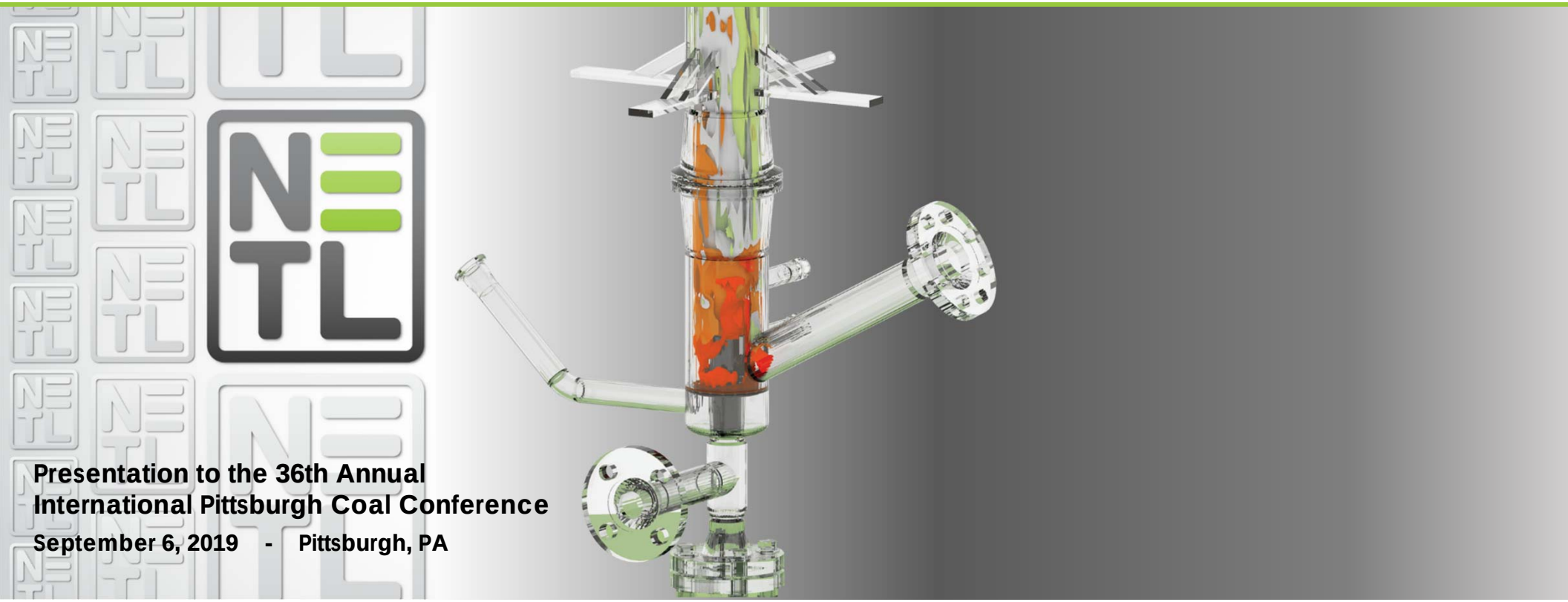
Accelerating Breakthrough Innovation in Clean Coal Technologies

Solutions for Today | Options for Tomorrow

Brian J. Anderson, Ph.D.
Director



Presentation to the 36th Annual International Pittsburgh Coal Conference

September 6, 2019 - Pittsburgh, PA

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 | NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL Snapshot

NATIONAL ENERGY TECHNOLOGY LABORATORY

By the Numbers

3 labs across U.S.

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

$6.3B total award value

$991M FY19 budget

Workforce

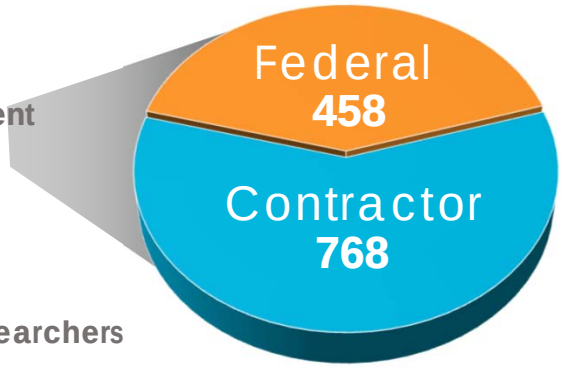
1,226 Full Time Equivalent Employees (FTEs)

