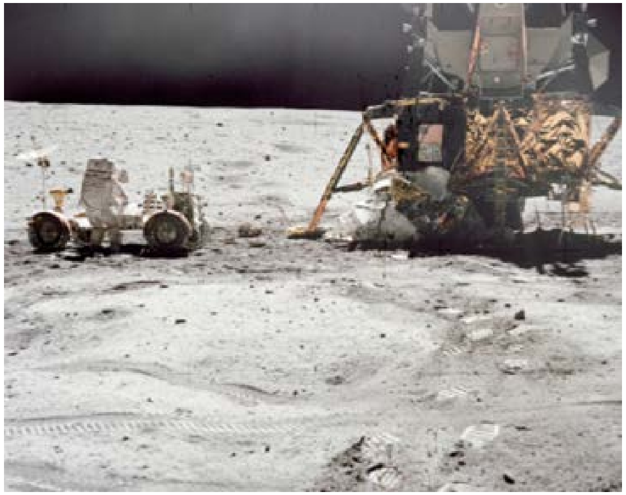
The Role of Advanced Materials and Manufacturing in Future NASA Exploration Missions

Michael A. Meador, NASA Game Changing Development Program, michael.a.meador@nasa.gov

Apollo Missions

Apollo 15

- ✓ 66.9 hours on Lunar surface
- ✓ 3 EVAs – 10 hours, 36 minutes
- ✓ Returned with 6.6 kg of Lunar materials



- Lunar Lander and Command Module constructed from:
  - ✓ Aluminum honeycomb with bonded aluminum facesheets
  - ✓ Stainless steel honeycomb filled with phenolic ablator for the heat shield
- Crews took everything they needed to complete their mission
- Technical issues, e.g., dust

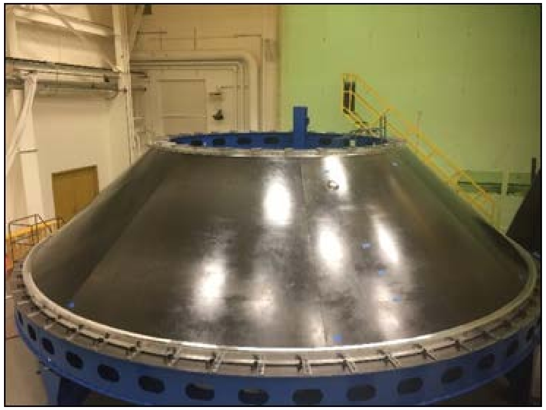
“An innovative and sustainable program of exploration ...”

“Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations;”
- *Space Policy Directive 1 (December 2017)*

- **Structurally efficient launch vehicles and spacecraft**
  - Lightweight materials
  - Multifunctionality
  - Damage tolerant
- **Robust habitation and excursion systems**
  - Missions will be longer than Apollo with longer duration and more numerous sorties/EVAs
  - Environment is harsh – dust, radiation, temperature
  - *In situ* resource utilization, including recycling, will be needed
  - In space manufacturing will be needed to create replacement parts, effect repairs
  - Astronaut health management will be more challenging, especially for Mars
- **Materials and chemistry are key to addressing these challenges**

3D Printed Mars Habitat Challenge Winning Concept – Team Zopherus (Rogers, AR)

