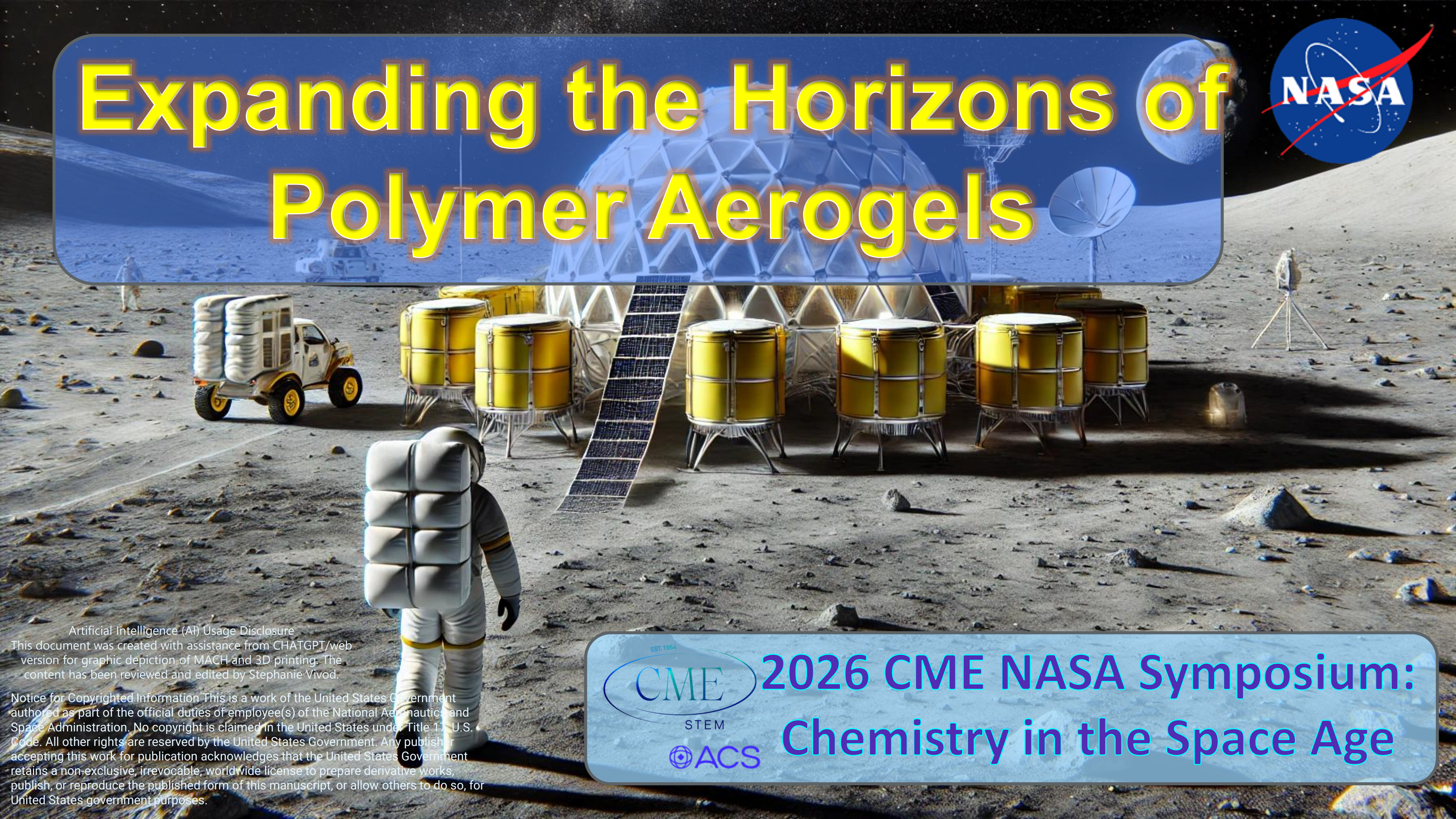
Expanding the Horizons of Polymer Aerogels



2026 CME NASA Symposium: Chemistry in the Space Age

Artificial Intelligence (AI) Usage Disclosure

This document was created with assistance from CHATGPT/web version for graphic depiction of MACH and 3D printing. The content has been reviewed and edited by Stephanie Vivod.

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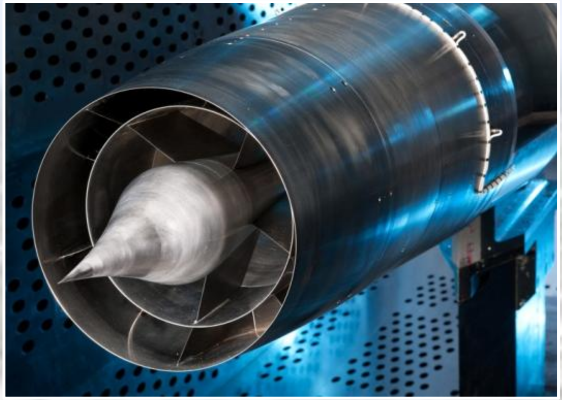
Research Chemical Engineer

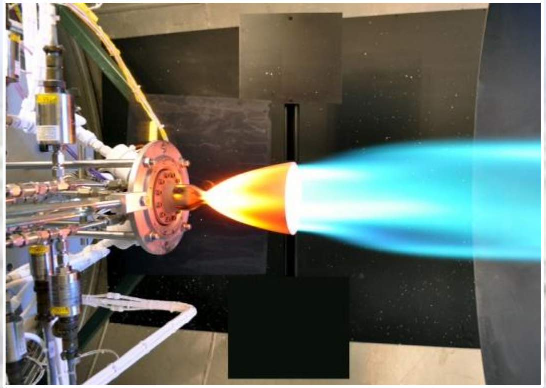
National Aeronautics and Space Administration

Materials and Structures Division

NASA Glenn Research Center Core Competencies

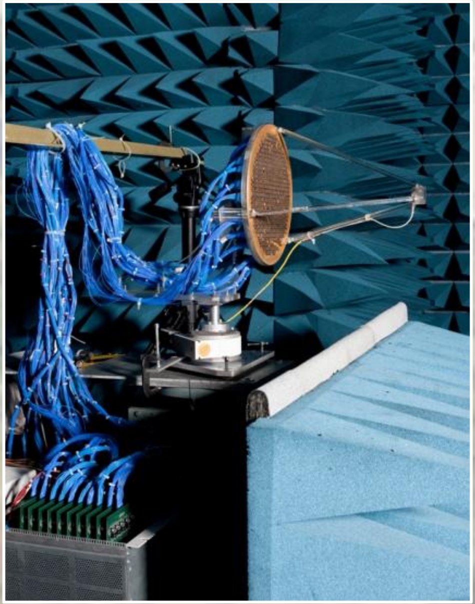


Air-Breathing Propulsion



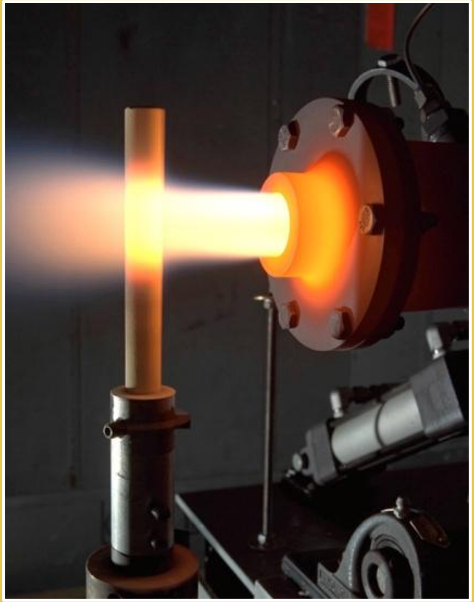
In-Space Propulsion and Cryogenic Fluids Management

Physical Sciences and Biomedical Technologies in Space



Communications Technology and Development

Power, Energy Storage and Conversion



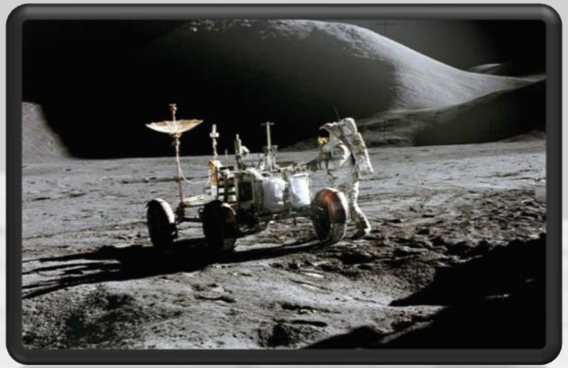
Materials and Structures for Extreme Environments

WE'RE GOING BACK!

Artemis Program: 2022-2027

https://www.nasa.gov/specials/artemis/

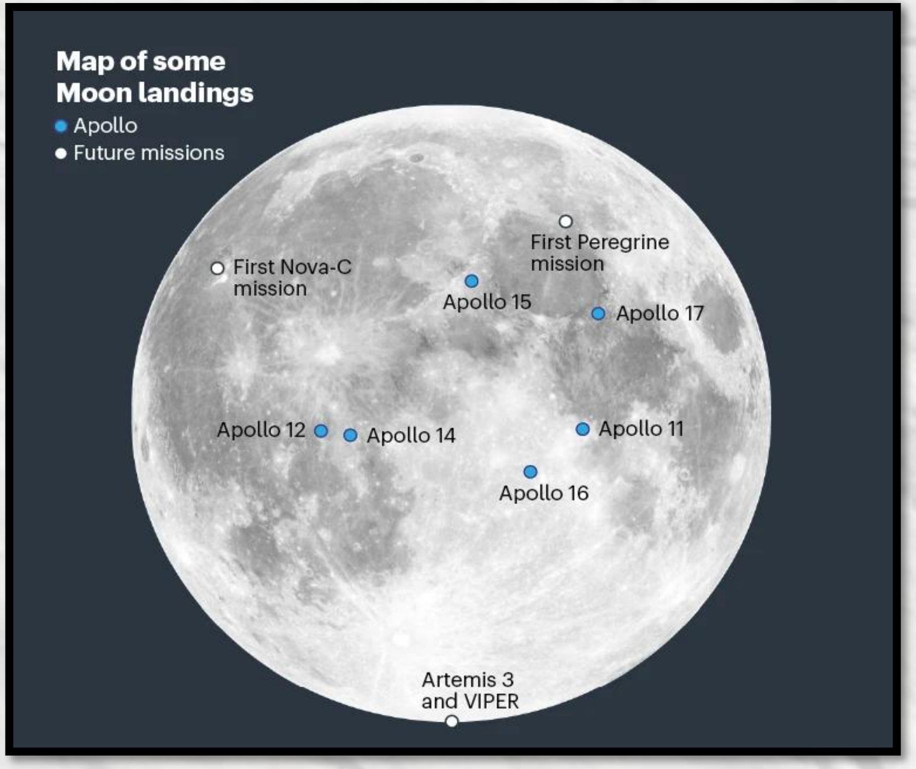
Apollo Program ran from 1961 to 1972



Apollo 15-Astronaut James B. Irwin, lunar module pilot, works on the Lunar Roving Vehicle

Moon Landing Missions:

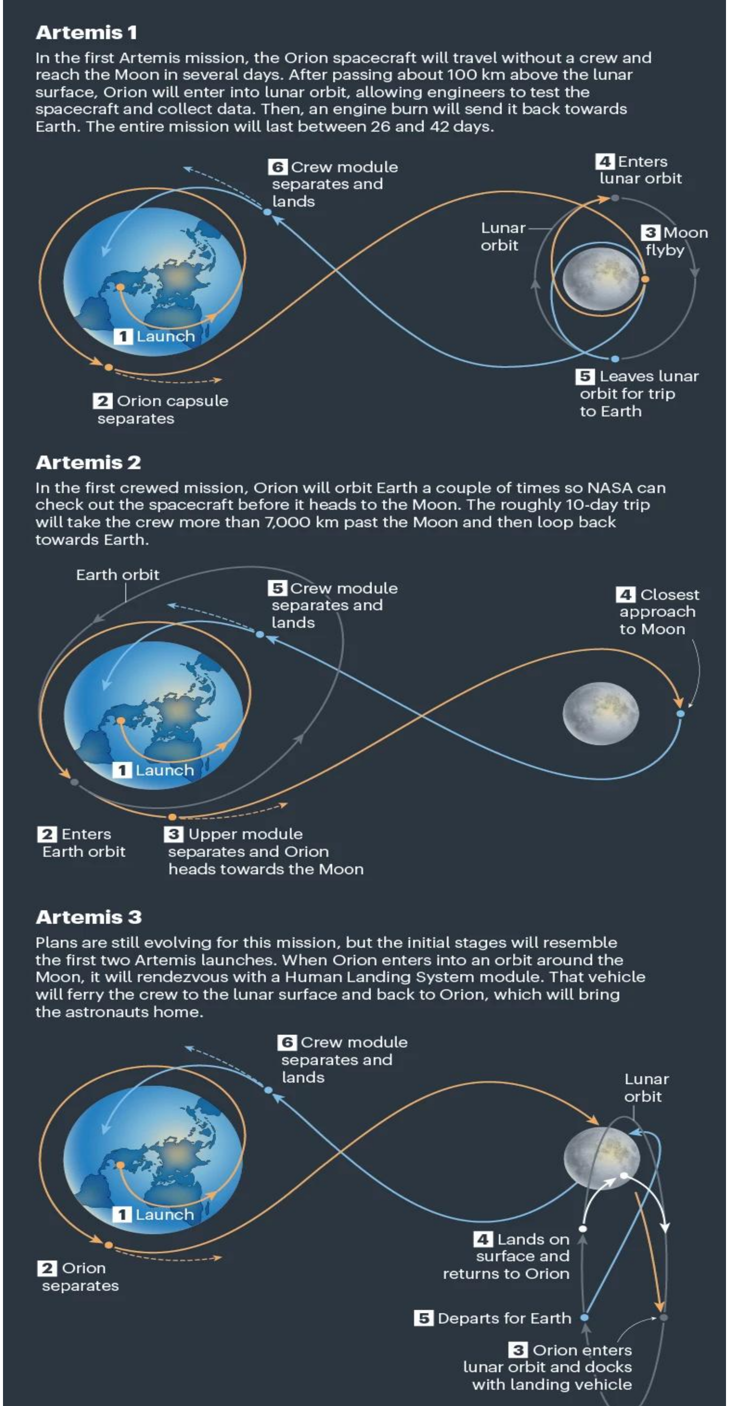
- **Apollo 11 (1969)** Neil Armstrong (Commander), Buzz Aldrin, Michael Collins
- **Apollo 12 (1969)** Charles "Pete" Conrad (Commander), Alan Bean, Richard Gordon
- ***Apollo 13 (1970)** James Lovell (Commander), Jack Swigert, Fred Haise
- **Apollo 14 (1971)** Alan Shepard (Commander), Edgar Mitchell, Stuart Rosa
- **Apollo 15 (1971)** David Scott (Commander), James Irwin, Alfred Worden
- **Apollo 16 (1972)** John Young (Commander), Charles Duke, Thomas Mattingly
- **Apollo 17 (1972)** Eugene Cernan (Commander), Harrison Schmitt, Ronald Evans



