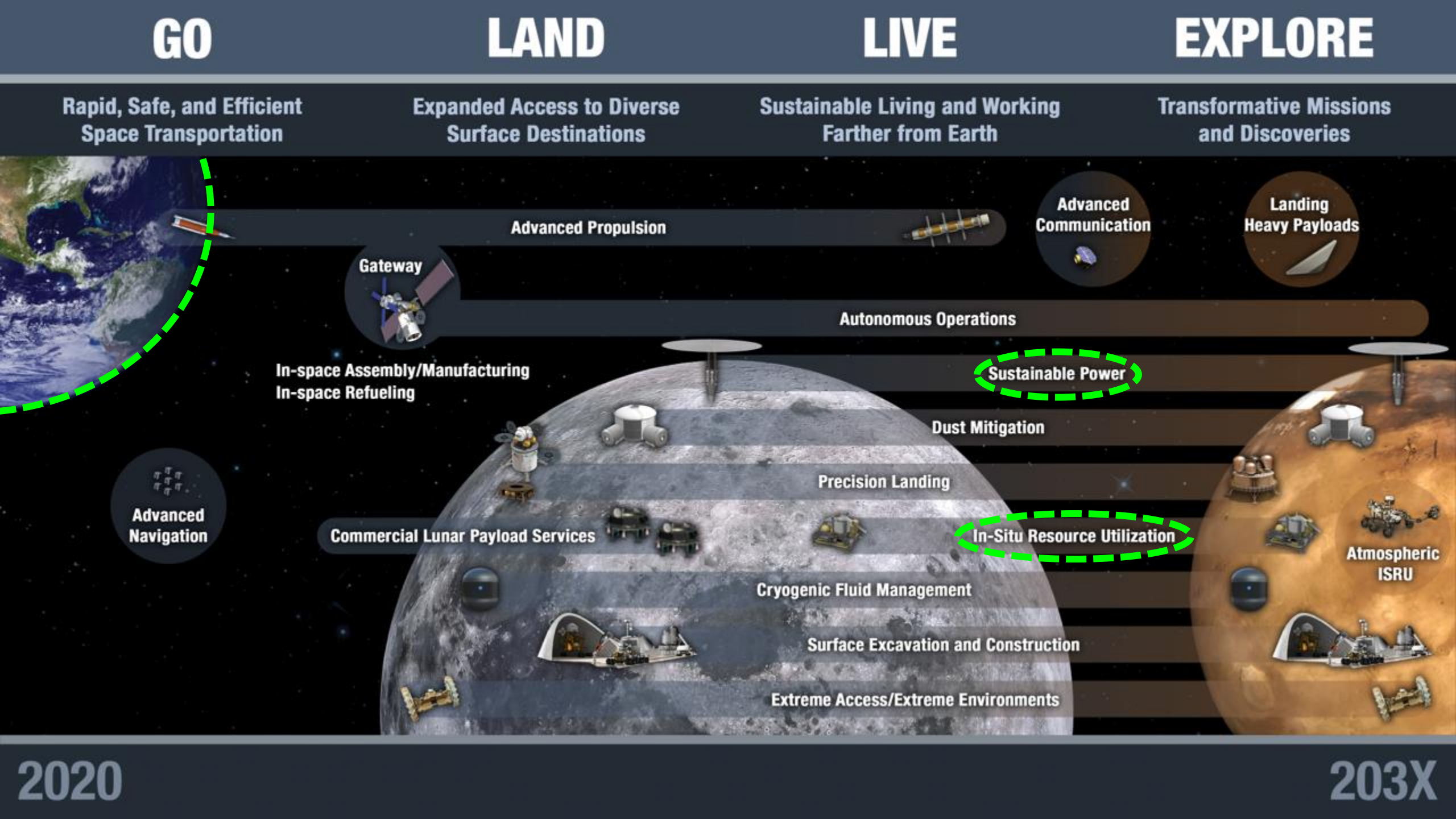


Space Shuttle Replacement Fuel Cell



Multi-Mission Space Exploration Vehicle

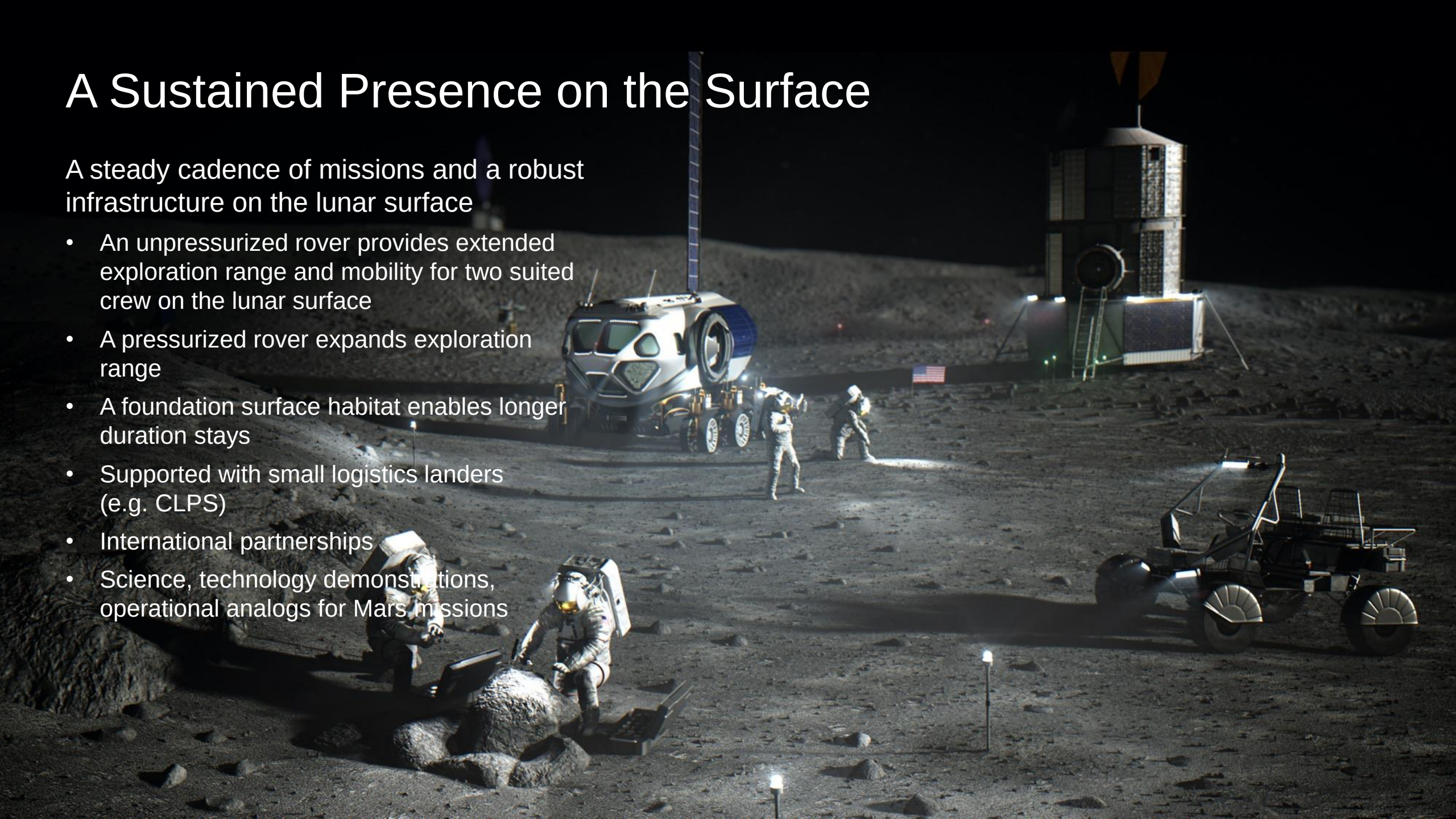
Current Activities


GO
LAND
LIVE
EXPLORE
Rapid, Safe, and Efficient Space Transportation
Expanded Access to Diverse Surface Destinations
Sustainable Living and Working Farther from Earth
Transformative Missions and Discoveries
Advanced Propulsion
Advanced Communication
Landing Heavy Payloads
Gateway
Autonomous Operations
In-space Assembly/Manufacturing
In-space Refueling
Sustainable Power
Dust Mitigation
Advanced Navigation
Precision Landing
Commercial Lunar Payload Services
In-Situ Resource Utilization
Atmospheric ISRU