Lightweight Multifunctional Materials



Polymer Matrix Composites

Carbon Nanotube Reinforced Composites

Polymer Aerogels

Composites Being Utilized in SpaceX Vehicles

Falcon Heavy

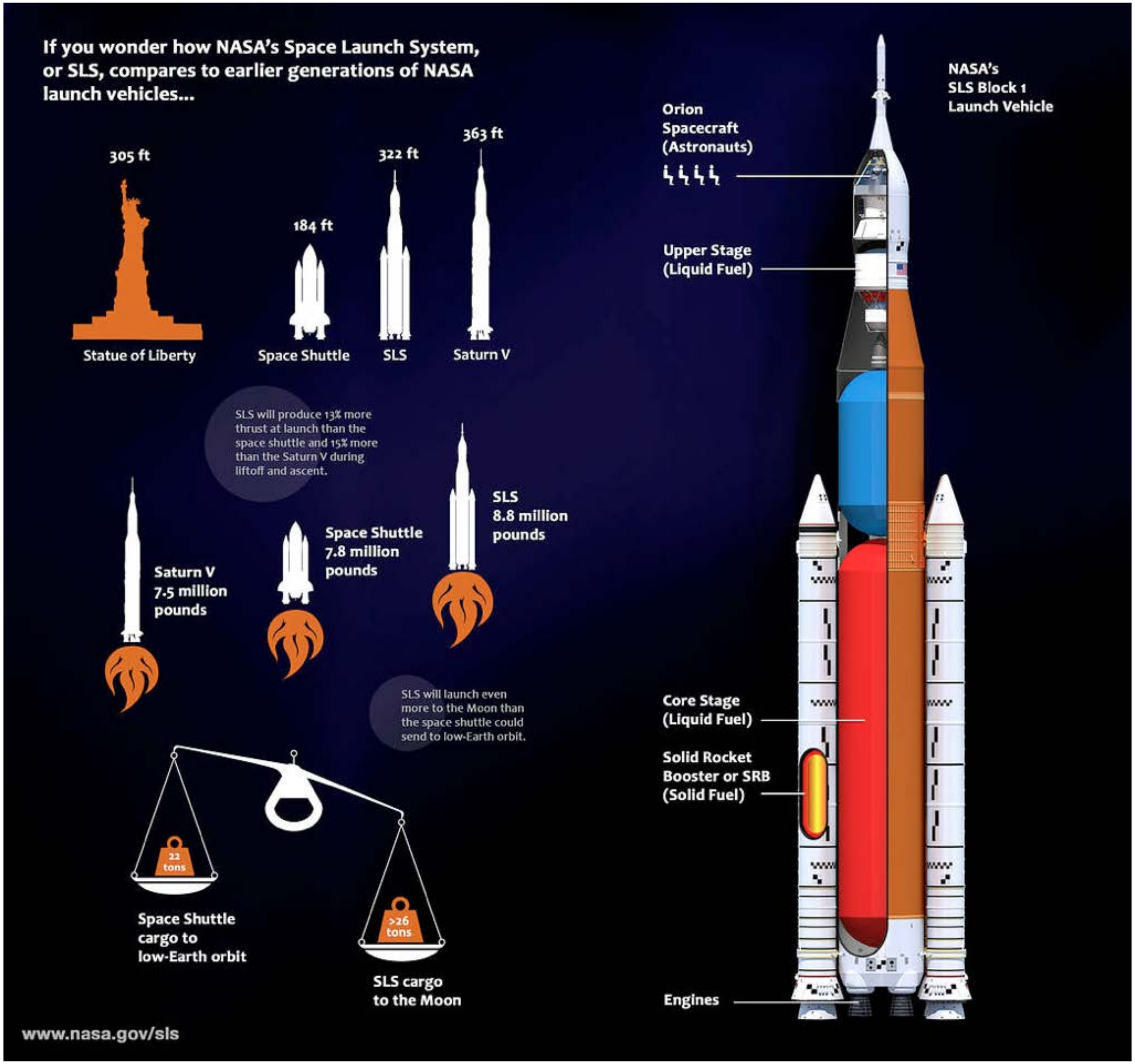
Fairing

Interstage

Landing Legs

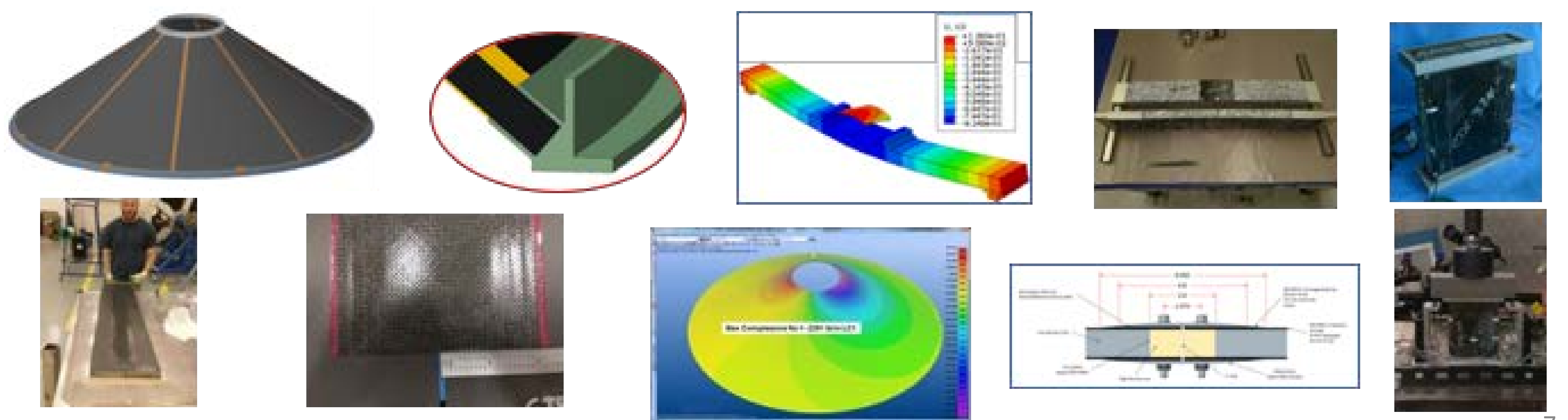
Mold for BFR Main Body

Space Launch System

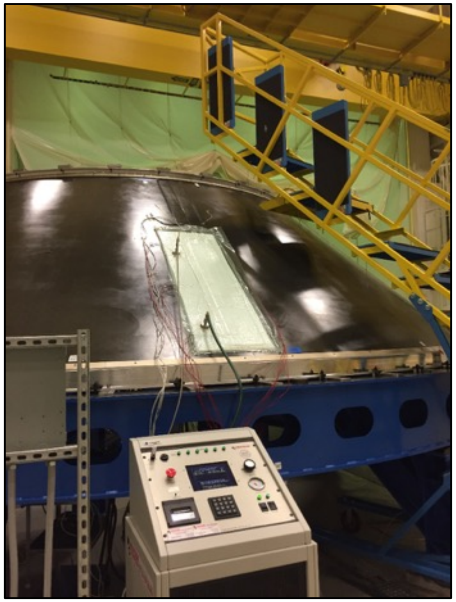


Composite Technology for Exploration (CTE)

- Develop and demonstrate critical composites technologies with a focus on weight-saving, performance-enhancing bonded joint technology for Space Launch System (SLS)-scale composite hardware to support future NASA exploration missions.
  - ✓ Improve the analytical capabilities required to predict failure modes in composite structures.
  - ✓ Support SLS payload adapters and fittings by maturing composite bonded joint technology and analytical tools to enable risk reduction.
- Focus on Payload Attach Fitting. Potential for significant reduction in joint mass, part count, assembly time and cost over bonded metallic joints
  - ✓ Reduce longitudinal joint mass by 87% (from 927 to 42 lb) and part count by 98% (from 2116 to 40)
  - ✓ Reduce circumferential joint mass by 62% (from 927 tp 358 lb) and part count by 98% (from 1673 to 40)



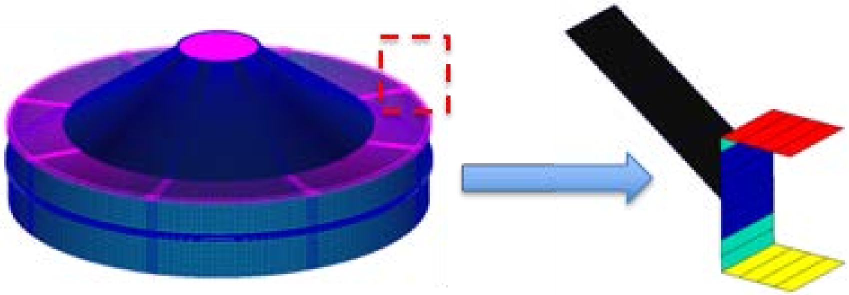
CTE Project Activities



Fabrication of composite bonded joints for Payload Adapter Manufacturing Demonstration Article

Materials Production

Composite Testing



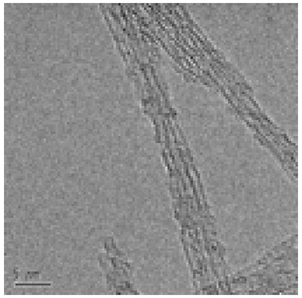
CTE Point Design

Design Optimization

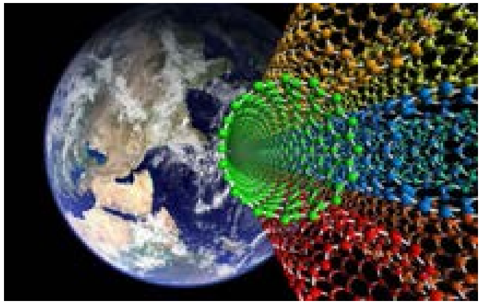
Project Manager: John Fikes, NASA Marshall

Lightweight, Multifunctional Materials- Carbon Nanotubes

- Carbon nanotubes (CNTs) have remarkable properties-
  - Specific strength 150X that of conventional carbon fibers, 100X aluminum
  - Elongation 10X that of conventional carbon fibers
  - Electrical and thermal conductivities ~10X that of high conductivity carbon fibers
- Widespread use of CNTs in aerospace hampered by inability to uniformly and reliably disperse them into polymers and other host materials
- Methods developed by industry allow for scale-able production of CNT reinforcements with potential as drop-in replacements for carbon fiber – could enable as much as 30% reduction in launch vehicle mass



