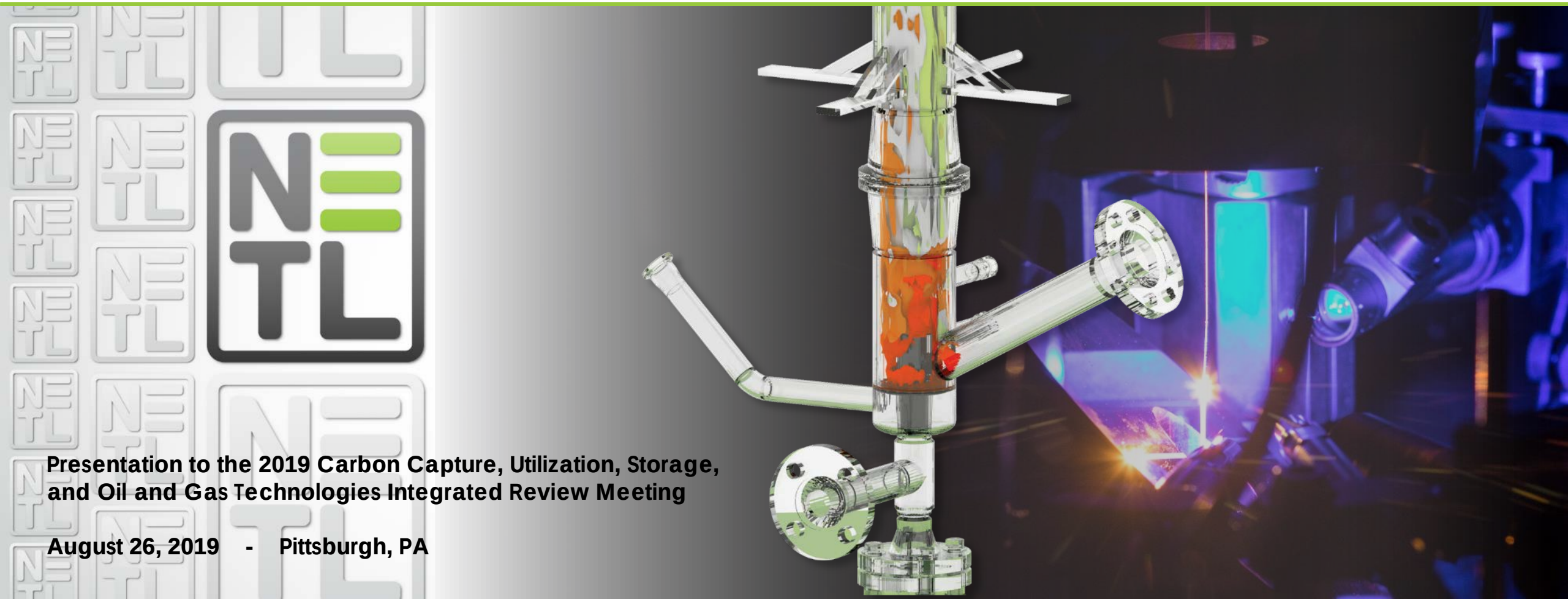
Driving Innovation and Technology Development for Carbon Capture, Utilization, Storage, and Oil & Gas

Solutions for Today | Options for Tomorrow

Brian J. Anderson, Ph.D.
Director



Presentation to the 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

August 26, 2019 - Pittsburgh, PA

MISSION

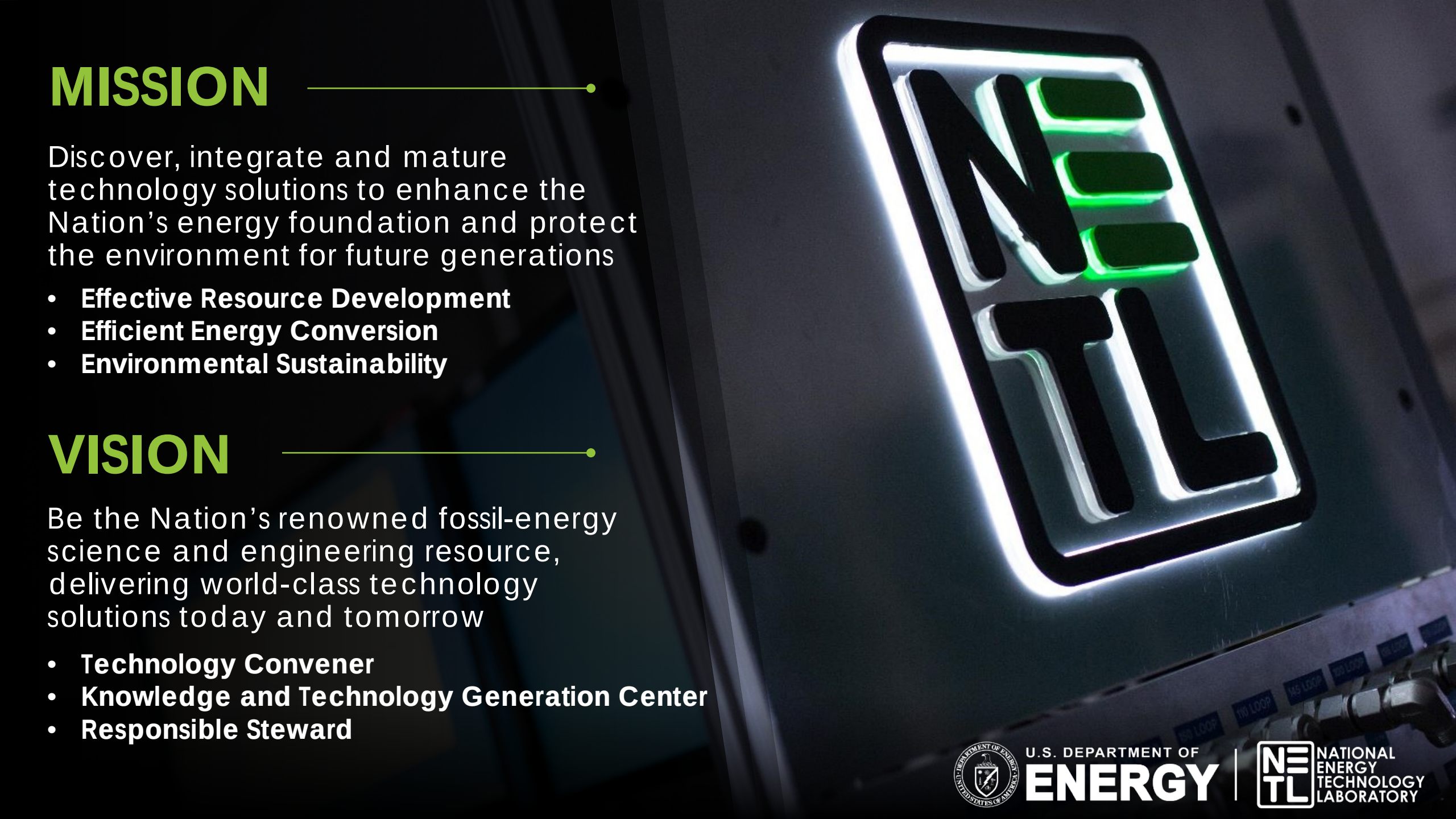
Discover, integrate and mature technology solutions to enhance the Nation's energy foundation and protect the environment for future generations

- **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**



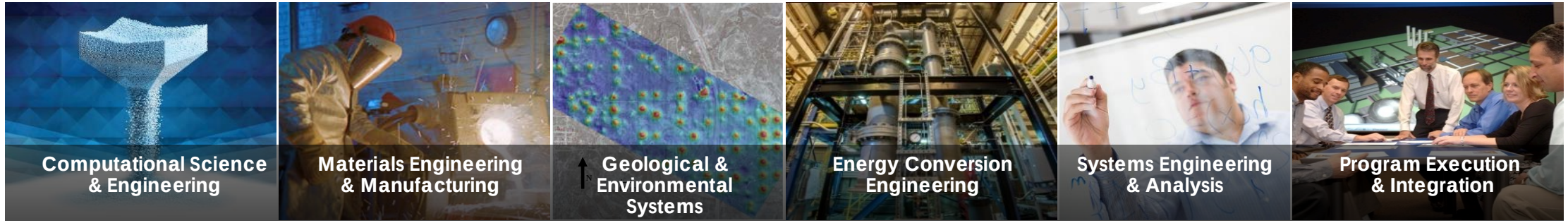
U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Fossil Energy Is Critical In All Sectors

EIA, Annual Energy Outlook 2017, Reference Case
https://www.eia.gov/totalenergy/data/monthly/pdf/flow/css_2017_energy.pdf

Core Competencies & Technology Thrusts

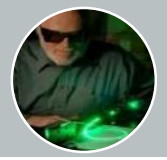
NATIONAL ENERGY TECHNOLOGY LABORATORY



Carbon Storage

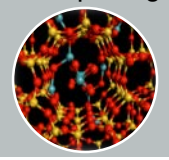
Carbon Capture

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

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.

