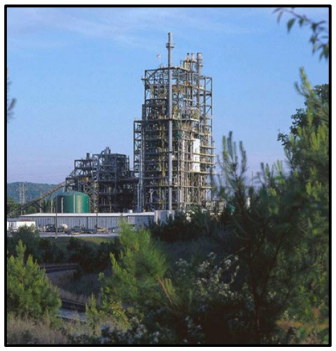
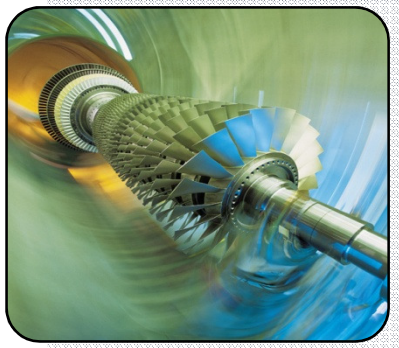
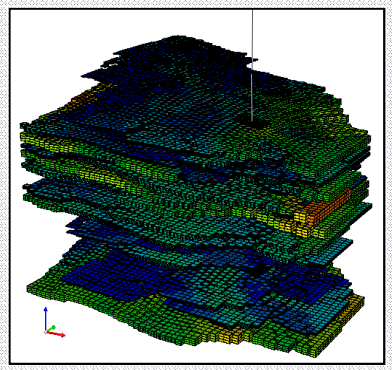