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

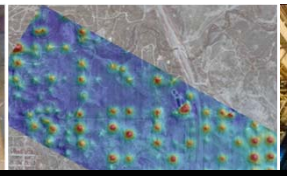
- Program planning, development, and execution
- Legal, Financial, Procurement and Head of Contracting Authority (HCA)
- Project Management Expertise

Core Competencies & Technology Thrusts

NATIONAL ENERGY TECHNOLOGY LABORATORY


Computational Science & Engineering


Materials Engineering & Manufacturing


Geological & Environmental Systems


Energy Conversion Engineering


Systems Engineering & Analysis


Program Execution & Integration

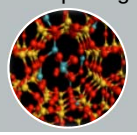
Carbon Storage

Carbon Capture

Sensors & Controls

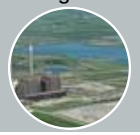
Advanced Materials

Advanced Computing



Advanced Energy Systems

Water Management



Rare Earth Elements

Enhanced Resource Production

Methane Hydrates

Offshore

Natural Gas Infrastructure

Unconventional

Energy Efficiency & Renewable Energy (EERE)

Vehicles

Solid State Lighting

Geothermal

Office of Electricity (OE)

Microgrid

Energy Storage

Cybersecurity, Energy Security, and Emergency Response (CESER)

Energy Security & Restoration

Cybersecurity

Coal Technology Thrusts

NATIONAL ENERGY TECHNOLOGY LABORATORY

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 CO_2 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 CO_2)

Developing & modeling sCO_2 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

NATIONAL ENERGY TECHNOLOGY LABORATORY

Upgrading the Existing Fleet

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

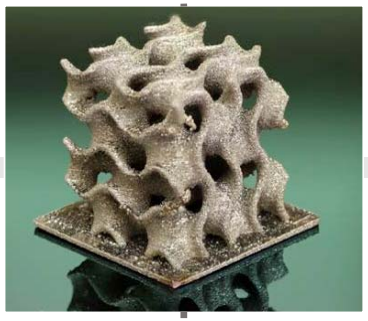
Advancing Next-Gen Power Plants

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 CO_2 capture

Reducing Water Use in Energy Production

Addressing water quality, sustainability, & availability for power generation

Upgrading the Existing Fleet

NETL Focus Areas

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

Reduced Mode Sapphire Optical Fiber and Sensing System

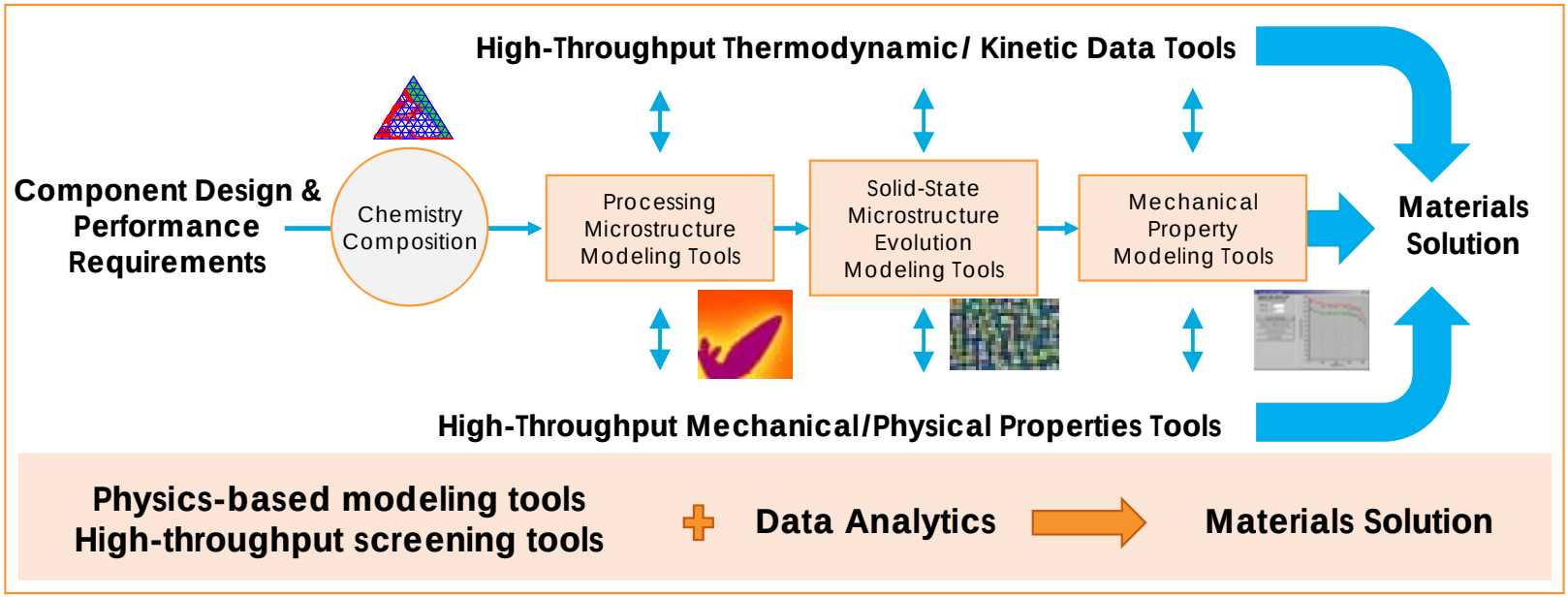
- With sponsorship by NETL, Virginia Tech developed harsh environment sensing technology.
- Researchers demonstrated in a industrial environment, advancing the technology from TRL 1 to TRL 7.
- Sensor system will enable real-time, accurate and reliable monitoring of temperatures inside a power plant's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

