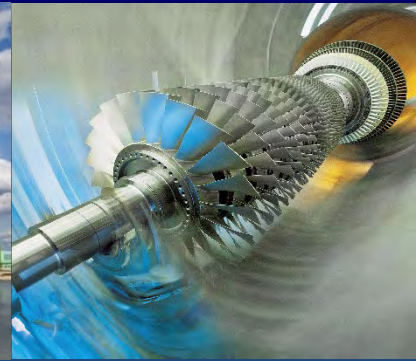


U.S. DEPARTMENT OF
ENERGY

Office of
Fossil Energy



Update on CCUS in the United States

CSLF Technical Group Meeting

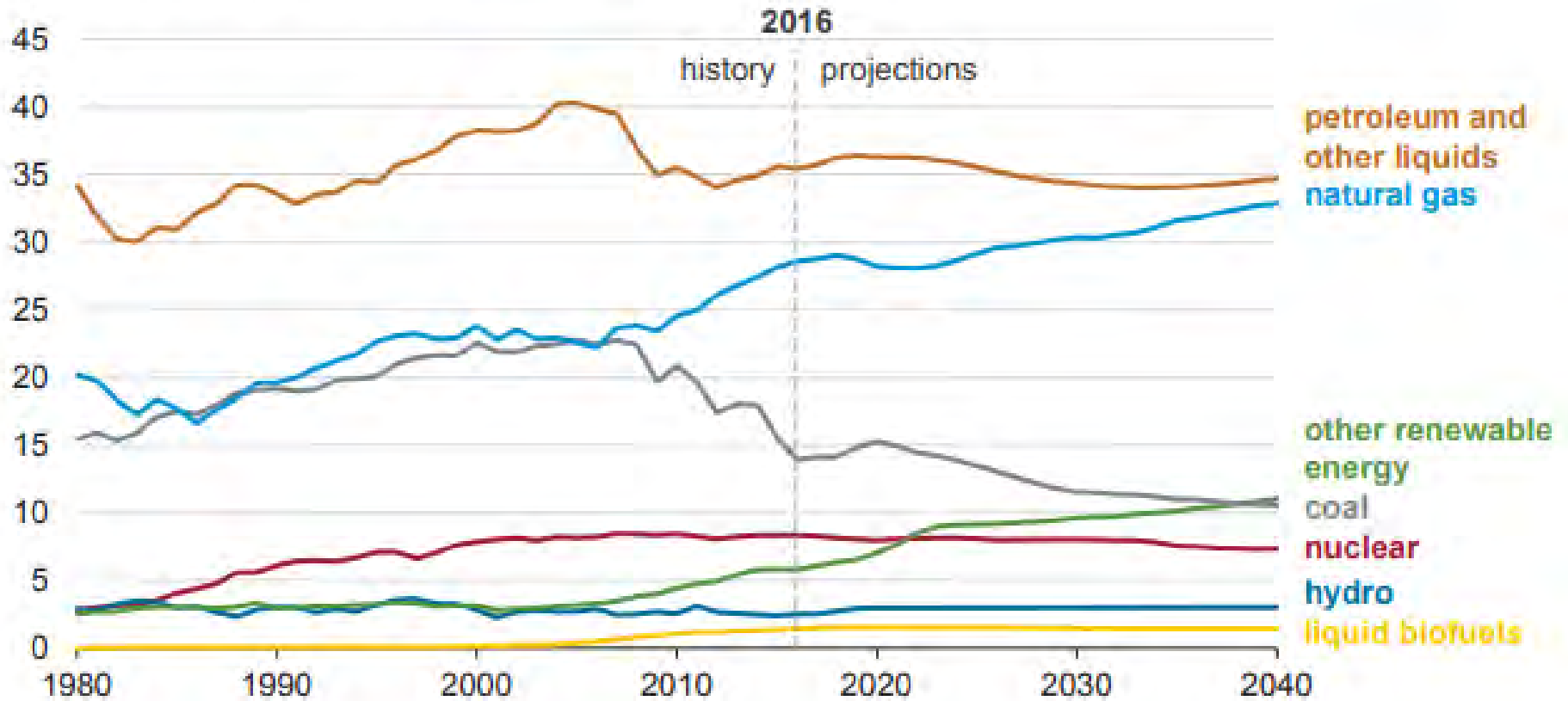
April 26, 2019

Mark Ackiewicz

Director, Division of CCUS R&D

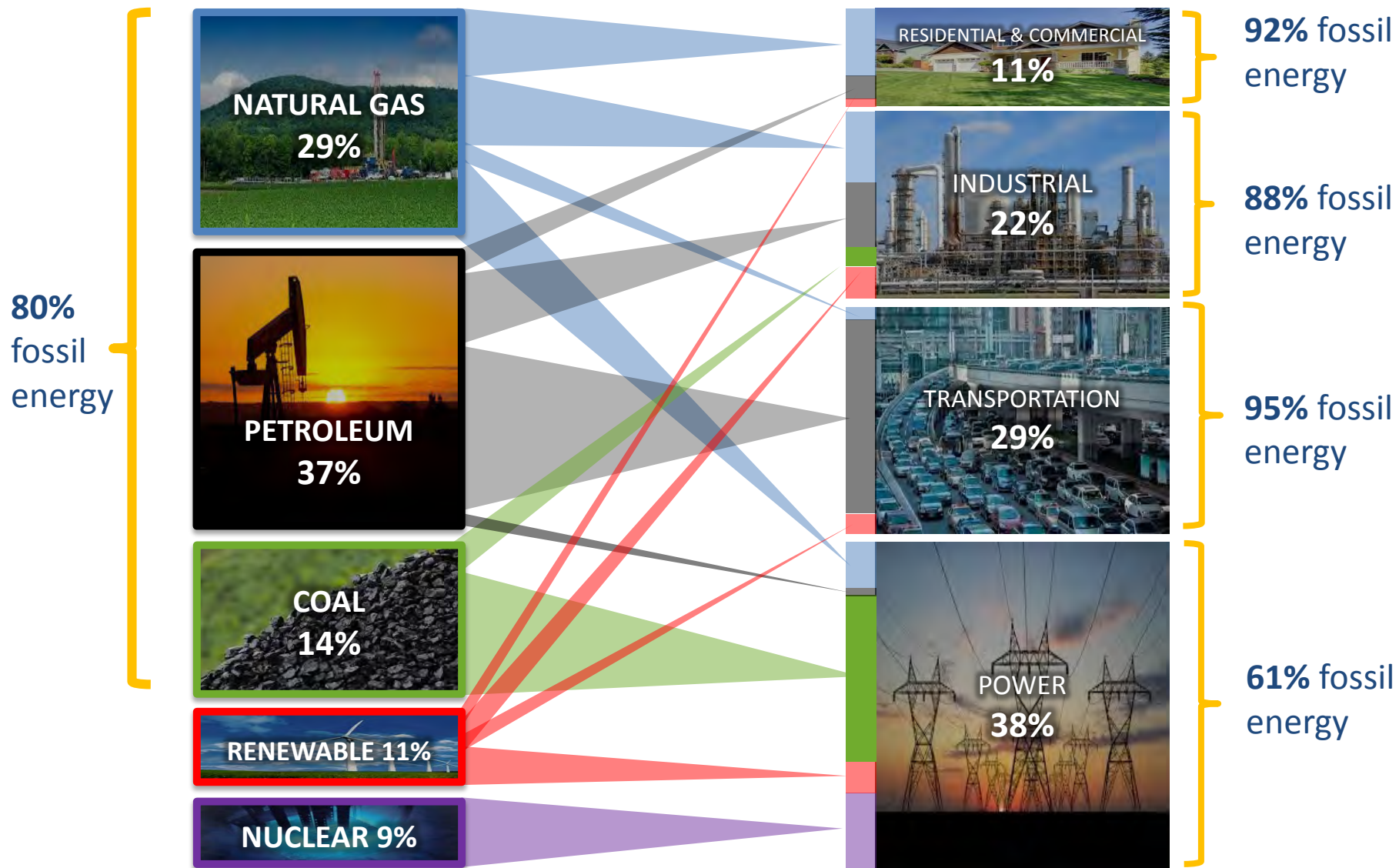
Domestic Energy Consumption to 2040

Energy consumption (Reference case)
quadrillion British thermal units



Source: U.S. Energy Information Administration (EIA).