Oil & Gas Technology Thrusts

Onshore Unconventional

Developing technologies to maximize resource recovery and reduce operational impacts in unconventional oil & gas plays.

Gas Hydrates

Characterizing gas hydrate resources and developing ways to tap their massive energy potential.

Offshore

Minimizing the environmental impacts of deepwater and ultra-deepwater oil & gas production.

Natural Gas Infrastructure

Developing technologies and practices to assess and mitigate methane emissions from natural gas transmission, distribution, and storage facilities.

EERE, OE and CESER Technology Thrusts

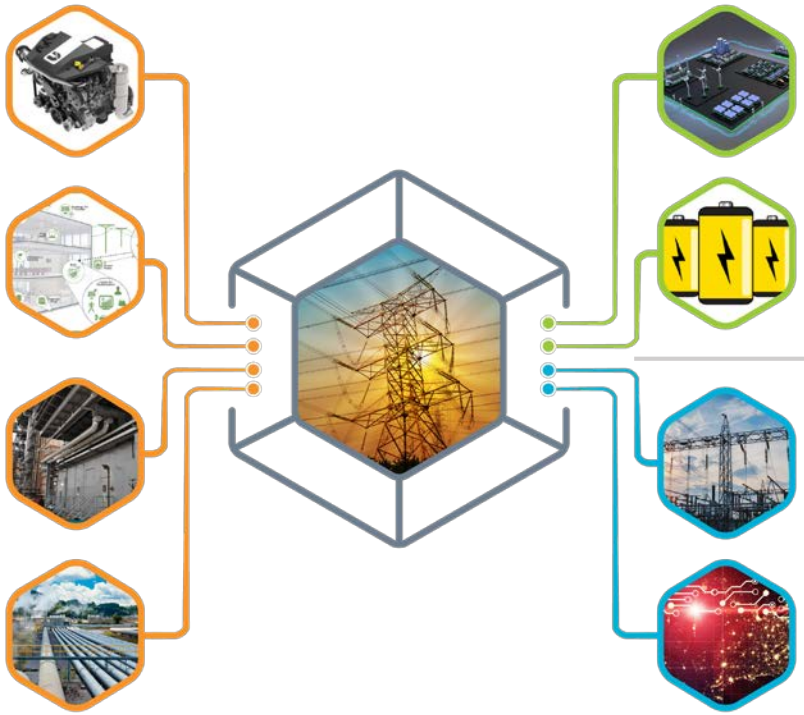
ENERGY EFFICIENCY & RENEWABLE ENERGY (EERE)

Vehicle Technologies

Building Technologies

Advanced Manufacturing (Combined Heat & Power)

Geothermal Technologies



OFFICE OF ELECTRICITY (OE)

Advanced Grid R&D

Transmission Permitting and Technical Assistance

CYBERSECURITY, ENERGY SECURITY, AND EMERGENCY RESPONSE (CESER)

Infrastructure Security & Energy Restoration

Cybersecurity for Energy Delivery Systems

Helping to Implement DOE & Gov't Programs for 25+ Years

- Office Construction Management
- Environmental Management
- Legacy Management
- Dept of Homeland Security
- Dept of Defense

Technical, Admin., Project Management Support

- Documented Procedures and Policies
- Disciplined Process w/Tracking

Implementation Mechanisms

- Acquisition (contracts)
- Financial Assistance (can only be awarded by Federal personnel)

NETL Budget

FY19 Budget
$991M

Coal Program

Carbon Capture	$101M
Carbon Storage	$ 98M
Adv. Energy Systems	$130M
Crosscutting	$ 56M
NETL Coal R&D	$ 36M
Rare Earth Elements	$ 18M
STEP	$ 22M
Transform. Coal Pilots	$ 25M

Oil & Gas Program

Natural Gas Tech.	$ 51M
Unconvent. FE Tech.	$ 46M

FE Program Support

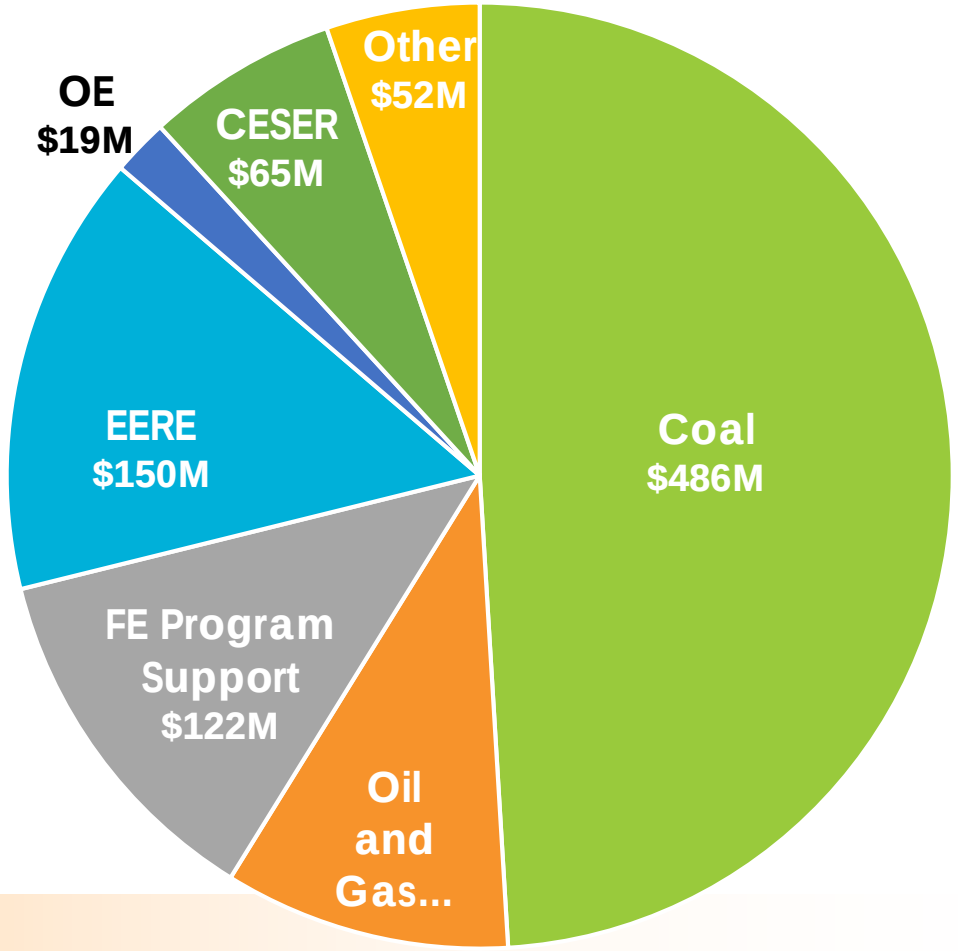
Program Direction	$ 27M
NETL Research & Ops.	$ 50M
NETL Infrastructure	$ 45M

