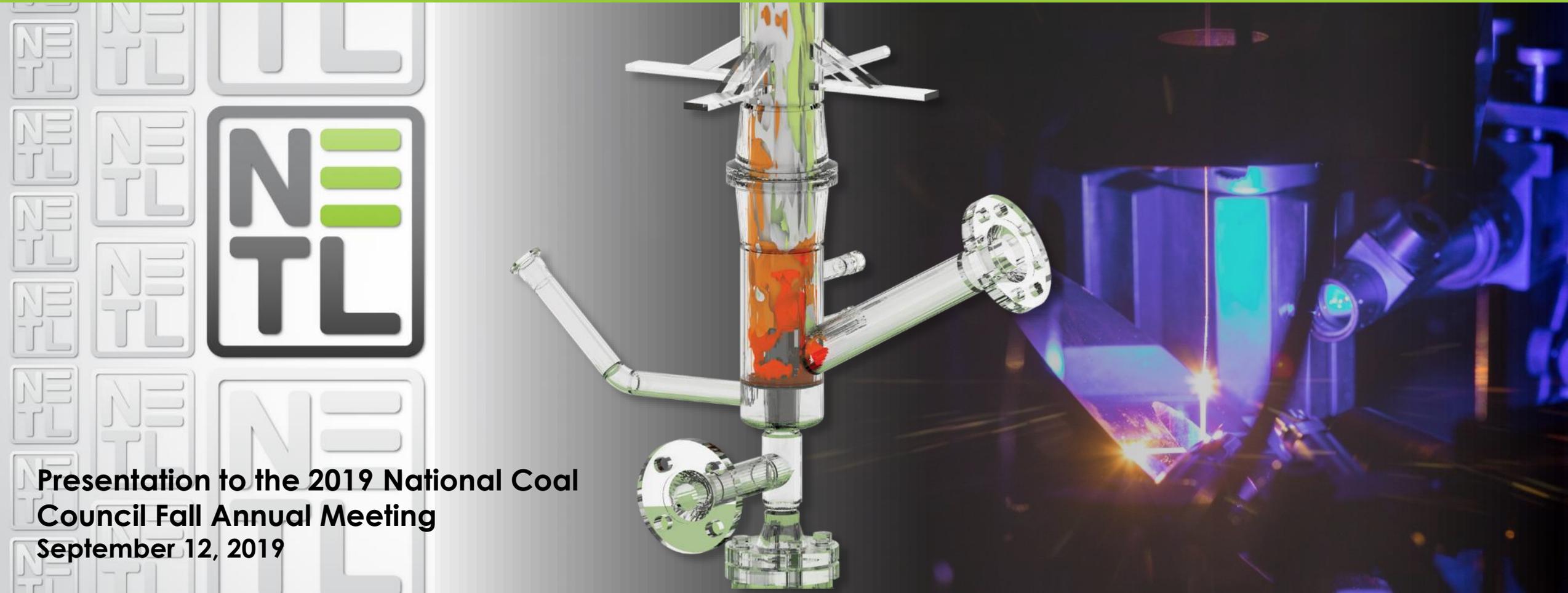


Accelerating Breakthrough Innovation in Clean Coal Technologies

Solutions for Today | Options for Tomorrow



Brian J. Anderson, Ph.D.
Director



Presentation to the 2019 National Coal
Council Fall Annual Meeting
September 12, 2019

MISSION

Discover, integrate and mature technology solutions to enhance the Nation's energy foundation and protect the environment for future generations

- **Effective Resource Development**
- **Efficient Energy Conversion**
- **Environmental Sustainability**

VISION

Be the Nation's renowned fossil-energy science and engineering resource, delivering world-class technology solutions today and tomorrow