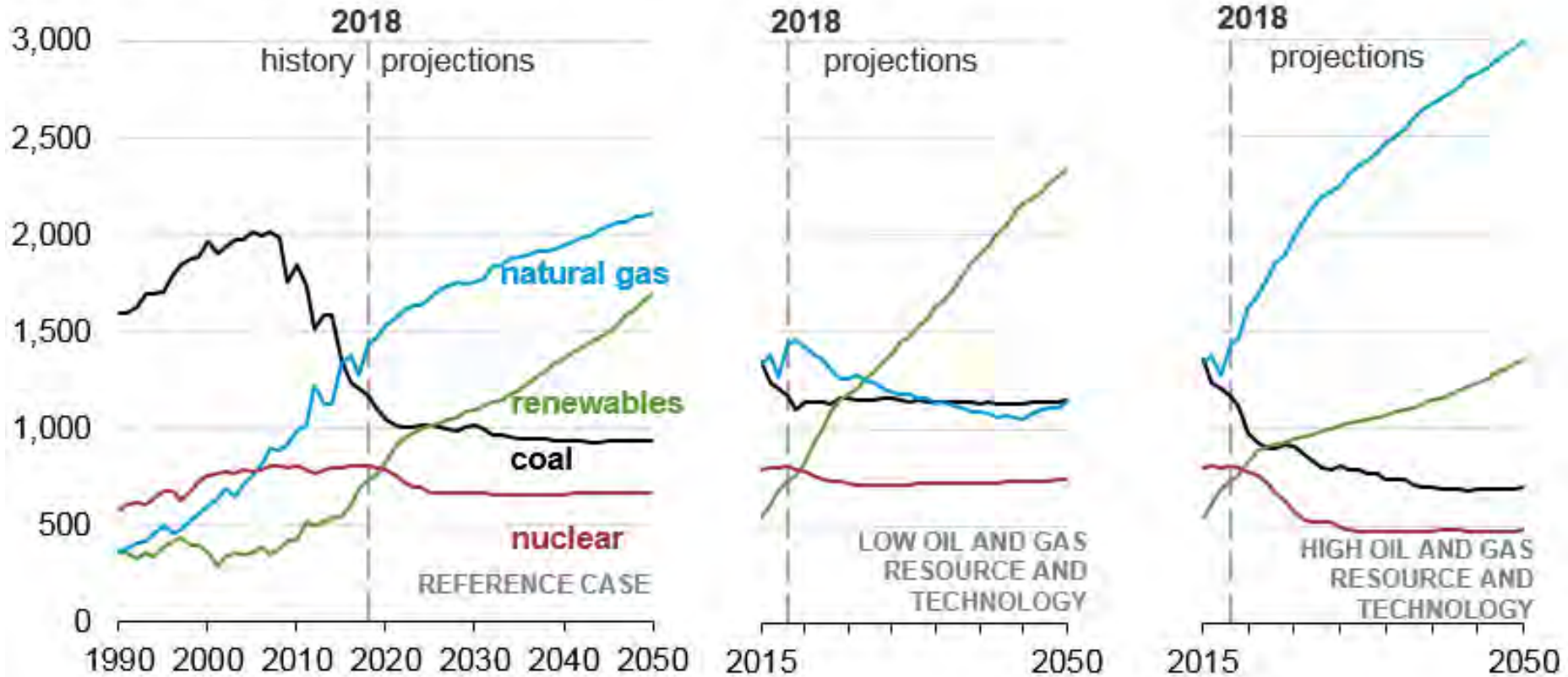
Fossil energy critical in all U.S. domestic sectors



Data source: U.S. Energy Information Administration (EIA), Monthly Energy Review December 2018

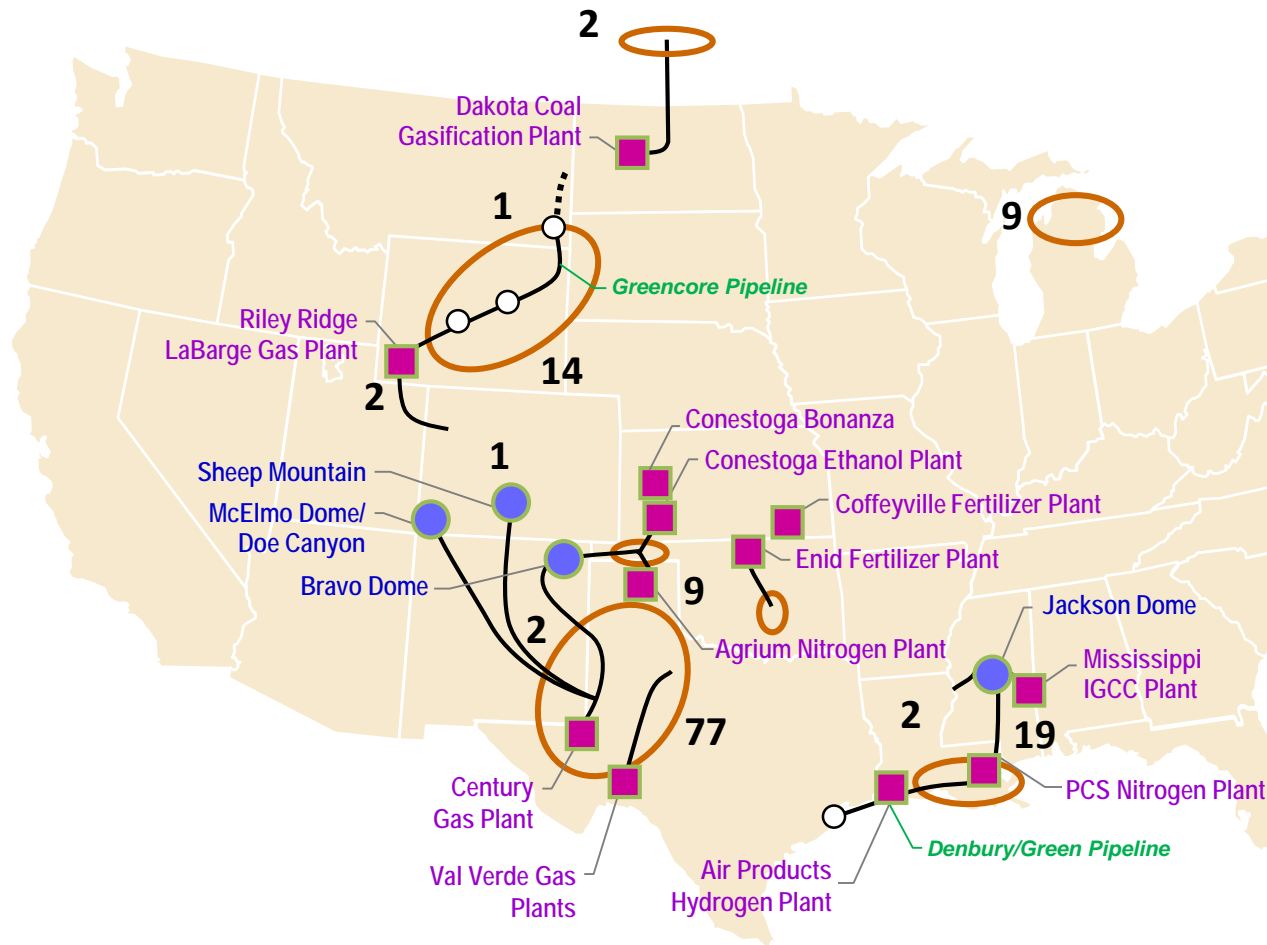
Price of natural gas a key factor in projecting future U.S. energy mix

