U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy

Fossil Energy's Carbon Capture, Utilization and Storage Activities

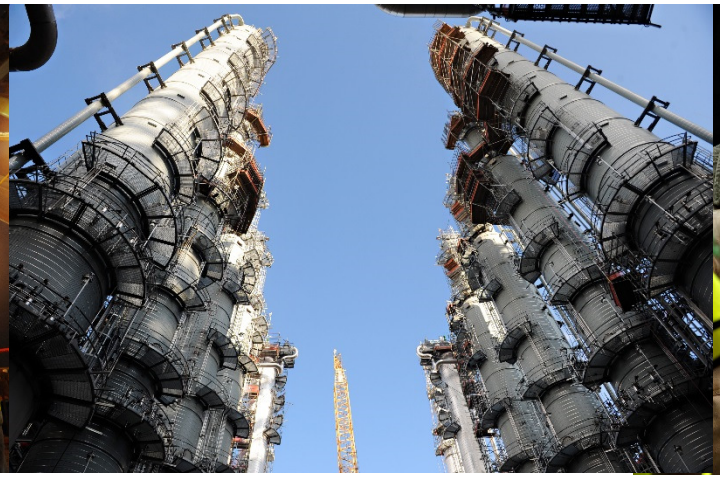
November 2018

John Litynski

Carbon Capture Program Manager

Administration Energy Priorities

- **Boosting Domestic Energy Production**
- **Grid Reliability and Resiliency**
- **Job Creation**
- **Energy Security**


United States Policy Incentives for CCUS - 45Q tax credits

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

- Tax benefits defined in "45Q" for qualified CCUS projects have been available since 2008
- The February 2018 "Bipartisan Budget Act of 2018" extended and significantly expanded the tax benefits:
  - **Increased the credit amount**:
    $20/ton → up to $50/ton for saline storage, 10/ton → up to $35/ton for EOR
  - **Expanded the qualified carbon oxides** to include carbon monoxide (CO)
  - **Expanded qualified uses** to include CO_2 utilization other than enhanced oil or natural gas recovery
  - **Lowered the qualifying threshold** for the amount of CO_2 captured to allow more industries to participate in the program
  - **Increased the flexibility** to allow credit assignment to capture or disposal facility
  - **Removed the program cap**

Major Demonstration Projects

Air Products Facility (Port Arthur, TX) – Began Operations 2013

- Built and operated by Air Products and Chemicals Inc. and located at Valero Oil Refinery in Port Arthur, TX
- State-of-the-art system to capture the CO_2 from two large steam methane reformers
- Captured gas transported via pipeline to oil fields in eastern Texas where it is used for EOR.
- Since 2013, the project has captured over three million metric tons of CO_2.

Petra Nova CCS (Thompsons, TX) – Began Operations 2017

- Joint venture by NRG Energy, Inc. and JX Nippon Oil and Gas Exploration
- Demonstrate the Mitsubishi Heavy Industries CO_2 capture technology ability to capture 90% of the CO_2 emitted from a 240-megawatt flue gas stream. (designed to capture/store 1.4 million tonnes of CO_2 per year)
- Captured CO_2 used for EOR at the West Ranch Oil Field in Jackson County, Texas, where it will remain sequestered underground

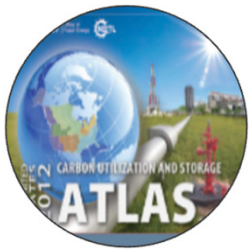
ADM Ethanol Facility (Decatur, IL) – Began Operations 2017

- Built and operated by Archer Daniels Midland (ADM) at their existing biofuel plant located in Decatur, IL
- **1 million metric tons of CO_2** as a by-product of the ethanol biofuels production process and store it in a deep saline reservoir
- First ever CCS project to use the EPA Underground Injection Class VI well permit in the United States that is specifically designed for CO_2 storage

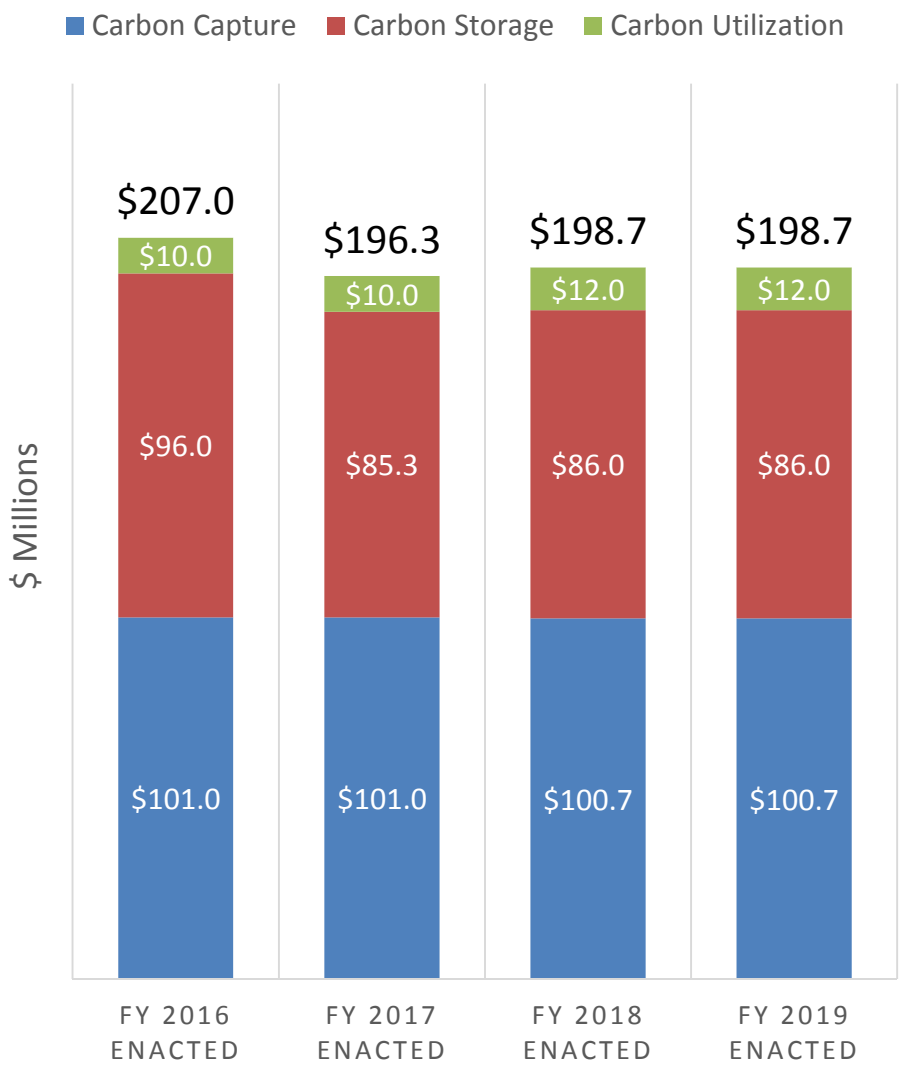
Federal Investment in Carbon Capture, Utilization and Storage R&D

Carbon Capture
R&D and scale-up technologies for capturing CO_2 from new and existing industrial and power-producing plants

CO_2 Utilization
R&D and technologies to convert CO_2 to value-added products



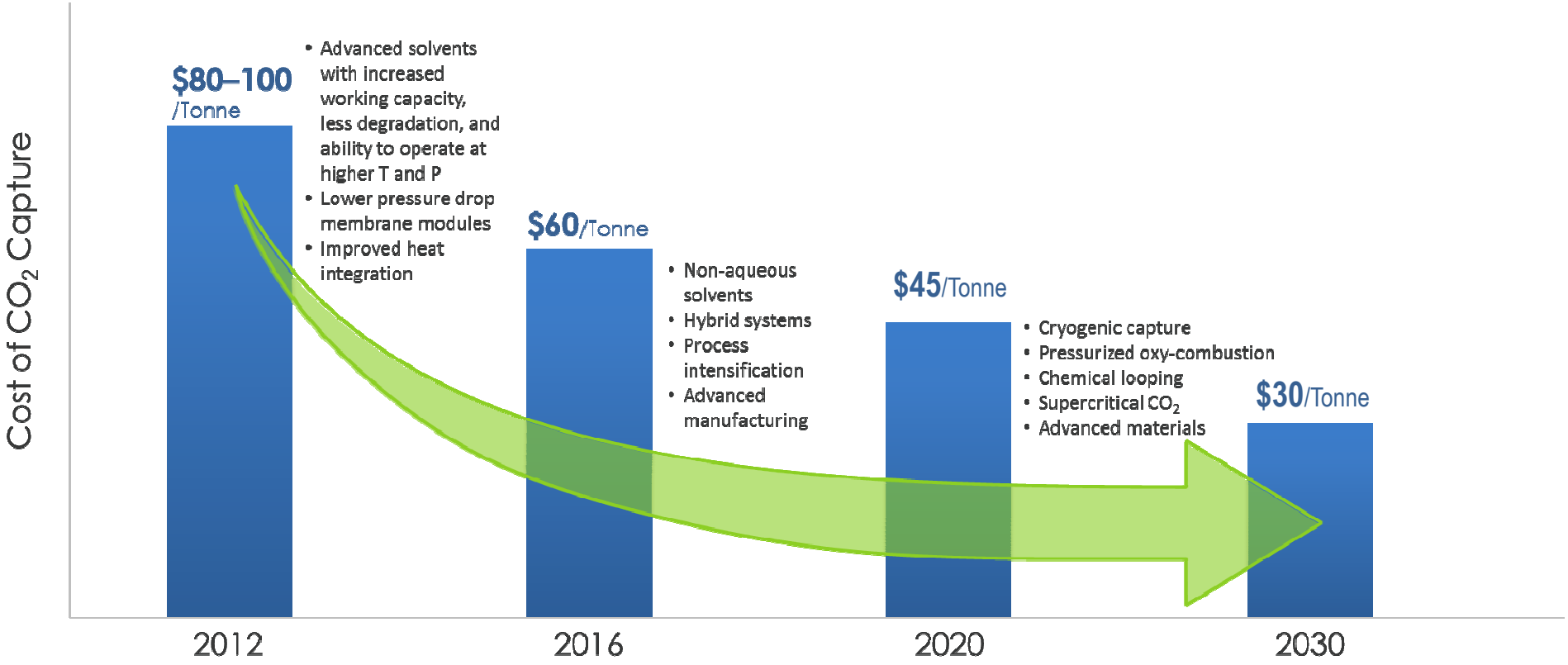
Carbon Storage
Safe, cost- effective, and permanent geologic storage of CO_2