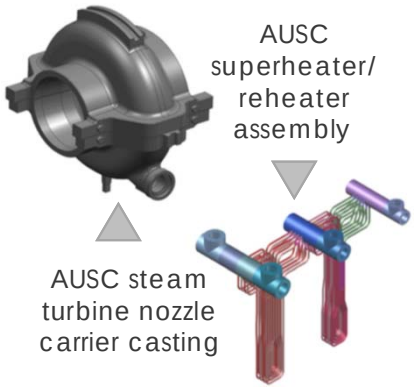
- Improving models to predict long-term materials performance
- Improving lower-cost, heat-resist alloys

Advancing Next-Gen Power Plants

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

Flexible operations to meet the needs of the grid

Innovative and cutting-edge components that improve efficiency and reduce emissions

Resilient power to Americans

Small compared to today's conventional utility-scale coal plants

Transform 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

Pioneering New Markets for 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

NATIONAL ENERGY TECHNOLOGY LABORATORY

COAL FEEDSTOCKS
$30-60/ton

Domestic Char
(Sample from Virginia Carbonite)

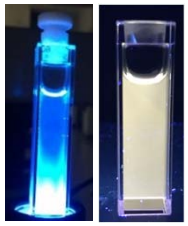
Coal Processing Technology

NEW ECONOMIC OPPORTUNITIES
$100,000/ton - $100,000,000/ton

Graphene-Enhanced Cement

Engineered Plastics

Low Cost Graphene Inks/Fluids

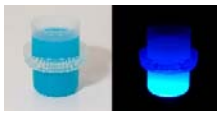


Carbon Quantum Dots

Stain & Water Resistant Textiles

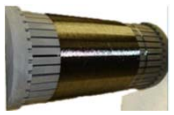
Electronic Displays

Pigments, Dyes, & Paints

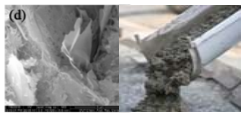


Optical Brighteners

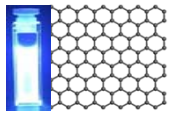
Photovoltaics & LEDs



Carbon Fiber



Additives for Construction Materials



Carbon Nanomaterials

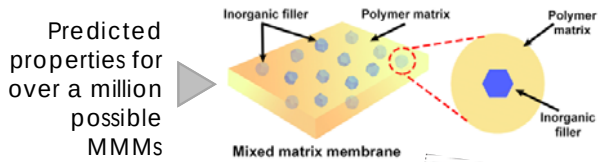
3D Printing Materials

Reducing the Cost of Carbon Capture

NETL Focus Areas

- Post-combustion: remove CO_2 from the combustion flue gas.
- Pre-combustion: capture CO_2 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

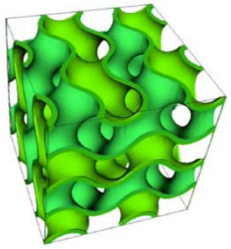


- NETL in-house researchers used high-throughput computational methodology to screen over **1 million** possible mixed matrix membranes (MMMs).
- NETL-developed polymers were found to enhance mechanical stability.
- MMMs, with NETL developed polymer, were estimated to **decrease** the cost of carbon capture from **$63 to $48 per metric ton** of CO_2 removed.

