Ohio Fuel Cell and Hydrogen Coalition Symposium

At Stark State University
20 November 2024

# Update on NASA Hydrogen and Fuel Cell Activities

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Fuel Cell Technology Lead (GRC)
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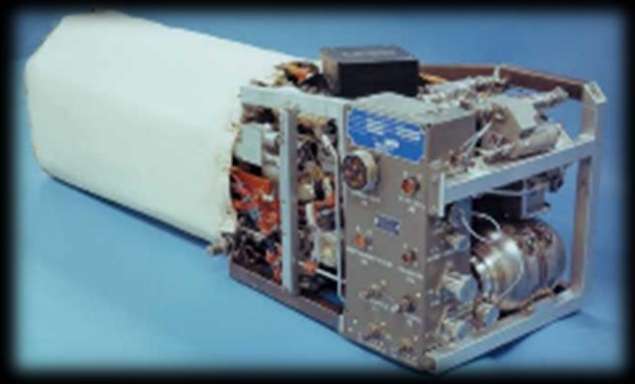
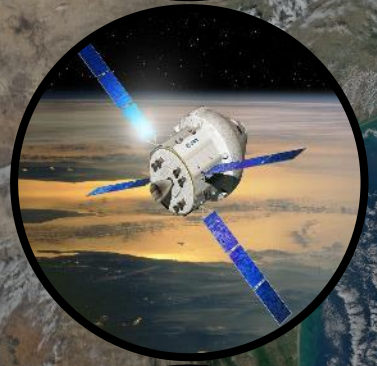


## Mission

We drive research, technology, and systems to advance aviation, expand human presence across the solar system, enable exploration of the universe, and improve life on Earth.



## Strategic Goals

- Expand Human Knowledge Through New Scientific Discoveries
- Extend Human Presence to the surface of the Moon and onto Mars for Sustainable Long-Term Exploration, Development, and Utilization
- Catalyze Economic Growth and Drive Innovation to address National Challenges
- Enhance Capabilities and Operations to catalyze current and future mission success