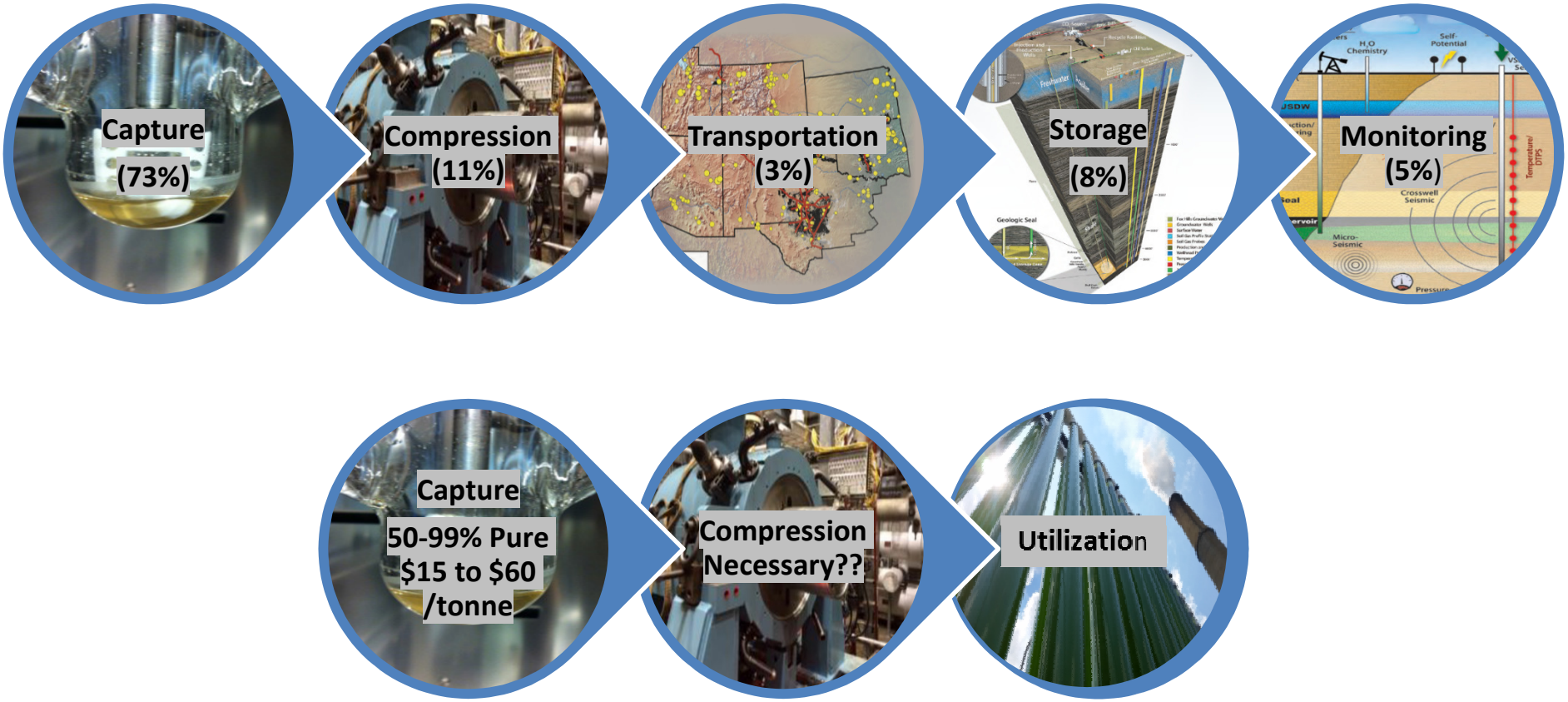
High-level R&D Program Goals and Challenges

- **Reduce the cost of capture**
  - Capital cost
  - Energy penalty
  - Integration
- **Develop viable carbon utilization alternatives**
  - Capital cost
  - Energy requirements
  - Lifecycle assessment
- **Reduce the risk of geologic storage**
  - Higher resolution and quantification (e.g., accurate characterization of faults and fractures)
  - Geomechanics (pressure and state of stress)
  - Cost

Carbon Capture Program Goals

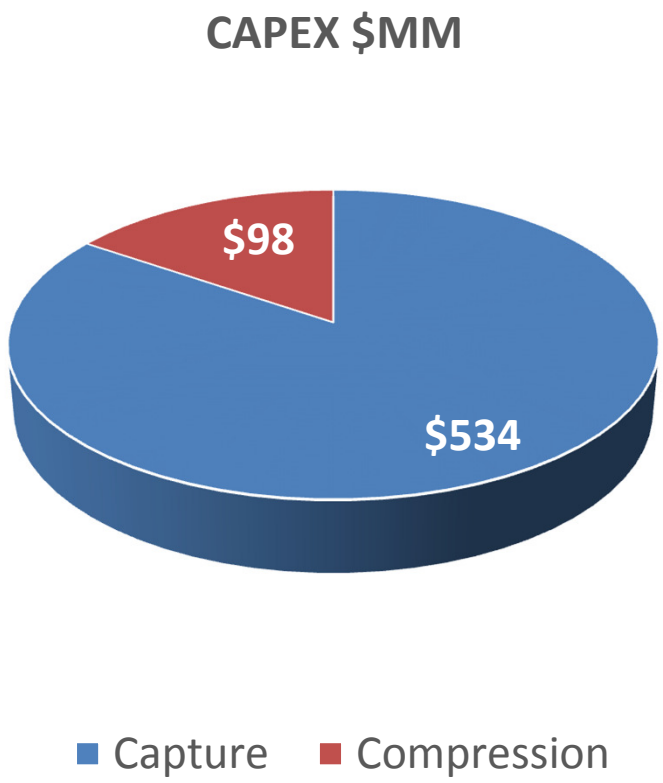


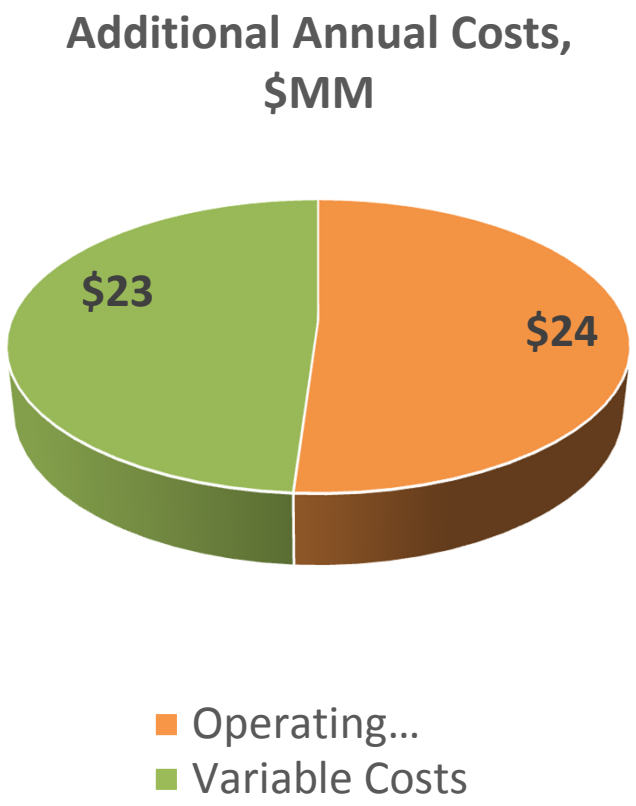
CCS and CCU Value Chains



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

Cost of Capture and Compression



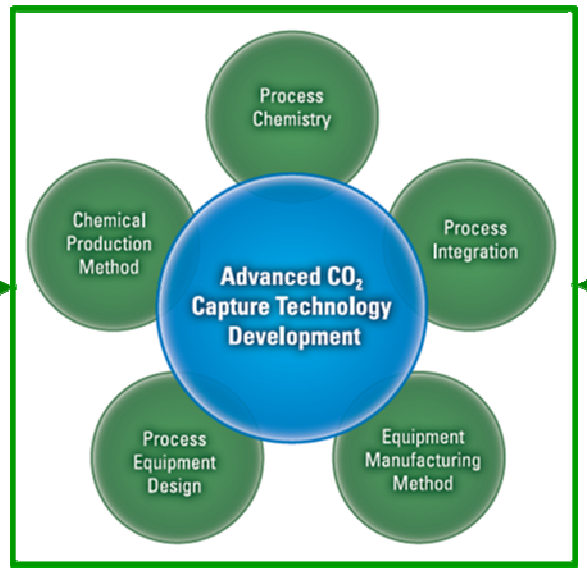


Carbon Capture

Carbon Capture R&D Pathways

Pre-Combustion

- *Solvents*
- *Sorbents*
- *Membranes*
- *Hybrid processes*
- *Water-gas shift reactor*