Electricity generation from selected fuels
billion kilowatthours



Source: EIA, Annual Energy Outlook 2019


Current CO₂-EOR Operations and CO₂ Sources (2014)





Oil Production (2014)	
CO ₂ -EOR Projects	136
Oil Production (MBbl/d)	300


CO ₂ Supplies (2014)	
Number of Sources	17
• Natural	5
• Industrial	12
CO ₂ Supply (Bcf/d)	3.5
• Natural	2.8
• Industrial	0.7

136 No. of U.S. CO₂-EOR Projects

 Natural CO₂ Source

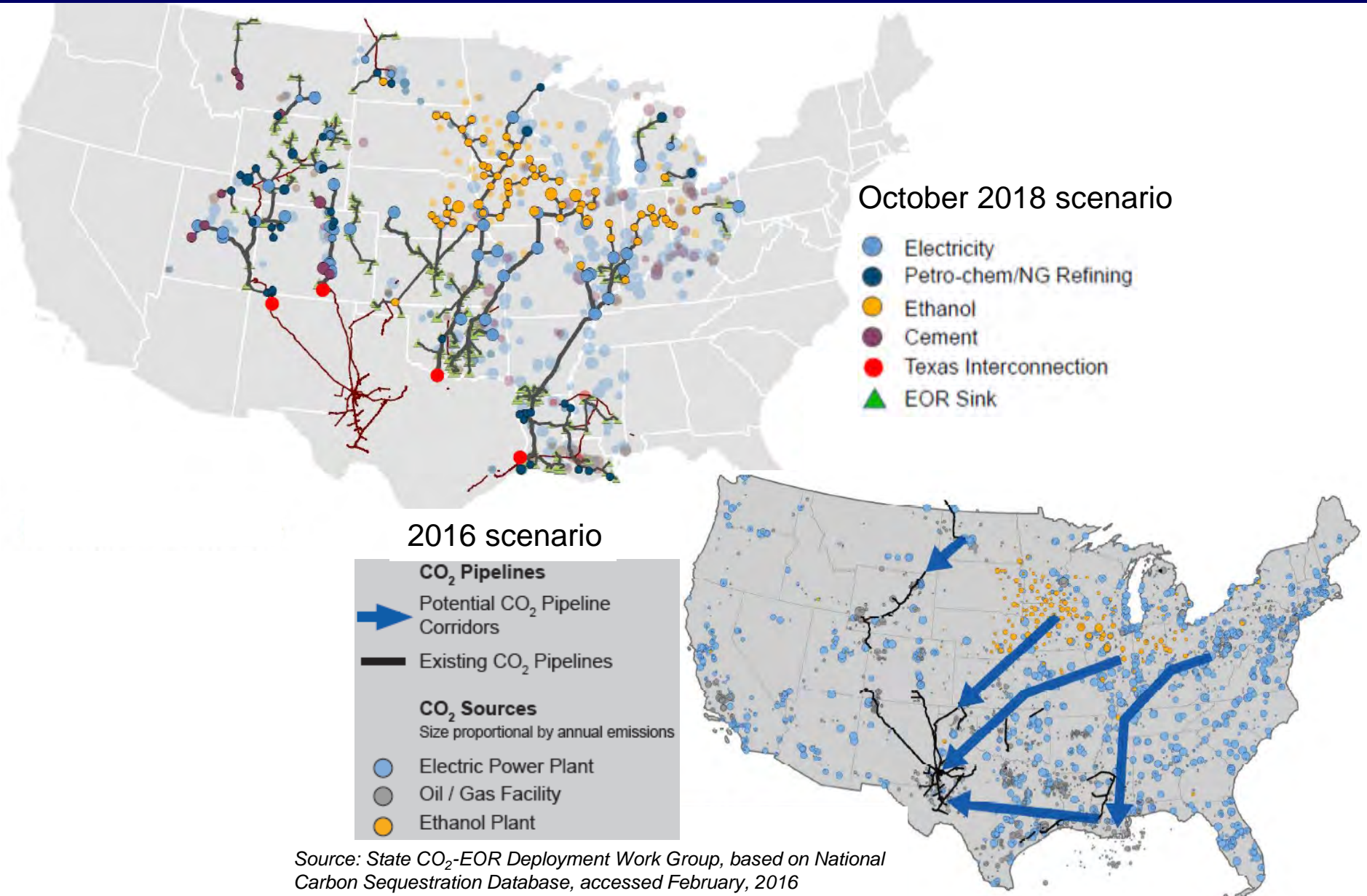
 Industrial CO₂ Source

 CO₂ Pipeline

 CO₂ Proposed Pipeline

Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2014 and other sources.

U.S. CO₂ pipeline infrastructure



Major CCUS demonstration projects

Air Products Facility (Port Arthur, TX) – operations began in 2013



- Built and operated by Air Products and Chemicals Inc. at Valero Oil Refinery
- State-of-the-art system to capture CO₂ from two large **steam methane reformers**
- **5.0 million metric tons of CO₂** captured and transported via pipeline to oil fields in eastern Texas for **enhanced oil recovery (EOR)** since March 2013

Petra Nova CCS (Thompsons, TX) – operations began in 2017



- Joint venture by NRG Energy, Inc. (USA) and JX Nippon Oil and Gas Exploration (Japan)
- Demonstrating Mitsubishi Heavy Industries' solvent technology to **capture 90% of CO₂ from 240-MW flue gas stream** (designed to capture/store 1.4 million metric tons of CO₂ per year)
- **Nearly 2.5 million metric tons of CO₂** used for **EOR** in West Ranch Oil Field in Jackson County, Texas since January 2017

ADM Ethanol Facility (Decatur, IL) – operations began in 2017



- Built and operated by Archer Daniels Midland (ADM) at its existing biofuel plant
- CO₂ from **ethanol biofuels production** captured and stored in **deep saline reservoir**
- **First-ever CCS project** to use new U.S. Environmental Protection Agency (EPA) Underground Injection **Class VI well permit**, specifically for CO₂ storage
- **1.0 million metric tons of CO₂** captured, **0.8 million metric tons** of which **stored**, since April 2017

Federal investment in DOE CCUS R&D



Carbon capture

R&D and scale-up technologies for capturing CO₂ from new and existing industrial and power-producing plants