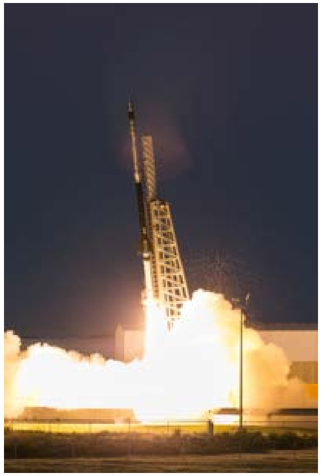
Purified Single Wall Carbon Nanotubes



Carbon Nanotube Space Elevator

1st Ever Demonstration of CNT Composites in Aerospace Structure

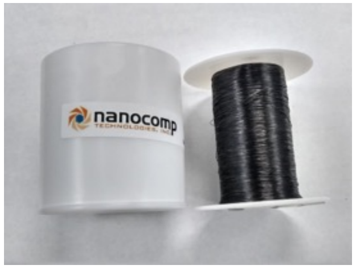
- Significantly improved the mechanical properties of CNT fibers and fiber reinforced composites – specific tensile strength on par with standard aerospace composites
- Developed flight heritage for CNT composites



Successful Flight Test on May 16. 2017

COPV Installed in Sounding Rocket Cold Gas Thruster System

Filament Winding of Composite Overwrap Pressure Vessel (COPV)



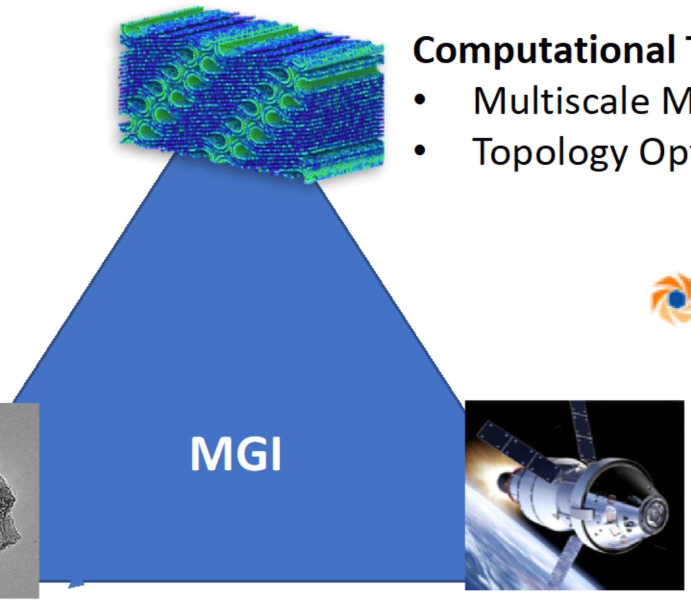
Carbon Nanotube (CNT) Fiber

NASA nanocomp TECHNOLOGIES, INC.

Further work is needed to develop composites that more fully exploit the unique properties of CNTs

- Better understanding of CNT growth mechanisms to allow better control of growth conditions (including improved catalysts)
- Modeling and simulation tools
- Surface functionalization chemistries and new resins

Institute for Ultra-strong Composites by Design (US-COMP)



Computational Tools
- Multiscale Modeling
- Topology Optimization

Experimental Tools
- Multiscale Characterization
- Panel Level Mechanical Tests

Digital Data for Design
- Structure/Property Relationships
- Mechanical Property Database

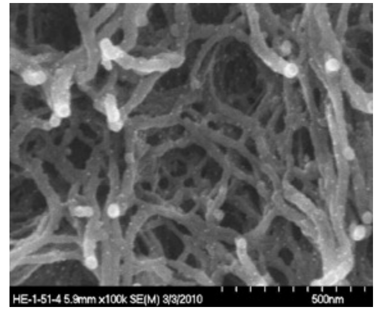
Develop integrated multiscale modeling and simulation, experimental tools, and design methods to enable the development of CNT reinforced composites with:

✓300% increase in tensile properties
✓50% increase in fracture toughness

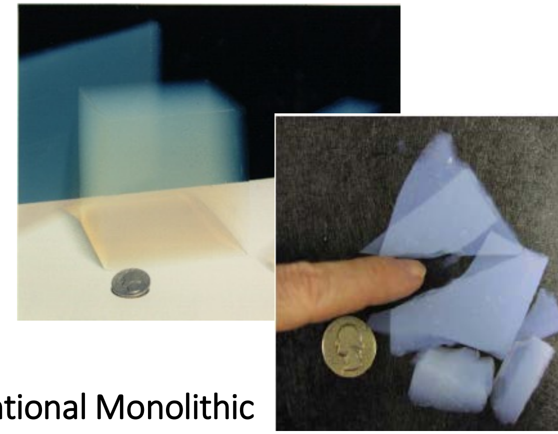
Technical Monitor: Emilie Siochi, NASA Langley

Aerogels

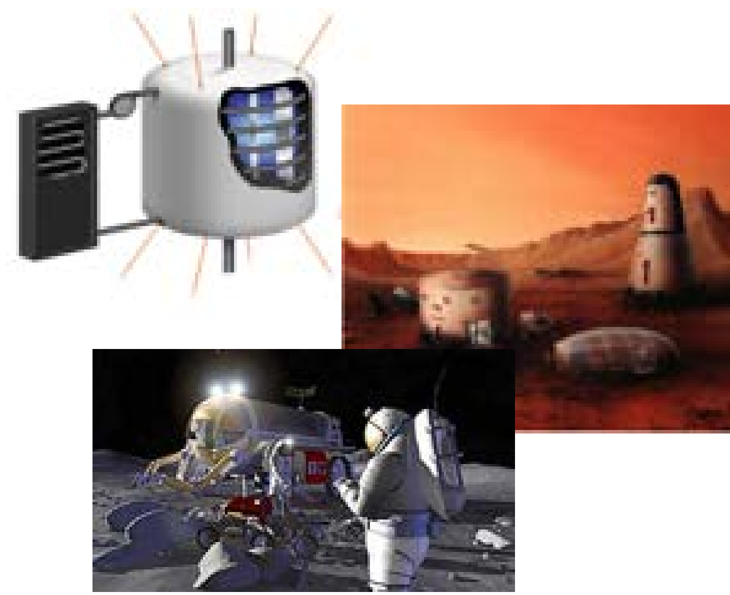
- Highly porous solids made by drying a wet gel without shrinking
- Pore sizes extremely small (typically 10-40 nm)—makes for very good insulation
- 2-4 times better insulator than fiberglass under ambient pressure, 10-15 times better in light vacuum
- Broad applications in aerospace limited by poor mechanical durability