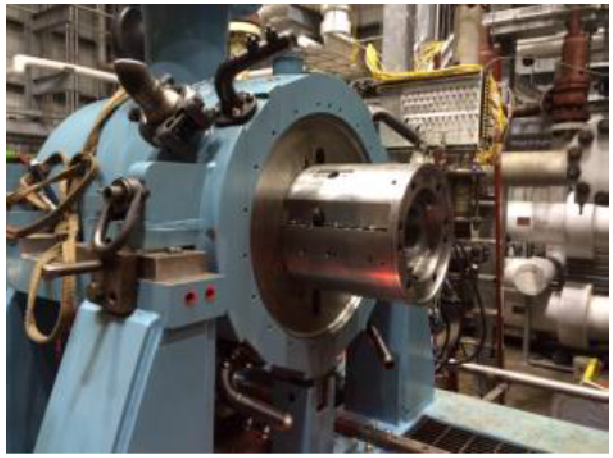


Post-Combustion

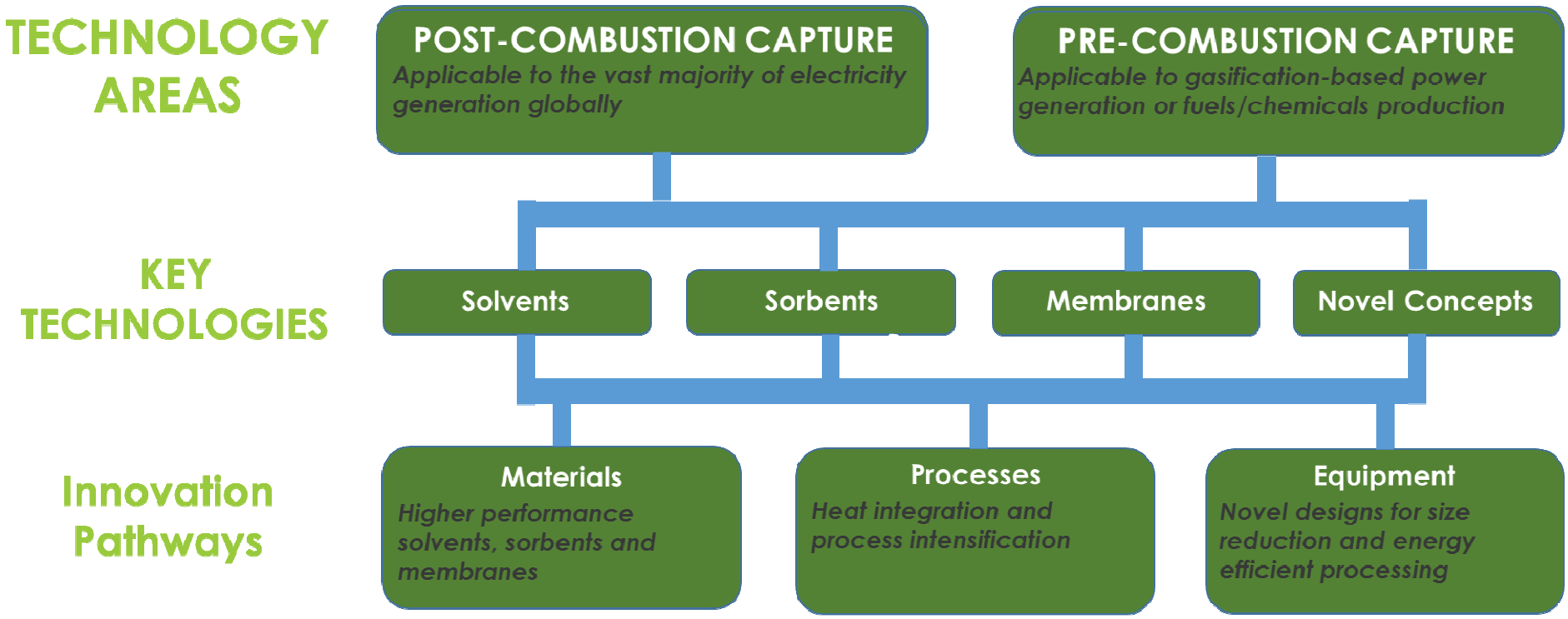
- *Solvents*
- *Sorbents*
- *Membranes*
- *Hybrid processes*

Advanced Compression

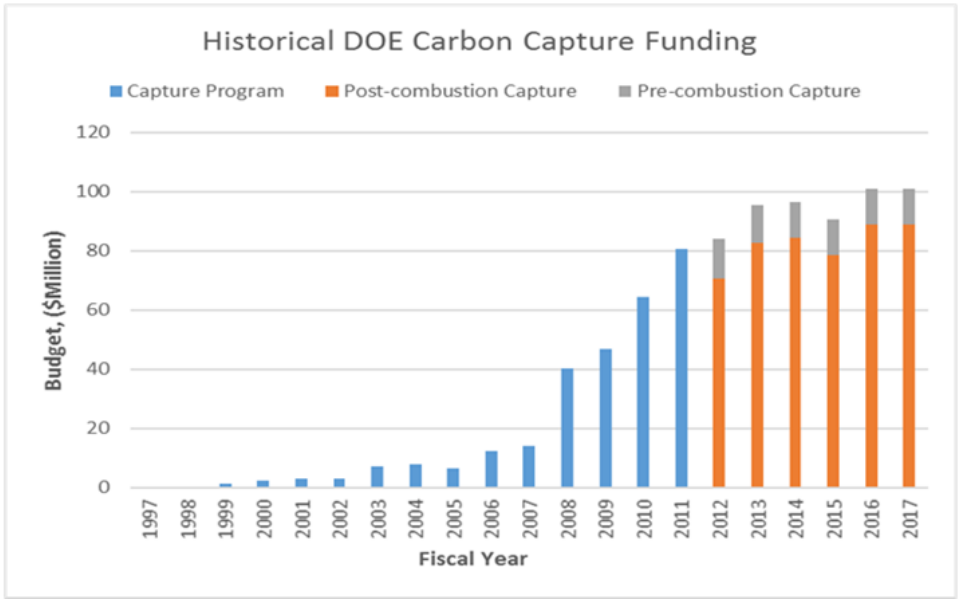
- *Intra-stage cooling*
- *Cryogenic pumping*
- *Supersonic shock wave compression*