Nature | Vol 605 | 12 May 2022

NASA is now preparing for an ambitious new era of sustainable human spaceflight and discovery

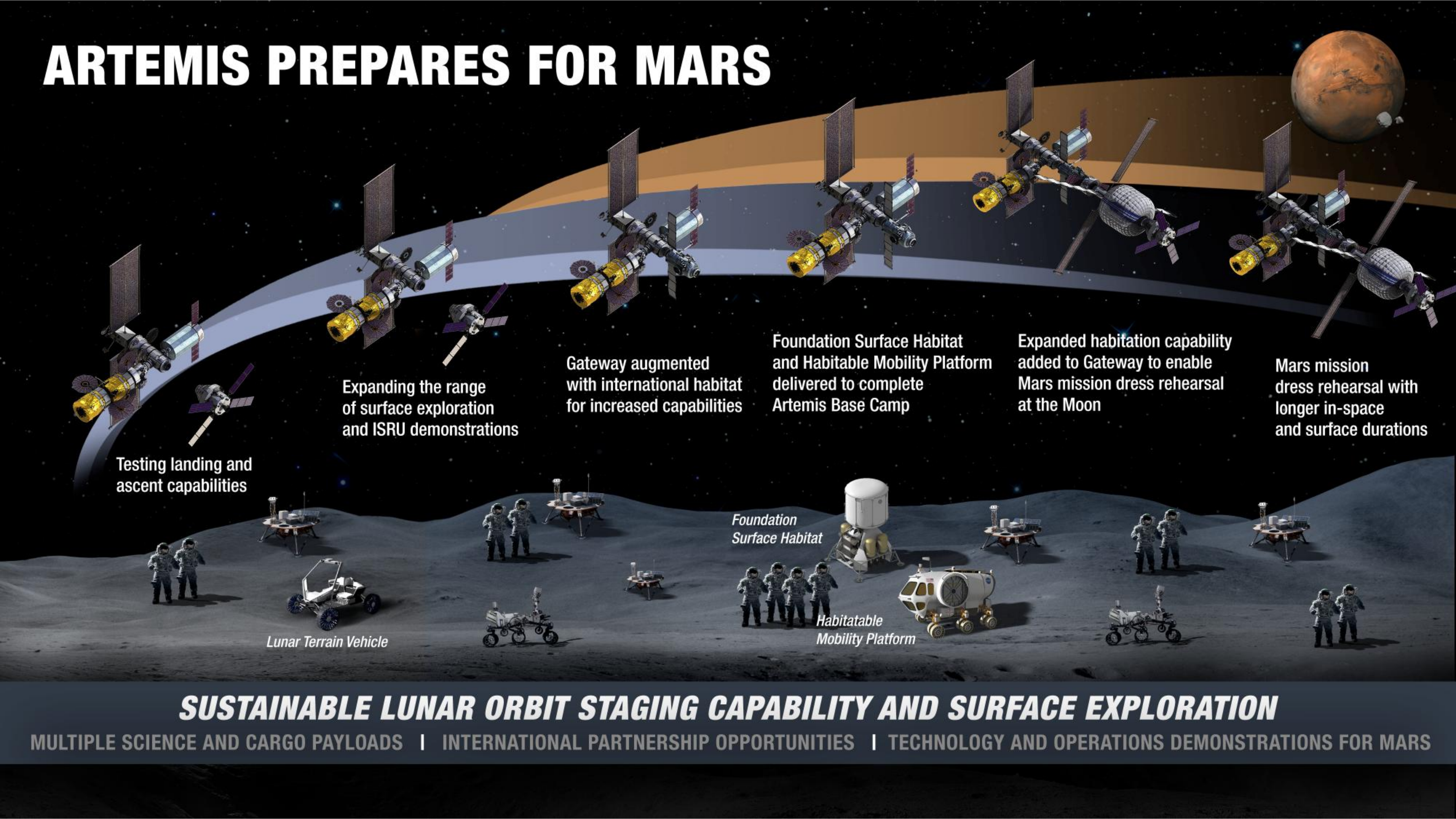
*mission aborted



doi: https://doi.org/10.1038/d41586-022-01253-6

Issues and Concerns with Space Exploration

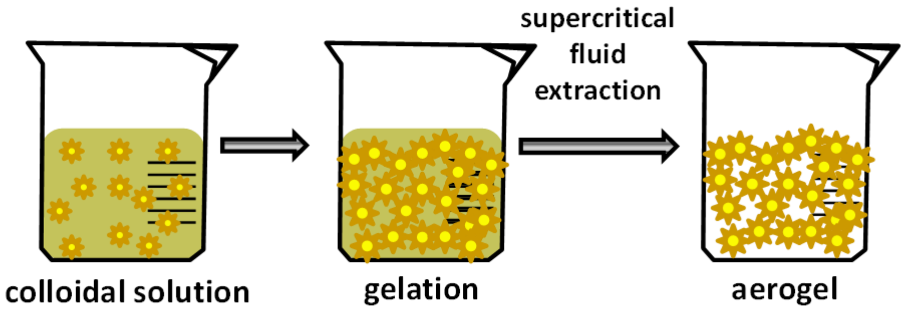
- Orbital debris
- Radiation
- Payload weight reduction
- Lunar dust
- Crew health and safety
- ISRU


ARTEMIS PREPARES FOR MARS
Testing landing and ascent capabilities
Expanding the range of surface exploration and ISRU demonstrations
Gateway augmented with international habitat for increased capabilities
Foundation Surface Habitat and Habitable Mobility Platform delivered to complete Artemis Base Camp
Expanded habitation capability added to Gateway to enable Mars mission dress rehearsal at the Moon
Mars mission dress rehearsal with longer in-space and surface durations
Lunar Terrain Vehicle
Foundation Surface Habitat
Habitatable Mobility Platform
SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION
MULTIPLE SCIENCE AND CARGO PAYLOADS | INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

The Wonderful World of Polymer Aerogels!

What is an aerogel?

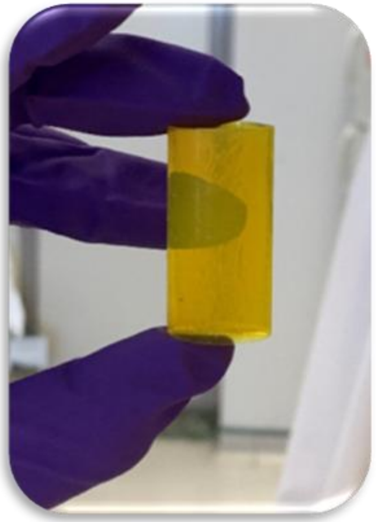
- An open-celled, light weight, porous material derived from a gel in which the liquid is replaced by gas while maintaining the self-assembled three-dimensional structure



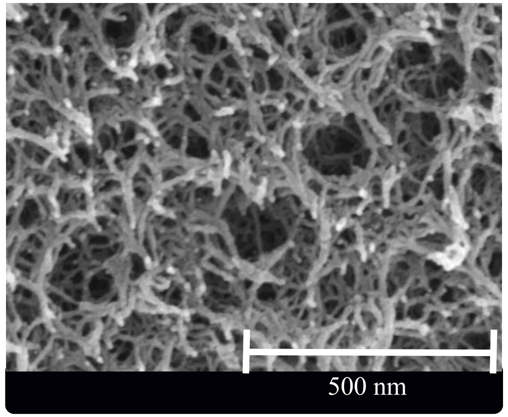
Aerogels made using sol-gel synthesis and supercritical fluid extraction

Many characteristics of aerogels are tailored by using various chemistries; however, all aerogels have these Typical Properties:

- High porosity (> 90 %)
- Nano-scale pore sizes (10-40 nm)
- Low density (0.1-0.2 g/cm^3)
- Large surface areas (400 – 850 m^2/g)
- Low thermal conductivity (~20mW/m·K)
- Low dielectric (1.1)
- Low refractive index (1.02-1.09)

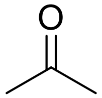


polymer aerogel cylinder (1g) (SA= 850 m2/g)

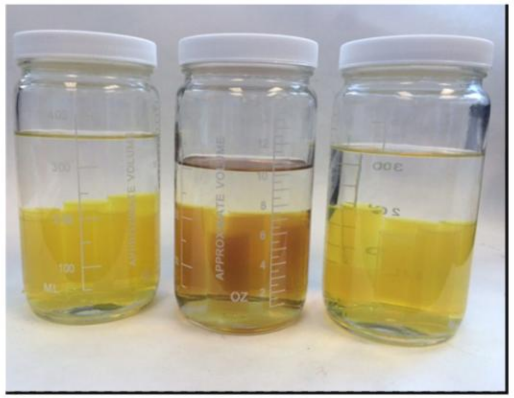


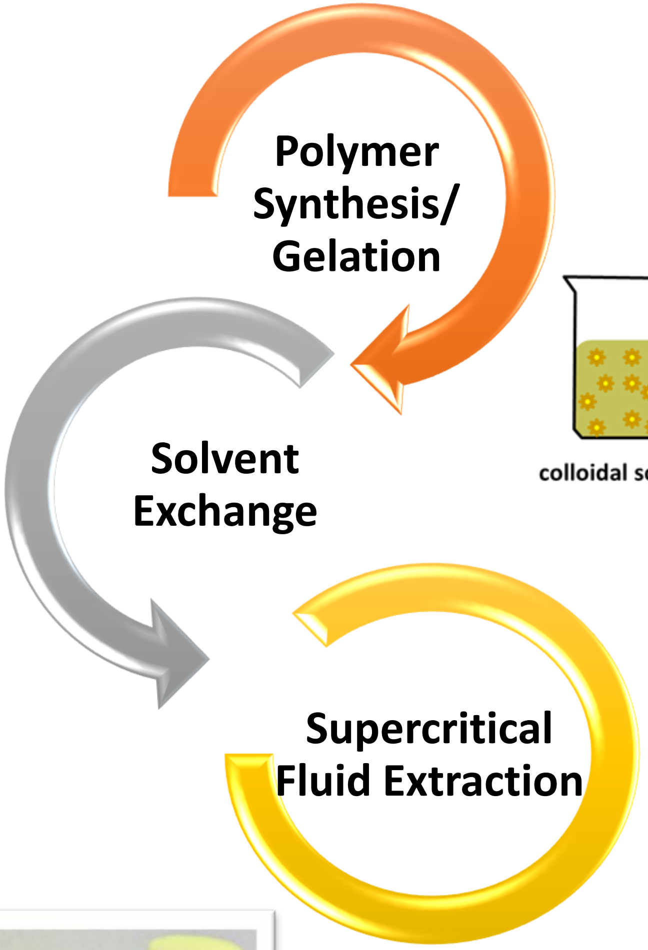
Scanning Electron Micrograph of polymer aerogel matrix

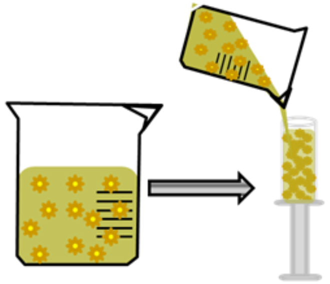
Aerogel Fabrication Process

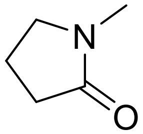


acetone

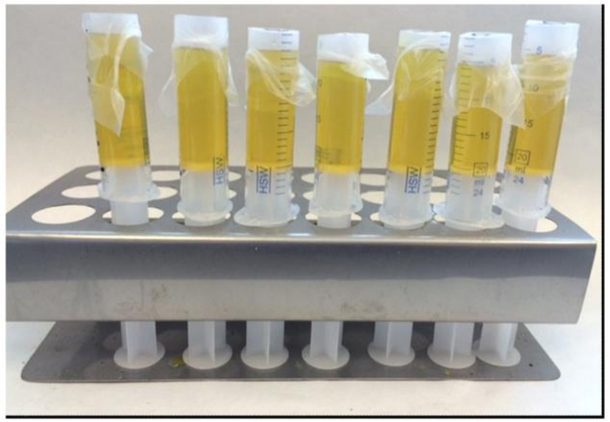


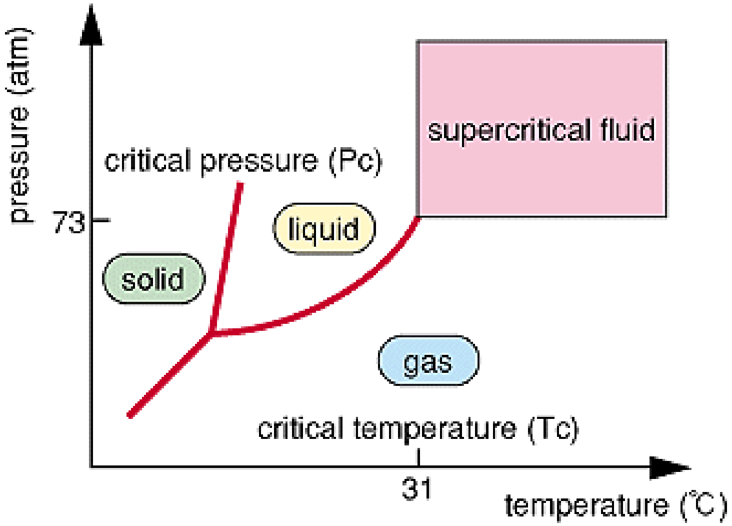


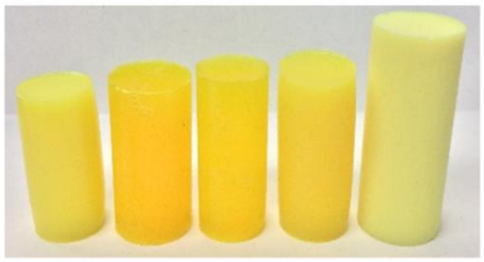




n-methylpyrrolidone (NMP)







