

# Overview: Advanced Materials & Manufacturing Development at NETL's Research and Innovation Center

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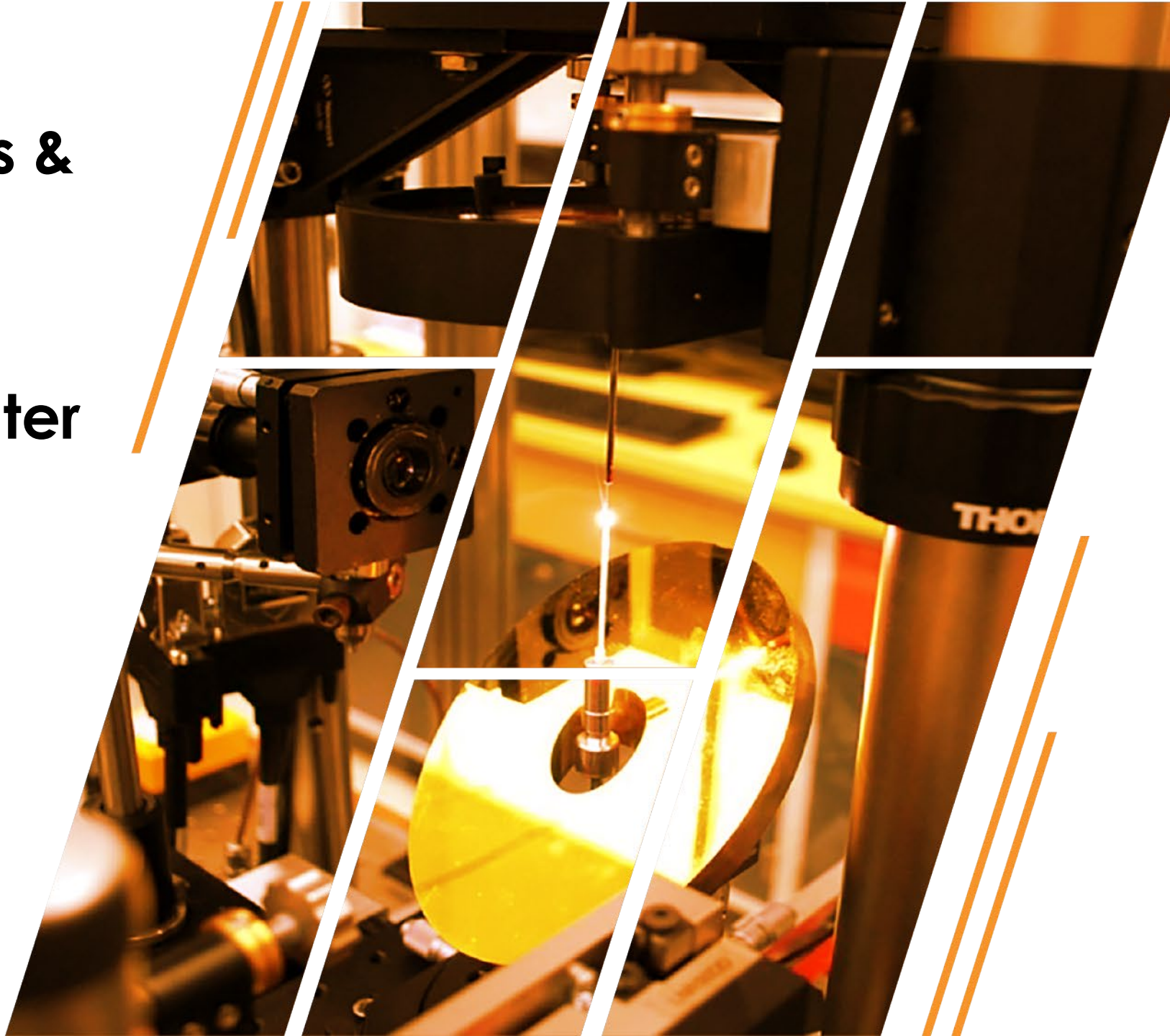
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<https://netl.doe.gov/>

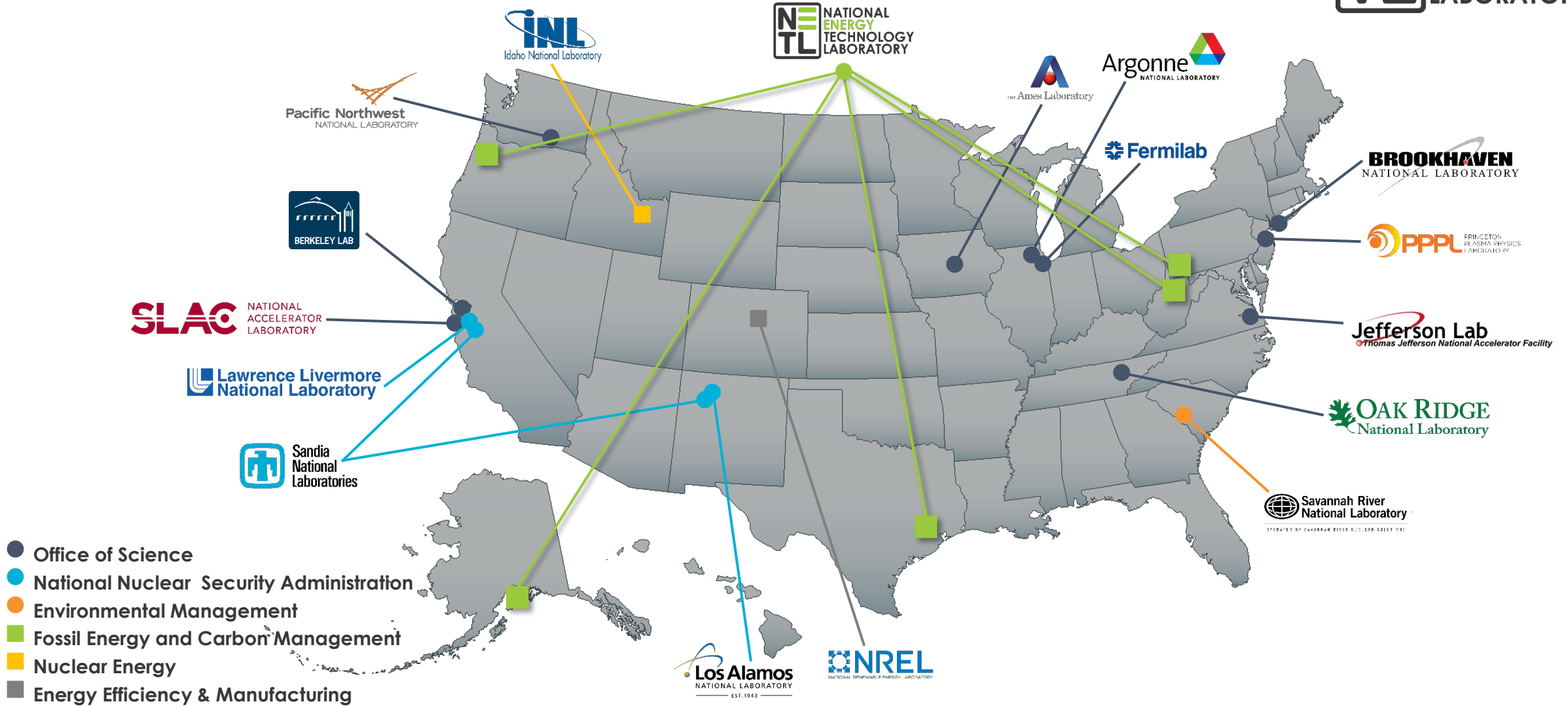
April 5, 2023



U.S. DEPARTMENT OF  
**ENERGY**



# The National Laboratory System



# The National Energy Technology Laboratory



## Organization Snapshot

### MISSION

Driving innovation and delivering solutions for an environmentally sustainable and prosperous energy future:

- Ensuring affordable, abundant and reliable energy that drives a robust economy and national security, while
- Developing technologies to manage carbon across the full life cycle, and
- Enabling environmental sustainability for all Americans.

