

Integrated Energy Systems of the Future

Solutions for Today | Options for Tomorrow



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NETL Director



Presentation to the 37th Annual
International Pittsburgh Coal Conference

September 9, 2020 - 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

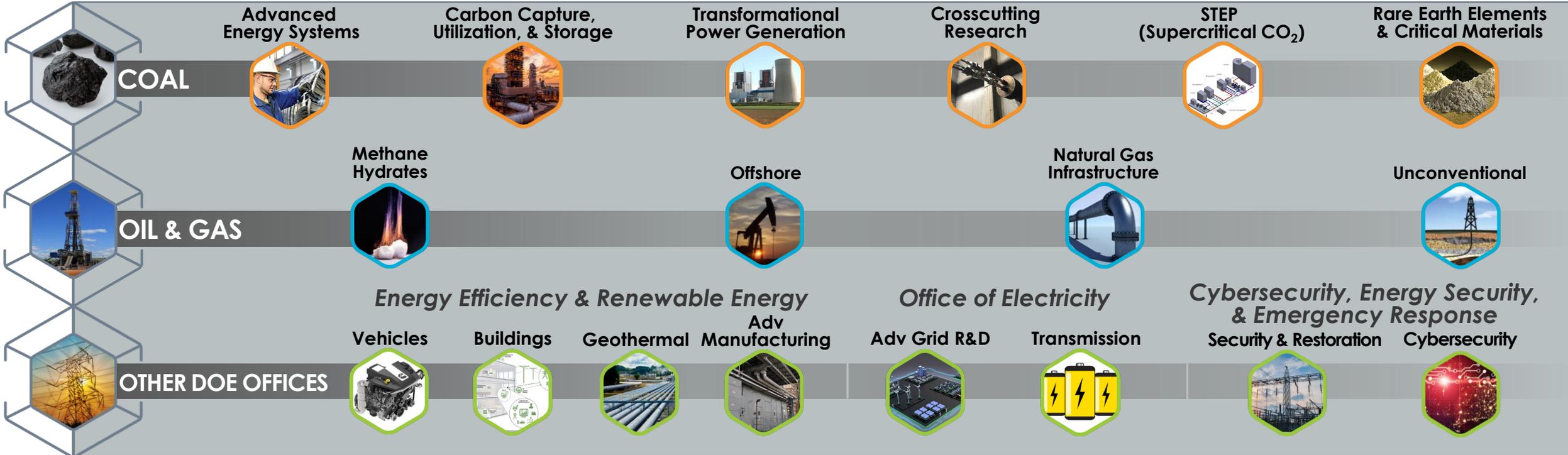
- **Technology Convener**
- **Knowledge and Technology Generation Center**
- **Responsible Steward**