Clean Coal R&D

John Litynski

Acting Director
Carbon Capture and Storage Division
U.S. Department of Energy

October 2016

2016 Fossil Energy Priorities

Major Demonstrations Projects – ARRA and CCPI funding

Carbon Capture - $116.6 M

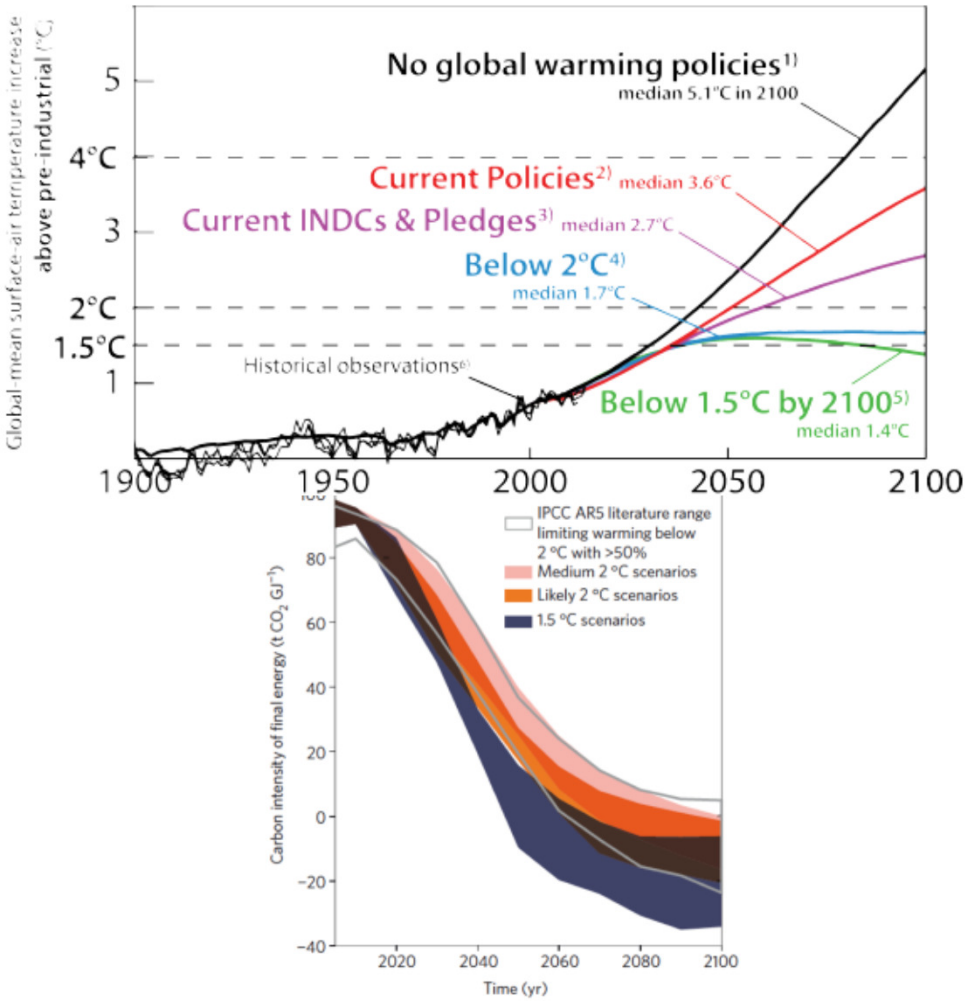
Carbon Storage - $108.8 M

Advanced Energy Systems - $39.4 M

Cross-cutting R&D - $51.2 M

Tax Incentives for CCS - $2B

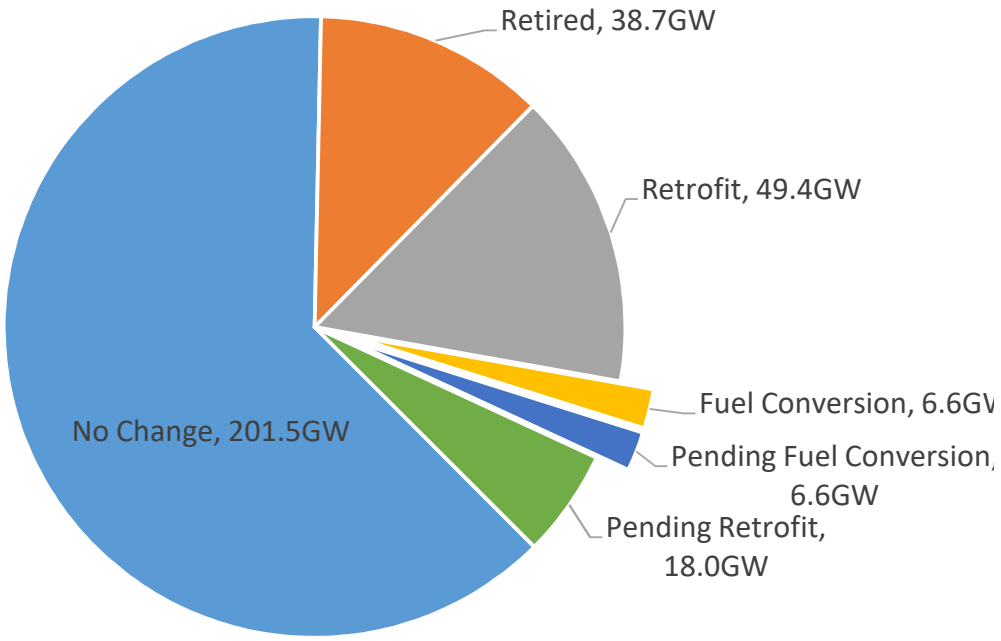
Loan Guarantee Office - $6B



Source: Climate Analytics

Changes to Existing Coal Fleet

- 13.2 GW of coal units have/will convert to natural gas due to MATS
- Additional units (unknown GW), are converting due to economics of low gas prices
- From January 2012 to April 2016, 119.2 GW of coal-fired units larger than 25 MW experienced MATS driven impacts

