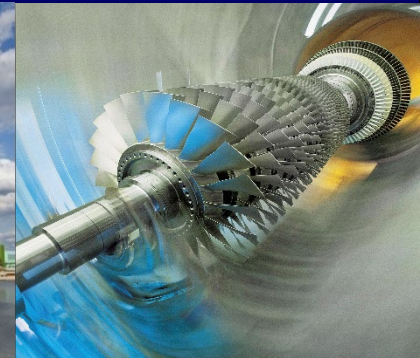


U.S. DEPARTMENT OF
ENERGY

Office of
Fossil Energy



DOE CCUS program overview

Jarad Daniels

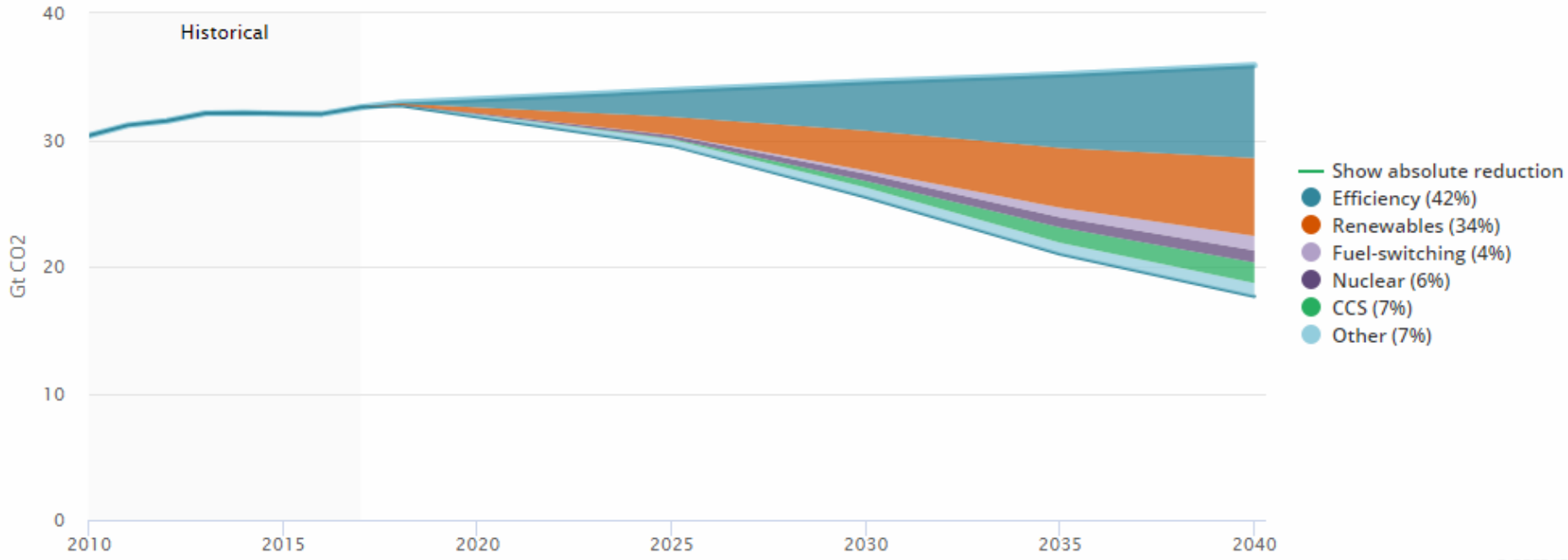
Office of Clean Coal and Carbon
Management, Office of Fossil Energy

PCOR Partnership Annual Membership Meeting

October 2019

Meeting climate and energy goals

Additional CO2 emissions reductions in the SDS vs. NPS



© OECD/IEA



CCUS is needed to reach sustainable development goals

•A global energy system that meets climate goals, provides universal energy access, and has reduced air pollution (IEA's Sustainable Development Scenario) requires 750 million tons per year of CCUS by 2030:

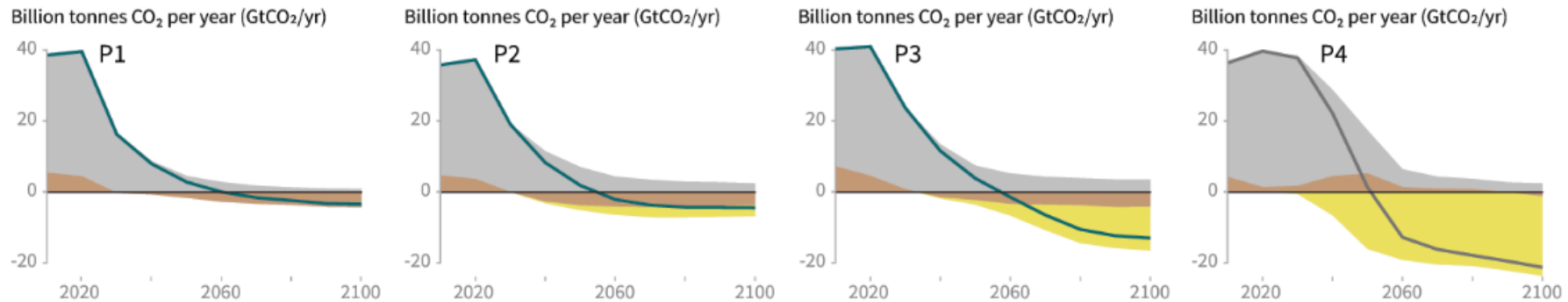
- 350 million tons per year in the power sector
- 400 million tons per year in 2030 in industry
 - 300 in industrial applications including cement, iron and steel production
 - 100 in fuel transformation applications including natural gas processing, hydrogen production and biofuels

•**CCS is needed in both developed and emerging economies**

IPCC Special Report: Pathways to 1.5°C

Breakdown of contributions to global net CO₂ emissions in four illustrative model pathways

● Fossil fuel and industry ● AFOLU ● BECCS



P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

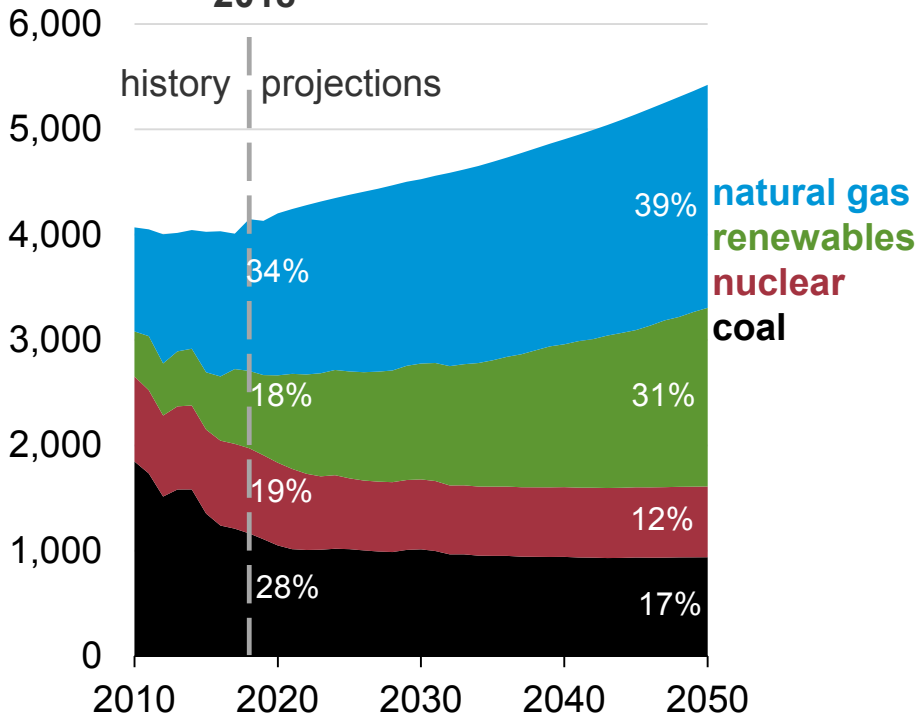
P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