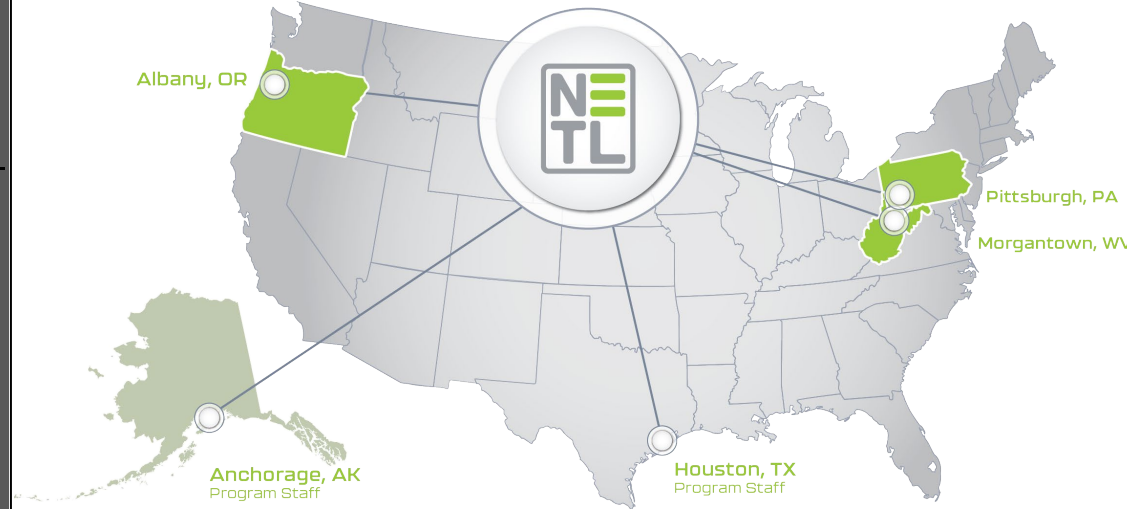
### VISION

To be the nation's premier energy technology laboratory, delivering integrated solutions to enable transformation to a sustainable energy future.

### MAJOR INITIATIVES

- Decarbonization & Carbon Management
- Environmentally Sustainable Supply Chains
- Integrated Energy & Industrial Systems
- Advanced Data & Computing Solutions for Applied Energy Challenges

### 3 RESEARCH LABS & 2 STRATEGIC OFFICES



- One of 17 DOE national laboratories
- One of three applied research national labs
- Government owned & operated
- **1000+** R&D projects in 50 states
- **\$5.0B** total award value
- **\$1.3B** FY23 budget

### IMPLEMENTS R&D PROJECTS FOR DOE'S OFFICES OF:

- Fossil Energy & Carbon Management
- Energy Efficiency Renewable Energy
- Electricity
- Cybersecurity, Energy Security, & Emergency Response
- Manufacturing, & Energy Supply Chains
- Grid Deployment
- Clean Energy Demonstrations

# Established & Expanding Partnerships



An Active Portfolio from Concept to Market Readiness

600+ partnerships with industry, academia, and gov't agencies

1000+ research and development projects nationwide



Updated January 2023



- Cooperative Research and Development Agreement (CRADA)
- Contributed Funds-In Agreement (CFA)
- Memorandums of Understanding (MOU)/ Memorandums of Agreement (MOA)
- Interagency Agreements (IAA)

- Interinstitutional Agreements (IIA)
- Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Programs
- Unsolicited Proposals (USP)
- Non-disclosure Agreement (NDA)
- Funding Opportunity Announcement (FOA)

## Available Technologies

- NETL's technology portfolio contains a broad range of innovations that have resulted from research
- Technologies and intellectual property available for licensing on NETL's website

### Available Technologies:

<https://www.netl.doe.gov/business/tech-transfer/available-technologies>

## Funding Opportunity Announcement (FOA)

- NETL uses FedConnect.net, Grants.gov and SAM.gov to post FOAs
- Proposals and applications are only accepted electronically through FedConnect.net or Grants.gov

### Funding Opportunities:

<https://www.netl.doe.gov/business/solicitations>

# Core Competencies & Technology Thrusts



Computational Science & Engineering

Materials Engineering & Manufacturing

Geological & Environmental Systems

Energy Conversion Engineering

Strategic Systems Analysis & Engineering

Program Execution & Integration

Carbon Capture & Removal

Adv Energy & Hydrogen

Carbon Utilization & Storage

Crosscutting Research

STEP (Supercritical CO<sub>2</sub>)

## CARBON MANAGEMENT



Methane Hydrates

Methane Mitigation Technology

Advanced Remediation Technologies

Minerals Sustainability

## RESOURCE SUSTAINABILITY



Energy Efficiency & Manufacturing

Office of Electricity

Cybersecurity, Energy Security, and Emergency Response

Vehicles

Buildings

Adv Manufacturing Geothermal

Adv Grid R&D

Energy Resilience

Security & Restoration

Cybersecurity

## OTHER DOE OFFICES



# Materials Engineering & Manufacturing



**MISSION:** **Materials to Enable**  
Decarbonization and Transitioning Energy Eco-Systems.

SCIENCE & DISCOVERY

MANUFACTURING

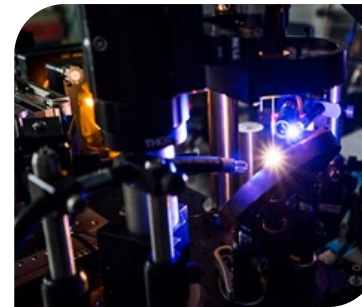
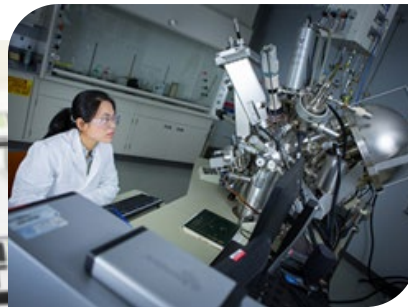
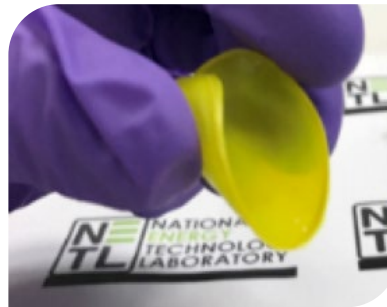
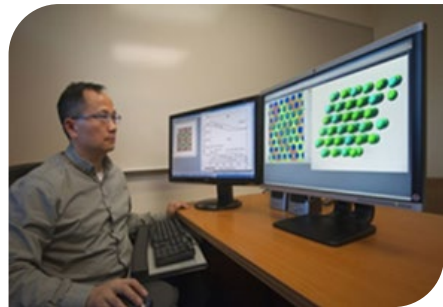
DESIGN & SYNTHESIS