Additive Manufacturing Utilizing 3D Printing

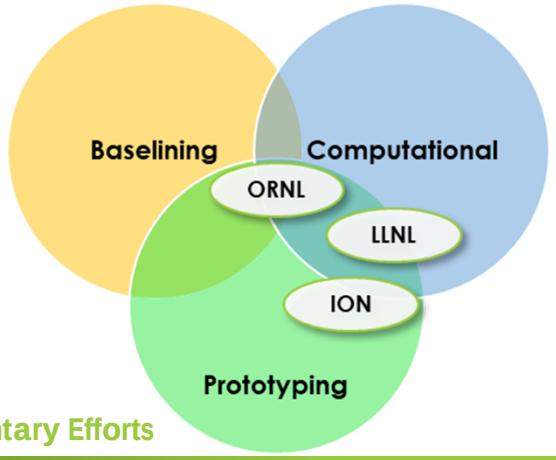
Advancing scale-up and commercialization of carbon capture technologies

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



Complementary Efforts

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

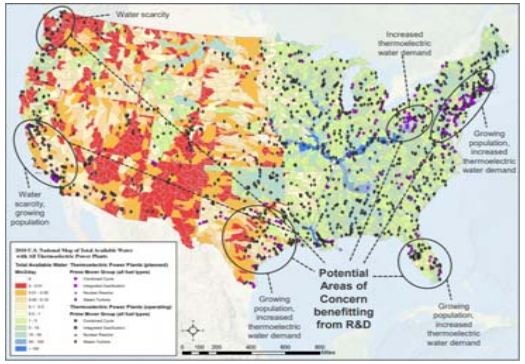
Reducing Water Use in Energy Production

NETL Focus Areas

- **Increasing** water efficiency and reuse to reduce water intake and lower overall operating costs.
- **Identifying** and treating alternative sources of water address energy-water system challenges.
- **Analyzing** energy-water system behavior to better inform decision-makers and scientists.

2018 Water Brief

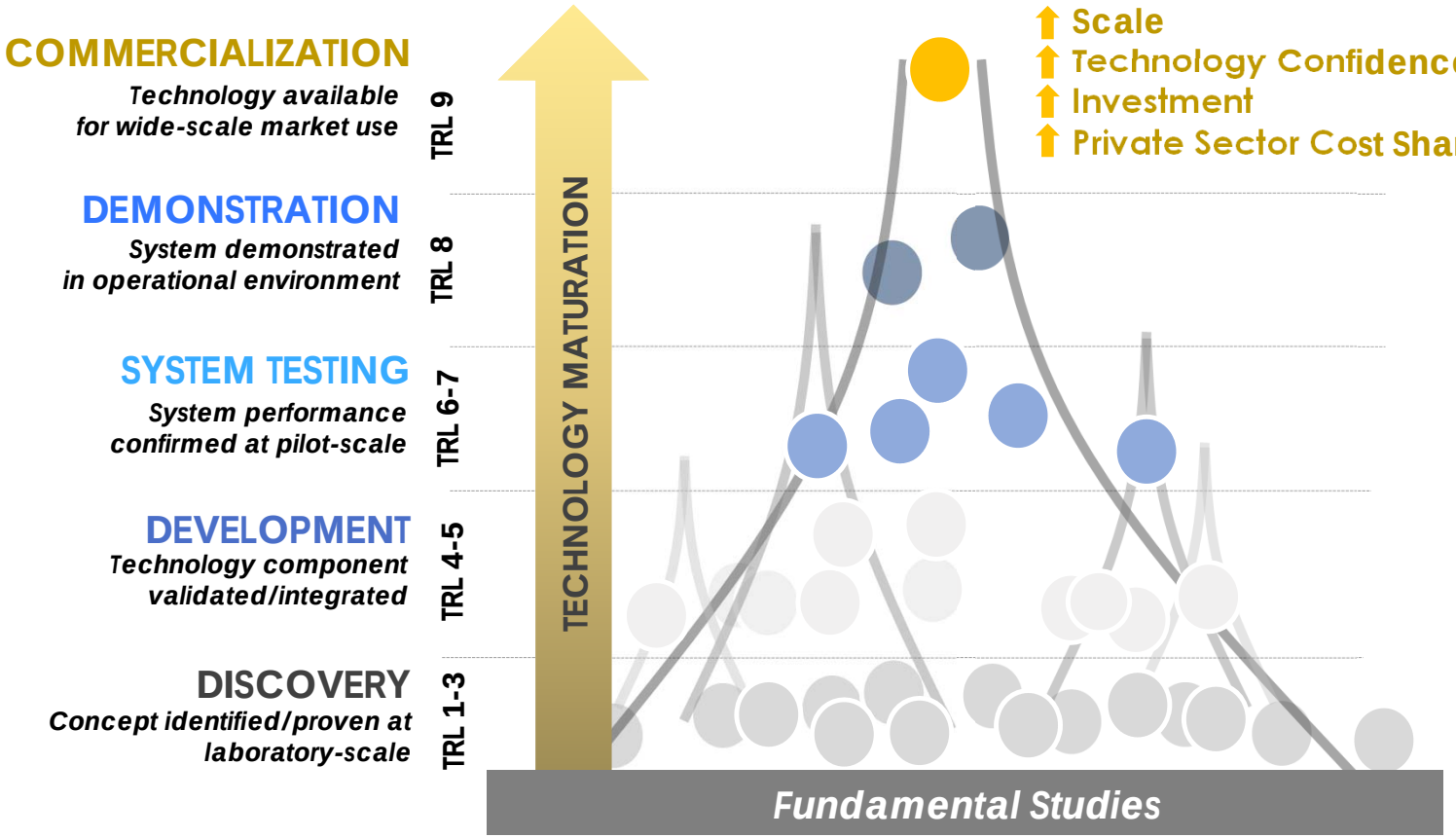
- Identifies regions of water scarcity with expected growth in thermoelectric power generation.
- Recommends R&D to curb thermoelectric water use in areas of concern.
- Predicts locations that would benefit from R&D deployment.