CO₂ utilization

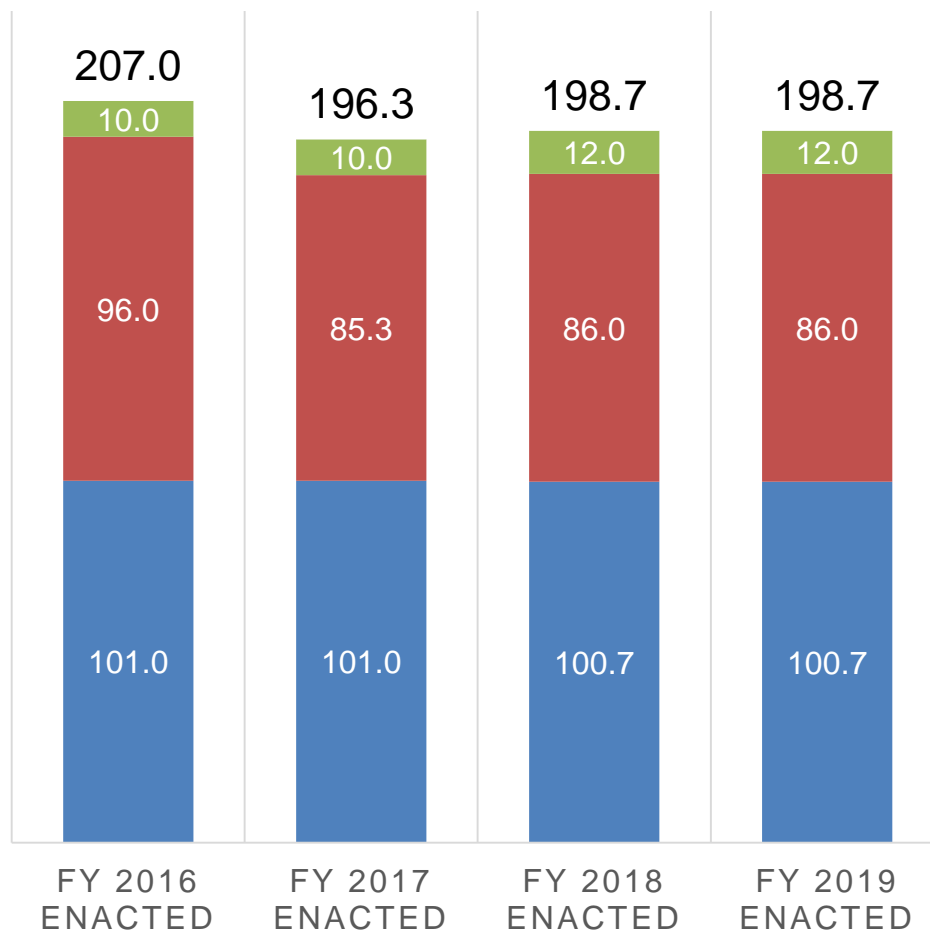
R&D and technologies to convert CO₂ to value-added products



Carbon storage

Safe, cost-effective, and permanent geologic storage of CO₂

\$ millions



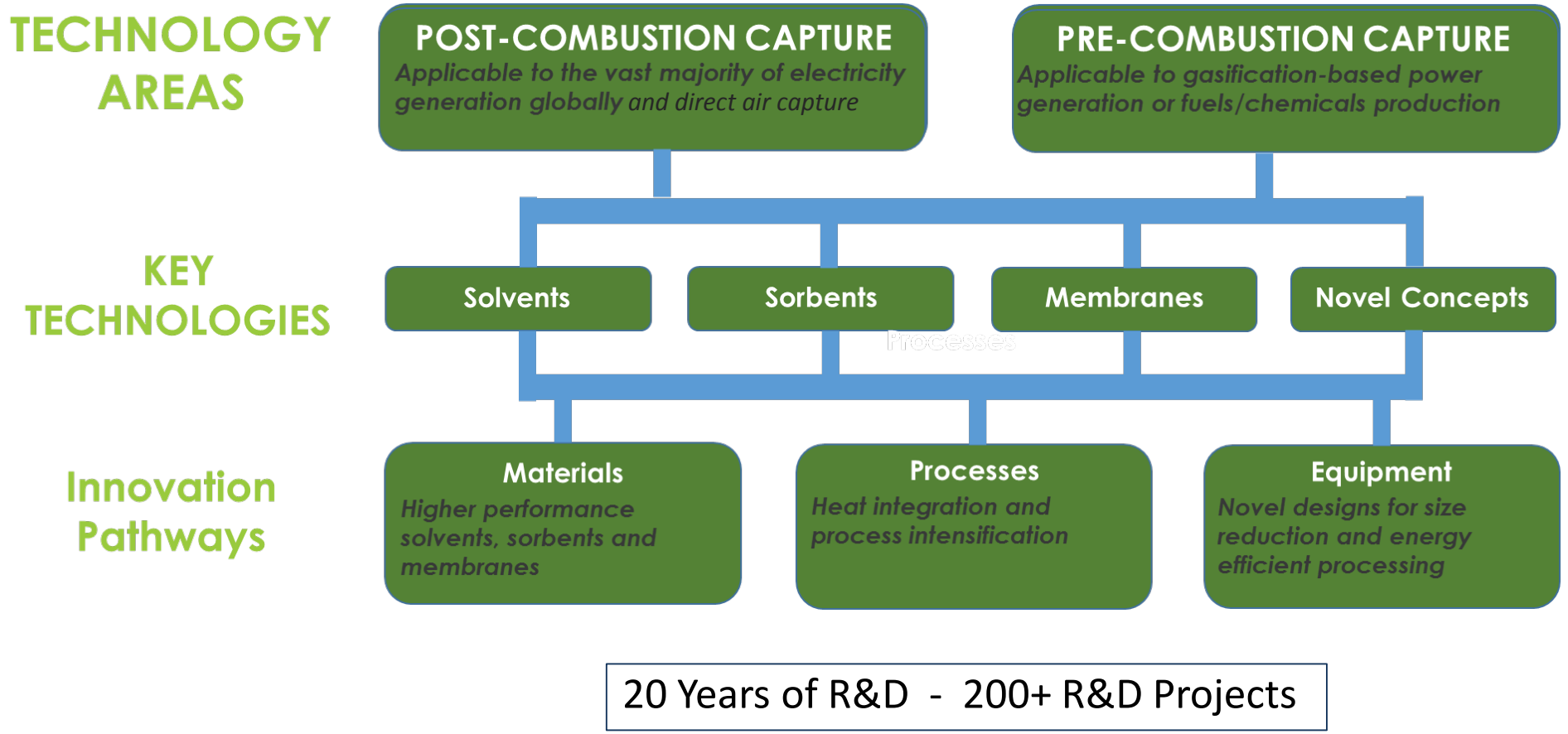
■ Carbon Capture ■ Carbon Storage ■ Carbon Utilization

High-level R&D program goals and challenges

- Reduce the cost of capture by 50%
 - Capital cost
 - Energy penalty
 - Integration or process intensification
- Develop viable carbon utilization altern
 - Reduce capital cost
 - Reduce energy requirements
 - Lifecycle assessment
- 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)
 - Cost / uncertainty / enabling real-time decision making



Carbon Capture R&D Program Structure and Focus



Post Combustion Capture

National Carbon Capture Center - Benefits to Program

- Operated by Southern Co Services
- Hosted at Plant Gaston, AL
- DOE funds 80% of operations
- Over 100,000 test hours (10+ years)
- Technologies from U.S. and six other countries since 2008 founding of NCCC
- More than 50 carbon capture technologies tested
 - 30+ Post combustion
 - 20+ Pre-combustion
- Dedicated staff of plant engineers
- Standard design guidelines
- Small (0.05 MWe) and Large (0.5 MWe) Solvent Test Units

Lab-Scale Unit



Bench-Scale Unit



Small Pilot-Scale Unit

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

Summary of Progress Developing Carbon Capture Technologies at the Small Pilot Scale



Pilot-scale Testing

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

* Project Completed

Engineering Scale Testing of Advanced Carbon Capture Technologies

Scaling of Carbon Capture Technologies to Engineering Scales Using Existing Host Site Infrastructure

Performer	Project Title	Technology
Research Triangle Institute	Engineering Scale Testing of Transformational Non-Aqueous Solvent-Based CO ₂ Capture Process at Technology Centre Mongstad (13MWe)	Non Aqueous Solvent
SRI International	Engineering Scale Demonstration of Mixed-Salt Process for CO ₂ Capture (15MWe)	Physical Solvent
Membrane Technology and Research, Inc.	Scale-Up and Testing of Advanced Polaris Membrane CO ₂ Capture Technology (1MWe+)	Membrane – Partial Capture
TDA Research, Inc.	Membrane-Sorbent Hybrid System for Post-combustion Carbon Capture (2MWe+)	Membrane / Sorbent – 90% capture
Fluor	Multi-component solvent test (13MWe)	Water lean solvent

- Existing solvent units for drop-in testing
- Supports 4000+ hours each project
- Solvents go through rigorous degradation tests to support environmental permitting at SINTEF
- Full analytical and operations staff support