2050 OUTLOOK FOR ELECTRICITY GENERATION IN UNITED STATES (EIA AEO 2019)

Electricity generation from selected fuels (Reference case)

billion kilowatthours

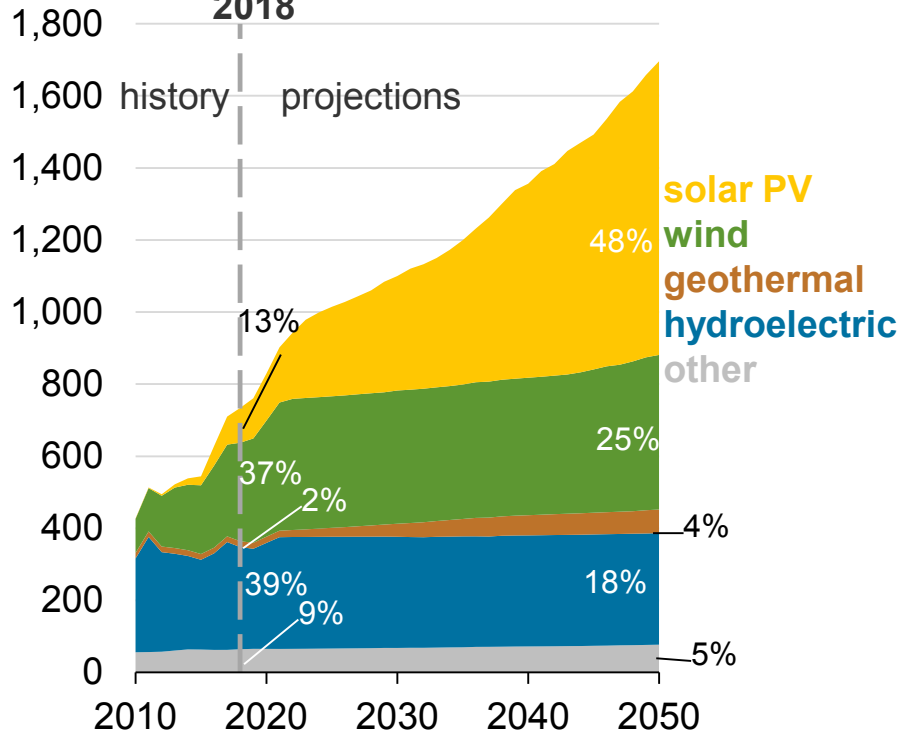
2018



Renewable electricity generation, including end-use (Reference case)

billion kilowatthours

2018

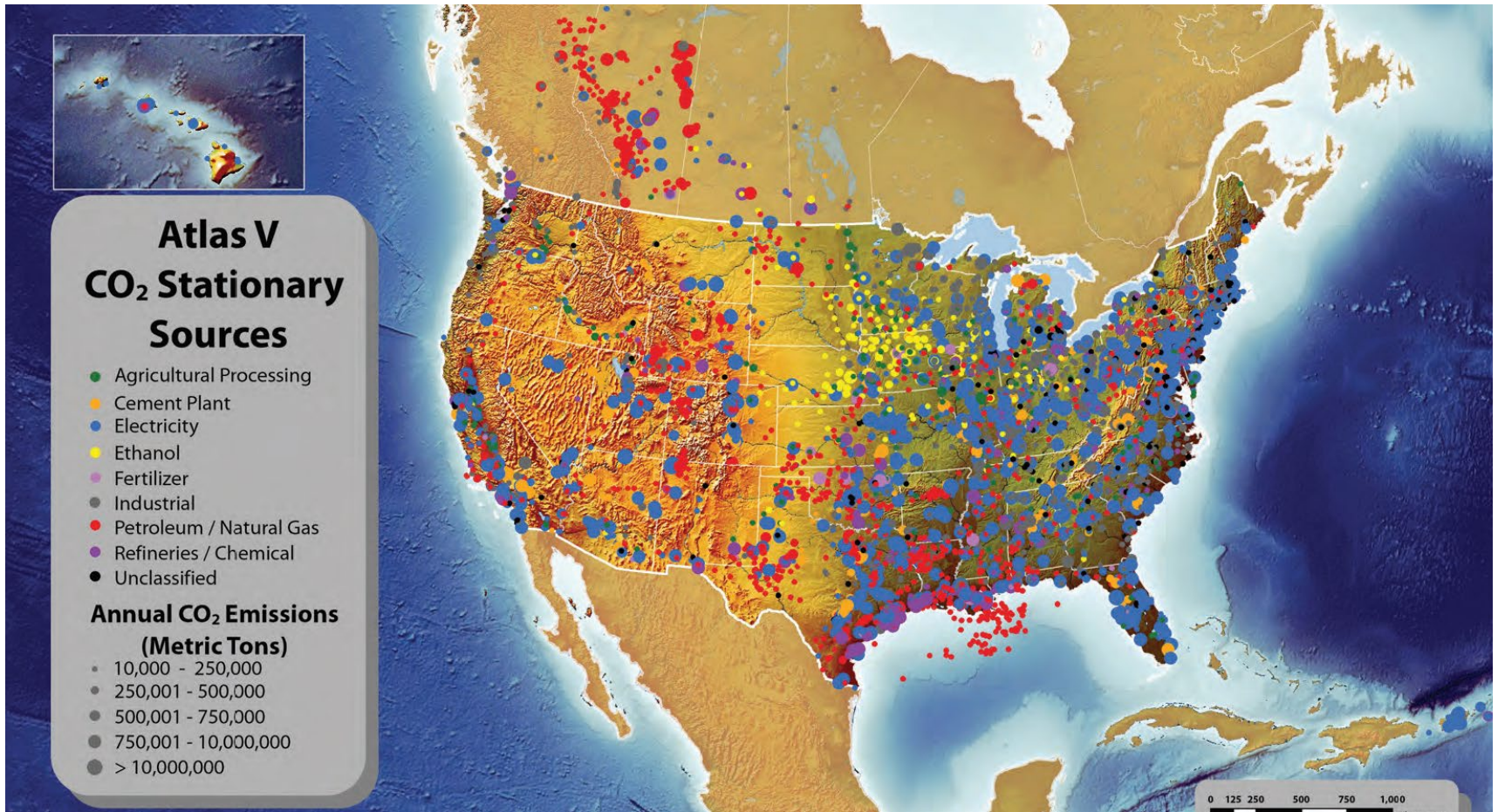


U.S. Leading on CCUS Research, Development, and Deployment

- Key international partnerships to leverage our strengths
- 40+ year history of CO₂ utilization for EOR
- Over 600 million tons of associated storage with EOR
- Over 4,500 miles of CO₂ pipeline in the United States
- The strongest country in developing the human capital and enablers for CCUS deployment (scientists, engineers, trades)
 - Broad R&D program engaging Private Industry, Universities, National Laboratories, small business, and the financial community.
- More major CCUS demonstrations than any other country
- Through the DOE/FE, leading one of the most globally recognized and successful RD&D programs on CCUS.... And leveraging this technology, science, and knowledge with other agencies for sound policy development.