Aerogel Properties Dependent on Structure and Chemistry

Structure

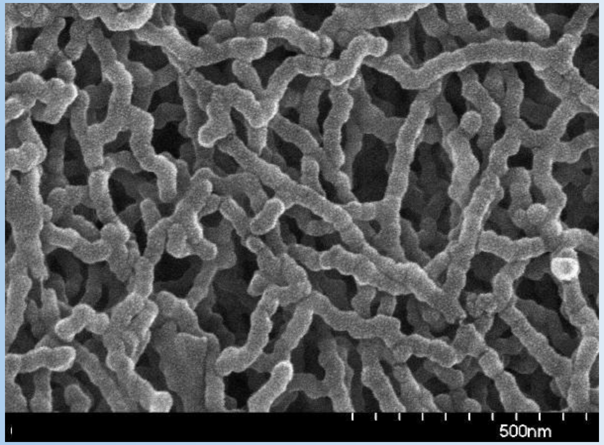
Universal Aerogel Architecture

Structure Defines Baseline Properties

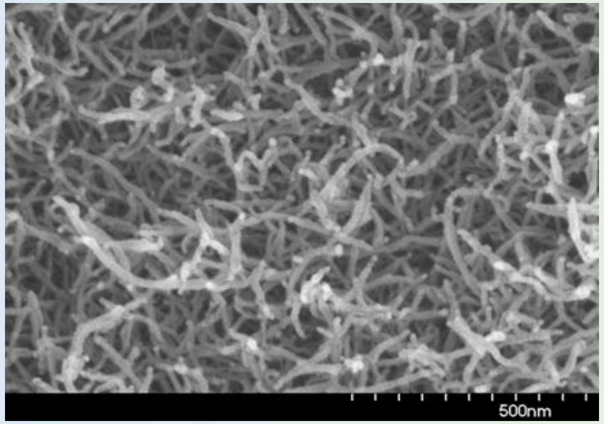
Chemistry Enables Performance Tuning

Chemistry

Tailorable Across Aerogel Systems



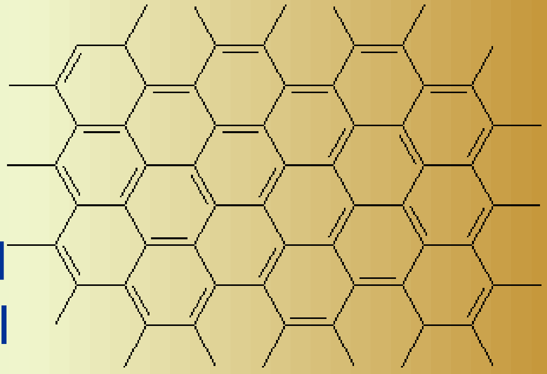
silica



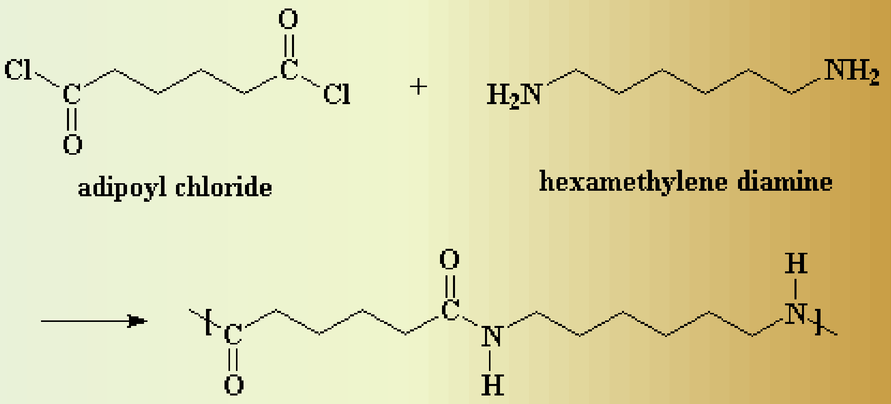
polymer

- High porosity
- Nano-scale pore size
- Low density
- High internal surface area
- Low Tc and dielectric

- Aromatics in backbone- increased modulus and thermal stability



a section of a sheet of graphite



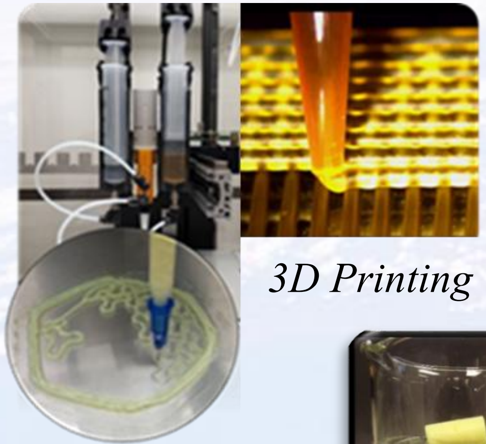
adipoyl chloride

hexamethylene diamine

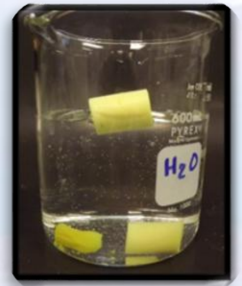
nylon 6,6

- Aliphatic in backbone- increased flexibility

Polyimide Aerogel Development at GRC

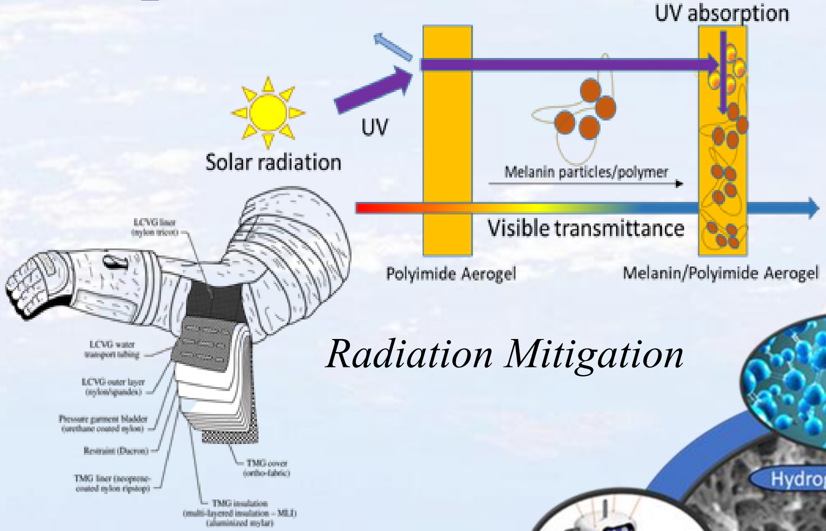


3D Printing

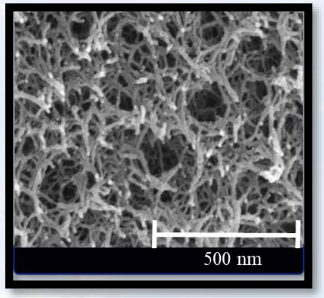


Tunable Hydrophobicity

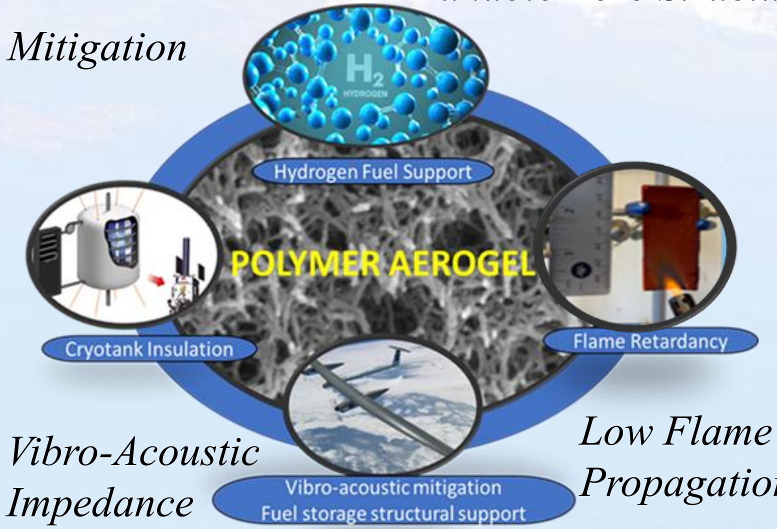
Orbital Debris Containment



Radiation Mitigation

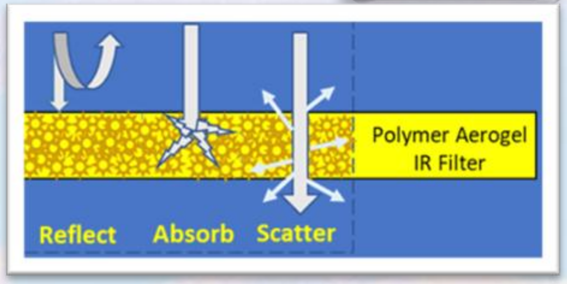


Tunable Pore Structure



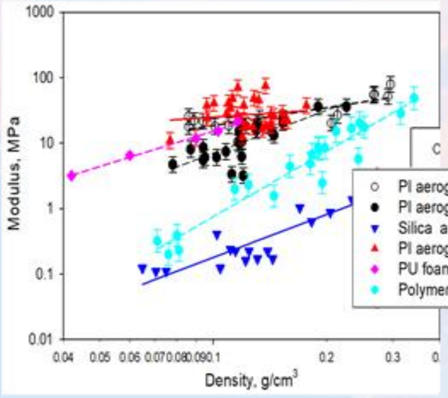
Vibro-Acoustic Impedance

Low Flame Propagation

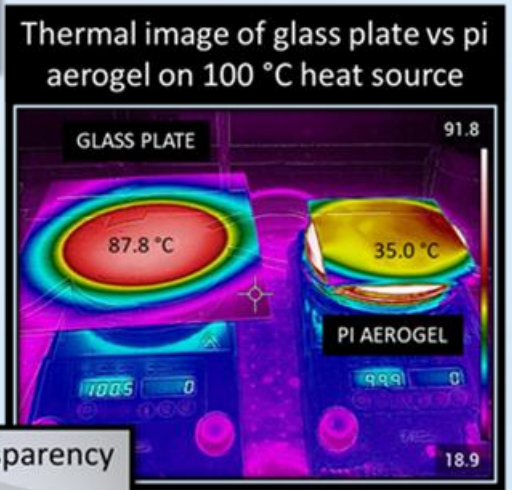


IR Filtration

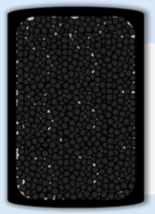
Enhanced Thermal Impedance



Improved Mechanical Properties

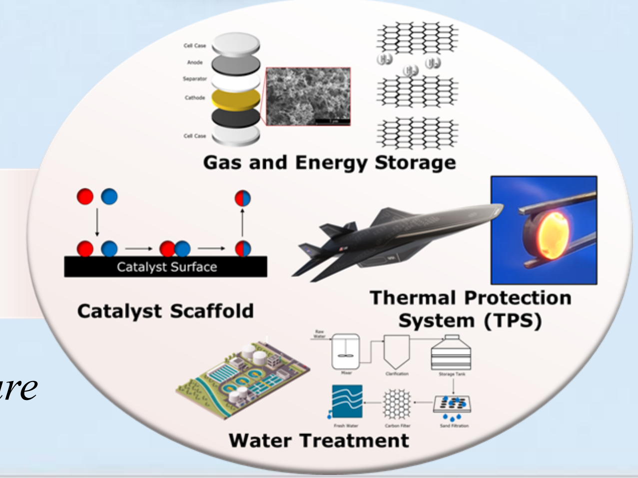


Tunable Transparency



Carbon Aerogel

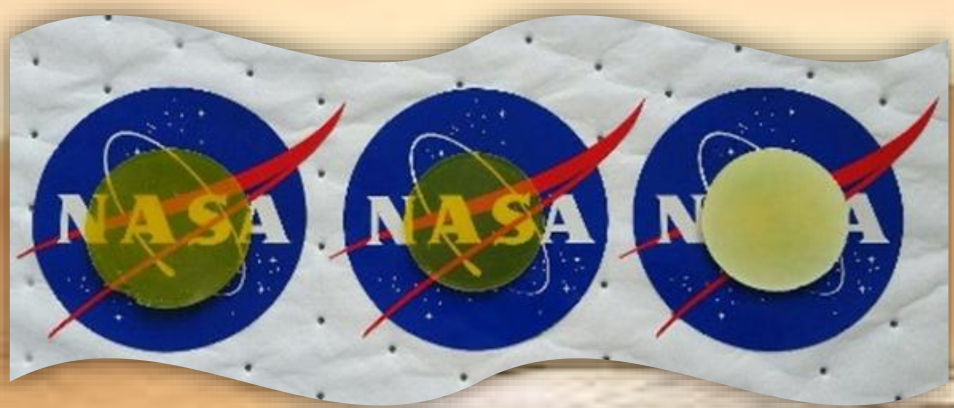
High Temperature Resistance



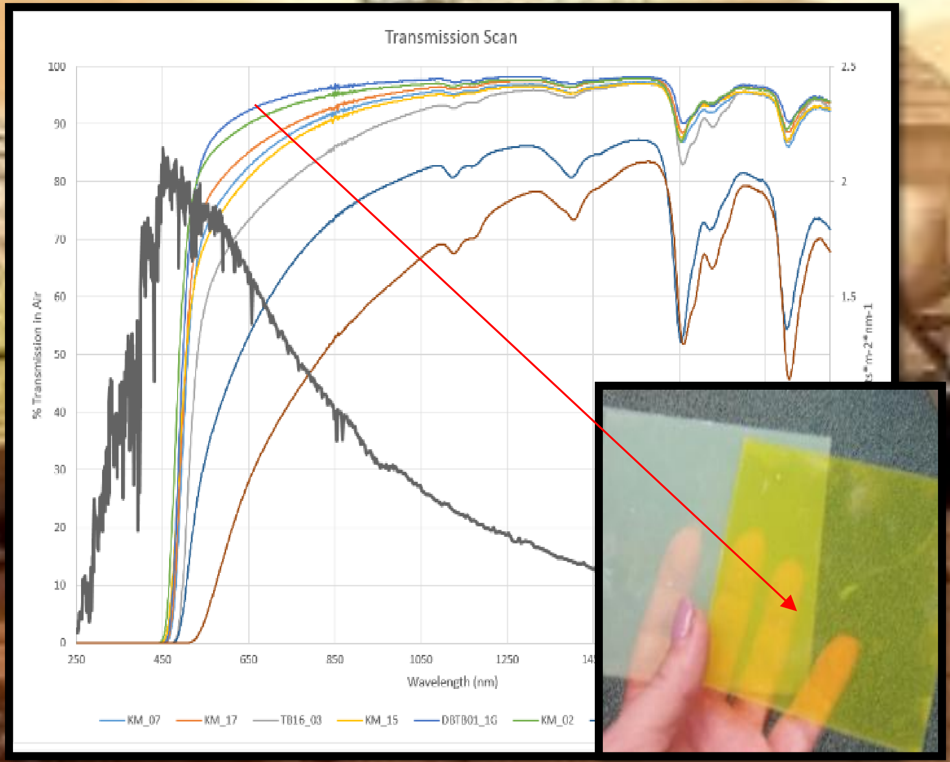
Polymer Aerogels for Passive Thermal Containment