# Fuel Cell and Hydrogen Applications 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*

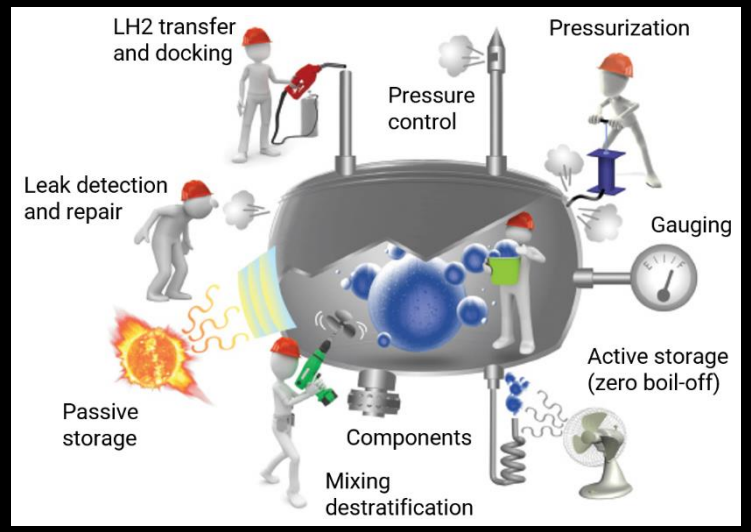
$H_2O$

## ***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*

$H_2$ $O_2$ $H_2$ $O_2$

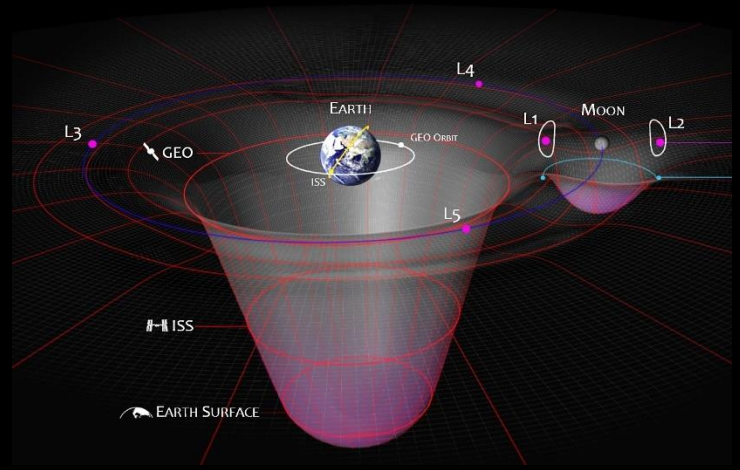


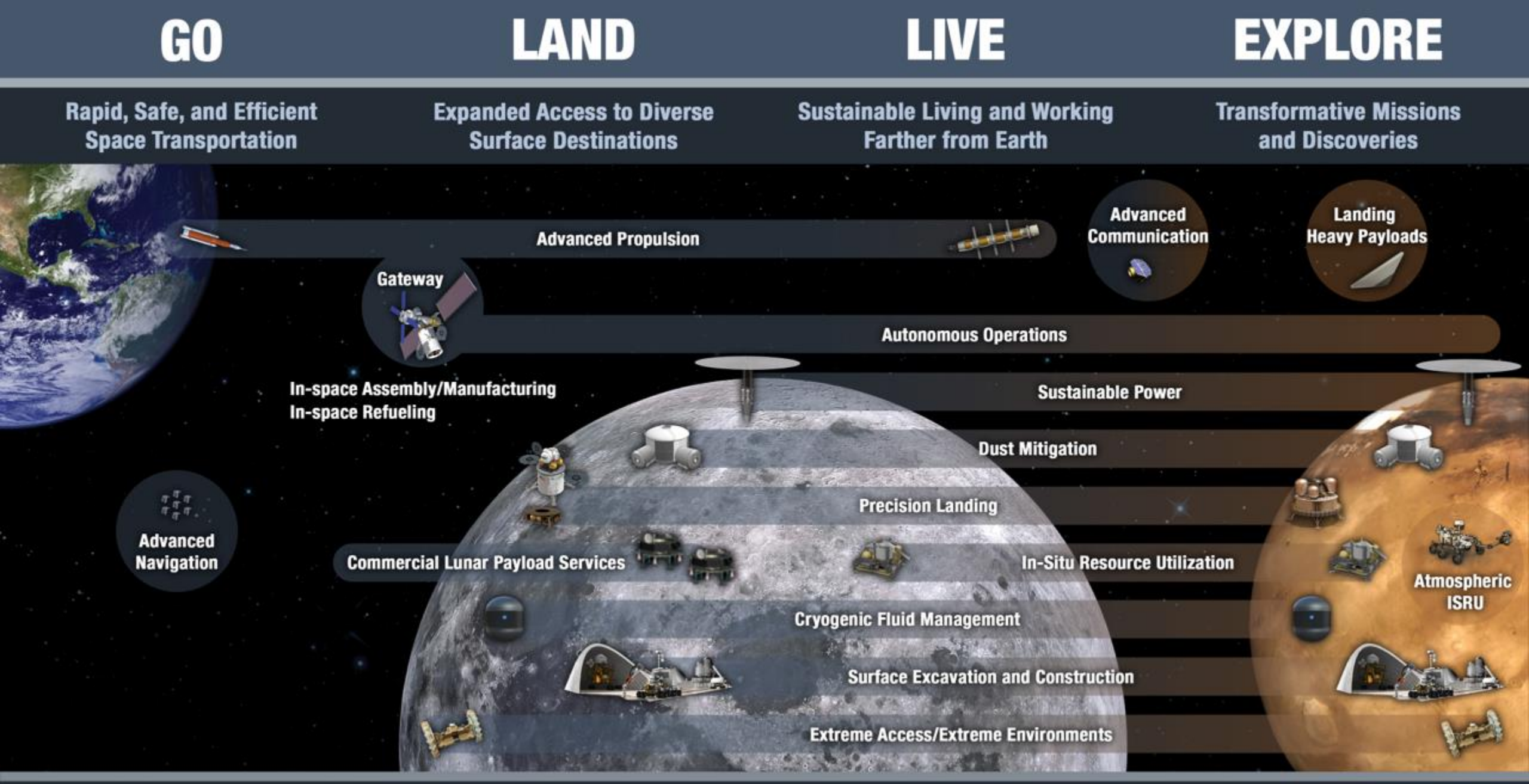

## ***Energy Storage***

*Long-term reactant storage and management*

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

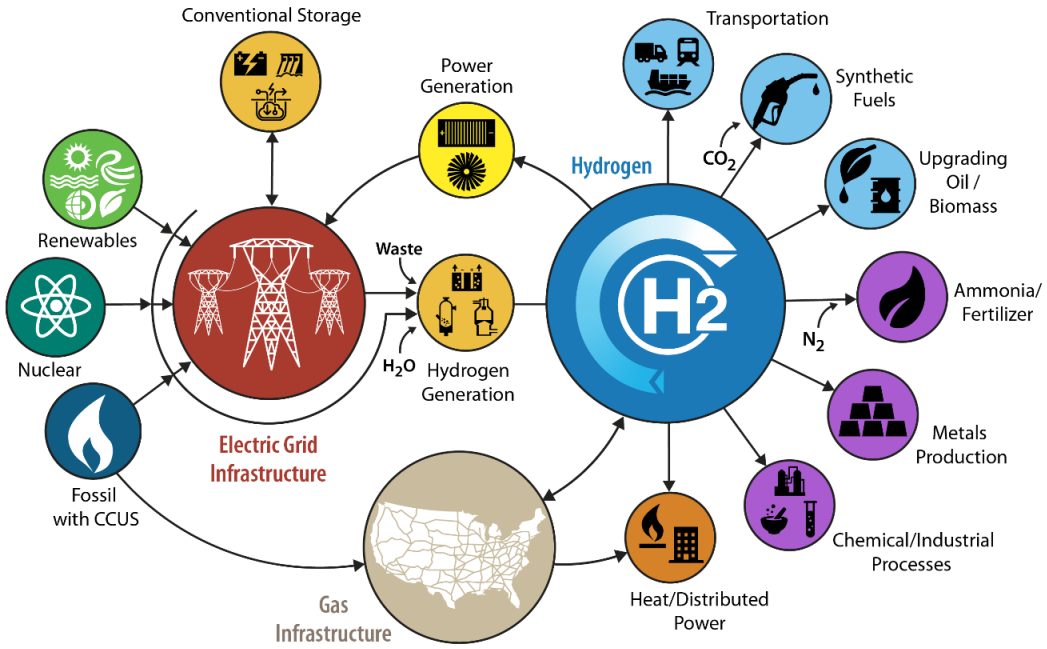
Cis-lunar space

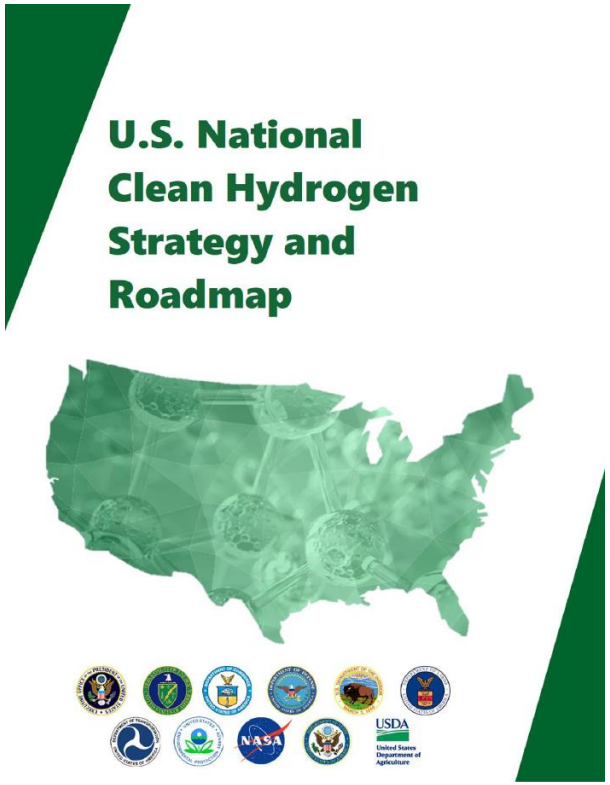



GO
LAND
LIVE
EXPLORE
Rapid, Safe, and Efficient Space Transportation
Expanded Access to Diverse Surface Destinations
Sustainable Living and Working Farther from Earth
Transformative Missions and Discoveries
Advanced Propulsion
Advanced Communication
Landing Heavy Payloads
Gateway
Autonomous Operations
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