CO₂ SOURCES



Credit 2008-2018:

\$20 per metric ton disposed of in secure geologic storage

\$10 per metric ton used for EOR or EGR in a qualified manner

Available credits: 75 million Tons

Updated Credit (included in the February 2018 “Bipartisan Budget Act of 2018”):

Credit available to qualified facilities for 12 year period

Applicable Amounts for projects placed in service on after the date of enactment

\$50 for secure geologic storage, with the credit increasing annually until the full value is reached in 2026

\$35 per metric ton for EOR, EGR, or utilization with the credit increasing annually until the full value is reached in 2026

Defines qualified Carbon Oxides (CO or CO₂)

Captured from an industrial source or the ambient air

Measured at point of capture and verified at the point of disposal/injection/use

Excludes gases recaptured during EOR process

Qualified facilities:

Construction must begin by Jan 1, 2024

Original planning and design includes carbon capture equipment

25,000 t/CO₂ captured and used or facilities that emit less than 500,000 tons

500,000 t/CO₂ captured for electric generating facilities

Utilization, including Photo- or chemo-synthesis, chemical conversion, other purposes for which commercial markets exist

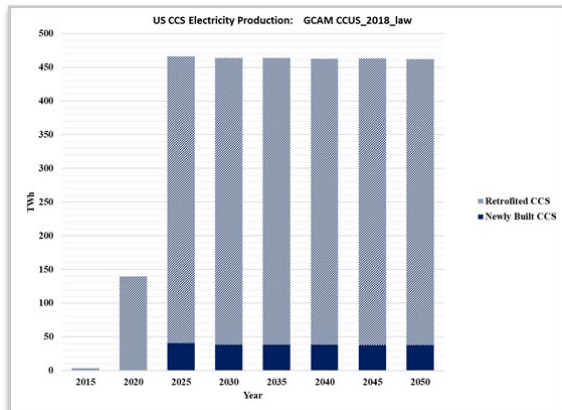
Credit can be claimed by owner of capture equipment or transferred to disposal/use entity

U.S. POLICY INCENTIVES FOR CCUS - 45Q TAX CREDITS

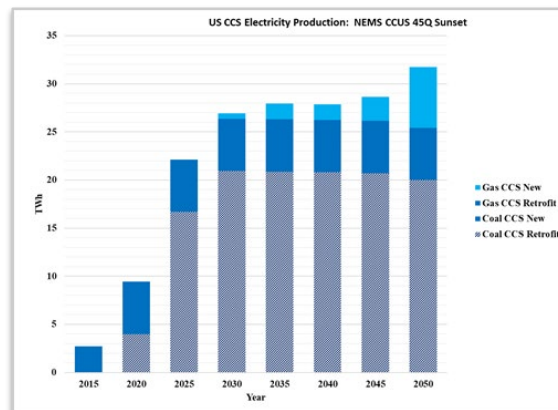
The 45Q tax credit provides an additional positive economic incentive for potential CCUS projects.

Regardless of modeling platform, analysts are finding that 45Q enables deployment of CCS in the power and industrial sectors.

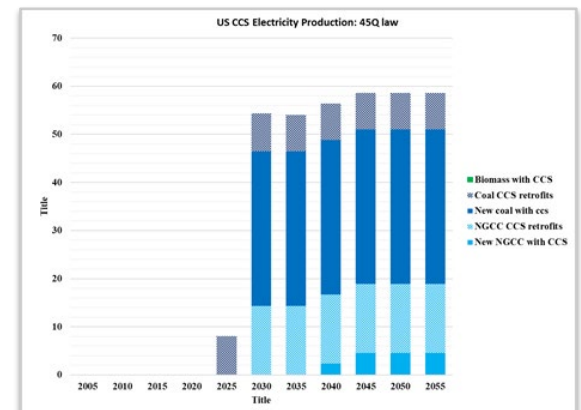
Comparison of electricity generation by CCS technologies – current 45Q



GCAM



NEMS



MARKAL

OFFICE OF CLEAN COAL AND CARBON MANAGEMENT

Mission:

Discover and develop advanced coal technologies that ensure America's access to resilient, affordable, reliable, and near-zero emitting coal energy resources.

R&D Priorities:

1. Advancing small-scale modular coal plants of the future, which are highly efficient and flexible, with near-zero emissions
2. Improving the performance, reliability, and efficiency of the existing coal-fired fleet
3. Reducing the cost of carbon capture
4. Creating new market opportunities for coal

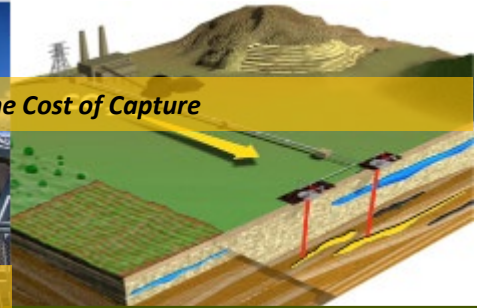


HOLISTIC APPROACH TO ENERGY GENERATION FROM FOSSIL FUELS



Coal R&D Overview

Advancing R&D for the existing coal fleet and plants of the future



Reducing the Cost of Capture

Creating New Markets for Coal

Advanced Energy Systems

Crosscutting Research

CO₂ Capture and Utilization

CO₂ Storage

Efficiency improvements for new and existing units

- Advanced energy materials
- Advanced gasification
- Solid oxide fuel cells
- Advanced coal processing
- Advanced Turbines
- Advanced Combustion
- Sensors and controls

Crosscutting technology development program

- Power Generation Efficiency
- Supercritical Transformational Electric Power
- Critical minerals
- Coal utilization science
- Transformational Coal Pilots
- University research
- SBIR/STTR*
- Technology Commercialization Fund (TCF)*

Reducing the cost of CO₂ capture for new and existing units

- Post-combustion capture
- Pre-combustion capture
- New pathways to utilize captured CO₂

Safely and permanently storing CO₂

- Safe use and permanent storage of CO₂ from power generation and industry
- Minimizing subsurface risks (coordinated with other subsurface offices, i.e., Oil and Gas)
- CO₂ infrastructure analysis

Note: Programmatic not necessarily budgetary groupings

**SBIR/STTR and TCF are managed under the Crosscutting Program but funded by all R&D programs*

Coal FIRST Technologies to Meet Opportunity

Goal: Develop the coal plant of the future needed to provide secure, stable, and reliable power.

