Parallax Advanced Research and The Ohio State University

HYDROGEN FUEL CELL

Hybrid Event (virtual & on-site)

Parallax ADVANCED RESEARCH

THE OHIO STATE UNIVERSITY SUSTAINABILITY INSTITUTE

THE OHIO STATE UNIVERSITY CENTER FOR AUTOMOTIVE RESEARCH

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

Giorgio Rizzoni

The Ford Motor Company Chair in Electromechanical Systems; Professor, Mechanical and Aerospace Engineering; and the Director of The Ohio State University Center for Automotive Research

CENTER FOR AUTOMOTIVE RESEARCH

OVERVIEW

THE OHIO STATE UNIVERSITY

CENTER FOR AUTOMOTIVE RESEARCH

CENTER FOR AUTOMOTIVE RESEARCH

OUR MISSION

To provide world-class education for the next generation of automotive industry leaders, through on-campus learning and continuous professional development;

To serve as a catalyst for innovation in automotive technology through collaborative, interdisciplinary research;

To support economic development, regionally and nationally.

RESEARCH AREAS OF EXPERTISE

PROPULSION SYSTEMS AND CONTROL

Contemporary Engines and Turbochargers
Thermofluids - Acoustics

IC Engine and Powertrain
Modeling - Control Diagnostics

Thermal and Energy Management

Vehicle Emissions

Control Systems

ELECTRIFICATION

Energy Storage
Materials and Cell Development – Material Synthesis and Characterization/Pouch Cell Fabrication

Hybrid and Electric Powertrain
Modeling - Control Diagnostics - xIL tools- Demonstration Vehicles

EV Charging and Grid Interaction

Electric Machine Design

AUTONOMOUS AND CONNECTED VEHICLES

Automated Driving

Advanced Driver Assistance Systems

Test Cases for Automated Vehicles

Driver-in-the-Loop Simulation

Vehicle Connectivity

V2V and V2X Communications

SAFETY AND SECURITY

Cybersecurity

Functional Safety

Pedestrian and Occupant Safety

System Fault Diagnosis

SMART MOBILITY

Transportation in Smart Cities

Data Platforms and Telematics

Mobility as a Service

Sustainability

OUR PEOPLE

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

OUR STUDENTS

31 undergraduate students

24 female students

87 graduate students

13 different countries

46
domestic

72
international

87

Masters and PhD students have graduated in the past 5 years prepared and ready to enter the workforce

OUR TEAM

21
Visiting Scholars

45
Research and Administrative Staff

89
CAR Collaborating Faculty

SELECT CURRENT RESEARCH PROGRAMS

FTA Low- and No-Emissions Transit Testing

ARPA-E NEXTCAR Phase 1 and 2

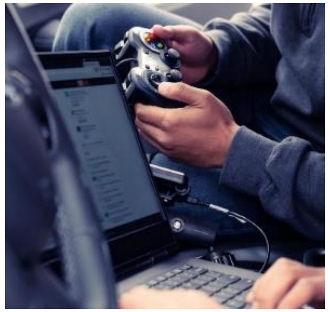
arpa-e

Urban Air Mobility and Aviation Electrification

NASA

Energy Storage Research

Mobility Division of Ohio State Cybersecurity Institute



DOT University Transportation Centers: *Crash Imminent Safety* and *Highly Automated Transportation Safety*

DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

Project Collaboration with TRC SMART Center

Over the past two years CAR, TRC and DriveOhio (ODOT) have partnered to win more than $30M in federal awards related to Smart Mobility.

METHODS OF ENGAGEMENT

BUSINESS UNITS

- SPONSORED RESEARCH
- MEMBERSHIP CONSORTIUM
- ENGINEERING SERVICES
- CONTINUING EDUCATION

EXPERIENTIAL LEARNING

- OUTREACH AND ENGAGEMENT
- MOTORSPORTS AT OHIO STATE
- STUDENT PROJECTS

RESEARCH

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH

RESEARCH AREAS OF EXPERTISE

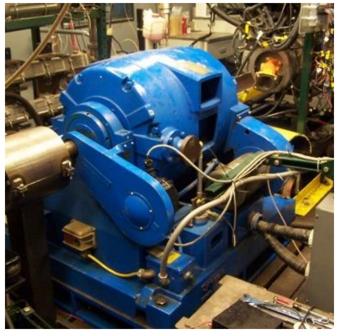
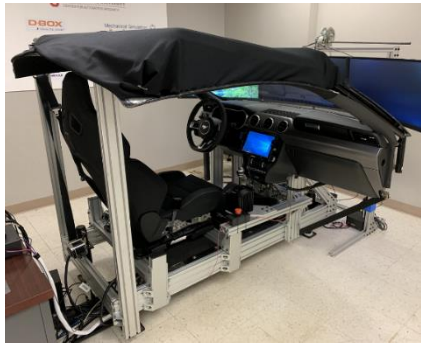
PROPULSION SYSTEMS AND CONTROL	ELECTRIFICATION	AUTONOMOUS AND CONNECTED VEHICLES	SAFETY AND SECURITY	SMART MOBILITY
Contemporary Engines and Turbochargers *Thermofluids - Acoustics* IC Engine and Powertrain *Modeling - Control Diagnostics* Thermal and Energy Management Vehicle Emissions Control Systems	Energy Storage *Materials and Cell Development – Material Synthesis and Characterization/Pouch Cell Fabrication* Hybrid and Electric Powertrain *Modeling - Control Diagnostics - xIL tools- Demonstration Vehicles* EV Charging and Grid Interaction Electric Machine Design	Automated Driving Advanced Driver Assistance Systems Test Cases for Automated Vehicles Driver-in-the-Loop Simulation Vehicle Connectivity V2V and V2X Communications	Cybersecurity Functional Safety Pedestrian and Occupant Safety System Fault Diagnosis	Transportation in Smart Cities Data Platforms and Telematics Mobility as a Service Sustainability

2021 FEDERAL AND INDUSTRY RESEARCH PARTNERS

- $12 million in new awards
- 104 active projects, engaging 83 different investigators

UChicago Argonne, LLC
Carnegie Mellon University
Hyper Tech Research, Inc.
STELLANTIS
State of Ohio Department of Transportation
PACCAR
NASA
Department of Transportation United States of America
EPS Electric Power Systems
Federal Transit Administration
LG
gm
infinity LABS
ORAU Oak Ridge Associated Universities
Automotive HGM Electronics
Ford
PennState
NEXCERIS where energy meets environment
Ohio Department of Higher Education
arpa·e
Department of Energy United States of America
Cummins
HONDA Honda R&D Americas
DENSO
U.S. AIR FORCE
TRC Transportation Research Center Inc.
NSF

LABS AND FACILITIES


- 4 Engine Test Cells
- Light- And Heavy-Duty Chassis Dynamometers
- Low Voltage Energy Storage
- High Powered Energy Storage
- Hydrogen Refueling
- Battery Materials Research and Fabrication
- Driving Dynamics Vehicle Simulator
- High Power Traction Drives
- Cybersecurity
- Hardware-In-The-Loop Control Development

The Ohio State University
CENTER FOR AUTOMOTIVE RESEARCH

- Integrates CAR research into graduate-level and continuing education opportunities
- Provide professionals with the cutting-edge knowledge required for innovation in the automotive industry

Opportunities:

- Fully tailored certificate programs and certifications to meet your needs
- Flexibility in course content and delivery (on-site, at CAR, online)

Challenging students of all majors, backgrounds, skill levels and degrees of experience to compete on one of seven student teams.

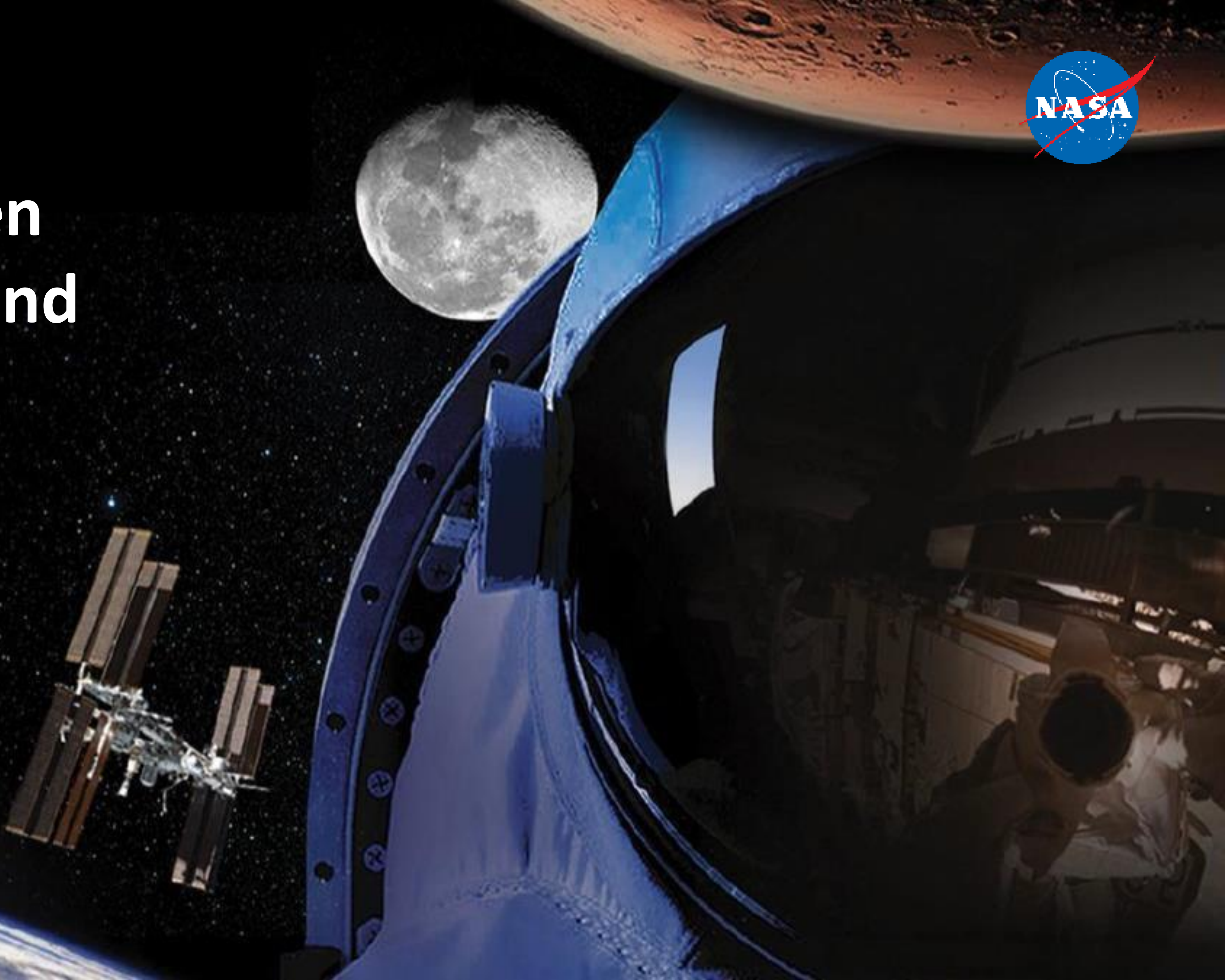
Ian Jakupca

Experience Fuel Cell Technology Lead at the NASA Glenn Research Center

National Aeronautics and Space Administration

NASA Hydrogen Technologies and Applications

Ian Jakupca
NASA Glenn Research Center
15 August 2022

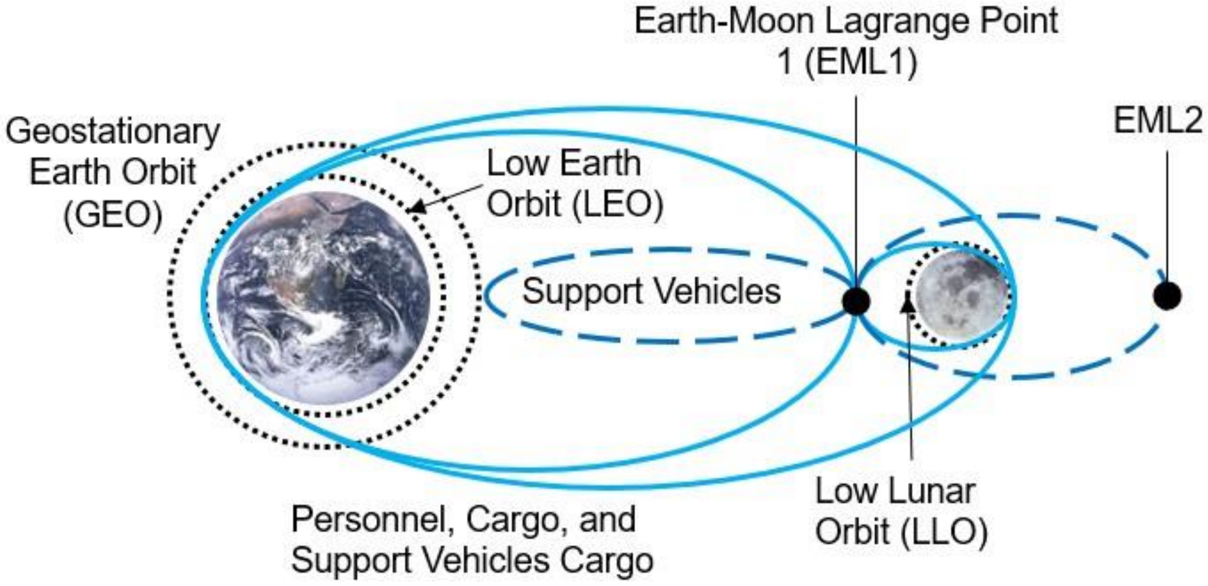


Presentation Overview

- NASA Overview
- Space Exploration
  - In Situ Resource Utilization (ISRU)
  - Space Synergies with Terrestrial Applications
- NASA Terrestrial Ties

Center for High-Efficiency Electrical Technologies for Aircraft (CHEETA)

Design Study for Hydrogen Fuel Cell Powered Electric Aircraft using Cryogenic Hydrogen Storage.



