Science of Multifunctional Materials Development for Aerospace Systems

Dr. Vadim F. Lvovich
NASA Glenn Research Center
Cleveland, OH
Branch Chief,
Materials Chemistry and Physics Branch
NASA’s missions to explore our world, solar system, galaxy and universe presents extraordinary complex challenges. These challenges can only be met with excellence in science and engineering, innovation, and rigorous team work.
NASA missions require safety, robustness, high specific energy / energy density, low weight, operation at temperature extremes...
NASA Glenn Research Center

Plum Brook Station Test Site
(Sandusky, OH)
- 6500 acres
- ~ 10 civil servants and 100 contractors

Lewis Field
(Cleveland, OH)
- 350 acres
- ~ 1550 civil servants and 1500 contractors
NASA Glenn 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
My Career at NASA

NASA Glenn Research Center (2012-  )
Branch Chief, Electrochemical Systems
Branch Chief, Materials Chemistry and Physics
Materials Research Driven by Key Aerospace Challenges

Advanced multifunctional materials for power, propulsion, communication systems

- Higher temperature and harsh environment for aerospace propulsion and planetary entry
- Lightweight requirements for large structures
- Low carbon and low emission aircraft
- Lightweight and durable mechanical system/mechanisms
- Long-term durability in harsh environments
- Computational modeling across multiple length scales
Materials Research

Synthesis & Processing

Mixing
Chemistry
Temperature
Pressure

Characterization
Composition, Structure
Porosity, Density

Materials
metals
ceramics
polymers
composites

Property Testing
Thermal
Electrical
Mechanical
Optical
High Temperature Materials

- Ceramic fiber materials
- SiC fiber with >2700°F temperature capability and mechanical stability
- High temperature alumosilicate aerogels for seals
- High temperature Polymer composites

Lightweight and Nanotechnology Materials

- Flexible Aerogel
- Nanotube Yarn
- Carbon Fiber-CNT Yarn Hybrid Reinforcement
- Boron Nitride nanotechnology
- Lattice Block

Power System and Multifunctional Materials

- Materials for High Power Density Electric Motors
- Lightweight Power Transmission Cable
- SiC High Voltage parts
- Energy Storage Materials
- Solid Oxide Fuel Cell Materials
High Temperature Materials

SiC fibers with high temperature resistance and mechanical strength

High Temperature Aerogels

High Temperature Polymer Composites and Resins
Lightweight & Nanotechnology Materials

**Strong, thin film polyimide aerogels**
- Lightweight cable insulation
- Multifunctional aerogel antenna

**Toughening of PMCs through nanocomposite approach**
- Normal PMC
- Nanotoughened PMC

**Additive Manufacturing of polymer composites**

**Boron Nitride based Nanotubes, Nanosheets & Nanocomposites**
- High strength Carbon Fiber-CNT yarn
Electrical and Power System Materials

High Power Density Solid Oxide Fuel Cell

Materials for high power density electric motor

Materials for high power density power electronics

Multifunctional structure with energy storage capability

Lightweight power transmission System

Thermoelectric-based energy harvesting

MoSi₂ CrSi₂ CoSi
Power system is 20-30% of spacecraft mass and costs 20% of the spacecraft budget.

The major power subsystems are:
- Power Generation/Conversion
- Energy Storage
- Power Management and Distribution

Space missions need a variety of power solutions:
- Solar power systems
- Nuclear power systems
- Batteries
  - primary and secondary (rechargeable)
- Fuel Cells
- New Technologies

![Diagram showing power generation and storage](attachment:image.png)
Progress in these areas requires advances in safe, low weight, very high energy batteries and fuel cells.
Electrochemical Systems

Power Generation
Fuel Cells

Power Conversion
Electrolyzers

Energy Storage
Batteries

FC Stack
MEA
BOP
Electrolyzer Stack

Regenerative Fuel Cell
Fuel Cell
Electrolyzer
Photovoltaic Array

Main Power Bus
Electrical Loads

H₂
O₂

H₂O

Main Power
Bus

kWe

kWe

kWe

www.nasa.gov
Batteries require multiple levels of design: chemical design of electrolytes and electrode materials, microstructural design of electrodes, and cell level component selection, sizing and performance simulations. Optimize designs for space missions requirements.
Emerging Energy Storage Technologies

• **Regenerative Fuel Cell (RFC) Systems**
  - Compact RFCs for very long duration (>100 hour) discharge times
  - Used for high power applications (>1kW)
  - Utilize waste heat from RFC system for thermal management
  - Currently under development for lunar applications and aircraft

• **Hybrid Energy Storage Systems**
  - Combined Battery + Super-Capacitor
  - Battery provides energy storage
  - Super-Capacitor supports very high current pulses at low temperatures
  - Currently under development for CubeSat missions
University / Higher Education Programs

NASA Internships & Scholarship Program

ARMD Aero Scholarship Program

LERCIP (GRC-Unique)

NASA Space Academy at Glenn

NASA MARTI at Glenn

Jenkins Grad. Fellowship Program (JGFP)

Interns/Research Associates (Undergraduates and Graduates)

GRC Mentors

GRC Mentors

GRC Mentors

GRC Advisors

GRC Advisors

Vanessa Webbs, PM-Internships & Scholarships
Vacant- Univ. Progs Specialist
Lynne Sammon, Ed. Progs. Specialist

NASA Glenn Faculty Fellowship Program

SGC/EPSCoR (Experimental Program to Stimulate Competitive Research)

National Space Grant College and Fellowship Program

NASA Postdoctoral Program (NPP)

GRC Colleagues

GRC Collaborators

Faculty

GRC Colleagues

GRC Advisors

MARTI – Multidisciplinary Aero Research Team Initiative
Useful Websites for Higher Education Opportunities

Recent Graduate Positions, Full Time jobs:
www.usajobs.gov

Internships ➔ OSSI (One Stop Shopping Initiative)
http://intern.nasa.gov/

NASA Postdoctoral Program (NPP)
http://nasa.orau.org/postdoc/ (https://npp.usra.edu after 1/16/’16)

NASA Glenn Faculty Fellowship Program (NGFFP)
http://www.nasa.gov/centers/glenn/education

NASA Space Technology Research Fellowships / Grants
http://www.nasa.gov/directorates/spacitech/strg/archives_nstrf.html