Cryogenic Fluid Management
Surface Excavation and Construction
Extreme Access/Extreme Environments
2020
203X

A Sustained Presence on the Surface

A steady cadence of missions and a robust infrastructure on the lunar surface

- An unpressurized rover provides extended exploration range and mobility for two suited crew on the lunar surface
- A pressurized rover expands exploration range
- A foundation surface habitat enables longer duration stays
- Supported with small logistics landers (e.g. CLPS)
- International partnerships
- Science, technology demonstrations, operational analogs for Mars missions



Electrochemical Activities Within NASA

Power Generation *(Fuel Cell Reaction)*

Electrochemically combine H_2 and O_2 into water, heat, and electricity

- *Launch Vehicles*
- *Mars/Lunar Landers*
- *Lunar/Mars surface systems*
- *Urban Air Mobility / Electrification of Aircraft*

H_2O

Water Electrolysis

Generate H_2 and O_2 from water

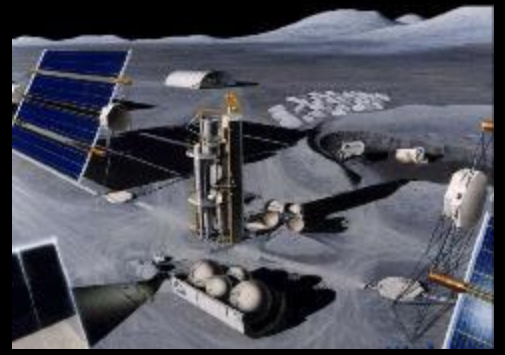
- *Breathing O_2 for Life Support Systems*
- *In-situ H_2 and O_2 Propellant Generation*
- *H_2 and O_2 for Energy Storage*
- *Terrestrial Hydrogen Economy*

H_2 O_2 H_2 O_2

Energy Storage

Long-term storage and management of H_2, O_2 and water

- *Launch Vehicles*
- *Mars/Lunar Landers*
- *Lunar/Mars surface systems*
- *Urban Air Mobility / Electrification of Aircraft*
- *Ground Support / Terrestrial Infrastructure*