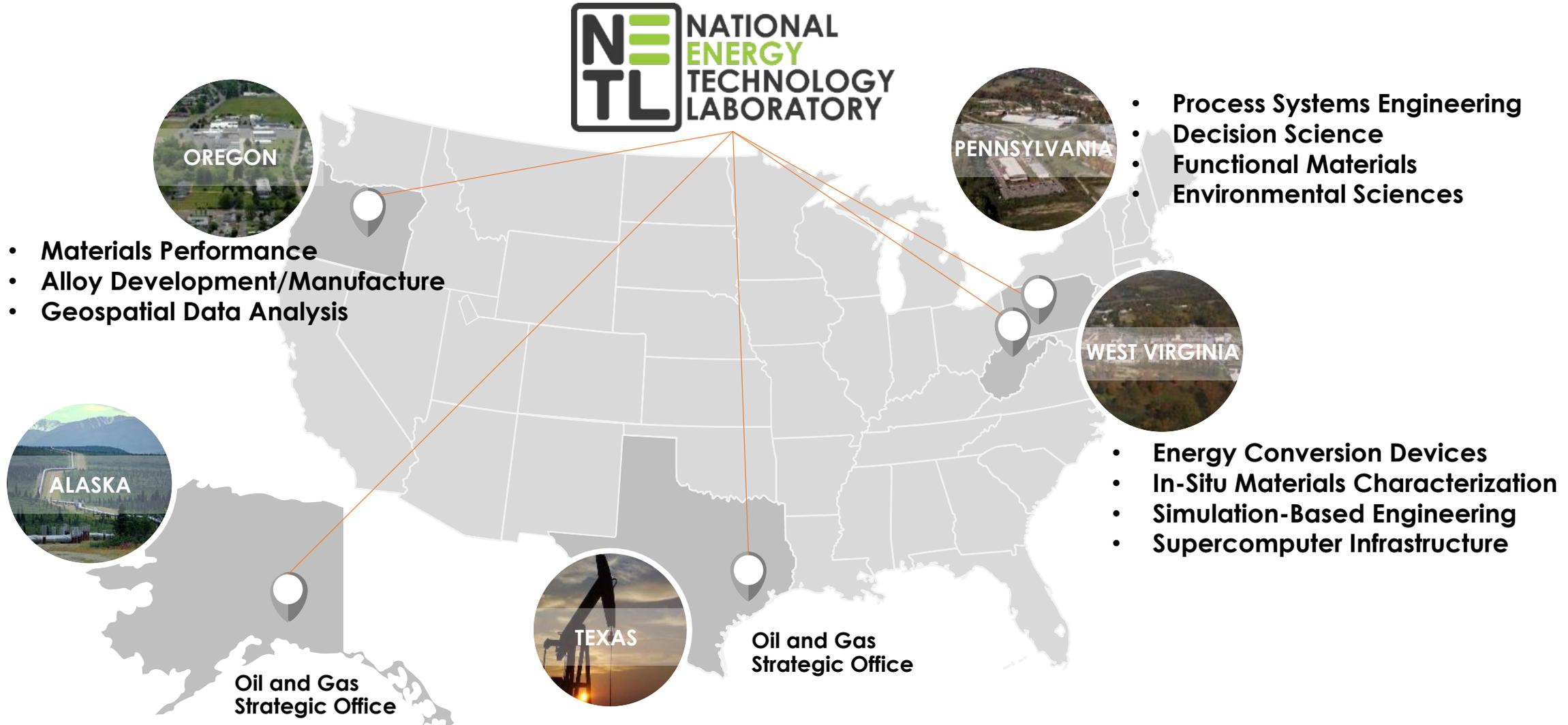
U.S. DEPARTMENT OF
ENERGY



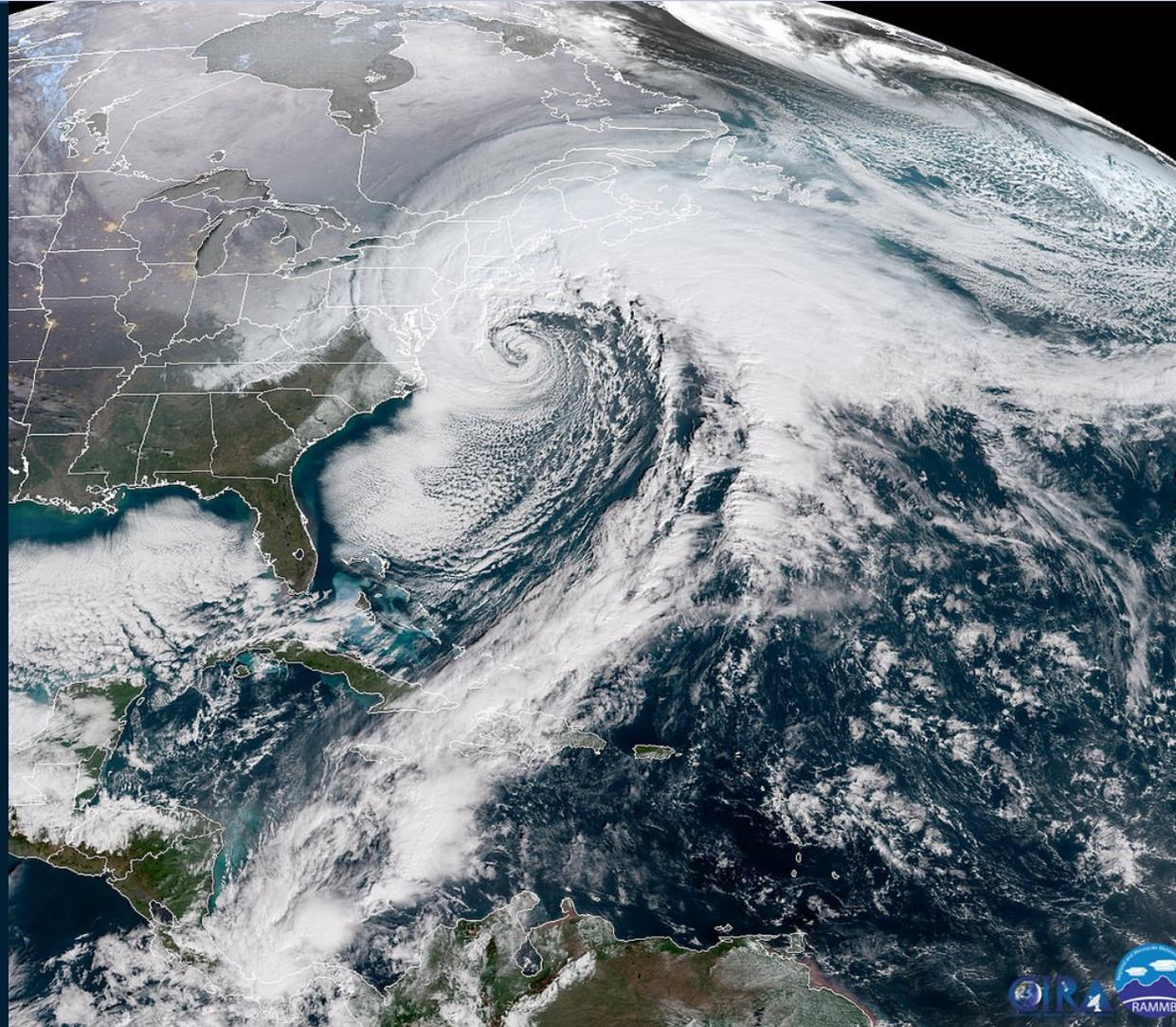
Core Competencies & Technology Thrusts



Three Research Campuses



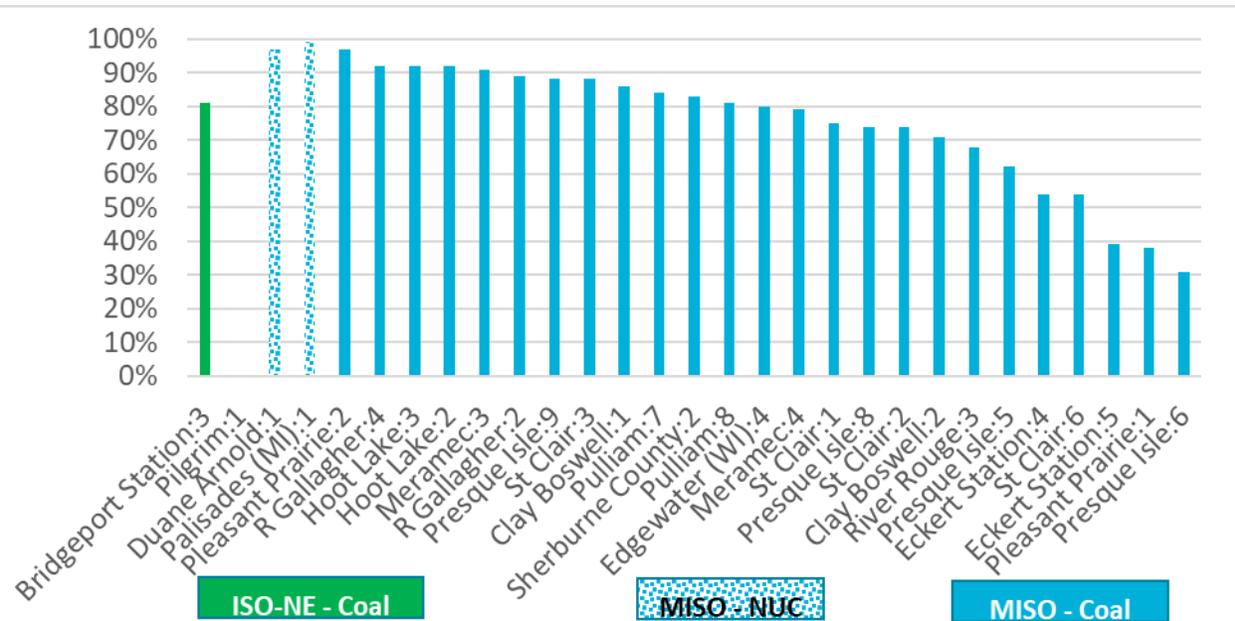
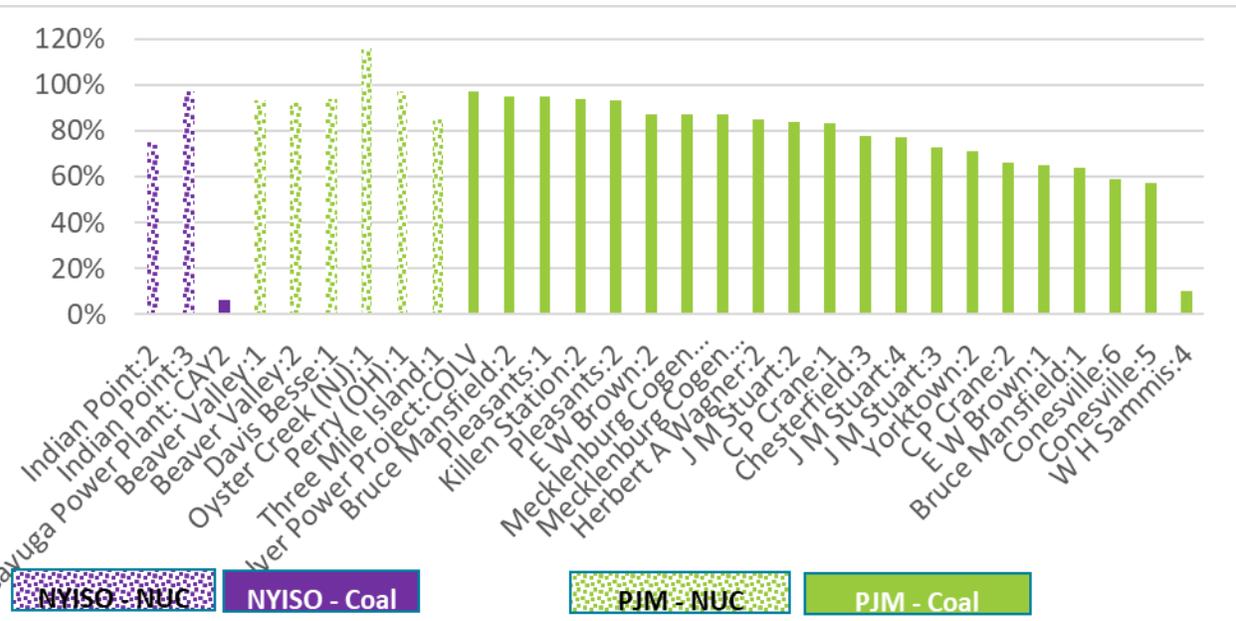
The “Bomb Cyclone”



NOAA's GOES-16 (GOES-East) satellite caught a dramatic view of the bomb cyclone moving up the East Coast on January 4, 2018.