Source: Technology Centre Mongstad

Design and Testing of Advanced Carbon Capture Technologies

Initial Engineering, Testing, and Design of a Commercial-Scale, Post-Combustion CO₂ Capture System

Lead	Project Title	Technology
Electric Power Research Institute	Initial Engineering Design of a Post-Combustion CO ₂ Capture System for Duke Energy's East Bend Station Using Membrane-Based Technology	Membrane – Partial Capture
ION Engineering LLC	ION Engineering Commercial Carbon Capture Design & Costing (C3DC)	Non Aqueous Solvent
University of North Dakota	Initial Engineering, Testing, and Design of a Commercial-Scale, Post-combustion CO ₂ Capture System on an Existing Coal-Fired Generating Unit – Milton R. Young Station	Amine Solvent

- **Directed by Congress in FY17 and supporting language in FY18 appropriations reports**
- **Feasibility studies to be complete in 12-24 months**
- **Deliverable is a cost estimate for a commercial scale application of the technology at potential host power plants**



East Bend Generating Station (KY)



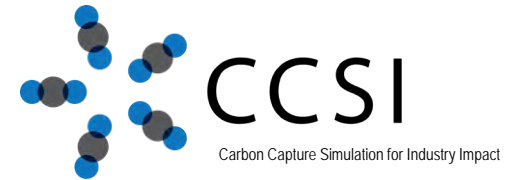
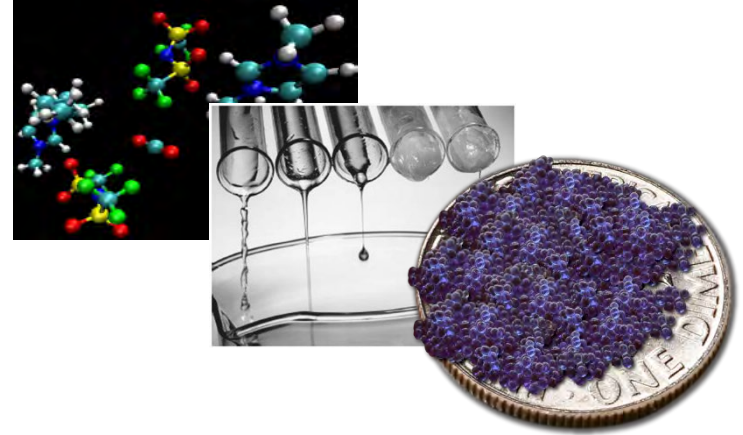
Milton R. Young Station (ND)



Gerald Gentleman Station (NE)

Future Carbon Capture Activities

- \$30/tonne - Transformational Carbon Capture Technologies for both pre and post combustion capture
- Direct Air Capture (leverage existing DAC projects, historical investments in post-and pre-combustion capture, and NAS study)
- Process development and design – R&D and Carbon Capture Simulation Initiative for Industry
- Technology Validation – National Carbon Capture Center and other test centers
- FEED Studies for Commercial Carbon Capture Plants – 2019 FOA



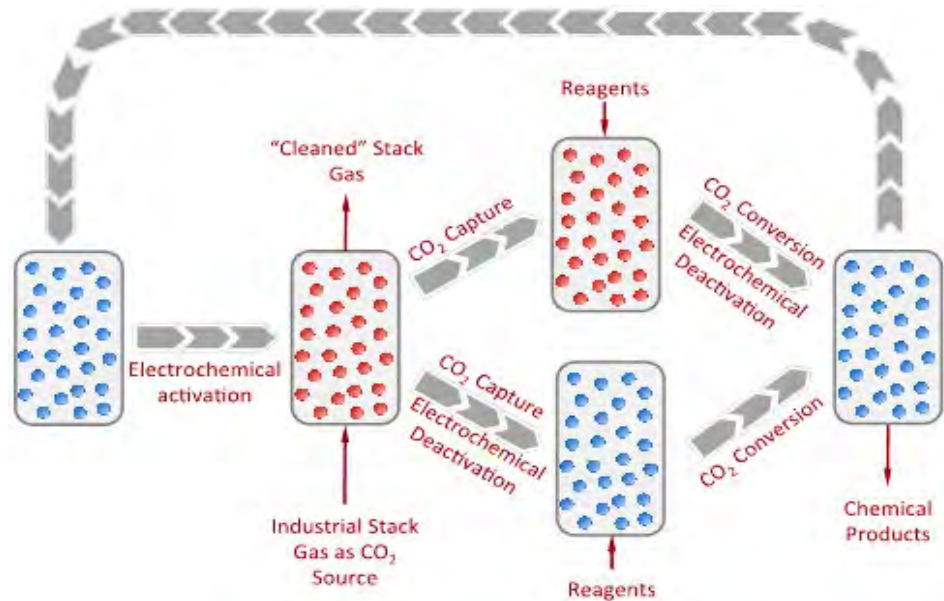
Carbon Utilization

Offset CO₂ capture costs + Fix CO₂ in stable products

Biological capture & conversion



Fuels & chemicals



Mineralization & cements



Approximately 20 active projects which span each of these areas.

Carbon Storage Infrastructure/Field Tests

Addressing Large-Scale Challenges

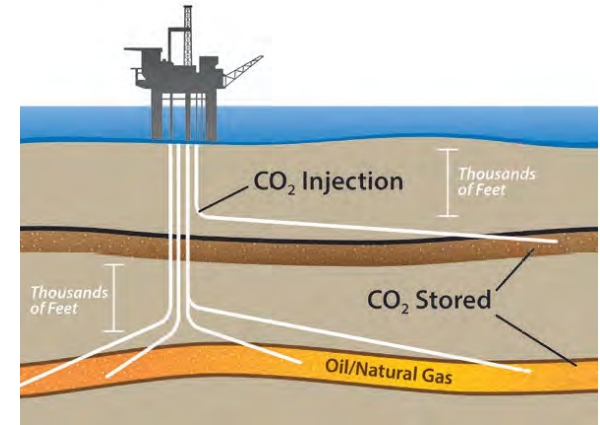
Regional Carbon Sequestration Partnerships (RCSPs)



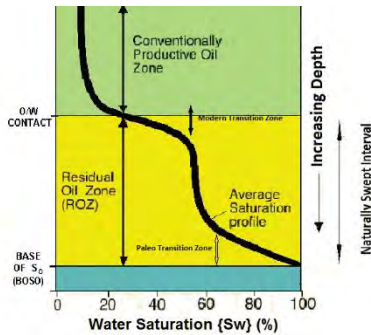
CarbonSAFE



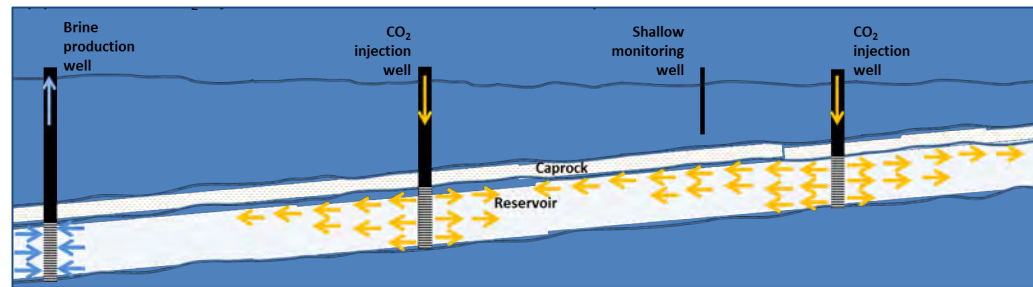
Offshore Storage



Unconventional EOR



Brine Extraction Storage Tests (BEST)