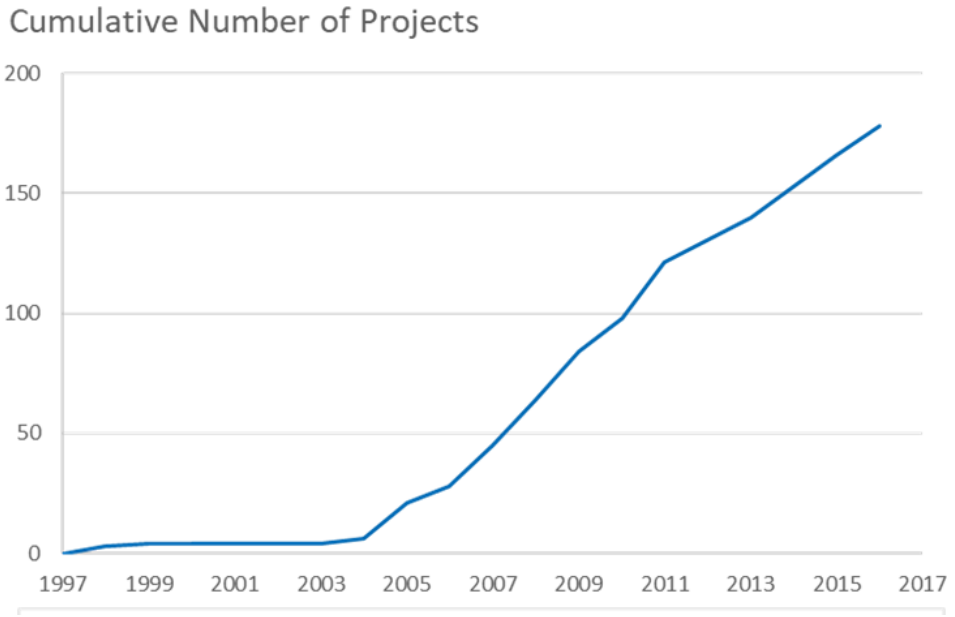


Carbon Capture R&D Program Structure and Focus



Carbon Capture R&D Program Projects and Funding



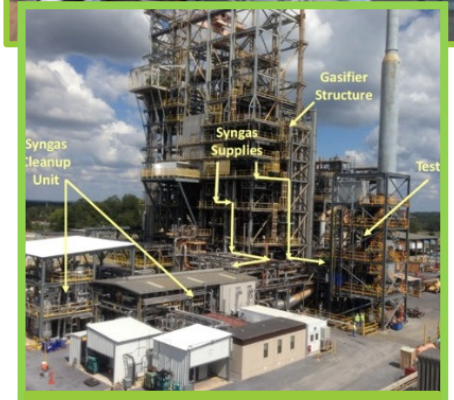


Post Combustion Capture
National Carbon Capture Center - Benefits to Program

- 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 40 carbon capture technologies tested
  - 20+ Post combustion
  - 20+ Pre-combustion
- Dedicated staff of plant engineers
- Standard design guidelines
- Small (0.05MWe) and Large (0.5MWe) Solvent Test Units
- 90+% of US developers opt for NCCC

Lab-Scale Unit

Bench-Scale Unit



TRIG - Gasifier

Small Pilot-Scale Unit

Summary of Progress Through Development of Carbon Capture Technologies

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

Cost Reduction	Energy Penalty Reduction	Program Activity
$100+/tonne	30+%	180+ Projects
$41/tonne	14-15%	15 Technologies Tested at Pilot Scale

Pilot-scale Testing

TECHNOLOGY HIGHLIGHTS	Innovation Pathways	PRINCIPAL DEVELOPER
POST-COMBUSTION		
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		
Ammonium Carbonate/Bicarbonate Solvent*	■	SRI International
Integrated Sorbent Process	■	TDA Research

Materials / Processes / Equipment

* Project Completed

Carbon Capture Simulation Initiative for Industry Impact (CCSI2)

CCSI
Carbon Capture Simulation Initiative

- **Develop new computational tools and models for industry**
  - Base development on industry needs/constraints
- **Demonstrate the capabilities of the CCSI Toolset on non-proprietary case studies**
  - Examples of how new capabilities improve ability to develop capture technology
- **Deploy the CCSI Toolset to industry**
  - T&E licenses, CRADA
  - Commercialization activities

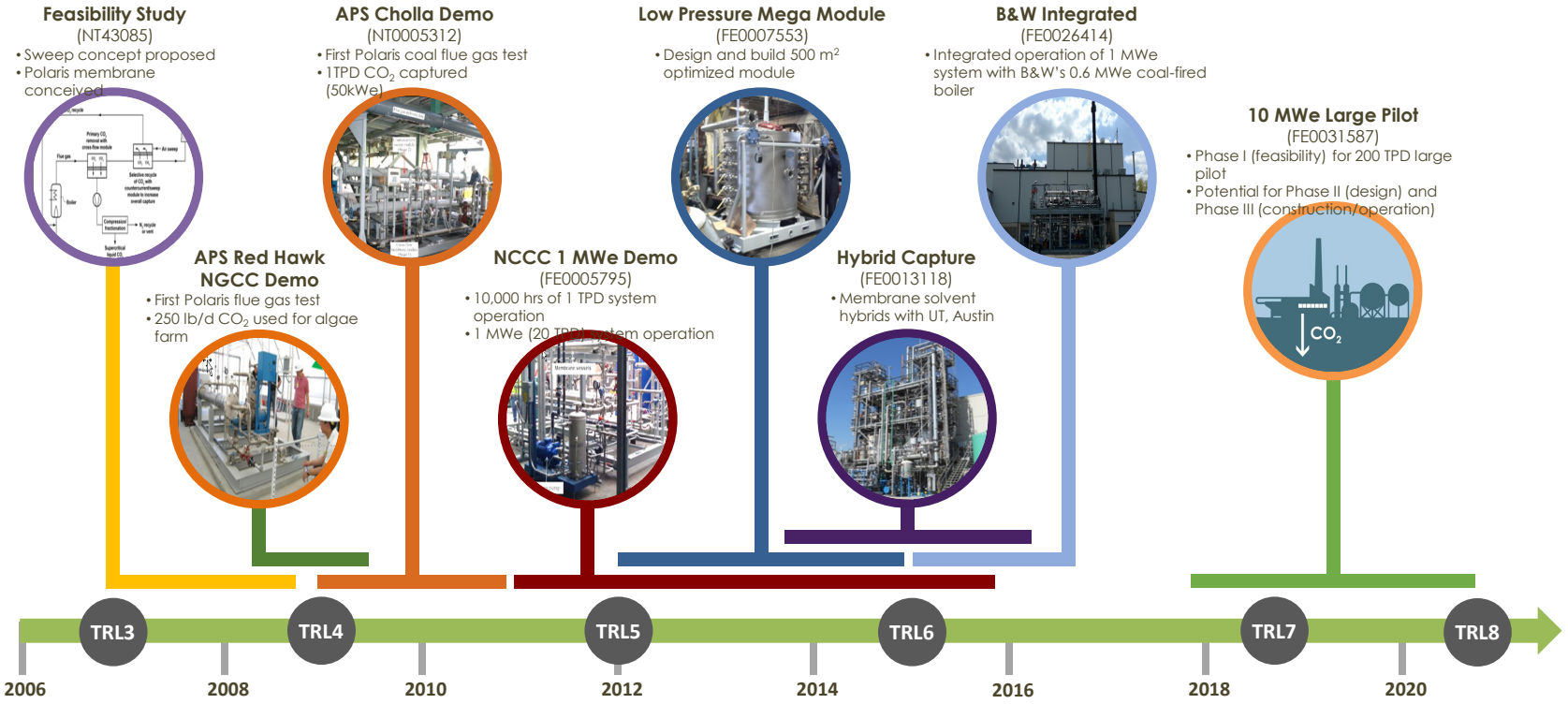
CCSI^2
Carbon Capture Simulation for Industry Impact

- **Work with industry partners on pilot projects**
  - Ensure success & maximize learning at this scale
    - Data collection & experimental design
    - Develop & Validate models
    - UQ to identify critical data
  - Develop demonstration plant design
    - Utilize optimization tools (OUU, Heat Integration)
    - Quantitative confidence on predicted performance
    - Predict dynamic performance

NETL
Berkeley Lab
Lawrence Livermore National Laboratory
Los Alamos National Laboratory Est. 1943
Pacific Northwest National Laboratory
Carnegie Mellon
West Virginia University
Princeton University
Boston University
The University of Texas at Austin

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

CO_2 Capture Development Timeline



*Add footnote here

Case Study of Technology Development Progression Through the Carbon Capture R&D Program – Ion Engineering

- ION has developed its technology by leveraging existing research facilities

2010

ION Engineering
Lab-pilot
0.05 MWe, $4M
Boulder, CO, USA

2012

Univ. of N. Dakota
EERC
0.25 MWe, $2M
Grand Forks, ND, USA

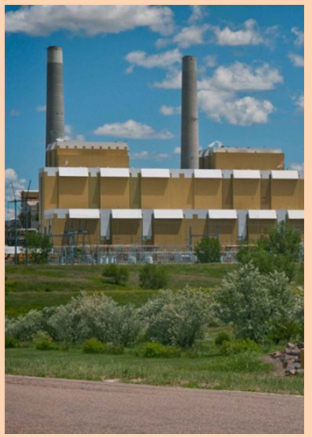
2015

National Carbon
Capture Center
0.5 MWe, $10M
Wilsonville, AL, USA

2016 - 2017

CO_2 Technology
Centre Mongstad
12 MWe, $15M
Mongstad, Norway

2018 - 2019



Design Study
NPPD
300 MWe, $3.5M
North Platte, NE, USA

FE0005799
10/01/2010 – 09/30/2013

FE0013303
10/01/2013 – 12/31/2017

FE0031595
05/30/2018 – 11/29/2019

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**
- **TCM offers considerable cost share and in-kind services at this scale ($6M+ in-kind each developer)**
- **Solvents go through rigorous degradation tests to support environmental permitting at SINTEF**
- **Full analytical and operations staff support**

Source: Test Centre Mongstad

FOA-0001791: Design and Testing of Advanced Carbon Capture Technologies

Topic Area 2 - Initial Engineering, Testing, and Design of a Commercial-Scale, Post-Combustion CO_2 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)