# U.S. National Clean Hydrogen Strategy and Roadmap

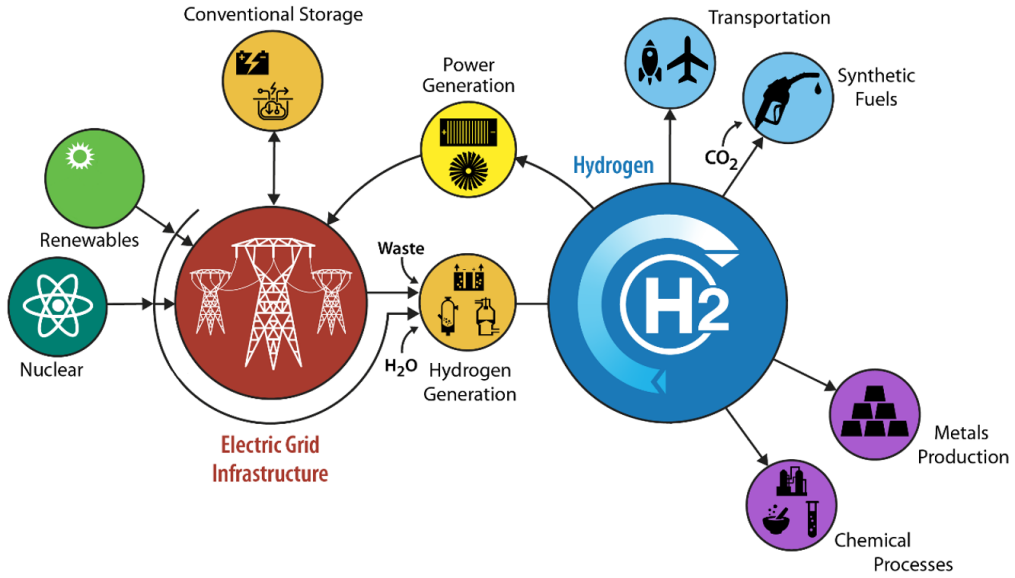
- U.S. National Clean Hydrogen Strategy and Roadmap outlines the Administration's plan to implement the Carbon-reduction activities outlined in the Bipartisan Infrastructure Law (BIL) and Inflation Reduction Act (IRA)
- Department of Energy (DOE) leads an "all-of-government" Hydrogen Interagency Taskforce (HIT) to guide the implementation of the Hydrogen Strategy and Roadmap

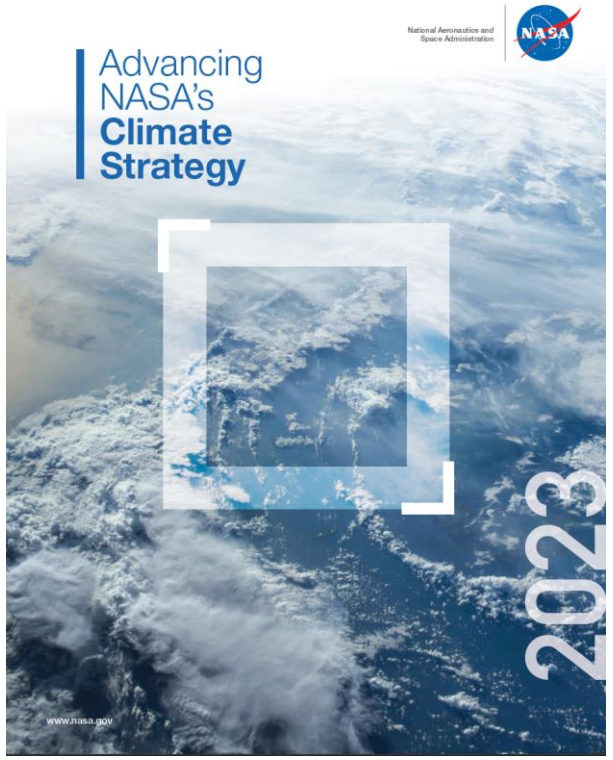


# NASA Climate Strategy

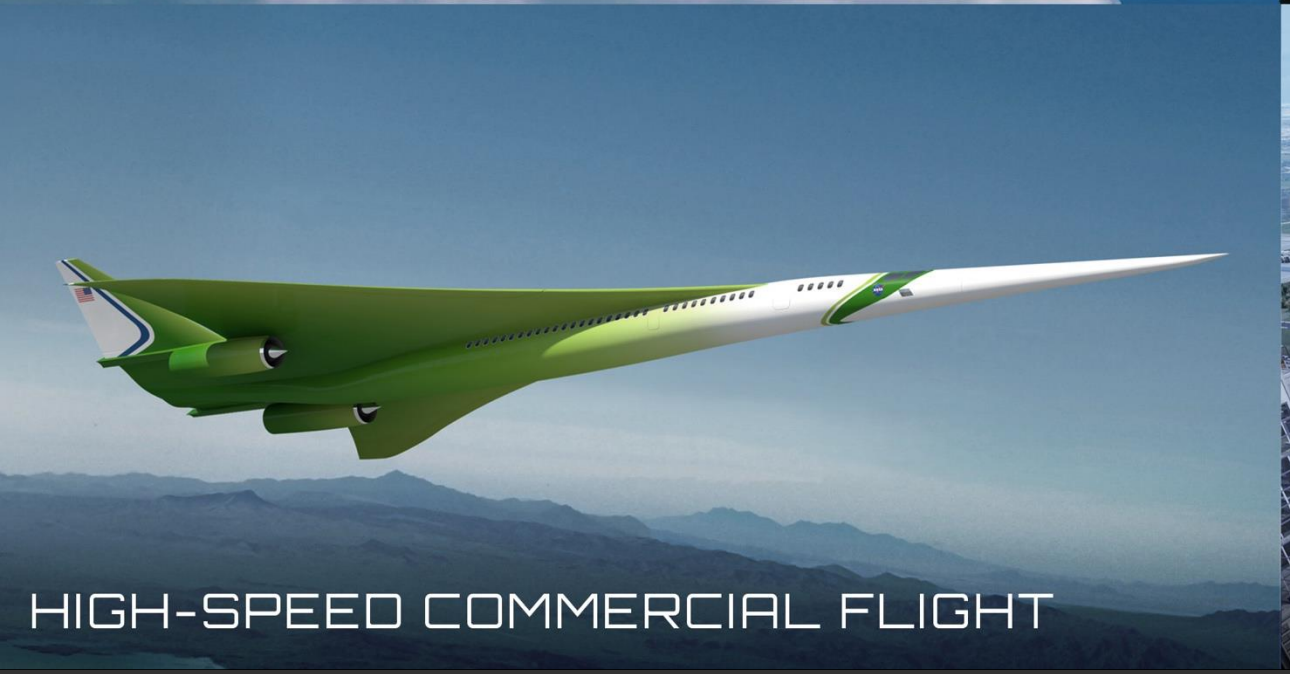
- NASA actively participates in the DOE Hydrogen Interagency Taskforce (HIT)
  - Supports all Working Groups and some Cross-cutting Teams
  - Hydrogen Training available to participating HIT agencies
- DOE HIT activities align with NASA Climate Strategy released last year



# Aeronautics







Four Transformations for Sustainability, Greater Mobility, and Economic Growth

# Sustainable Flight National Partnership Benefits

Small Core Gas Turbine for 5%-10% fuel burn benefit

Electrified Aircraft Propulsion for ~5% fuel burn and maintenance benefit

Sustainable Aviation Fuels for reduced lifecycle carbon emissions

Transonic Truss-Braced Wing for 5%-10% fuel burn benefit

High-Rate Composites for 4-6x manufacturing rate increase

Integrated Trajectory Optimization for 1%-2% reduction in fuel required and minimization of contrail formation