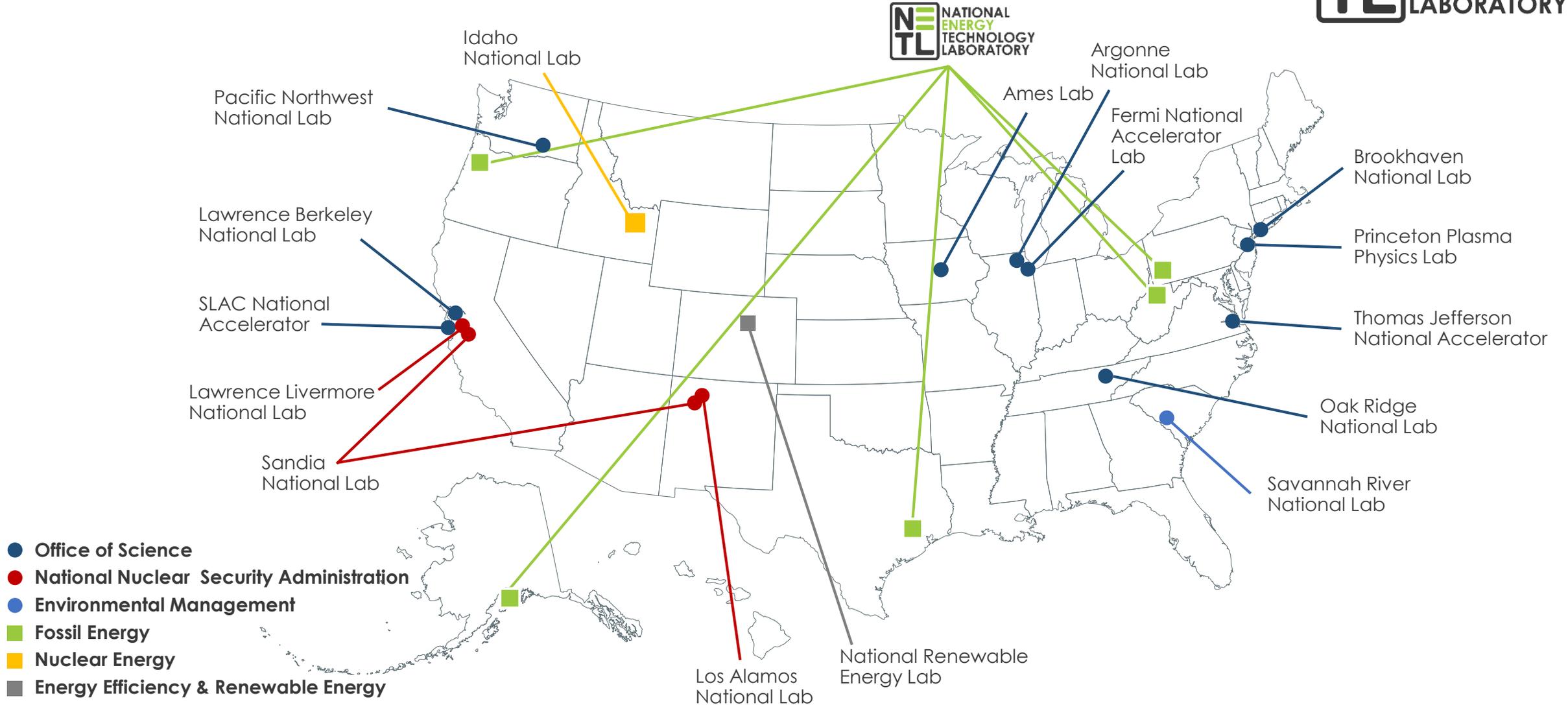
- **Technology Convener**
- **Knowledge and Technology Generation Center**
- **Responsible Steward**



U.S. DEPARTMENT OF
ENERGY



The National Laboratory System



By the Numbers

3 labs across U.S.

900+ R&D projects in **50** states

\$6.3B total award value

\$991M FY19 budget

Workforce

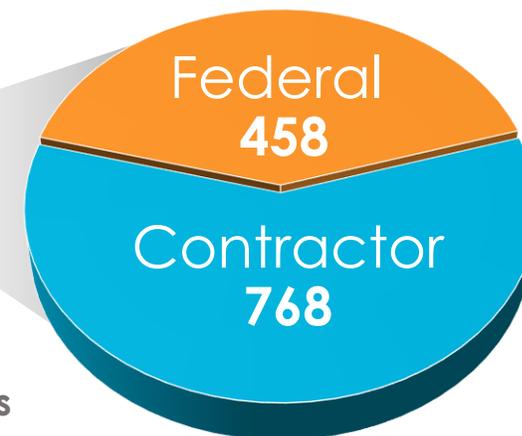
1,226 Full Time Equivalent Employees (FTEs)

70 Joint Faculty

109 Postdoctoral Researchers

54 Graduate Students

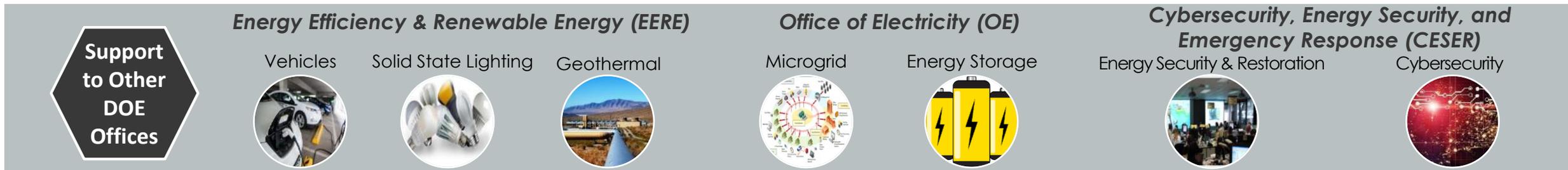
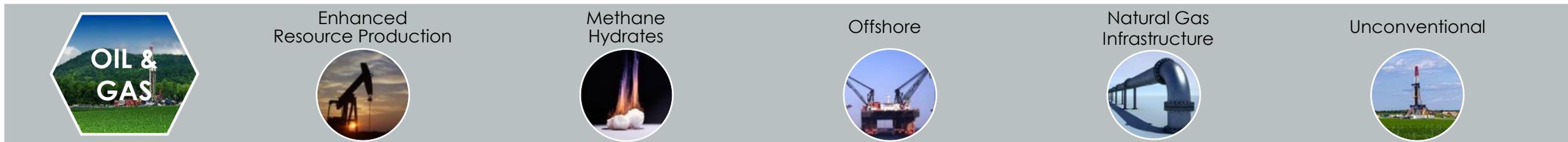
40 Undergraduate Students



NETL possesses an array of authorities to manage & implement complex R&D programs

- Program planning, development, and execution
- Legal, Financial, Procurement and Head of Contracting Authority (HCA)
- Project Management Expertise

Core Competencies & Technology Thrusts



Coal Technology Thrusts

Advanced Energy Systems

Developing & deploying advanced, more efficient, & robust coal-based power technologies to optimize the use of our abundant domestic fossil energy resources & leverage existing infrastructure.