EVALUATIONS AT CONDITION

FIELD TRIALS



**TECHNOLOGY  
DEPLOYMENT**



*Soft materials, Engineered particles, Advanced alloys, Composites, Coatings, & Ceramics*

# Materials Engineering & Manufacturing



## Key Facilities

### Advanced Alloy Signature Center

Liquid metals processing laboratory, thermo-mechanical processing laboratory, and severe environment corrosion & erosion research laboratories

Enables NETL and partners to pilot alloy solutions at scales that **readily translate to industrial practice**

### Functional Materials Development Laboratories

Full suite of materials synthesis, fabrication and testing capabilities for developing designer functional materials for energy applications

Enables **development and testing** of targeted and rationally designed functional materials in **ideal and realistic environments**

### Carbon Materials Manufacturing Facility

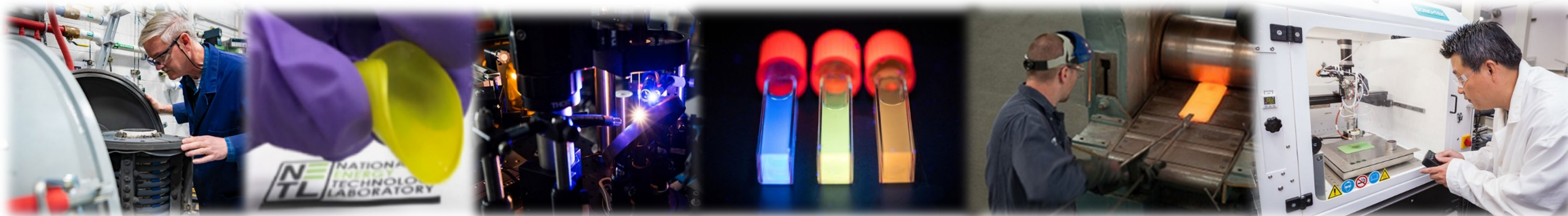
Synthesis and processing capabilities for producing carbon nanomaterials and other carbon materials for **incorporating into products** for evaluation

Allows NETL and partners to develop and take **new carbon materials to market**

### Advanced Sensors Development Laboratories

Capabilities for fabricating long single crystal fiber optics, depositing functionalized thin films, and developing distributed interrogation techniques.

Enables the development of distributed **harsh environment** distributed fiber optics sensors





# Computational Materials Capabilities

## COMPUTATIONAL RESOURCES AVAILABLE FOR MULTI-SCALE MATERIALS MODELING AND DATA SCIENCE

### Center for Computational Science and Engineering - JOULE 2.0

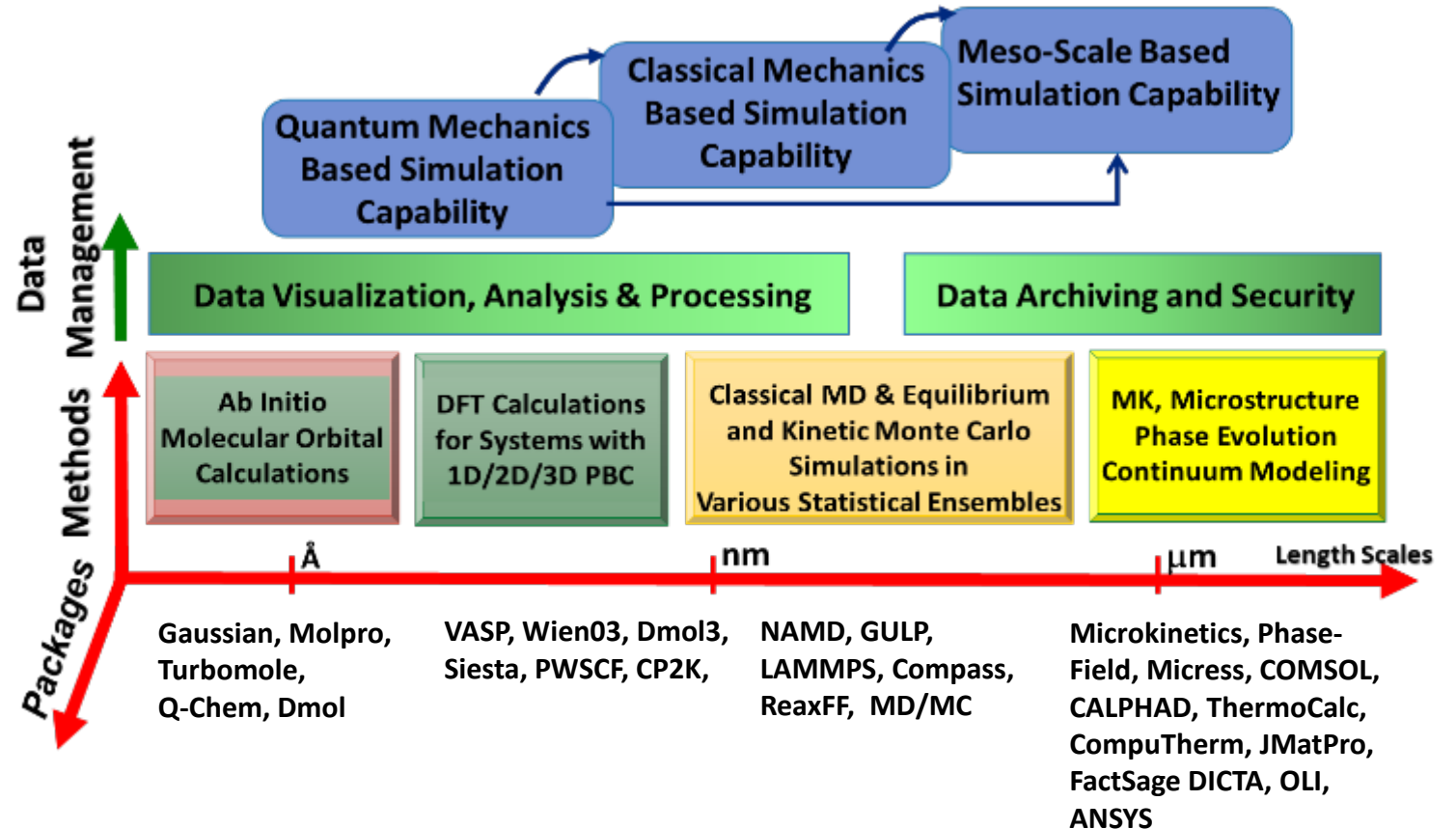


- ★ At **3.6 petaflops** JOULE is the **10<sup>th</sup> fastest** supercomputer within DOE National Laboratories.
- ★ This provides NETL and partners with high-performance computational power to solve challenges in energy and other sectors.

### Center for Artificial Intelligence and Machine Learning - WATT



- ★ Links **104 GPUs** with **19 petabytes** of storage to provide unparalleled opportunities for the use of AI/ML to enable scientific discovery and R&D acceleration.