Mars Oxygen ISRU Experiment (MOXIE)

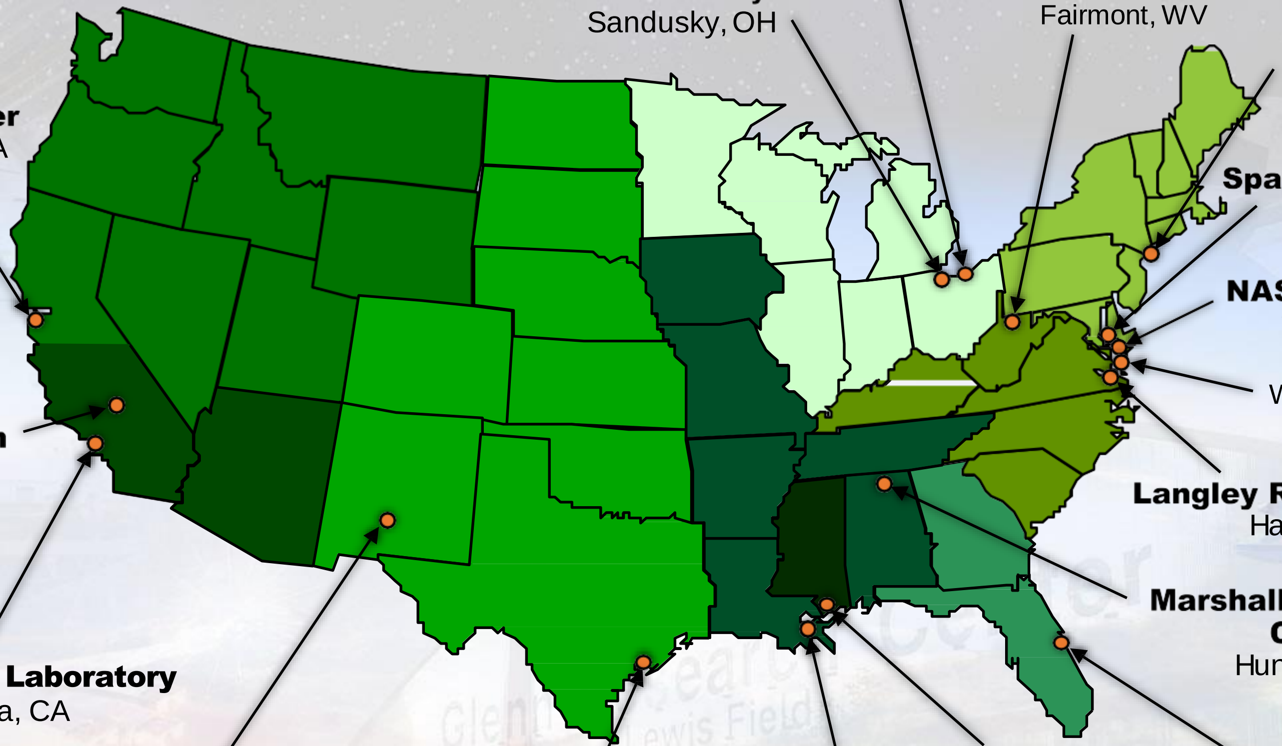
Aboard Perseverance, demonstrated the first production of oxygen from the atmosphere of Mars Apr. 2021.

NASA Centers and Installations

National Aeronautics and Space Administration

10 Main NASA Centers

- NASA Headquarters
- 4 Research Centers
- 5 Flight Centers



Ways to Partner with NASA

National Aeronautics and Space Administration

Technology Licensing

- Commercial entities using NASA technologies & software to benefit commercial endeavors
    - https://technology.nasa.gov/

Small Business Funding & Awards

- SBIR & STTR funding for small businesses & joint university small business ventures, respectively
    - https://sbir.nasa.gov/
- **SBIR Ignite** is a new way for small businesses that have a commercially-viable technology idea to use NASA as a steppingstone towards commercial success
    - https://sbir.nasa.gov/ignite

University Grants

- Space Technology Research Grants (STRG) provides funding to graduate students to tenured faculty members to advance space concepts to higher TRLs
    - https://www.nasa.gov/directorates/spacetech/strg/about.html

Grant Solicitations

- Directorate-level program funding provided through NSPIRES & displayed on Grants.gov
    - https://nspires.nasaprs.com/external/

Procurement

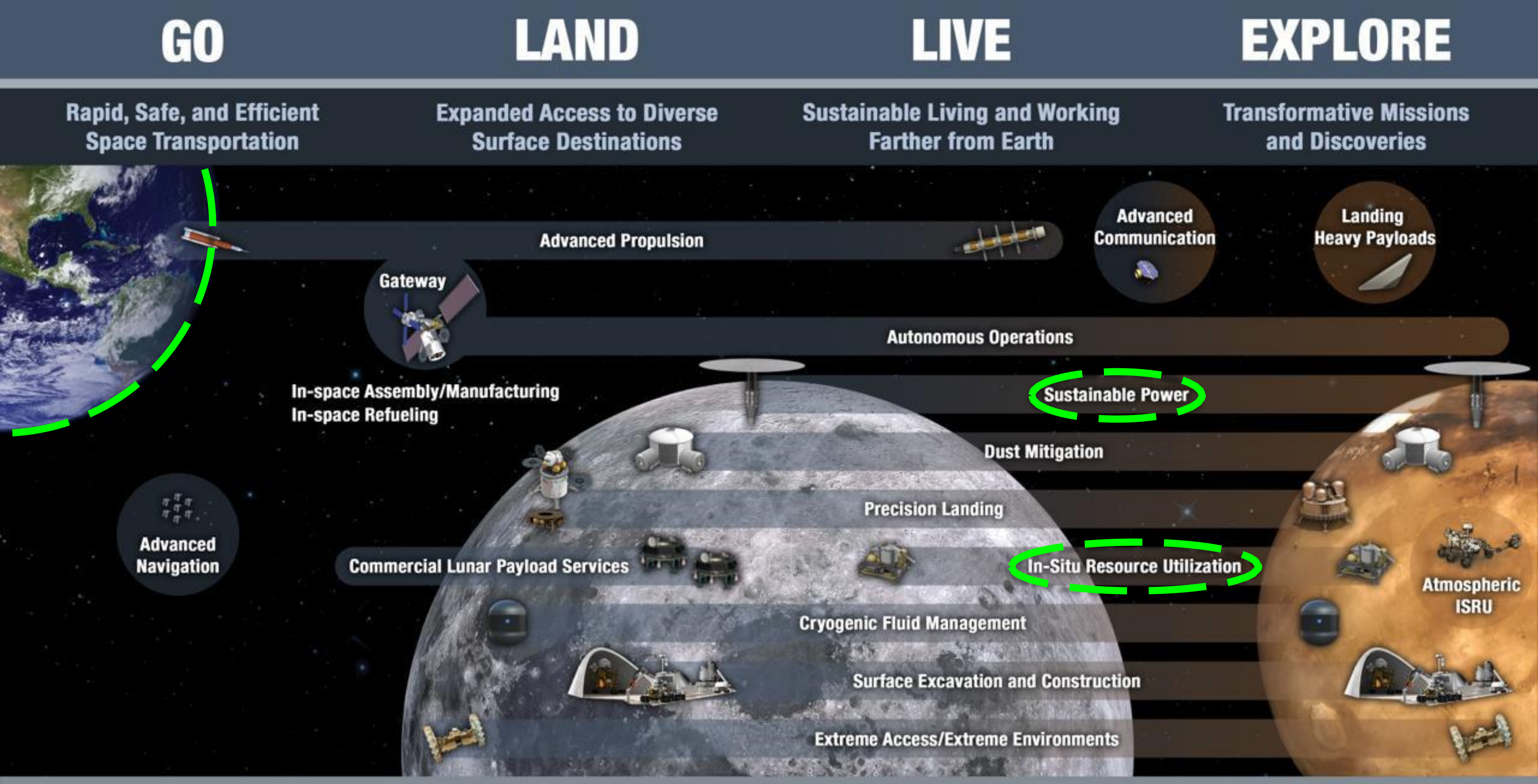
- NASA purchases of services, consumables, equipment, etc. from commercial providers
    - https://www.nasa.gov/office/procurement

NASA Facilities & Expertise

- Accessing NASA's facilities, equipment & SMEs through Reimbursable or non-reimbursable Space Act Agreements (SAA); these are similar to CRADAs
    - https://www.nasa.gov/partnerships.html

Networks and Ecosystems

- T2X & T2U programs for startups & university engagement, respectively
- Regional resources, cluster mapping, etc. for entrepreneurs


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
Precision Landing
Advanced Navigation
Commercial Lunar Payload Services
In-Situ Resource Utilization
Atmospheric ISRU
Cryogenic Fluid Management
Surface Excavation and Construction
Extreme Access/Extreme Environments

Terrestrial Hydrogen Applications

- *Water Electrolysis to supply the Hydrogen economy*
  - *Grid Stabilization / load balancing*
  - *Micro-grids*
  - *Primary Electrical Power*
- *Fuel cells for primary direct current (DC) electrical power*
  - *Industrial motors*
  - *Mobility platforms*
  - *Electric aircraft / Urban Air Mobility (UAM)*

Center for High-Efficiency Electrical Technologies for Aircraft (CHEETA)

Design Study for Hydrogen Fuel Cell Powered Electric Aircraft using Cryogenic Hydrogen Storage

University of Illinois @ Urbana-Champaign
Image Credit: CHEETA Project Image

The Space Launch System rocket core stage comes alive during the Green Run hot fire test on 16 Jan. 2021 at NASA’s Stennis Space Center near Bay St. Louis, Mississippi.
Image Credit: NASA

NASA's all-electric X-57 Maxwell prepares for ground vibration testing at NASA's Armstrong Flight Research Center in California.
Credits: NASA Photo / Lauren Hughes

We’re going to the Moon to learn to live on other planets and for the benefit of all humanity.

With the Artemis lunar exploration program, NASA will put the first woman and first person of color on the lunar surface and build a sustainable presence there and in lunar orbit.

The Artemis Program Snapshot

Space Launch System

Commercial Lunar Payload Services

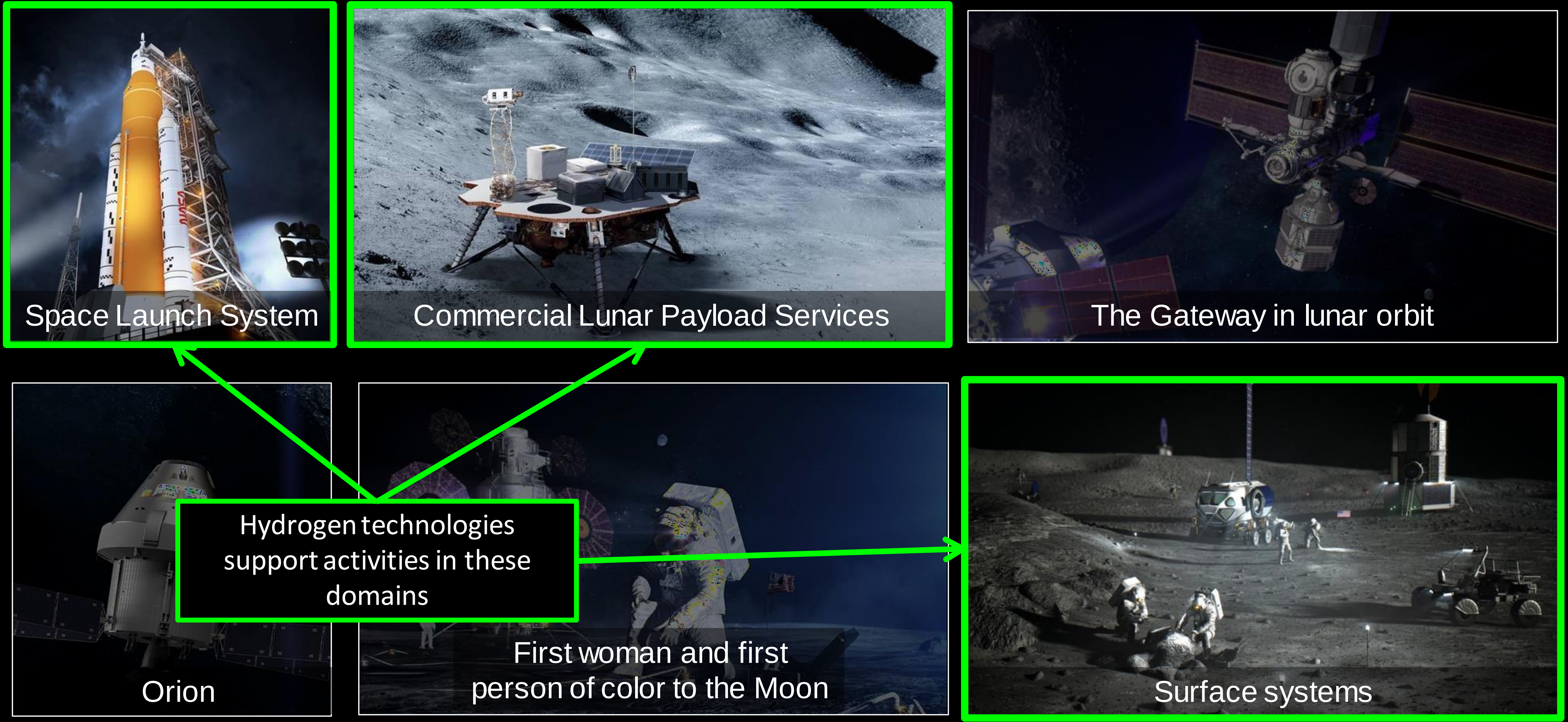
The Gateway in lunar orbit

Orion

First woman and first person of color to the Moon

Surface systems

The Artemis Program Snapshot



ARTEMIS BASE CAMP

A truly sustainable infrastructure 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

EXPLORATION CAPABILITIES

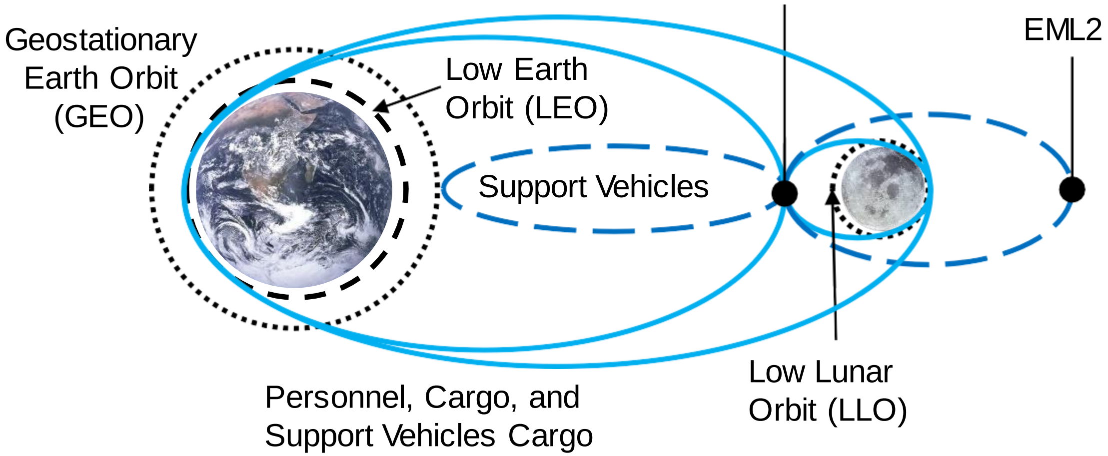
The technologies and systems that allow the crew to thrive and work in space

- Regenerative life support systems enable longer-duration missions
- Crew health and performance technology keeps astronauts safe and healthy
- New systems reduce mass, volume, and the need for resupply