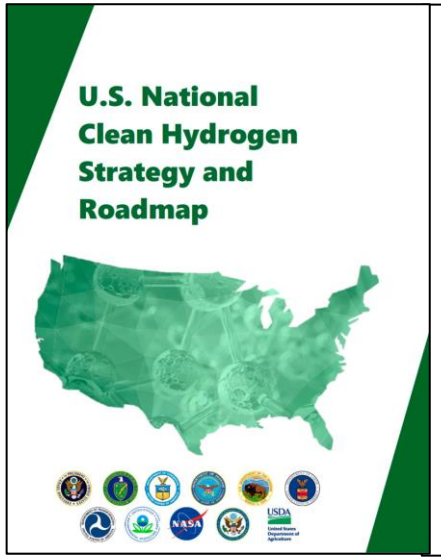
Next-generation transports using up to 30% less fuel, current and future fleets flying optimal trajectories, engines burning sustainable aviation fuels for net-zero lifecycle greenhouse gas emissions

# Beyond-SFNP as part of a National Strategy


## FAA

Net-Zero GHG emissions from aviation by 2050

Assumption of SAF-dominated aviation fuels landscape




## DOC/DOD/DOE/DOI/DOL/ DOT/EPA/NASA/USDA+

National clean H2 production and infrastructure strategy

National H2 production goals:

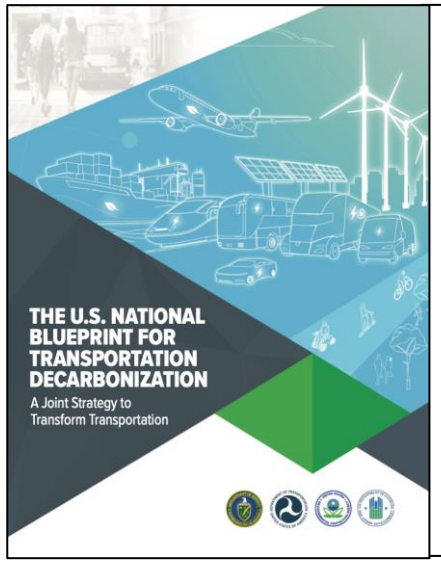
- 10 MMT/year by 2030
- 20 MMT/year by 2040
- 50 MMT/year by 2050


## DOE/DOT/FAA/USDA/EPA

References US Aviation Climate Action Plan goals

Establishes national goals for SAF production of:

- 3B gal/year by 2030
- 35B gal/year by 2050




## DOE/DOT/EPA/DOH

Transportation sector wide decarbonization strategy

Three strategic pillars:

1. Community redesign
2. Improved efficiency
3. Transition to clean fuels

NASA contributes aeronautics and space perspectives, technologies, and experience

# TACP exploration … beyond-SFNP, toward zero-carbon pathways


**Transformational Tools and Technologies Project**

- Green Aviation exploratory investments
- Aviation battery systems and prognostic safety
- Advanced materials & structures
- MDAO tools for advanced vehicle configuration design


**Convergent Aeronautics Solutions Project**

- Powering Sustainable Airports 2075
- Airports as Energy Nodes
- Solid-state batteries for UAM
- Multi-MW DEP-PAI aircraft concepts and technologies
- Hydrogen-fueled aircraft concepts and technologies
- Power beaming


**University Innovations Project**

- University Leadership Initiative – Zero Emissions Aviation Strategy
- University Student Research Challenge (USRC)
- Gateways to Blue Skies Competition


*Transformative Aeronautics Concepts Program serves as the ARMD Innovation Ecosystem evolving an opportunity roadmap*

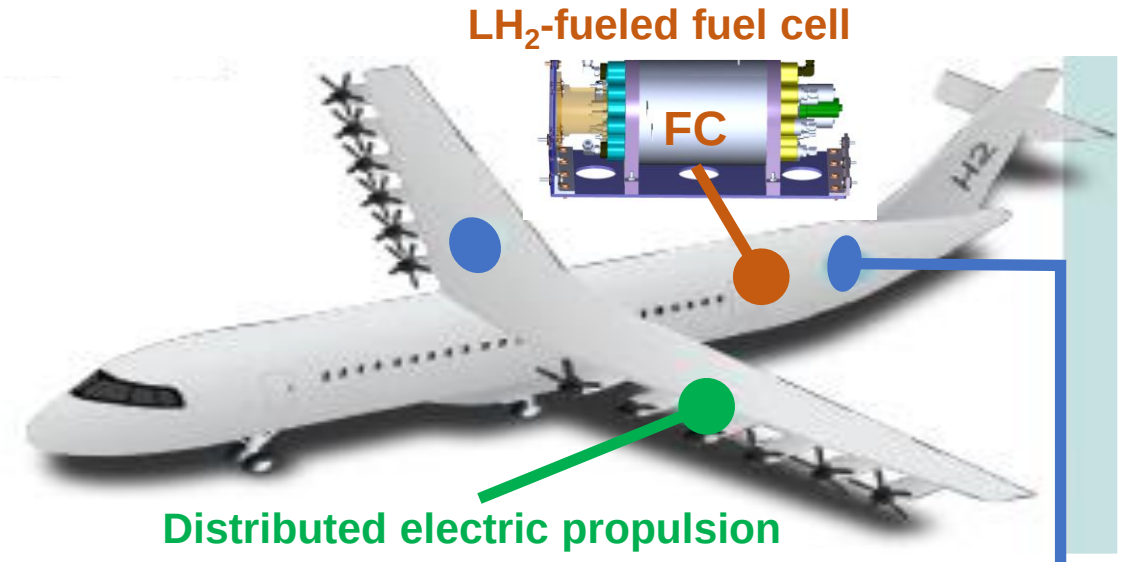
TACP's Sustainable Aviation portfolio is a fertile breeding ground for low-TRL concepts and technologies. Strong ties between AAVP and TACP are foundational to this transformation.

# $CH_2$ARGE – Commercially-viable Hydrogen Aircraft for Reduction of Greenhouse Emissions

**Led by NASA Glenn Research Center , PI: V. Lvovich**

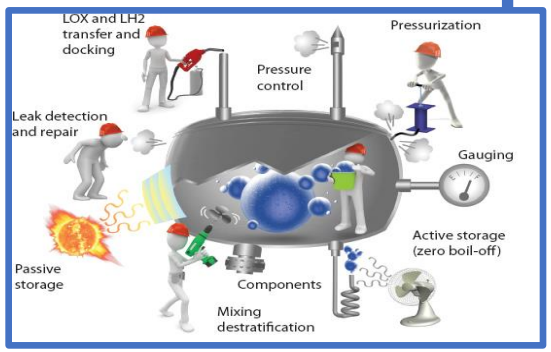
- Engages five NASA centers
- Intent: Decarbonize regional and narrow-body markets
- Concept: LH2-fueled, $H_2$-air fuel-cell powered, cryo-cooled DEP

- Conducting conceptual design / system trades for aircraft architecture, technologies, components, and performance requirements
- Evolving roadmaps for aircraft architecture, thermal management systems, cryogenic systems, and fuel cells
- Enhancing component performance entitlements by applying AI/ML and physics-based modeling to materials database for cryogenic and fuel-cell materials. Testing enabling materials.
- Establishing tools for system-level TMS design & power architecture analysis
- Studying environmental impact of predicted emissions




**Vision vehicle and Design mission**

- 80-200 PAX
- 500-3000 nm range
- Cruise Mach 0.4-0.8
- Highly efficient wing




**$LH_2$ tanks on wings or behind PAX cabin**

CH2ARGE exercises NASA's role in $H_2$-fueled EAP, advances technology pathways and readiness, develops workforce & capabilities, and leverages NASA space-side competencies in LH2 technology & operations

# Collaborative Hydrogen Aero Testing Area

**Opportunity:**

There is a large and increasing need for hydrogen test capabilities for the development of components, subsystems, and systems for aircraft and other transportation systems. Industry is showing a desire to develop systems for clean energy solutions, but testing with hydrogen, and especially liquid hydrogen is challenging and costly. Furthermore, there is a need to explore the trade-space around operational aircraft refueling. There may be synergistic ways to combine the two problems.