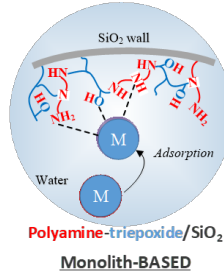
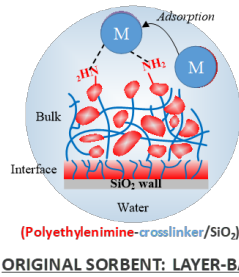
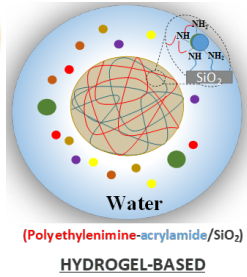


# Impact & Innovation

## Materials Engineering & Manufacturing: Enabling Advanced Technologies

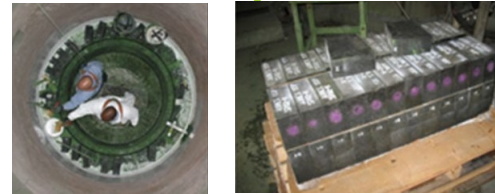
### NETL'S FAMILY OF BASIC IMMOBILIZED AMINE SORBENTS

Low-cost materials for gas and water purification applications



Separate CO<sub>2</sub> from flue gas, REE from process & waste streams.  
Pb and other contaminants from water.

### NETL DEVELOPED REFRACTORY BRICK FOR GASIFICATION



- Licensed to Harbison-Walker, commercially produced as **Aurex 95P**.
- NETL technology **doubled refractory service life**. Used in nearly **every slagging gasifier** world-wide.

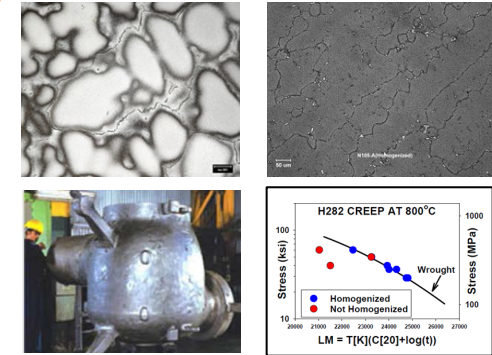
### NETL'S ALLOY HOMOGENIZATION COMPUTATIONAL TOOL.



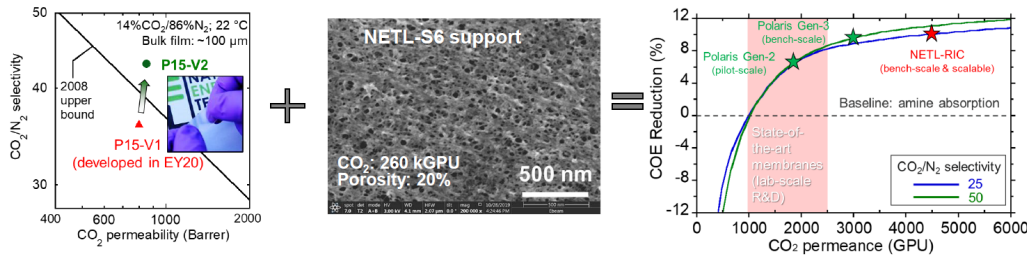
Enabling technology for **Advanced Ultra-Super Critical Steam Turbines**

Specified heat-treatments:

- Special Metals:  
ESR/VAR 10,000 lb superalloy ingot
- GE: 1/2 actual size cast valve body for an A-USC turbine  
18,500 lb. superalloy casting



### CARBON CAPTURE MEMBRANES

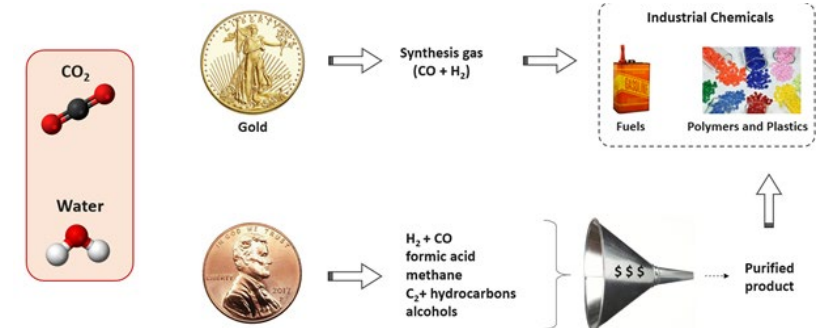


- NETL's thin film composite membrane for post-combustion carbon capture outperforms any commercially available polymer membranes (CO<sub>2</sub> permeance of > 4200 Gas Permeance Units (GPU) and CO<sub>2</sub>/N<sub>2</sub> selectivity of >30 under lab conditions).
- Produced through scalable role to role manufacturing.



**15 R&D 100 Awards (2008-2022)**

### NETL'S CATALYSTS FOR CONVERSION OF CO<sub>2</sub> INTO VALUE-ADDED PRODUCTS



Catalyst materials and reactor designs to selectively convert CO<sub>2</sub> into fuels, alcohols, hydrocarbons, CO, polymer and plastics

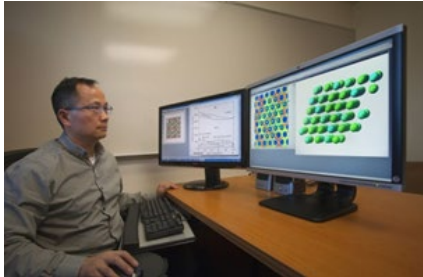
# Alloy Development Research & Capabilities



**Affordable, Durable Alloys:** Integrated Materials Engineering Approach: Computational Materials Engineering Coupled with Manufacturing at Scale and Performance Assessment at Condition.

- ✓ Aluminum
- ✓ Steels
- ✓ High Entropy Alloys (HEAs)
- ✓ Design & Development
- ✓ Copper
- ✓ Superalloys
- ✓ Refractory Alloys
- ✓ Manufacturing

## Design & Discovery



## Prototype Alloy Concepts at Scales that Readily Translate to Industrial Practice.

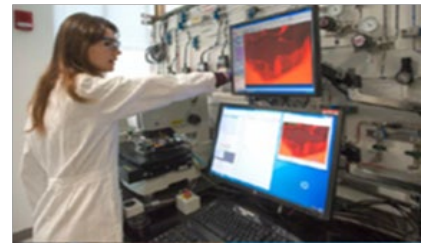
### Melt Processing

- Air Induction Melting: up to 300 lbs
- VIM: 10, 50 and 500 lbs
- Vacuum Arc Remelt/Electro-Slag Remelt VAR/ESR: 3 to 8 inch diameter crucibles