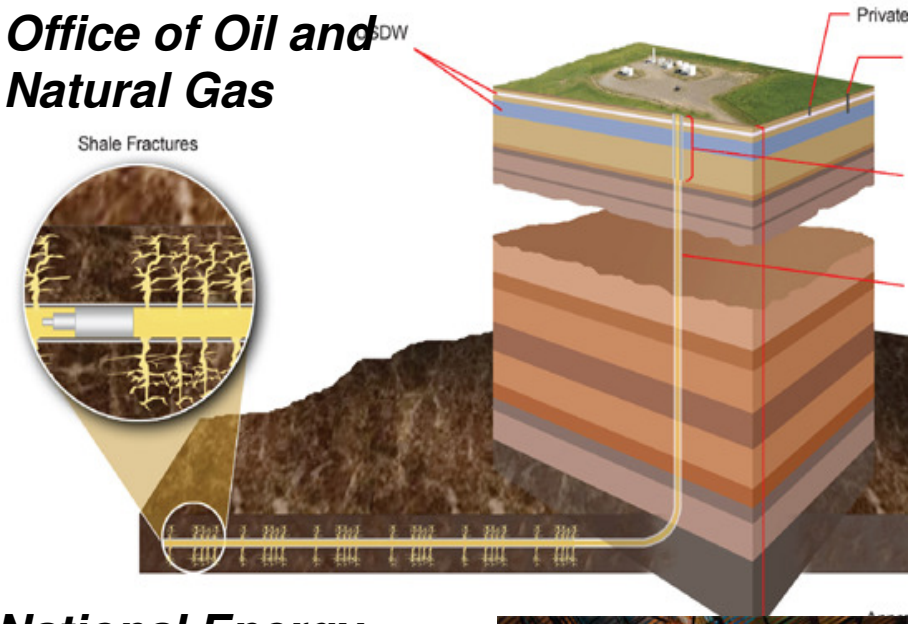


Data from January 2012 to April 2016

Office of Fossil Energy

Office of Clean Coal and Carbon Management

Office of Oil and Natural Gas

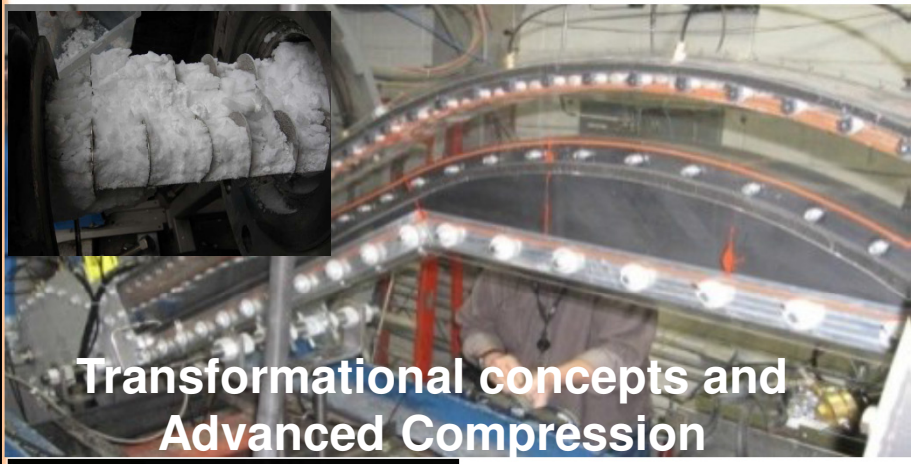


Strategic Petroleum Reserves

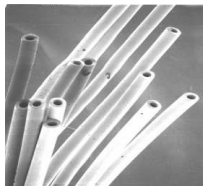
National Energy Technology Laboratory

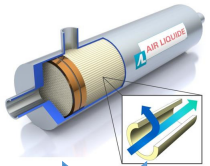
We will need CCUS

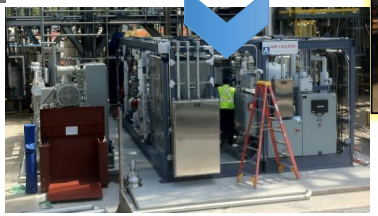
Advanced CO_2 capture technologies: Many pathways to success



Advanced membranes



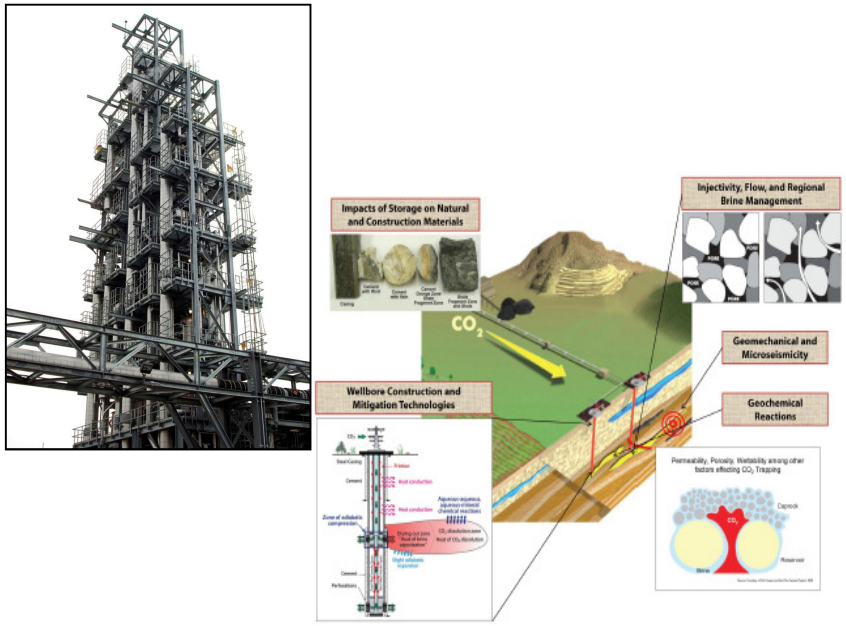




Solid sorbents

CCUS Technology Development and Market Mechanisms

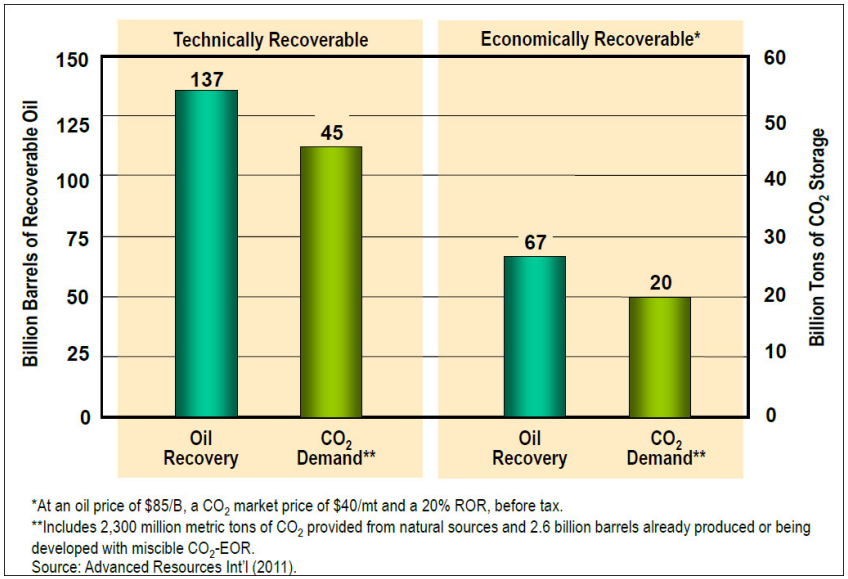
Technology Push



- Research and Development
- Demos (integration and learning)

Market Pull

Domestic Oil Supplies and CO_2 Demand (Storage) Volumes from "Next Generation" CO_2-EOR Technology**



*At an oil price of $85/B, a CO_2 market price of $40/mt and a 20% ROR, before tax.
**Includes 2,300 million metric tons of CO_2 provided from natural sources and 2.6 billion barrels already produced or being developed with miscible CO_2-EOR.
Source: Advanced Resources Int'l (2011).