Carbon Capture, Utilization, & Storage

Advancing technologies & techniques to effectively capture, safely store, & economically utilize CO₂ derived from power generation & other industrial processes.



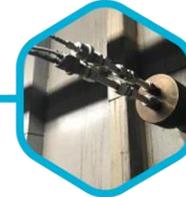
Transformational Coal Pilots

Developing pilot-scale transformational coal technologies aimed at enabling step-change improvements in coal-powered systems accelerating their readiness for the marketplace.



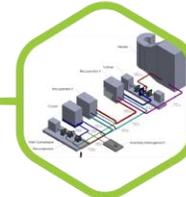
Crosscutting Research

Accelerating science & engineering-based solutions across multiple operational platforms to optimize plant performance, reduce O&M costs & water consumption, & develop the next-generation of structural & functional materials.



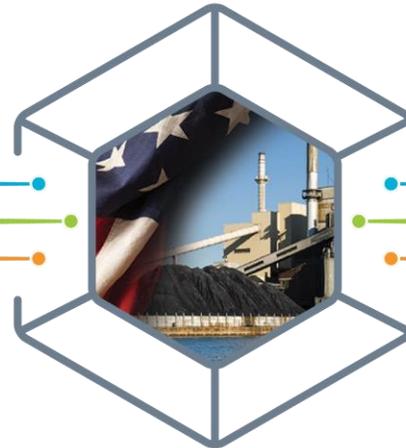
STEP (Supercritical CO₂)

Developing & modeling sCO₂ power cycles with the potential to achieve efficiencies greater than 50%, with broad applicability to fossil, nuclear, waste-heat, & concentrated solar energy power systems.



NETL Coal R&D

Developing novel extraction, processing, & manufacturing technologies to produce a cost-competitive domestic supply of rare earth elements from U.S. coal & coal by-products to sustain our Nation's robust economy.



Evolving Topics in Coal

Upgrading the Existing Fleet



Improving the performance, reliability, & efficiency of the existing coal-fired fleet

Advancing Next-Gen Power Plants



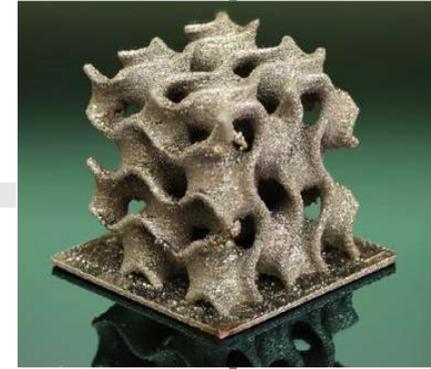
Advancing small-scale, modular coal plants that are highly efficient, flexible, & near-zero emissions

Pioneering New Markets for Coal



Enhancing the value of coal as a feedstock & deriving new value-added products from coal

Reducing the Cost of Carbon Capture



Developing advanced computational & simulation tools, & transformational technologies to reduce the cost of CO₂ capture

Reducing Water Use in Energy Production



Addressing water quality, sustainability, & availability for power generation

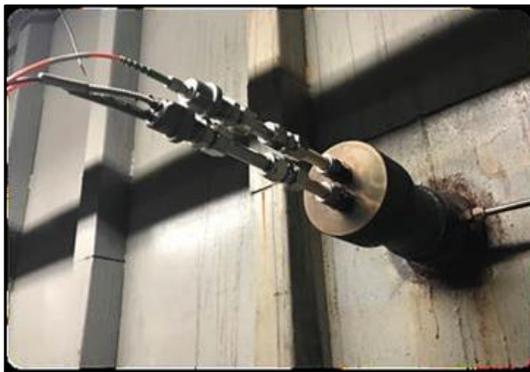


NETL Focus Areas

- Sensors, Diagnostics, and Controls to Improve Prediction, Performance, and Reliability
- Power Plant Component Improvement
- Data Analytics Driven Controls

Improving the performance, reliability, & efficiency of the existing coal-fired fleet

Reduced Mode Sapphire Optical Fiber and Sensing System



- With sponsorship by NETL, Virginia Tech developed harsh environment sensing technology.
- Researchers demonstrated in a industrial environment, advancing the technology from TRL 1 to TRL 7.
- Sensor system will enable real-time, accurate and reliable monitoring of temperatures inside a power plant's boiler system, lowering operating costs through better operational control.