Aerogels for Surviving the Lunar Night (ASLAN)

Tunable opacity



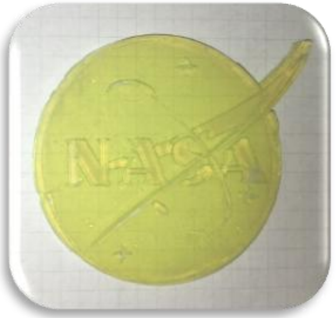
PTC for habitats, greenhouses, terraforming

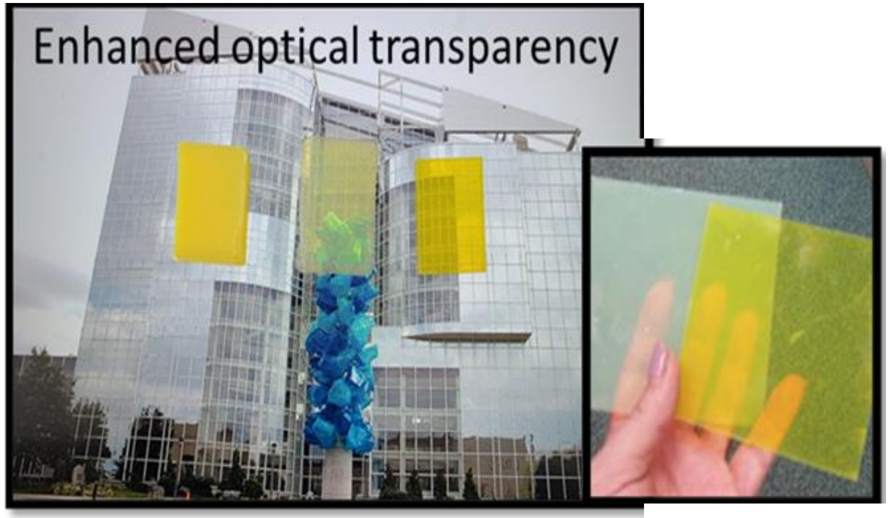


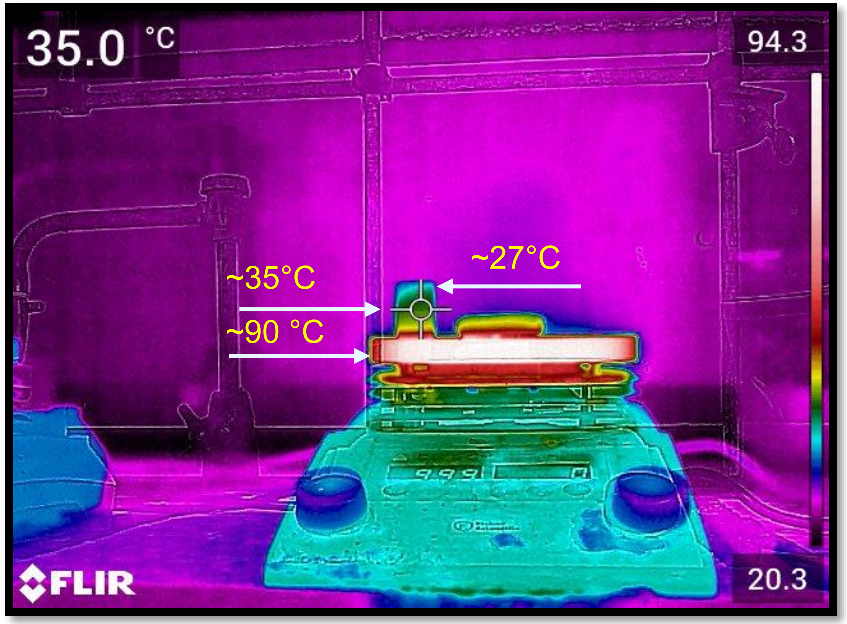
Higher transmissivity and optical clarity with fluorinated monomer

Vivod, et al. ACS Appl. Mater. Interfaces 2020 (7) 8622-8633

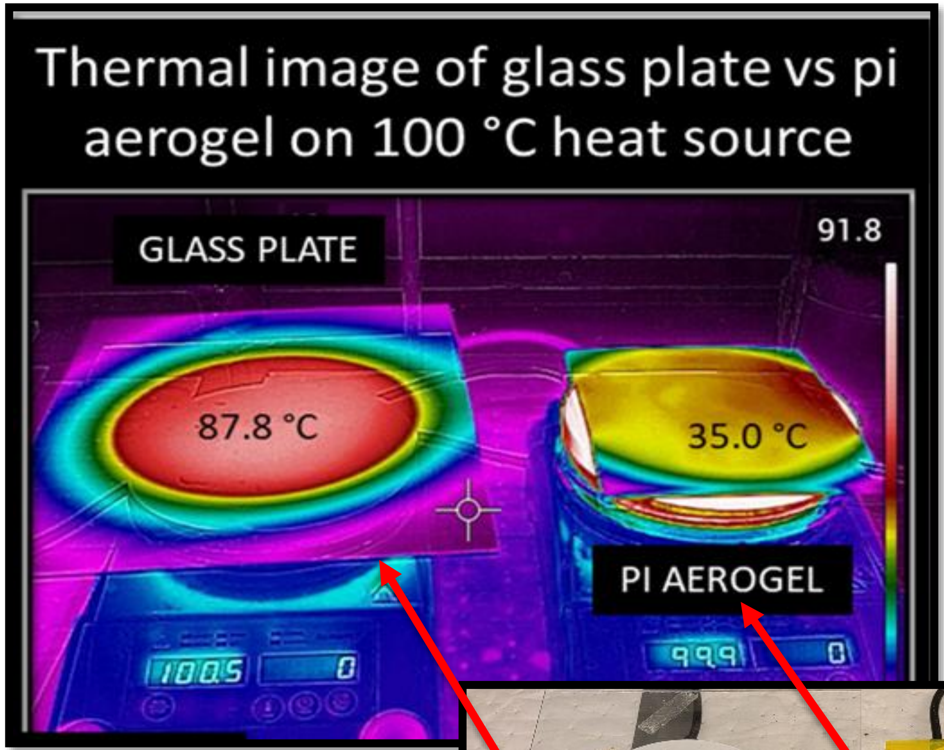
Thermal Imaging of PI Aerogel vs Plate Glass







Heat transfer through a pi aerogel cylinder (left) and block (right)-30 min



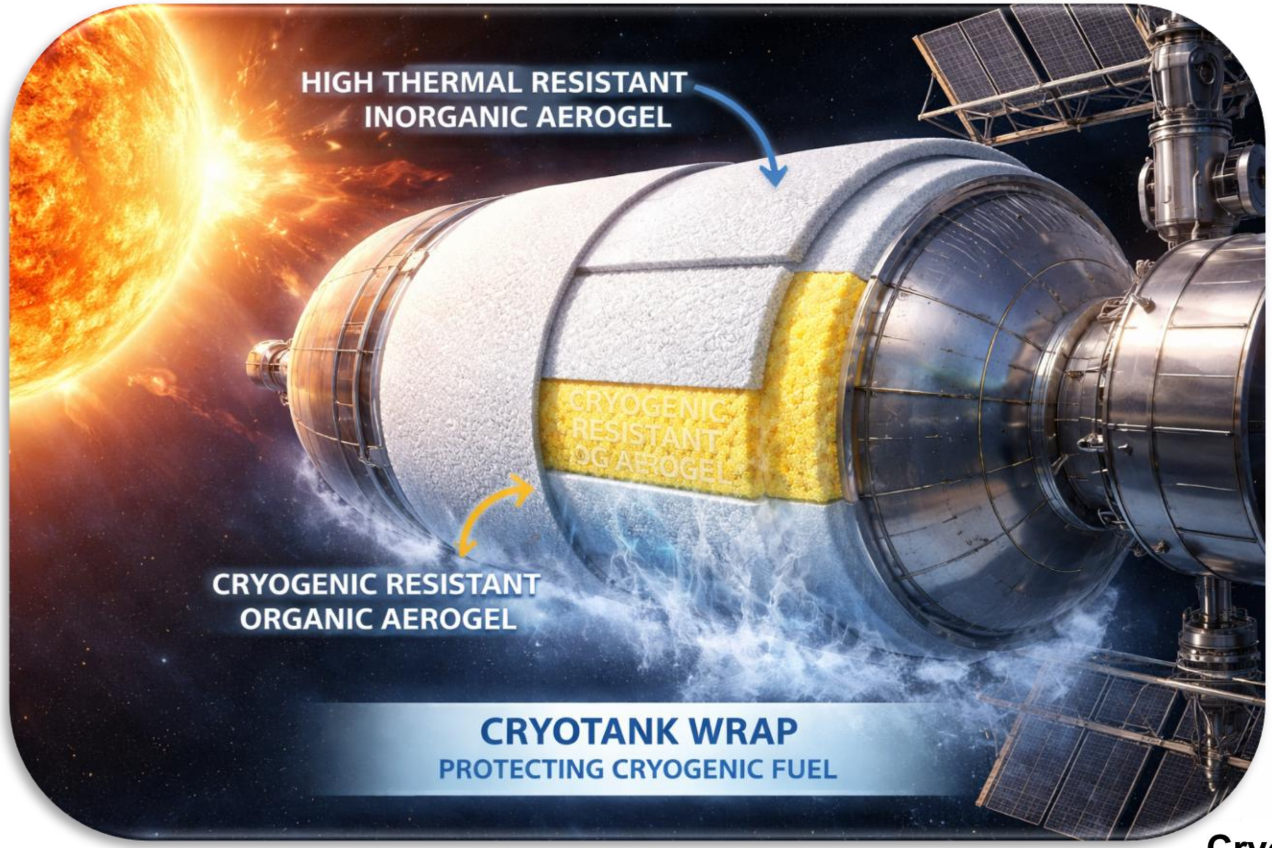
Polyimide aerogel is 30-60 times more thermally insulating than glass plating at room temperature and ambient pressure

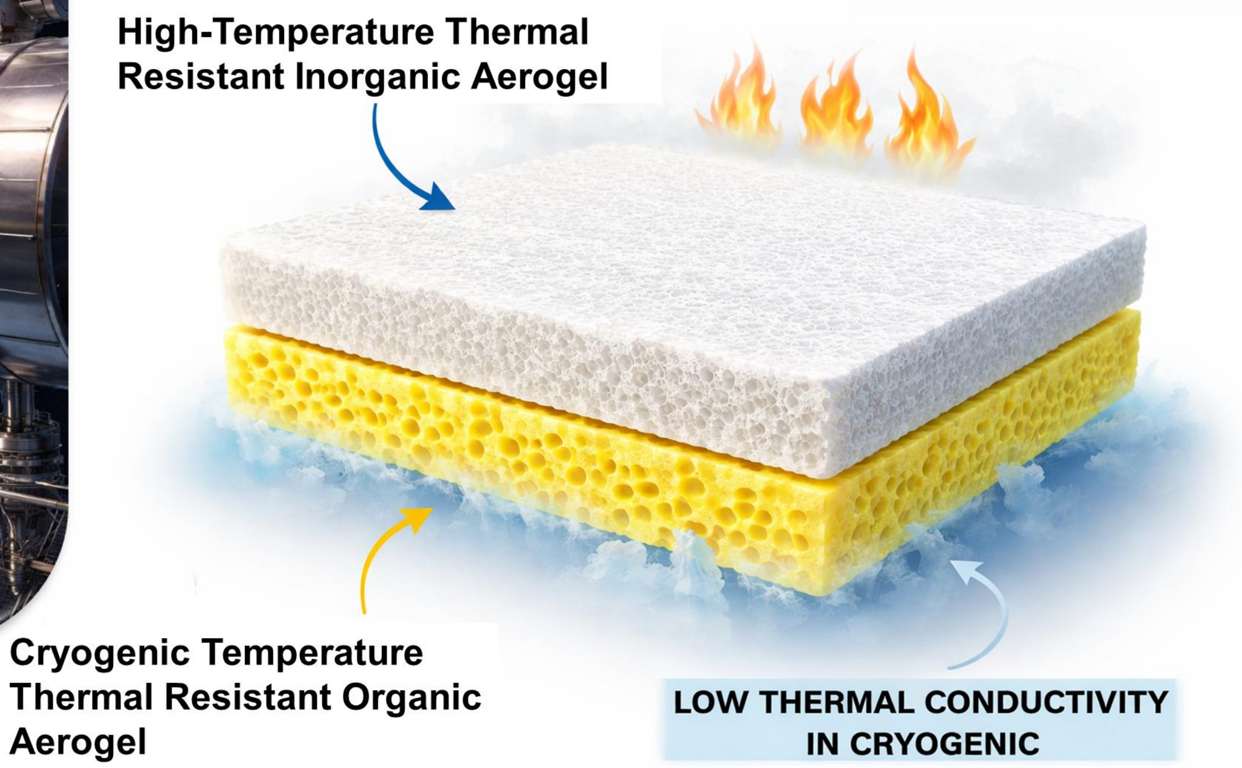
Thermal resistance = thickness/area*thermal conductivity

$$\frac{t_{aerogel}}{A * \lambda_{aerogel}} = \frac{t_{glass}}{A * \lambda_{glass}} \rightarrow \frac{t_{glass}}{t_{aerogel}} = \frac{\lambda_{glass}}{\lambda_{aerogel}} = 30$$