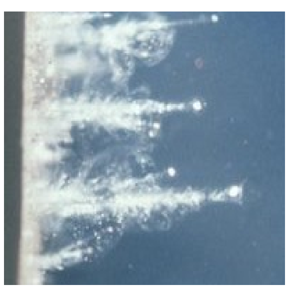
SEM Image of a Silica Aerogel



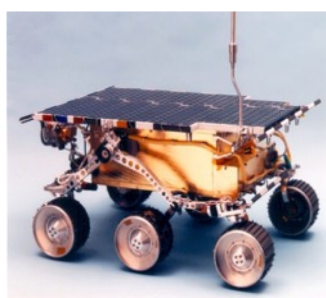
Conventional Monolithic Silica Aerogels



Potential Applications in Human Exploration

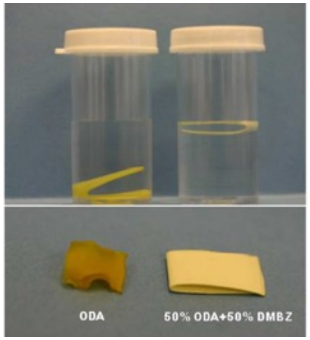


Cosmic Dust Collector (Stardust)

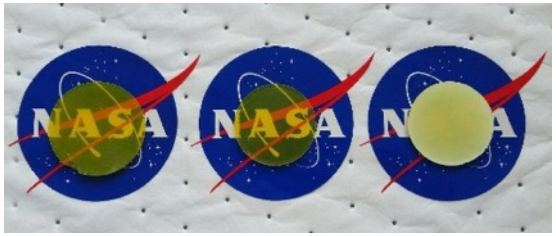


Insulation on Mars Rovers

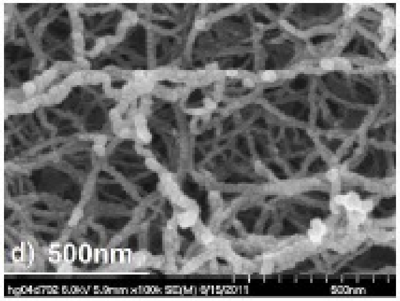
Polymer Aerogels



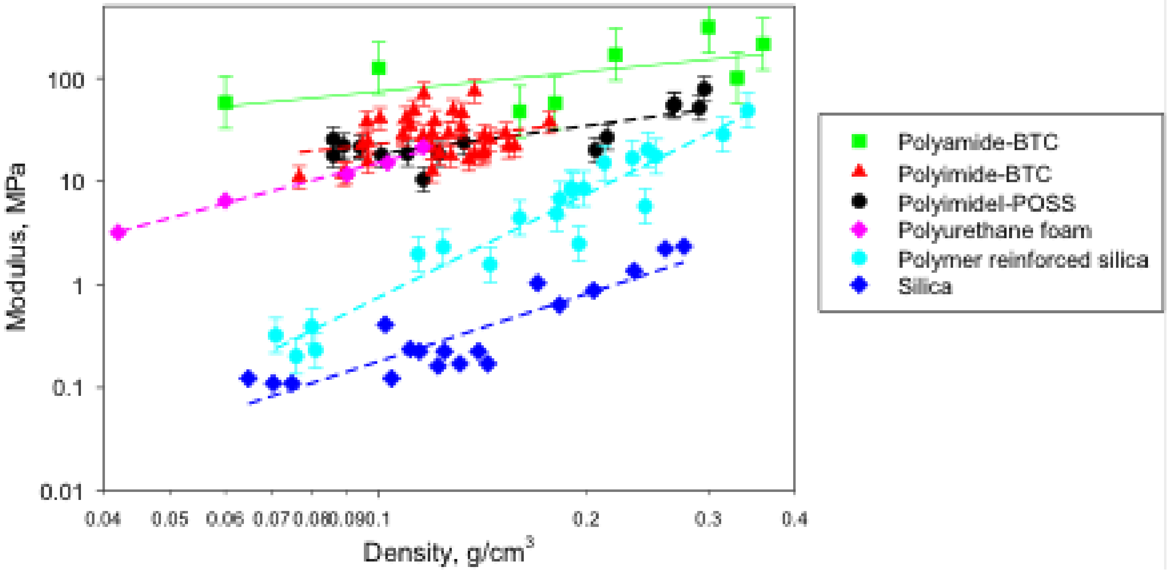
Hydrophilic
to
hydrophobic



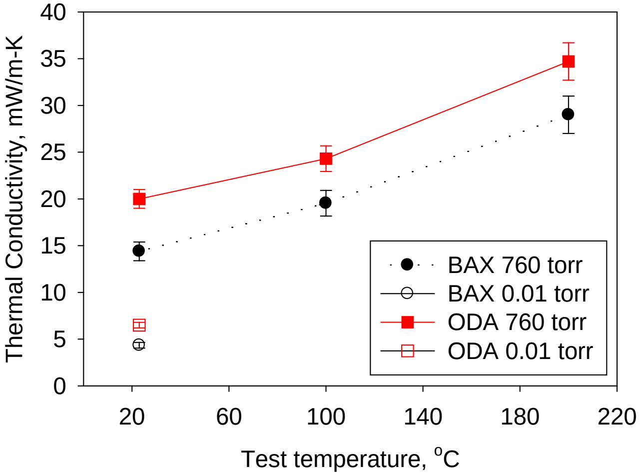
Clear to opaque



Pore structure



Mechanical properties



Low thermal conductivity

In Space Manufacturing

What is it?

Develop and demonstrate a capability for robust, reliable, on-demand manufacturing to support needs of future long-duration human exploration missions

- Replacement parts, repairs, new components
- Metals, plastics, and electronics
- Fabrication and recycling of waste materials

Why is it important?

- Resupply mission paradigm used on ISS not feasible for long-duration missions far from Earth
- Addresses significant logistics challenges for long-duration missions by reducing mass, providing flexible risk coverage, and enabling new capabilities that are required for Exploration missions.

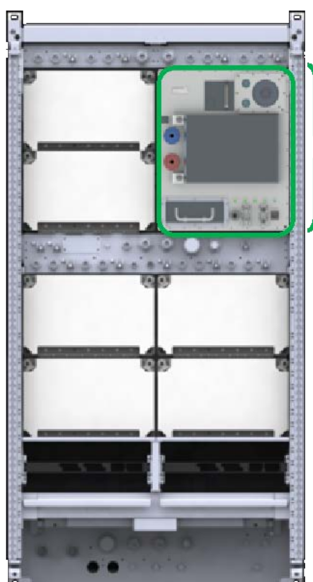
"One-stop shop" for AM design, materials, & technology expertise for NASA User Community.

Leverage industry to meet NASA needs (i.e. Agency knowledge-base for terrestrial technology).