Non-Fossil Programs

EERE	$150M
OE	$ 19M
CESER	$ 65M

Strategic Partnerships

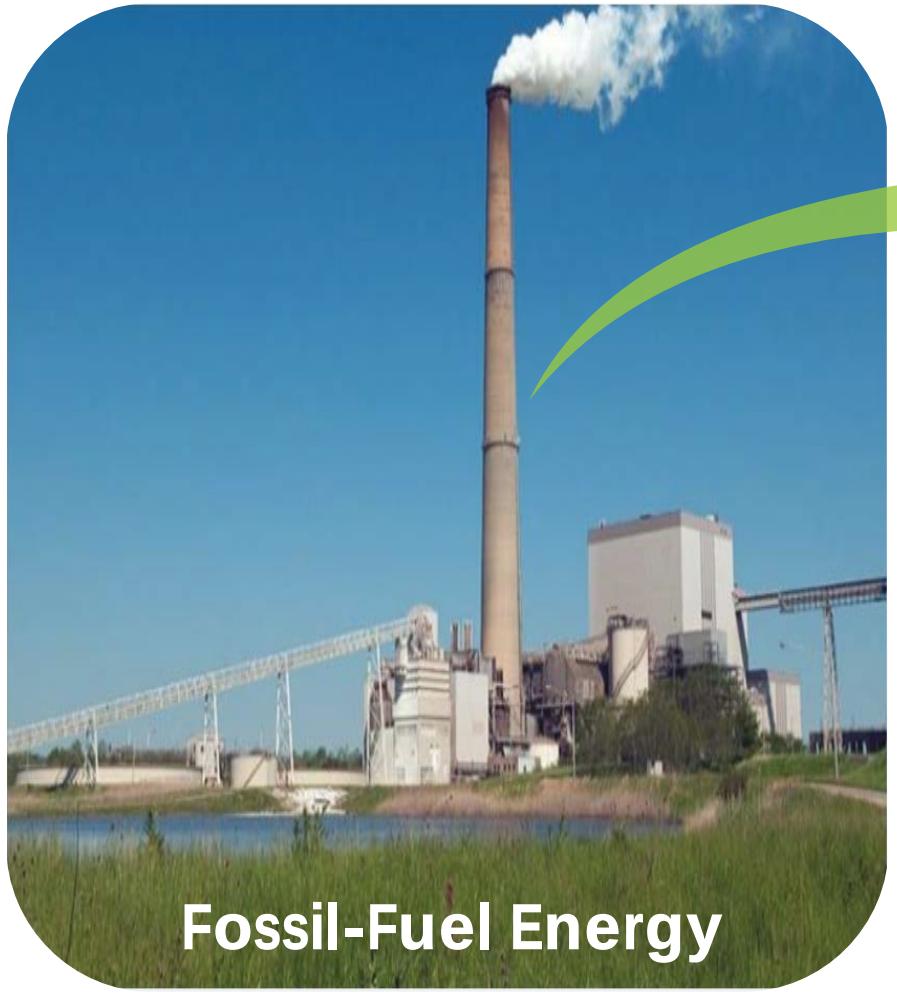
Other	$ 52M



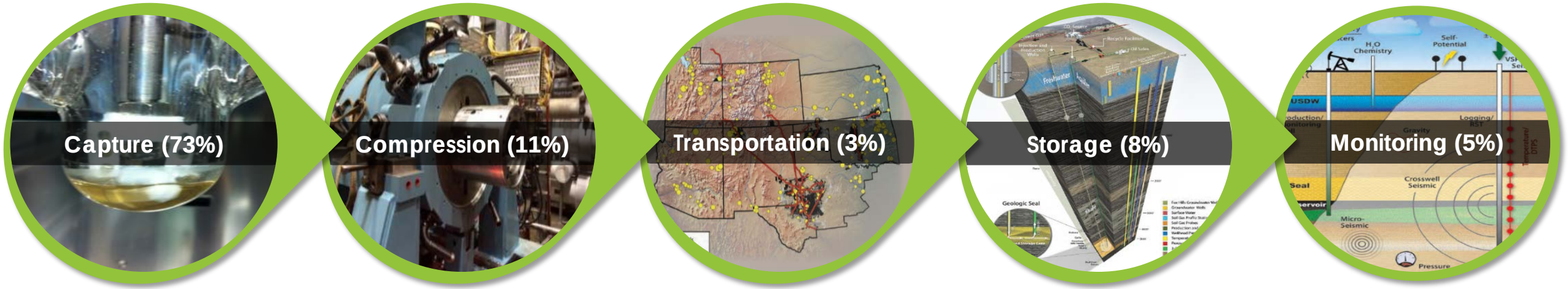
CCUS and O&G programs make up ~30% of NETL's Budget

Carbon Capture, Utilization and Storage (CCUS)

Program Areas



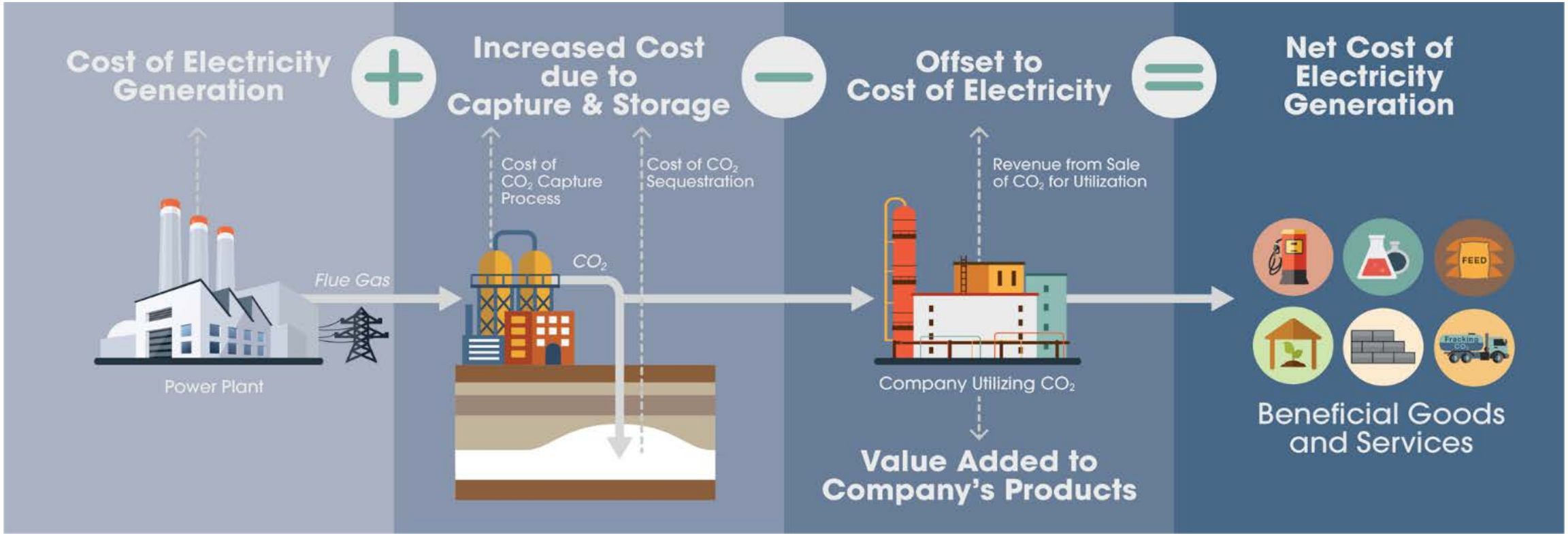
Carbon Capture and Storage Value Chain



Source: NETL, Cost and Performance Baseline for Fossil Energy Plants, Revision 3, July 2015

Carbon Utilization is Market Driven

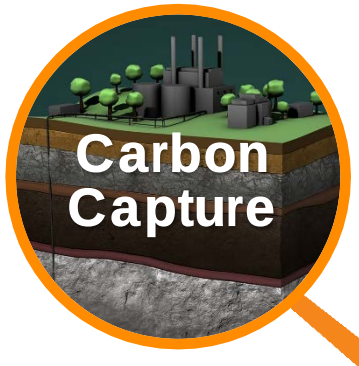
CO_2 Utilization Can Offset CCS Power Generation Costs



A consumer purchases a product, which is produced using CO_2; the manufacturer of the product requires CO_2, which was captured and purchased from a plant that emits CO_2. It may be financially attractive for either the generator or user to pay other parties to capture, purify, or transport the CO_2.