Retiring coal and nuclear units provided grid reliability during the Bomb Cyclone in 2018

On January 5, 2018, 59 different units were slated for retirement with a combined capacity of 24.5 GW generated over 460,000 MWh at an average utilization of 78%



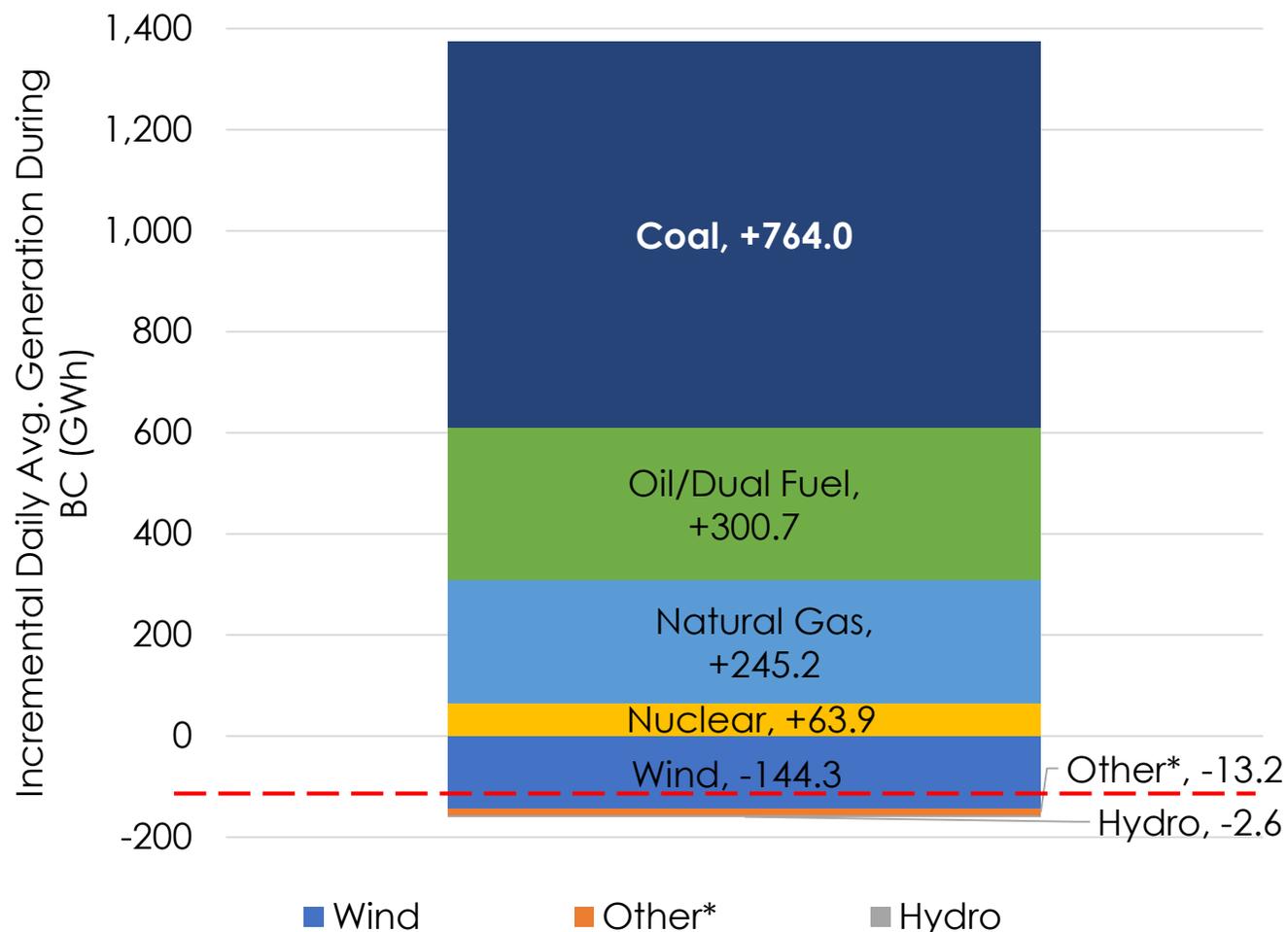
- To compensate for this generation loss, an additional 3.1 BCF of natural gas would have been required in the four RTO/ISO regions
- This is the equivalent of adding nearly thirty-one 630 MW NGCCs running at 100% capacity factor

RTO/ISO	# Units	Generation on January 5, 2018 (MWh)	Combined Nameplate Capacity (MW)	Utilization (%)
ISO-NE	2	7,759	1,065	30%
MISO	27	133,749	7,004	80%
NYISO	3	49,772	2,613	79%
PJM	27	269,891	13,815	81%

Generation Resilience during the Bomb Cyclone, Six ISOs



Daily Incremental Contribution, Dec 27, 2017-Jan 8, 2018

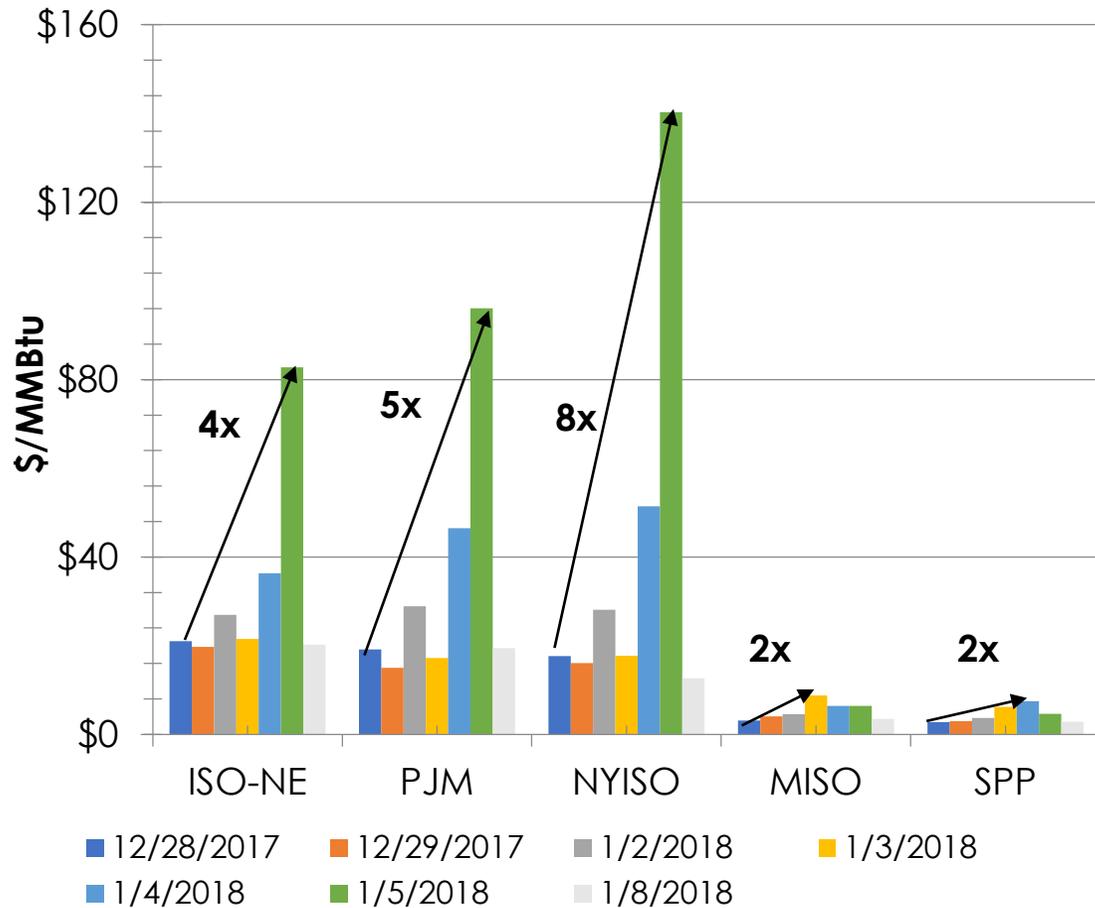


* 'Other' includes misc. categories, including other, refuse, solar, diesel, and multiple fuels