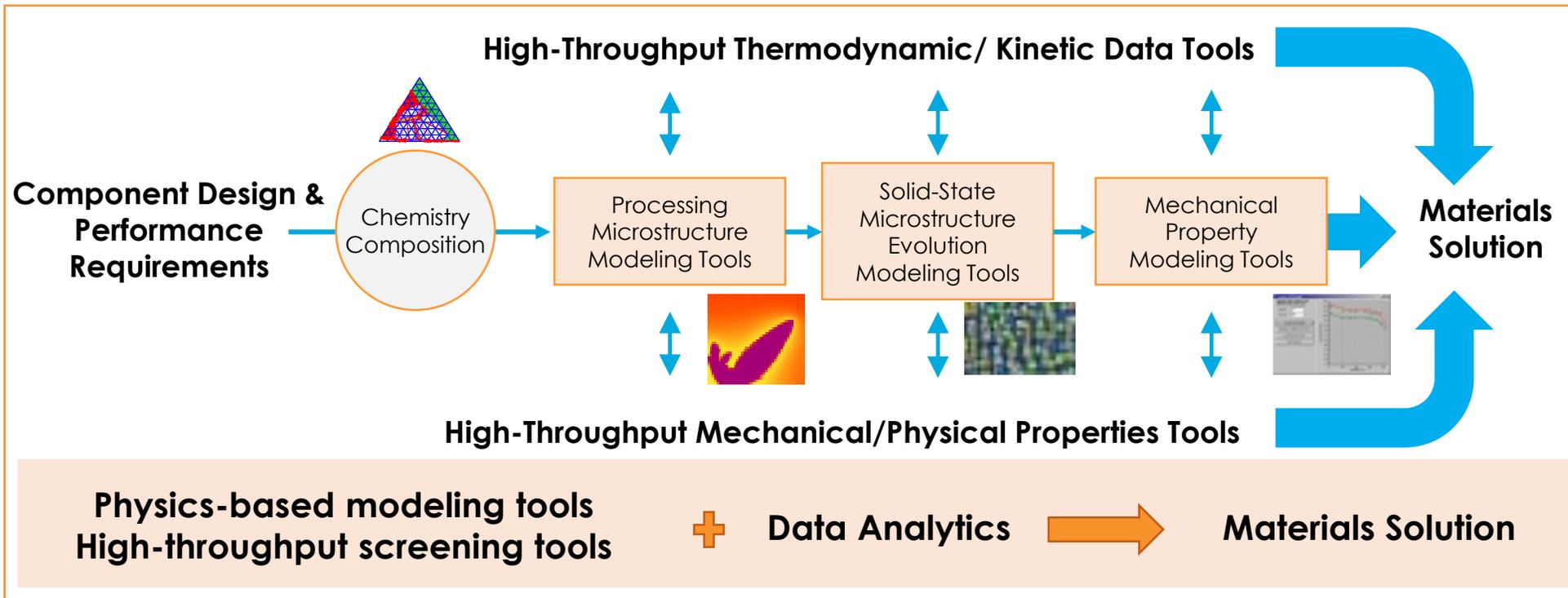
Addressing Advanced Material Challenges

eXtremeMAT



A joint research effort utilizing world-leading DOE National Lab resources:

- Materials design
- High performance computing power
- Advanced processing & manufacturing
- In-situ characterization
- Performance assessment at condition



Research Goals

- Improving models to predict long-term materials performance
- Improving lower-cost, heat-resist alloys

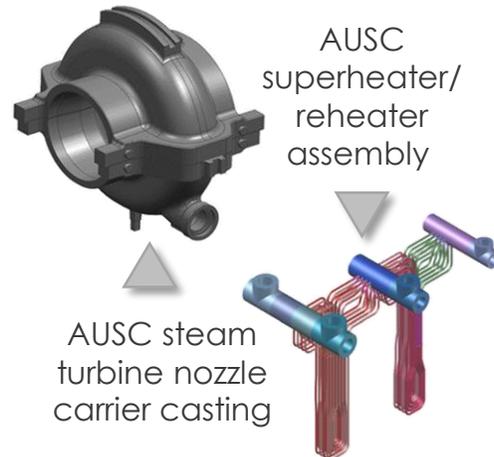


Advancing small-scale, modular coal plants that are highly efficient, flexible, & near-zero emissions

NETL Focus Areas

- Modular power plants
- Stable power generation
- Flexible and highly efficient operations
- Accommodate ongoing transitions from simple arrangement to complex energy systems

Advanced Ultra-supercritical Technology



AUSC ComTest Project:

- Validating technology applicable to fossil, nuclear, and renewable power generation
- Accelerating development of domestic supply chain
- Higher efficiency and lower emissions
- Minimizing risk for building AUSC plants
- Designed world's first integrated AUSC steam turbine at 760°C

Coal FIRST Initiative

Providing secure, stable, and reliable power

The R&D under the **Coal FIRST** initiative will support future power plants

-  **F**lexible operations to meet the needs of the grid
 -  **I**nnovative and cutting-edge components that improve efficiency and reduce emissions
 -  **R**esilient power to Americans
 -  **S**mall compared to today's conventional utility-scale coal plants
 -  **T**ransform how coal technologies are designed and manufactured
- Design criteria includes:**
- High overall plant efficiency
 - Unit sizes of ~50-350 MW
 - Near-zero emissions
 - High ramp rates and minimum loads
 - Integration with thermal or other energy storage
 - Minimized water consumption
 - Reduced design, construction, and commissioning schedules from conventional norms
 - Enhanced maintenance features
 - Integration with coal upgrading, or other plant value streams
 - Capable of natural gas co-firing



Enhancing the value of coal as a feedstock & deriving new value-added products from coal

NETL Focus Areas

- Identify new manufacturing processes for converting coal into high-value products beyond traditional energy markets.
- Evaluate costs and technical performance of coal-based materials compared to derivatives of other feedstocks.
- Characterize the best markets for coal-based manufacturing and associated barriers.