Future Commercial-Scale Deployment

Integrated R&D Approach



2017
Large Capture Pilots Initiated

2020
R&D Completed for Carbon Capture 2nd Generation Technologies

2025
Integrated CCS Projects Deployed

2035
Transformational Technologies Available for Deployment

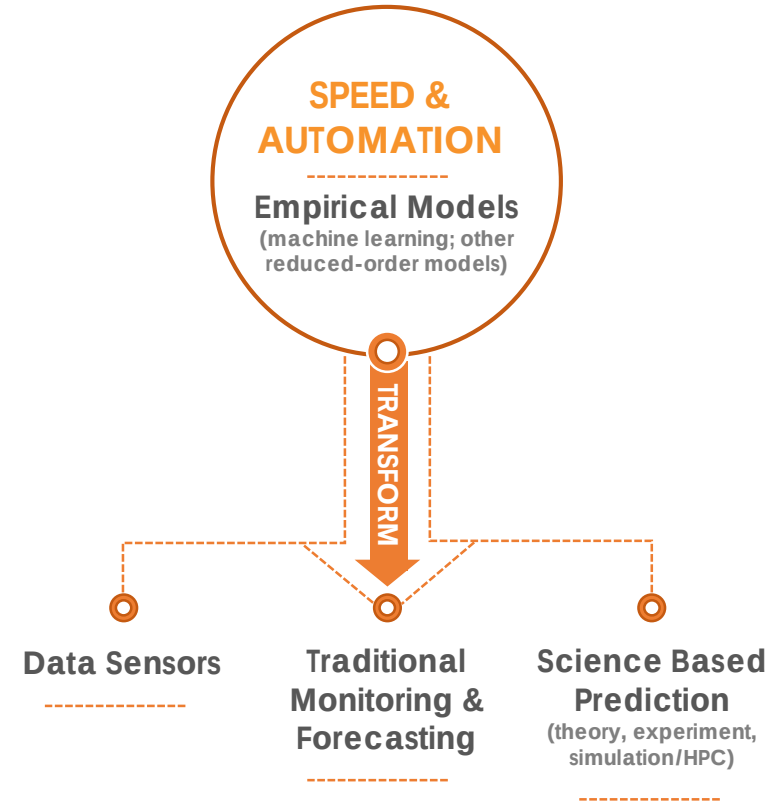
2017
Initiate Storage Feasibility for Integrated CCS

2022
Commercial-scale Storage Complexes Characterized

Deployments

How can machine learning transform subsurface operations?

Machine learning extracts knowledge from complex data rapidly



Traditional methods are robust but slow.

Speed: Machine learning captures complex systems behavior through complex but rapid empirical models.

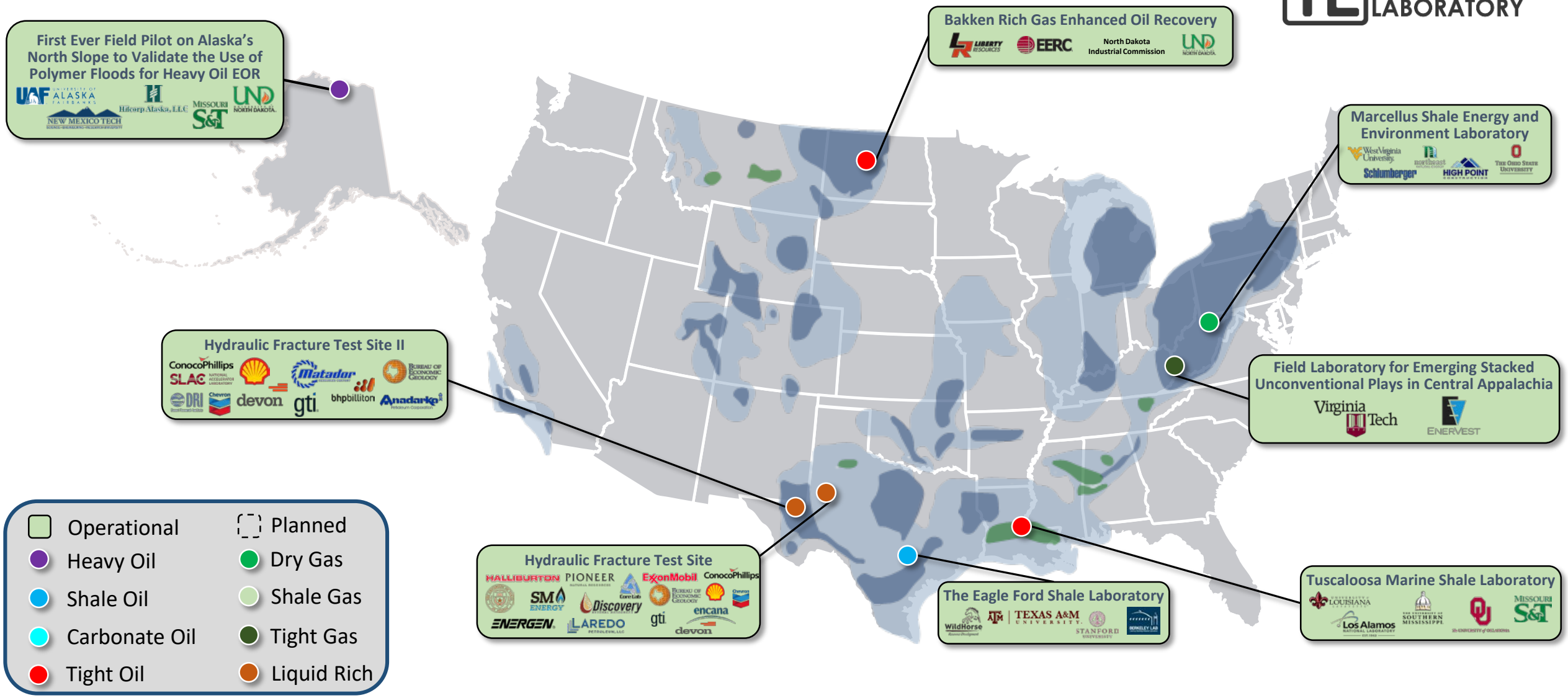
- Provides knowledge in time to inform a decision.
- Enables previously impractical applications, like virtual learning, real-time visualization, and real-time forecasting.

Lower Cost: Machine learning converts data to knowledge with minimum expert labor, dramatically lowering cost of processing monitoring data.

Automation: Machine learning with sensor and control systems can improve efficiency in reservoir management.

Risk Assessment: Machine learning helps enable uncertainty quantification, which can improve risk management

Current Field Laboratory Locations



Real-Time Control in the Subsurface

A Three Pronged Approach

Rapid Data to Knowledge

Autonomous Monitoring

Vision: Enable the extraction of more information at lower cost from subsurface environments via smart sensor systems, edge–cloud analysis platforms, etc.