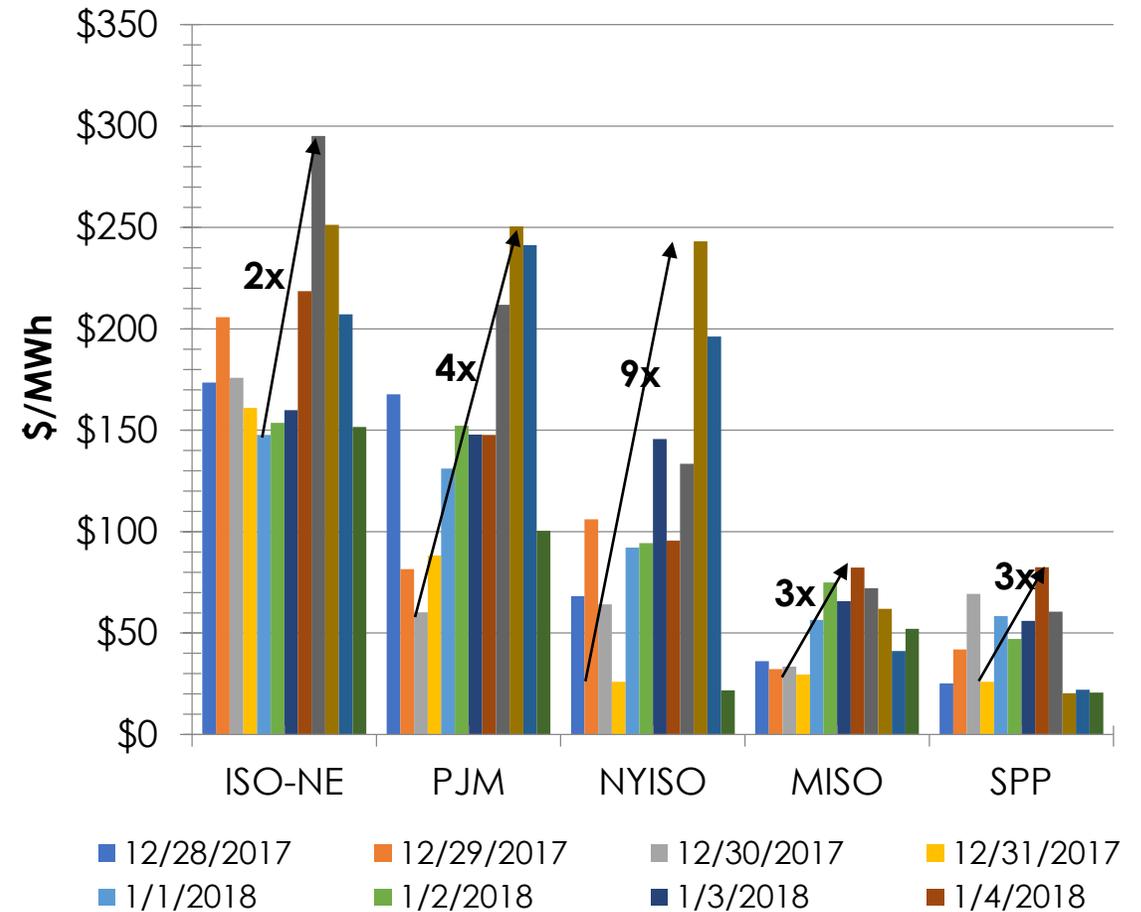
- Coal provided 55% of the incremental daily generation needed.
- Combined, fossil and nuclear energy plants provided 89% of electricity during peak demand.
- In PJM, the largest of the ISOs, coal provided the most resilient form of generation, providing 3X the increment from natural gas and 12X nuclear.
- Without all coal, PJM would have experienced shortfalls leading to interconnect-wide blackouts.
- Due to natural gas pipeline and delivery constraints, fuel oil provided almost all the surge capacity in the Northeast.
- Sharp increases in natural gas spot prices exceeded 300% across the Northeast and Mid-Atlantic, reaching \$140.25/MMBtu on January 5.

Gas and Power Price Spikes

**Regional natural gas spot prices,
December 28, 2017–January 8, 2018**



**Daily load weighted average marginal electricity price,
December 28, 2017–January 8, 2018**



Fossil Energy Is Critical In All Sectors





Center for Computational Science and Engineering JOULE 2.0

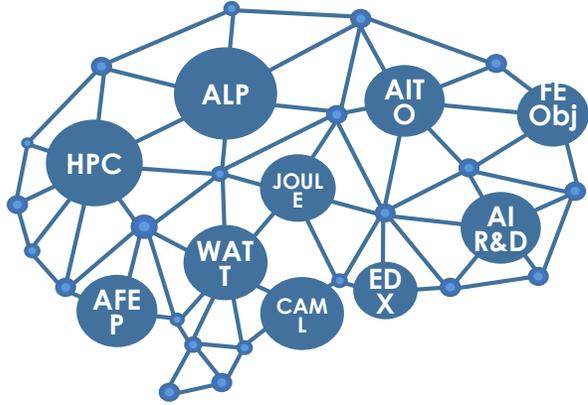
- At **3.6 petaflops** JOULE is the **10th fastest** supercomputer within DOE National Laboratories.
- This provides NETL researchers dedicated high-performance computational power to solve challenges in energy.



Center for Artificial Intelligence and Machine Learning WATT

- Links **104 GPUs** with **16 petabytes** of storage to provide unparalleled opportunities for the use of AI/ML to enable scientific discovery and R&D acceleration.

Science-Based Artificial Intelligence/ Machine Learning



Science-based Artificial Intelligence/Machine Learning Institute (SAMI)

Enables crosscutting applications
of science-based AI/ML within
the defense, aerospace,
automotive, security, health and
medical sectors.

A Three-Pronged Approach

- (1) Combine science-based modeling and AI/ML to address previously unanswerable problems or achieve fast, robust results.
- (2) Enhance data handling functions including curation, management, and transformation of data.
- (3) Research and accumulate AI/ML knowledge to establish standards and framework for energy AI/ML

PARTNERSHIPS

SAMI combines the strengths of NETL's fossil energy subject matter experts, computational scientists, and data scientists with those of experts in AI/ML at external institutions.

AI/ML for Deep Understanding and for Connecting Scales

AI/ML methods can provide scale-bridging models for transferring information between scales