Recovering rare earth elements from coal and coal by-product streams

- NETL is extracting rare earth elements (REEs) from the full spectrum of coal and coal-based materials.
- Supports three first-of-a-kind, domestic extraction, separation and recovery facilities.
- REEs are in the form of oxides and/or salts, which can either be directly used or converted into rare earth metals for end-use commodity.



Development of Adv. REE Separations Concepts

Bench-Scale Facility for the Extraction, Separation and Recovery of REEs from Coal-Based Resources



Domestic Coal to High-Value Products

Enabling Marketable Carbon Products and Manufacturing Technologies

COAL FEEDSTOCKS

\$30-60/ton



Domestic Char
(Sample from Virginia Carbonite)

Coal Processing
Technology



NEW ECONOMIC OPPORTUNITIES

\$100,000/ton - \$100,000,000/ton



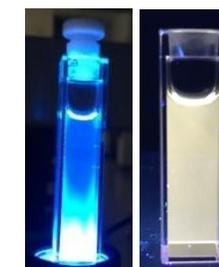
**Graphene-Enhanced
Cement**



**Engineered
Plastics**



**Low Cost Graphene
Inks/Fluids**



**Carbon
Quantum Dots**



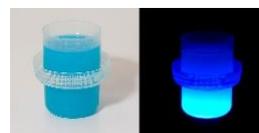
**Stain & Water
Resistant Textiles**



**Electronic
Displays**



**Pigments,
Dyes,
& Paints**



**Optical
Brighteners**



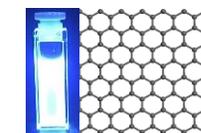
**Photovoltaics
& LEDs**



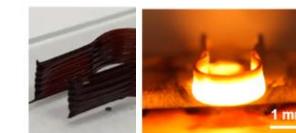
**Carbon
Fiber**



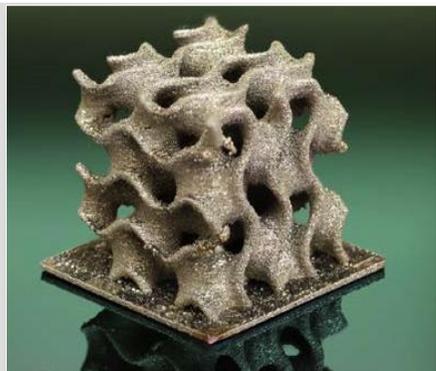
**Additives for
Construction
Materials**



**Carbon
Nanomaterials**



**3D Printing
Materials**



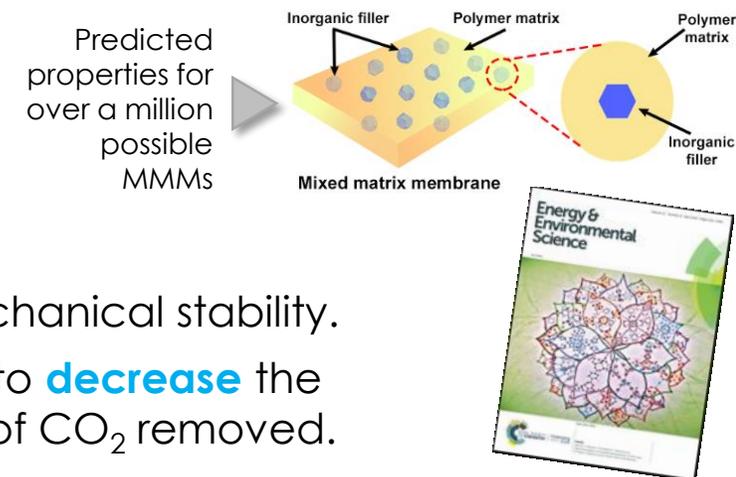
Developing advanced computational & simulation tools, & transformational technologies to reduce the cost of CO₂ capture

NETL Focus Areas

- Post-combustion: remove CO₂ from the combustion flue gas.
- Pre-combustion: capture CO₂ prior to combustion.
- Compression to increase the pressure and reduce the volume flow, enabling efficient transport.

Computational Tools to Rapidly Screening of Novel Carbon Capture Materials

- NETL in-house researchers used high-throughput computational methodology to screen over **1 million** possible mixed matrix membranes (MMMs).
- NETL-developed polymers were found to enhance mechanical stability.
- MMMs, with NETL developed polymer, were estimated to **decrease** the cost of carbon capture from **\$63 to \$48 per metric ton** of CO₂ removed.

