

U.S. Regulatory and R&D Efforts to Advance Carbon Capture Technologies IEAGHG PCCC September 8th, 2015

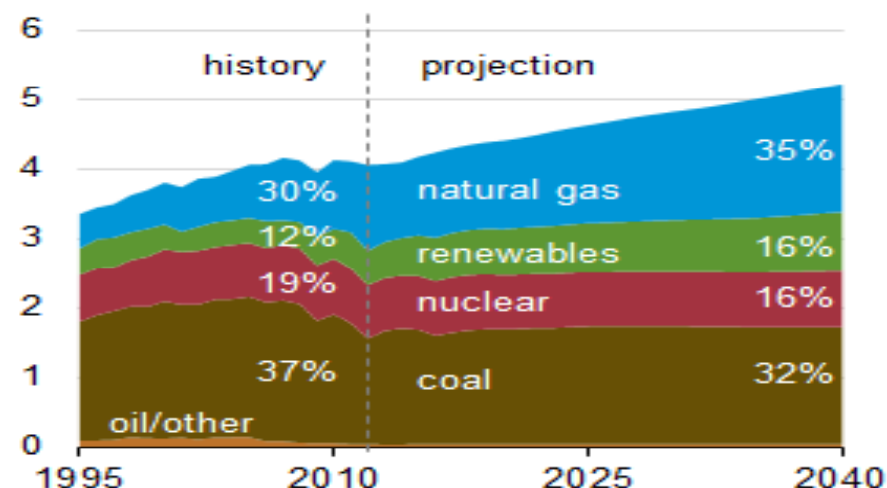
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Office of Clean Coal and Carbon Management

Energy Generation in the United States

U.S. electricity generation by fuel (1995-2040)

AEO2014 Reference case
trillion kilowatthours



United States Annual Electricity Generation (MWh) 2008 - 2013					Total Capacity (MW)
Source	2008	2013	Change	% Change	2013
Coal	1,985,801	1,584,194	-401,607	-20.2%	312,293
Natural Gas	882,981	1,125,691	242,710	27.5%	455,214
Nuclear	806,208	789,016	-17,192	-2.1%	104,182
Hydroelectric	254,831	268,548	13,717	5.4%	78,215
Solar	864	9,022	8,158	944.2%	3,053
Wind	55,363	167,992	112,629	203.4%	59,082
Geothermal	14,840	15,775	935	6.3%	2,782
Biomass	55,034	61,885	6,851	12.4%	4,885
Other	63,466	48,904	-14,562	-22.9%	84,753
Total	4,119,388	4,071,027	-48,361	-1.2%	1,104,459



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Source: EIA electricity database 2015; EPA 2013 GHG Emissions Database

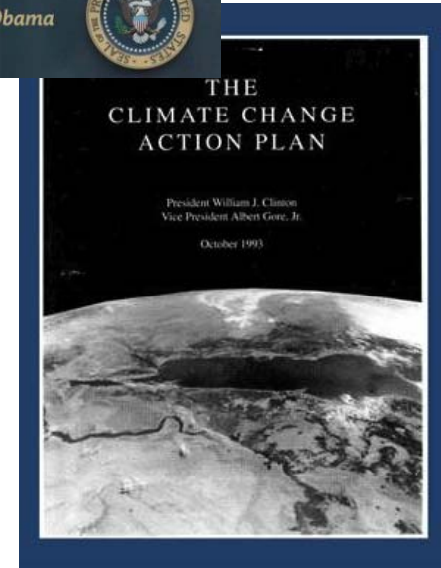
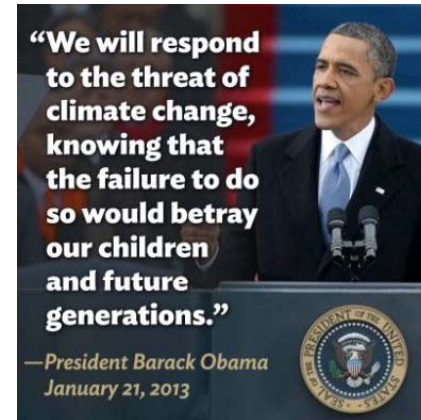
CCS/CCUS is the key technology for this era of fossil energy abundance

United States Policy drivers

- President's Climate Action Plan
- EPA draft rules
 - 111 (b) – New Sources
 - 111 (d) – Existing Sources
- EPA GHG Reporting Rules for CCS (RR & UU)