In Space Manufacturing- Current Capabilities

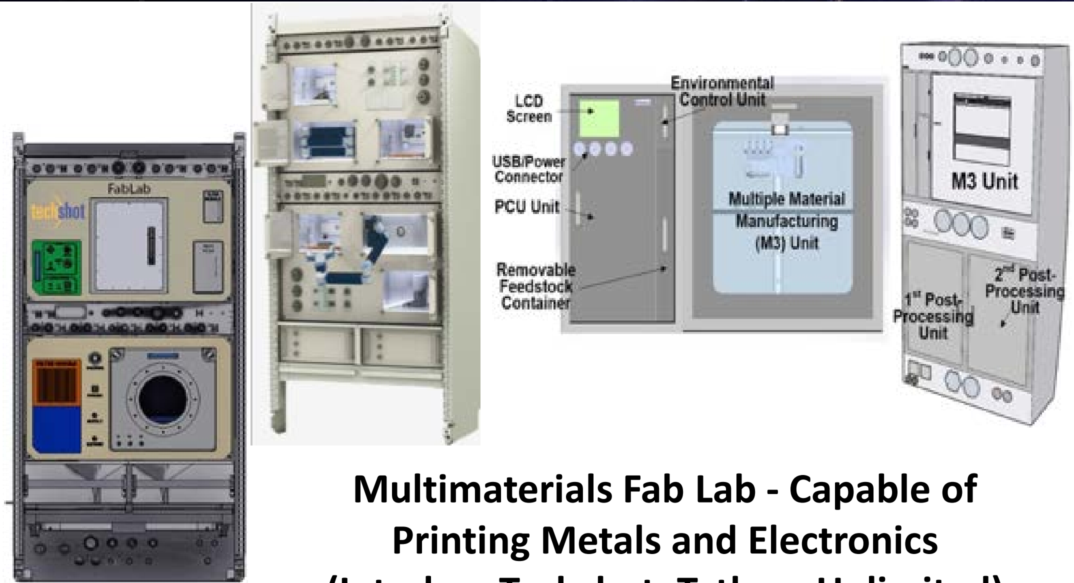
1st 3-D Printer (Fused Deposition Modeling) Demonstration in Space (Made in Space – 2014)

Dedicated Additive Manufacturing Facility Established on ISS – 3-D Printing Capability for NASA and Other Customers (Made in Space – 2016)

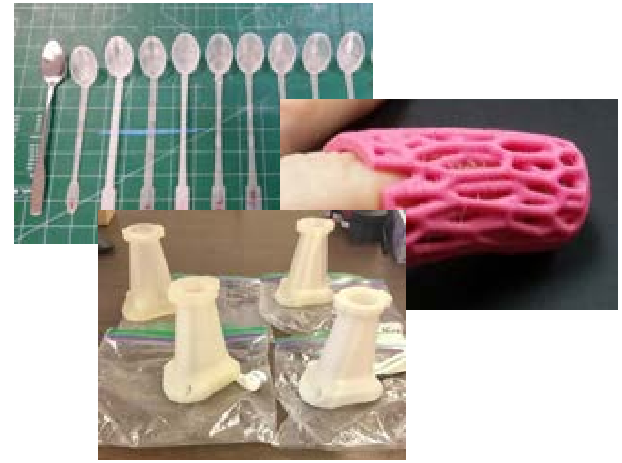


Refabricator (Integrated Recycler/3-D Printer) Installed and Activated on ISS (SBIR with Tethers Unlimited – 2019)

In Space Manufacturing – Under Development



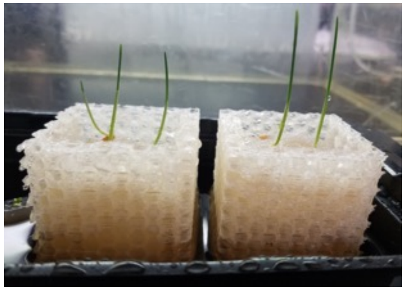
Multimaterials Fab Lab - Capable of Printing Metals and Electronics (Interlog, Techshot, Tethers Unlimited) – ISS Installation in FY22

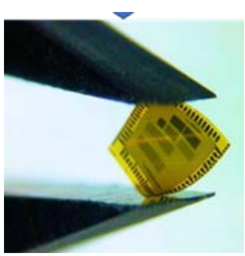


Medical and Food Packaging Refabricator – Integrated Sterilizer, Recycler, Printer (Tethers Unlimited)

How can chemistry help?

- Polymer recycling - Better materials and processes (lower energy, robust properties)
- Converting available resources into feedstock materials (atmosphere, regolith, waste materials)
- Understanding effects of microgravity on materials during fabrication and part durability/performance
- Lower energy fabrication processes (additive)





In-Space Manufacturing Materials Development & Design Database (Metals, Electronics, & Biologically-derived feedstocks)

In Situ Resource Utillization (ISRU)

ISRU involves any hardware or operation that harnesses and utilizes ‘in-situ’ resources to create products and services for robotic and human exploration

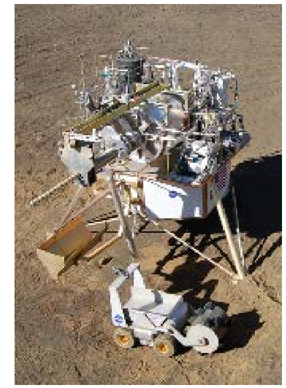
Resource Assessment (Prospecting)

sampling, sniffing, analyzing species

Resource Acquisition

abrasive environment, low-pressure gases

Resource Processing/ Consumable Production



Chemical processing plant

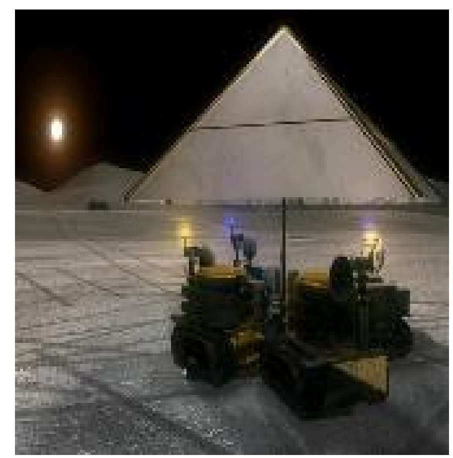
In Situ Manufacturing

Processing in-situ feedstock into parts

In Situ Construction

changing properties of loose in-situ materials into consolidated structural materials

In Situ Energy



Generation and storage of electrical, thermal, and chemical energy

Nanotechnology and ISRU?

Nanomaterial catalysts or catalyst substrates for increased active area in reactors

Insulation material for hot (reactors) and cold (cryo tanks) components in the not-quite-a-vacuum environment on Mars

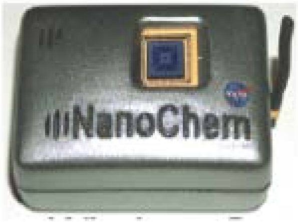
Sabatier catalyst material after vibration testing

Improved or self-healing coatings and electronics for excavation and construction equipment dealing with abrasive materials