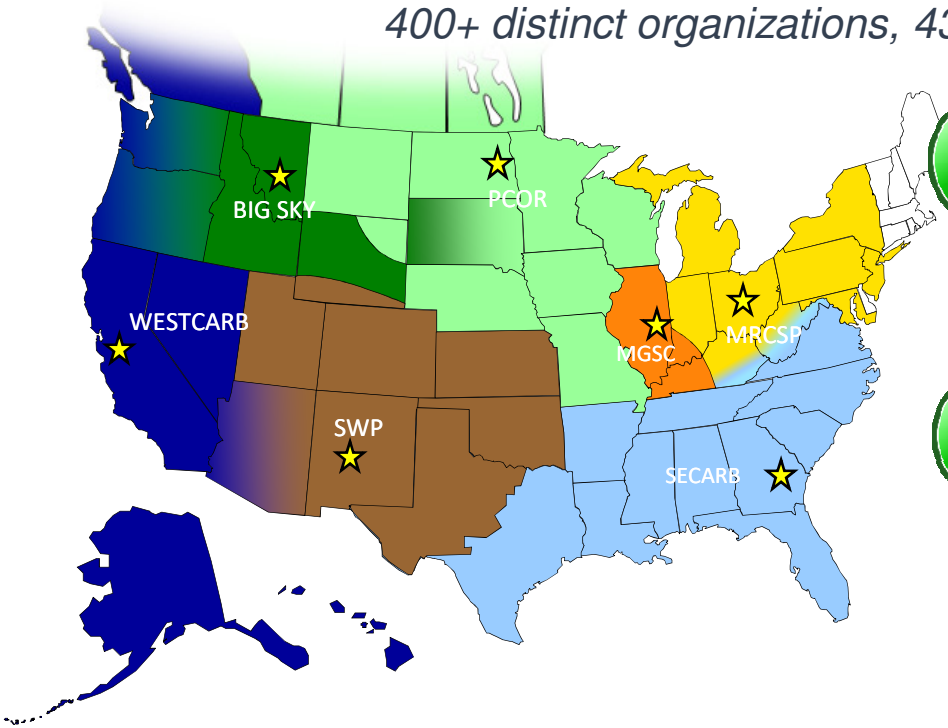
- Existing Market Mechanisms: Enhanced Oil Recovery (EOR)
  - 65 million tons per year of CO_2 to produce nearly 300,000 barrels of oil per day
- Regulatory Framework (Evolving)
- Financing (Tax Credits and Loan Guarantees)

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)

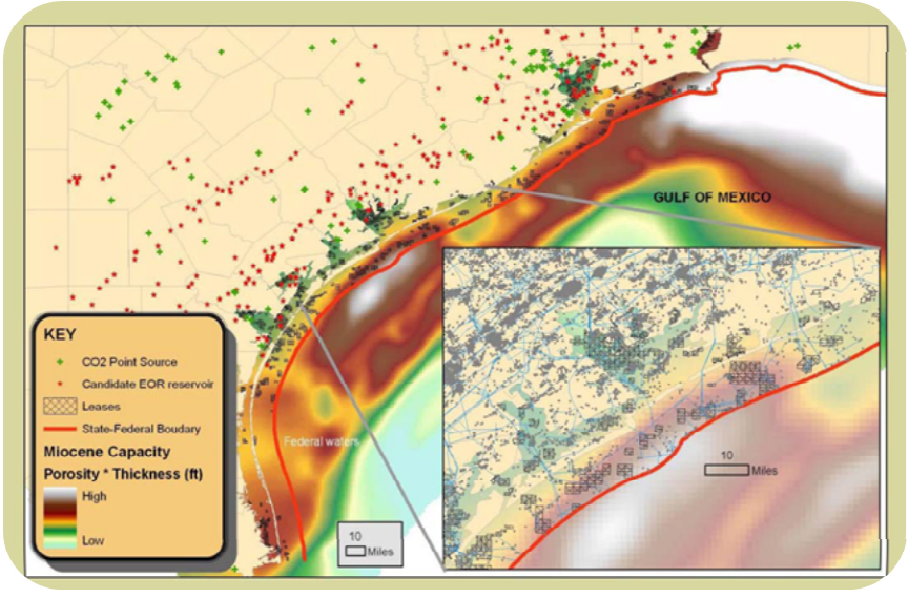
20 injection tests in saline formations, depleted oil, unmineable coal seams, and basalt

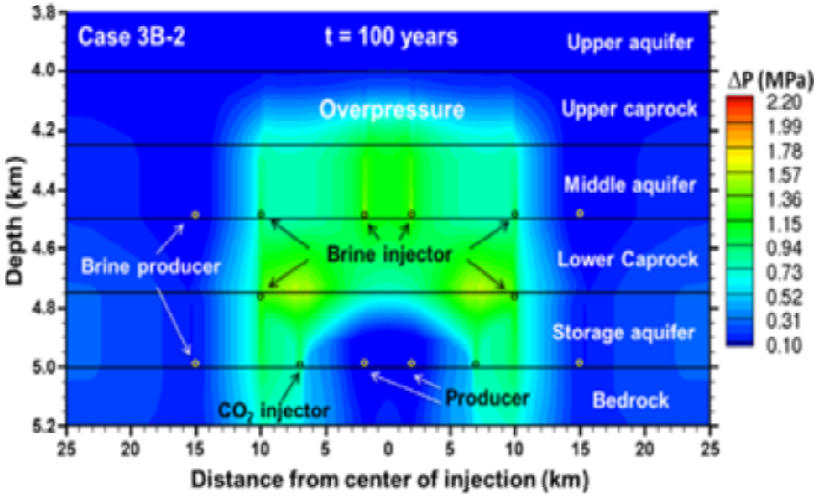
Development Phase (2008-2018+)