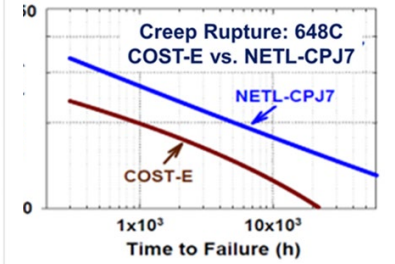
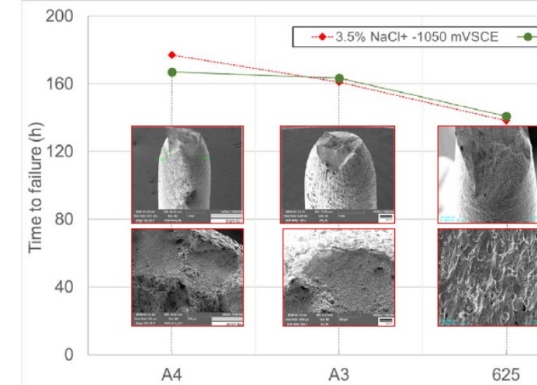
### Thermo-Mechanical Processing

- Heat-treatment furnaces: 1650°C, inert atmospheres and controlled cooling.
- Press Forge: 500 Ton
- Roll mills: 2 and 4 high configuration
- Extrusion Press: 800 Ton (on-line CY24)

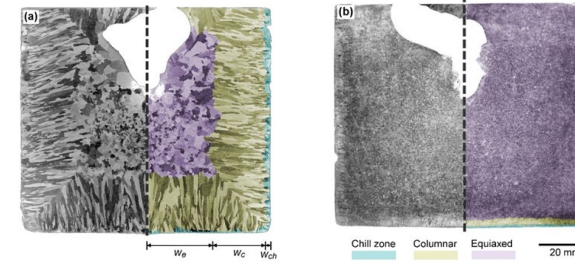
## Assessment at Condition



## NETL HEA with Superior Resistance to Hydrogen

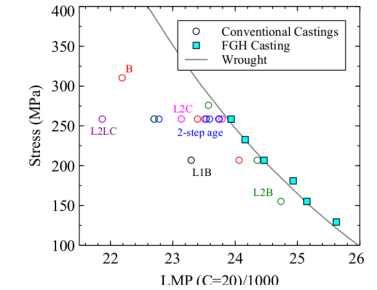


NETL Fe-9Cr Alloy with an Increase Temperature Capability of ~50oF for this important class of steel.



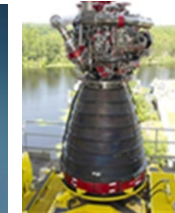
Conventional casting  
Non-Uniform Microstructure

NETL-modified casting  
Uniform Microstructure



Modified cast alloy equivalent performance to wrought alloys

**Outcomes: alloys with superior performance for Energy, Aerospace, Automotive, Defense and Biomedical applications.**



# Sensors for Critical Infrastructure & Extreme Environments



## Advanced Sensors for Energy Efficiency, Safety, Resilience, and Sustainability

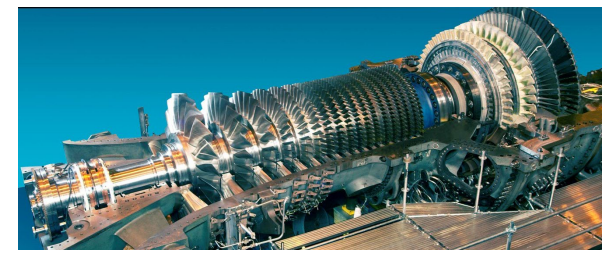
- ✓ Monitor systems and conditions
- ✓ Improve performance & efficiency
- ✓ Enhance reliability & safety
- Temp, acoustics, chemical, gas, corrosion
- Composite nano-materials, thin films & fiber optics, sensor devices development

**Multiple Sensor Platforms**

- Distributed Fiber Optics
- Surface Acoustic Wave
- Electrochemical
- LIBS
- Raman

GENERATION

**Turbines:** Real-time fuel composition and combustion temperature for improved service life and efficiency



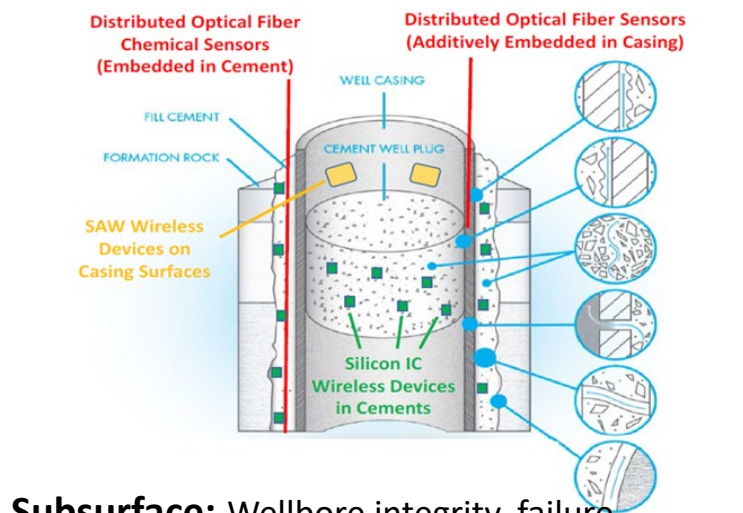
## ENERGY DELIVERY & STORAGE



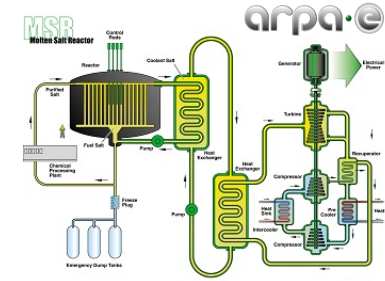
**Pipelines:** Monitor corrosion, gas leaks, T, acoustics to predict/prevent failures. NG, H<sub>2</sub>, CO<sub>2</sub>



**Grid:** Transformer, powerline failure prediction, fault detection, state awareness

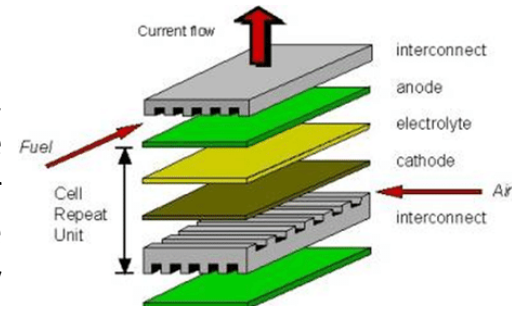


**Subsurface:** Wellbore integrity, failure prediction, leak detection. Geologic storage of CO<sub>2</sub>, H<sub>2</sub>/NG, or abandoned wells.