The R&D under the Coal FIRST (Flexible, Innovative, Resilient, Small, Transformative) initiative will support future power plants that:

- Are capable of **Flexible** operations to meet the needs of the grid
- Use **Innovative** and cutting-edge components that improve efficiency and reduce emissions
- Provide **Resilient** power to Americans
- Are **Small** compared to today's conventional utility-scale coal
- Will **Transform** how coal technologies are designed and manufactured.



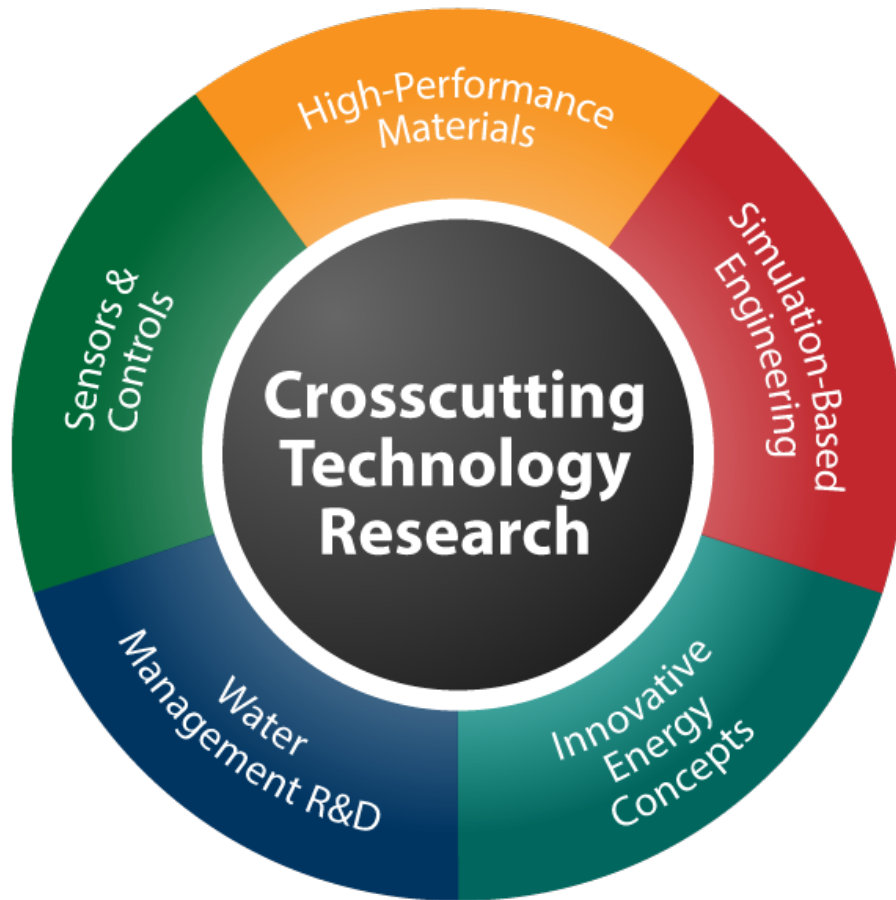
TRAITS OF THE COAL FIRST TECHNOLOGIES

- High overall plant efficiency (40%+ HHV or higher at full load)
- Small (unit sizes of approximately 50 to 350 MW)
- Near-zero emissions
- Capable of high ramp rates and minimum loads
- Integration with thermal or other energy storage (e.g. chemical production)
- Minimized water consumption
- Reduced design, construction, and commissioning schedules from conventional norms (e.g., advanced process engineering and parametric design methods for modular design)
- Enhanced maintenance features to reduce maintenance and minimize forced outages
- Integration with coal upgrading, or other plant value streams (e.g., co-production)

CO₂ Capture Integral to the Design



CROSSCUTTING RESEARCH & ANALYSIS – PROGRAM AREAS



High Performance Materials

- Ultrasupercritical Boilers & Turbines
- High-strength metallic & intermetallic alloys
- Computational Material Modeling

Simulation-based Engineering

- High fidelity models
- Advanced power system process simulations

Innovative Energy Concepts

Water Management R&D

- Advanced / Novel Heat Transfer and Cooling Systems
- Water Treatment and Reuse
- Process Efficiency and Heat Utilization
- Data, Modeling, and Analysis

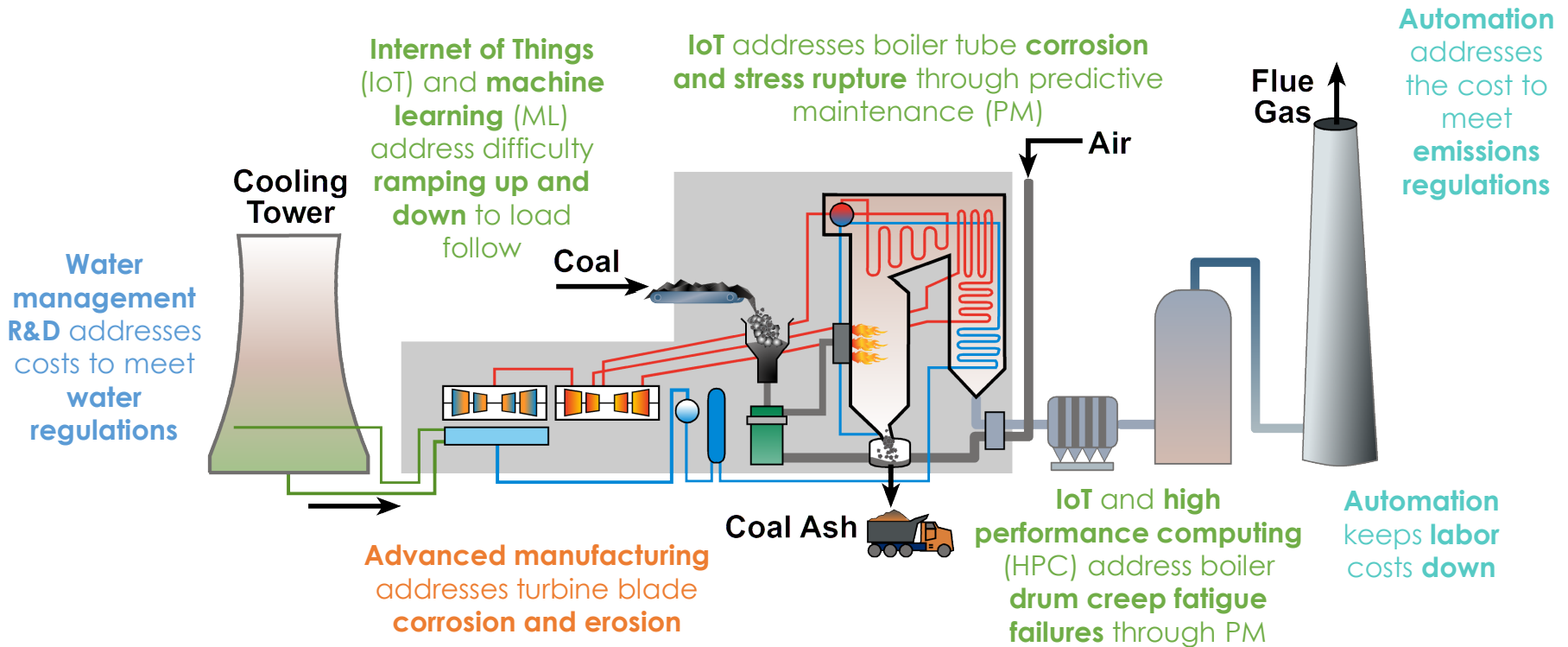
Sensors and Controls

- Advanced Sensing
- Distributed Intelligent Control
- Harsh Environment Application