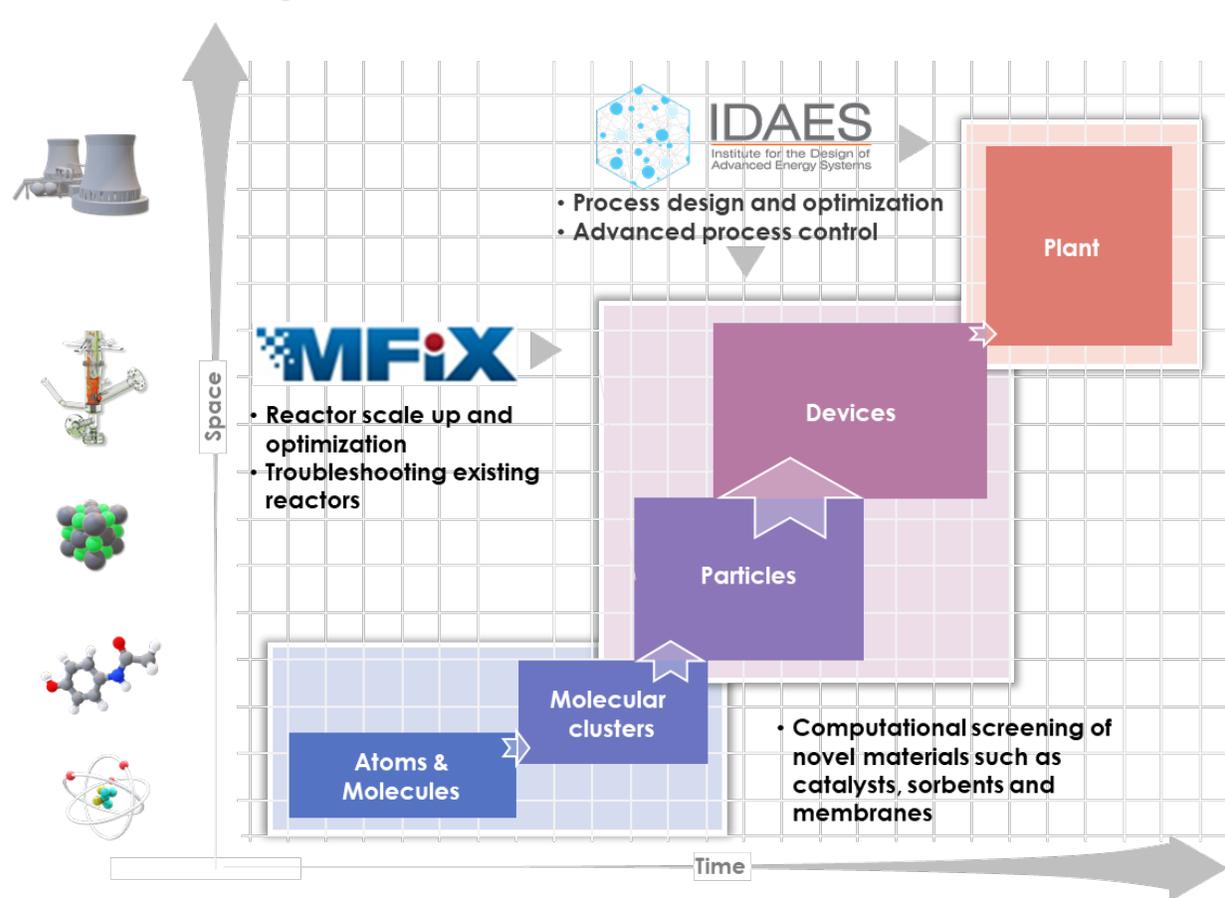
Deep understanding

Enabling domain scientists to extract knowledge from vast amounts of experimental or computationally generated data

Connecting scales

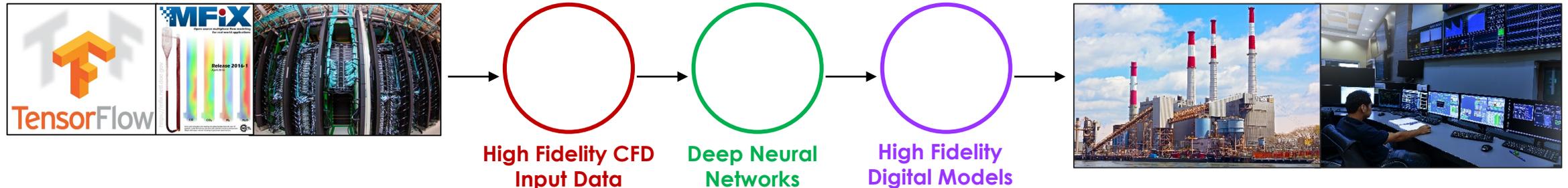
Multiscale simulations (atomic to process scale) is increasingly important to assist fossil energy technology development:

- Quantum mechanics-based simulation
- Classical mechanics-based simulation
- Mesoscale-based simulation
- Device-scale simulation
- Process systems simulation



AI/ML for power plant resiliency and reliability

- NETL is internationally recognized for detailed, scalable, high-speed single- and multi-phase computational fluid Dynamics (CFD) models to assess current—and redefine future—energy conversion processes.
- NETL is developing surrogate models based CFD for prognostics and diagnostics during powerplant operations



Dynamic spatial and temporal real-time hi-fidelity digital models running on standard computer platform used for prognostics and diagnostics during operations

Process Systems Engineering

DOE/NETL Flagship Multi-lab Computational Programs



Integrated Platform for Process Systems Engineering

Increasingly dynamic operations

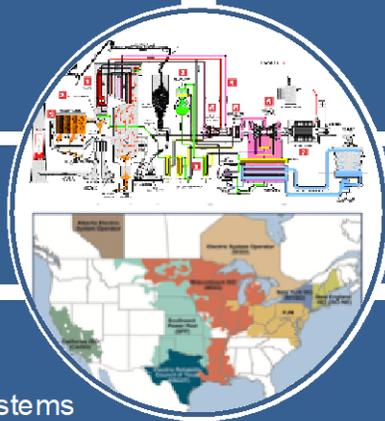
30+ years of progress in algorithms, hardware, modeling approaches

Greater linkages among scales

Advances in continuous nonlinear optimization (dynamics, uncertainty)

Support for innovative concepts, systems, and technologies:
Process Intensification; Hybrid Systems

Advances in discrete optimization (algorithms and formulation)



[Open Source Release: github.com/IDAES/idaes-pse](https://github.com/IDAES/idaes-pse)



Reducing technical risk associated with scale-up

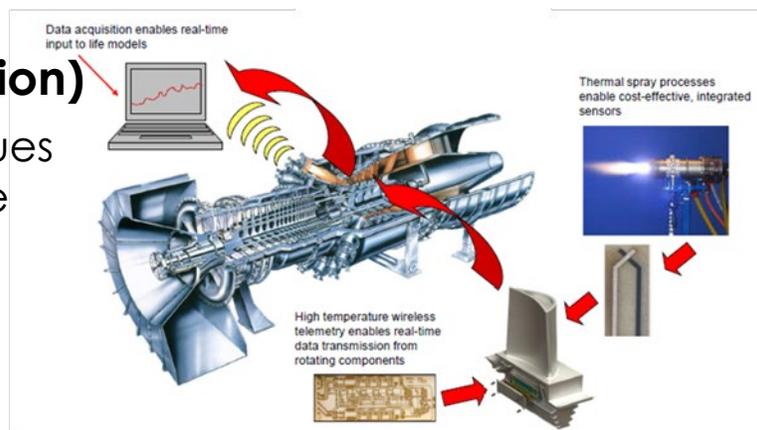


Extramural Efforts & Collaborations

OPERATIONS-BASED ASSESSMENT

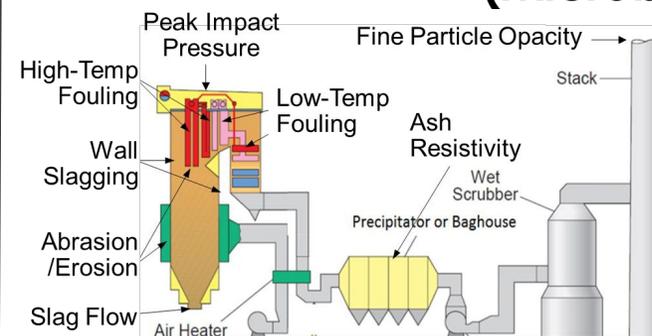
(Siemens Corporation)

AI-based techniques for component life estimation and enabling design improvements



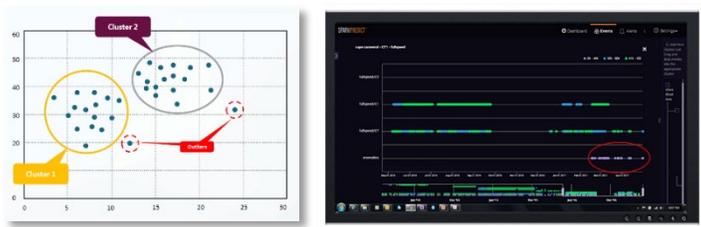
CONDITION-BASED MONITORING

(Microbeam Technologies)



Improve boiler performance and reliability through the integrated use of condition-based monitoring and AI predictions of the impacts of coal quality

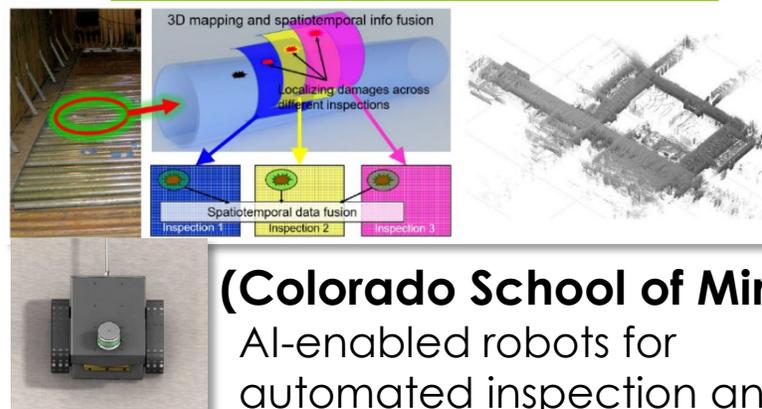
COMPONENT HEALTH MONITORING



(SparkCognition)

Unsupervised techniques for understanding operational conditions and flagging anomalies