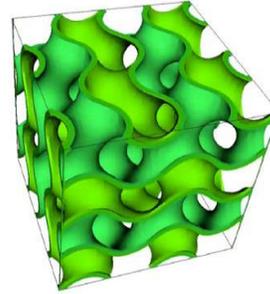


Additive Manufacturing Utilizing 3D Printing

Advancing scale-up and commercialization of carbon capture technologies



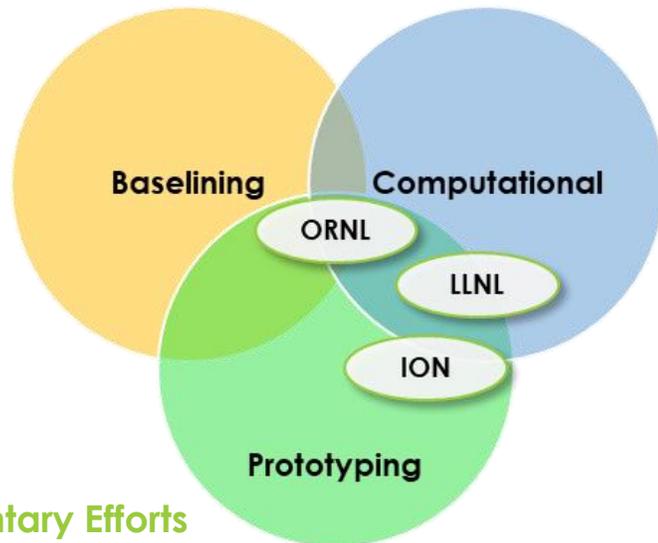
ORNL Prints Intensified Devices with Heat exchanger integrated into pack



LLNL creates silicon-based gyroid structures with one micrometer resolution



ION uses 3D Printing to develop internal absorber mass transfer and heat exchange



- Intensify thermodynamic operations
- Improve process performance
- Reduce equipment size
- Lowers capital and operating costs