Accelerating the Rate of RD&D - Transformational

Partnership between national labs, academia, and industry

Accelerate deployment by 50% in TRL 2-5 range

Parallel paths for materials discovery – synthesis – process design

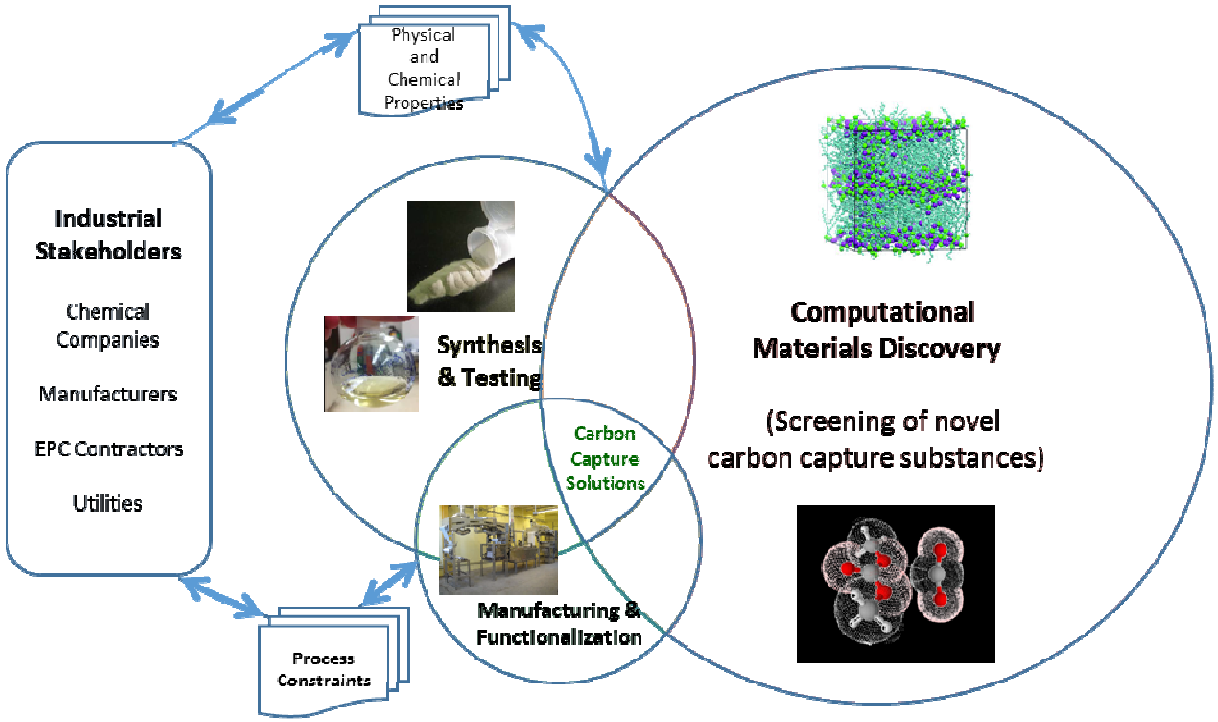
Leverage advanced computing

Robotics for rapid synthesis and analytical capabilities

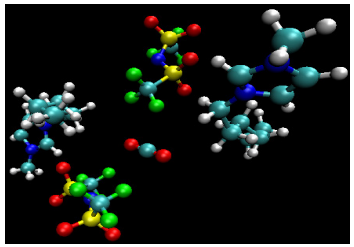
DOCCSS Labs

- **PNNL - Solvents**
- **LBNL – Metal Organic Frameworks**
- **NETL – CCSI2, materials**
- **LLNL – Adv Manufacturing**

"Transformational Technology Development"



Non-aqueous and phase change solvents



Molecular Design

Advanced Manufactinrg

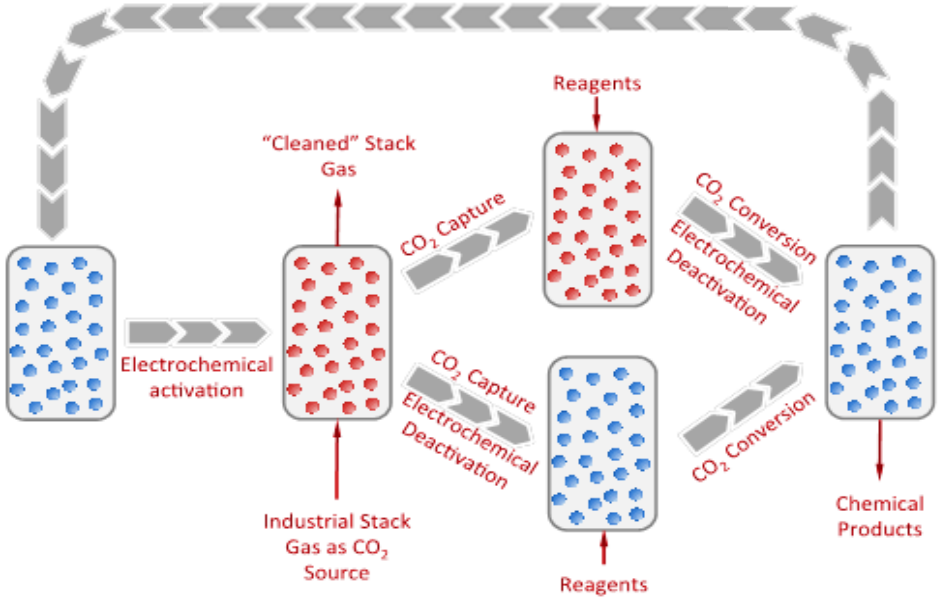
Carbon Utilization

Carbon Use & Reuse

Offset CO_2 capture costs + Fix CO_2 in stable products

Biological Capture & Conversion

Fuels & Chemicals



Mineralization & Cements

FOA-1849 - Novel Methods for Making Products from Carbon Dioxide or Coal

Objective: Develop novel marketable products using CO2 or coal as a feedstock while supporting the goals of both the Carbon Use and Reuse, and the Coal Beneficiation programs. Both use similar platforms (i.e. catalysis and other chemical methods) to convert CO2 or coal to generate valuable products.

This FOA has 3 distinct Areas of Interest (AOIs), with different requirements for each:

- **AOI 1: Lab-scale CO2 Conversion (Abiotic only)**
- **AOI 2: Field-scale CO2 Conversion (Biotic or Abiotic)**

} **$7M**

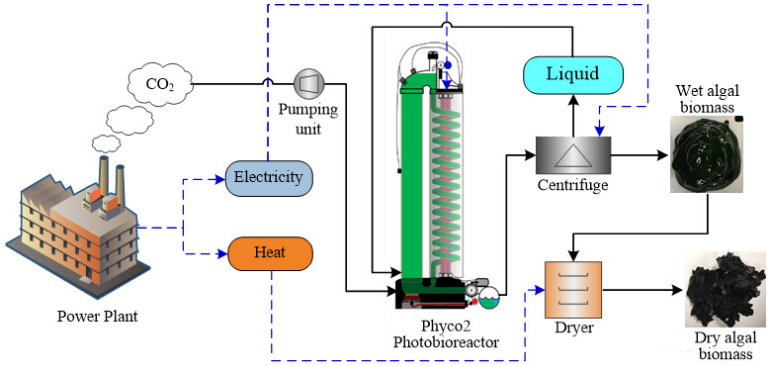
- **AOI 3: Coal Beneficiation Pilot Plant Testing - $6M**

Awards planned Q1 FY2019

Algae-Based Utilization Projects

U of Kentucky – Duke Energy's East Bend Station - *ALGIX LLC*

CO_2 to Bioplastics: Beneficial Re-use of Carbon Emissions using Microalgae

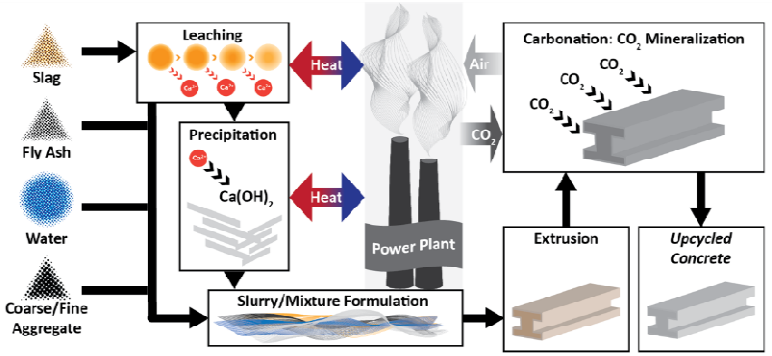


Michigan State University - *$PHYCO_2$*

FOA 1622 – FY16 and FY17 Funded Projects

Concrete Based Utilization

Performer	Project Title
University of California Los Angeles	Upcycled "CO_2-Negative" Concrete for Construction Functions
University of Michigan	Storing CO_2 in Built Infrastructure: CO_2 Carbonation of Precast Concrete Products
C-Crete Technologies, Inc	CO_2 Mineralization Using Porous Carbon and Industrial Wastes to Make Multifunctional Concrete