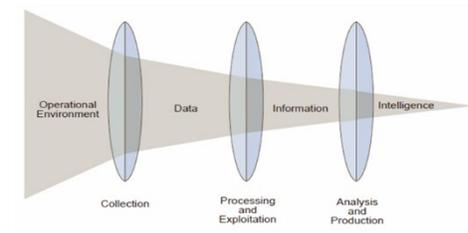
DIAGNOSTICS & INSPECTION



(Colorado School of Mines)

AI-enabled robots for automated inspection and repair of boiler furnace walls

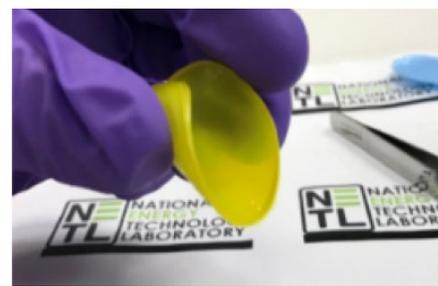
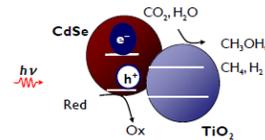
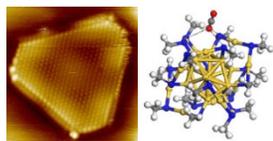
CYBERSECURITY



(Southern Company)

Protect power systems by melding IT/OT sensor and platform information, data analytics, & AI

Atomistic Design and Discovery to Pilot Plant Demos



DESIGN & SYNTHESIS

CHARACTERIZATION

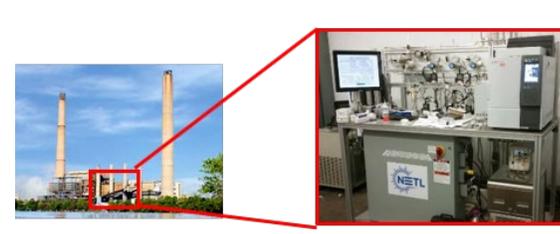
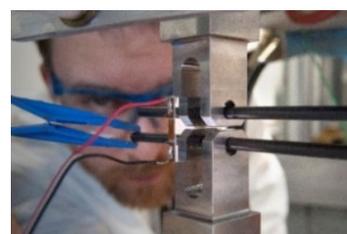
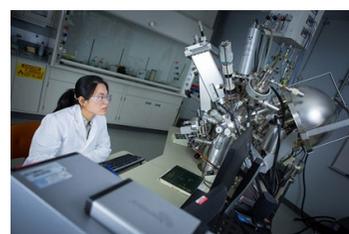
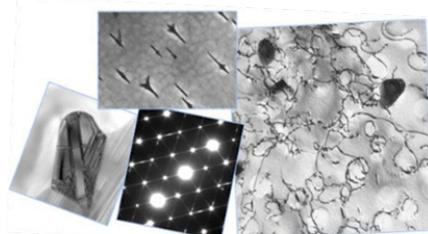
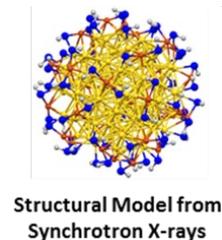
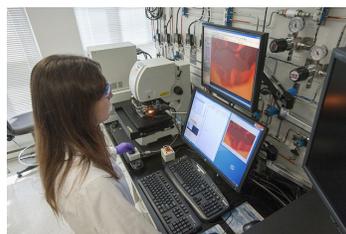
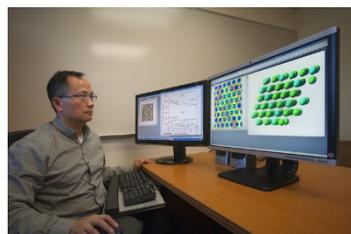
MANUFACTURING

TECHNOLOGY
DEPLOYMENT

SCIENCE & DISCOVERY

LAB EVALUATIONS AT CONDITION

FIELD TRIALS



Advanced Alloy Development and Manufacturing

Affordable, durable advanced alloys

Materials Challenges

- Higher Temperatures, Higher Pressures, Corrosion & Oxidation → Extreme Environments
- Large Components → Manufacturability
- Long Service Life Span >100,000 hrs → Durability
- Penetration of Renewable → Cycling Operational Conditions

Research Focus at NETL

- Increase temperature capability and service-life by improved alloy design and manufacturing
- Computational Materials Engineering guide development
- Demonstrate concepts at scales relevant to industry
- Heat-Resistant Steels
- Nickel-Base Superalloys
 - AUSC: cast versions of wrought alloys & adapting aerospace alloys
 - Increase γ fraction/solvus of commercial alloys
 - High-entropy matrix Ni-based superalloy
 - Grain boundary re-design of commercial alloys
- High Entropy Alloys
- eXtremeMAT

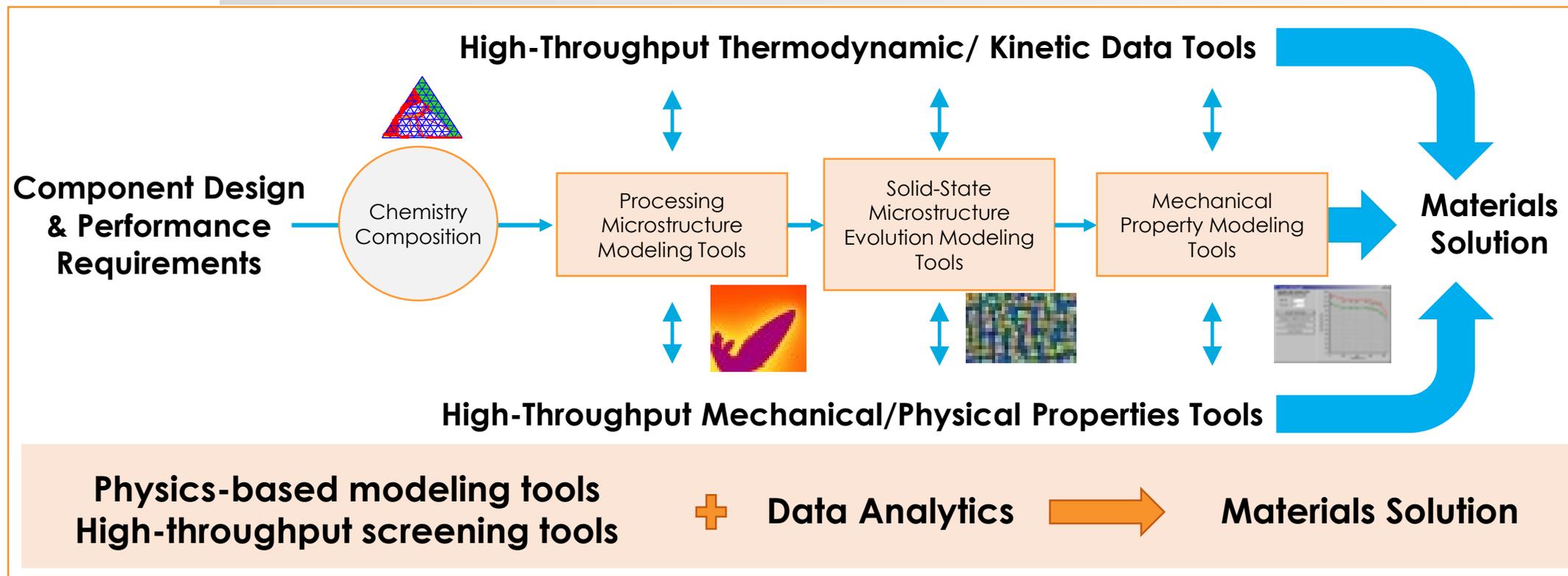
Advanced Alloy Development Facility

Creates facility for U.S. industry, DOE labs, other government agencies, and academia to prototype alloy solutions, bridging the “valley of death” and accelerating commercialization.