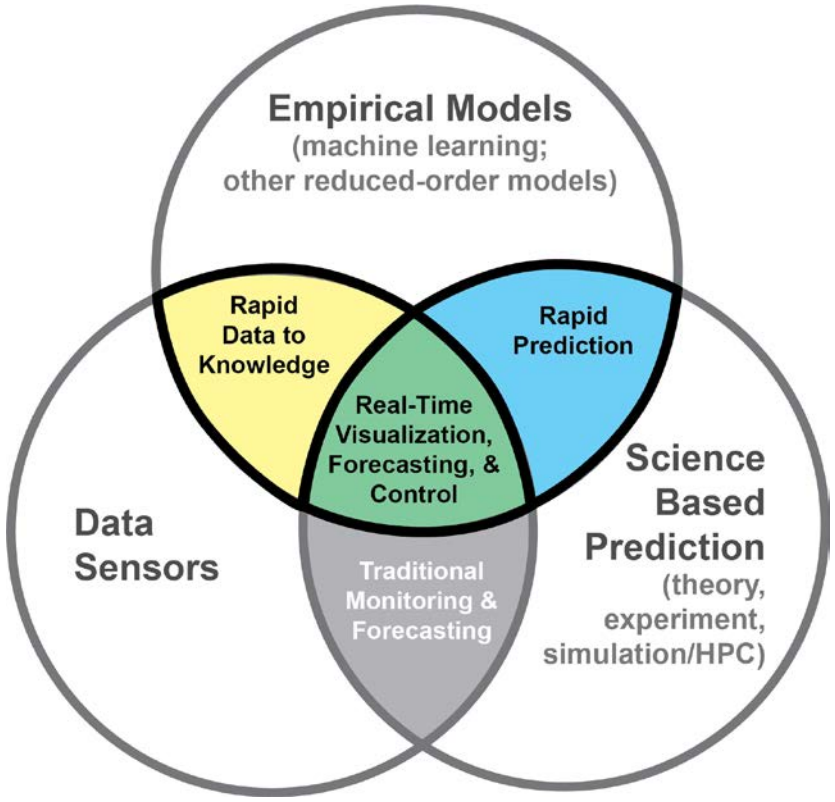
Big Data Management

Vision: Generate protocols and tools to allow access, transfer, curation, quality control, and maintenance of public and private datasets.

Rapid Prediction

Virtual Learning

Vision: Enable a virtual learning environment for exploring and testing strategies to optimize reservoir development, management, & monitoring prior to field activities.



Real-Time Visualization

"CT" for the Subsurface

Vision: Transform reservoir management via dramatic improvements in subsurface visualization, exploiting ML to achieve speed and enhanced detail.

Real-Time Forecasting

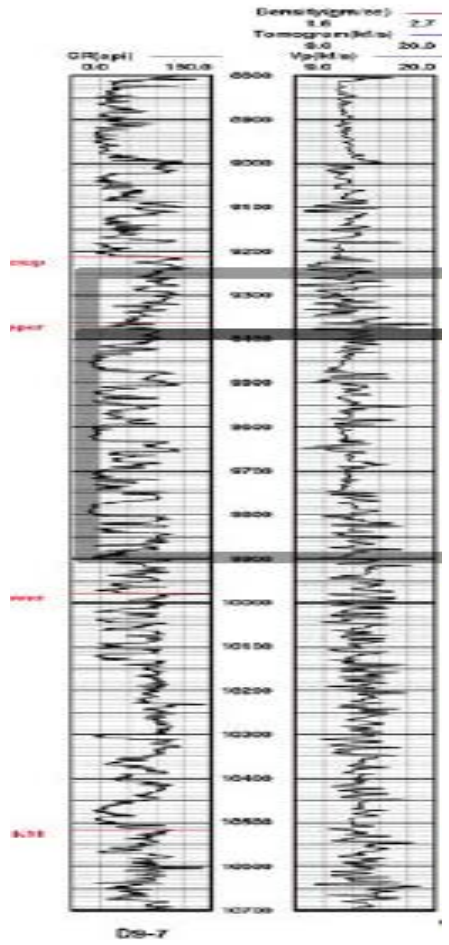
"Advanced Control Room"

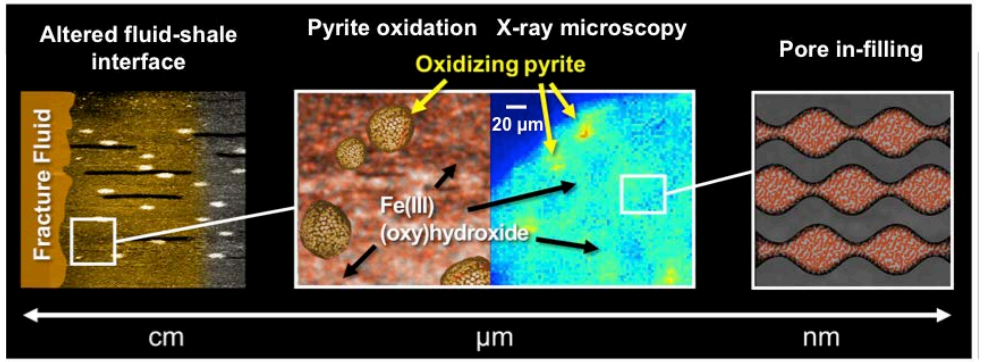
Vision: Transform "human-in-the-loop" decisions on reservoir management by rapid visualization of forecasted behavior for different operational decisions.

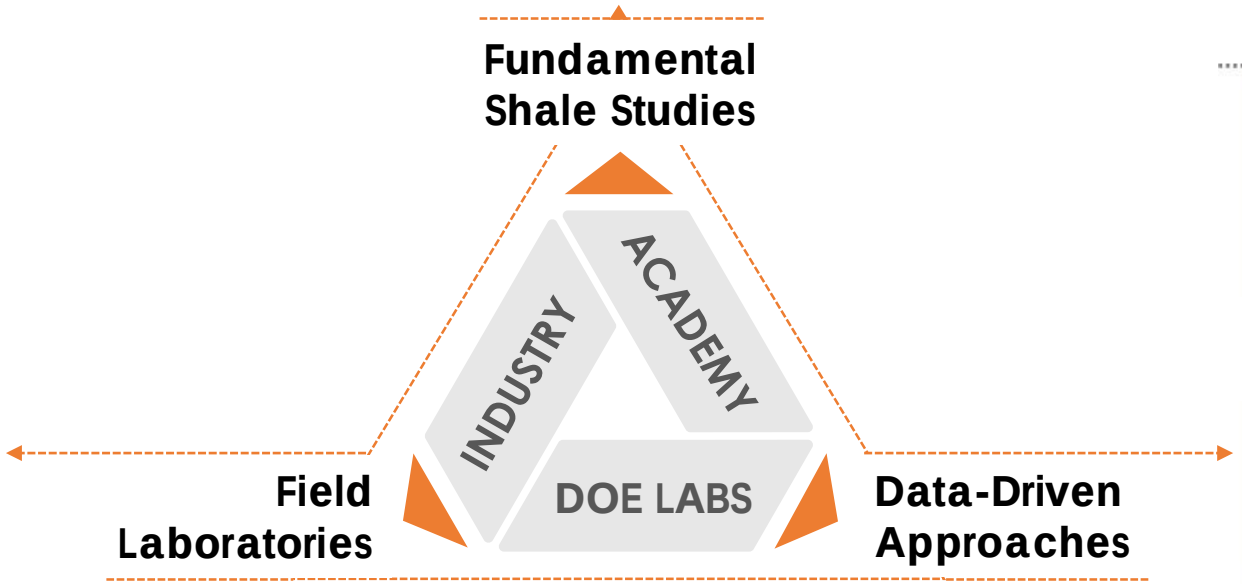
Common FE Vision for Exploiting Machine Learning to Transform Subsurface Operations