How 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

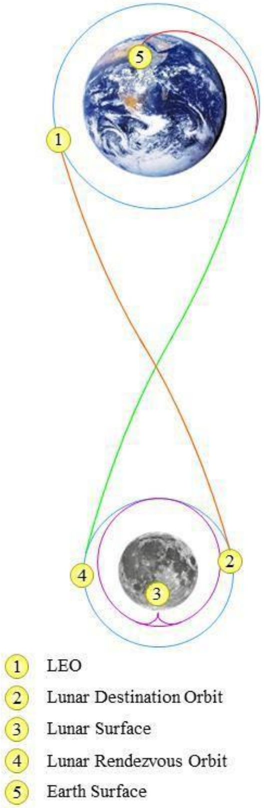


Potential >283 mT launch mass saved in LEO = 3+ SLS launches per Mars Ascent

- 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

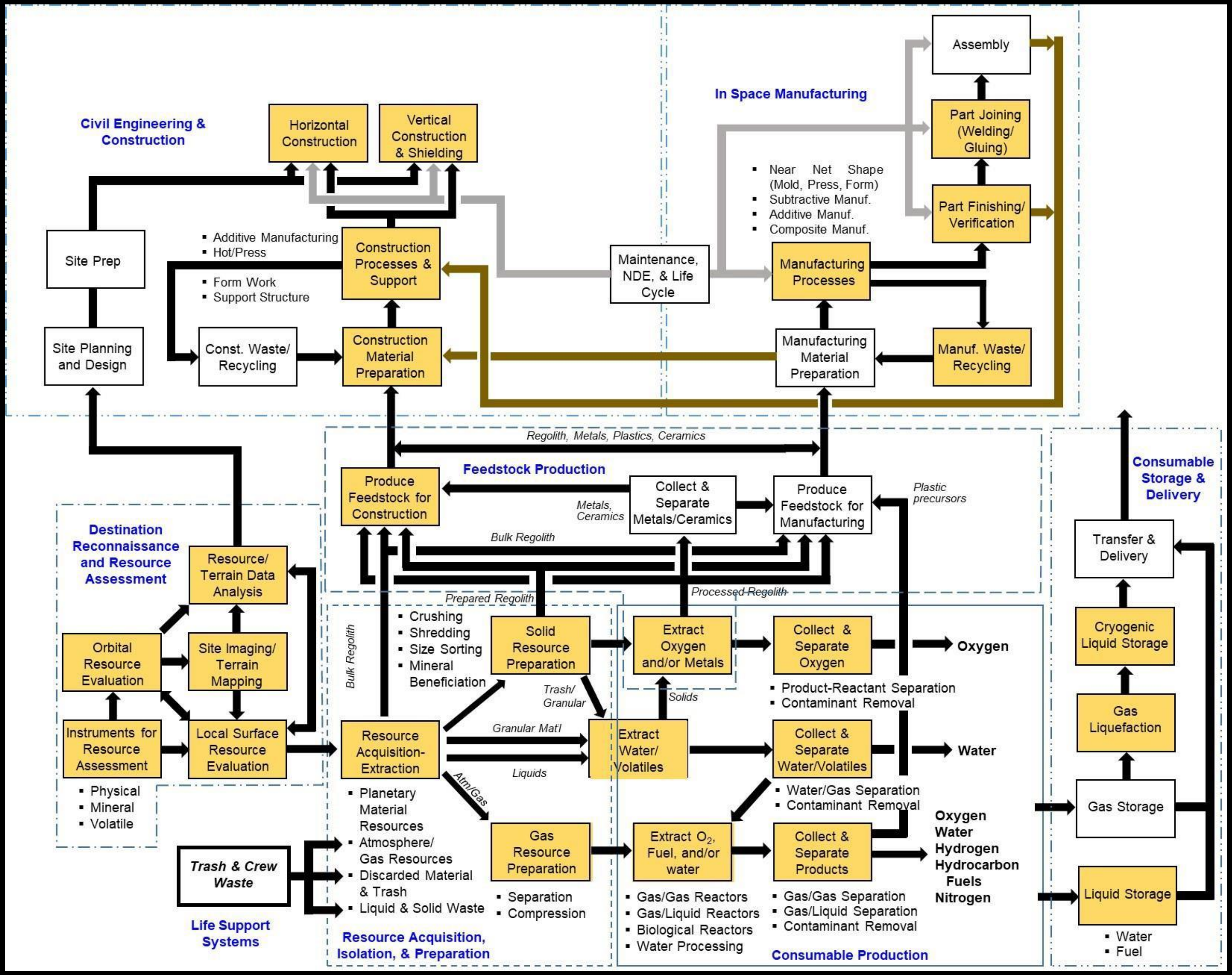
- Crew Ascent Stage (1 way): 3 to 6 mT O_2
- Single Stage (both ways): 40 to 50 mT O_2/H_2



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

In Situ Resource Utilization (ISRU) on the Lunar Surface

Manufacturing from locally sourced materials

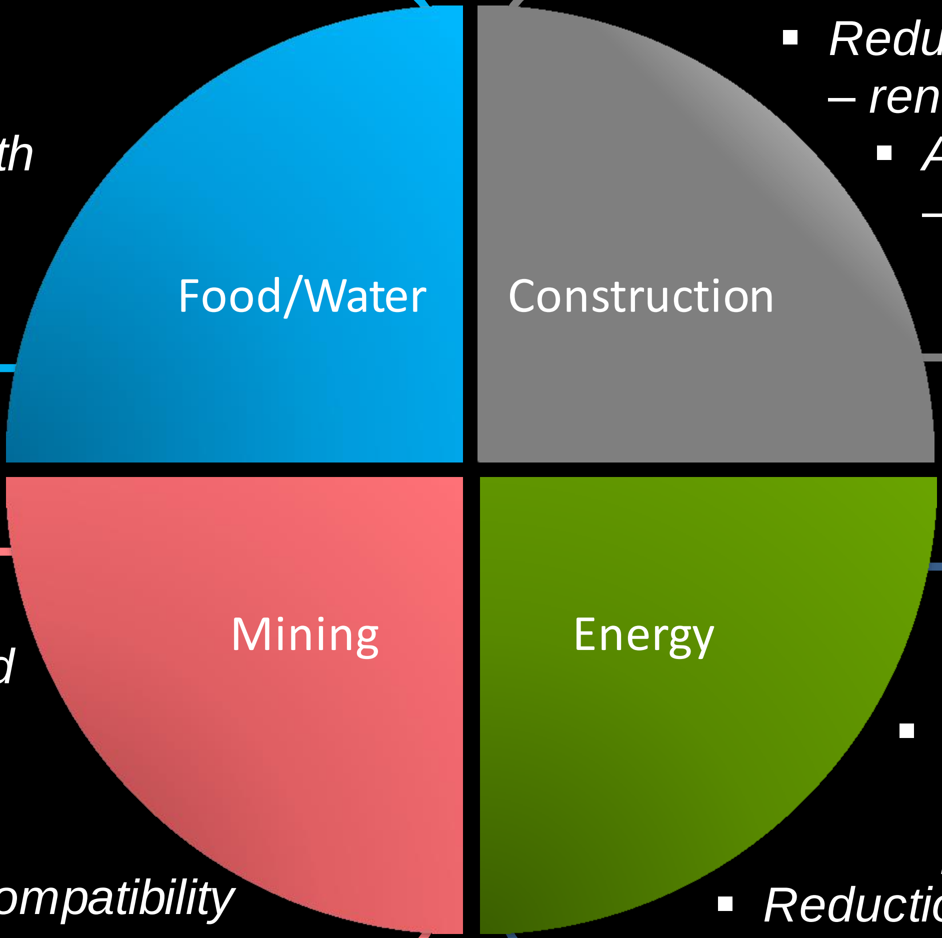


Simplified ISRU Functional Block Diagram

= funded work

- **Using Space Resources reduces cost**
  - **Making at point-of-use saves mass**
  - **Reduces required number of launches**
  - **Opens potential to reuse mission transportation assets**
- **Using Space Resources increases safety**
  - **Shortens logistical chain**
  - **Minimizes impact of shortfalls in other system performance**
- **Using Space Resources enhances/enables new capabilities**
  - **Extends/enhances missions**
  - **Increased surface mobility and access**
  - **Increased science**
- **Learning to use Space Resources can help us on Earth**
  - **Lunar environment is an engineering crucible**

Space Exploration Synergistic with Terrestrial Needs



Food/Water

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

Construction

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

Mining

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

Energy

- *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.

Presentation Review

- NASA Overview
- Space Exploration
  - In Situ Resource Utilization (ISRU)
  - Space Synergies with Terrestrial Applications
- NASA Terrestrial Ties

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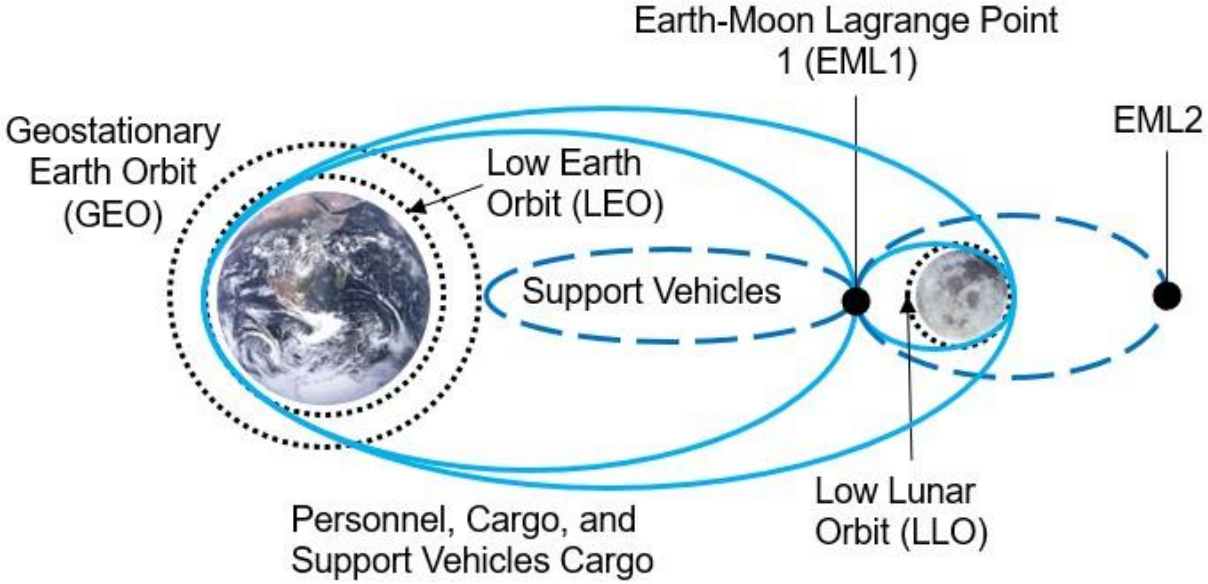


Mars Oxygen ISRU Experiment (MOXIE)

Aboard Perseverance, demonstrated the first production of oxygen from the atmosphere of Mars Apr. 2021.

Questions can be sent via e-mail to
Ian Jakupca (ian.j.jakupca@nasa.gov)


Thank you for your attention.

Dr. Thomas Peng

Research Chemist at the Air Force Research Laboratory Energy Office

AFRL

Energy Agility for Space Vehicle Applications Enabled by Bipropellant Consuming Solid Oxide Fuel Cells (SOFCs)

Hydrogen Fuel Cell – Hybrid Event
Monday August 15, 2022

Dr. Thomas L. Peng – Principal Investigator

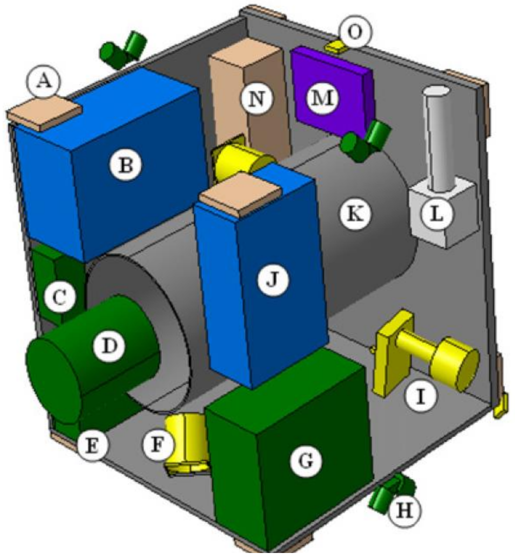
Motivation

- Problem:
  - Deployed spacecraft are expected to remain in operation for years without servicing
  - Spacecraft mass and volume limitations make it challenging, and often impossible, to load a spacecraft with all the equipment needed to be able to respond to all possible threats or fulfill possible needs. Want dual function systems
  - Need electrical power to run what capabilities are loaded
- GPS Satellite USA-132
  - Launched July 23, 1997 (24 years ago)
  - Still Operational
- SpaceX Falcon 9
  - Maximum Payload Volume: 145m^3, 145,000L
  - Maximum Payload Mass to LEO: 22,800 kg
  - Cost per launch $62M
    - $2,720/kg
    - $430,000/m^3, $430/L

SpaceX Falcon 9 Users Guide: August 2021
SpaceX Falcon 9 Capabilities and Services: 2021

Operating power requirement values.