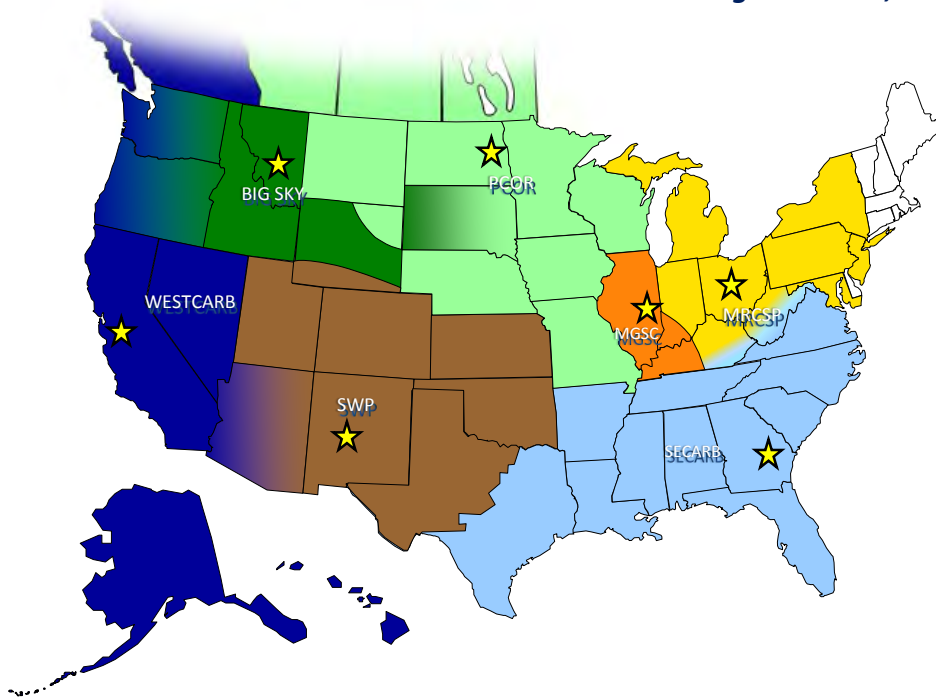


Regional Carbon Sequestration Partnerships

Developing the Infrastructure for Wide Scale Deployment

Seven Regional Partnerships

400+ distinct organizations, 43 states, 4 Canadian Provinces



- Engage regional, state, and local governments
- Determine regional sequestration benefits
- Baseline region for sources and sinks
- Establish monitoring and verification protocols
- Validate sequestration technology and infrastructure



Characterization Phase (2003-2005)

Search of potential storage locations and CO₂ sources

Found potential for 100s of years of storage



Validation Phase (2005-2011)

20 injection tests in saline formations, depleted oil, unmineable coal seams, and basalt





Development Phase (2008-2018+)

6 large scale injections (over 10 million tons injected)

Commercial scale understanding and validation

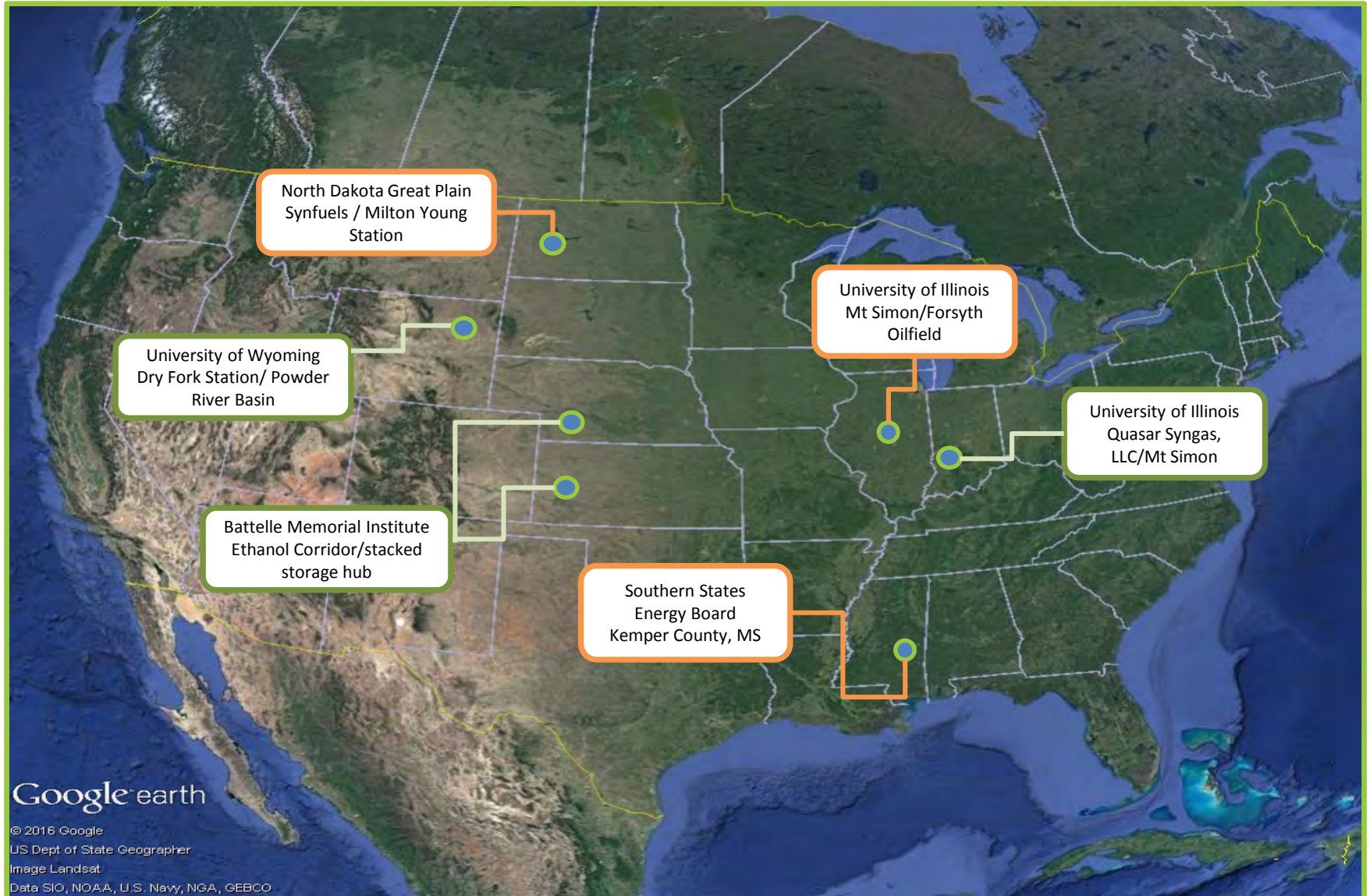
Carbon Storage Assurance Facility Enterprise (CarbonSAFE)

- Goal: Identify and certify geologic storage sites at commercial volumes (50+ million metric tons of CO₂)
- Phase I: Integrated CCS Pre-Feasibility (12-18 months) 
 - Formation of a team
 - Development of a plan encompassing technical requirements, economic feasibility and public acceptance, and
 - High-level technical evaluations of the sub-basin and potential CO₂ source(s)
- Phase II: Storage Complex Feasibility (2 years) 
 - Includes and extends the pre-feasibility work, focusing on one or multiple specific reservoirs within the defined storage complex
 - Data collection; geologic analysis; identification of contractual and regulatory requirements and development of plans to satisfy them; subsurface modeling to support geologic characterization, risk assessment, and monitoring; and public outreach
- Phase III: Site Characterization (Under Development)