RASSOR excavator delivering regolith

Flexible Aerogel insulation

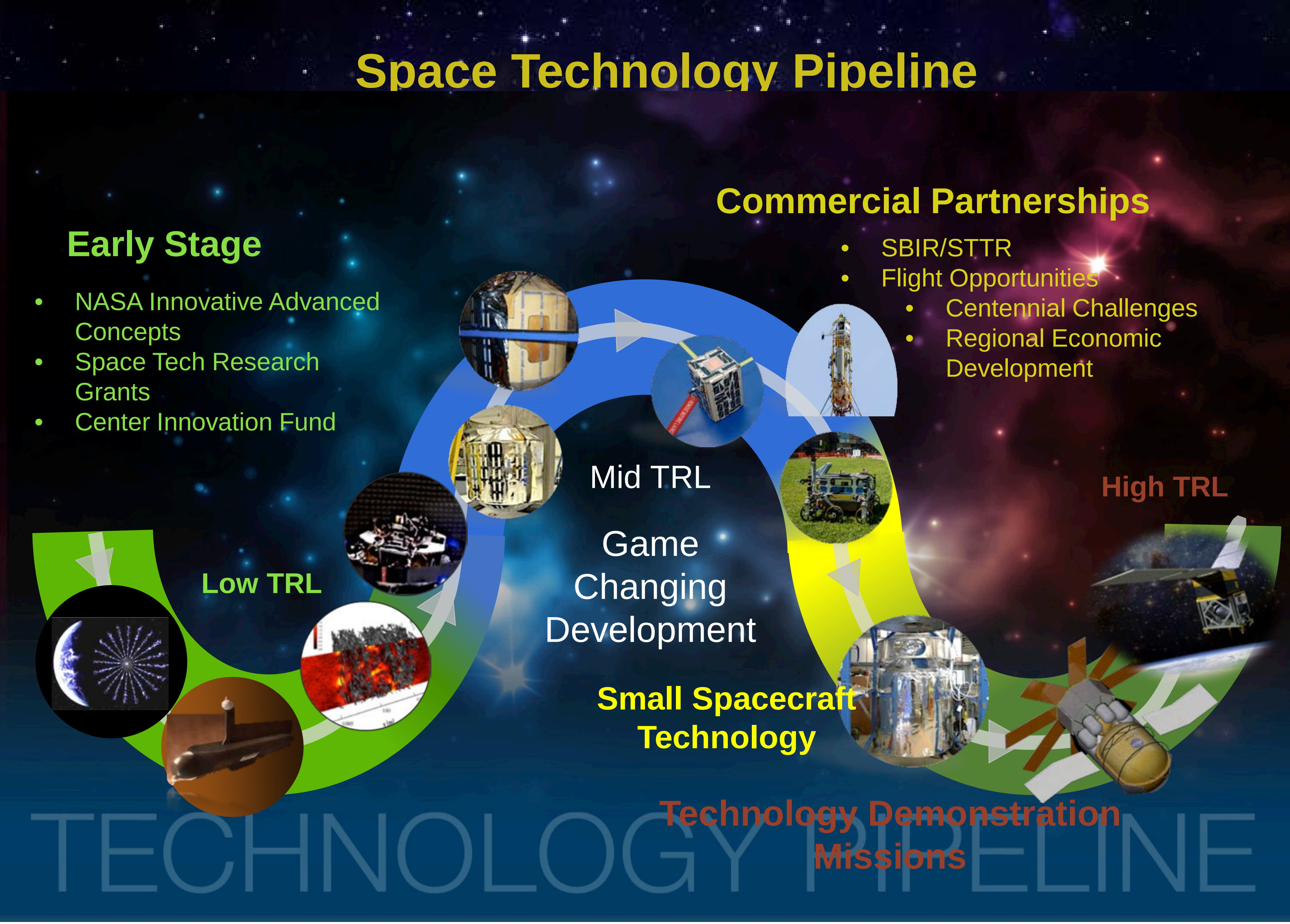
Nanosensors for prospecting, hazard detection, and health mgmt of our chemistry plant



(L) CNT "Electronic Nose"; (R) Nanochemsensor flown on ISS

Nanomaterial sorption materials to increase mass adsorbed to mass adsorbent ratio for Mars atmosphere acquisition or during gas separation steps

Sorption pump prototype unit


Space Technology Pipeline
Early Stage
• NASA Innovative Advanced Concepts
• Space Tech Research Grants
• Center Innovation Fund
Commercial Partnerships
• SBIR/STTR
• Flight Opportunities
• Centennial Challenges
• Regional Economic Development
Low TRL
Mid TRL
Game Changing Development
Small Spacecraft Technology
High TRL
Technology Demonstration Missions
TECHNOLOGY PIPELINE

Space Technology Research Grants
Opportunities to Propose

Engage Academia: *tap into **spectrum** of academic researchers, from graduate students to senior faculty members, to examine the theoretical feasibility of ideas and approaches that are critical to making science, space travel, and exploration more effective, affordable, and sustainable.*

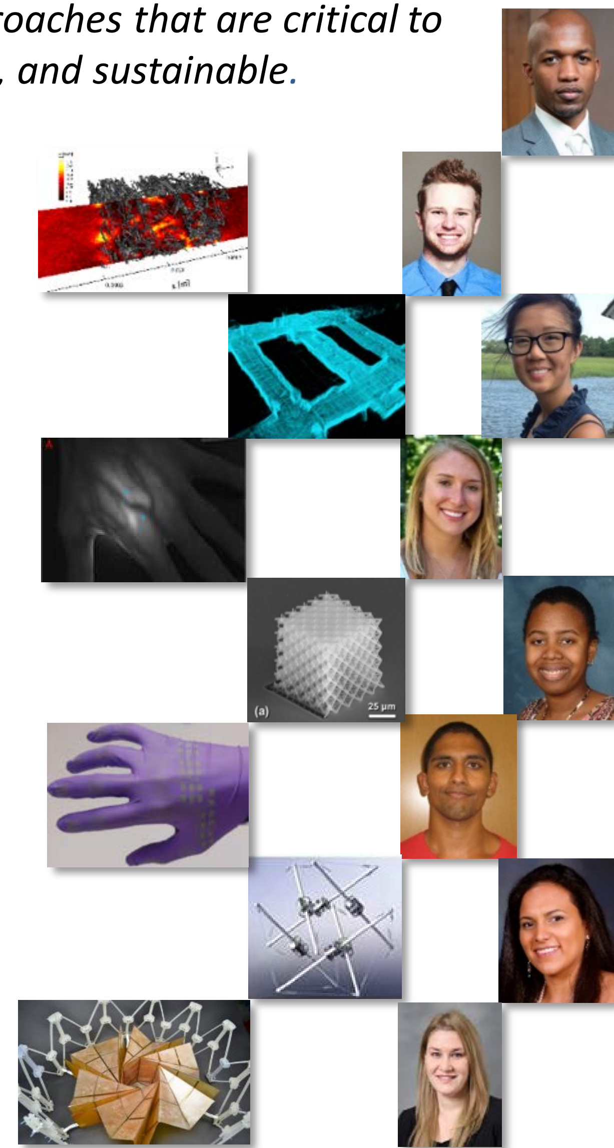
NASA Space Technology Research Fellowships
- Graduate student research in space technology; research conducted on campuses and at NASA Centers and not-for-profit R&D labs

Early Career Faculty
- Focused on supporting outstanding faculty researchers early in their careers as they conduct space technology research of high priority to NASA's Mission Directorates

Early Stage Innovations
- University-led, possibly multiple investigator, efforts on early-stage space technology research of high priority to NASA's Mission Directorates
- Paid teaming with other universities, industry and non-profits permitted