Six potential geographic Areas of Concern that require an R&D plan are shown on a graphic of total available water (2010) overlaid with thermoelectric power generation (2018).

Technology Development Pathway

An Active Portfolio from Concept to Market Readiness



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 CO_2 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

TECHNOLOGY MATURATION

Scale
Technology Confidence
Investment

TRL 9

2016
Full Scale Commercialization

TRL 7-8

2011
First-of-a-kind Integrated Coal CCS Small Commercial Scale Plant

First fully Integrated Coal CCS Plant – 500 tons/day Alabama Power

TRL 6-7

2008
Pre-Commercial Prototype Validated in Relevant Environment

First Commercial Plant - w/ Improved KM CDR Process® - 400 tons/day

TRL 4-5

1994 & 1999
Component/Subsystem Validated – KM CDR Process and Improved Process Validated

KM CDR Process® Developed

TRL 2-3

Early 1990s
Proof-of-Concept Developed – Initial Carbon Capture Development

MHI/KEPCO Pilot Plant – 2 tons/day

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

NATIONAL ENERGY TECHNOLOGY LABORATORY

FE has **over 600 partnerships with industry and academia** and funds **nearly 900 R&D projects** nationwide.

LARGE BUSINESS PARTNERSHIPS

SIEMENS, B&W, Aerojet Rocketdyne, Penske, Southern Company, Ramaco Carbon, Fort Wayne Metals, GE Power & Water, EPRI Electric Power Research Institute, Praxair, PPG, GM, Cummins, Battelle, Volvo, bp, Alcoa

SMALL BUSINESS PARTNERSHIPS

FuelCell Energy, ION Engineering, ARI, Xtalic, SOTACARBO Sustainable Energy Research Centre, Sporian Microsystems, Inc, VIONX Energy, PSE, Liquid Ion Solutions, DERP Tech Distributed Electric Renewable Power, ATREX Energy, REDOX

ACADEMIC PARTNERSHIPS

LSU, Virginia Tech, University of Wyoming, USC University of Southern California, Case Western Reserve University, West Virginia University, University of Pittsburgh, University of Alaska Fairbanks, Texas A&M University, University of Kentucky, Penn State, Iowa State University, Princeton University, Carnegie Mellon University, Clemson University, Oregon State University

GOVERNMENT PARTNERSHIPS

ARL Discover Innovate Transition, Berkeley Lab, Alaska Energy Authority, EPA United States Environmental Protection Agency, U.S. Air Force, NIST National Institute of Standards and Technology U.S. Department of Commerce, NSF, USGS science for a changing world, Oak Ridge National Laboratory, Ames Laboratory, Pacific Northwest National Laboratory, Los Alamos National Laboratory, National Park Service

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!

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