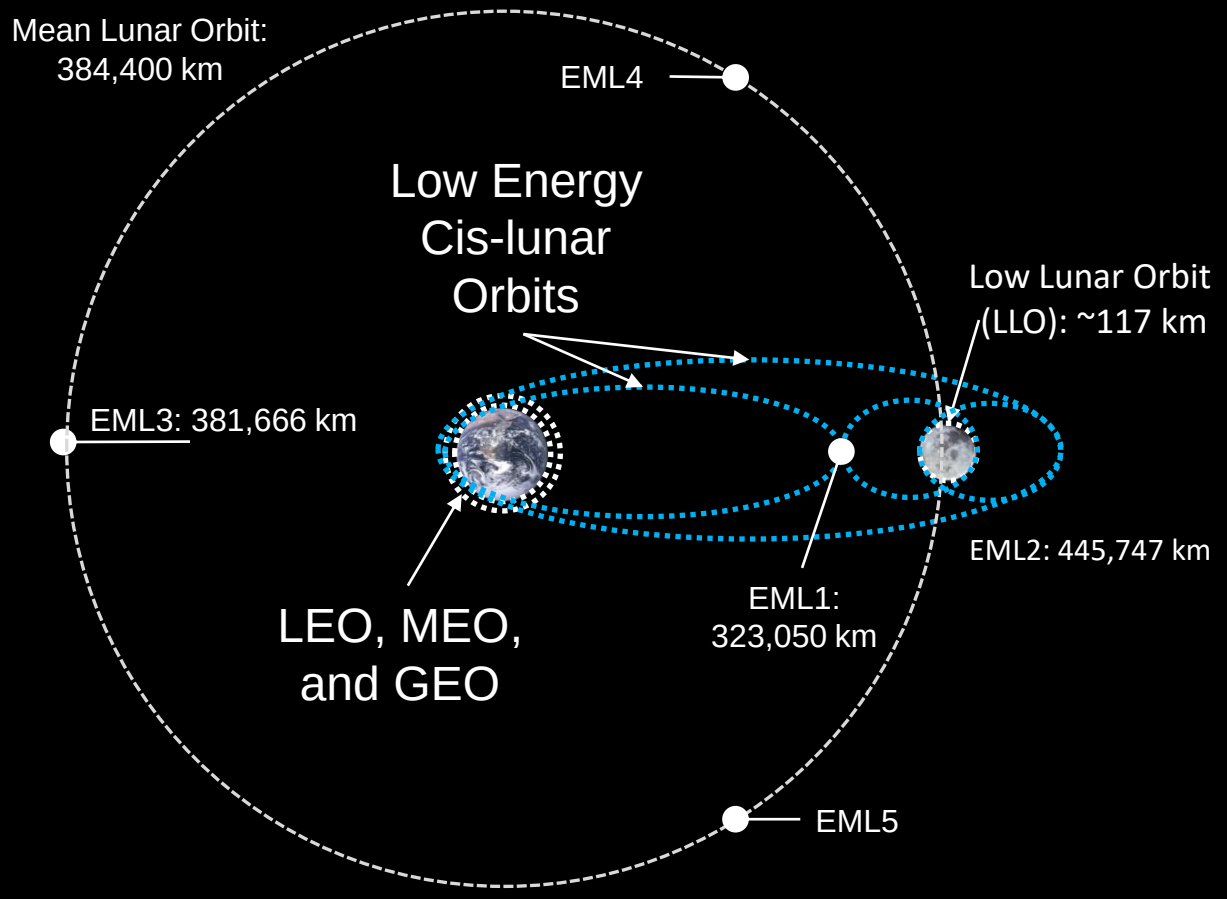
Hydrogen Transfer and Storage

Transporting Hydrogen through cis-lunar space is complicated

Variable Storage times
- Supply vehicle can launch days to months before target vehicle

No buoyancy to help separate the cryogenic fluids from evolved gases
- Complex multi-phase fluid flow

Complex Thermal Environment
- Very large temperature differences between sun-facing and deep-space facing surfaces
- Radiation only available heat sink
- Challenging to pre-cool target system while retaining cryogenic fluids within the system



Lagrange Points of the Earth-Moon (EM) System as viewed from above the Earth-Moon Orbital Plane