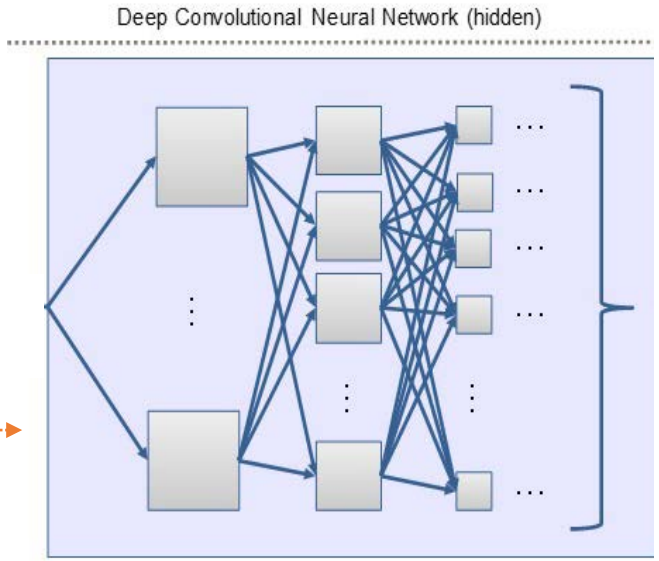
Intelligent Oil & Gas Infrastructure

Integrating fundamental studies, field labs, and machine learning









Methane Hydrates

Program Mission

- Advance scientific understanding of methane hydrates as they occur in nature.
- Develop tools and technologies to safely produce methane hydrates as a viable energy source.
- Collaborate with partners (industry, academia, and international agencies) to better characterize resource potential.

Challenges

- Incomplete characterization of the scale of the resource.
- Difficulty in developing commercial-scale production capabilities in methane hydrate locations (deepwater and onshore Arctic).

Current Research Thrusts

- Complete resource characterization and assessment in the Gulf of Mexico.
- Evaluate and demonstrate methane hydrate exploration and production technologies in the Alaskan North Slope.

Technology Development Pathway

An Active Portfolio from Concept to Market Readiness

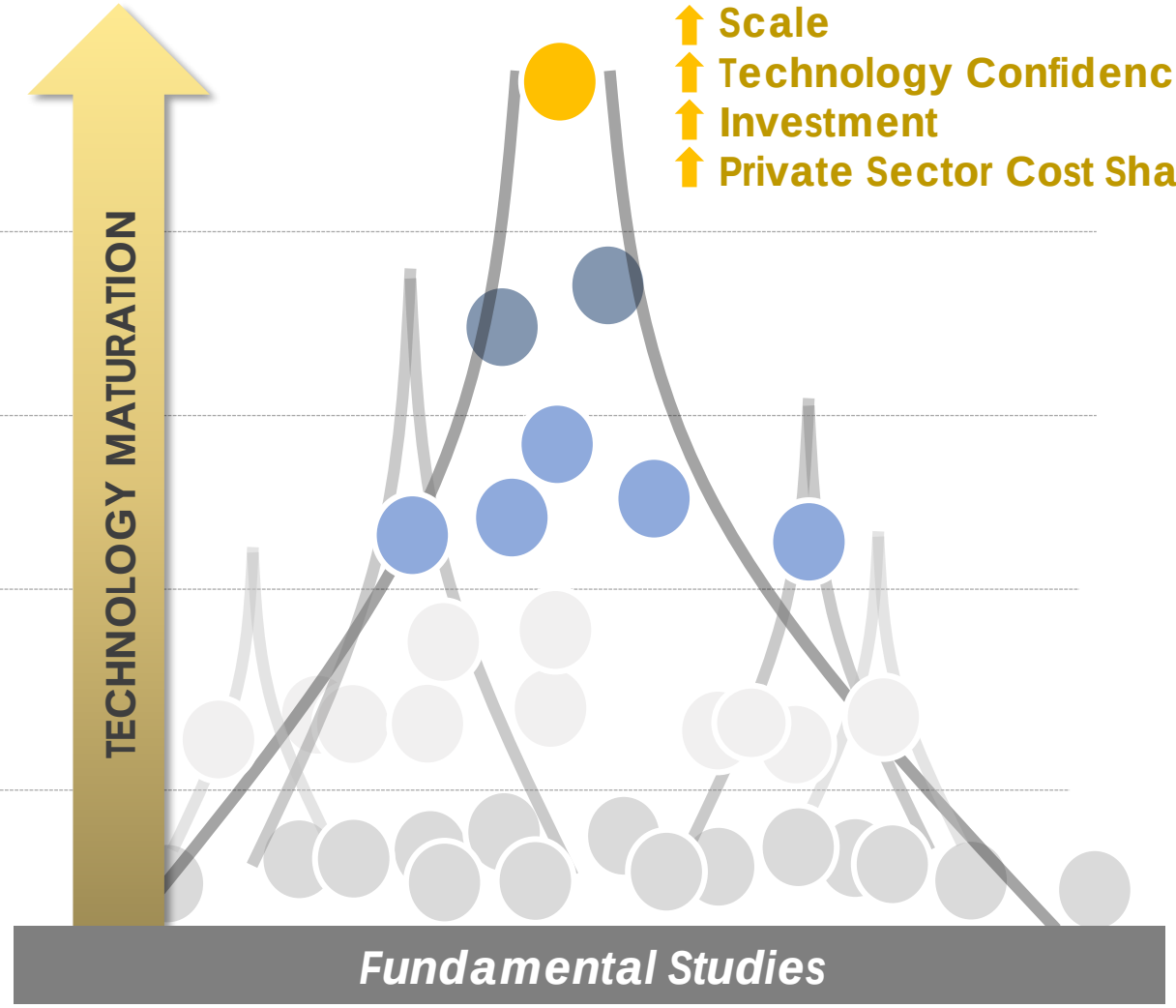
COMMERCIALIZATION
Technology available for wide-scale market use

DEMONSTRATION
System demonstrated in operational environment

SYSTEM TESTING
System performance confirmed at pilot-scale

DEVELOPMENT
Technology component validated/integrated

DISCOVERY
Concept identified/proven at laboratory-scale



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

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 Amethyst Research Incorporated · XTALIC · SOTACARBO Sustainable Energy Research Centre · Sporian Microsystems, Inc · VIONX ENERGY · PSE · Liquid Ion Solutions · DERP TECH Distributed Electric Renewable Power · ATREX ENERGY Powerful Possibilities · REDOX Redox Power Systems, LLC

ACADEMIC PARTNERSHIPS

LSU · Virginia Tech · University of Wyoming · USC University of Southern California · Case Western Reserve University think beyond the possible · West Virginia University · University of Pittsburgh · University of Alaska Fairbanks · Texas A&M University · UK University of Kentucky · Penn State 1855 · Iowa State University · Princeton University · Carnegie Mellon University · Clemson University South Carolina 1889 · Oregon State University OSU

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!