**Nuclear:** Core monitoring and molten salt temperatures for reactor fuel efficiency & reactor safety

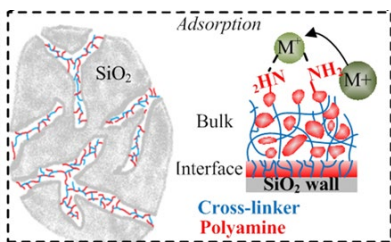
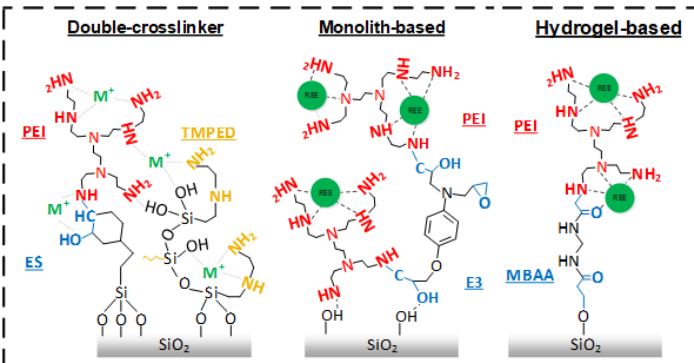
**SOFCs:** Fuel concentration & temperature gradients for improved lifetime and efficiency



# Carbon Capture – Sorbents & Membranes

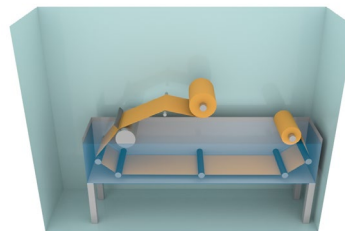
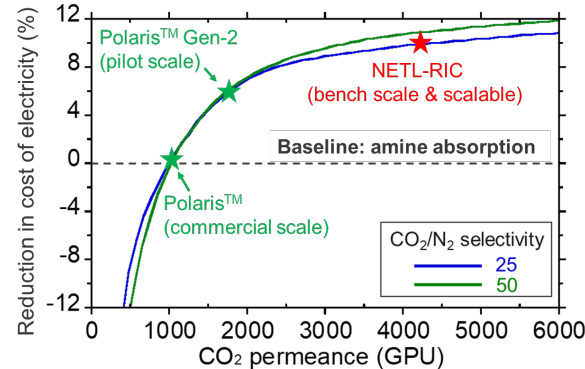
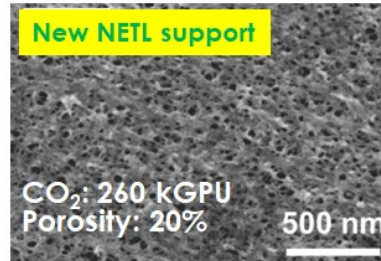
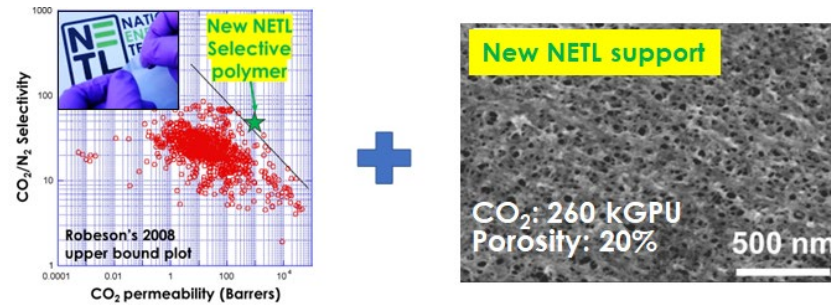
Developing novel materials and processes to reduce the cost of carbon capture

## NOVEL SORBENTS



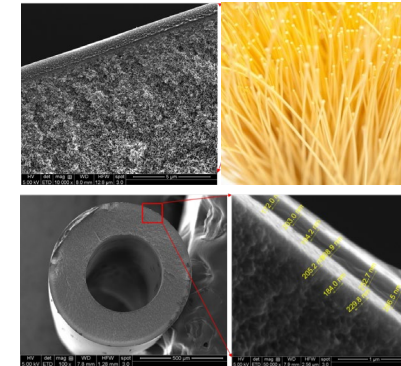
Granular

## CO<sub>2</sub> SEPARATION MEMBRANES



NETL roll-to-roll fabrication

## HOLLOW FIBER THIN FILM COMPOSITES



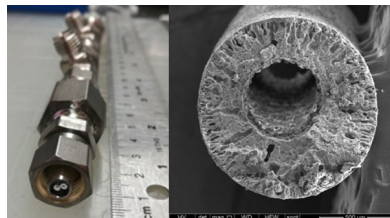
NETL's hollow fiber membrane supports have ultra-high permeance, small surface pore size, and resistance to mild solvents – an ideal combination for thin film composites

## CAPTURE MATERIALS PERFORMANCE

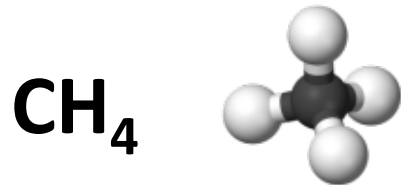
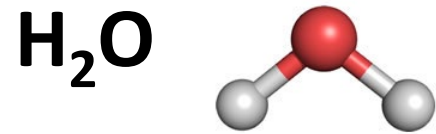
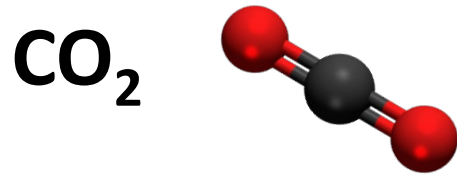


NETL's membrane flue gas test unit at the National Carbon Capture Center, for long-term stability testing under real conditions including moisture and contaminants

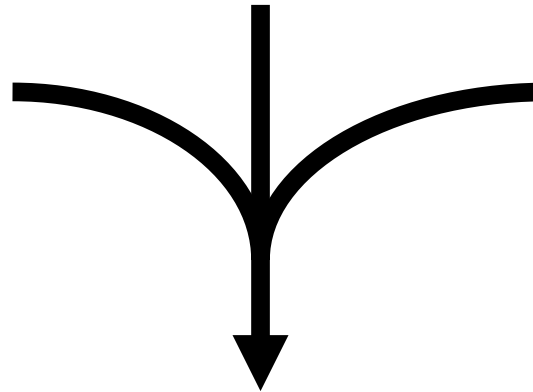
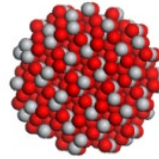
Hollow Fiber



# Catalytic Carbon Conversion



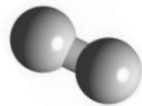
Catalyst



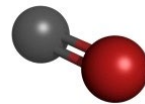
Excess Carbon-Free Electrons



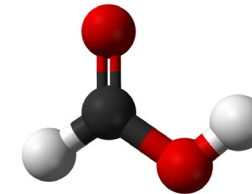
Polymers & Plastics



Hydrogen



Carbon Monoxide



Formic Acid



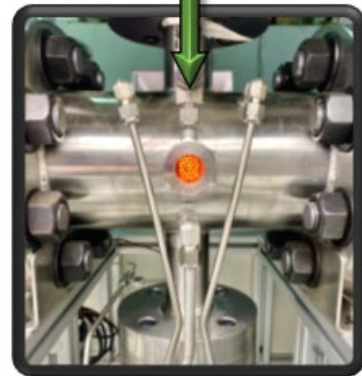
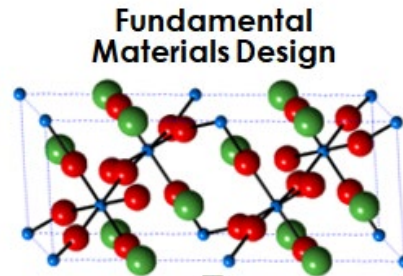
Alcohols / Fuels

# Enhanced Catalytic CO<sub>2</sub> and Natural Gas Conversion Techniques

## • Microwave Conversion

Microwave reactors use electricity to produce carbon-neutral H<sub>2</sub> and CO (syngas) with record setting energy efficiency.