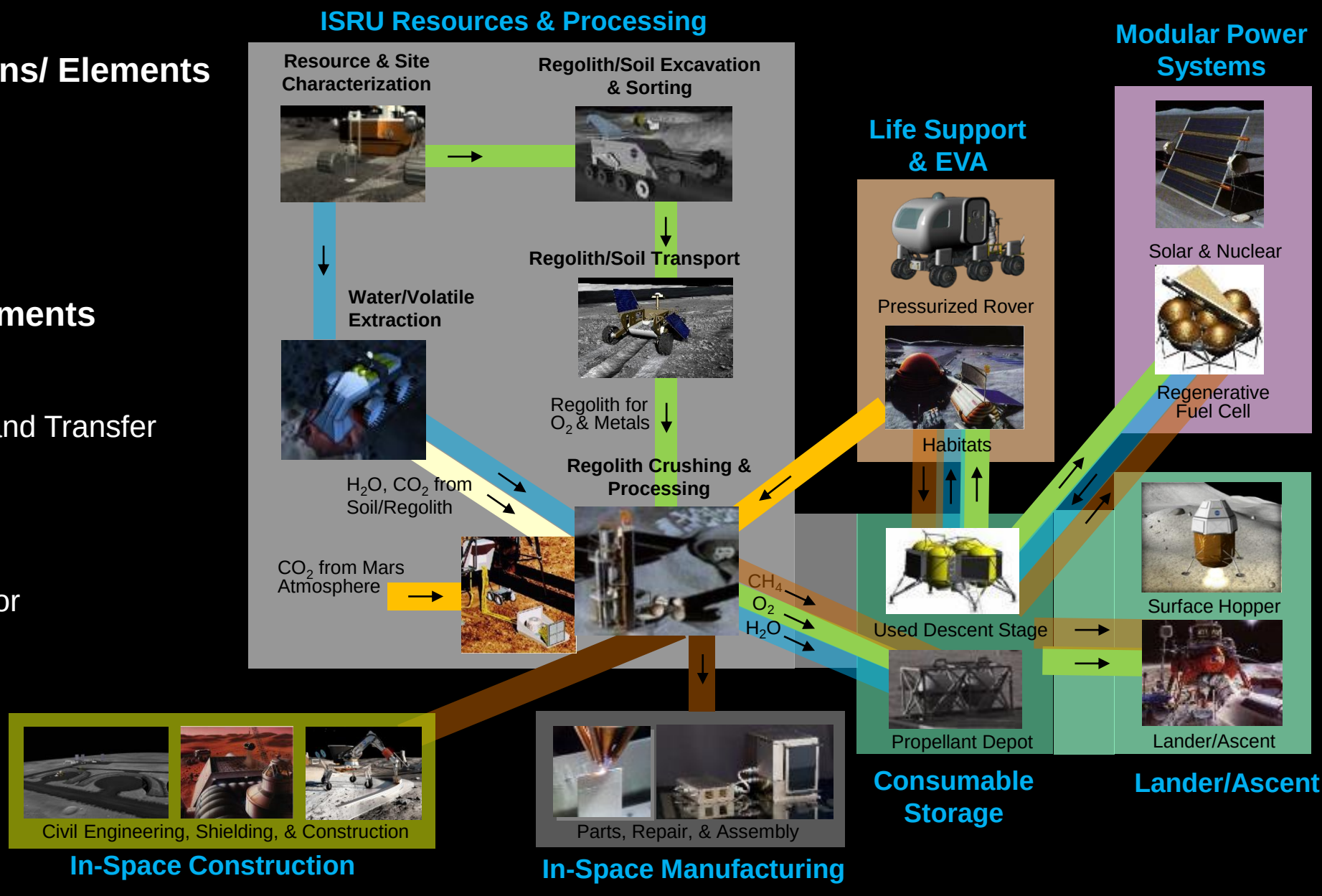
Image Not to Scale

In-situ Resource Utilization (ISRU)

Modular Power Functions/ Elements
- Power Generation
- Power Distribution
- Energy Storage (O_2 & H_2)

Support Functions /Elements
- ISRU
- Life Support & EVA
- O_2, H_2, and CH_4 Storage and Transfer