8 large scale injections (over 1 million tons each)	Commercial scale understanding and validation

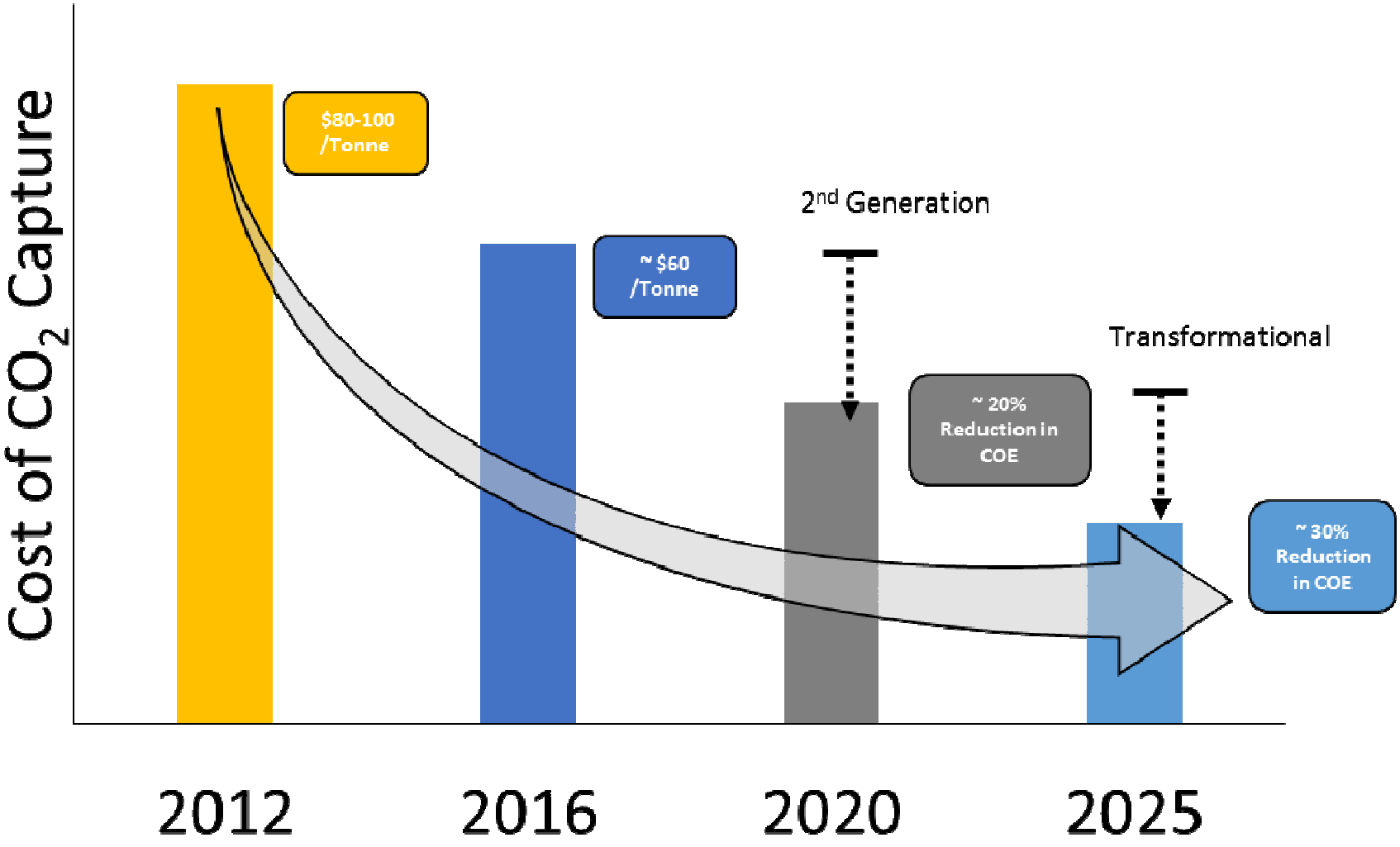
Carbon Sequestration Program R&D

- Brine Extraction Storage Test (BEST)
- Offshore storage
- National Risk Assessment Program (NRAP)
- Risk assessment, model validation, modelling uncertainty qualification, etc.
- SubTER: Monitoring, verification and accounting
- Develop and demonstrate tools for characterization and mapping of potential storage reservoirs
- CarbonSAFE: Large scale (50+ million tons), long-term site characterization