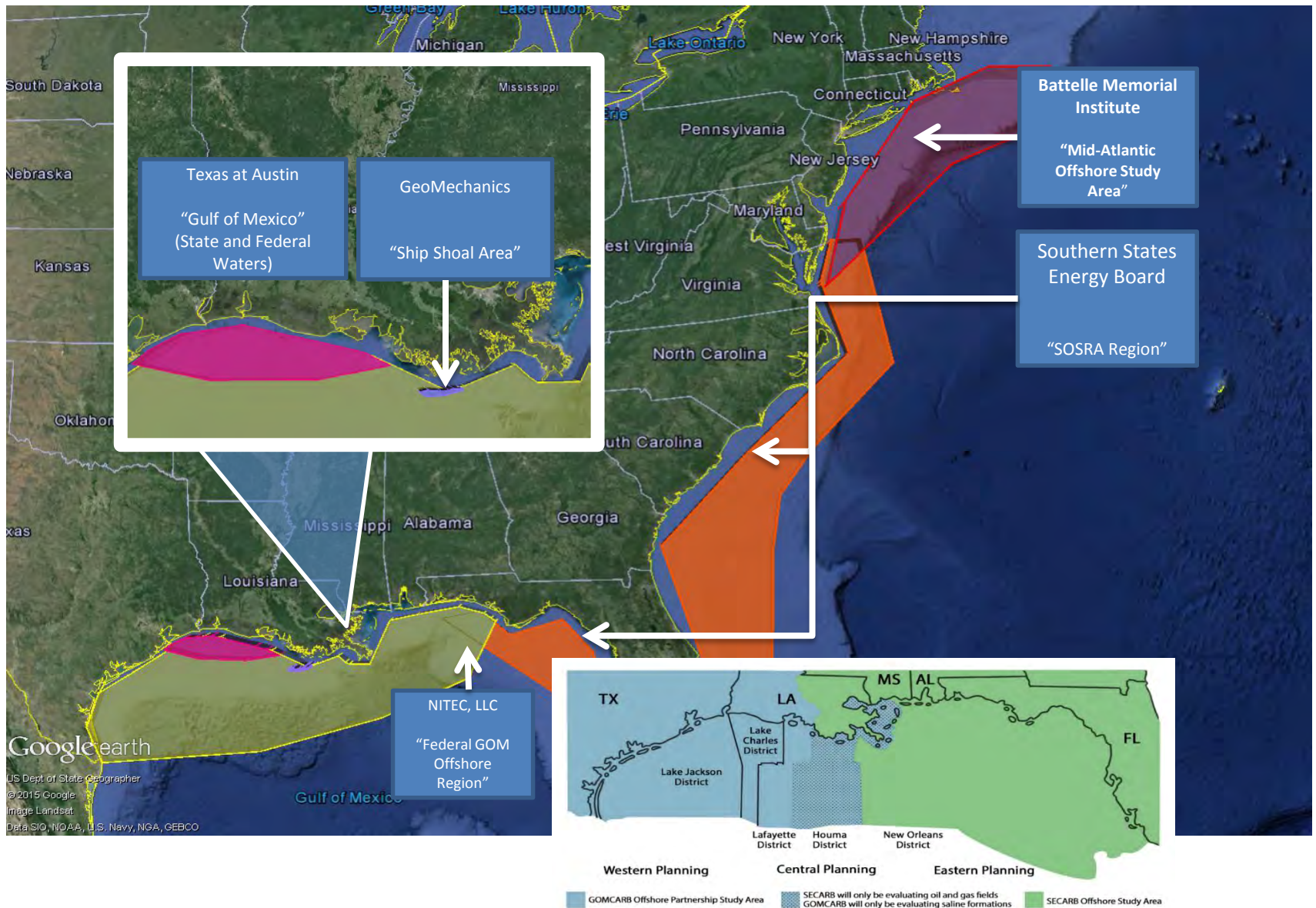
CarbonSAFE Phase I: Integrated CCS Pre-Feasibility



CarbonSAFE Phase II



Offshore Resource Assessment Projects



Brine Extraction Storage Test (BEST) Project Locations

DE-FOA-0001260

Project Locations

Rock Springs Uplift
University of Wyoming-
DE-FE0026159

Johnsons Corner
University of North
Dakota EERC-
DE-FE0026160

Decatur Site
University of
Illinois-
DE-FE0026136

Devine Test Site
University of
Texas at Austin-
DE-FE0026137

Plant Smith
Electric Power
Research Institute-
DE-FE0026140

Phase 1 projects

Projects selected
for Phase 2

Advanced Storage R&D

- **35 active projects (primarily universities and national labs; some industry)**
- **Wellbores:**
 - Ensuring integrity
- **Monitoring**
 - Seismic
 - Data
 - Intelligent Monitoring Network Systems
 - Fiber Optics
- **Stress state**
 - Determine in-situ stress state to reduce uncertainty
 - Understand geomechanical impact of vertical pressure migrations due to injection on state of subsurface stress

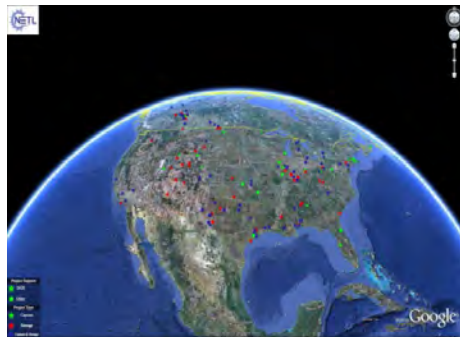
Future Carbon Storage Activities

- **Regional Deployment Initiative – current FOA**
- **CarbonSAFE Phase III – directed by Congress in FY2019 Appropriations**
- **Machine learning applications**
- **Transformational sensor development**
 - Improved accuracy, reliability and performance
 - Characterize faults and fractures
- **Modeling and simulation tools**

KNOWLEDGE SHARING PRODUCTS



Worldwide CCS Project Database



Policy Incentives for CCUS - 45Q tax credits

“Technology push” through R&D is matched with “market pull” through financial incentives

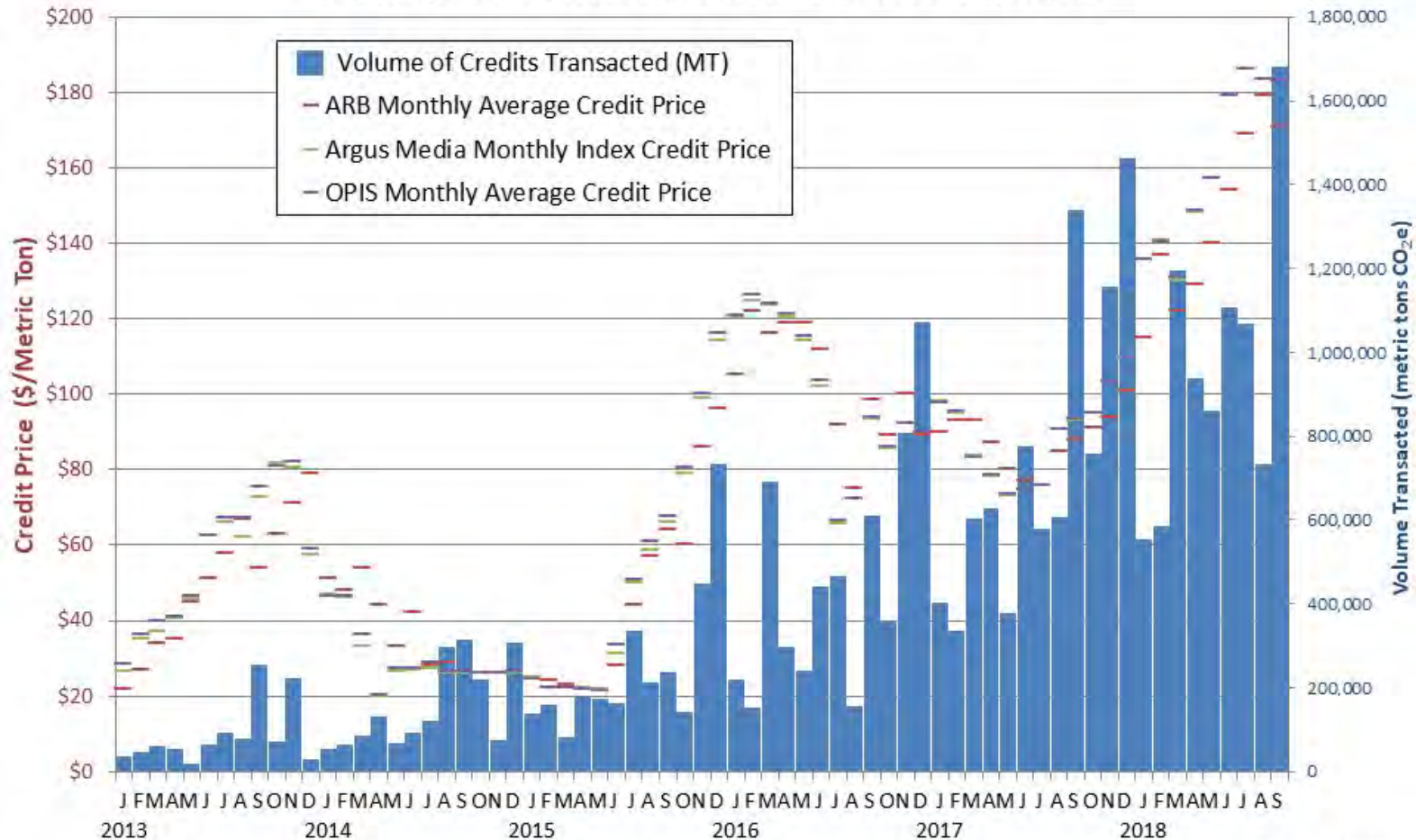
	Threshold by Facility Type (ktCO ₂ /y)			Credit in 2026 (\$/t)
	Power Plant	Industrial Facility	Direct Air Capture	
Dedicated Storage	500	100	100	50
EOR	500	100	100	35
Utilization	25	25	25	35