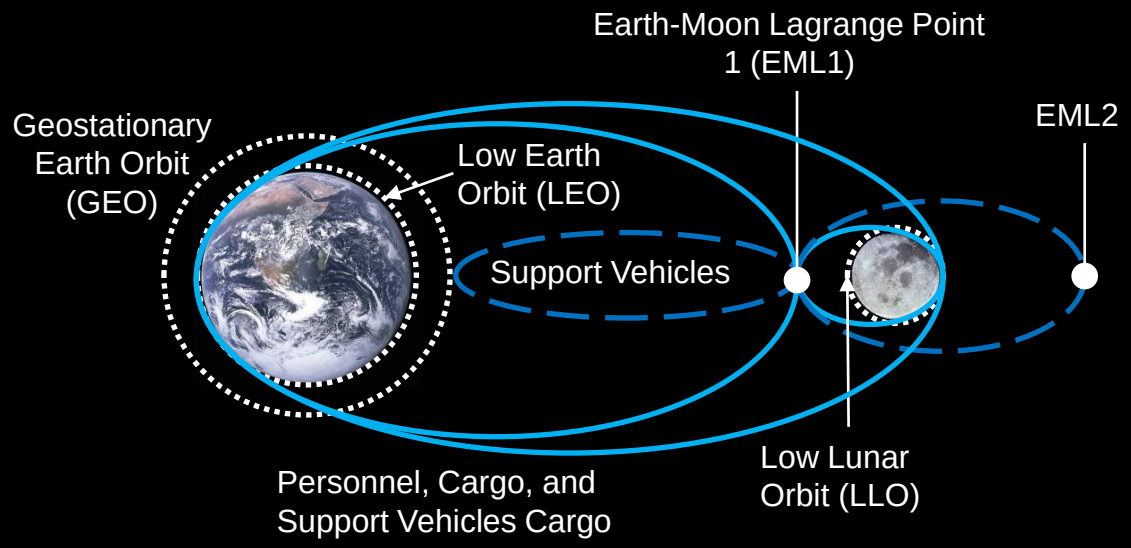
Shared Hardware to Reduce Mass & Cost
- Solar arrays/nuclear reactor
- Water Electrolysis
- Reactant Storage
- Cryogenic Storage
- Mobility



Making Propellants on Planetary Surfaces Saves on Launches and Cost (Gear Ratio Effect)

Every 1 kg of propellant made on the Moon or Mars saves 7.5 to 11.2 kg in LEO

- Enable exploration by staging required resources in forward locations
  - Earth Orbit (LEO, GEO)
  - LaGrange Points (EML1 and EML2)
  - Lunar Orbit
  - Lunar Surface
- Resources include propellant depots, propellant production facilities (initially H_2 and O_2), and consumable storage

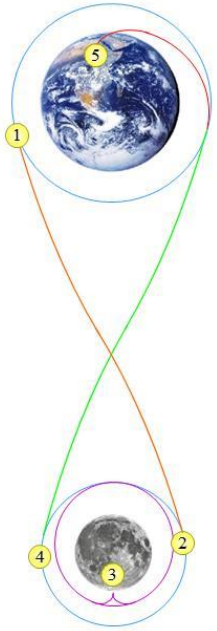


Potential >283 mT launch mass saved in LEO = 3+ SLS launches per Mars Ascent

- Savings depend on in-space transportation approach and assumptions; previous Mars gear ratio calculations showed only a 7.5 kg saving
- 25,000 kg mass savings from propellant production on Mars for ascent = 187,500 to 282,500 kg launched into LEO