University Training



Advanced Technologies and the Existing Fleet



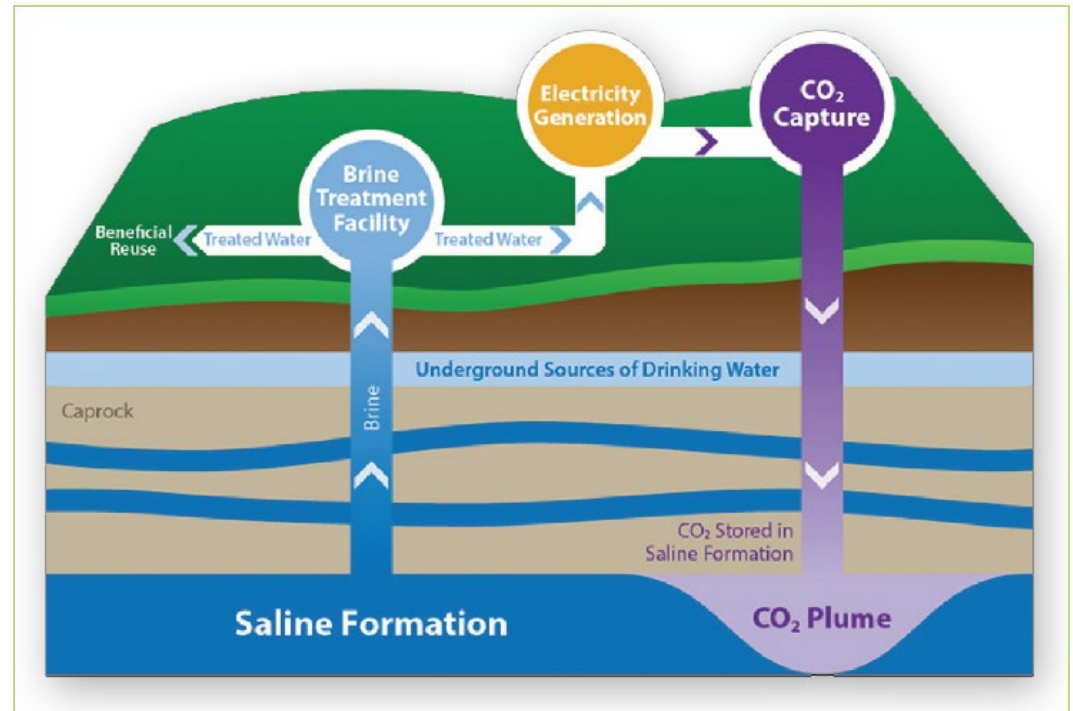
Leveraging Technologies to Improve Coal Plants



EXCITING TIME FOR CCUS

Carbon capture, utilization, and storage (CCUS) is increasingly becoming widely accepted as a viable option for fossil-based energy to lower their carbon dioxide (CO₂) emissions.

- 45Q
- Responses to DOE funding opportunities
- Increased investment interest
- Cost reductions



HIGH-LEVEL R&D PROGRAM GOALS AND CHALLENGES

Reduce the cost of capture by 50%

- Capital cost
- Energy penalty
- Integration or process intensification

2012: \$80/tonne
2016: \$60
2020: \$40
2030: \$30

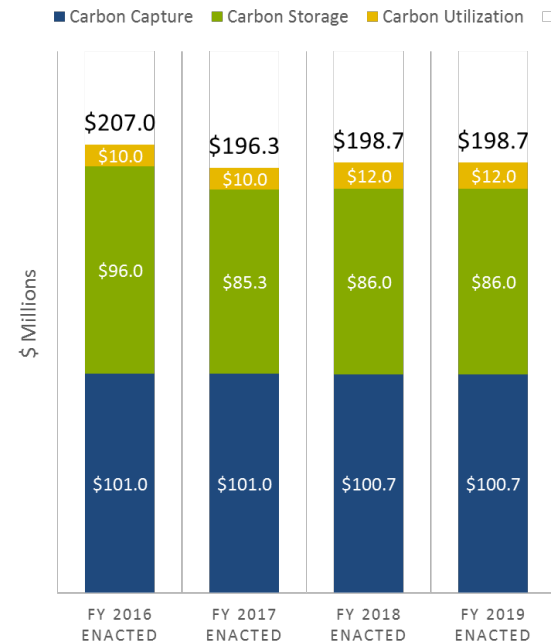
Source: NETL, Cost and Performance Baseline for Fossil Energy Plants, Revision 3, July 2015

Develop viable carbon utilization alternatives

- Reduce Capital cost
- Reduce energy requirements
- Lifecycle assessment better than existing products

Reduce the risk of geologic storage – improve monitoring and simulation

- Higher resolution and quantification (e.g., accurate characterization of faults and fractures)
- Geomechanics (pressure and state of stress)
- Costs/uncertainty/enabling real-time decision making



CCUS FEDERAL FUNDING OPPORTUNITIES

Carbon capture, utilization, and storage (CCUS) is increasingly becoming widely accepted as a viable option for fossil-based energy sources—such as coal- or gas-fired power plants and other industrial sources—to lower their carbon dioxide (CO₂) emissions.

September 13, 2019 DOE announced:

- \$110 million in Federal funding award selections
 - Front-End Engineering Design (FEED) Studies for Carbon Capture Systems on Coal and Natural Gas Power Plants (DE-FOA-0002058, 000001)
 - Regional Initiative to Accelerate CCUS Deployment (DE-FOA-0002000)
- \$35 million for a new Funding Opportunity Announcement (FOA)
 - Carbon Storage Assurance Facility Enterprise (CarbonSAFE): Site Characterization and CO₂ Capture Assessment



CCUS FEED STUDIES SELECTIONS

Front-End Engineering Design (FEED) Studies for Carbon Capture Systems on Coal and Natural Gas Power Plants (DE-FOA-0002058, 000001)