Subsystem/component	Power (W)
AOCS	
Star tracker	4.0
Gyroscope	1.0
Reaction wheels	12.0
Communications	
Receiver (Rx) and RF distribution unit	6.0
Transmitter (Tx)	25.0
On-board data handling	
On-board computer	22.0
Payload	
Narrow angle camera	10.0
Propulsion	
T5 Ion engine PPU—HIGH	600.0
T5 Ion engine PPU—LOW	38.0
Hollow cathode thruster PPU	80.0
Power	
Power control unit	7.0
Power distribution unit	3.0
Battery heaters	60.0
Mechanism	
Solar array drive mechanism	9.0



Legend

A	Antenna
B	PCDU
C	HCT PPU
D	T5 ion engine
E	XFCU
F	Reaction wheel
G	T5 PPU
H	HCT
I	Star tracker
J	Secondary batteries
K	Center tube structure
L	Camera
M	On-board computer
N	Transceiver
O	Sun sensor

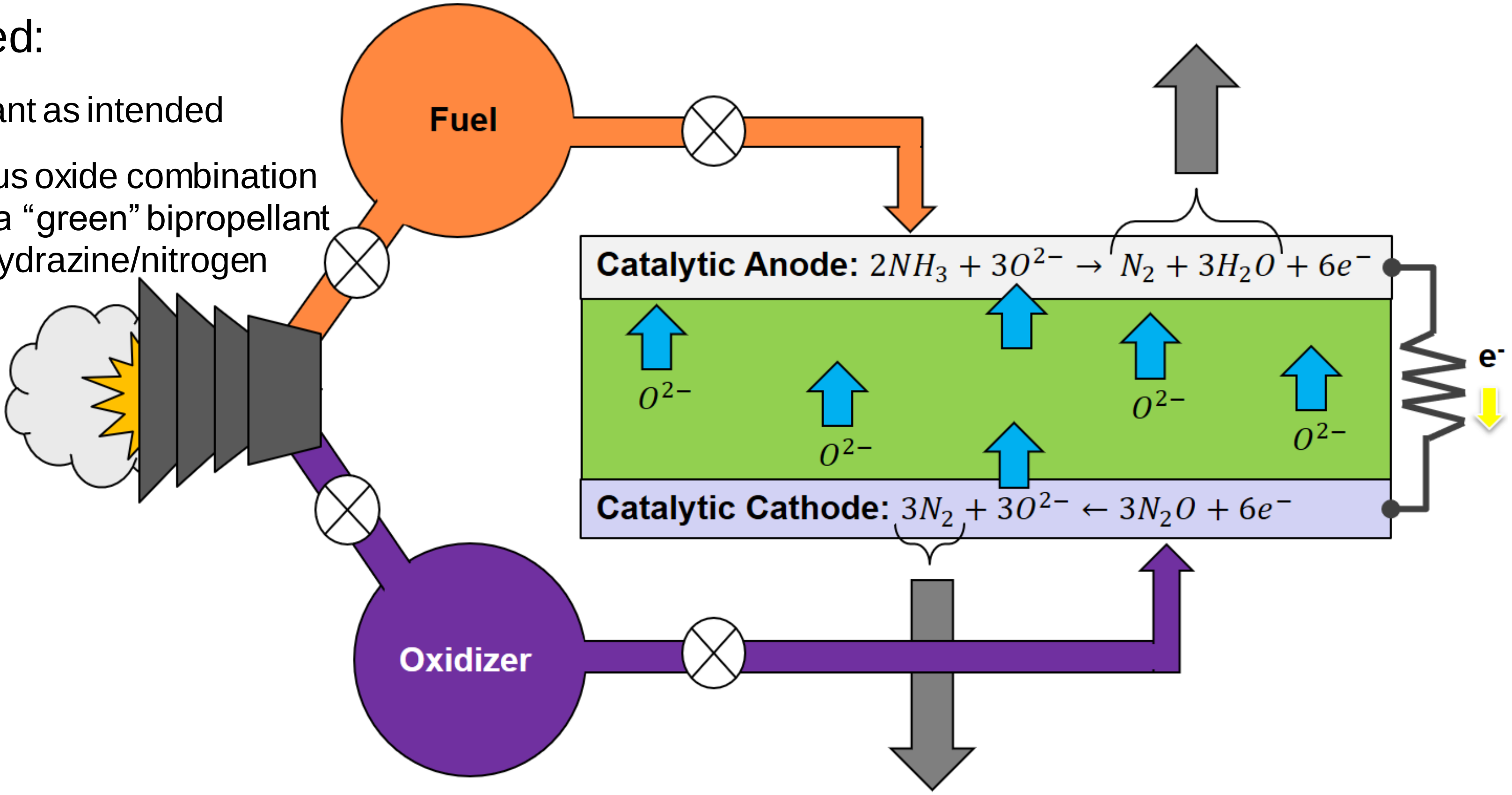
S. Ulrichetal. ActaAstronautica 64(2009) 244 –255 247

Problem Mitigation

- Establish operational flexibility on how energy stowed onboard a spacecraft is used by developing a fuel cell that can generate electricity by consuming bipropellant
- **B**ipropellant **E**nabled **E**lectrical **P**ower **S**upply (BEEPS)

If thrust needed:

- Burn bipropellant as intended
- ammonia/nitrous oxide combination considered as a “green” bipropellant alternative to hydrazine/nitrogen tetroxide pair



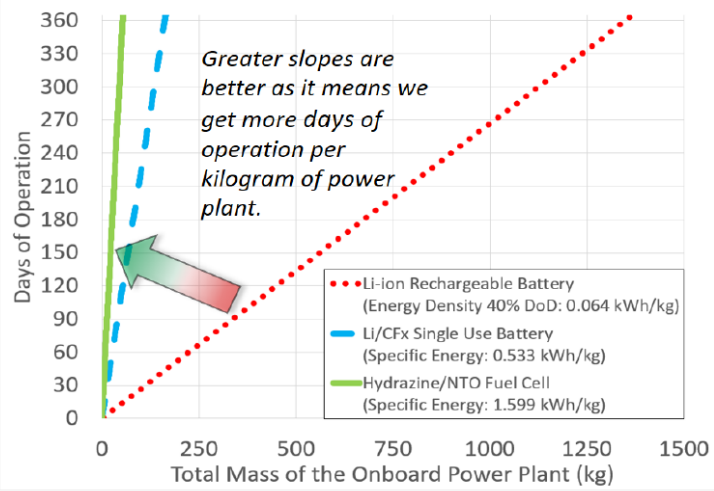
If electricity needed:

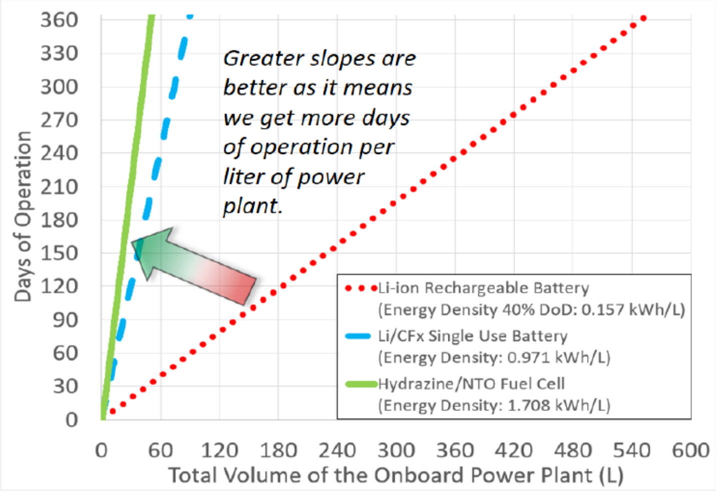
- Feed bipropellant into SOFC to generate electricity
- SOFC used since high operating temperature means not susceptible to poisoning
- If proven to work with ammonia/nitrous oxide combination, should work with traditional hydrazine/nitrogen tetroxide

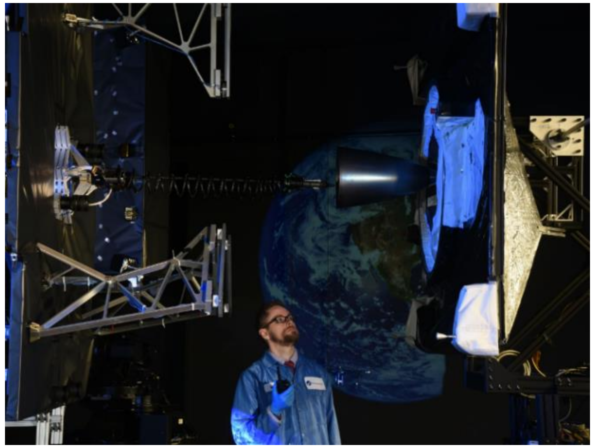
Benefits

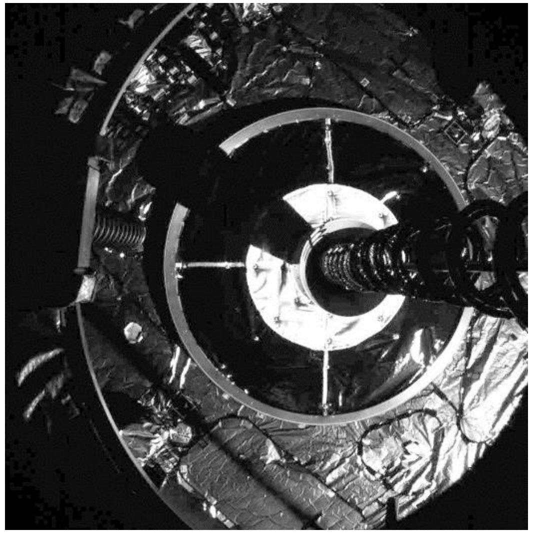
- Establishes an electrical power plant by tapping the existing fuel and oxidizer supply in a bipropellant thruster equipped spacecraft
- For large volumes, have substantially larger energy densities than batteries
- Do not suffer self discharge so there is no expiration date on when energy must be used.
- Allows redesigns to achieve the desired output voltage and current without perturbing the chemical storage tank designs
- Enables bipropellant thruster and stored electricity replenishment with a single refueling operation
- SOFC used are resistant to poisoning and do not need expensive catalytic metals to function

Mass and Volume Cost to run a 10W Satellite









https://www.space.com/private-satellites-docking-success-northrop-grumman-mev-1.html

Challenges

- Electrochemistry
  - Catalytic electrode design
  - Solid state electrolyte design
- Fuel Cell Operation
  - Optimal feed pressures
  - Optimal feed rates
  - Optimal operation temperature
  - Optimal exhaust recirculation and release rate
- Bipropellant Compatibility
  - Identify bipropellants we can run fuel cell on
- Creating a fuel cell that outputs useful voltages and currents
  - Cell design
- Thermal Control
  - Establishing >600^{o}C operating temperature
  - Isolating hot fuel cell from the rest of the satellite
- Fuel / Oxidizer / Exhaust Management
  - Gas manifolds
  - Integration with bipropellant thruster
- Space Operations Development
  - What can we do if we have fuel cells that can provide different amounts of electrical power for different amounts of time?

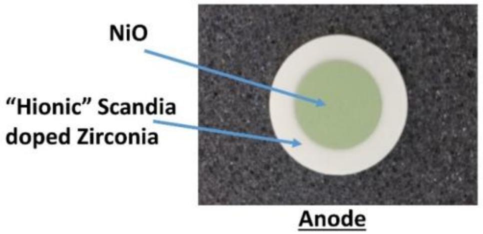
Electrochemistry and Fuel Cell Operation

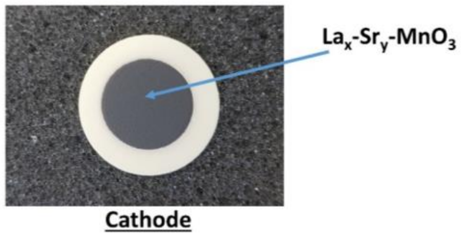
NextCell Electrolyte Supported Button Cell:

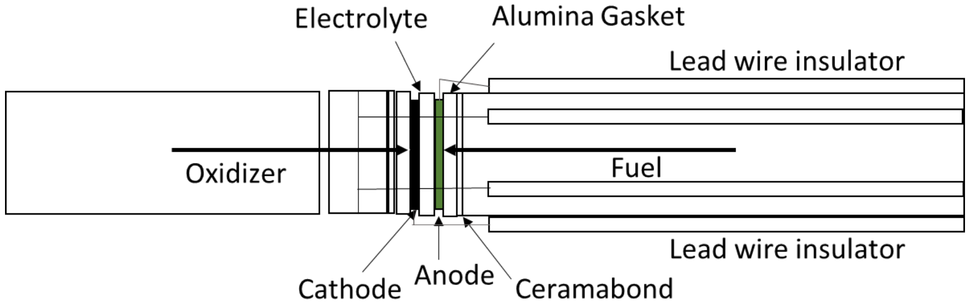
Anode: Nickel Oxide (NiO) / (12.5 mm Diameter / ~50 µm thickness)

Cathode: Lanthanum strontium manganite (LSM) / (12.5 mm Diameter / ~50 µm thickness)

Electrolyte: (Hionic™ (Scandia-doped Zirconia)) / 20 mm diameter ~150 µm thickness)

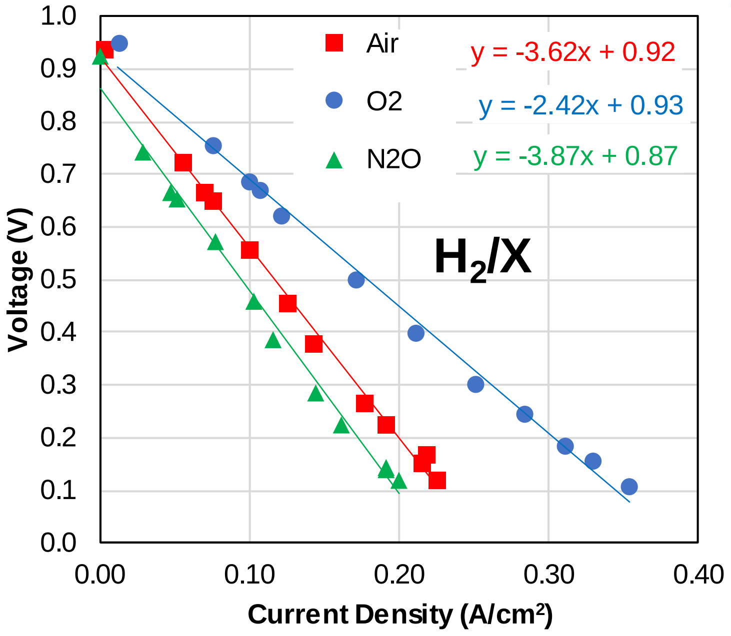


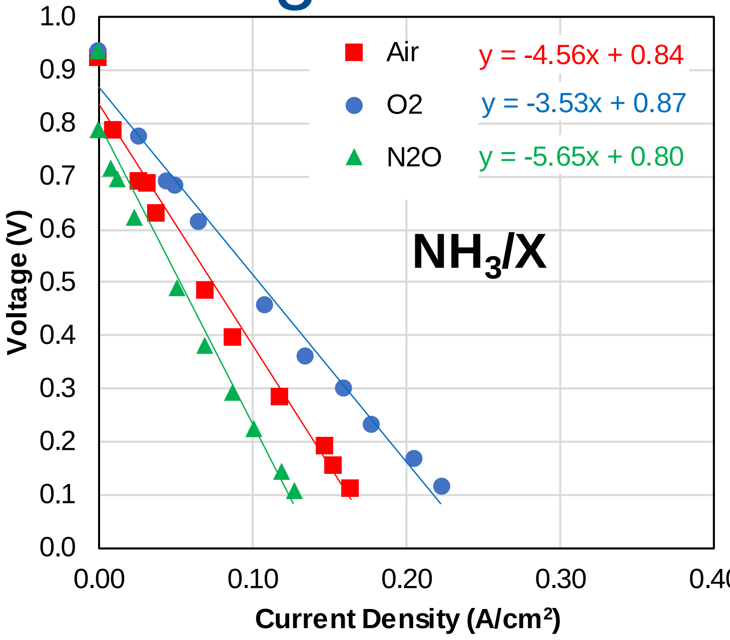


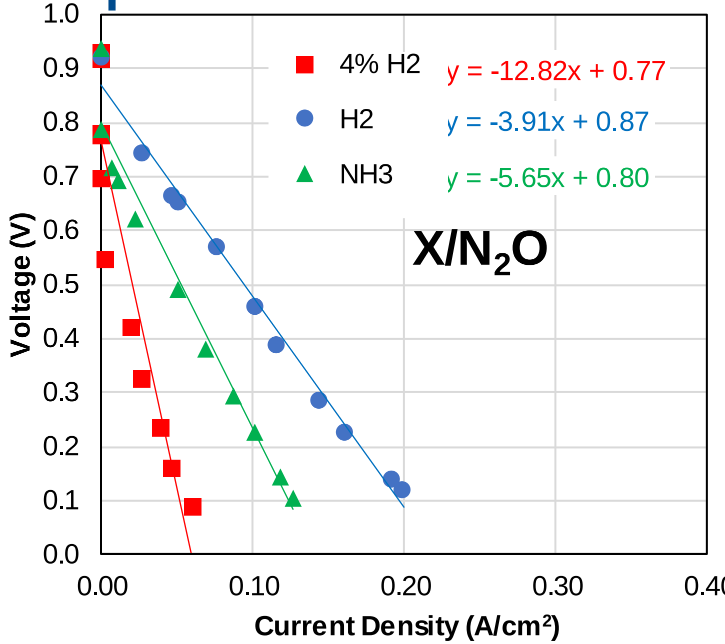


- Button cells are used as proof of concept
- Scribner test station: EIS analyzer, multi-gas unit, potentiostat
- Reactant Gases
  - 4% H_2 in N_2, H_2, NH_3, Air, O_2, N_2O
- Electrochemical Characterization
  - OCV, VI curves, and EIS