VISIT US AT: **www.NETL.DOE.gov**

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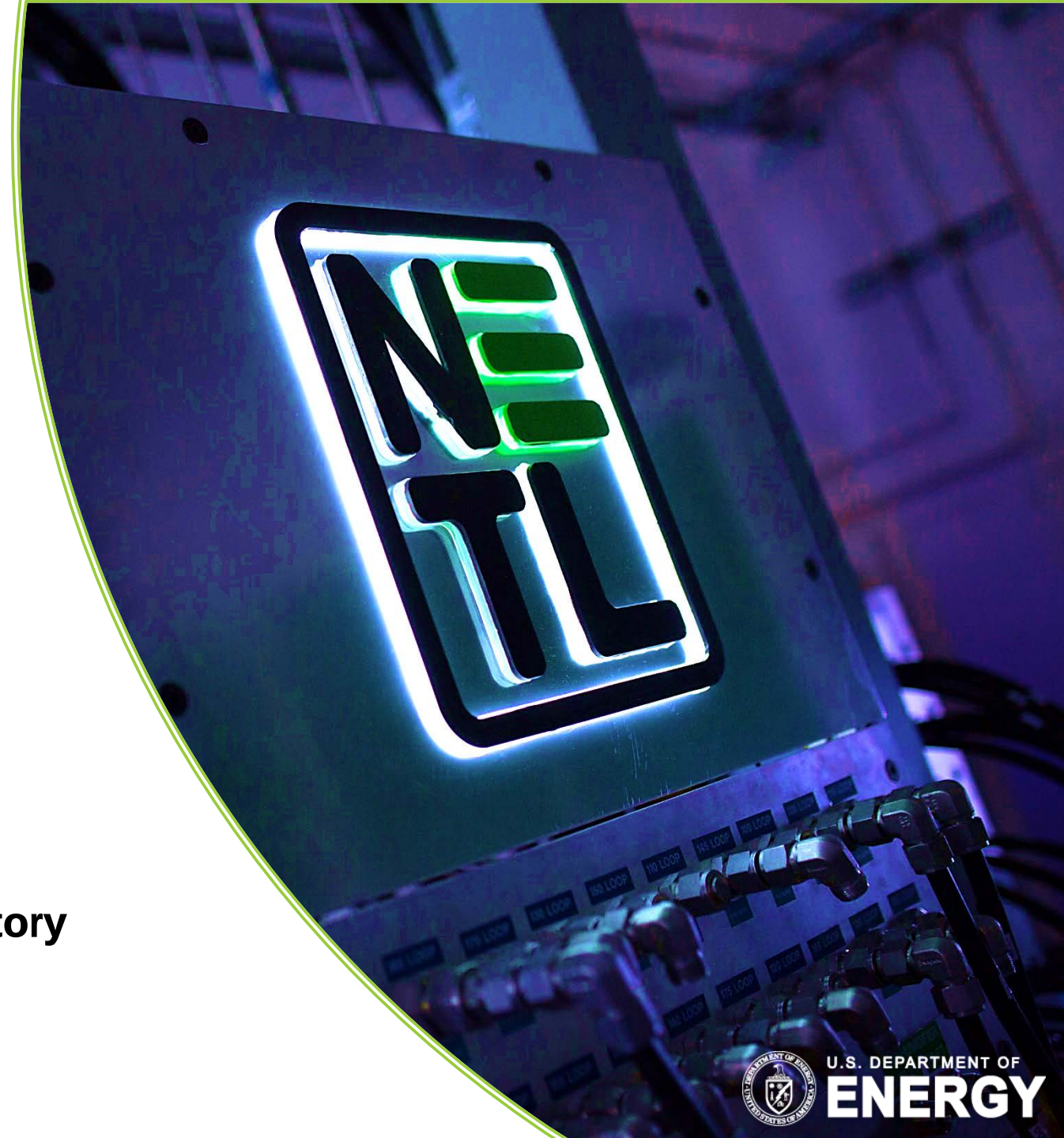
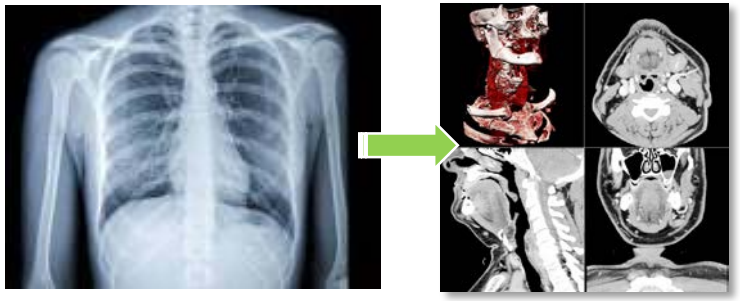


Real-Time Visualization

Real-Time Visualization

"CT" for the Subsurface



Vision: Transform reservoir management via dramatic improvements in subsurface visualization, exploiting ML to achieve speed and enhanced detail.

- **Real time** means in seconds to days—rapidly enough to inform the decision being made.
- **Visualization** means imaging of relevant information at the resolution necessary to make a decision.
- **Relevant information** means knowledge in a form needed by the decision maker (distribution in 3D, uncertainties, etc.)

Three Crosscutting Imaging Targets That Would Transform Subsurface Understanding	Potential Technology Pathways to Achieve Imaging Goals
1. **Rock Properties**: Rock type (facies), porosity, permeability, saturation, and fluid flow at the 1-m scale	• **Joint inversion** of multiple geophysical datasets (gravity, EM, pressure, InSAR, seismic, …)
2. **Pressure/stress** at the reservoir scale or at the basin scale	• **Multi-INT** (e.g., could include well logs, geophysical, reservoir simulations, etc.)
3. **Relevant faults and/or fracture networks** and/or fast flow paths in the area of interest	• **Tonal-Noise** Tomography

Virtual Learning

NATIONAL ENERGY TECHNOLOGY LABORATORY

Virtual Learning

Vision: Enable a virtual learning environment for exploring and testing strategies to optimize reservoir development, management, & monitoring prior to field activities.

Virtual learning means experiential learning in a computer based environment that responds to a user's actions in real time, simulating the behavior of the subsurface system based on physics-based knowledge.

Physics-based knowledge means that the relevant subsurface processes must be known, well characterized, and able to be simulated with high fidelity.

Real-time is enabled by (1) coupling the high fidelity simulations with rapid, empirical methods (e.g., machine learning) and (2) exploiting developments for rapid visualization gaming environments.

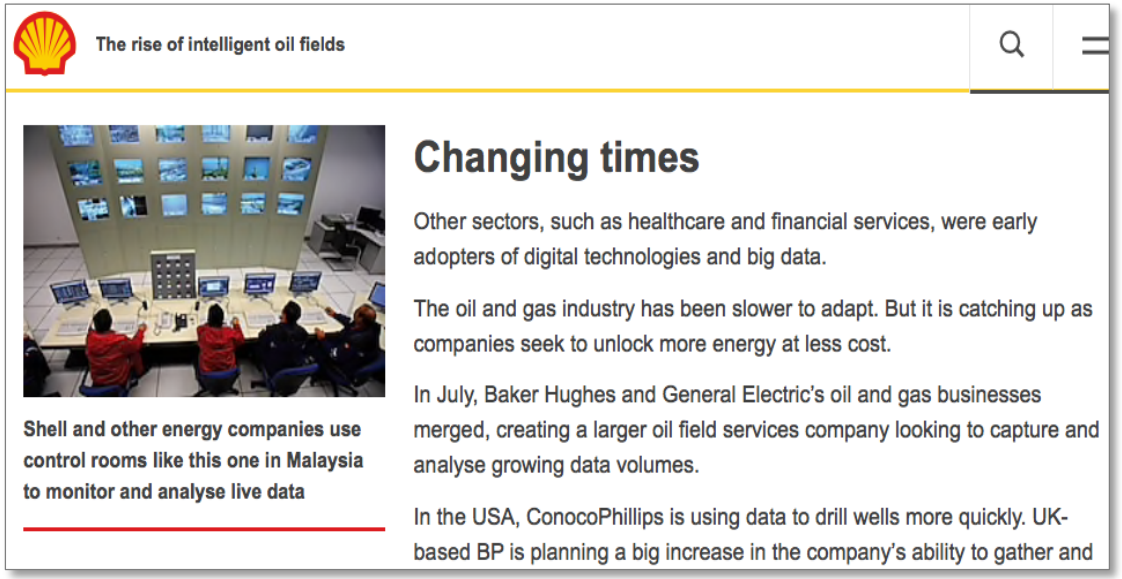
Real-Time Forecasting

Real-Time Forecasting

"Advanced Control Room"

Vision: Transform "human-in-the-loop" decisions on reservoir management by moving advanced control rooms from visualization of live data to visualization of forecasted behavior for different operational decisions.

- **Real time** means in seconds to minutes—rapidly enough to inform the decision.
- **Forecasted behavior** means pressure evolution, injection/production rates, hydrocarbon recovery, storage efficiency, etc.