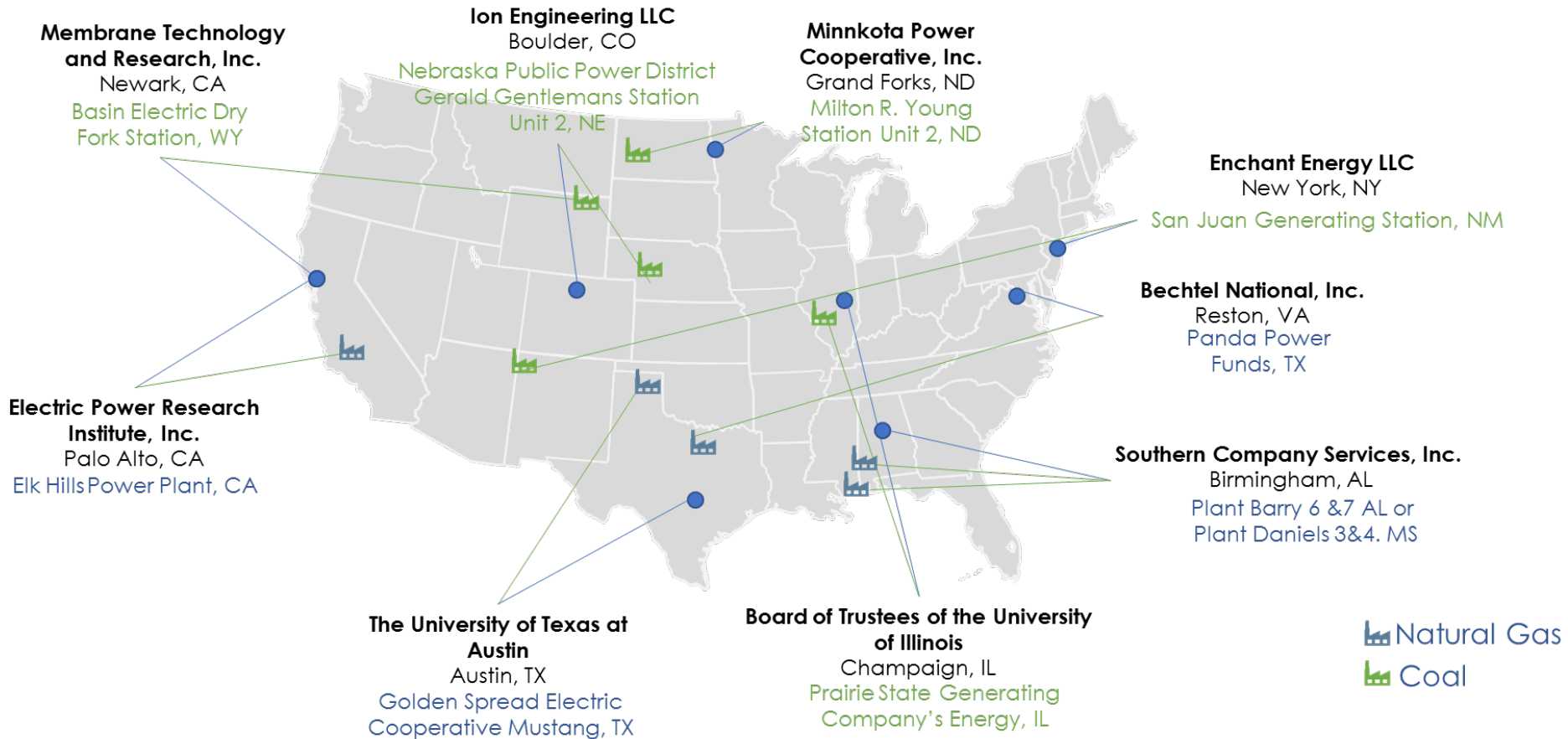
Projects will support FEED studies for commercial-scale carbon capture systems

- \$55.4 million in Federal funding awarded
- Nine projects selected

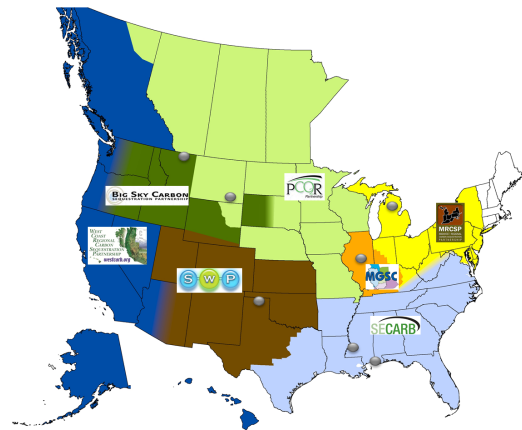
Awardee	Project
Bechtel National 	FEED Study for Retrofitting a 2x2x1 Natural Gas-Fired Gas Turbine Combined Cycle Power Plant for Carbon Capture Storage/Utilization – MEA Solvent
The Board of Trustees of the University of Illinois 	Full-Scale FEED Study for Retrofitting the Prairie State Generating Station with an 816 MWe Capture Plant Using Mitsubishi Heavy Industries of America Post-Combustion CO2 Capture Technology – MHI Solvent
Electric Power Research Institute 	Front End Engineering Design Study for Retrofit Post-Combustion Carbon Capture on a Natural Gas Combined Cycle Power Plant – Fluor’s amine-based Econamine FG Plus
Enchant Energy 	Large-Scale Commercial Carbon Capture Retrofit of the San Juan Generating Station – Commercial Solvent
Ion Engineering 	Commercial Carbon Capture Design & Costing: Part Two – Ion Engineering Non- aqueous Solvent
Membrane Technology and Research Inc. 	Commercial-Scale Front-End Engineering Study for MTR’s Membrane CO2 Capture Process – MTR, Inc Polymeric Membrane
Minnkota Power Cooperative Inc. 	Front-End Engineering & Design: Project Tundra Carbon Capture System – Fluor’s amine-based Econamine FG Plus
Southern Company Services 	Front End Engineering Design of Linde-BASF Advanced Post-Combustion CO2 Capture Technology at a Southern Company Natural Gas-Fired Power Plant – Linde BASF amine Solvent
The University of Texas at Austin 	Piperazine Solvent/Advanced Stripper Front-End Engineering Design (PZAS FEED)

COMMERCIAL CARBON CAPTURE FEED STUDY PROJECTS

\$55M DOE - 2019



DEVELOPING THE INFRASTRUCTURE FOR WIDE SCALE DEPLOYMENT



Regional Carbon Sequestration Partnerships (RCSPs)

Recognized globally as an important CCUS initiative the RCSPs have been instrumental in developing the infrastructure, tools, and capabilities to help facilitate widespread deployment of CCUS in the United States.

- Injected over 11 million metric tons of CO₂ for secured storage
- Served as sites for field testing new technologies
- Helped engage regional, state, and local stakeholders.

Carbon Storage Assurance Facility Enterprise (CarbonSAFE)

Identify and certify geologic storage sites at commercial volumes (50+ million metric tons of CO₂).

- Phased approach to develop an integrated CCS storage complex constructed and permitted for operation by 2025
- 6 feasibility phase projects currently active
- FOA0001999 recently released. \$35M for 1-2 projects to begin full characterization of a site leading to an approved permit to begin construction



CARBONSAFE FUNDING

Carbon Storage Assurance Facility Enterprise (CarbonSAFE): Site Characterization and CO₂ Capture Assessment (DE-FOA-0001999)

Projects will accelerate wide-scale deployment of CCUS through assessing and verifying safe and cost-effective anthropogenic CO₂ commercial-scale storage sites, and carbon capture and/or purification technologies.