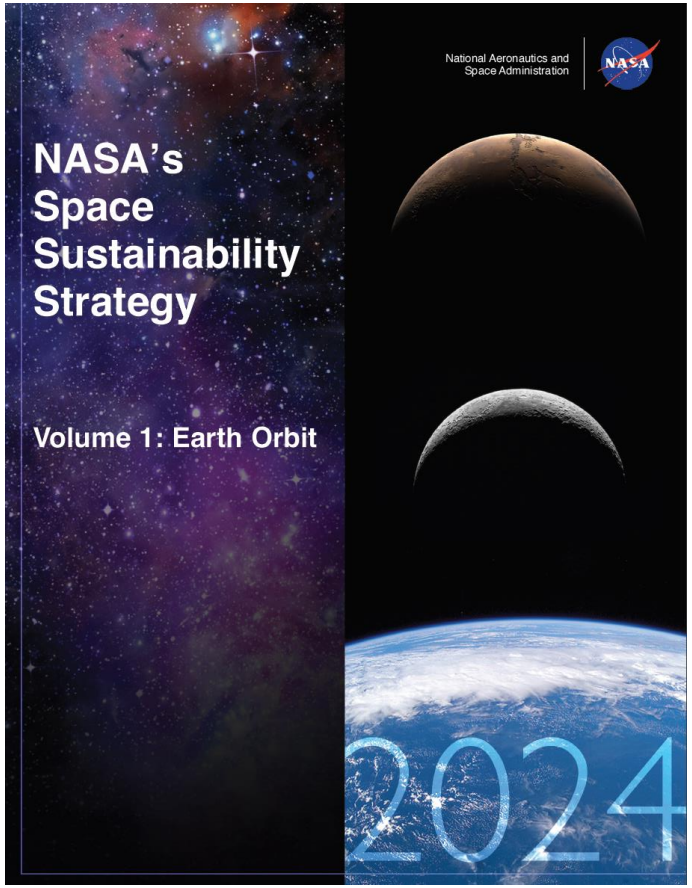

**"Wicked-Wild" Idea:**

Development of an airport-like liquid hydrogen test and development center of excellence that can support US Industry and US Government development needs utilizing NASA's facilities and experience that provides capabilities within practical timelines.

# Space

# NASA's Space Sustainability Strategy

- NASA defines space sustainability as the ability to maintain the conduct of space activities indefinitely into the future in a manner that is safe, peaceful, and responsible to meet the needs of the present generations while preserving the outer space environment for future activities and limiting harm to terrestrial life.
- The Agency will increase its role as a global leader in space sustainability by fulfilling the following key responsibilities.
  - Provide science and technology leadership in the United States and the global space community on space sustainability topics.
  - Support equitable access to and use of space now and in the future.
  - Ensure that NASA's missions and operations—including those it undertakes with non-NASA entities—maintain or enhance space sustainability.



# NASA Moon2Mars – Mission Architecture


- **Human Lunar Return**
- **Foundational Exploration**
- **Sustained Lunar Evolution**
- **Humans to Mars**

**Lunar Infrastructure (LI)**

LI-1: Develop an incremental Lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.

**Mars Infrastructure (MI)**

MI-1: Develop Mars surface power sufficient for an initial human Mars exploration campaign