Source: McCoy, 2018

- Credit available to qualified facilities for 12 year period
- Defines qualified Carbon Oxides (CO or CO₂)
- Measured at point of capture and verified at the point of disposal/injection/use
- Qualified facilities:
 - 1) Construction must begin by Jan 1, 2024;
 - 2) Original planning and design includes carbon capture equipment
- Credit can be claimed by owner of capture equipment or transferred to disposal/use entity

California's Low Carbon Fuel Standard

Monthly LCFS Credit Price and Transaction Volume



Last Updated 10/10/2018

This chart tracks credit prices and transaction volumes over time. Monthly average credit prices reported by Argus Media and OPIS [used with permission] are shown along with ARB monthly average price.

Source, California ARB (2018)

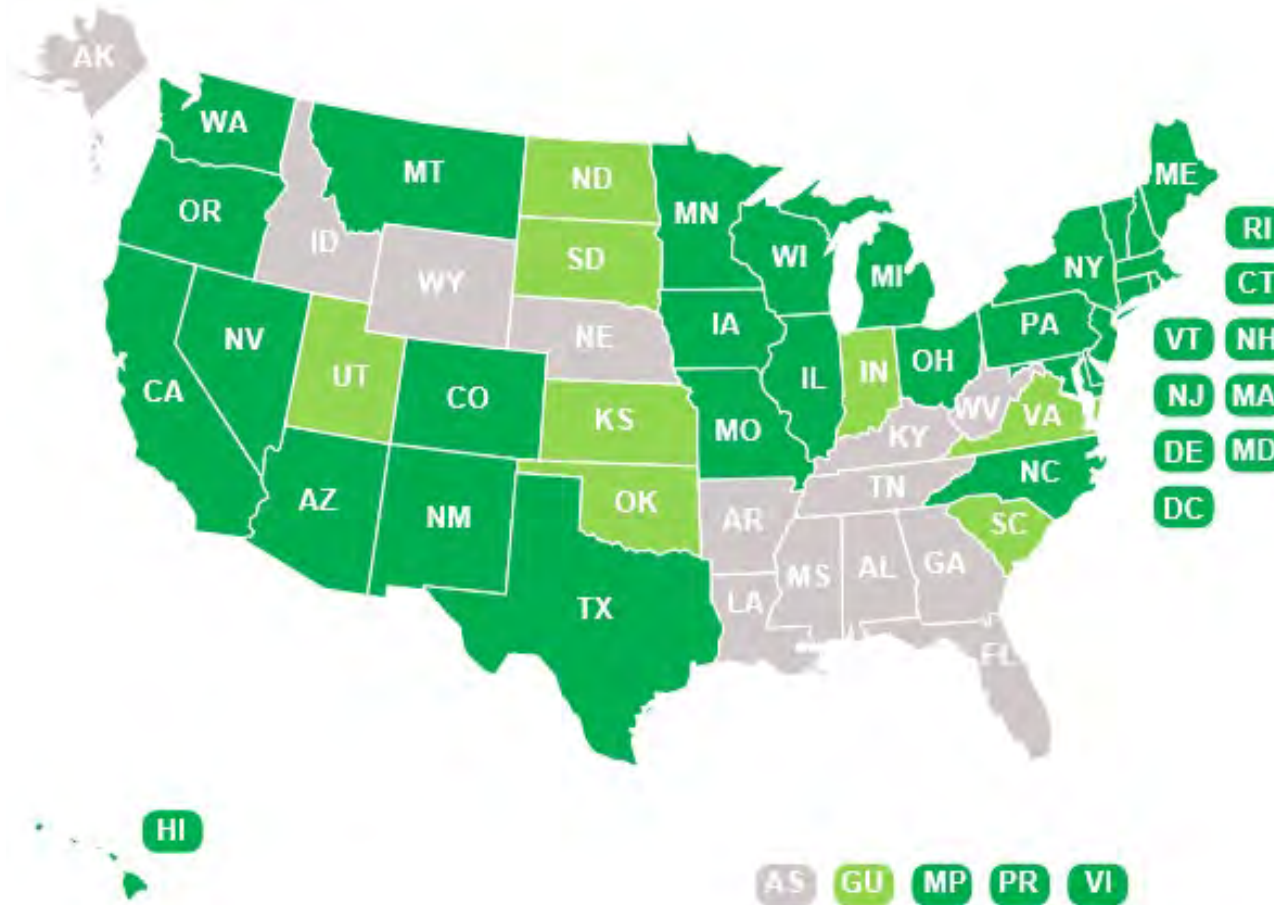
State renewable portfolio or clean energy standards can include carbon capture

Source: <http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx>

States and territories with Renewable Portfolio Standards

States and territories with a voluntary renewable energy standard or target

States and territories with no standard or target



U.S. role in multilateral CCUS partnerships

- ❑ **International Energy Agency (IEA)**
 - Working Party on Fossil Fuels (Chair)
 - Greenhouse Gas R&D Programme (GHG) *ExCo member*
 - Clean Coal Centre (CCC) *ExCo Chair*
 - CCS Unit – CCS Roadmap and International CCS Regulatory Network
- ❑ **Carbon Sequestration Leadership Forum (CSLF)**
 - *Secretariat and Policy Group Chair*
- ❑ **Clean Energy Ministerial (CEM) - CCUS Initiative**
 - *CCUS Initiative Lead*
- ❑ **Accelerating CCUS Technologies (ACT) Initiative**
- ❑ **Mission Innovation CCUS Initiative**
- ❑ **Asia Pacific Economic Cooperation Expert Group on Clean Fossil Energy (APEC EGCFE)**
 - *EGCFE Chair*
- ❑ **UN Economic Commission for Europe (UNECE)**
 - *Sustainable Energy Bureau Vice Chair*
- ❑ **Global CCS Institute**



The US: A global leader on CCUS research, development, and deployment

- **40+ year history of CO₂ utilization for EOR**
- **Over 600 million tons of associated storage with EOR**
- **Over 4,000 miles of CO₂ pipelines in the United States**
- **Strong efforts 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.
- **Has successfully invested in major CCUS demonstrations**
- **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.**

Thank You.