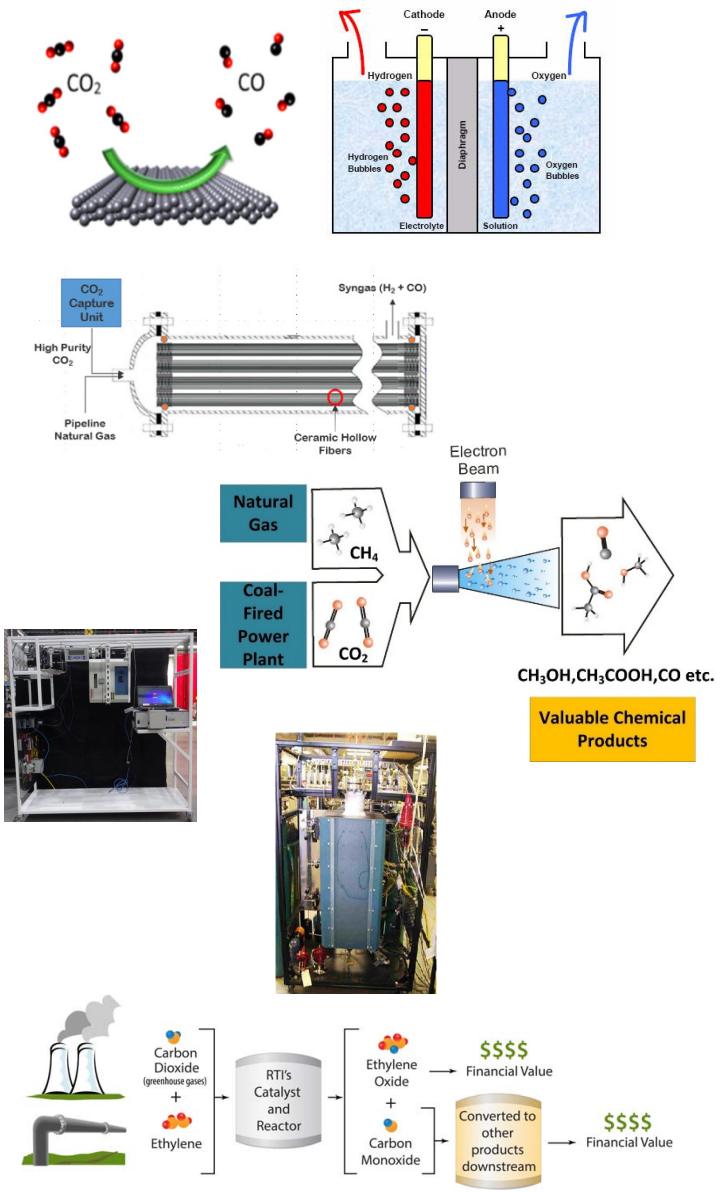


Engineered Cementitious Composites (ECC)

FOA 1622 – FY16 and FY17 Funded Projects

Fuels and Chemicals

Performer	Project Title
University of Delaware	Electrochemical Conversion of Carbon Dioxide to **Alcohols**
Gas Technology Institute	Nano-Engineered Catalyst Supported on Ceramic Hollow Fibers for Utilization of CO_2 in Dry Reforming to Produce **Syngas**
Gas Technology Institute	High Energy Systems for Transforming CO_2 to **Valuable Products**
Southern Research Institute	Low-Temperature Process Utilizing Nano-Engineered Catalyst for **Olefin** Production
TDA Research	A New Process for CO_2 Conversion to **Fuel** (Sorbent Based Conversion)
Research Triangle Institute	Novel Catalytic Process Technology for Utilization of CO_2 For **Ethylene Oxide and Propylene Oxide**



Carbon Storage

Key Challenges for Deployment

- Geomechanics
  - Induced seismicity
  - Caprock and wellbore fracture mechanics
- Improved accuracy of characterization of faults and fracture networks
- Improved accuracy of assessment of stress state
- Reservoir management strategies and technologies (e.g., pressure and plume management, intelligent/autonomous monitoring systems and sensors)
- Tools for experts and non-experts
  - Data infrastructure
  - Modeling and simulation tools for regulators and would-be operators
  - Protocols and tools for post-injection site care

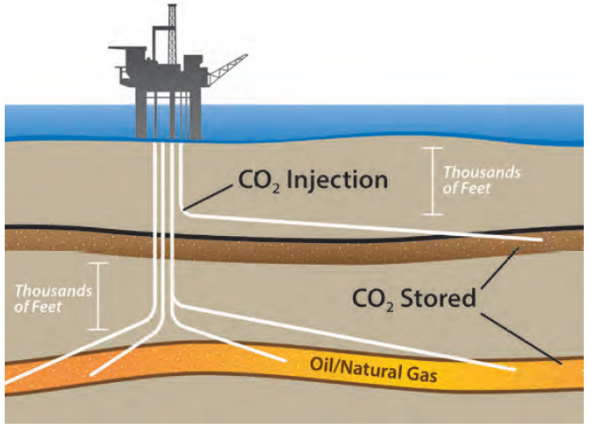
Carbon Storage Infrastructure

Addressing Large-Scale Challenges

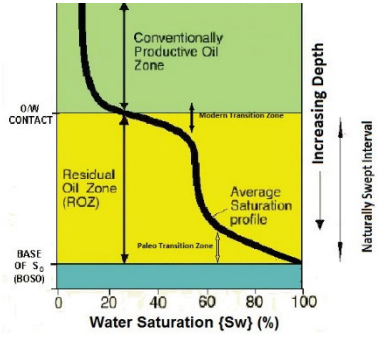
Regional Carbon Sequestration Partnerships (RCSPs)

CarbonSAFE

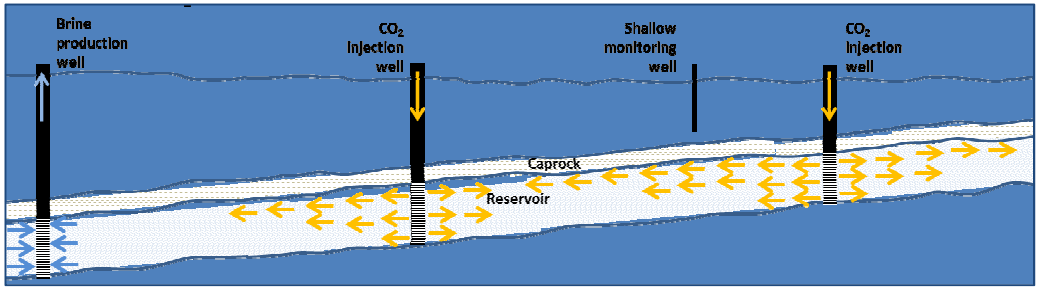
Offshore Storage



Unconventional EOR



Brine Extraction Storage Tests (BEST)

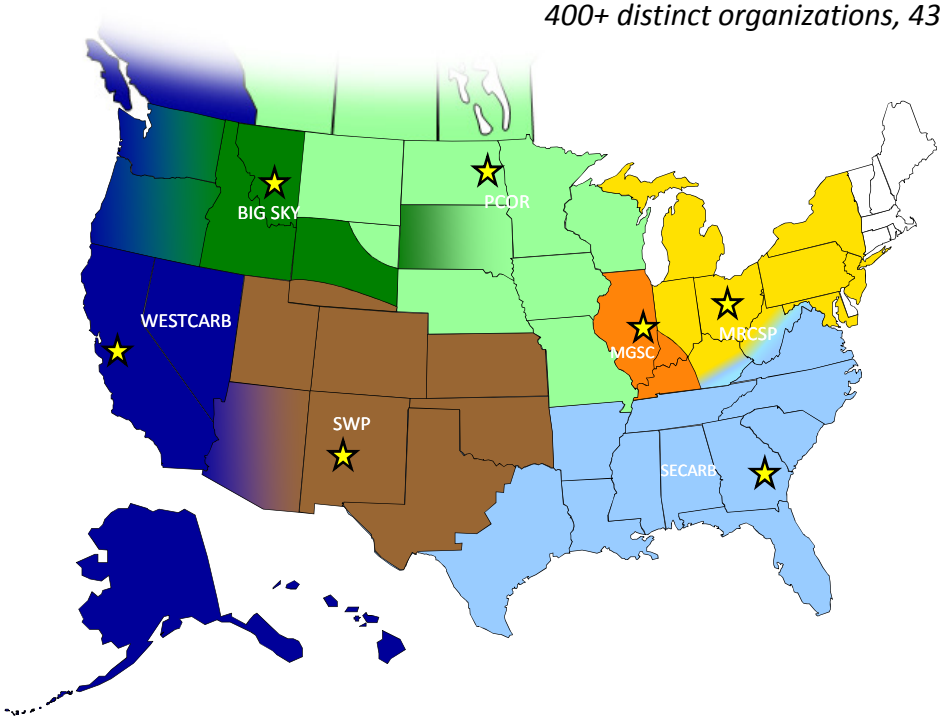


Regional Carbon Sequestration Partnerships

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 CO_2 sources	Found potential for 100s of years of storage