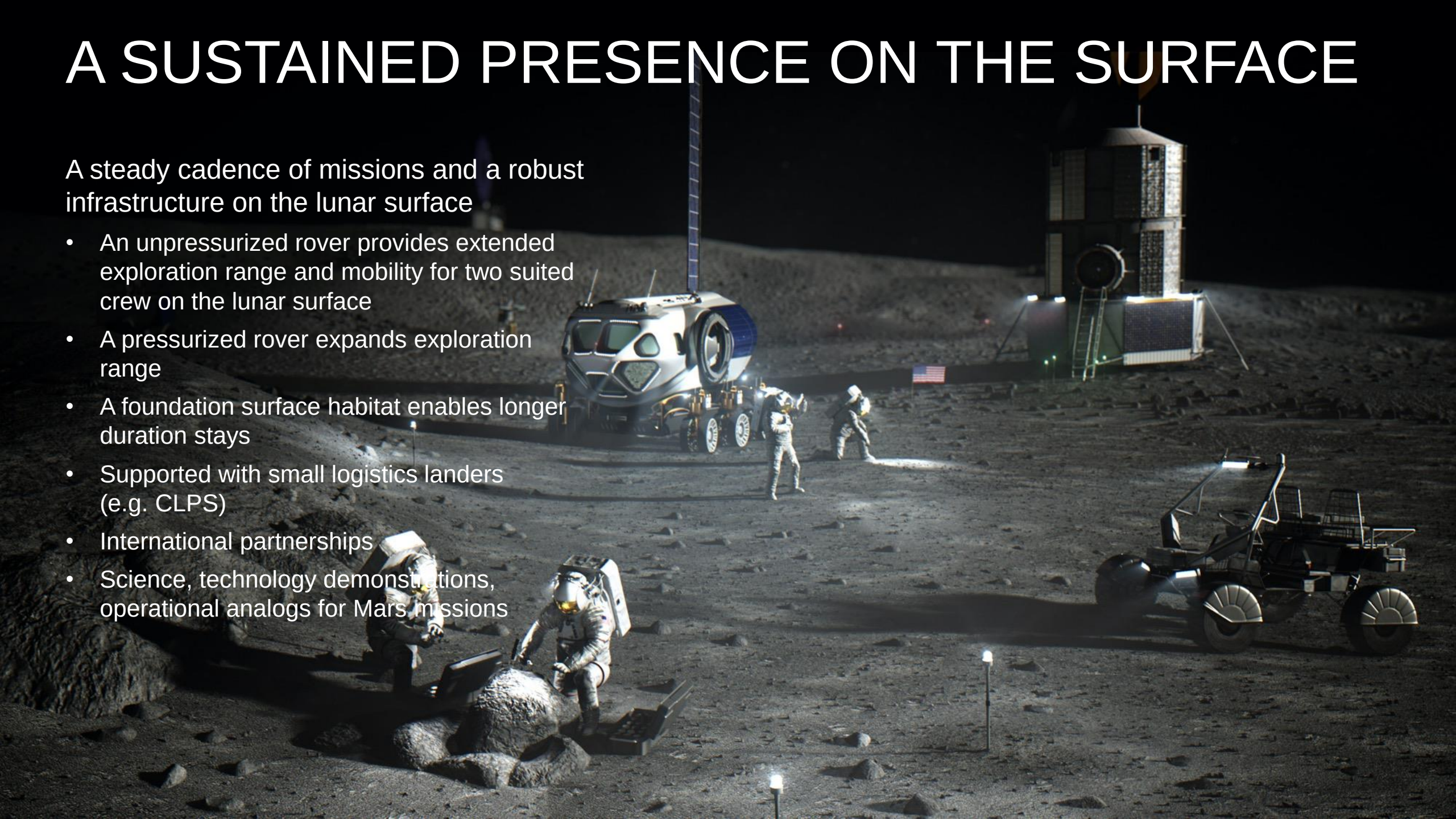
NASA Moon to Mars Architecture

Executive Summary

Architecture Definition Document

Artemis

# A SUSTAINED PRESENCE ON THE SURFACE

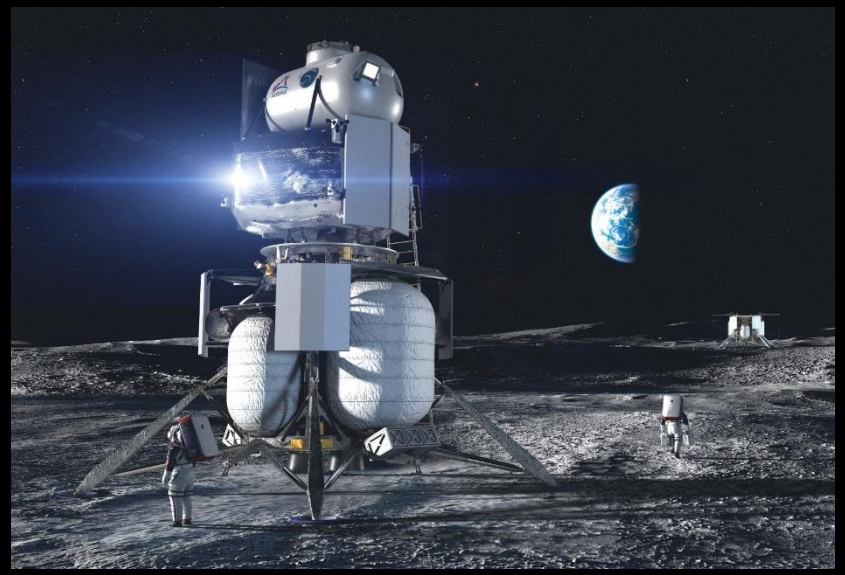


A steady cadence of missions and a robust infrastructure on the lunar surface

- 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

# Known Space Technical Gaps

1. **Availability:**
   - New technologies not yet flight qualified for microgravity applications
   - No flight-qualified fuel cell since the end of the Space Shuttle Program
2. **Operational Life:**
   - Pure oxygen reactants provide challenging operational environment
   - Space Missions have limited maintenance options
   - Long dormancy periods with large thermal variations
3. **System Integration**
   - Advantageously leveraging different systems to reduce overall vehicle mass
   - Putting it all together in a low-mass cost-effective package
4. **Specific Energy**
   - Increase system-level specific energy to increase vehicle payload capacity

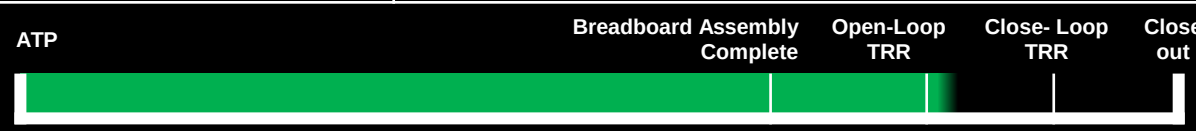


# Regenerative Fuel Cell Project

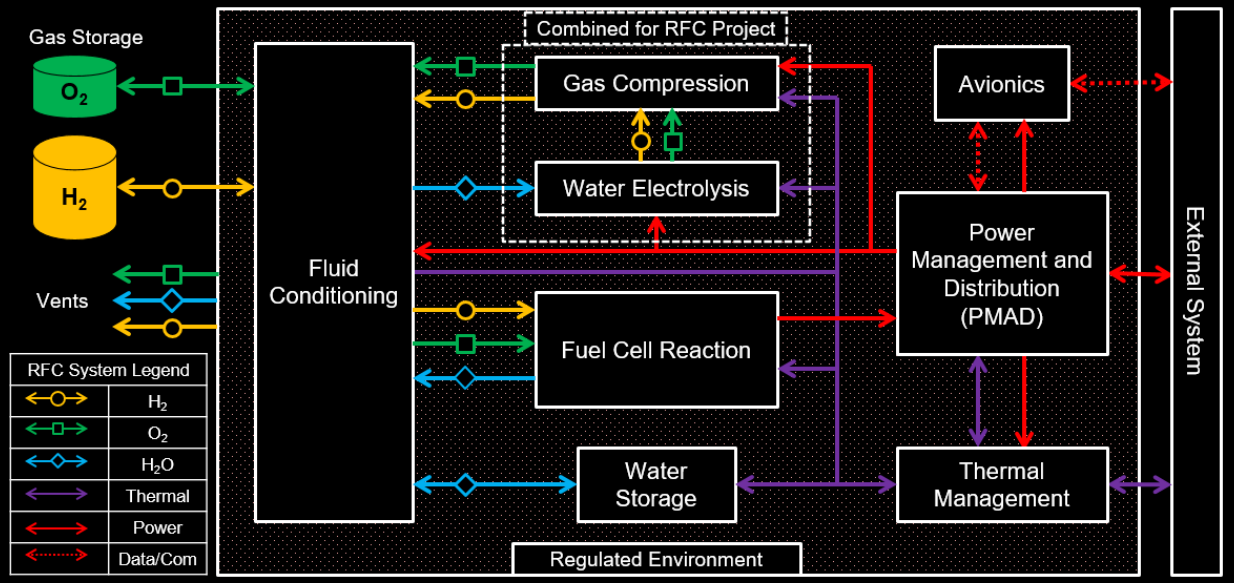
- Available energy storage technologies have low specific energies (W·hr/kg) imposing unacceptable mass onto lunar surface missions
- NASA funds research of multiple technologies to maximize specific energy, including hydrogen ($H_2$) / oxygen ($O_2$) regenerative fuel cell (RFC) energy storage technology
- RFC project to assess viability of optimized discrete *system* technology for potential inclusion into lunar surface missions