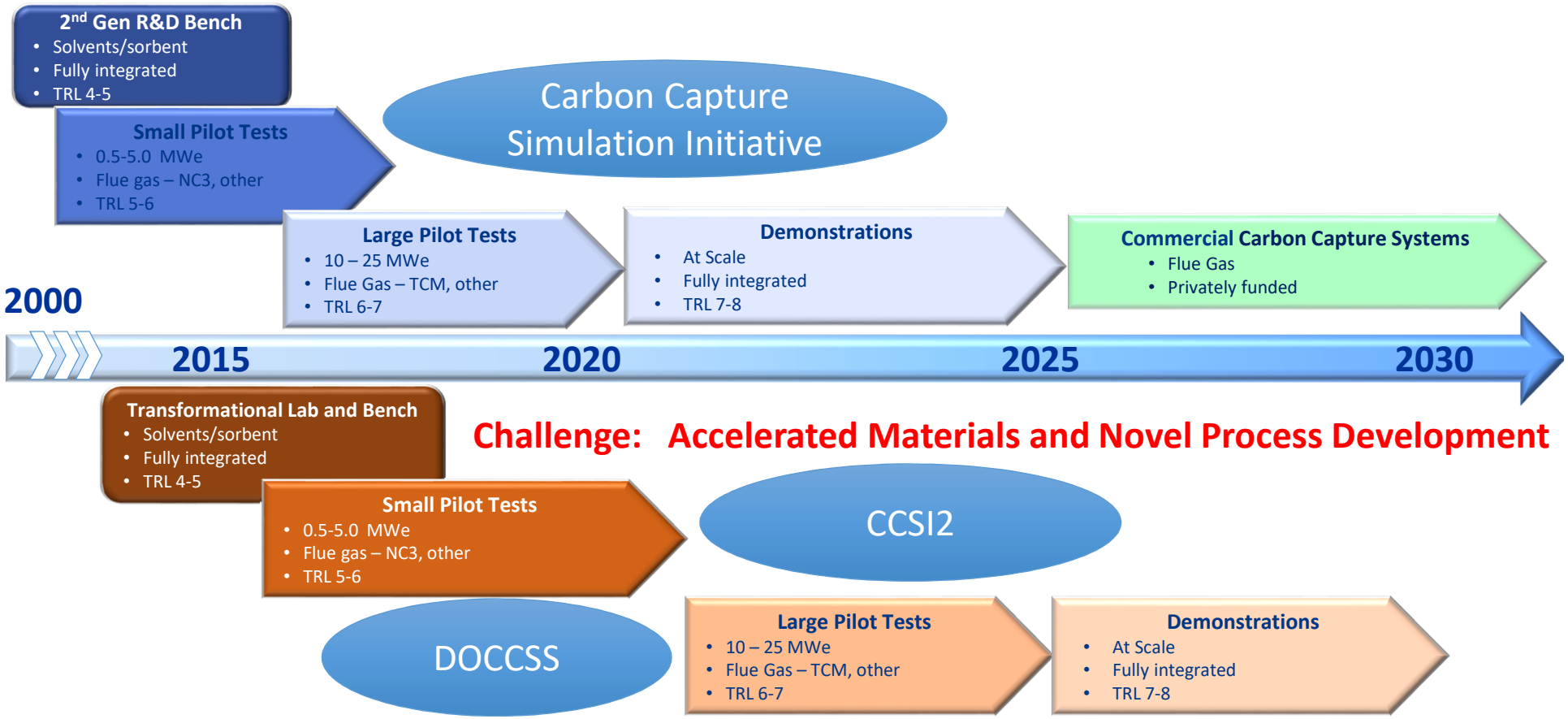




DOE CCUS Goals



DOE Technology Development Schedule



Southern Company Services, Inc. CCPI-2

Kemper County Advanced IGCC with CO_2 Capture

- Kemper County, MS
- 582 MWe (net) with duct firing; 2 TRIG™ gasifiers, 2 Siemens combustion turbines, 1 Toshiba steam turbine
- Fuel: Mississippi lignite
- 67+% CO_2 capture (Selexol® process); 3,000,000 tons CO_2/year
- EOR: Denbury Onshore LLC, Treetop Midstream Services LLC
- Total DOE CCPI Project: $2.01 B; DOE Share: $407 MM
- Total estimated project cost: ~$ 6.7B

Key Dates

- **Project Awarded: Jan. 30, 2006**
- **Project moved to MS: Dec. 5, 2008**
- **NEPA Record of Decision: Aug. 19, 2010**
- **Initiate excavation work: Sept. 27, 2010**
- **Operations: Q3-2016**

Status

- **Plant construction >99% complete**
- **Peak construction labor 6,121**
- **Lignite mine in commercial operation: June 2013**
- **Combined cycle commercial operation on natural gas: Aug. 2014**
- **First Syngas production July 2016**

Petra Nova – NRG W.A. Parish CCPI-3

Advanced Post Combustion CO_2 Capture

- Thompsons, TX (near Houston)
- 240 MWe slipstream at NRG Energy's W.A. Parish power plant (originally 60 MWe)
- Fuel: PRB sub-bituminous coal
- 90% CO_2 capture (KM CDR Process®) 1,400,000 tonnes CO_2/year
- EOR: Hillcorp West Ranch oil field
- Total Project Cost: ~$1 billion
  DOE Share: $190 million

Key Dates

- **Project Awarded: May 2010**
- **Air Permit: December 2012**
- **NEPA Record of Decision: May 2013**
- **Financial Close: July 2014**
- **Construction: March 2014 (LNTP); July 2014 (NTP)**
- **Full Capacity Operation: January 2017**

Status

- **Regenerator and Absorber have been set.**
- **Cooling tower is complete.**
- **Installation of piping, electoral wire and drilling of wells is continuing.**
- **Construction: 95% complete (8/15/16)**
- **Begin CCS commissioning June 1, 2016**