Patent No .: US 10,800,883 B1 Optically Transparent Polyimide Aerogels

Multi-layer Aerogel Composite Hybrid (MACH)





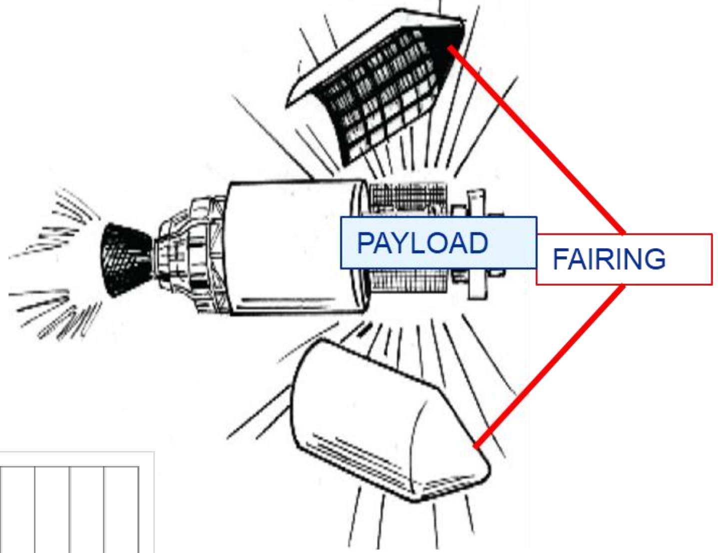
Composite aerogel material for applications exposed to opposing thermal extremes

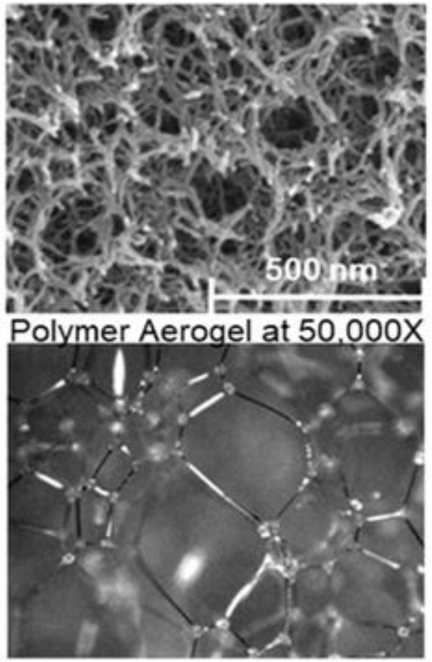
AI GENERATED CONTENT

Artificial Intelligence (AI) Usage Disclosure
This graphic was created with assistance from CHATGPT (webversion) for creating images. The content has been reviewed and edited by Stephanie Vivod.

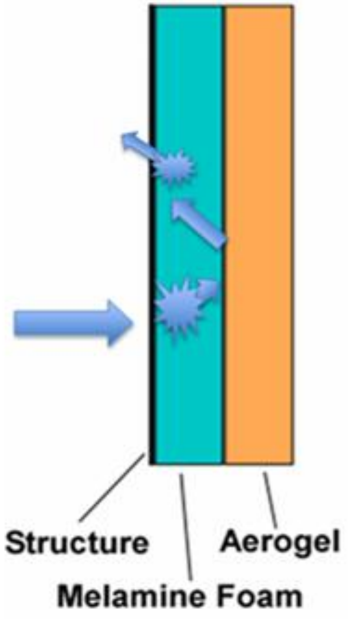
Acoustic Impedance Materials for Noise Mitigation

- Vibro-acoustic loads pose threat to payload launch survivability
- Aerogels will add damping to the structure, which reduces the amplitude of the vibration and noise transmission in addition to weight reduction

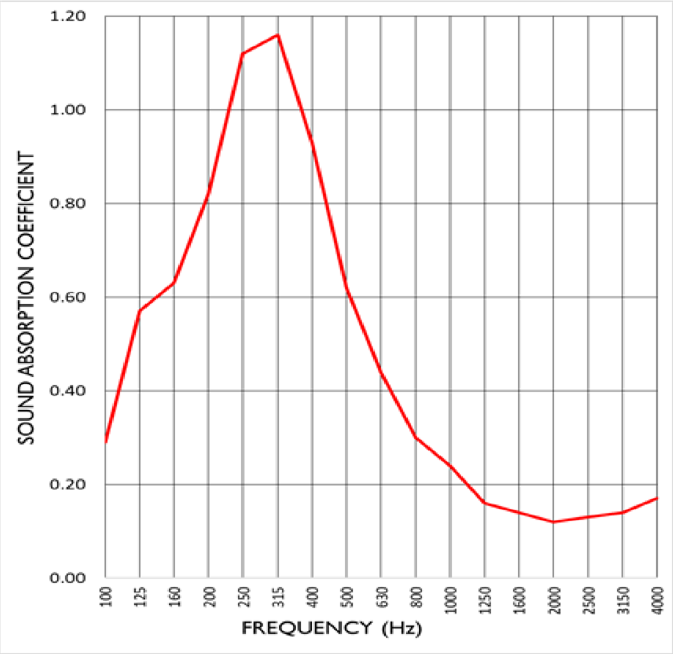




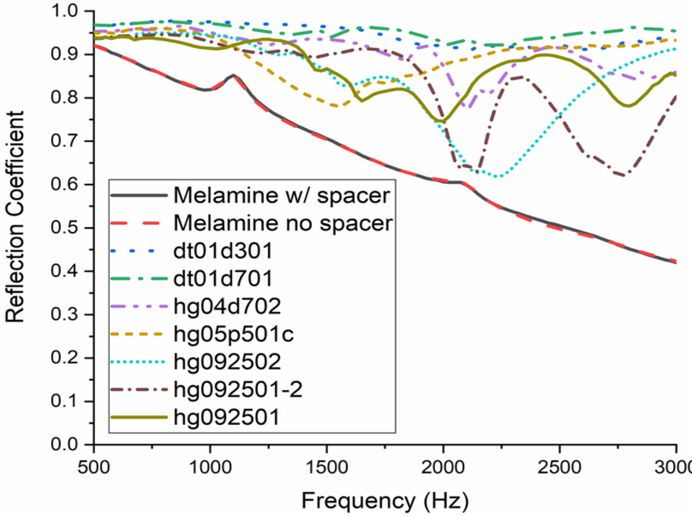
Melamine Foam at 80X



Absorbing material with aerogel as reflective backing



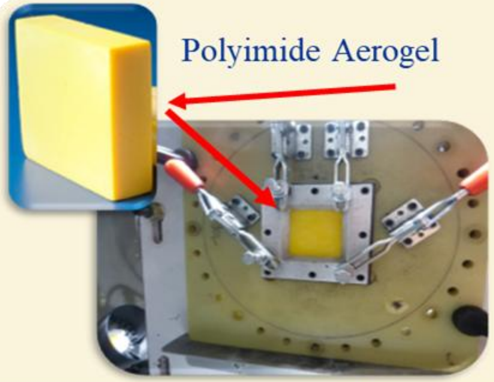
Absorption coefficient of polyimide aerogels/melamine foam composite



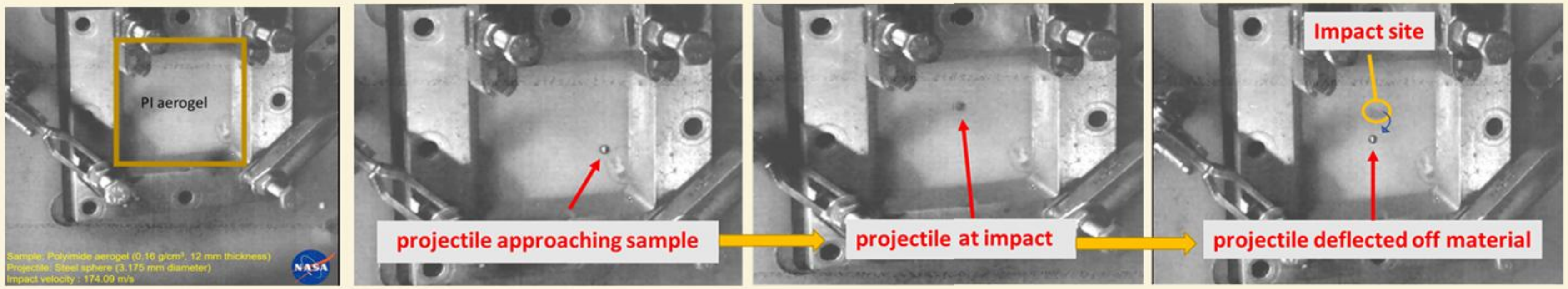
Reflection coefficient of polyimide aerogels vs melamine foam

Orbital Debris Remediation and Energy Absorption

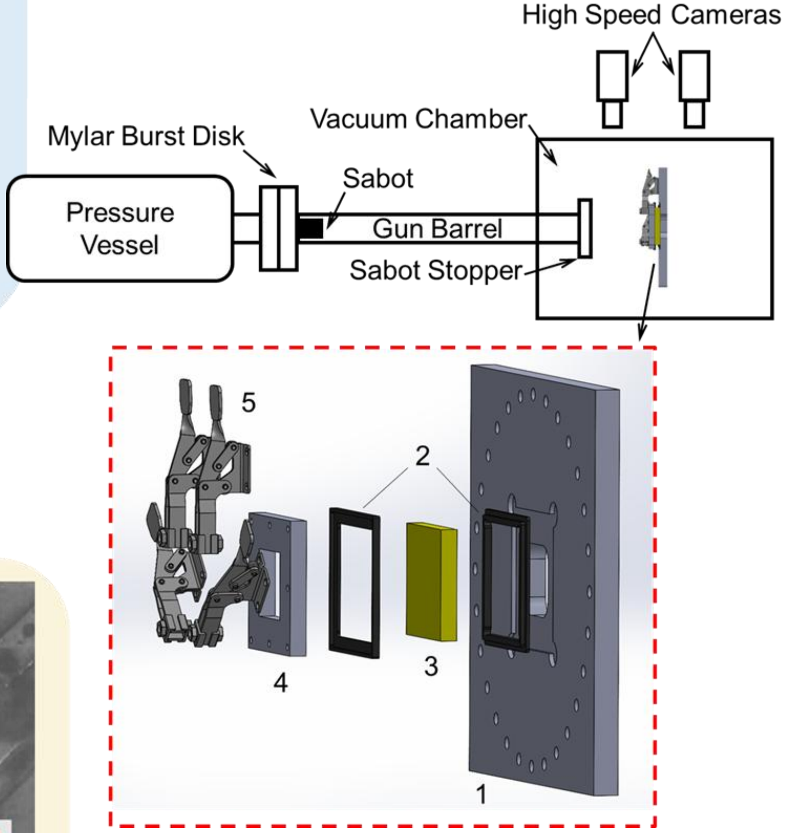
Originally investigated as a debris remediation material for secondary ejecta in a Whipple plate, polymer aerogel was found to also act as an energy absorbing material. This led to further studies for ballistic impact, energy dissipation, and high velocity particulate capture.



NASA GRC Ballistic Impact Lab



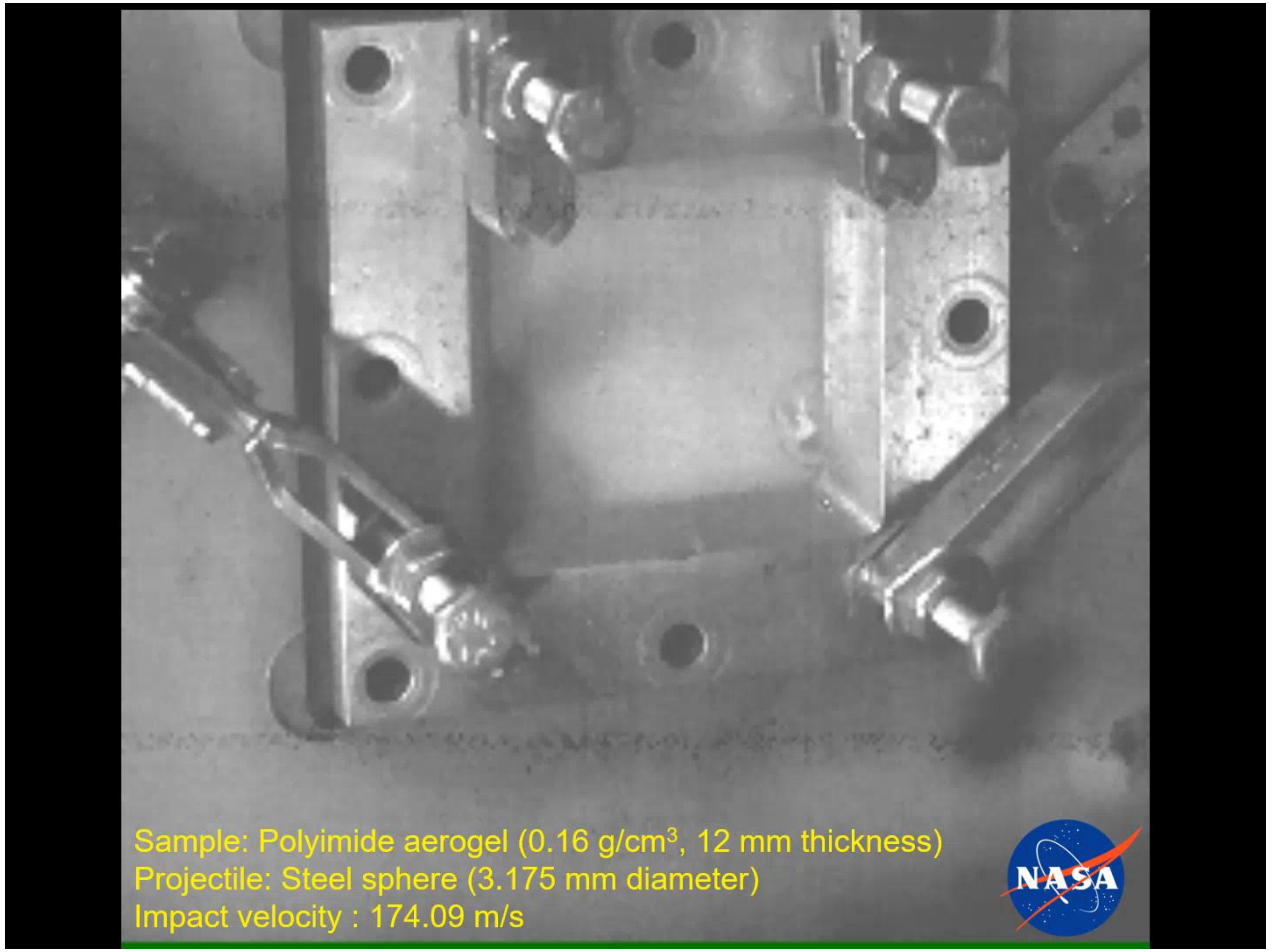
3 mm steel sphere traveling at 174m/s, impacts a 12mm (0.47”) thick polyimide aerogel and is deflected