**Regenerative Fuel Cell Project Overview**

| | |
|---|---|
| Design & Build $H_2$ / $O_2$ RFC System | • 50 psia Fuel Cell stack (Infinity Fuel Cell and Hydrogen)<br>• 1800 to 2500 psia Electrolyzer (Giner)<br>• Self-supporting sub-systems<br>• Automated control system |
| ≥ 2 month autonomous closed-loop test under laboratory conditions | • Full system pressures and multiple cycles<br>• Open-loop operation for system functional verification<br>• Closed-loop operation for reactant purity verification |

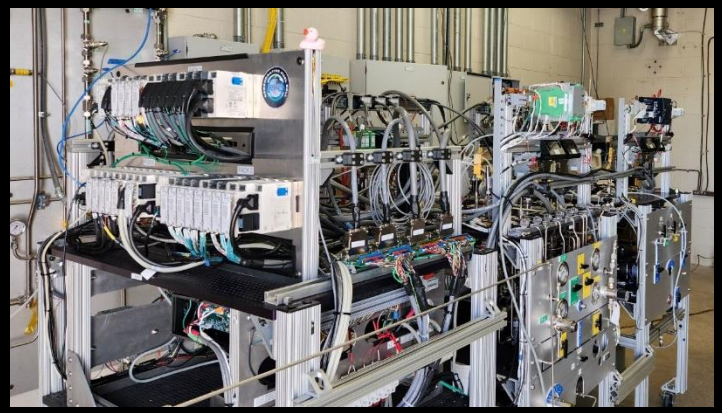



Simplified RFC Functional Block Diagram




Breadboard System Testing

- ☑ Component Verification
- ☑ System Assembly
- ☑ System Verification
- → ☐ Open-Loop Testing
- ☐ Closed-Loop Testing



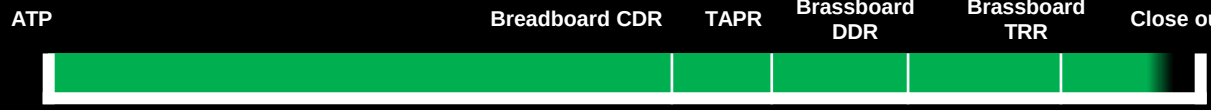
Breadboard RFC System in B334 / TC 110

# Bi-furcated Reversible Alkaline Cell for Energy Storage (BRACES) Tipping Point

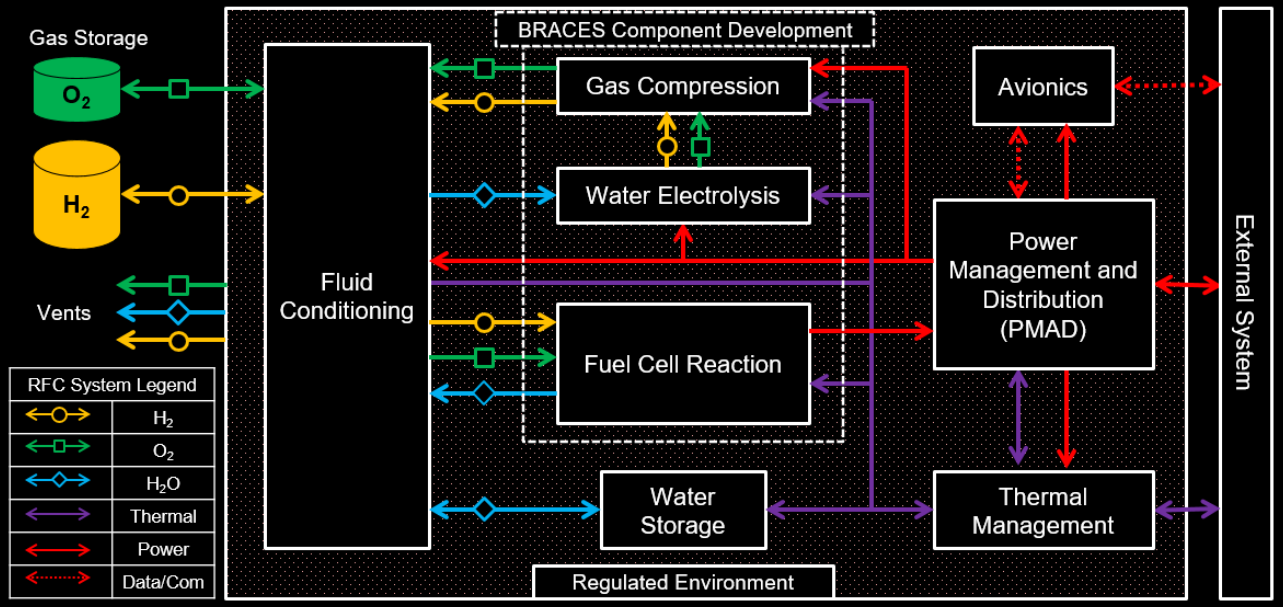
- Available energy storage technologies have low specific energies (W·hr/kg) imposing unacceptable mass onto lunar surface missions
- NASA funds research of multiple technologies to maximize specific energy, including hydrogen ($H_2$) / oxygen ($O_2$) regenerative fuel cell (RFC) energy storage technology
- BRACES project to assess viability of *unitized stack* design for potential inclusion into lunar surface missions

**BRACES Tipping Point Overview**

| | |
|---|---|
| Design & Build Unitized Stack (pH Matter) | • 250 bar (~3600 psia) Unitized stack<br>• Unitized stack to demonstrate electrolysis and fuel cell reactions |
| Design & Build Test Systems (pH Matter) | • Automated independent control system<br>• Breadboard system for Laboratory testing<br>• Brassboard system for Thermal-Vacuum test |
| Brassboard Verification Testing (GRC) | • Verify open-loop operation for system cyclic operation and performance metrics |

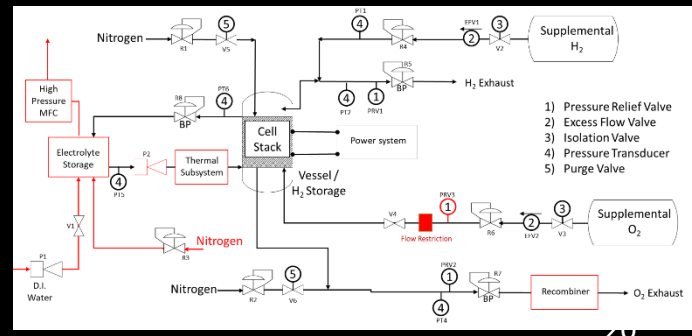



Simplified BRACES Functional Block Diagram




<u>pH Matter</u>
- Component Development (Stack)
- Breadboard System Design, Assembly, and Verification

<u>GRC</u>
- Breadboard System Open-loop Laboratory Testing (No Reactant Storage)