Confirmed Viability of Driving SOFC with Bipropellant







NH_3 is likely decomposing into N_2 and H_2. Similarly, N_2O is likely decomposing into N_2 and O_2

- ~0.95V at 0 current density for all NH_3 and N_2O combinations similar to the Open Circuit Voltage of H_2:O_2 pair

Ohmic loss, specifically ohmic loss due to electrolyte resistance, is the major loss mechanism

- Voltage vs current density slopes, aside from the 4%H_2/N_2O pair, are similar

H_2/X Data:

- Pure O_2 performs best as expected
- N_2O, with 36% O_2 mass percentage from $N_2O \rightarrow N_2 + ½O_2$ decomposition expected to perform better than 23% O_2 found in air. This suggests incomplete N_2O decomposition

NH_3/X Data:

- Lower power output than H_2/X may be due to endothermic decomposition of NH_3 which can cool the fuel cell

X/N_2O Data:

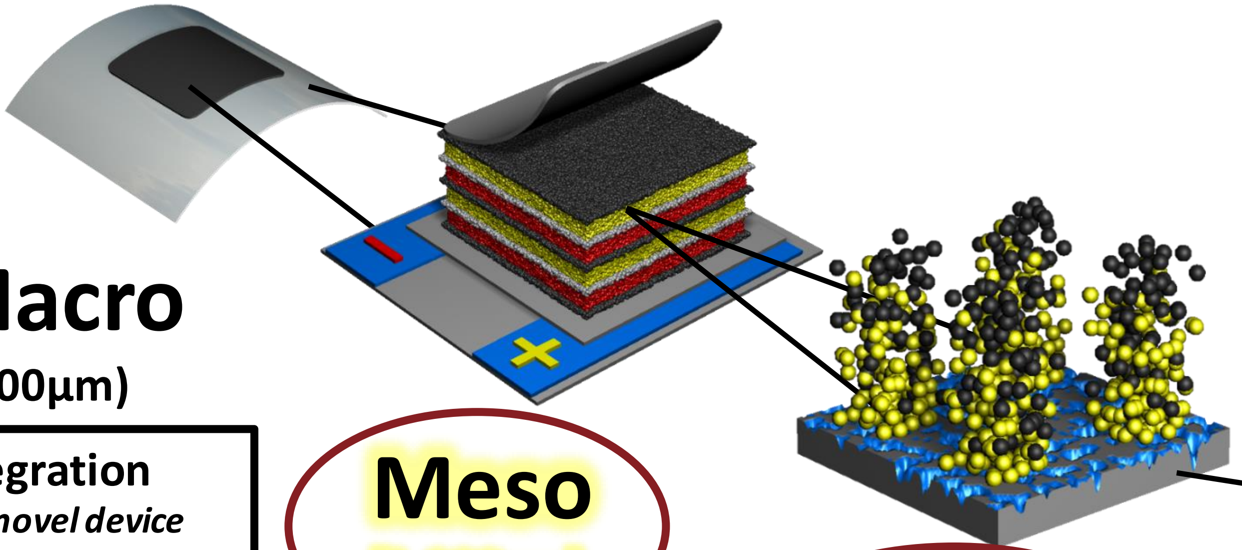
- Sharp drop in voltage with increasing current density observed when the SOFC is fed 4%H_2 and N_2O may be due to mass transport limits arising from low concentration of H_2

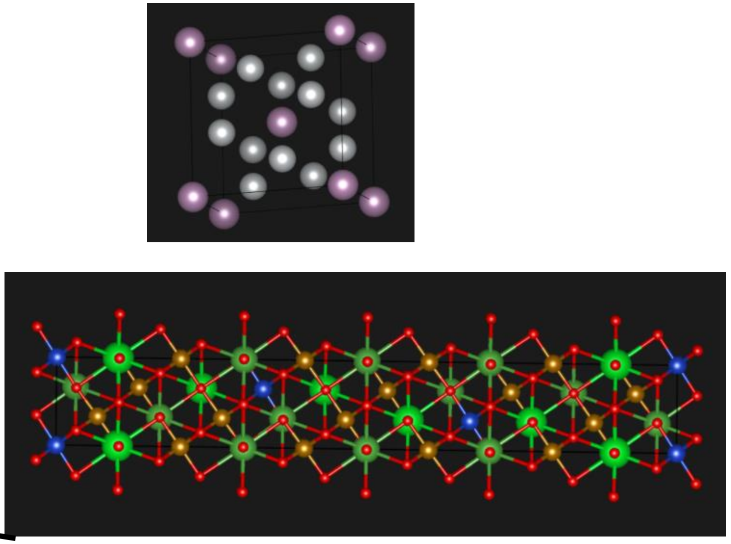
Unexpectedly, NH_3/X with its endothermic decomposition of NH_3 performed better than X/N_2O with its exothermic decomposition of N_2O

- Incomplete decomposition of N_2O may be limiting X/N_2O performance

<u>Test Conditions</u>
Temp: ~ 800°C, Pressure: Ambient
Flows: 150/150 sccm
SOFC: NiO/Scandia-doped Zirconia/LSM

Design of New Fuel Cell Electrodes and Electrolytes





Macro

(>100µm)

Integration
(build novel device stacks)

Meso

(1-100µm)

Thickness optimization for mass transport, electronic and ionic flux
(tailor bulk properties and electrochemical behavior)

Micro

(100nm-2µm)

Functional grading of composition and porosity; interfacial contact
(tailor electrochemical behavior)

Atomic

Electronic structure calculations and design of novel mixed ionic/electronic conductors via *ab initio* methods

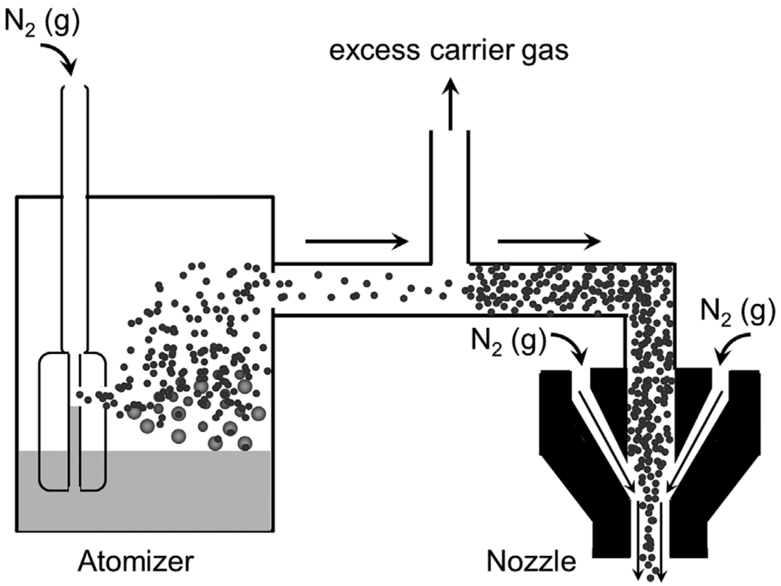
Aerosol Jet printing enables controlled deposition of active materials

Processing Parameters control microstructure, properties, and electrochemical performance

- Anode / Electrolyte Ink Formulation
  - (micro/atomic)
  - Power loading
  - Solvent
  - Binders / plasticizer
  - Pore formers

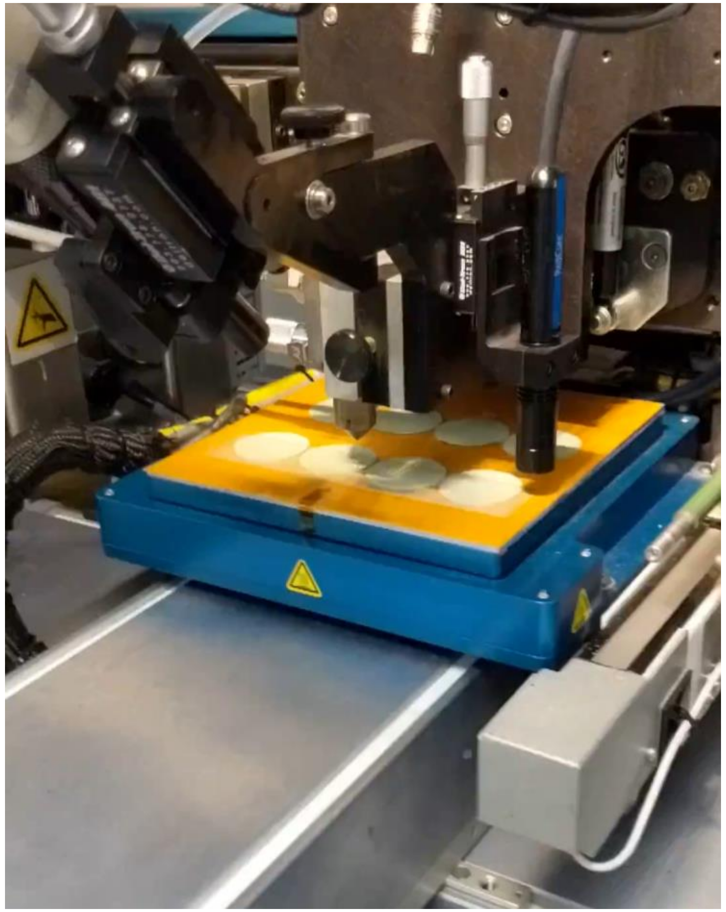
- Aerosol Jet Printing
  - (macro/meso)
  - Exhaust Flow Rate
  - Atomizer Pressure
  - Substrate Temperature
  - Raster Speed
  - Number of Layers

- Thermal Processing
  - Additive Burnout
  - Sintering Profiles



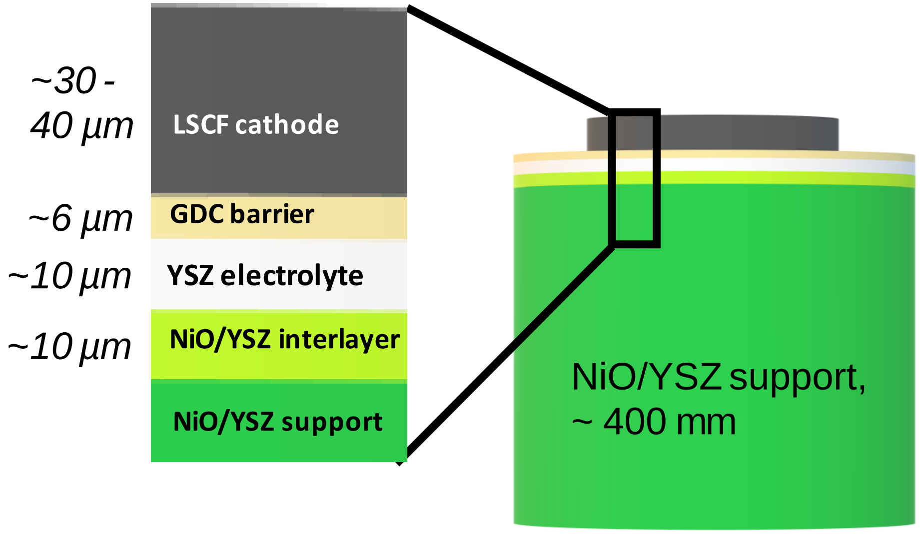
→ Improved printed layer properties

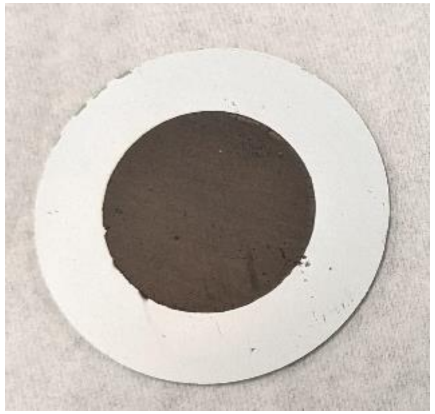
- **Density/Porosity**
- **Thickness**
- **Tortuosity**

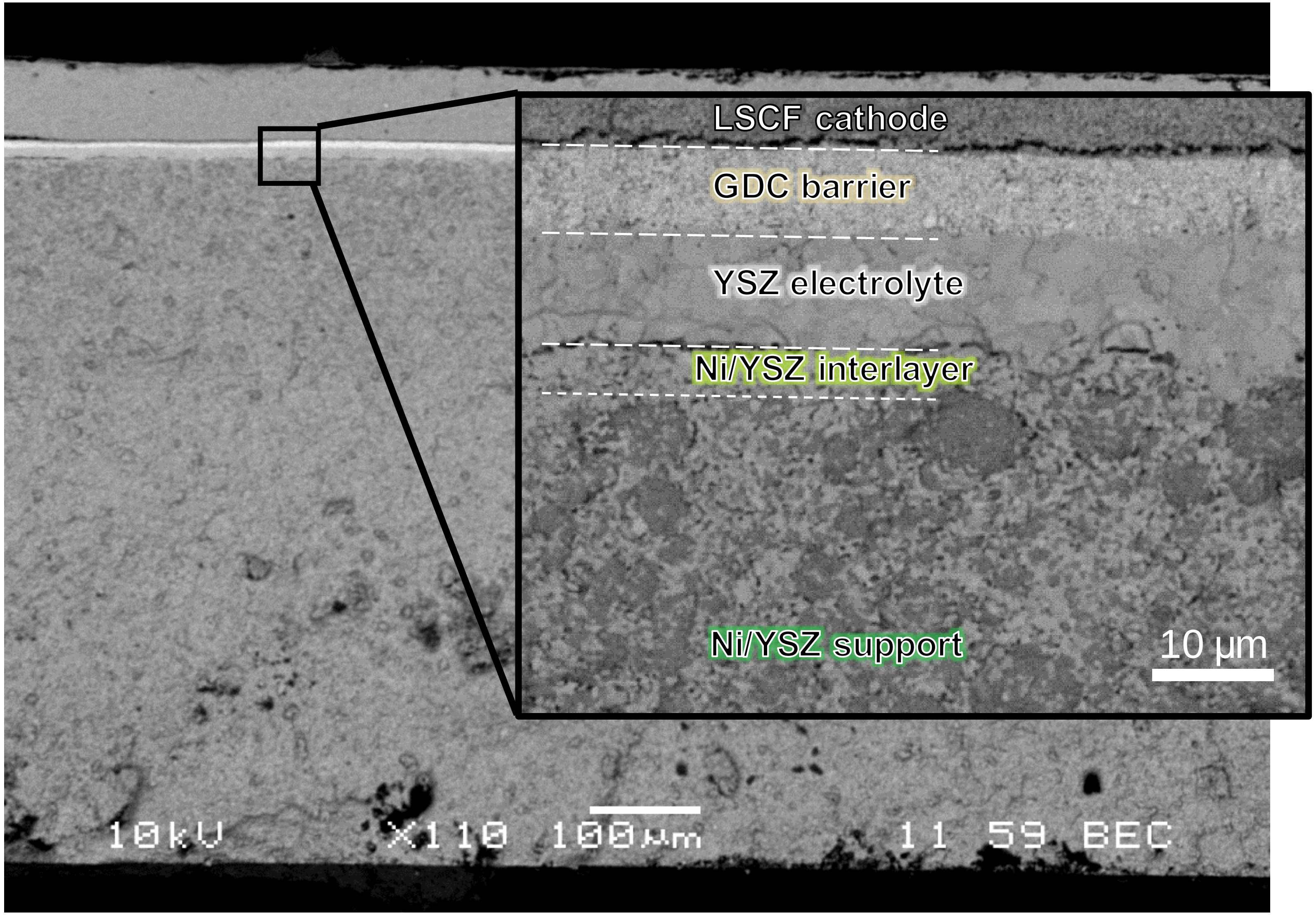


AJ printing of anode interlayer on NiO-YSZ support

Anode supported architecture shows conformal layers and ability to control thickness and composition (*layer delamination shown is artifact of manual fracture for cross-section SEM*)