Air Products & Chemicals, Inc. ICCS Area 1

Steam Methane Reforming with CO_2 Capture

- Port Arthur, TX (Hydrogen plant at Valero Refinery)
- 90%+ CO_2 capture (Vacuum Swing Adsorption) from 2 steam-methane reformers (SMRs) yielding ≈925,000 tonnes CO_2/year
- ≈30 MWe cogeneration unit to supply makeup steam to SMRs and operate VSA and compression equipment
- CO_2 to Denbury "Green" pipeline for EOR in Texas at West Hastings oil field
- Total Project: $431 MM; DOE Share: $284 MM (66%)

Key Dates

- **Phase 2 Awarded: June 15, 2010**
- **FEED completed: Nov. 2010**
- **Permit By Rule (PBR) and Standard Air Permits issued: May 2011**
- **NEPA FONSI: July 2011**
- **Construction started: Aug. 2011**
- **Operation started: Dec. 2012**

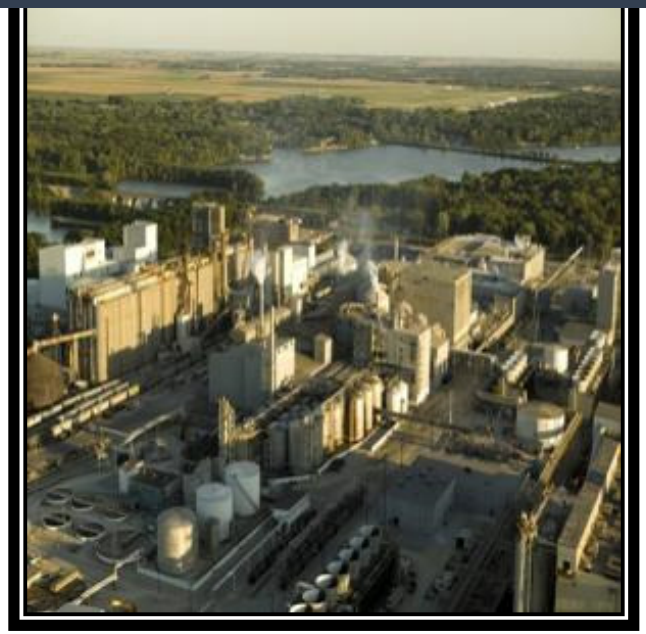
Status

- **PA-1 initiated operation: March 3, 2013**
- **PA-2 initiated operation: Dec. 16, 2012**
- **Full capacity achieved: April 2013**
- **Has operated >100% of design when needed**
- **1 MM tonnes CO_2 delivered as of 4/24/14**
- **2 MM tonnes CO_2 delivered as of 5/15/15**
- **Over 2.8 MM tonnes of CO_2 delivered as of 4/15/16**

Archer Daniels Midland Company ICCS Area 1

CO_2 Capture from Biofuel Plant

- Decatur, IL
- CO_2 (>99% purity) is a by-product from production of fuel-grade ethanol via anaerobic fermentation
- Up to 90% CO_2 capture, dehydration (via tri-ethylene glycol) & compression
- ~900,000 tonnes CO_2 /year
- Sequestration in Mt. Simon Sandstone saline fm.
- Total Project: $208 MM; DOE Share: $141 MM (68%)



Key Dates

- **Phase 2 Awarded: June 15, 2010**
- **FEED Completed: April 2011**
- **NEPA FONSI: April 2011**
- **Construction started: May 2011**
- **UIC Class VI Injection Well Permit: Sept. 2014; UIC Class VI Operating Permit: Early 2016**
- **Sequestration start at full rate: 1Q-2017**

Status

- **Construction ~99% complete Apr. 2016**
- **Two monitoring wells drilled: Nov. 2012**
- **New Hans substation energized: Nov. 2014**
- **Commissioning compression and dehydration system completed: Sept. 2015**
- **Injection well drilled and completed: Sept. 2015**
- **Waiting for final EPA authorization to start CO2 injections using Class VI UIC permit.**

R&D focus shifting to deployment

Integrated projects

- Focus on next generation of large pilots (10-50 MW)
- Focus on retrofits of existing coal plants
- Need for more industrial projects, natural gas power projects

CO_2 capture:

- Solvents, sorbents, membranes, phase-change technologies
- Focus on transformational solutions and manufacturing

CO_2 storage

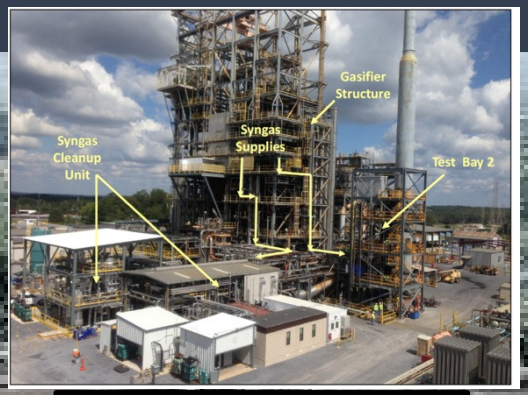
- More large-scale saline formation injections would help
- Focus on managing risks (e.g., induced seismicity)

Financing (cost recovery) is the main deployment issue

National Carbon Capture Center

Pilot Solvent Test Unit

- 5 year $150MM
- $100MM Capture Funding
- Independent Test Facility
- Supports Capture & Gasification