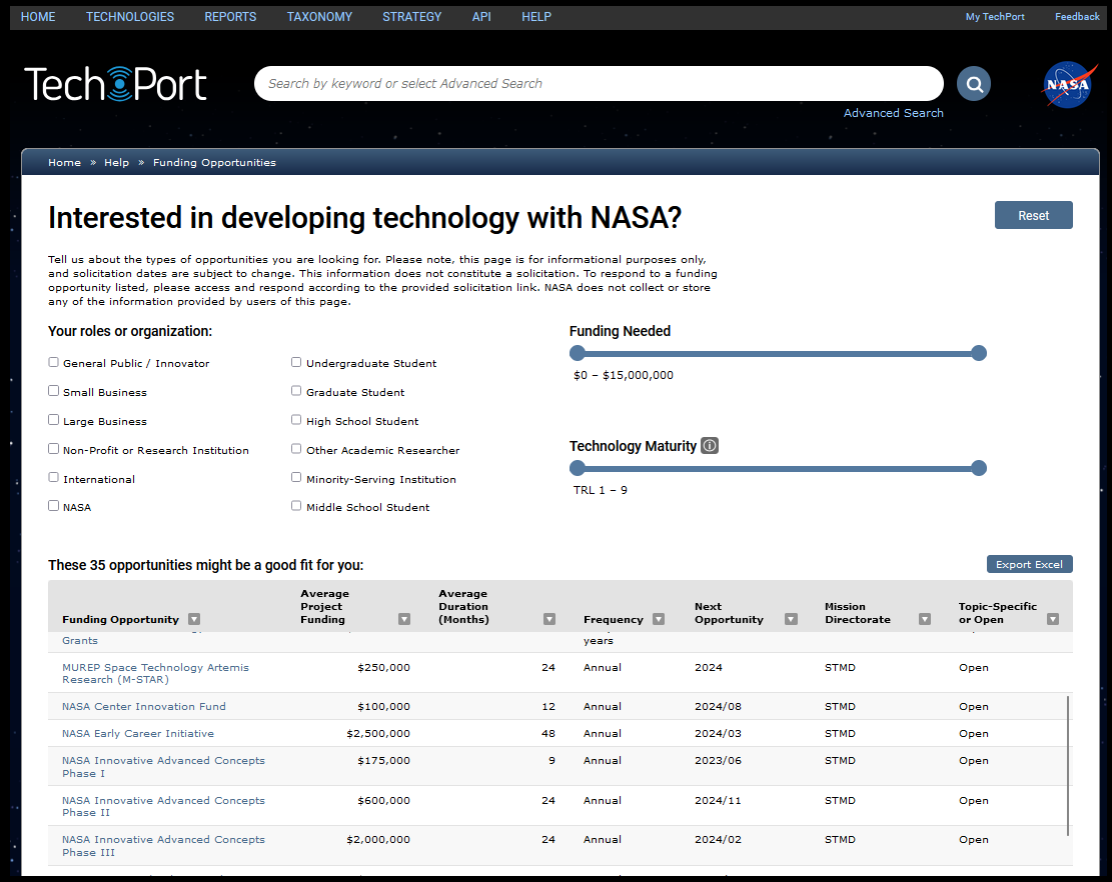


# Working With NASA

# NASA TechPort

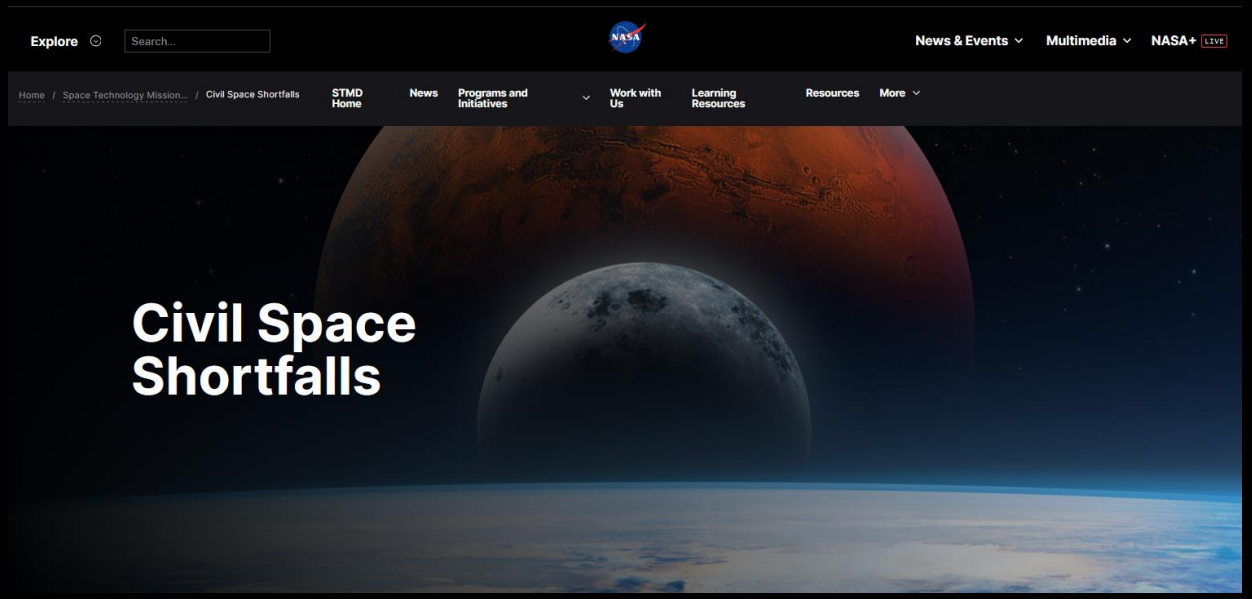
Public portal into NASA for:

- Research topics
  - Strategic Framework
  - NASA Technology Taxonomy
- Collaborations
  - Lunar Surface Innovation Consortium (LSIC)
  - Minority Serving Institutions (MSI)
  - Small Spacecraft Systems Virtual Institute (S3VI)
  - NASA's Technology Transfer Program
- NASA Funding Opportunities
  - ARMD, SMD, STMD
  - Grants
  - Graduate / Post-graduate positions
  - Solicitations (e.g. NSPIRES, SBIR / STTR, NIAC, etc.)



# NASA Priorities

NASA's Space Technology Mission Directorate (STMD) leads the development, demonstration, and infusion of transformational technologies that enhance NASA's efforts to explore the unknown in space, benefit life on Earth, and solve critical stakeholder needs.




STMD's investment strategy informs its portfolio:

1. Align with the Administration and the NASA Administrator's priorities that address the Blueprint Objectives (Artemis)
2. Focus on investments that support science priorities identified in the Decadal Surveys
3. Foster creation and growth of the space economy through partnering with industry and supporting small business innovation
4. Engage NASA's workforce to deliver innovative solutions to the nation's toughest technology challenges
5. Encourage transformative, cross-cutting technologies that benefit NASA as well as other government agencies
6. Empower a broad community of innovators and academia through emphasis on early-stage investments


# Questions?


Thank you for your attention.