Matlab/Simulink System Model of Al-SOFC

Advantages of system-level simulation over CFD or multiphysics FEM: we can quickly study

Size

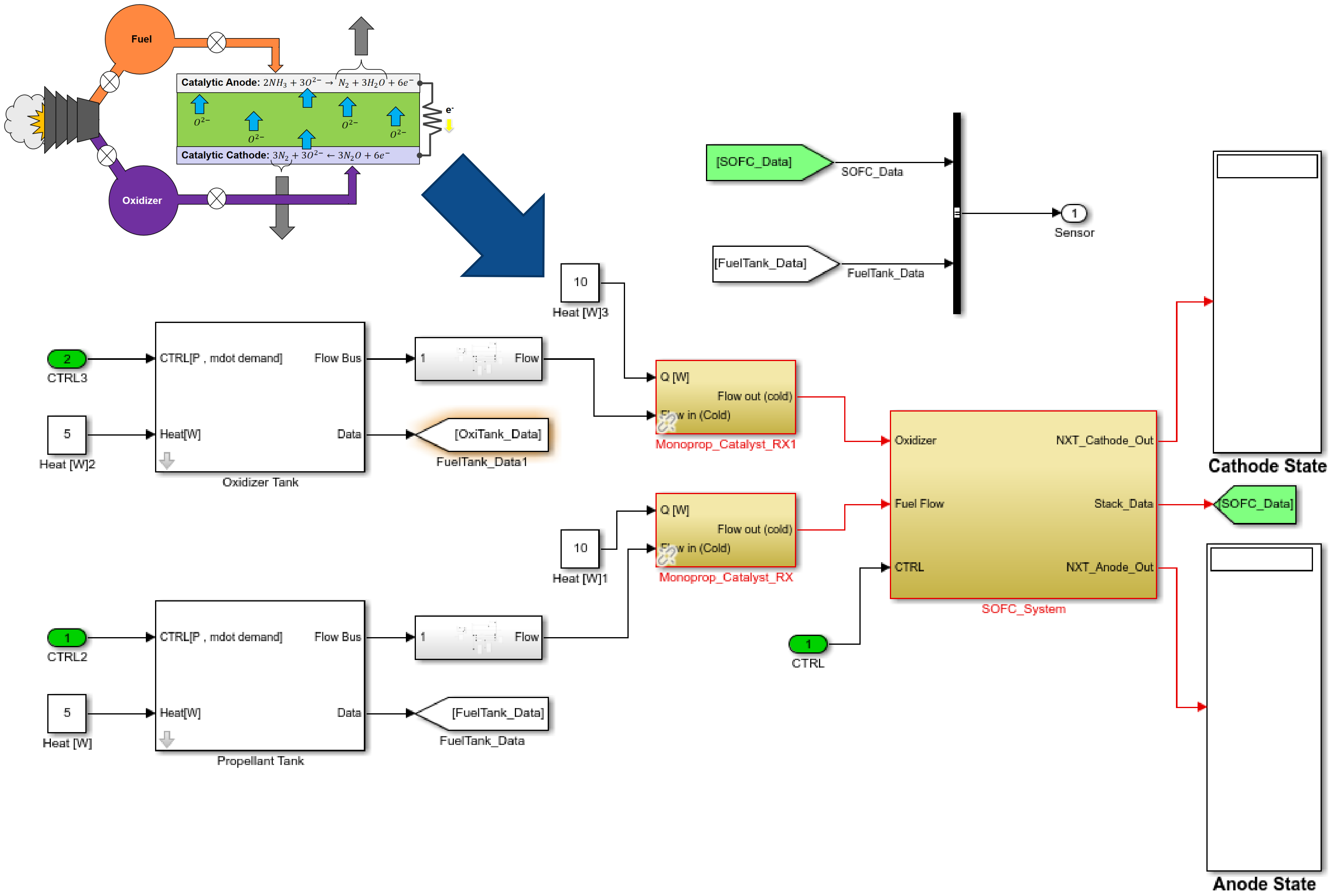
Weight

And

Power

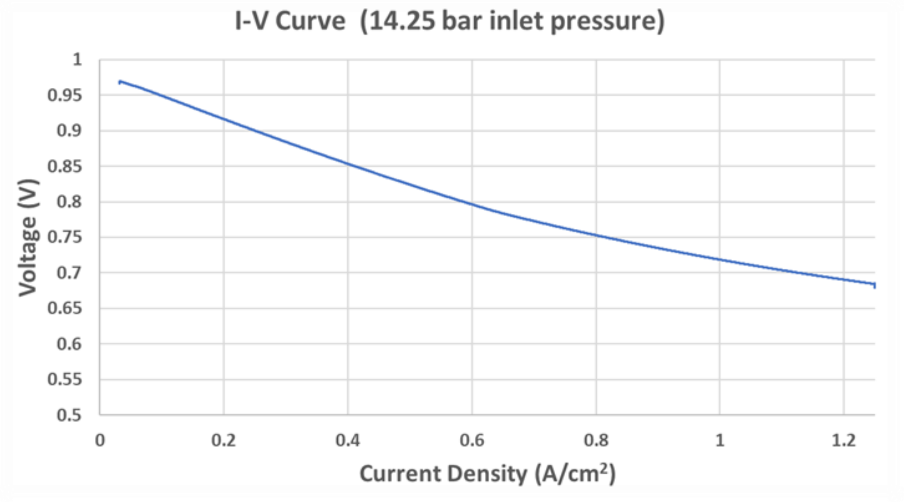
of the integrated system with many components. This physics model allows us to extrapolate results from lab fuel cell tests to the integrated space power system. Details included:

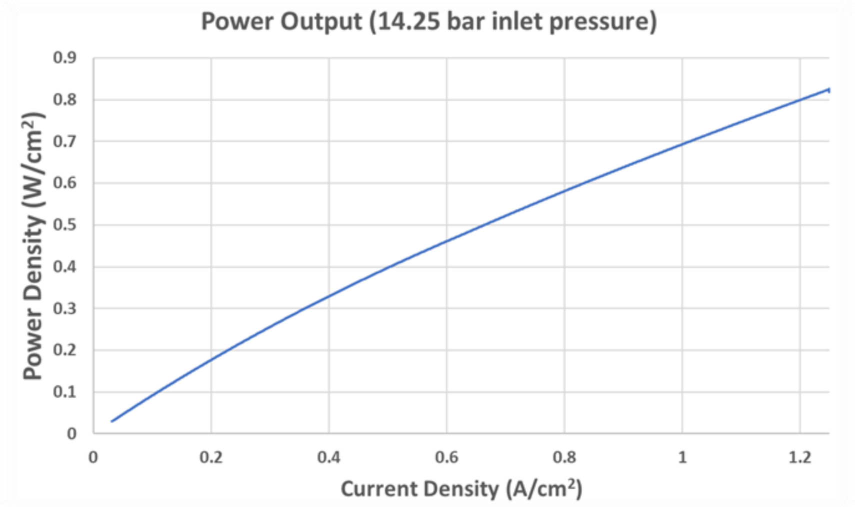
- Electrochemistry
- Bipropellant decomposition kinetics
- Two-phase catalyst bed flow/reactions
- Propellant tank dynamics
- Heat transfer

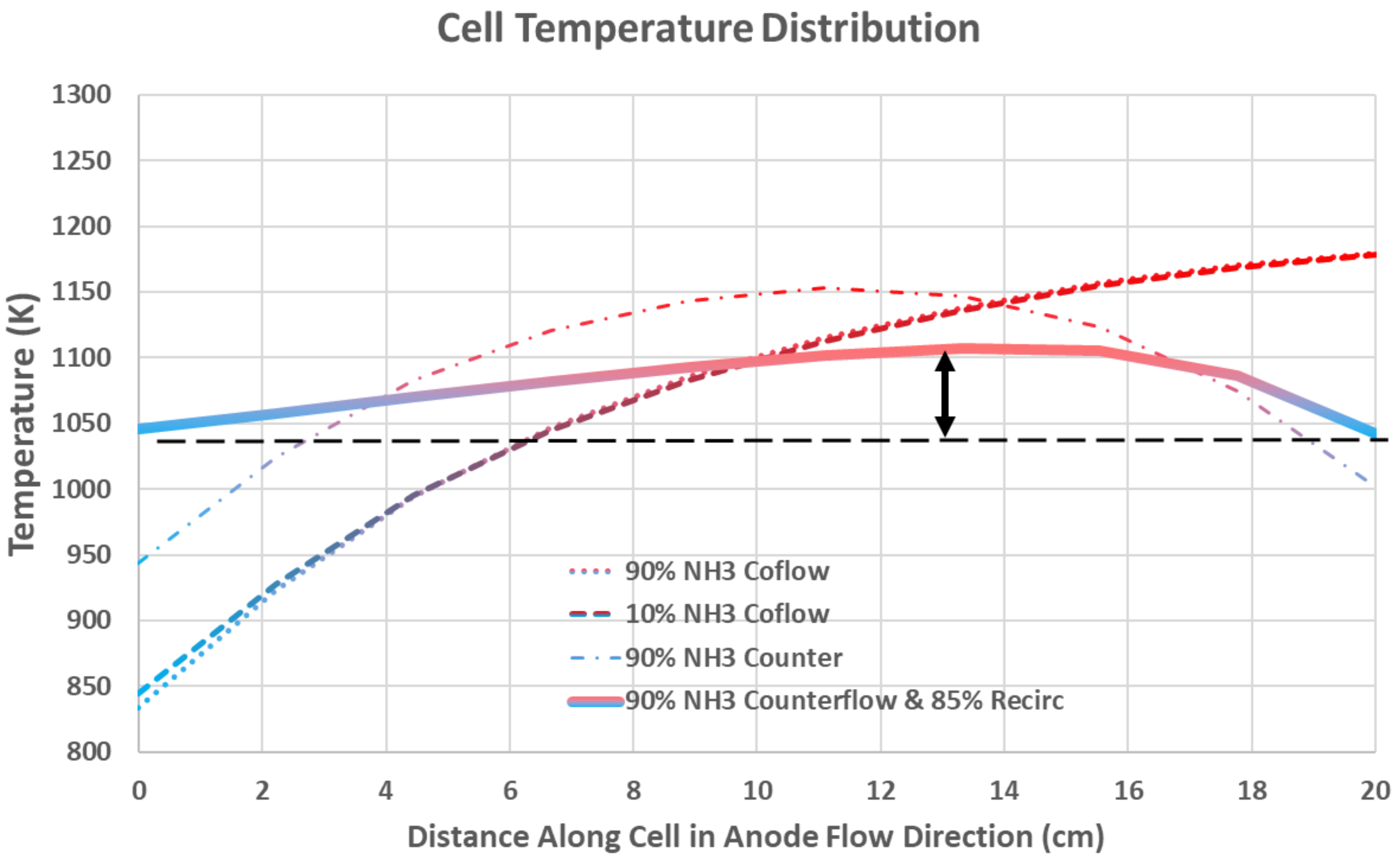


Matlab/Simulink System Model of Al-SOFC

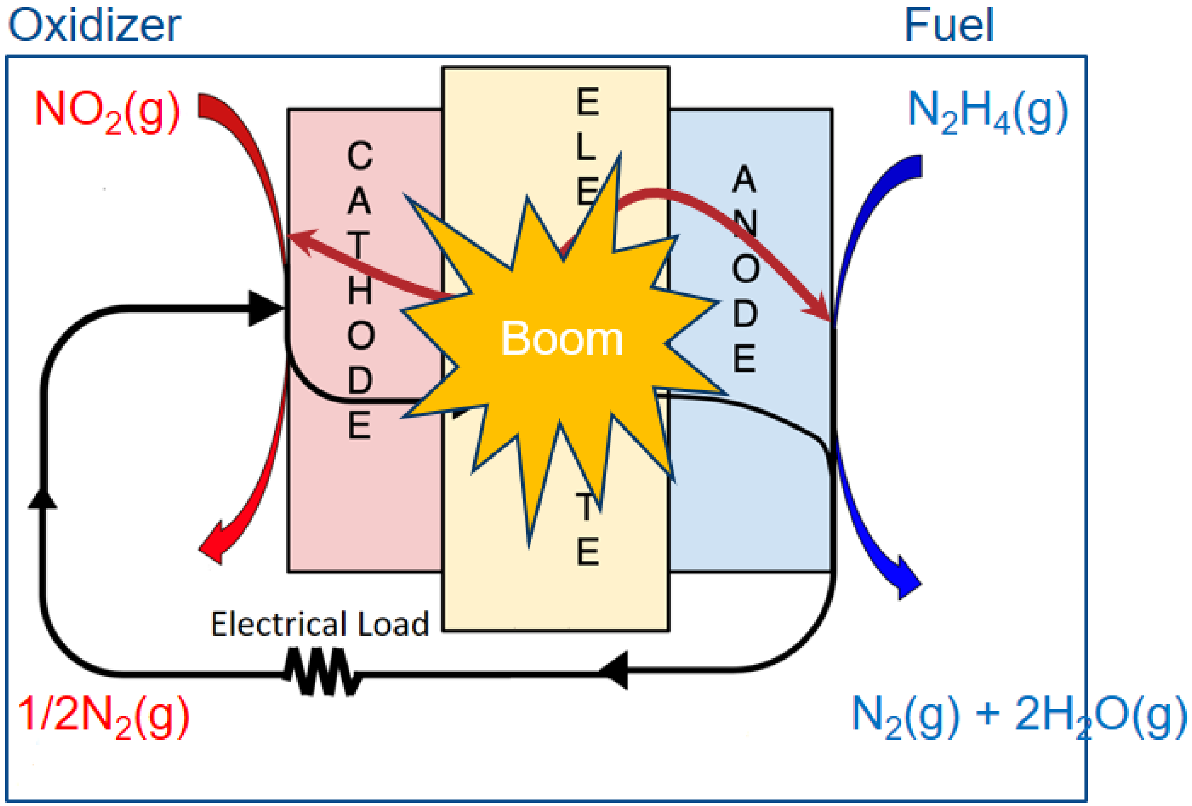
Results of Simulated Fuel Cell Test Thermal and Power Analysis