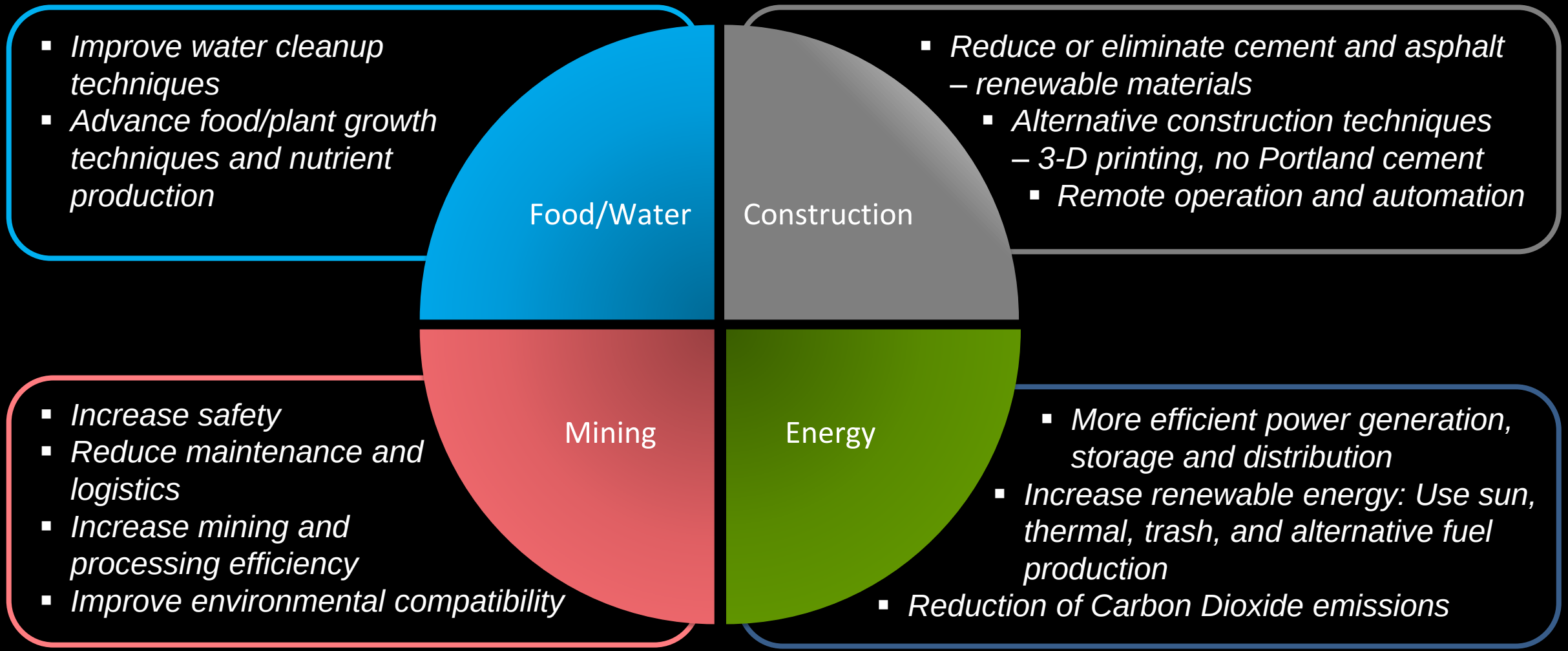
Moon Lander: Surface to NRHO

- Crew Ascent Stage (1 way): 3 to 6 mT O_2
- Single Stage (both ways): 40 to 50 mT O_2/H_2



A Kilogram of Mass Delivered Here…	…Adds This Much Initial Architecture Mass in LEO	…Adds This Much To the Launch Pad Mass
Ground to LEO	-	20.4 kg
LEO to Lunar Orbit (#1→#2)	4.3 kg	87.7 kg
LEO to Lunar Surface (#1→#3; e.g., Descent Stage)	7.5 kg	153 kg
LEO to Lunar Orbit to Earth Surface (#1→#4→#5; e.g., Orion Crew Module)	9.0 kg	183.6 kg
Lunar Surface to Earth Surface (#3→#5; e.g., Lunar Sample)	12.0 kg	244.8 kg
LEO to Lunar Surface to Lunar Orbit (#1→#3→#4; e.g., Ascent Stage)	14.7 kg	300 kg
LEO to Lunar Surface to Earth Surface (#1→#3→#5; e.g., Crew)	19.4 kg	395.8 kg

Lunar Exploration is Synergistic with Terrestrial Needs



- *Improve water cleanup techniques*
- *Advance food/plant growth techniques and nutrient production*

- *Reduce or eliminate cement and asphalt – renewable materials*
  - *Alternative construction techniques – 3-D printing, no Portland cement*
    - *Remote operation and automation*