The rise of intelligent oil fields

Shell and other energy companies use control rooms like this one in Malaysia to monitor and analyse live data

Changing times

Other sectors, such as healthcare and financial services, were early adopters of digital technologies and big data.

The oil and gas industry has been slower to adapt. But it is catching up as companies seek to unlock more energy at less cost.

In July, Baker Hughes and General Electric's oil and gas businesses merged, creating a larger oil field services company looking to capture and analyse growing data volumes.

In the USA, ConocoPhillips is using data to drill wells more quickly. UK-based BP is planning a big increase in the company's ability to gather and

Potential Operational Decisions

- How to adjust production rates and volumes in multiple wells to maximize recovery, sweep efficiency, …
- How to adjust CO_2 injection & brine production in multiple wells to maximize storage and minimize pressure plume
- Where to place infill wells to increase total recovery
- When to inject fluids for managing reservoir pressure to increase total recovery

Big Data Analytics to Illuminate Knowledge in Large Datasets

Rapid Data to Knowledge

"Big Data Management"

- **ML big data analytics to probe characteristics of legacy wellbores that tie to integrity ⇢ providing a statistical basis for evaluating potential for leakage.**

  DOE-funded studies have developed ML based platforms and produced regionally specific statistics on wellbore characteristics that can be used by CO_2 projects to assess risk.

- **ML big data analytics to extract trends in geologic characteristics in offshore reservoirs ⇢ providing a method to assess potential risks/impacts at regional scale.**

  DOE-funded studies and toolsets can interface with various databases to assess impacts associated with potential blowouts in the Gulf of Mexico.

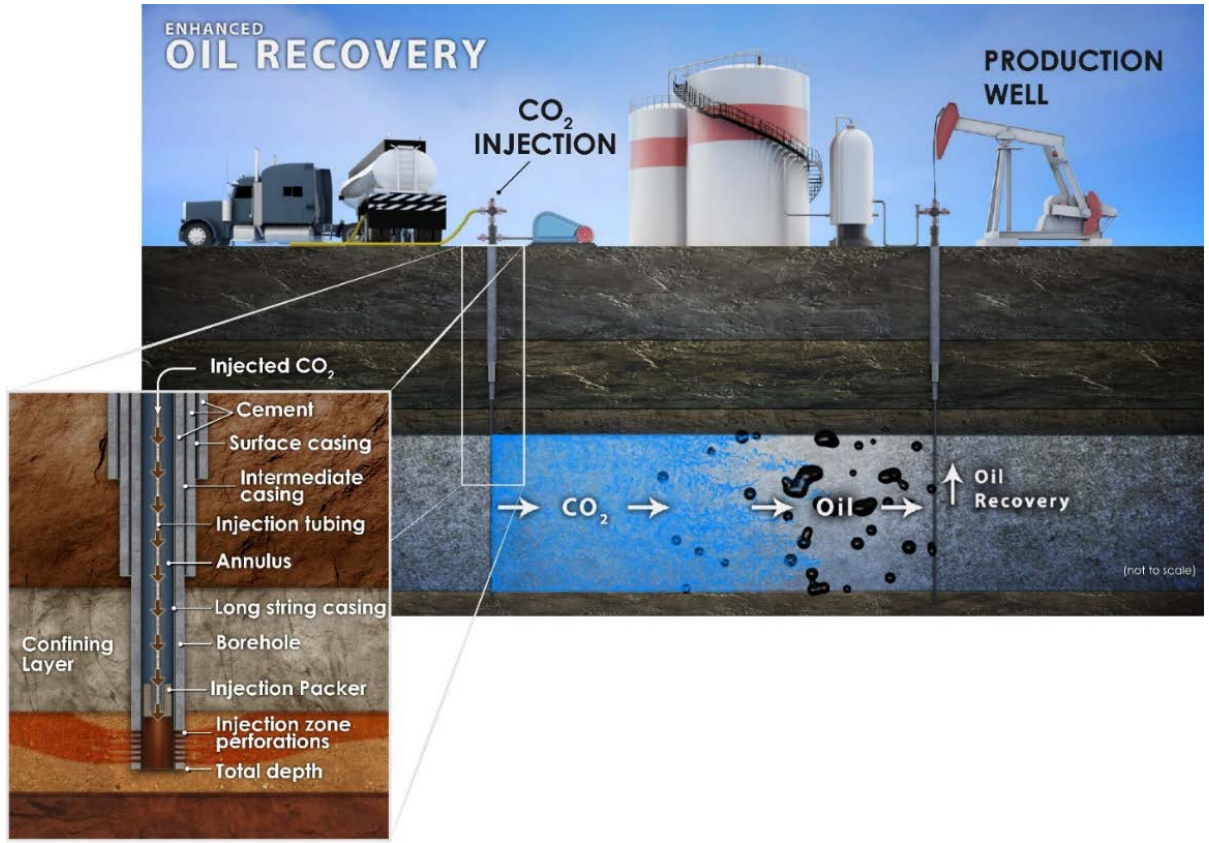
- **ML big data analytics to identify collective knowledge embodied in datasets across plays for unconventional reservoirs ⇢ searching for strategies that could lead to improved recovery efficiencies.**

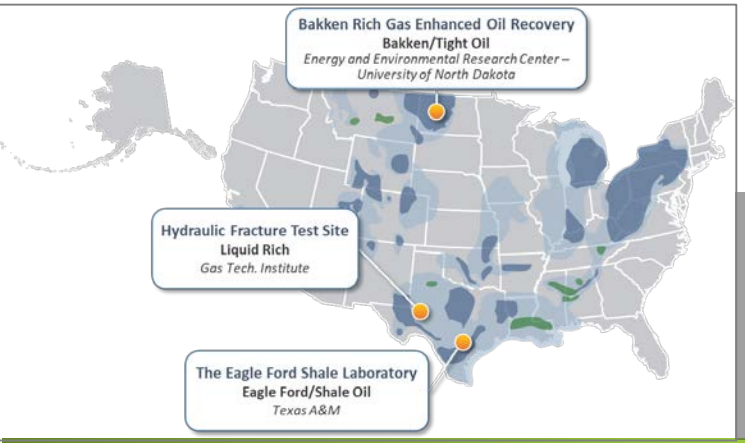
  DOE-funded study—in collaboration with industry partner—hopes to demonstrate the potential of big data analytics in improving recovery efficiency, providing impetus for data sharing across operators.

Enhanced Oil Recovery (EOR)

Field Characterization and Validation of Novel Processes

- Up to two-thirds of conventional crude oil discovered in U.S. fields remains unproduced due to fluid dynamic limitations.
- The use of CO_2 or associated gas as an EOR mechanism are gaining momentum as methods to improve oil production from depleted fields.
- NETL funds field research in the Wolfcamp, Eagle Ford, and Bakken shales focused on improving our understanding of EOR processes.





- Wolfcamp and the Bakken are injecting "rich gas" (more C_3 through C_7) associated with oil production into the reservoir as a mechanism improve reservoir pressure and drive more oil to producing wells.
- Eagle Ford is assessing the feasibility of "huff n' puff" EOR with associated gas.

Methane Hydrate Research in Alaska

NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE/NETL leads a National R&D program in Gas Hydrate S&T

- Enabled by the Methane Hydrate R&D Act of 2000
- Collaboration/coordination with 6 federal agencies (USGS, BLM, BOEM, NSF, NRL, NOAA)
- Extensive and active international engagements (Japan, Korea, India, New Zealand, others)

Alaska North Slope is a "natural laboratory" to assess gas hydrates production technology

- Long-term testing remains the #1 priority in global gas hydrate science
- The only feasible spot world-wide to attempt long-term testing (gas hydrates onshore with infrastructure)

A collaborative effort to develop a Project is ongoing

- Partners are JOGMEC, State of Alaska, USGS, and Petrotechnical Resources, Alaska
- BP operated the first phase of the program (a stratigraphic test) which was successful