Hypergolic Bipropellant Compatibility



Hydrazine(s) + NTO
State-of-the-art
(1950's Technology)

Ionic Liquids + Oxidizers (NTO, HNO_3, H_2O_2
Emerging "Green Propellent"" Technology

J. Phys. Chem. A, **112**, 7816 (2008)

NASA, **CR-127057** (1972)

Controlled Decomposition of N_2H_4

❑ Produce Benign Fuel Mixture:

- ❑ $N_2H_4 \rightarrow N_2 + 2H_2$ ($\Delta H = -95.4$ kJ mol^{-1}) (1)
- ❑ $3N_2H_4 \rightarrow N_2 + 4NH_3$ ($\Delta H = -157.4$ kJ mol^{-1}) (2)

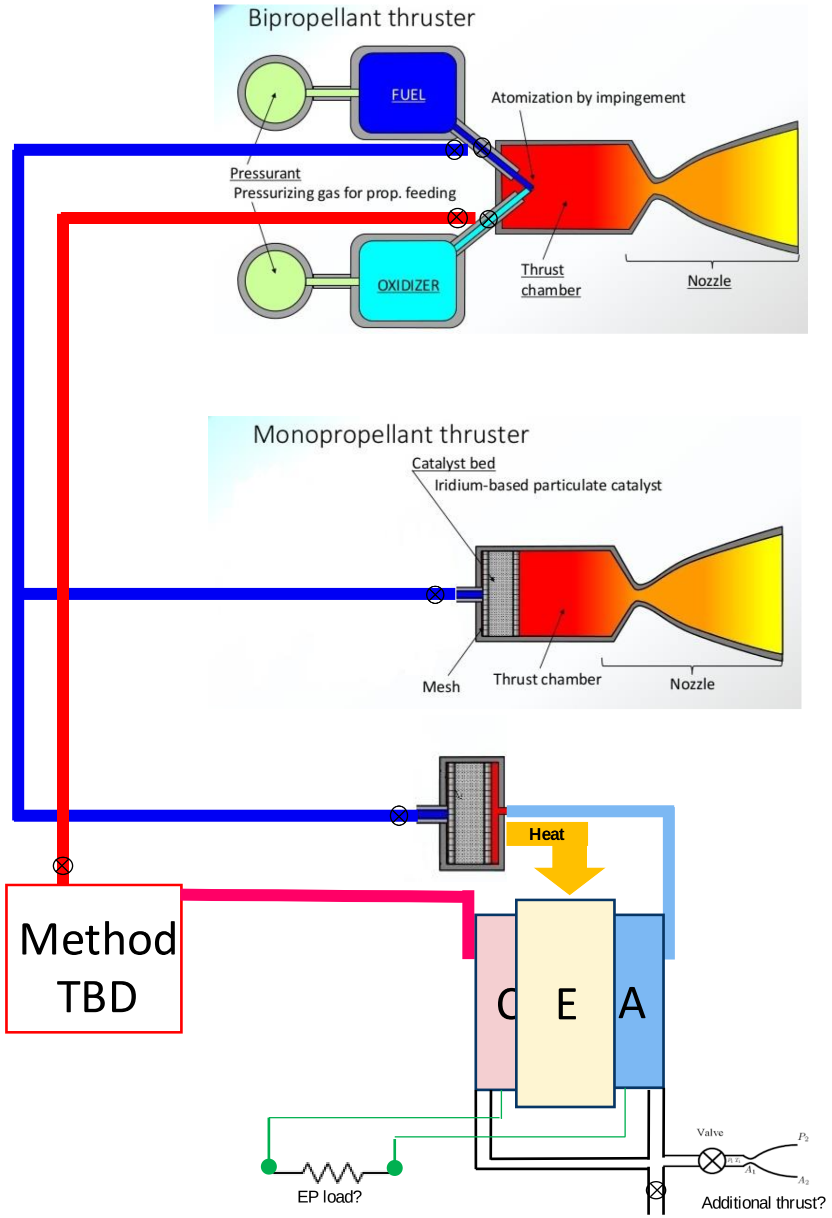
The overall decomposition can be expressed as follows:

$$3N_2H_4 \rightarrow 4(1-x)NH_3 + (1 + 2x)N_2 + (6x)H_2 \quad (3)$$

Where selectivity, x, for (1) can be determined over S405 catalyst conditions (Temperature, Pressure, Reaction Time), with:

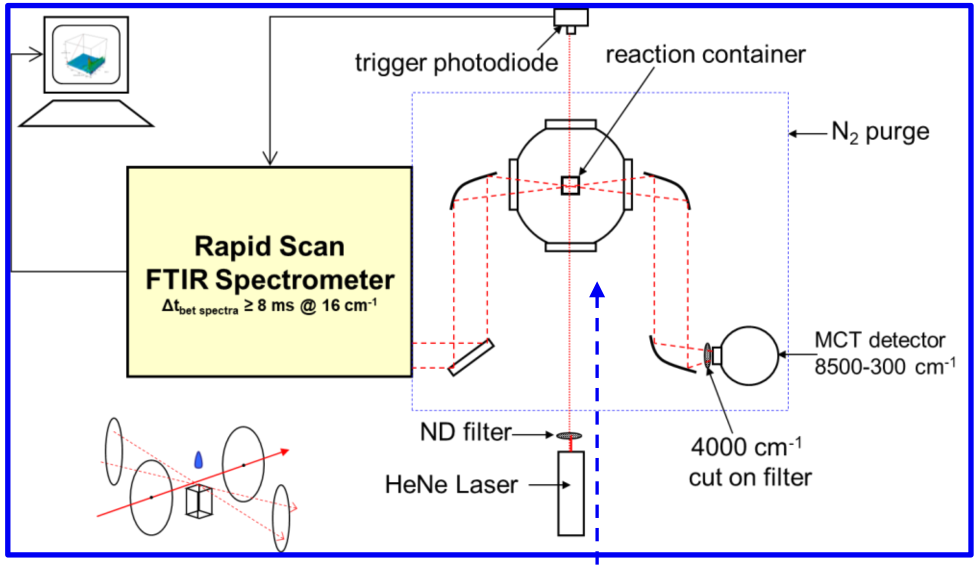
$$x = 1/2[H_2] / (1/2[H_2] + 3/4[NH_3])$$

$$= 2[H_2] / (2[H_2] + 3[NH_3]) \quad (4)$$

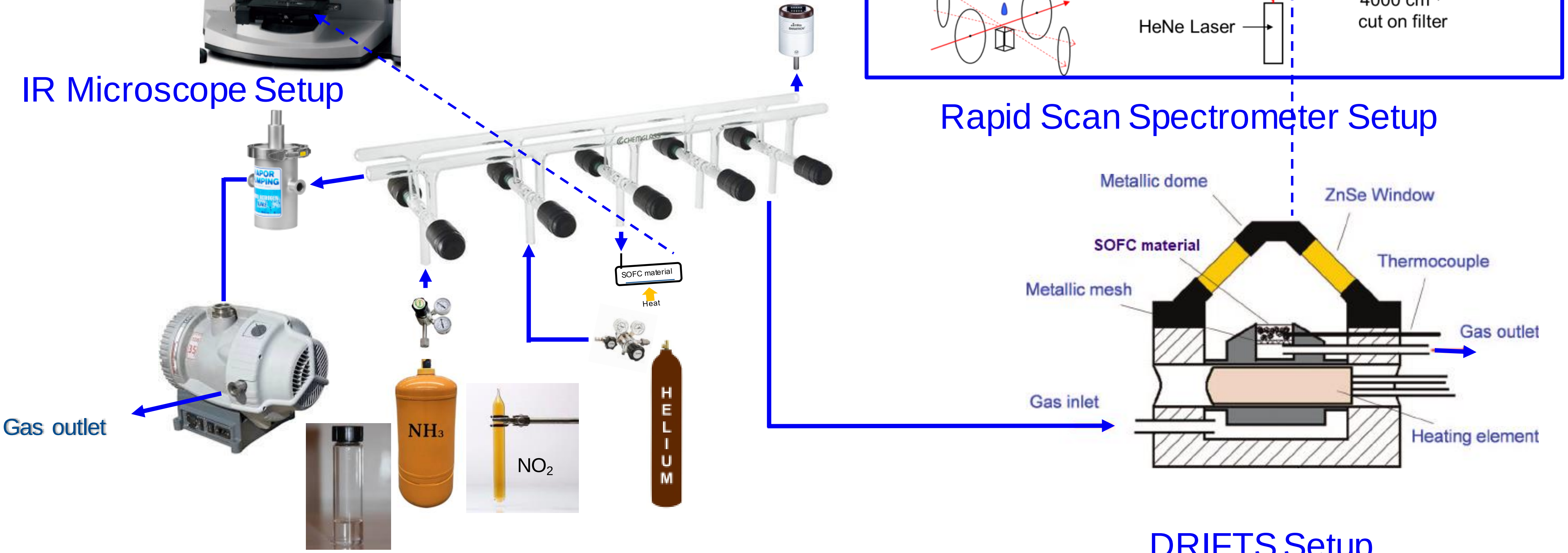


FTIR Methods

- FTIR Spectroscopy has been a workhorse in hypergolic propellant research



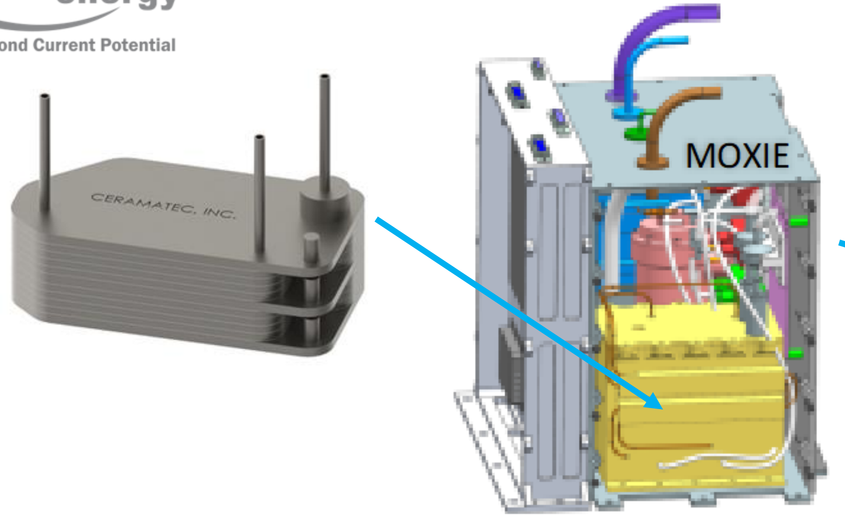
Rapid Scan Spectrometer Setup

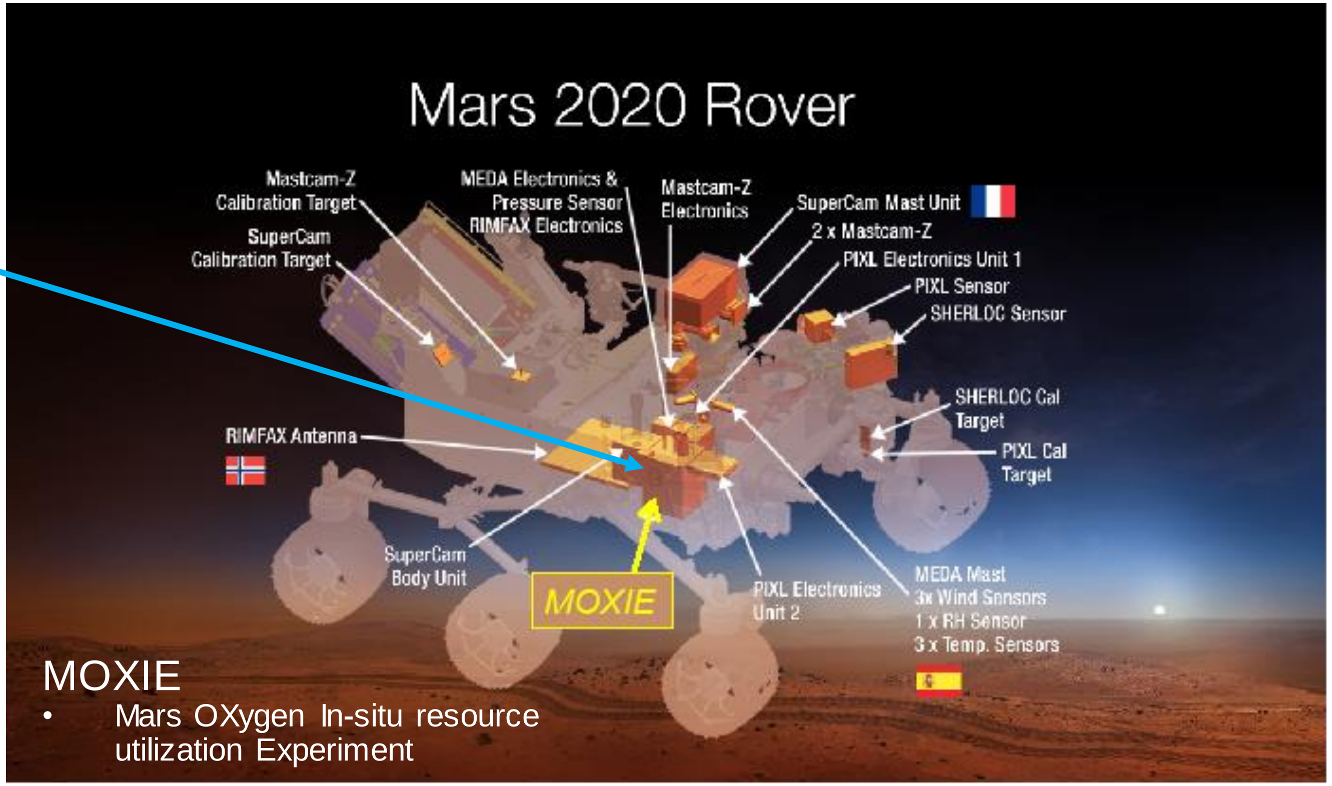


DRIFTS Setup

Useful Voltage / Thermal Control / Gas Flow Management

OxEon energy
Beyond Current Potential





MOXIE Statistics

- CO_2 to $2CO + O_2$ electrolysis device designed and fabricated by the OxEon Energy Team

Mass: 12 kg (stack: 770 g)
Power: 350 W (peak)
50 W Stack
Size: 23.9 x 23.9 x 30.9 cm
Oxygen Production: 10 g/hr
Oxygen Purity: 99.6%