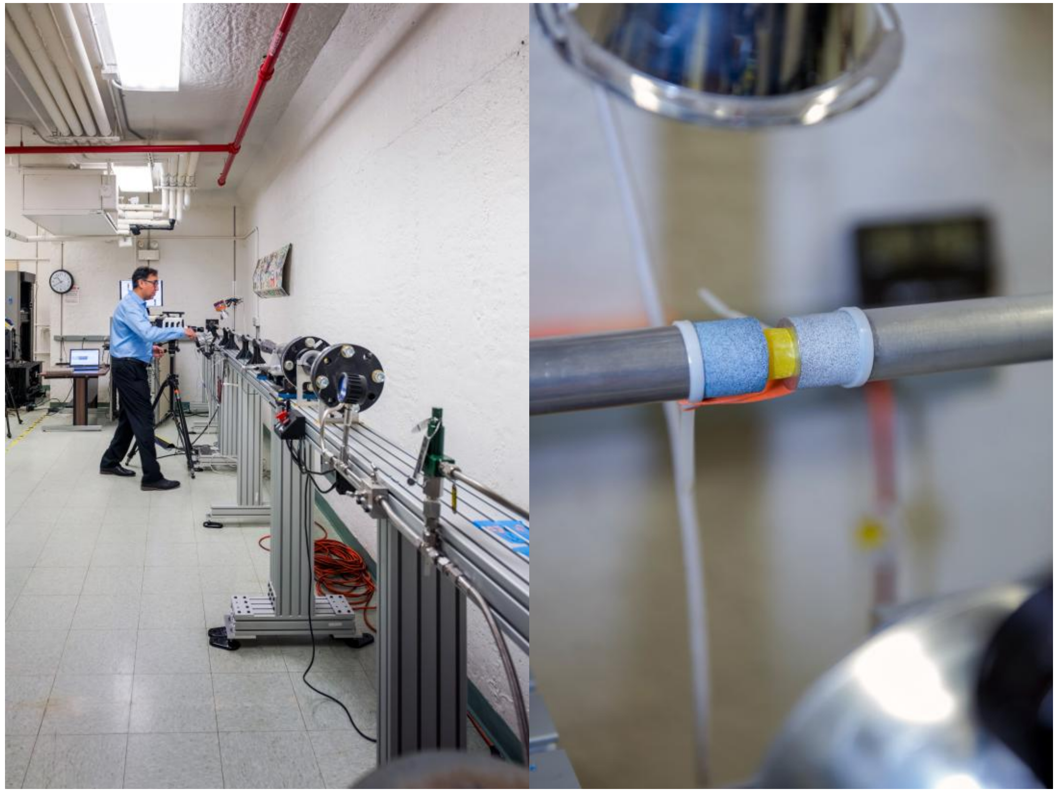


Experimental setup schematic
Projectile: steel ball, 3 mm diameter

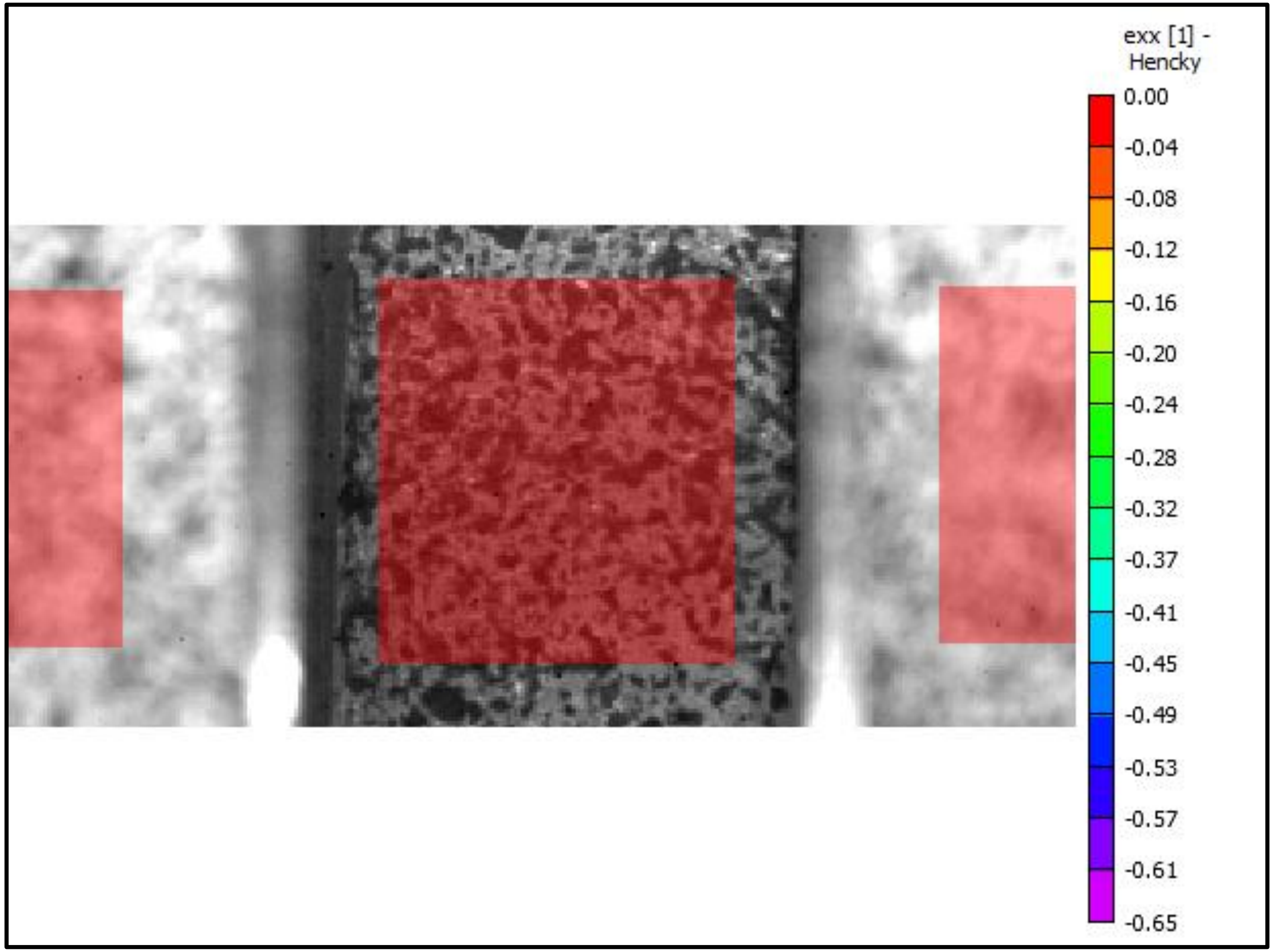
Malakooti, Vivod et al., Science Reports 12, 13933 (2022)

Ballistic Impact Test Results

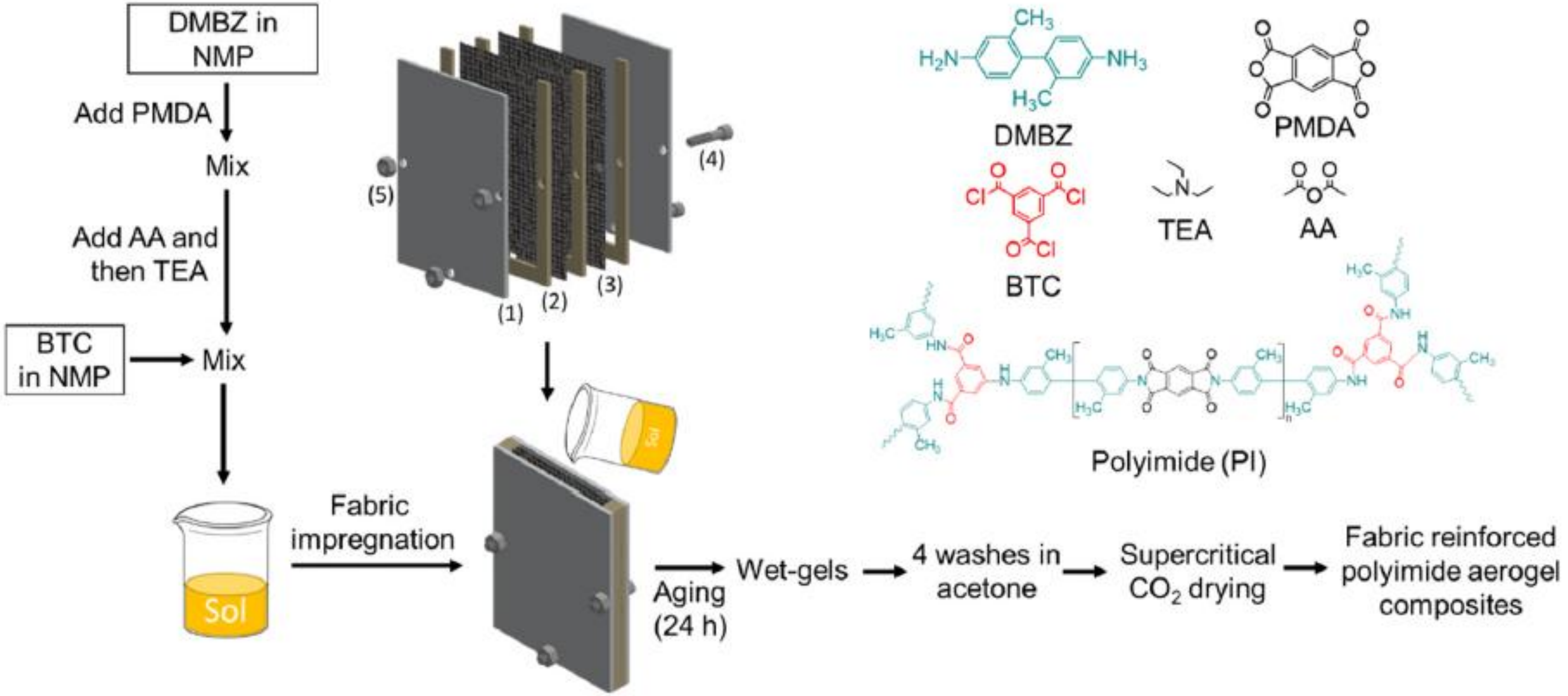




2D high-speed DIC analysis – Polyimide aerogel axial strain field under high strain rate compression experiment at room condition

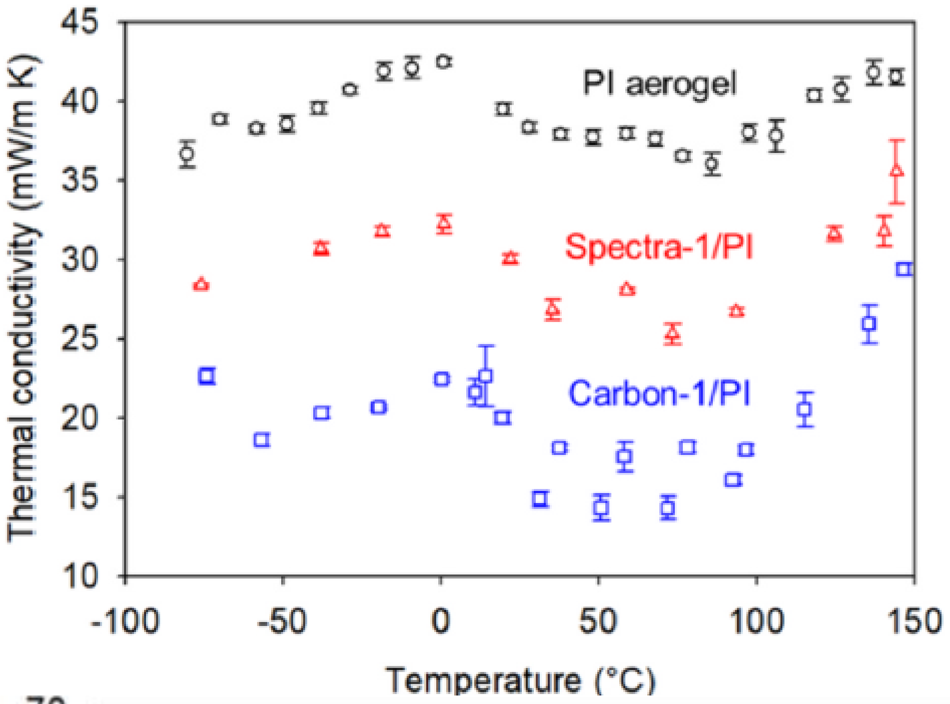


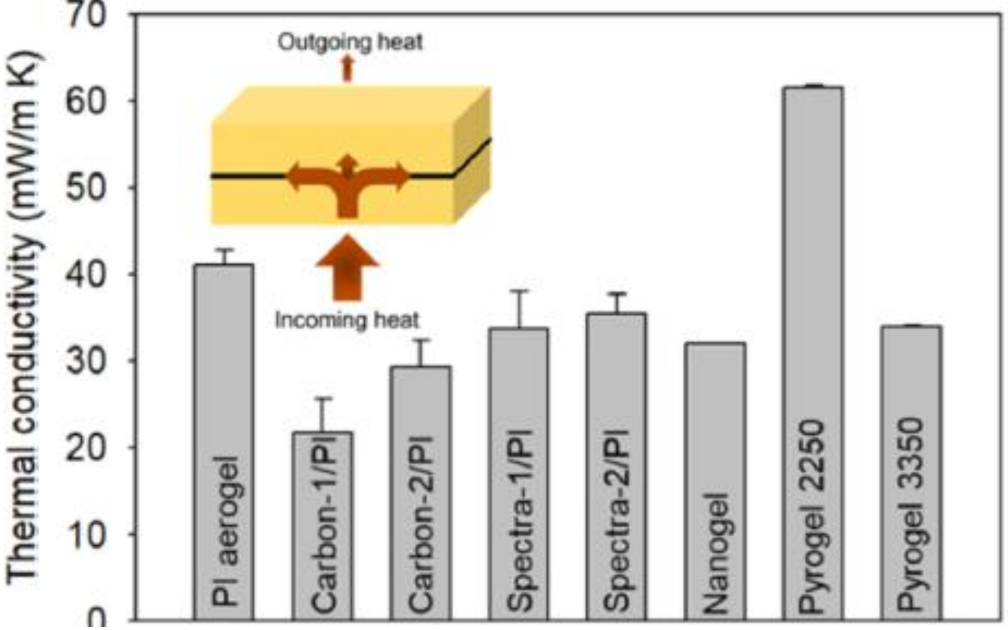
Preparation of Fabric Reinforced Polyimide Aerogel Matrix Composites