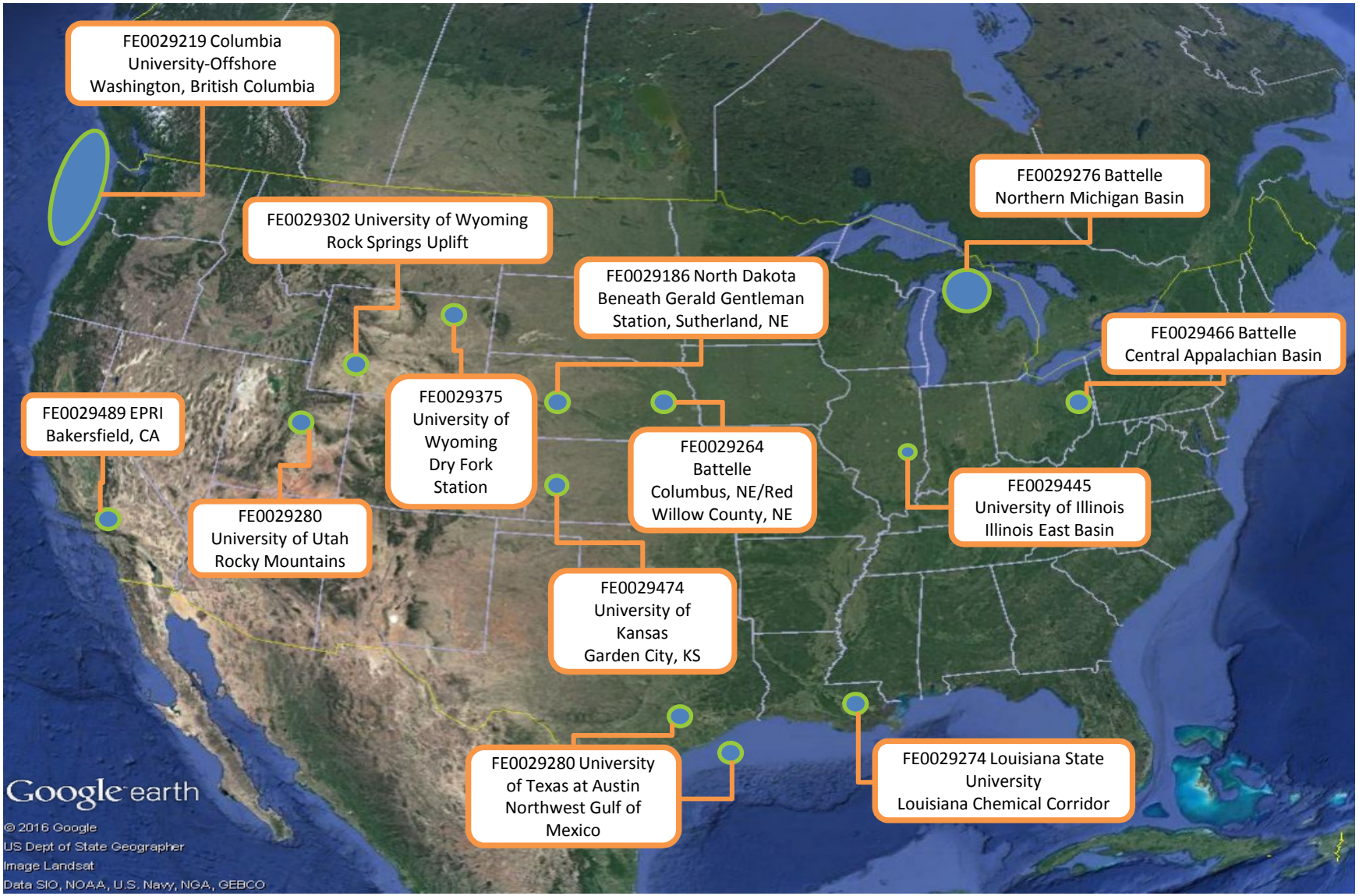
Validation Phase (2005-2011)

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

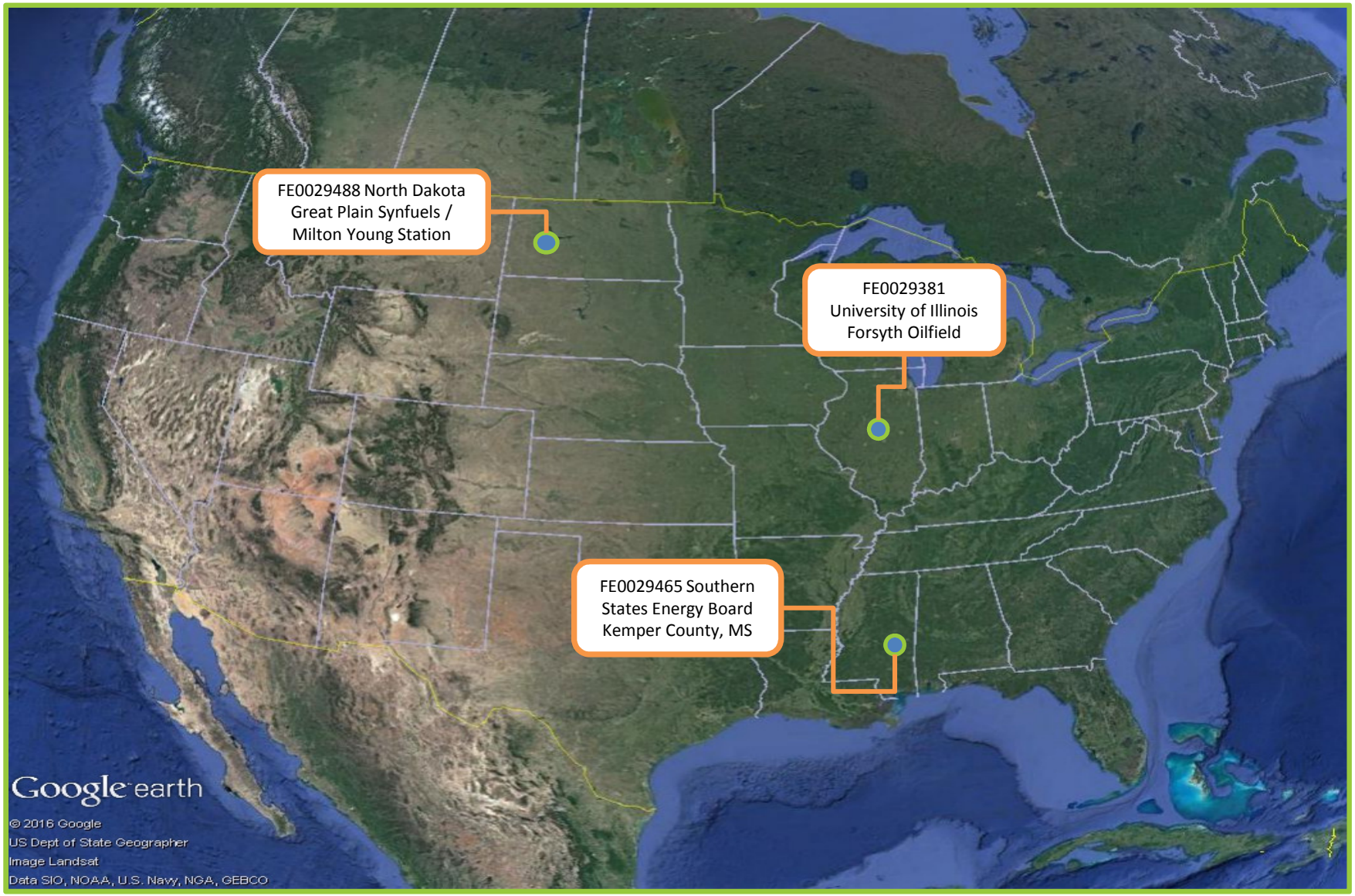
Development Phase (2008-2018+)

6 large scale injections (over 10 million tons injected)	Commercial scale understanding and validation