"MOXIE is sponsored by NASA's Space Technology Mission Directorate and Human Exploration and Operations Mission Directorate. It is a joint venture between NASA, JPL, and MIT. "

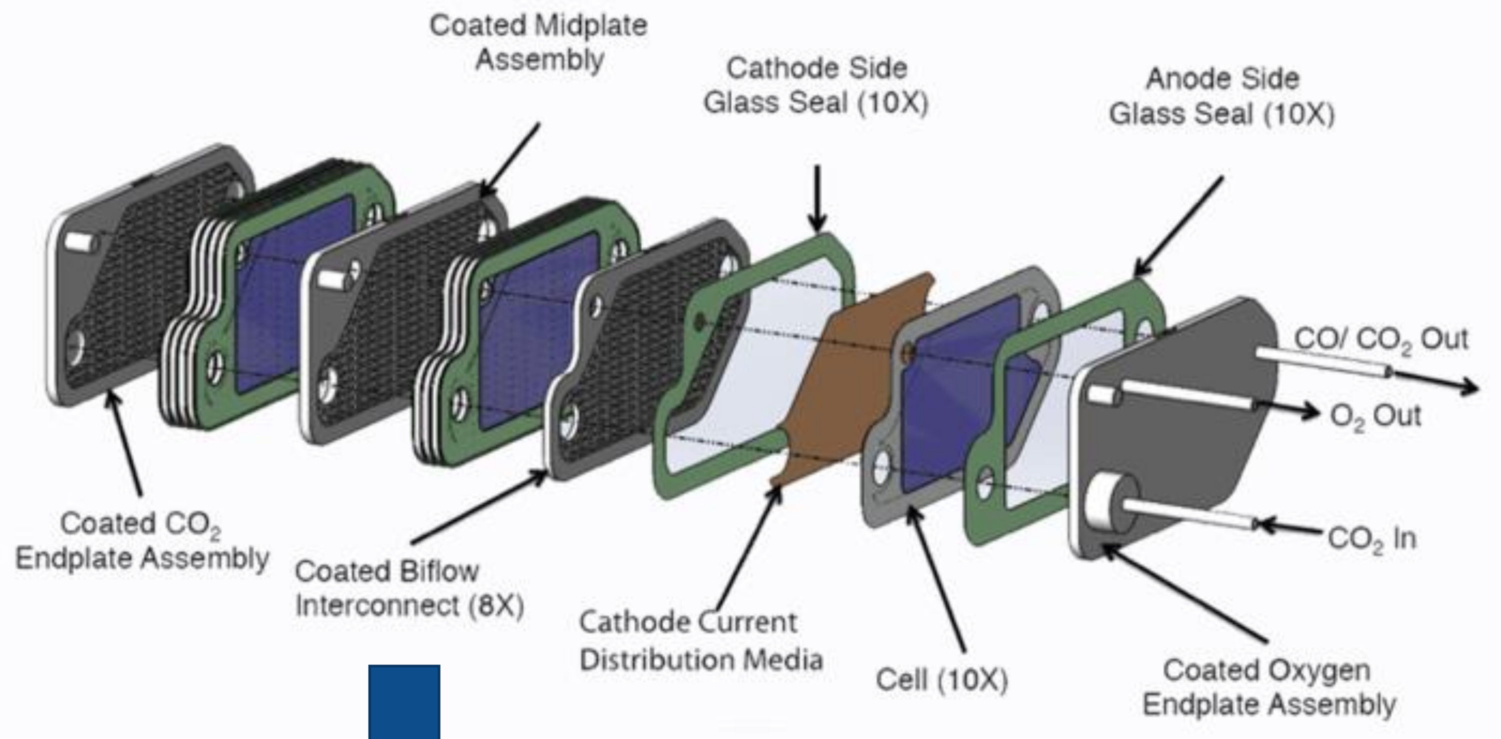
NASA Jet Propulsion Laboratory (JPL) Team's Responsibility:

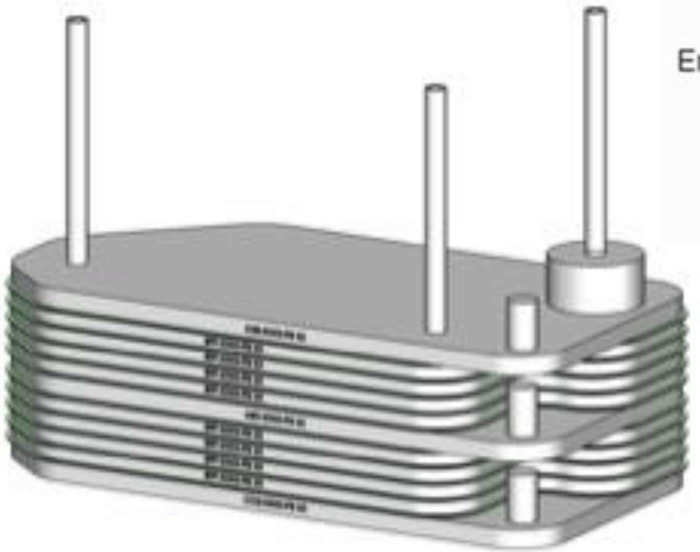
- Packaging
- Flight qualification testing
- Rover installation

MOXIE Stack Design

OxEon Team's Responsibility:

- Materials Selection
- Stack Design
- Fabrication
- Testing
- Test coordination at JPL





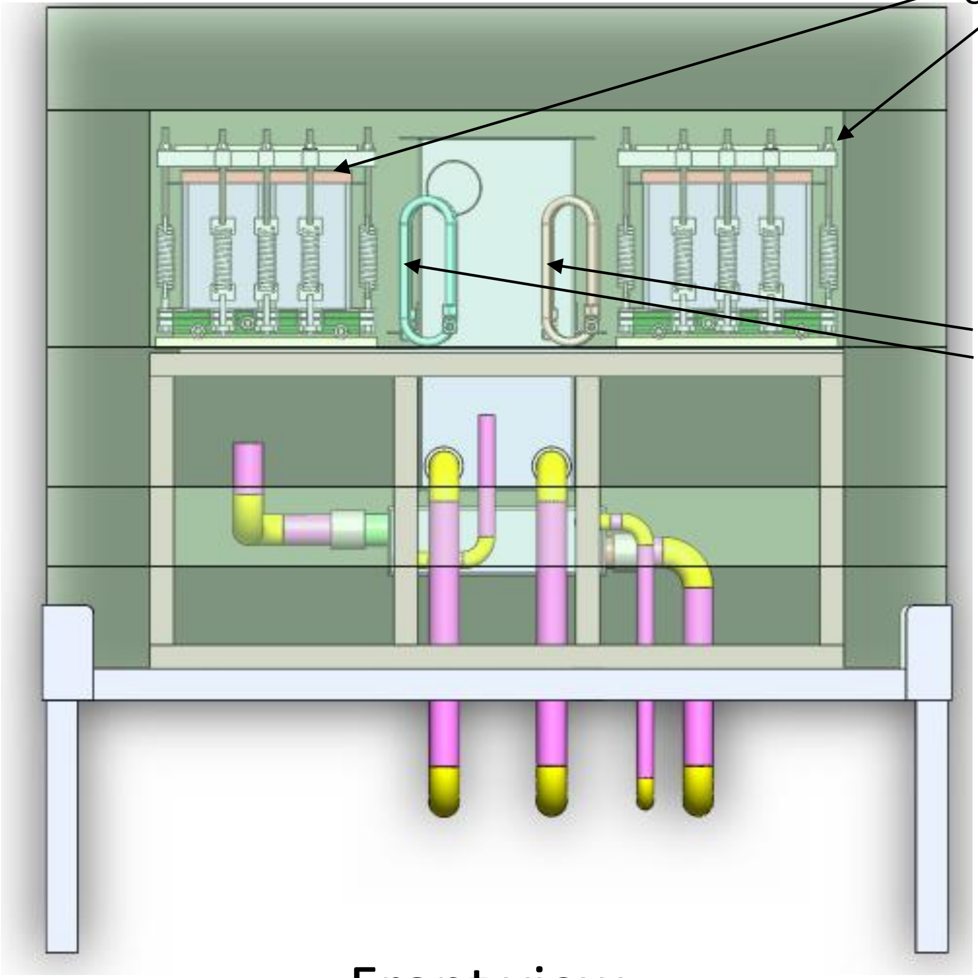
Final Moxie stack assembly

20 kW SOEC / 10 kW SOFC System Balance of Plant

- 4x 50W (5-cell stacks) to be delivered by December 12, 2021

Approximate box size: 57" L x 38" W x 60" H

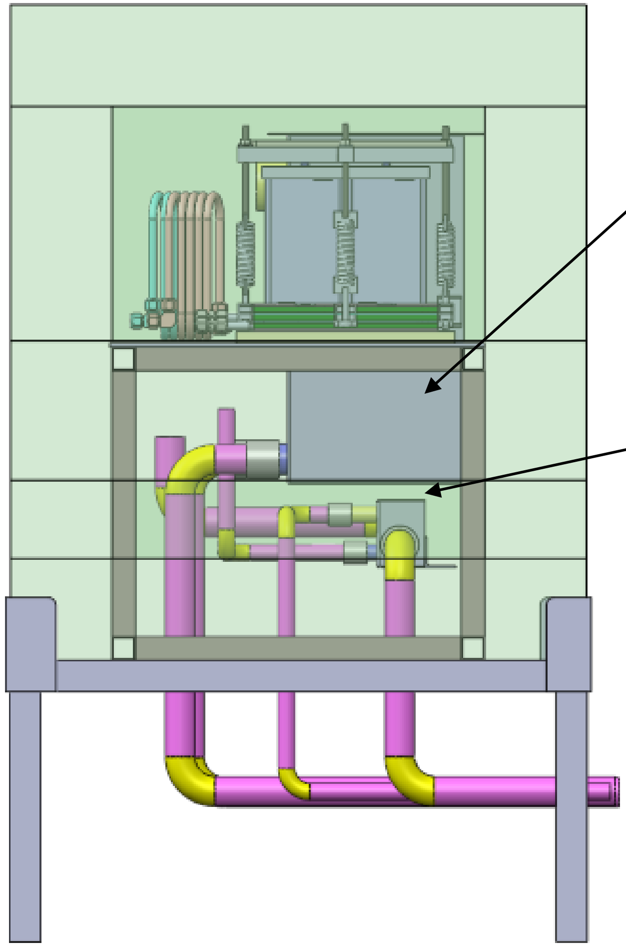
Quad Cell Stacks



Pre-heaters (preliminary sketch)

Box dimensions: 57"L x 38"H x 60"H.

Front view



HX-1 (Air)

HX-2 (H_2/ steam)

Side view

Conclusions:

- It is viable to generate electricity by supplying a green bipropellant pair, specifically ammonia (NH_3) and nitrous oxide (N_2O), to a Solid Oxide Fuel Cell (SOFC)
- Bipropellant decomposition appears to be a major factor in the electric power an SOFC can output
- Significant work still needs to be done before a fuel cell which can be integrated with a bipropellant thruster can be realized

Requests:

- Looking for new electrodes, electrolytes, seals, and fuel cell designs to consider

Acknowledgements

Kirtland AFB, New Mexico

- Dr. Thomas Peng (afrl.vss@us.af.mil)
- Professor Fernando Garzon (UNM/Sandia)
- Professor Lok-kun Tsui (UNM)
- Dr. Andre Spears (UNM)
- Dr. John Plumley (UNM)
- Dr. Robert Walters (AFRL/RVS)
- Valerie Lawdensky (AFRL/RVS)

Wright-Patterson AFB, Ohio

- Dr. Doug Dudis (AFRL/RXS)
- Dr. Joseph Fellner (AFRL/RQQ)
- Dr. Jay Deiner (AFRL/RQQ)
- Dr. Will Huddleston (UDayton)
- Professor Rory Roberts (TnTech)
- Aaron Bain (TnTech)
- Tyler Edwards (TnTech)

Edwards AFB, California

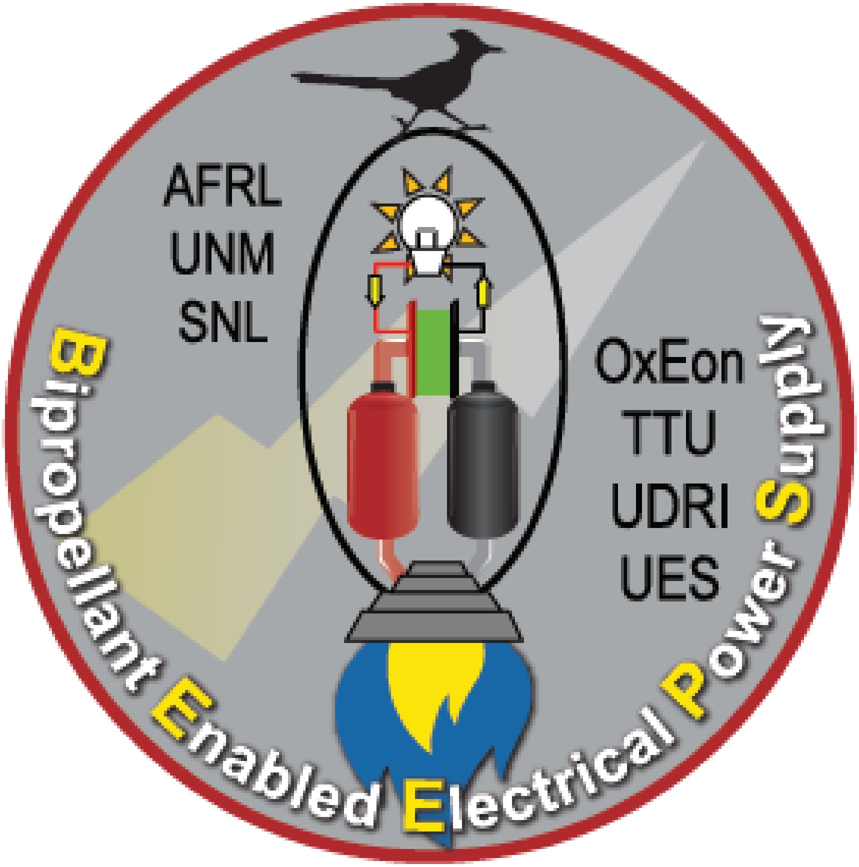
- Dr. Ghanshyam Vaghjiani (AFRL/RQR)
- Ethan Sichler (AFRL/RQR)
- Dr. Justin Koo (AFRL/RQR)

OxEon Energy, Utah

- Dr. Elango Elangovan (info@oxeonenergy.com)
- Joseph Hartvigsen (OxEon)

- Expertise
  - Thermal Control
  - Energy Storage and Electrochemistry
  - Additive Manufacturing, Catalyst, and Electrolyte design
  - Fuel Cell Modeling
  - Spacecraft Propulsion and Operations
  - Fuel Cell Design and Assembly

Questions?


AFRL
UNM
SNL
OxEon
TTU
UDRI
UES
Bipropellant Enabled Electrical Power Supply

THANK YOU

Parallax
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SUSTAINABILITY INSTITUTE

THE OHIO STATE UNIVERSITY
CENTER FOR AUTOMOTIVE RESEARCH