- Up to \$35 million in Federal funding

Key FOA Activities

Complete a detailed site characterization of a commercial-scale CO₂ storage site (50 million metric tons of captured CO₂ within a 30 year period)

Apply and obtain an underground injection control class VI permit to construct an injection well

Complete a CO₂ capture assessment

Perform all work required to obtain a National Environmental Policy Act determination for the site






REGIONAL CCUS SELECTIONS

Regional Initiative to Accelerate CCUS Deployment (DE-FOA-0002000)

Projects will address key CCUS technical challenges; facilitate data collection, sharing, and analysis; evaluate regional infrastructure; and promote regional technology transfer.

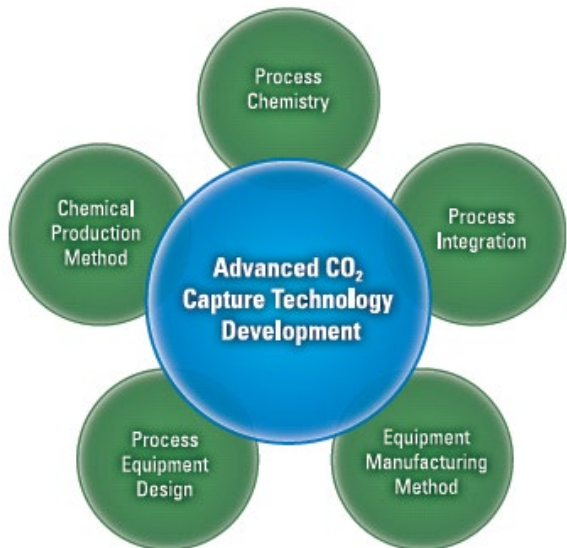
- \$20 million in Federal funding awarded
- Four projects selected

Awardee	Project
Battelle Memorial Institute 	Regional Initiative to Accelerate CCUS Deployment in the Midwest and Northeastern USA
New Mexico Institute of Mining and Technology 	Carbon Utilization and Storage Partnership of the Western United States
Southern States Energy Board 	Southeast Regional Carbon Utilization & Storage Partnership (SECARB-USA)
University of North Dakota 	Plains Carbon Dioxide Reduction (PCOR) Partnership Initiative to Accelerate CCUS Deployment



Carbon Capture: Post-Combustion, Pre-Combustion, and Direct Air Capture - Focus on Cost Reduction, Energy Penalty, and Integration

Requires improvements in multiple areas



Summary of Carbon Capture R&D Program Advancement of 2nd Generation Technologies

Cost Reduction
\$100+/tonne

\$41/tonne

Energy Penalty Reduction
30+%

14-15%

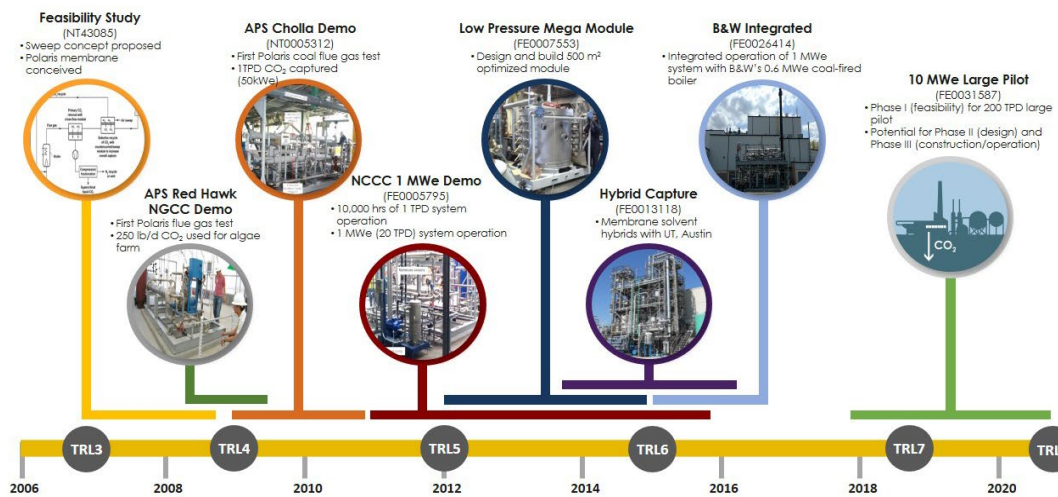
Program Activity
180+ Projects

15 Technologies Tested at Pilot Scale

Pilot-scale Testing

TECHNOLOGY HIGHLIGHTS	Innovation Pathways	PRINCIPAL DEVELOPER
POST-COMBUSTION		
Imbedded Amine Sorbent*	Materials, Processes, Equipment	ADA-ES
Low-water Amine Solvent	Materials, Processes, Equipment	Fluor/MHI
Hybrid Solvent/Membrane	Materials, Processes, Equipment	Gas Technology Institute
Amino-silicone Solvent*	Materials, Processes, Equipment	General Electric Company
Amine/Imidazole Solvent Mixture* (Large Pilot)	Materials, Processes, Equipment	ION Engineering
Advanced Amine Solvent Process*	Materials, Processes, Equipment	Linde/BASF
Advanced Membrane Process*	Materials, Processes, Equipment	MTR
Nozzle-based Solvent Contactor*	Materials, Processes, Equipment	Neumann Systems Group
Mixed Salt Solvent Process*	Materials, Processes, Equipment	SRI International
Carbon-based Sorbent*	Materials, Processes, Equipment	SRI International
Alkalinized Alumina Sorbent*	Materials, Processes, Equipment	TDA Research
Optimized Amine Solvent Process	Materials, Processes, Equipment	University of Kentucky
Piperazine Solvent/Flash Stripper	Materials, Processes, Equipment	URS/University of Texas
PRE-COMBUSTION		
Ammonium Carbonate/Bicarbonate Solvent*	Materials, Processes, Equipment	SRI International
Integrated Sorbent Process	Materials, Processes, Equipment	TDA Research

* Project Completed



Case Study of Technology Development Progression Through the Carbon Capture R&D Program – Membrane Technology Research, Inc.