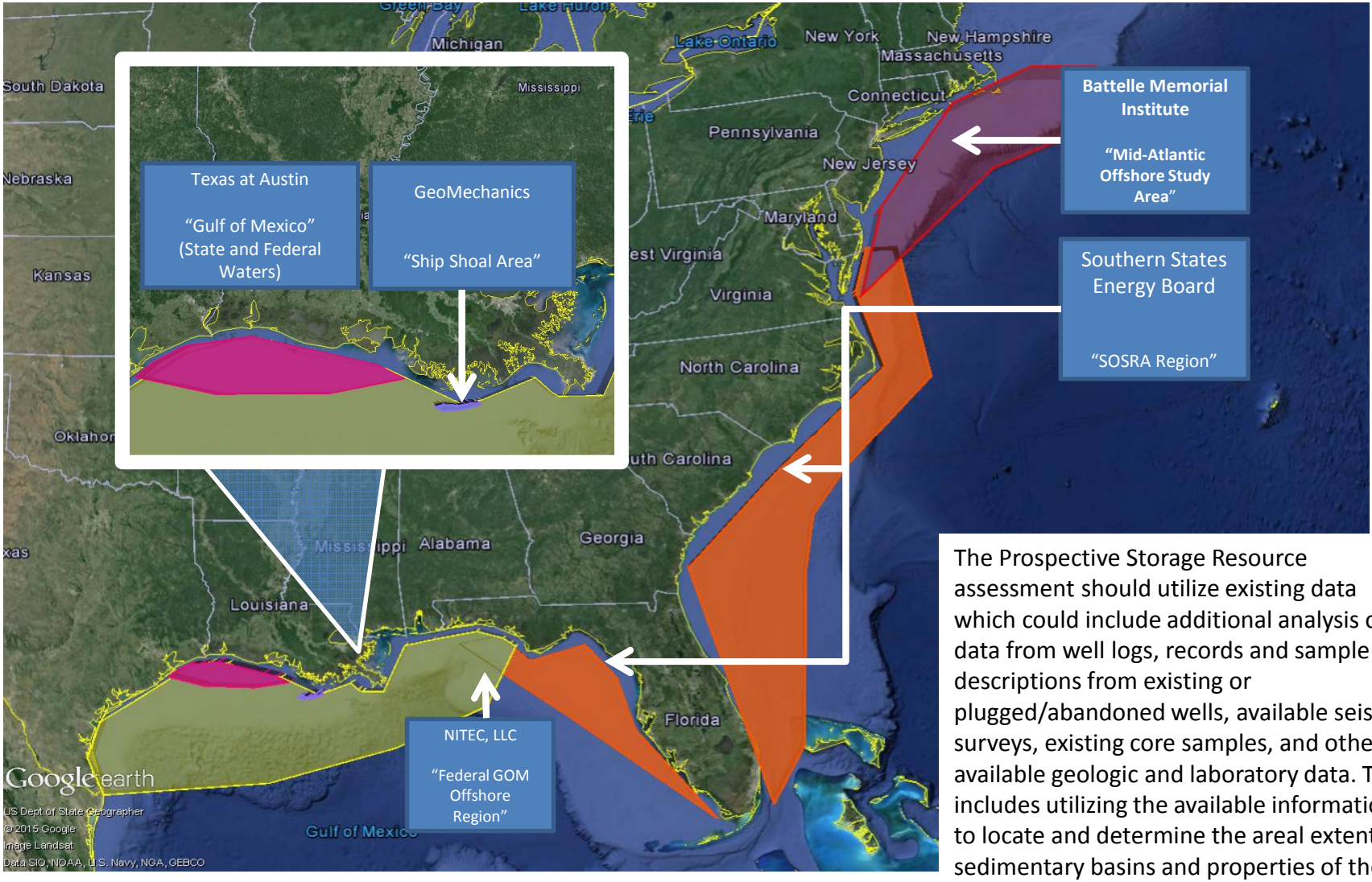
CarbonSAFE Phase I: Integrated CCS Pre-Feasibility



CarbonSAFE Phase II: Storage Complex Feasibility

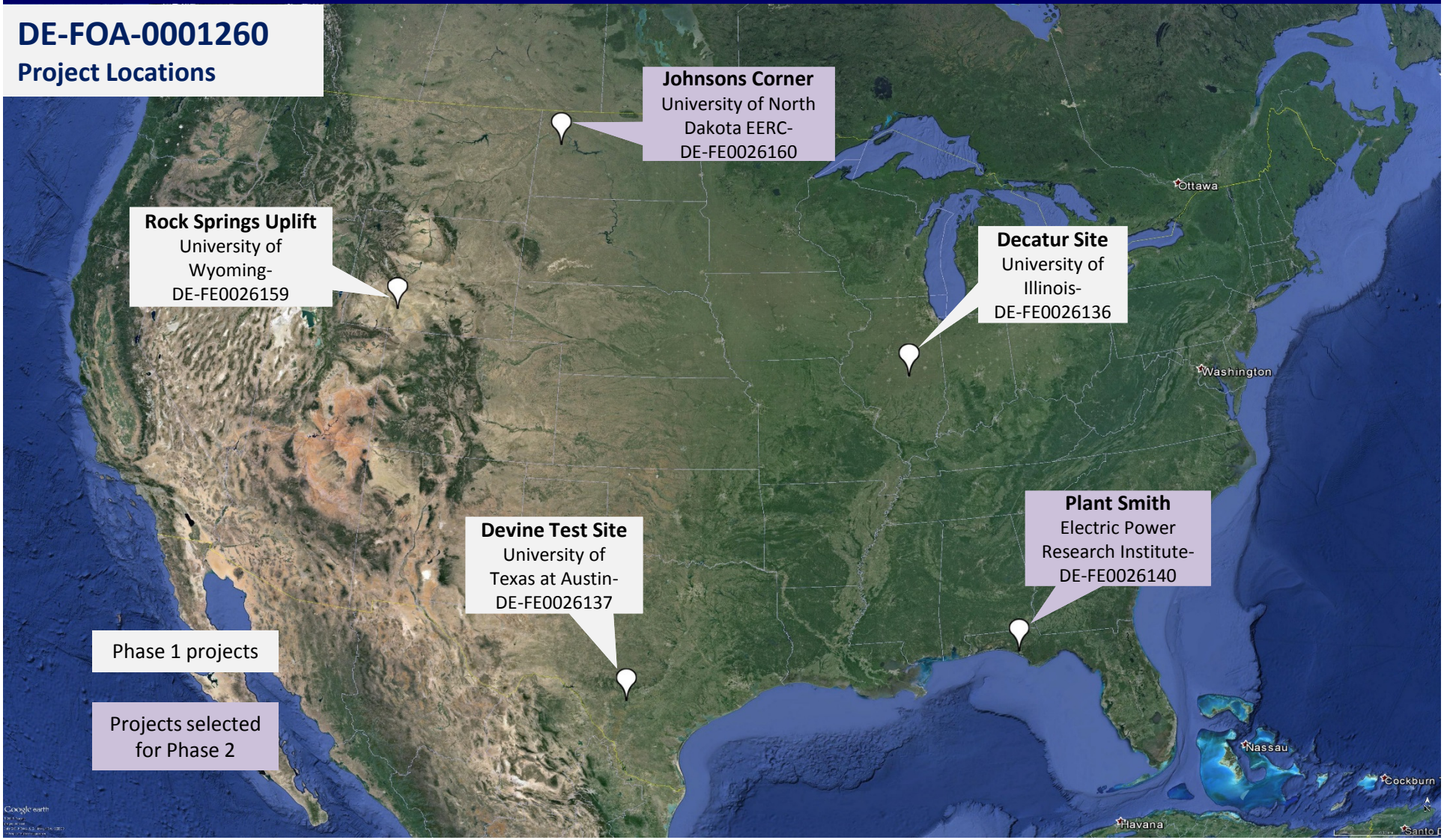


Offshore Resource Assessment Projects



The Prospective Storage Resource assessment should utilize existing data which could include additional analysis of data from well logs, records and sample descriptions from existing or plugged/abandoned wells, available seismic surveys, existing core samples, and other available geologic and laboratory data. This includes utilizing the available information to locate and determine the areal extent of sedimentary basins and properties of the geological formations within those basins (potential storage reservoirs and seals).

Brine Extraction Storage Test (BEST) Project Locations



Associated Storage

Projects researching the CO_2 storage associated with enhanced hydrocarbon recovery demonstrate additional CO_2 storage and domestic production potential and support development of new or improved technologies that may be adopted by industry.

Key program objectives include…

- Characterizing geologic settings in the United States that are "non-conventional CO_2-EOR targets (e.g., ROZ, shale)
- Developing and validating methods that address technology challenges associated with recovering crude oil and storing CO_2 in conventional and non-conventional settings
- Developing and validating technology improvements and operation/maintenance changes that promote more effective associated storage of CO_2

FOA: Developing Technologies for Advancement of Associated Geologic Storage in Basinal Geo-Laboratories (Infrastructure)

- Aim is to select projects that establish a geo-laboratory and advance technologies, through computational, analytical, bench scale, and field laboratory studies, for associated storage in high priority basins.
- FOA closed June, 2018.
- Projects selected; $9M total DOE funding

National Risk Assessment Partnership (NRAP)

NRAP is developing toolsets to reduce uncertainty and quantify potential impacts related to release of CO_2 and induced seismicity.

Technical Team

NATIONAL ENERGY TECHNOLOGY LABORATORY

BERKELEY LAB

Los Alamos NATIONAL LABORATORY EST.1943

Pacific Northwest NATIONAL LABORATORY

Stakeholder Group

AEP AMERICAN ELECTRIC POWER

Blue Source

bp

EPA United States Environmental Protection Agency

ExxonMobil

ieaghg

IEc

MIT

NRDC

Schlumberger

SOUTHERN STATES ENERGY BOARD

STANFORD UNIVERSITY

RRC Texas Railroad Commission

USGS

THE UNIVERSITY OF UTAH

Wade, LLC

WHITING

ZURICH Because change happenz

www.edx.netl.doe.gov/nrap

Questions