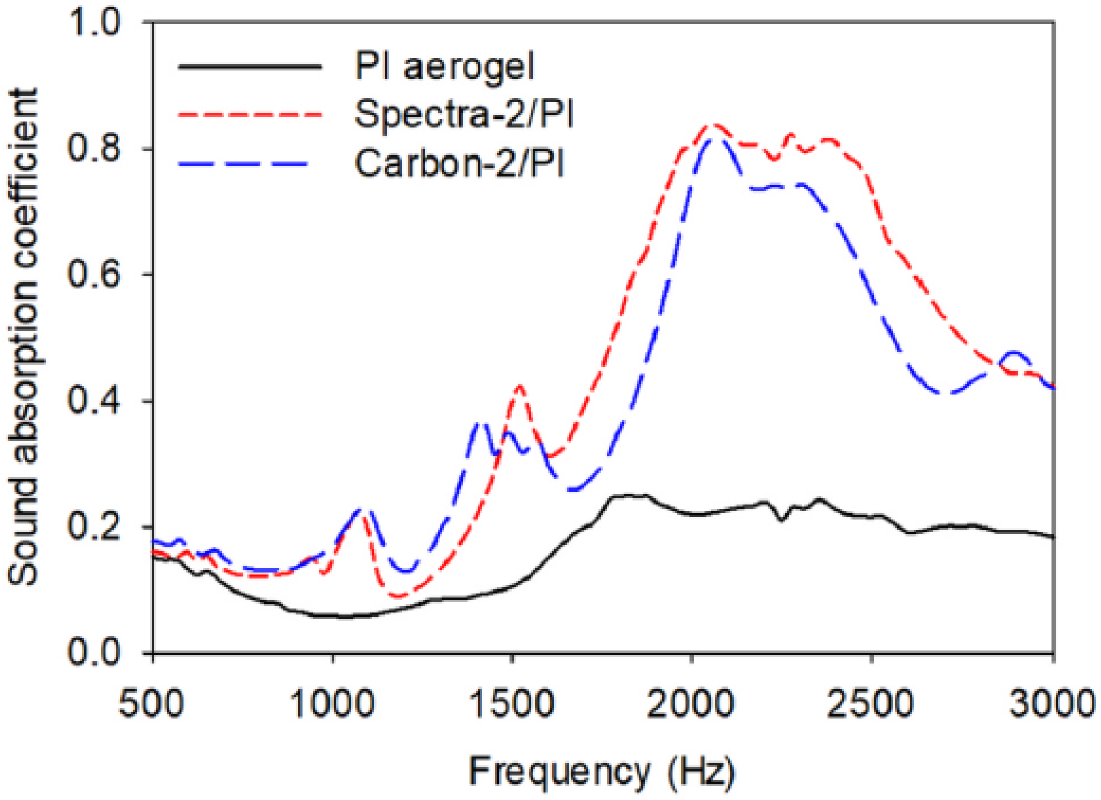
S. Malakooti et al. *Composites Part B* 260 2023 110751

Reduced Tc with Ballistic Fabric Incorporation

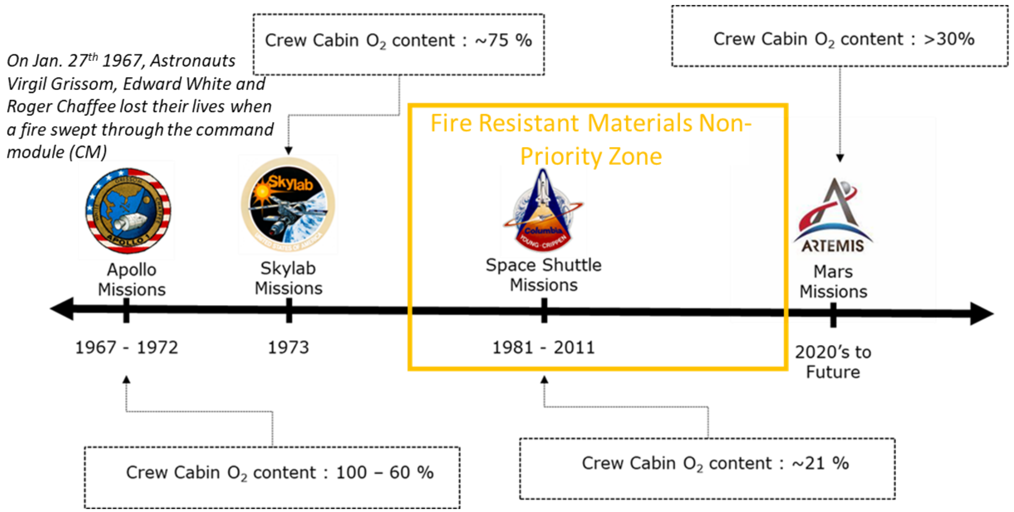


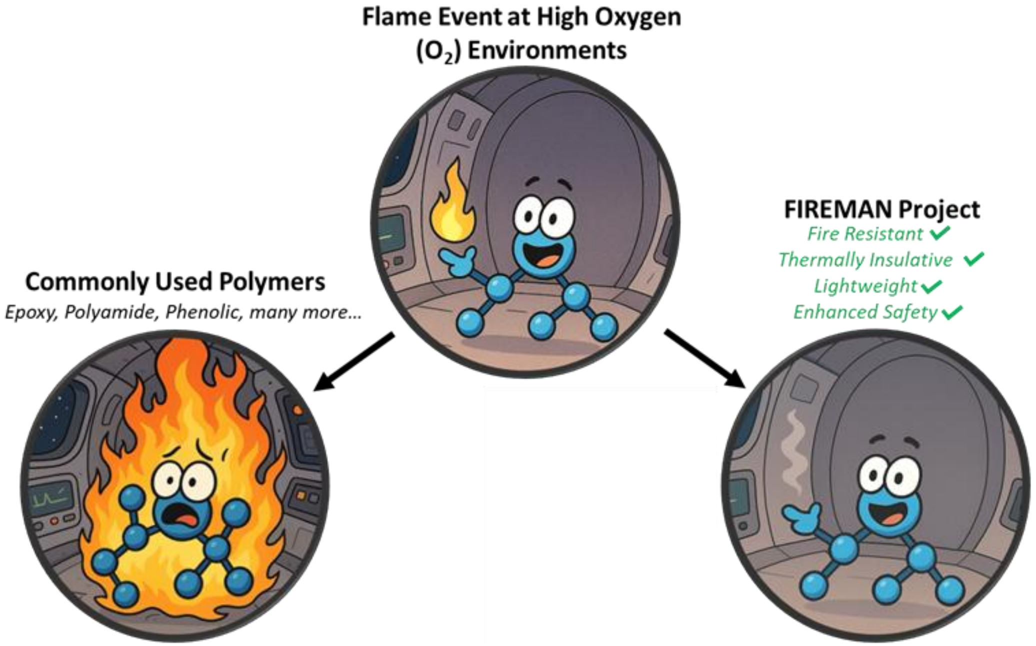


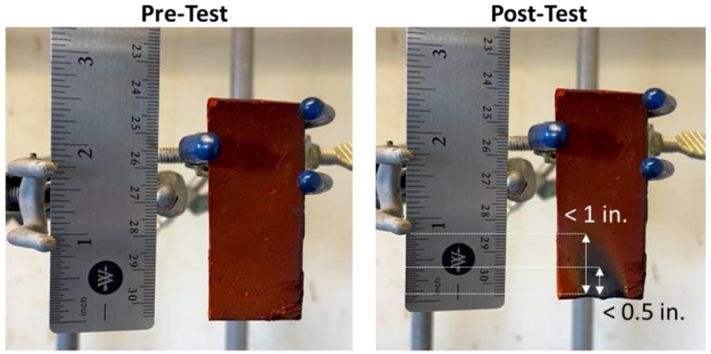
Enhanced Sound Absorption with Ballistic Fabric Incorporation



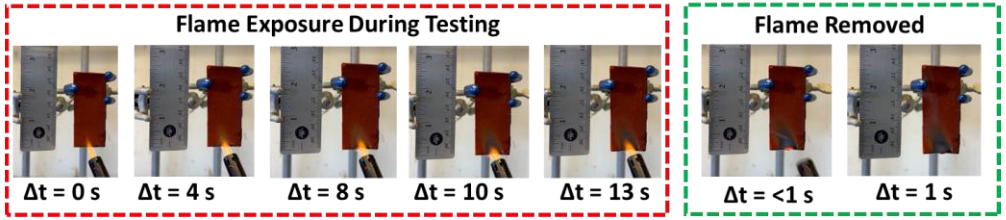
Fireproof Insulation for Resistive Environments in Materials for Aeronautics and Navigation (FIREMAN)





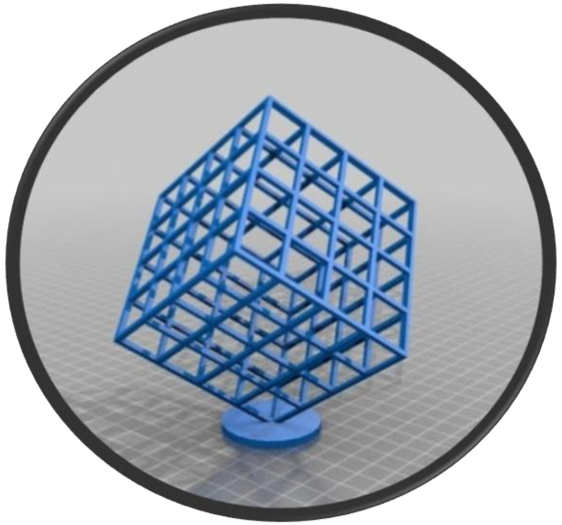


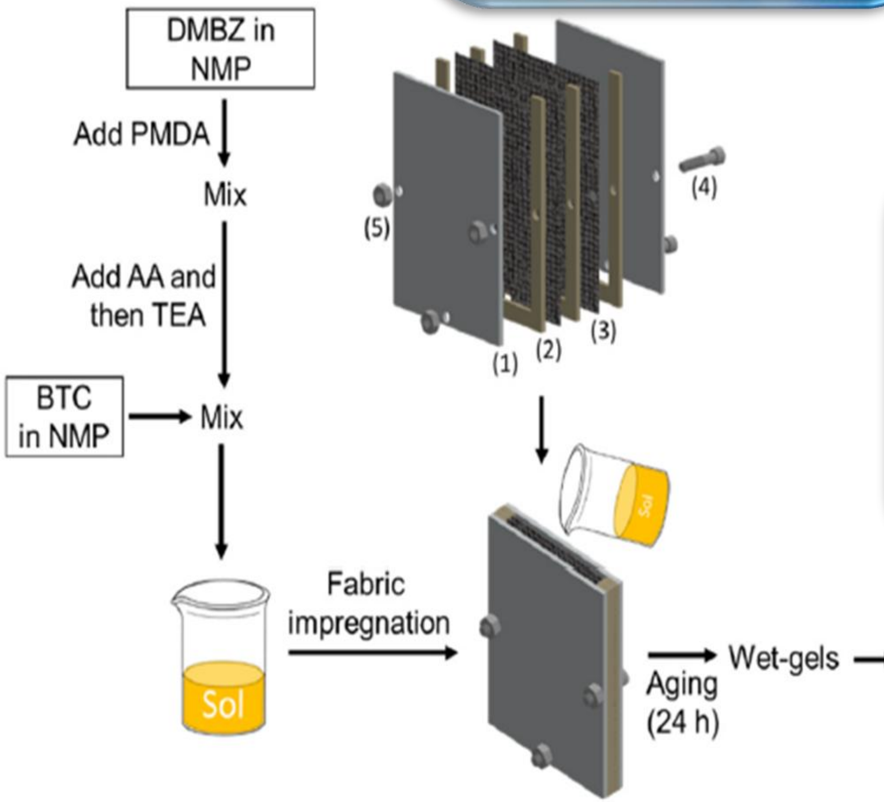
Vertical Flame Propagation NASA-STD-6001B



Limitation of Polyimide Aerogel Manufacturing

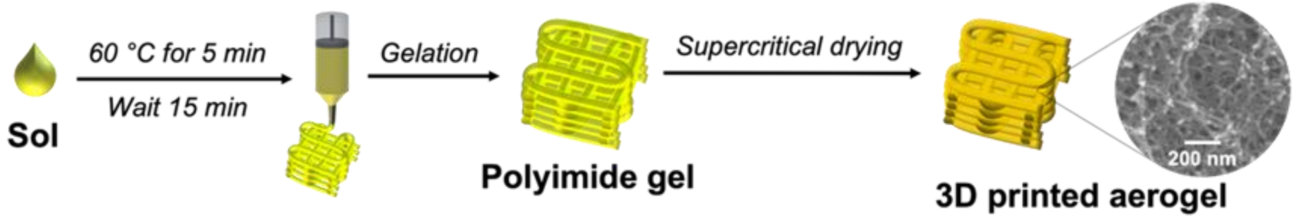
Currently aerogels are produced by molds and film casting, limiting applications for unconventional structures and rapid fabrication