Space Technology Research Institutes
- University-led, integrated, multidisciplinary teams focused on high-priority early-stage space technology research for several years

Accelerate development of groundbreaking high-risk/high-payoff low-TRL space technologies



STRG Opportunities to Propose -*NSTRF*

Eligibility Requirements for NSTRF

1. **Pursuing or seeking to pursue advanced degrees directly related to space technology.**
2. **Are U.S. citizens or permanent residents of the U.S.**
3. **Are or will be enrolled in a full-time master's or doctoral degree program at an accredited U.S. university in fall 2019.**
4. **Are early in their graduate careers.**

NSTRF**18**: http://tinyurl.com/NSTRF2018
NSTRF**17**: http://tinyurl.com/NSTRF2017
NSTRF**16**: http://tinyurl.com/NSTRF2016
NSTRF**15**: http://tinyurl.com/NSTRF2015
NSTRF**14**: http://tinyurl.com/NSTRF14
NSTRF**13**: http://tinyurl.com/NSTRF13
NSTRF**12**: http://tinyurl.com/NSTRF12-OCT
NSTRF**11**: http://tinyurl.com/NSTRF11-OCT

Application Components

1 **Application Cover Page** **(Program Specific Data Questions)**
2 **Personal Statement**
3 **Project Narrative**
4 **Degree Program Schedule**
5 **Curriculum Vitae**
6 **Transcripts**
7 **GRE General Test Scores**
8 **Three Letters of Recommendation**

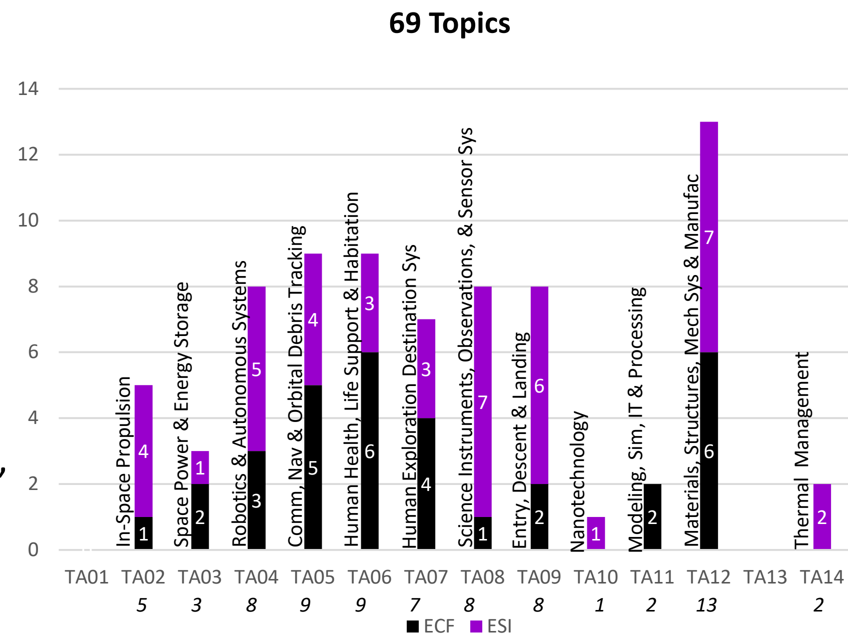
Award Value

Fellowship Budget Category	Max value
Student Stipend	$36,000
Faculty Advisor Allowance	$11,000
Visiting Technologist Experience Allowance	$10,000
Health Insurance Allowance	$1,000
Tuition and Fees Allowance	$17,000
TOTAL	**$75,000**

STRG Opportunities to Propose -*ECF and ESI*

Technical Characteristics:

- Unique, disruptive or transformational space technologies
- Low TRL
- Specific topics tied to Technology Area Roadmaps and the NRC's review of the roadmaps
- Big impact at the system level: performance, weight, cost, reliability, operational simplicity or other figures of merit associated with space flight hardware or missions



http://tinyurl.com/NASA-14ECF http://tinyurl.com/NASA-15ECF http://tinyurl.com/NASA-16ECF http://tinyurl.com/NASA-17ECF http://tinyurl.com/NASA-18ECF
http://tinyurl.com/NASA-14ESI http://tinyurl.com/NASA-15ESI www.tinyurl.com/NASA-16ESI http://tinyurl.com/NASA-17ESI http://tinyurl.com/NASA-18ESI

PI Eligibility Summary:

Both ECF and ESI proposals must be submitted by accredited U.S. universities

Early Career Faculty

- Untenured assistant professor and on tenure track
- U.S. citizen or permanent resident
- No current or former Presidential Early Career Awards for Scientists and Engineers (PECASE)
- No Co-Investigators

Early Stage Innovations

- Tenured or tenure-track faculty from proposing university
- Co-Investigators are permitted
- ≥ 50% of the proposed budget must go to the proposing university
- ≥ 70% of the proposed budget must go to universities

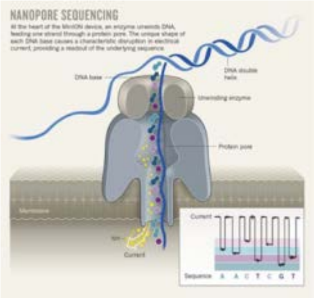
Summary

- Materials are an enabler for future sustainable, long-duration human exploration of the Moon and Mars
- NASA is actively pursuing R&D to address these needs, including intramural research, grants with universities, contracts with industry
- Opportunities exist for students and faculty to become involved in these R&D efforts and help NASA bring humans back to the Moon and, someday, put them on Mars

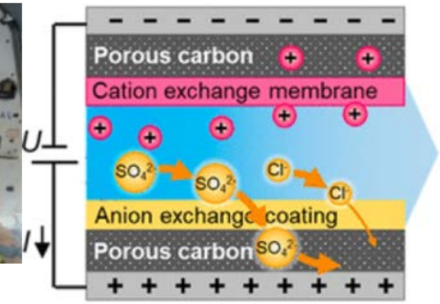
Examples of Current Supported Work

Lightweight Materials

***In Situ* Resource Utilization and In Space Manufacturing**



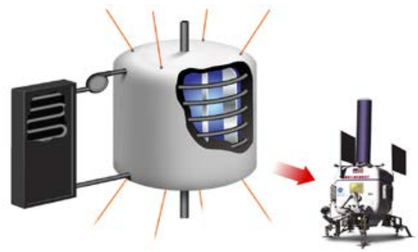
Sensors and Diagnostics



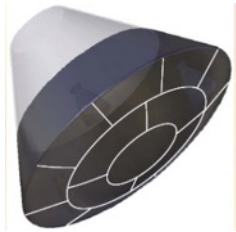
Resin coated CDI

Life Support

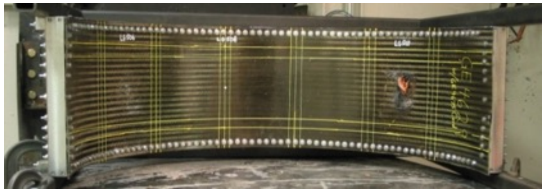
Potential applications for durable aerogels in aeronautics and space exploration