Computational Materials Discovery & Experimental Validation

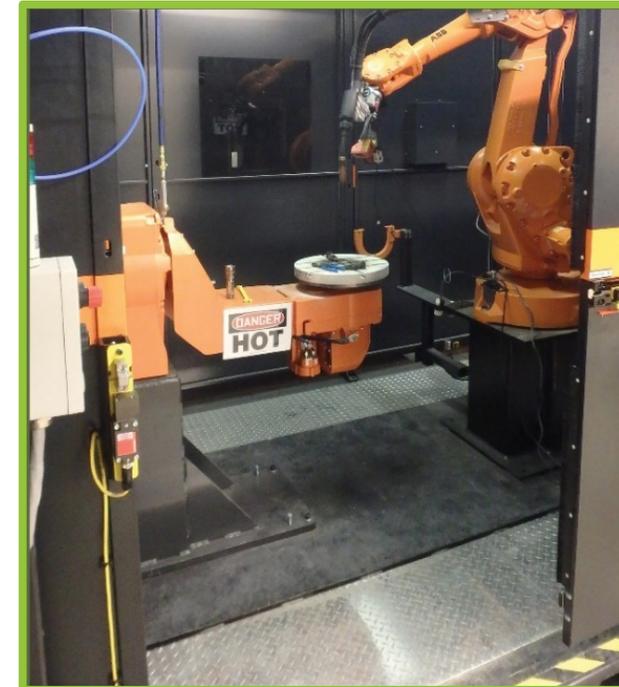
eXtremeMAT **Research Goal** Develop method & framework for accelerating introduction of new materials into existing & advanced energy systems.



Additive Manufacturing of Power Plant Alloys Enable Testing and Modeling

Wire + Arc Additive Manufacturing (WAAM)

- A promising advanced manufacturing technique was used to fabricate coupons for testing from two different alloys:
 - *Grade 91 – a popular creep strength enhanced ferritic alloy*
 - *Inconel 740H – a nickel-based superalloy designed to withstand advanced ultrasupercritical steam conditions*
- Multiple coupons of each alloy were fabricated for evaluation, each with different building parameters, such as
 - *Electric current*
 - *Travel speed*
 - *Wire feed rate*
 - *Coupon width*
- Microstructure and various properties of the coupons were characterized.
- Information will be used in future work to benchmark an integrated computational materials engineering model for alloys with a graded structure.



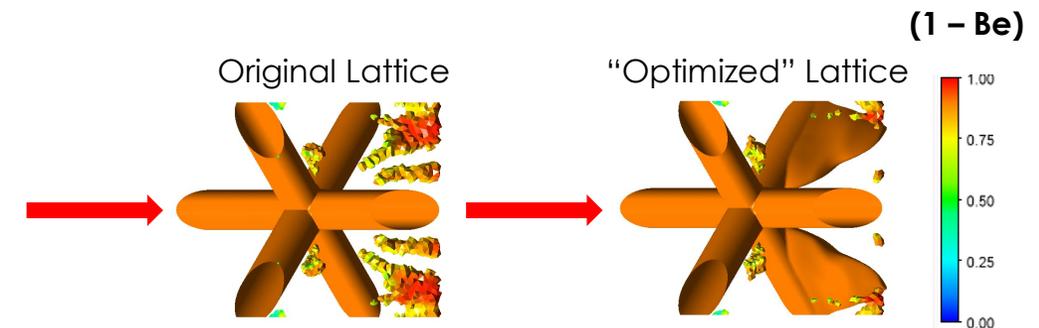
Integrated Transpiration and Lattice Cooling Systems Developed by Additive Manufacturing with Oxide-Dispersion Strengthened (ODS) Alloys

Advanced thermal protection innovation

- Advanced turbine development calls for higher efficiency with high turbine inlet temperature.
- The primary goal of this research is to develop an innovative approach to provide an improved level of thermal protection for turbine airfoils, based on the integrated transpiration and internal cooling concept.

Recent Accomplishments

- Identified configurations suitable for optimization to maximize effectiveness of transpiration and internal cooling using lattice structures.
- Developed a successful approach to produce ODS powder suitable for AM and lattice structures.
- Developed an optimization algorithm and integrated new unit-types into the algorithm to optimize lattice structures for internal cooling.
- Developed a successful approach to make ODS structures for integrated transpiration and internal cooling.



Contours of loss parameter (1-Be) illustrating locations where entropy has been decreased through optimization of the lattice structure for internal cooling of turbine components.

NETL uses energy conversion technologies to support the development of transformational processes, including:

- Non-thermal chemical conversion
 - *Microwave, radio frequency, and laser energy to control or modify traditional catalytic reactions*
- sCO₂ power cycles
 - *High-efficiency alternative to steam power for fossil, nuclear, and concentrated solar power*
- Compound cycles
 - *High efficiency and flexibility from combinations of turbine/piston/fuel cells*
- Modular gasification
- Advanced thermal storage
 - *Low-cost demand response by non-electrical energy storage*

Microwave Reaction Chemistry

Significantly improves the energy efficiency of industrial processes, increasing selectivity, and enabling scalable and distributed low carbon applications.

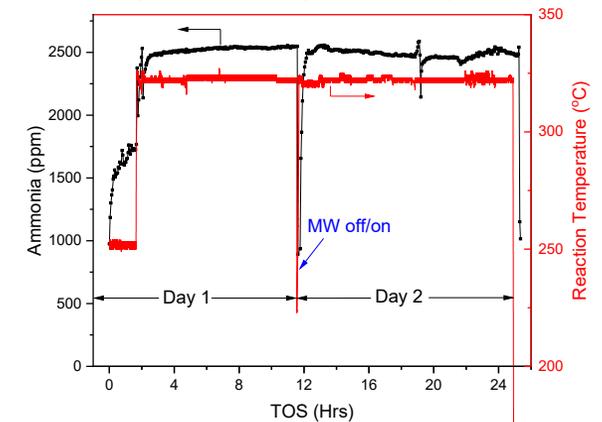


Microwave Reaction Chemistry

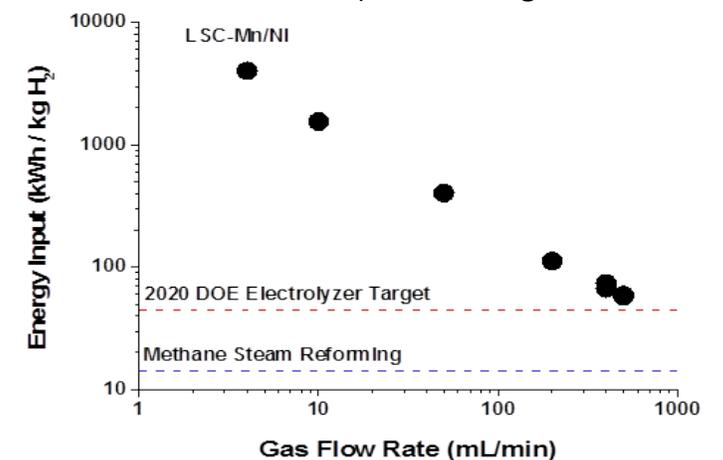
- Microwave catalysis technology has the potential to be the next frontier of science in the chemical process industry & manufacturing industries
 - Process intensification
 - Modular and distributed solutions
 - Rapid Startup/shutdown
 - Enhanced reaction rate and selectivity
- Enables electrification of chemical production
 - NETL microwave technology development can play a particular role in natural gas utilization by providing processes for conversion of methane to value added chemicals
 - Potential for significant energy efficiency improvement, energy productivity, and capital cost reduction for converting natural gas to aromatics and olefins in a single-step process
 - Potential viability of dry methane reforming for distributed production of Blue Hydrogen production from natural gas and captured CO₂
 - Potential for viability of on-demand production of ammonia from natural gas with variable and intermittent energy sources



Ammonia synthesis: rapid startup/shutdown



Methane Dry Reforming



Optimizing Reaction Science for Energy Conversion



NETL's ReACT Facility

State-of-the-art (>6000 sq ft) laboratory with a focus on Transformative Chemical Reaction Science

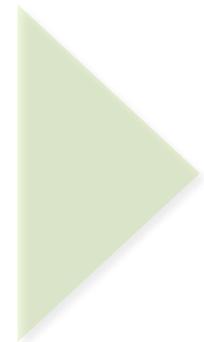
Facility Features

Fuel flexible – gaseous hydrocarbon fuels, coal, liquid hydrocarbon fuels, biomass, coal and biomass mixtures, and syngas