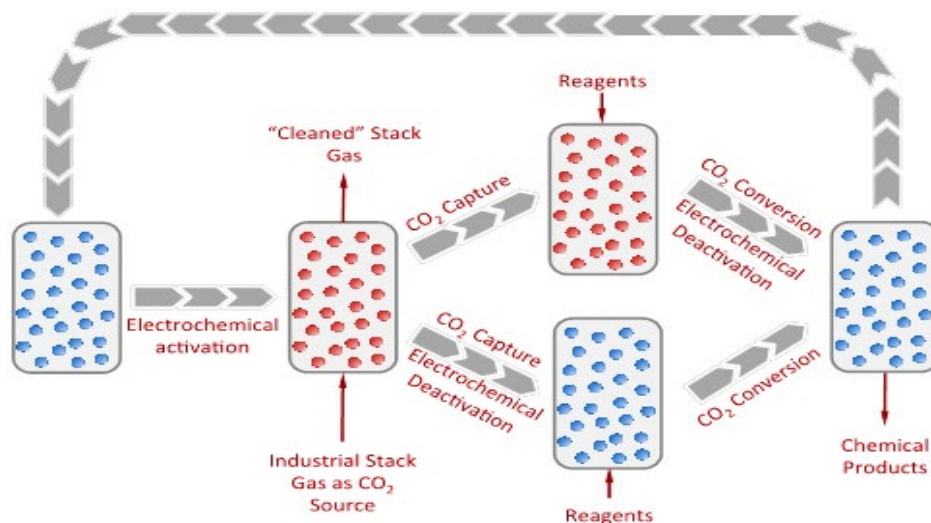
CARBON UTILIZATION

OFFSET CO₂ CAPTURE COSTS + FIX CO₂ IN STABLE PRODUCTS

Biological Capture & Conversion



Fuels & Chemicals



Mineralization & Cements



24 Active Projects – Recently selected 11 lab and 4 field-scale projects

Catalysis and Biological Pathways - Fuels and Chemicals

- Projects creating CO or direct to fuels using renewable energy and/or hydrogen

Concrete: Solidia Technologies - Utilizes CO₂ to make cement and concrete

- Reduce carbon footprint up to 70%
- \$1.9M DOE investment leveraged by industry
- Oil and Gas Climate Initiative's Climate Investment Funded and other parties

Clean Energy Ministerial



Saudi Arabia



United States



South Africa



Norway



Japan



United Kingdom



United Arab Emirates



Mexico



China



Canada



Netherlands

Lead countries: Norway, Saudi Arabia, the United States and United Kingdom

Participating CEM members: Canada, China, Japan, Mexico, Netherlands, South Africa and United Arab Emirates (in addition, the European Commission is an observer)

Industry including the oil and gas community

Financial institutions including multilateral development banks (MDBs)

Organizations: Carbon Sequestration Leadership Forum (CSLF), International Energy Agency (IEA), IEA Greenhouse Gas R&D Programme (IEAGHG), Mission Innovation (MI), Global CCS Institute (GCCSI), and Oil and Gas Climate Initiative (OGCI)

Other relevant CEM Initiatives: 21st Century Power Partnership, Power System Flexibility, Investment and Finance Initiative, Long-term scenario campaign, Clean Energy Solutions Center

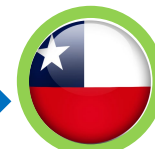
MINISTERIAL MEETINGS COUPLED WITH YEAR-ROUND TECHNICAL WORK



CEM9 - 2018
EU and 4 Nordics



CEM10 - 2019
Canada



CEM11 - 2020
Chile

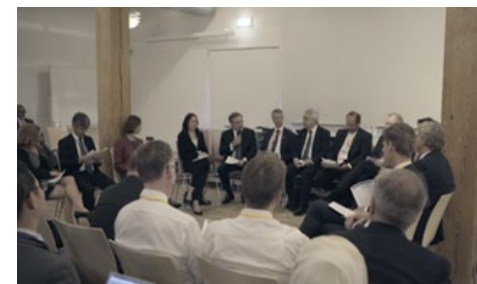
Year round technical work

Global analysis

In-country work



In-country technical workshops




Industry and government dialogues



High-level policy discussions

CEM CCUS Initiative – OGCI collaboration


24 May 2019
UNDER EMBARGO until Wednesday 29 May at 13:00hrs Pacific Daylight Time (UTC-7)



Vancouver, 29 May 2019

Clean Energy Ministerial CCUS Initiative and Oil & Gas to collaborate on speeding up CCUS

- In November 2018, global energy leaders met in Edinburgh to support the global development of an economically viable CCUS. The Clean Energy Ministerial CCUS Initiative and Oil & Gas Climate Initiative agree to collaborate on speeding up CCUS.
- The CEM Carbon Capture, Utilization and Storage Initiative will require strong public-private cooperation. CEM CCUS in which to strengthen collaboration to achieve this.
- The CEM Carbon Capture, Utilization and Storage Initiative will explore potential modalities and procedures to further:
 - Identifying possible new strategic investments in CCUS countries and beyond, with emphasis on projects at commercial scale;
 - Considering processes to collaborate to support the development of joint projects through the early stages, up to FEED stage, and further to FID as appropriate;
 - Advancing CCUS globally by creating and fostering sustained dialogue on policy, regulatory and risk-sharing mechanisms and principles to support CCUS project development; and by sharing non-proprietary knowledge gained from projects;
 - Accelerating the development of new and existing CCUS technologies and reducing costs.
- It is recognised that collaboration would take on different forms in different jurisdictions – It is not intended to propose a uniform way to collaborate on advancing projects. Various public-private collaboration models exist and the parties would discuss their merits in different circumstances and work together to create processes that suit each jurisdiction and project opportunity.
- The role of financial institutions should be investigated, and financial institutions, whether commercial banks or development banks, should be encouraged to join the process.
- OGCI and CEM CCUS will establish a joint Task Group to explore this potential collaboration in further detail.



Clean Energy Ministerial CCUS Initiative and the Oil & Gas Climate Initiative agree to collaborate on speeding up CCUS


30 May 2019

At a CEM-10 side-event yesterday, the CCUS Initiative and Oil & Gas Climate Initiative agreed to collaborate on speeding up CCUS. The CCUS Initiative and Oil & Gas Climate Initiative will explore potential modalities and procedures to further:
a. Identifying possible new strategic investments in CCUS countries and beyond, with emphasis on projects at commercial scale;
b. Considering processes to collaborate to support the development of joint projects through the early stages, up to FEED stage, and further to FID as appropriate;
c. Advancing CCUS globally by creating and fostering sustained dialogue on policy, regulatory and risk-sharing mechanisms and principles to support CCUS project development; and by sharing non-proprietary knowledge gained from projects;
d. Accelerating the development of new and existing CCUS technologies and reducing costs.

4. It is recognised that collaboration would take on different forms in different jurisdictions – It is not intended to propose a uniform way to collaborate on advancing projects. Various public-private collaboration models exist and the parties would discuss their merits in different circumstances and work together to create processes that suit each jurisdiction and project opportunity.

5. The role of financial institutions should be investigated, and financial institutions, whether commercial banks or development banks, should be encouraged to join the process.

6. OGCI and CEM CCUS will establish a joint Task Group to explore this potential collaboration in further detail.



<https://www.cleanenergyministerial.org/news-clean-energy-ministerial/clean-energy-ministerial-ccus-initiative-and-oil-gas-climate>

- On 29 May 2019, CEM CCUS Initiative and OGCI announced our intention to collaborate
- Focus: accelerating CCUS projects with emphasis on key hubs and clusters

NATIONAL PETROLEUM COUNCIL

The National Petroleum Council (NPC), a federally chartered and privately funded advisory committee, was established by the Secretary of the Interior in 1946 at the request of President Truman. In 1977, the U.S. Department of Energy was established and the NPC's functions were transferred to the new Department.

The purpose of the NPC is solely to advise, inform, and make recommendations to the Secretary of Energy with respect to any matter relating to oil and natural gas or to the oil and gas industries submitted to it or approved by the Secretary. The NPC does not concern itself with trade practices, nor does it engage in any of the usual trade association activities.



QUESTIONS ??? / DISCUSSION ???

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