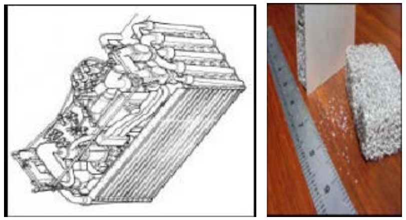
Cryotank Insulation



Heat shielding



Fan engine containment
(Ballistic protection)



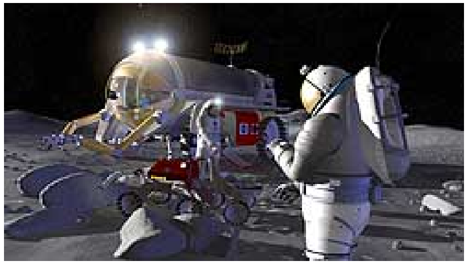
Air revitalization

Ultra-lightweight, multifunctional
structures for habitats, rovers

Sandwich
structures

Propellant tanks

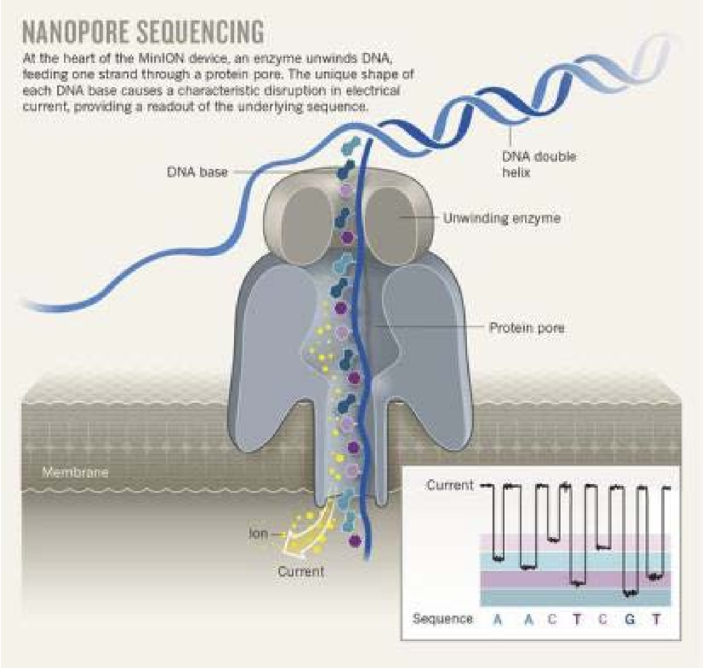
Inflatable decelerators



Insulation for EVA suits,
habitats and rovers

Nanopore-Based Gene Sequencing

- Need for real-time sequencing of DNA on ISS
  - Previously samples were returned to Earth for analysis
  - Inform medical decisions (remediation, medical countermeasures, infectious disease diagnosis) and support ISS research
  - Could be adapted for robotic exploration missions to identify life on other planets
- MinION nanopore sequencer provides a low volume/power sequencing capability for ISS
  - ~ 54 cm^3, <120 grams, powered via USB port
  - Enables real-time sequencing of DNA, RNA, proteins

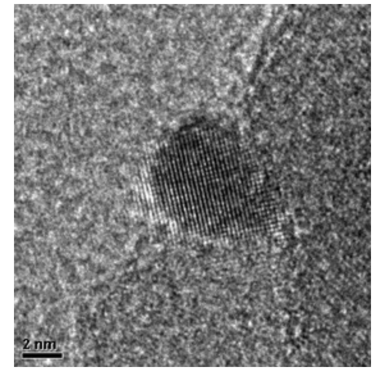


Astronaut Kate Robbins Performs 1st Gene Sequencing on ISS on 8/26/16

MinION Nanopore Sequencer Developed by Oxford Nanopore Technology

Gold Nanoparticle Catalysts Enhance CO Oxidation

- Breathing protection is a critical need for astronauts on ISS in emergencies
  - Conventional “Scotty Bottles” used by firefighters are bulky and heavy and do not provide hours of protection needed
  - Filtering respirators on ISS can remove aerosols, smoke particulates, acid and organic vapors but not CO
  - Conventional oxidation catalysts not effective in cold, wet conditions
- Nano-gold catalysts capable of oxidizing CO at rates >10 that of CO generated in a worst case fire emergency on ISS
  - Certified for use on ISS in 2012
  - Modified version planned for Orion capsule



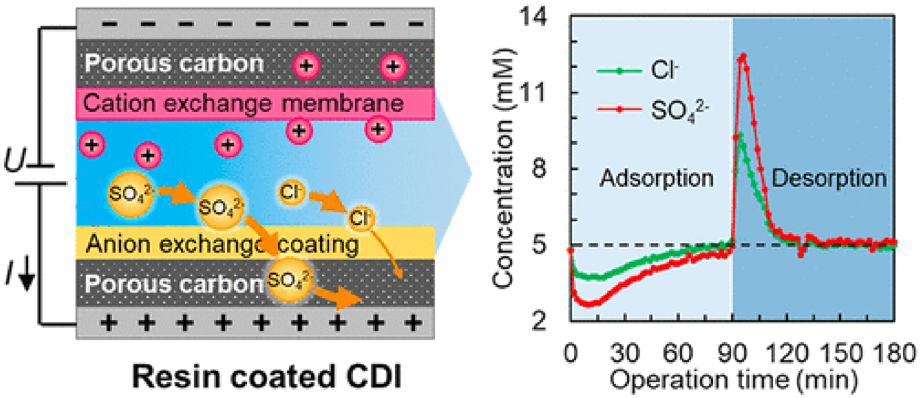
TEM Image of Nano-gold Oxidation Catalyst

ISS Crew Fire Safety Training

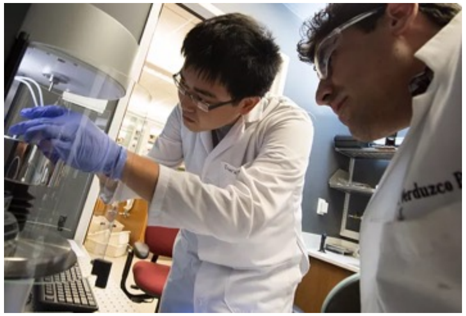
NASA/Rice Collaborate on Water Purification

- Long duration human space exploration requires compact, low power demand, reliable water purification systems
- NASA Johnson Space Center and the NSF’s Nanotechnology-Enabled Water Treatment Center at Rice University are collaborating to:
  - Evaluate water purification developed for terrestrial applications for use in space exploration
  - Provide opportunities for students to be involved in NASA technology development

2018 NEWT/NASA summer intern group



Capacitive Deionization Process Developed for Descaling of Boiler Water Being Evaluated for Urine Processing



Professor Rafael Verduzco served as host & mentor for the 2018 NASA/NEWT summer students