Complementary Efforts

Technology Development Pathway

An Active Portfolio from Concept to Market Readiness



COMMERCIALIZATION

Technology available for wide-scale market use

TRL 9

DEMONSTRATION

System demonstrated in operational environment

TRL 8

SYSTEM TESTING

System performance confirmed at pilot-scale

TRL 6-7

DEVELOPMENT

Technology component validated/integrated

TRL 4-5

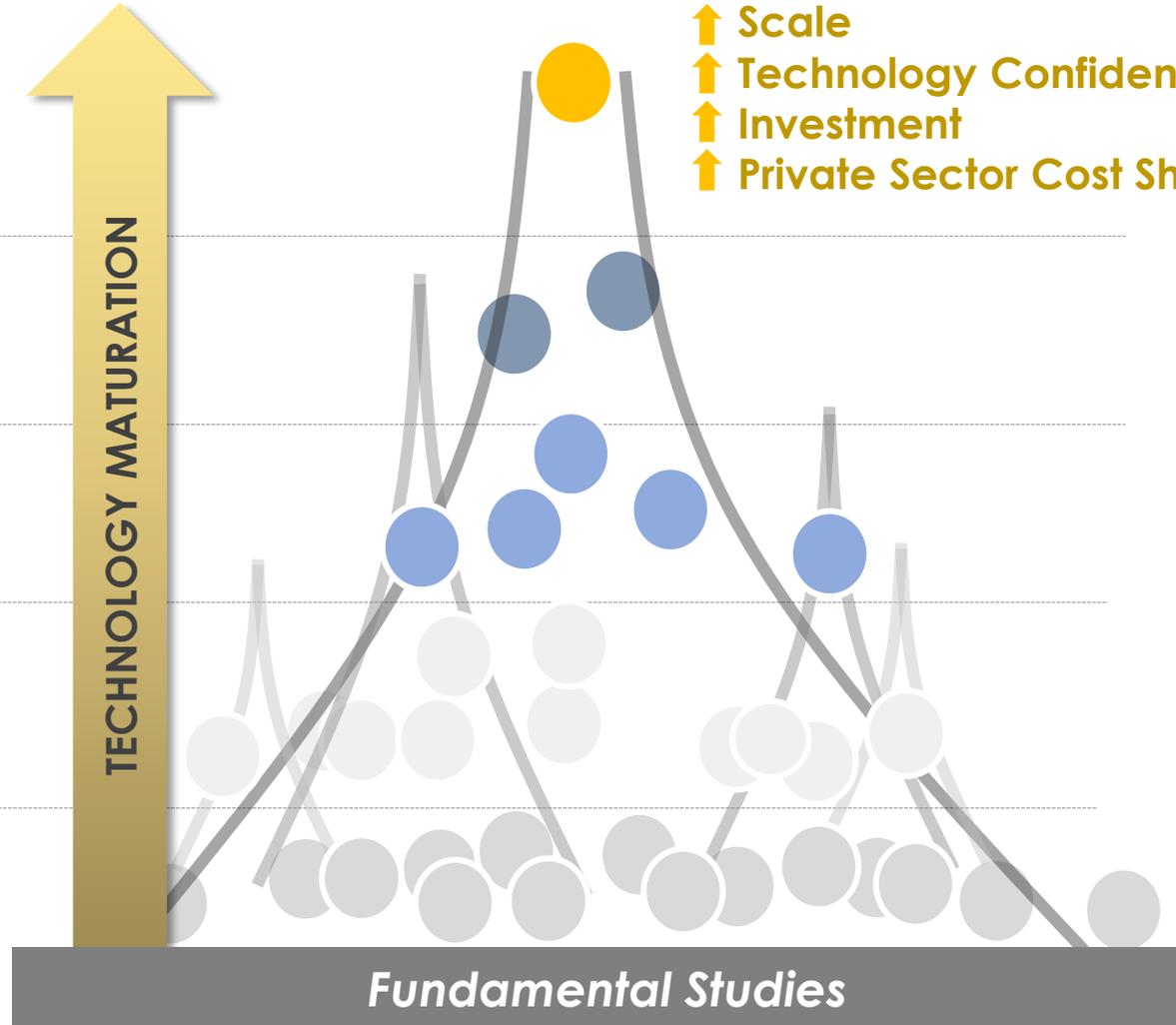
DISCOVERY

Concept identified/proven at laboratory-scale

TRL 1-3

TECHNOLOGY MATURATION

- ↑ Scale
- ↑ Technology Confidence
- ↑ Investment
- ↑ Private Sector Cost Share



KNOWLEDGE-BASED DECISION MAKING

- **Systems Engineering and Integration**
 - Engineering analysis
 - Pre-FEED/FEED studies
 - NEPA
- **Decision Science and Analysis**
 - Screening studies
 - Techno-economic analysis
 - Technology Readiness Assessments

Petra Nova CO₂ EOR CCS Plant



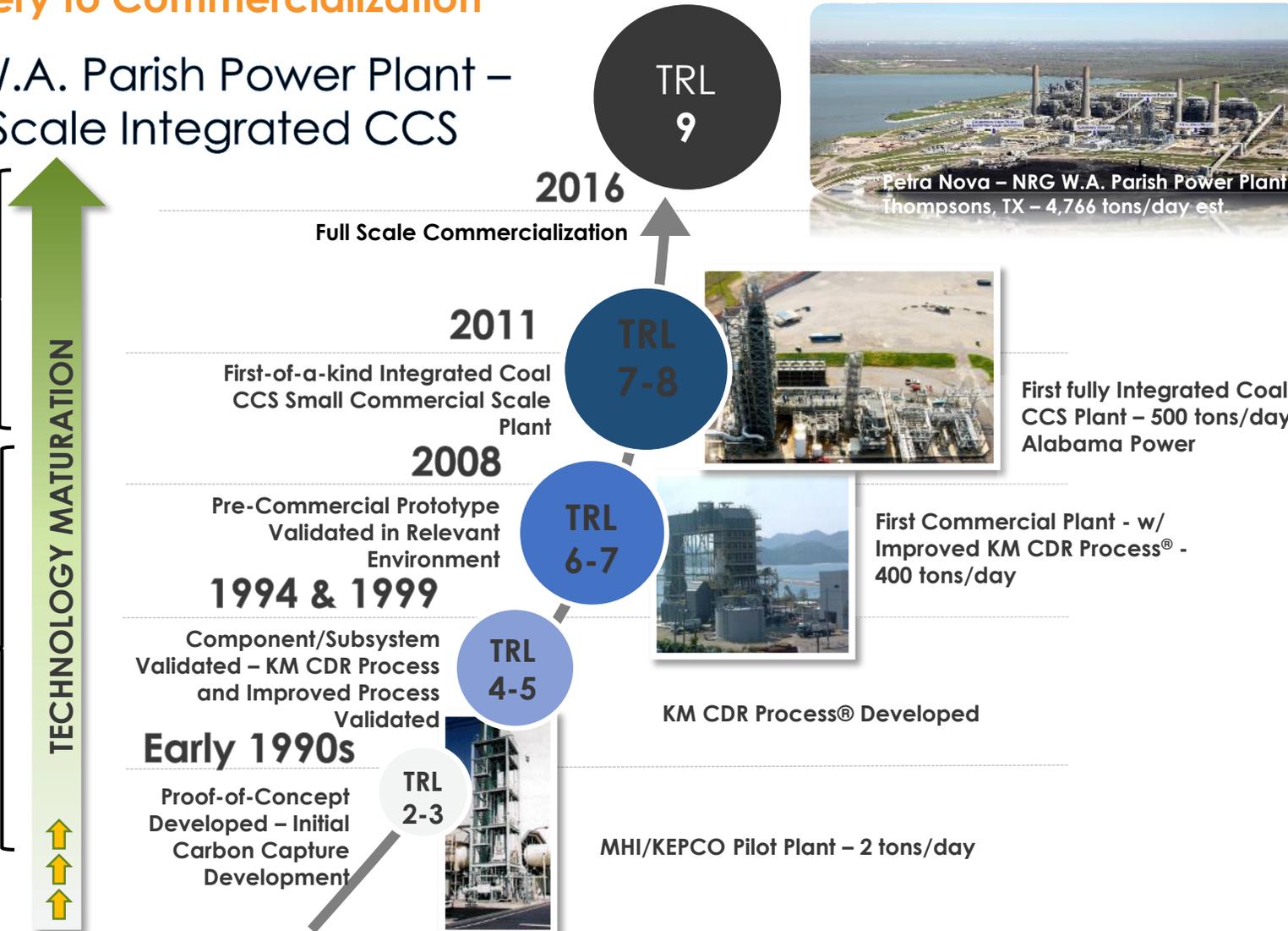
From Discovery to Commercialization

NRG W.A. Parish Power Plant – Full Scale Integrated CCS

Government – Industry Partnership to Commercialization

Industry Leading the Effort

Scale Technology Confidence Investment



TRL 9 COMMERCIALIZATION

Technology available for wide-scale market use

TRL 8 DEMONSTRATION

System demonstrated in operational environment

TRL 6-7 SYSTEM TESTING

System performance confirmed at pilot-scale

TRL 4-5 DEVELOPMENT

Technology component validated/integrated

TRL 1-3 DISCOVERY

Concept identified/proven at laboratory-scale

Established & Expanding Partnerships



An Active Portfolio from Concept to Market Readiness

FE has **over 600 partnerships with industry, academia and other government organizations** and funds **900+ R&D projects** nationwide.