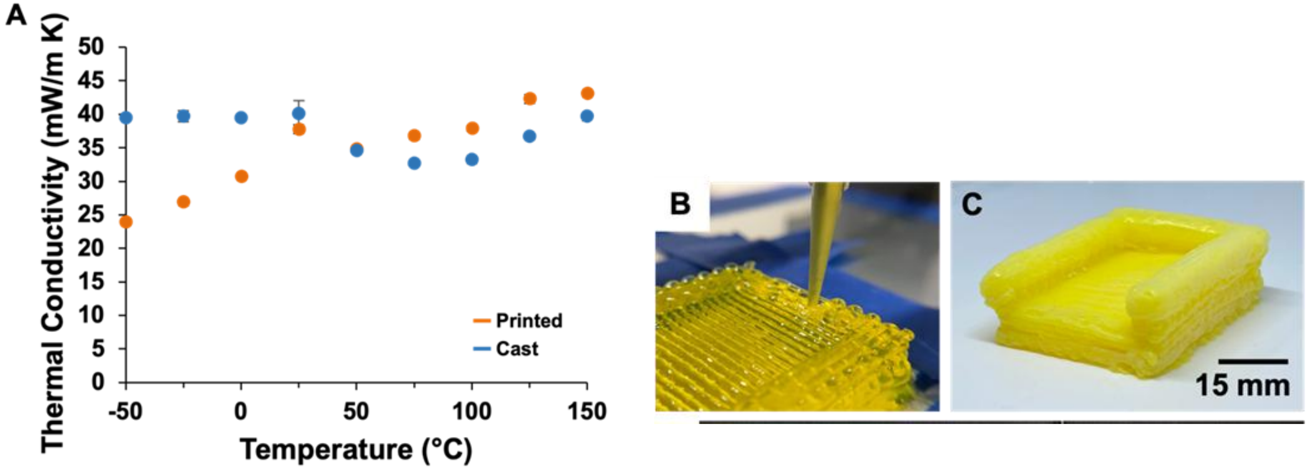




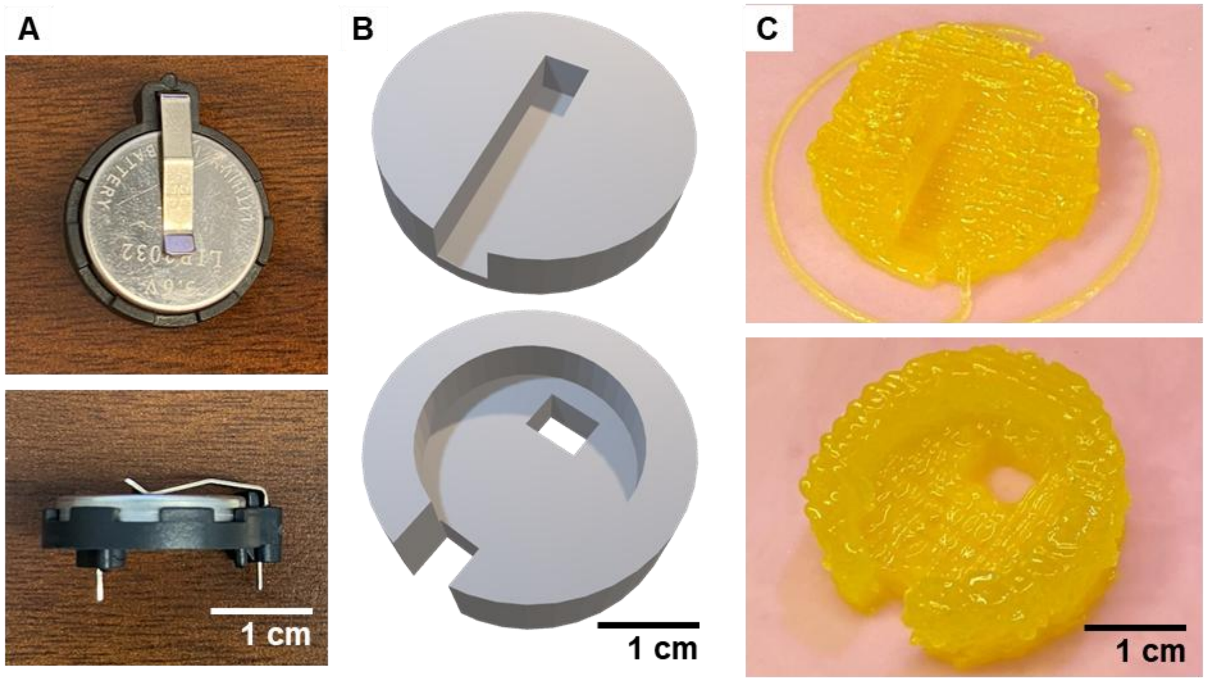
Increasing the architectural complexity of aerogels increases its versatility

Direct Ink Writing (DIW) of Polyimide Aerogels





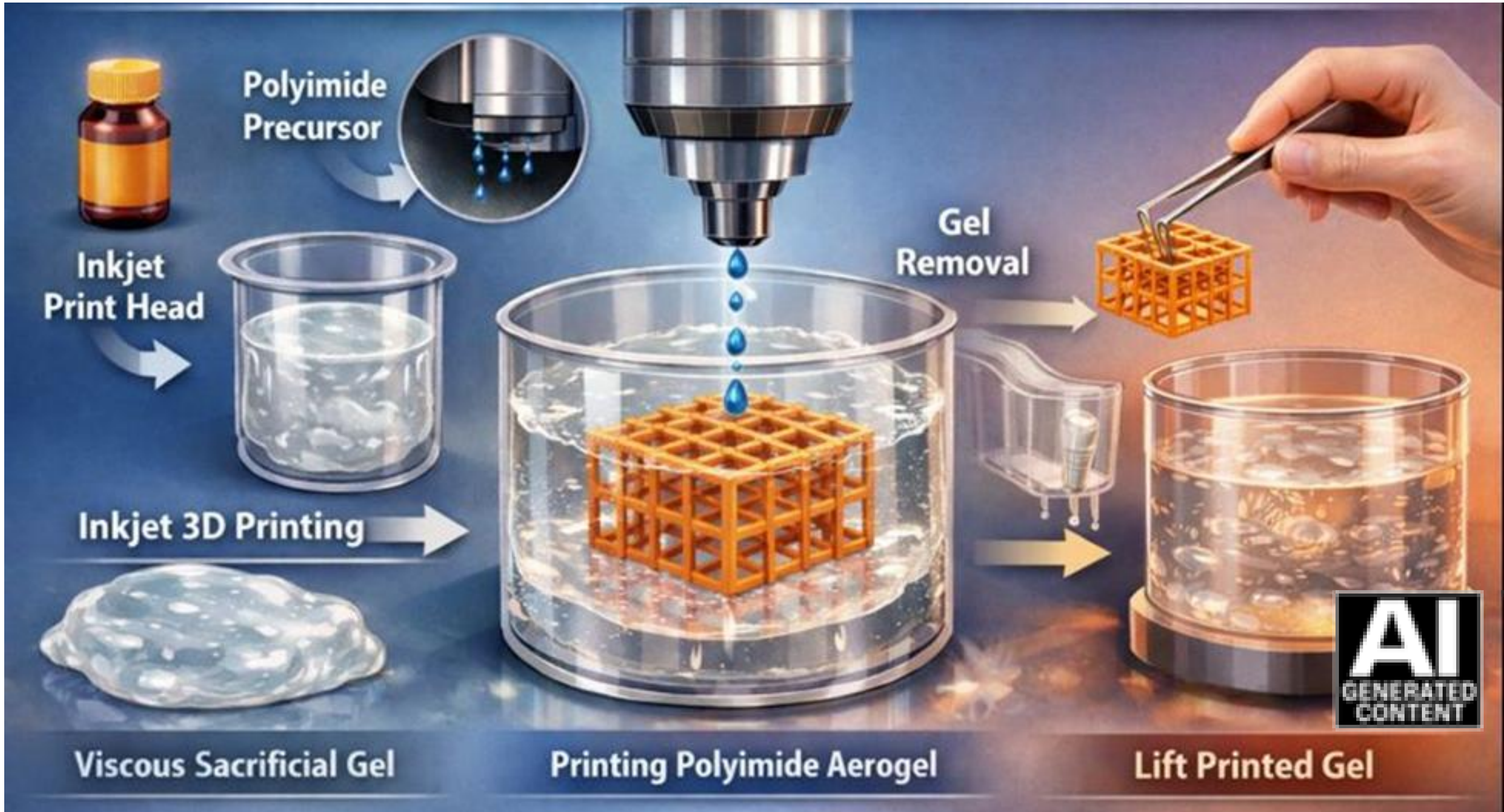
(A) Thermal conductivity of cast and printed aerogels at various temperatures (n=3). (B) 3D printing of thermally insulating aerogel enclosure. (C) Dried enclosure.



- Printed aerogel casings can improve ionic conductivity in solid-state electrolyte coin cell batteries
- Aerogels can be printed into complex geometries to create conformal insulators that can improve the performance of electronics in demanding environments

Design and printing of thermally insulating battery enclosure. (A) Coin-cell battery in plastic holder. (B) 3D design of thermally insulating enclosure; (top) lid (bottom) bottom. (C) As-printed enclosure parts.

Aerogel Rapid Prototyping



LEW-TOPS-171-Rapid Aerogel Prototyping Using 3D Printing (LEW 20156-1)

Rapid prototyping of polymer aerogels via direct-write printing into a sacrificial bath that supports the precursor during gelation, enabling free-standing, complex aerogel architectures.

Artificial Intelligence (AI) Usage Disclosure
This image was created with assistance from CHATGPT (webversion) for creating images. The content has been reviewed and edited by Stephanie Vivod.

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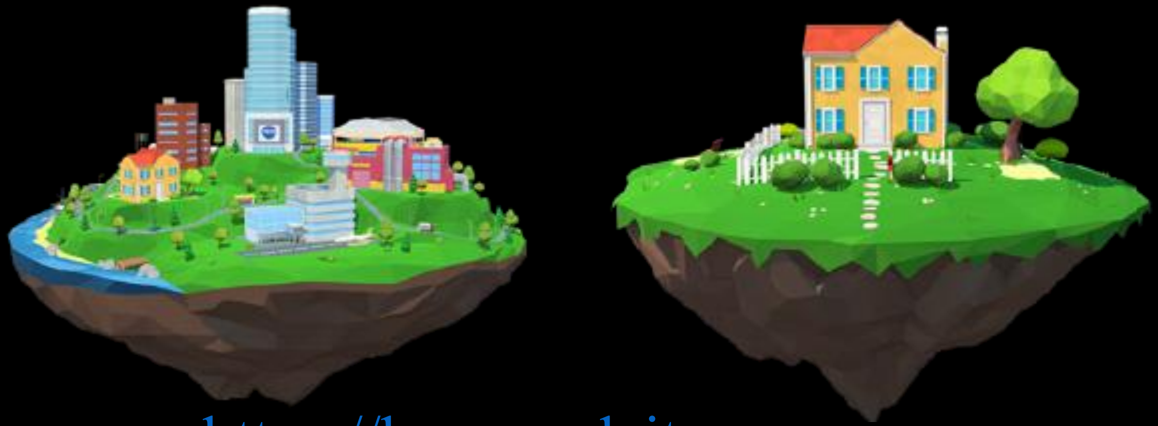

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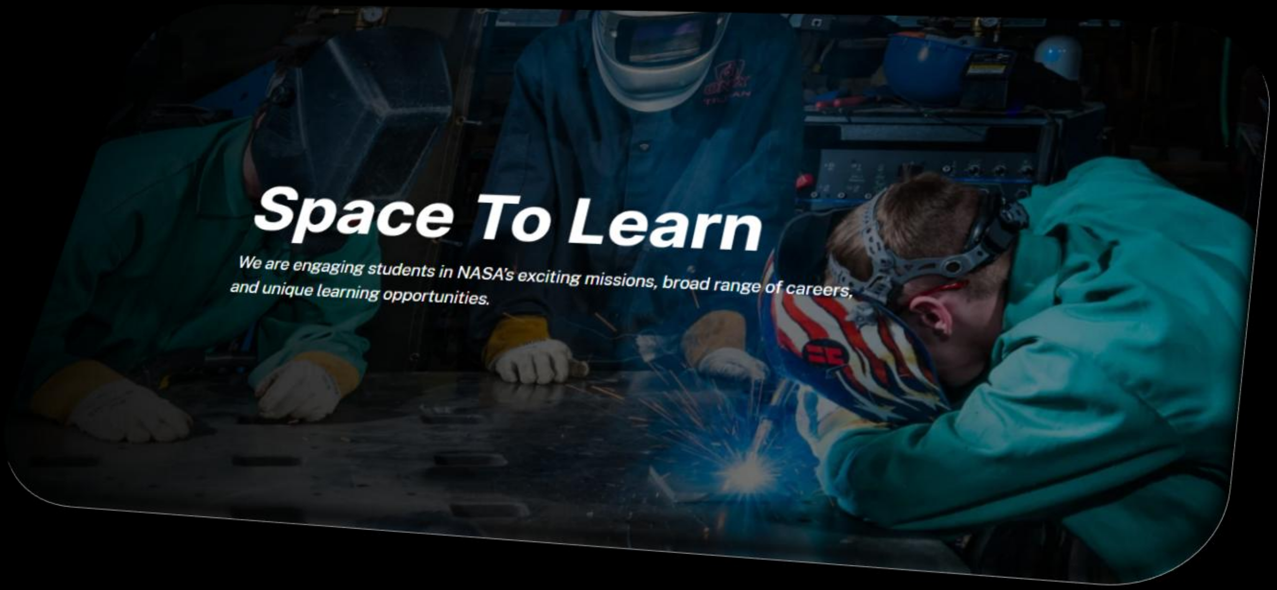

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The Polymer Aerogel Innovation and Research Laboratories are dedicated to advancing the science and engineering of lightweight, high-performance aerogel materials to address the most demanding challenges in aerospace, aeronautics, and advanced technology sectors. Our mission is to pioneer innovative solutions in thermal management, structural insulation, energy absorption, and multifunctional material systems through the design, fabrication, and characterization of next-generation polymer aerogels. By fostering collaboration across government, industry, and academia, we strive to accelerate the transition of laboratory breakthroughs into real-world applications that enable safer, more efficient, and more technically advanced exploration and innovation.


THANK YOU!