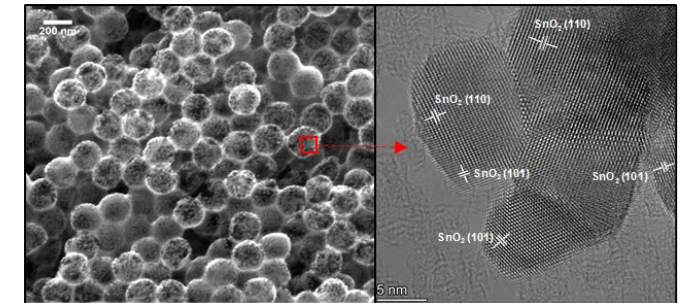
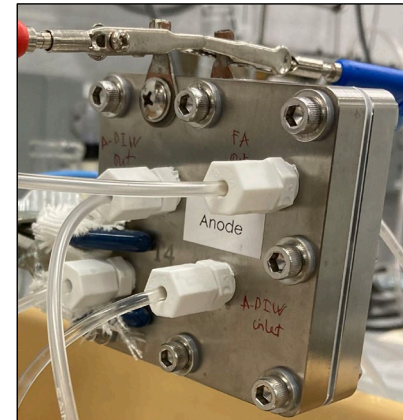
- Impact:
  - Sustainable use of natural gas and captured CO<sub>2</sub> to produce carbon neutral H<sub>2</sub> and syngas.
  - Allow development of modular reactors for on-demand chemical production.



Pre-pilot Scale Microwave  
Demonstration

## • Electrochemical Conversion

Advanced materials synthesis atomic-level computational modeling develop high activity catalysts that replace expensive precious metals. Prototype reactors validate performance at industrially-relevant conditions.



# Carbon Materials Manufacturing

Carbon Value Chain 

## Domestic Feedstocks

Coal & Mining Waste



Plastic Waste



Oil

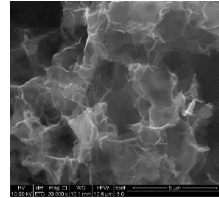


Biomass



## Novel Carbon Materials

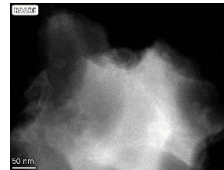
3D & Few-layer Graphene



Graphite

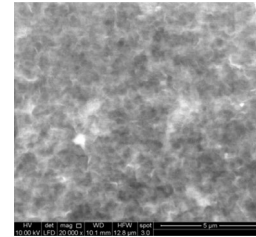


Graphene Nanoflakes



Porous Carbons

Graphene Oxide



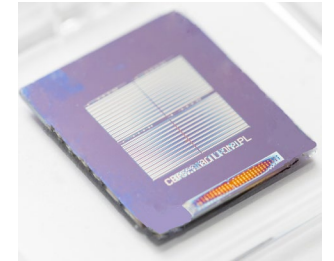
Carbon Quantum Dots

## Performance Testing

Energy Storage  
(Battery & Supercaps)



Carbon Electronics



Sensors



Construction Materials





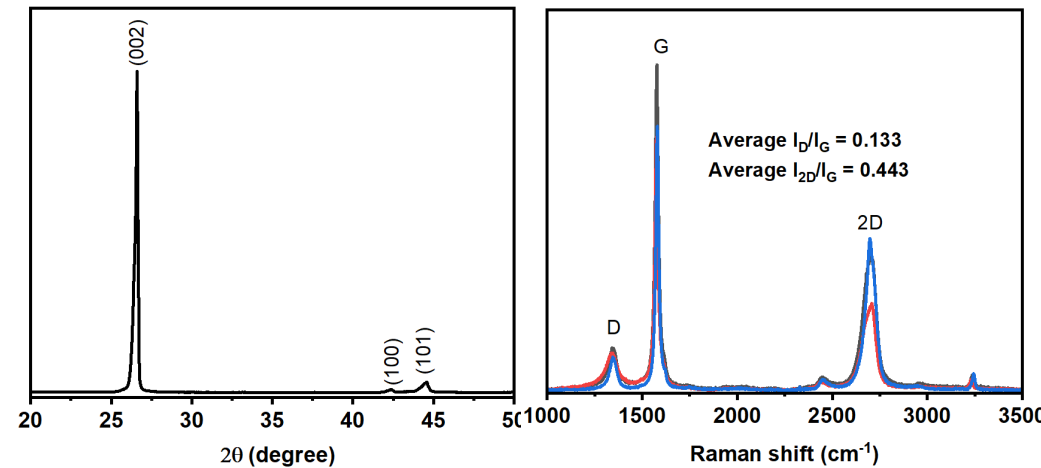
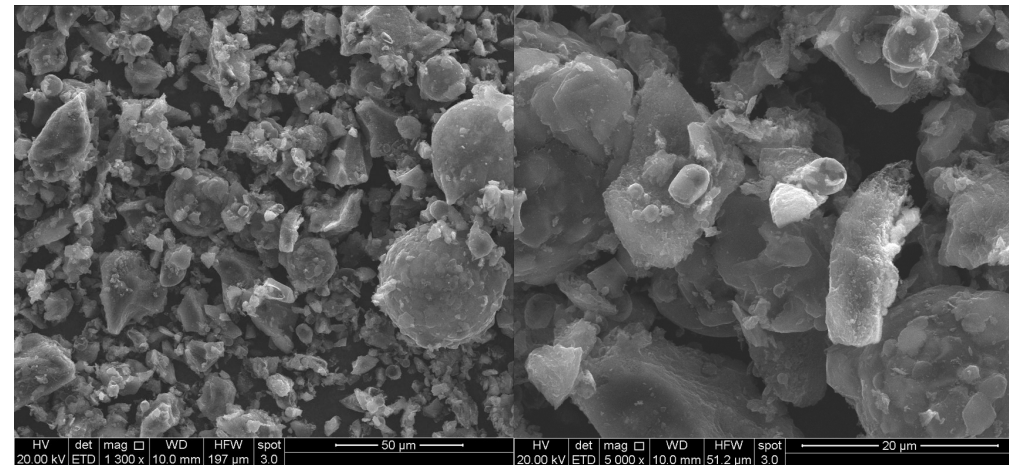
# Manufacturing Graphite from Waste Carbons and Blends



## Low-temp Catalytic Graphitization:

- Converts waste coal, waste plastic, & biomass to graphite.
- Works w/multiple forms of coal waste & carbon waste
- Waste blends will be investigated
- Lowers Process Intensity:
  - Temp ~ 1500 C
  - Time ~ 3 hours
- Degree of Graphitization > 90%
- **Produces Battery Grade Graphite**

## Graphitized Powder River Basin Coal Char



## Carbon Waste & Blends

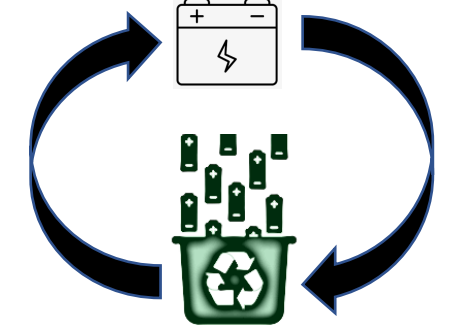
Plastics Coal/Mining Biomass



↓  
**Graphite**



## Battery & EES Devices



End of Service Life  
Carbon Mineral Recovery

- **Carbon Electronics**

- Memristor Computer Memory Devices
- Capacitors
- Electrodes



**Benefits:**

- Atomically thin dielectric materials
- Lowering costs & onshoring manufacturing
- Scalable manufacturing process
- Enhanced Performance