Equipped with advanced diagnostics – high-speed imaging, thermal imaging and online gas analysis

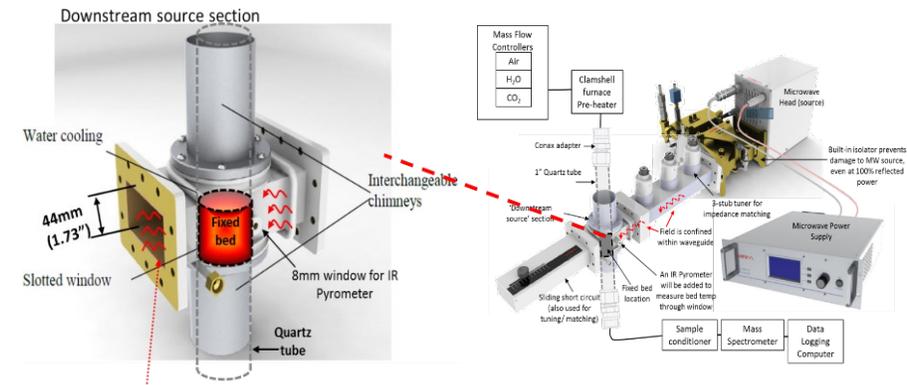
Wide range of Temperature & Pressure (1000°C/600 psi)

Fully automated 24/7 unattended operations



- Increase power cycle efficiency
- More power generation for less fuel
- Fewer emissions
- Optimize chemical reactor designs for specific chemical transformations

No other known facility in the world has this capability



Accomplishments

- ✓ Stakeholder input (Request for Information)
- ✓ 13 Concept Studies performed
- ✓ Seven Pre-FEED Studies completed in April/May 2020

Pre-FEED Study deliverables posted here:

<https://netl.doe.gov/coal/tpg/coalfirst/concept-reports>

- ✓ Selected 7 R&D projects for components of promising systems of future coal plants

Announcement:

<https://www.energy.gov/fe/articles/foa-2057-project-selections>

- ✓ FOA-0002180 for Design Development and FEED Studies Released

Announcement:

<https://www.energy.gov/fe/articles/foa-2180-issuance>

Next Steps

- Award FEED studies
Fall/Winter 2020

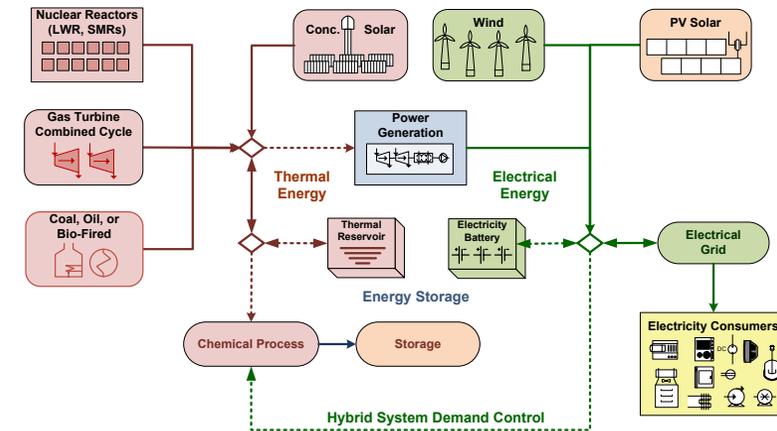


DOE Initiatives

Tri-Lab & Grid Modernization Lab Consortium

Tri-Lab

- Integrated systems analysis, modeling, and optimization.
- Integrated systems engineering, development, and testing.
- Innovative, core multisector and multiprogram technologies.
- Approaches for security and resilience of integrated energy systems.



Tightly Coupled Hybrid Energy Systems



Grid Modernization Lab Consortium

- A strategic partnership between DOE and 13 National Laboratories to bring together leading experts and resources to collaborate on national grid modernization goals.
- Hybrid system design, optimization, and analysis.
- Resilience modeling.



Established & Expanding Partnerships



An Active Portfolio from Concept to Market Readiness

600+ partnerships with industry, academia & govt organizations

900+ research and development 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>

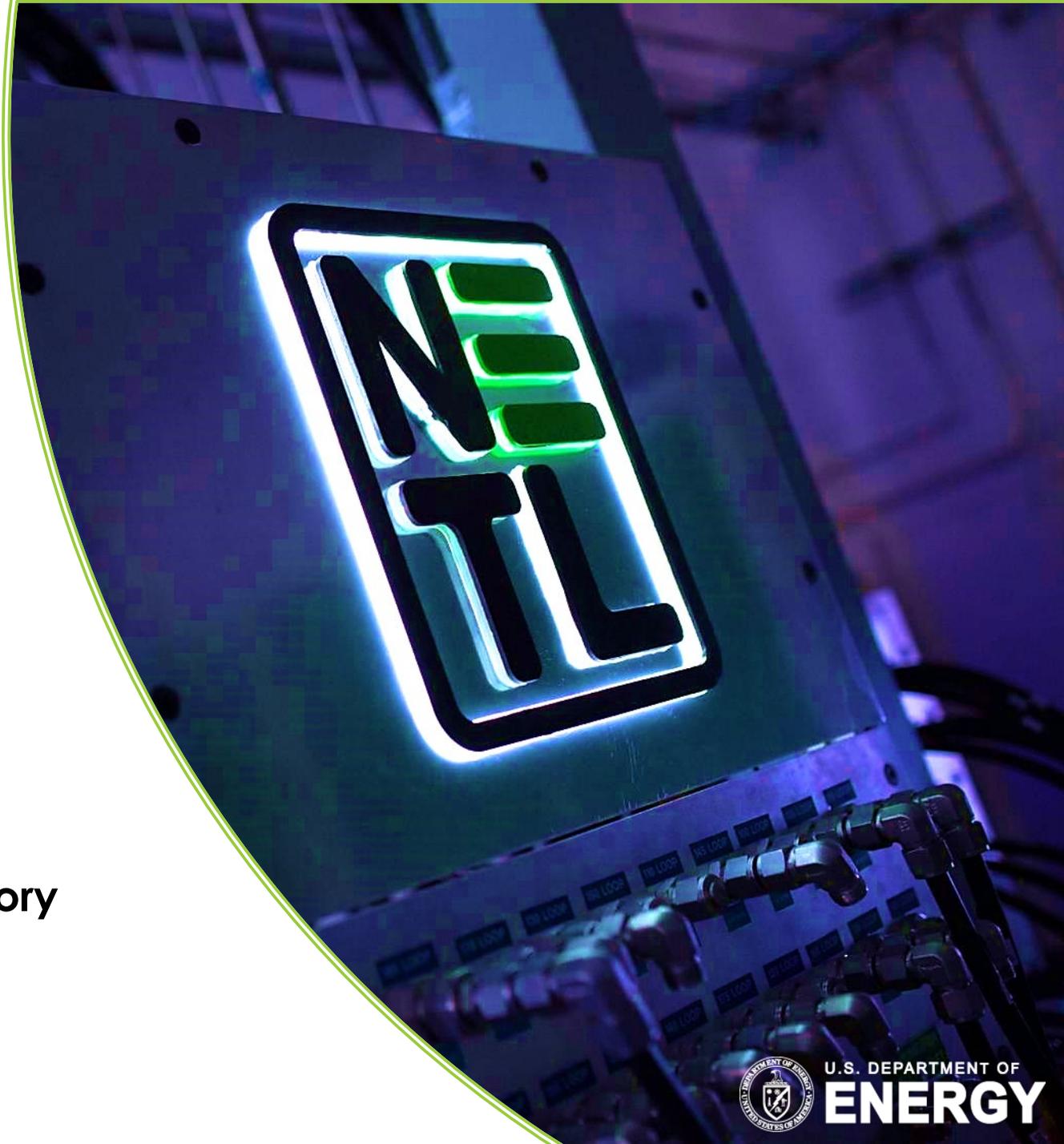
Thank You!

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