TRIG Gasifier

Post Combustion

- ❑ PC4 Facility – 4.3MWe
- ❑ Real PC flue gas
- ❑ Bench through pilot scale
- ❑ >90,000 hours of testing
- ❑ 25+ Technologies tested
- ❑ "Tech-Flexible"

Pre Combustion

- ❑ 6.3MWe Trig gasifier
- ❑ Air- or O_2 fired syngas
- ❑ Bench through pilot scale
- ❑ ~38,000 hours of testing
- ❑ "Tech-Flexible"
- ❑ Sensors, biomass, catalysts, sorbents, membranes, others

U.S. DEPARTMENT OF ENERGY · NETL · SOUTHERN COMPANY · EPRI ELECTRIC POWER RESEARCH INSTITUTE · nrg · ArchCoal · AEP AMERICAN ELECTRIC POWER · DUKE ENERGY · CLOUD PEAK ENERGY · Luminant

– World Class Carbon Capture Technology Test Facility –

Adding value through utilization

Many utilization pathways are very difficult - we should seek to increase value broadly

Not crazy (in order of increasing difficulty)

- EOR, EOR+, ROZ (potential for negative C oil)
- Mineralization (baking soda, limestone)
- Methanol, Urea, etc. production
- Enhanced water recovery (brine-extraction and storage; BEST)
- CO_2-algae (animal feed, nutraceuticals, biomass feed, biofuel)
- CO_2 polymers

Crazy but large volumes

- CO_2-fuels or chemical
- CO_2 splitting

Industrial CCS Program

- **Regional Feasibility Studies**
  - Performed as Public-Private Partnerships w/ Cost Share
  - Regions include: Gulf Coast, Illinois Basin, Great Northern Plains, California, and Appalachia
  - Will include EOR and Saline Injection as well as new business models (Appalachia)
- **Specific Research by Sector**
  - Chemical and Refinery Industry
  - Metals and Mineral Industry
  - Cement
  - Methane
  - Paper
- **Modeling Upgrades (EPSA/EIA)**

Industrial CCS Regional Engagement Effort

Goal: Start removing industrial emitted CO_2 from the atmosphere/system now with technologies on hand.

Implementation effort will be public-private partnership, regionally focused, and adaptive to regional market differences

Effort will start a concurrent long term engagement in a difficult region, specifically Appalachia, to build understanding of CO_2 economies in non-intuitive areas.

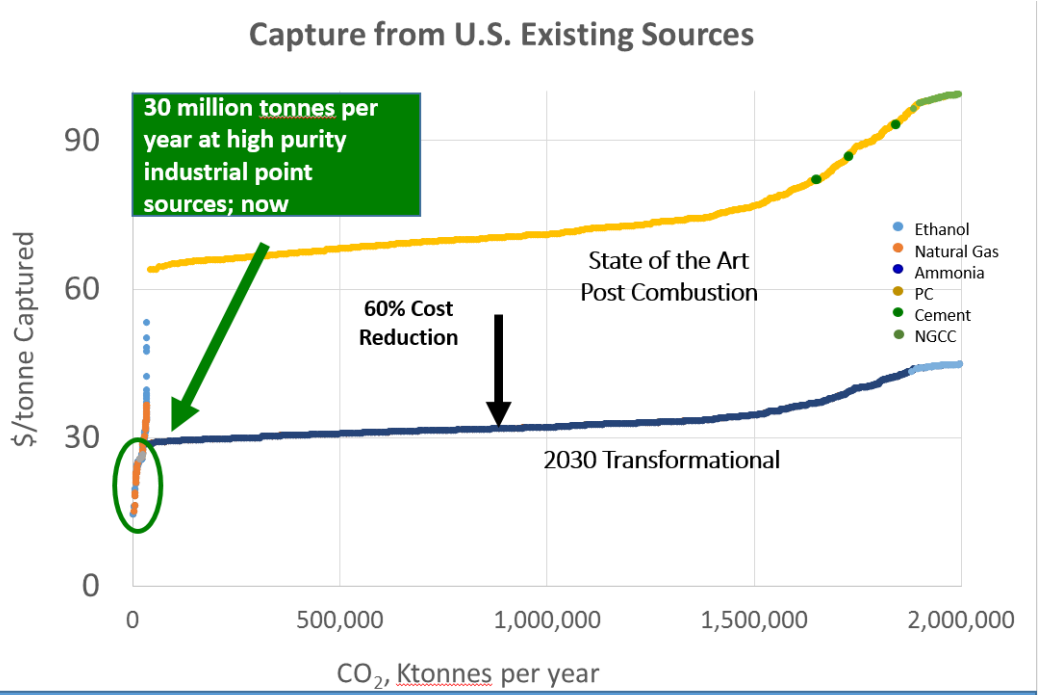
Regions:

Gulf Coast, Illinois Basin, Great Northern Plains, California, Appalachia

Market Basis: EOR, Tax Credits, and State Clean Fuel Laws

Business Possibilities:

- "Hub" Development – Gulf
- Expanding Demos (ADM) – Illinois Basin
- Oil Refinery – California, Gulf Coast
- Coal to Chemical - GNP



If RDD&D is successful, can capture approximately 400 million metric tons of CO2 per year at roughly $30 per metric ton of CO2 and 1000 million metric tons at under $35 by 2030

THANK YOU

contact: john.litynski@hq.doe.gov