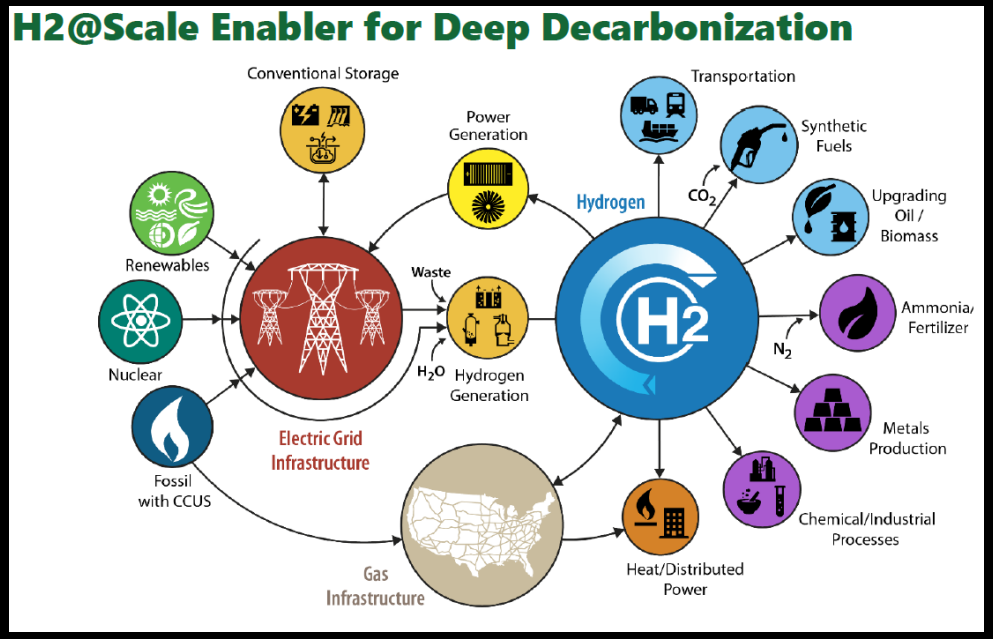
- *Increase safety*
- *Reduce maintenance and logistics*
- *Increase mining and processing efficiency*
- *Improve environmental compatibility*

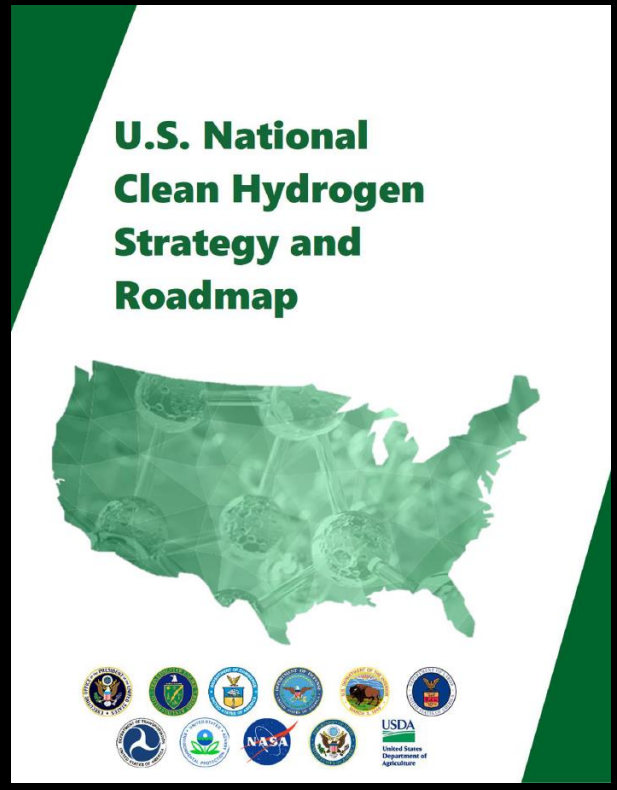
- *More efficient power generation, storage and distribution*
- *Increase renewable energy: Use sun, thermal, trash, and alternative fuel production*
- *Reduction of Carbon Dioxide emissions*

Promote *Reduction, Reuse, Recycle, Repair, Reclamation*
…for benefit of Earth, and living in Space.

U.S. National Clean Hydrogen Strategy and Roadmap

- U.S. National Clean Hydrogen Strategy and Roadmap outlines the Administration's plan to implement the Carbon-reduction activities outlined in the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA)
  https://www.hydrogen.energy.gov/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf
- Department of Energy (DOE) leads an "all-of-government" Hydrogen Interagency Taskforce (HIT) to guide the implementation of the Hydrogen Strategy and Roadmap
  https://www.hydrogen.energy.gov/interagency.html






Thank you for your attention.



Questions?