- **Construction Materials and Infrastructure Enhancement**

**Cement & Concrete Composites**



**Coal-derived graphene nanoflake in cement/concrete formulations:**

- Increases compressive and flexural strength by 15-35%
- Reduces porosity by 35% and permeability by 100%,
- Improves durability by reducing penetration of water and corrosive salts into cement/concrete by ~65%

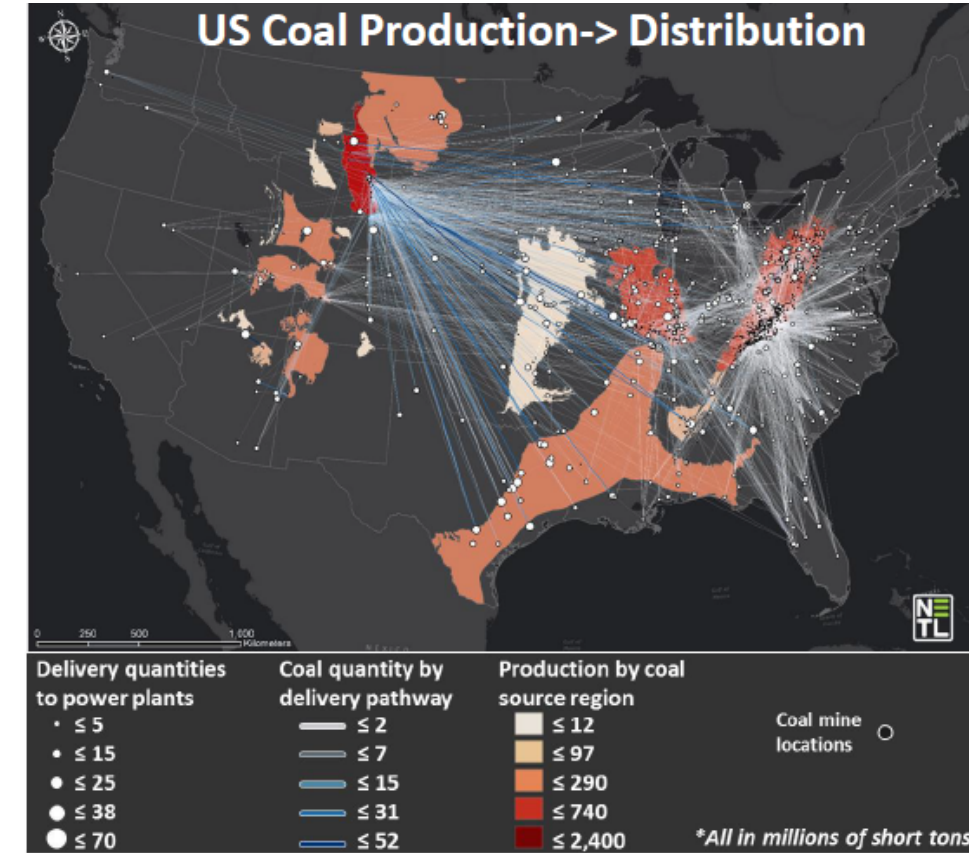
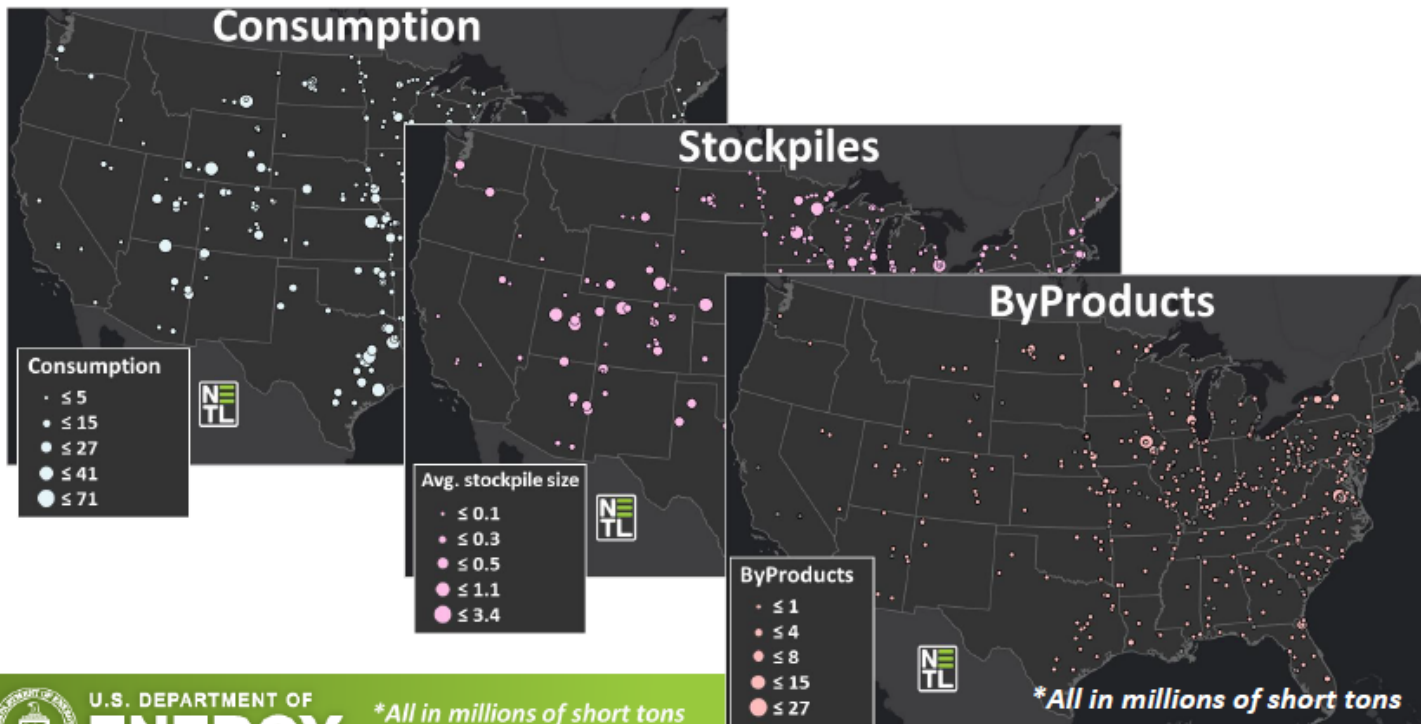
# REE and CM from Waste Streams

Characterize domestic coal throughout its lifecycle to optimize as a resource:

- Reduce cost of coal ash disposal/recycling
- Increase usage in materials (concrete, drywall, etc.)
- Reduce carbon footprint

Opportunity to use for identifying inefficiencies, vulnerabilities and threats along supply chains

- Natural disasters, economic, environmental, etc.



Geodatabase containing over 90,000 records spanning:

- 2168 mines
- 636 power plants
- 85,072 domestic coal deliveries

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