How to work with NETL



The TOOLBOX



- Cooperative Research and Development Agreement (CRADA)
- Contributed Funds-In Agreement (CFA)
- Memorandums of Understanding (MOU)/ Memorandums of Agreement (MOA)
- 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 IP 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 FedBizOpps.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>

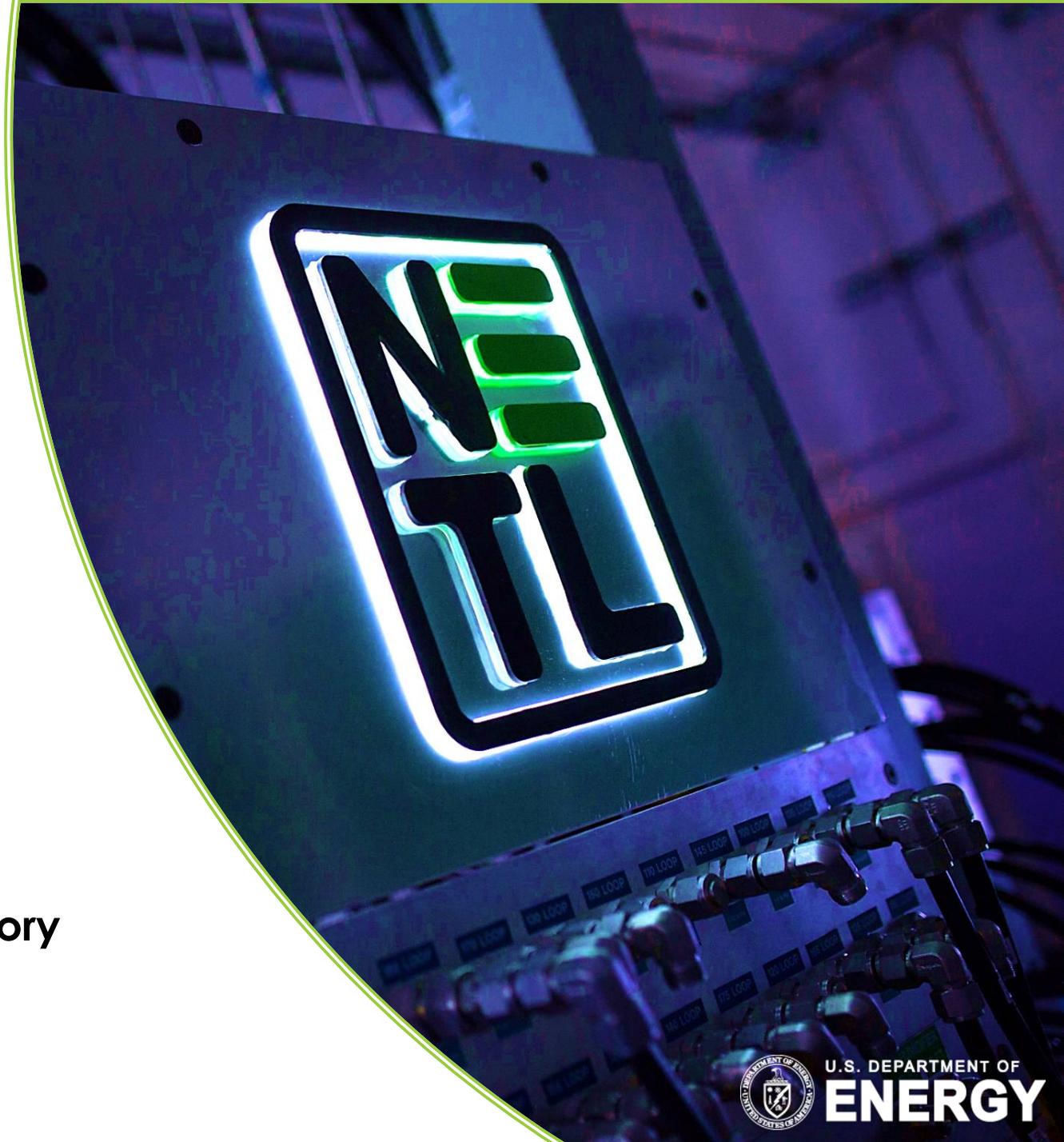
THANK YOU FOR VISITING!

VISIT US AT: www.NETL.DOE.gov

 @NETL_DOE

 @NETL_DOE

 @NationalEnergyTechnologyLaboratory



U.S. DEPARTMENT OF
ENERGY