Global economic context

- Investors speak
- Global coal increase
- Cost of mitigation without CCS



A \$6B climate mitigation program at DOE



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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

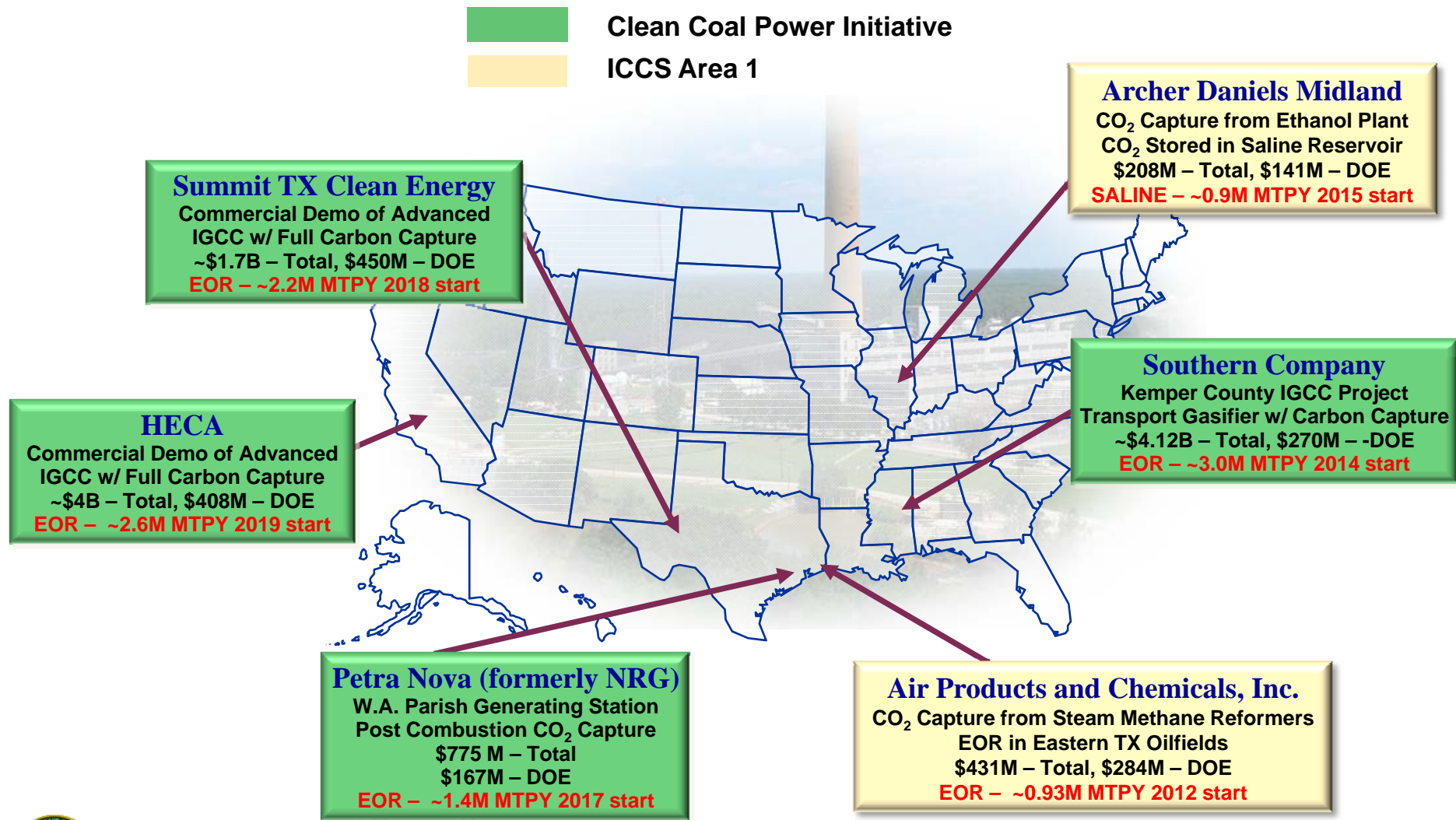


Photo courtesy of the White House, Pete Souza

“Over the past six years, we’ve done more than ever before to combat climate change, from the way we produce energy, to the way we use it.”

Major CCS 1st Gen Demonstration Projects

Project Locations & Cost Share



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Operational! >2 M tons stored so far

Kemper County, MS
Southern Co., 2013
(Anticipated Start - 2016)



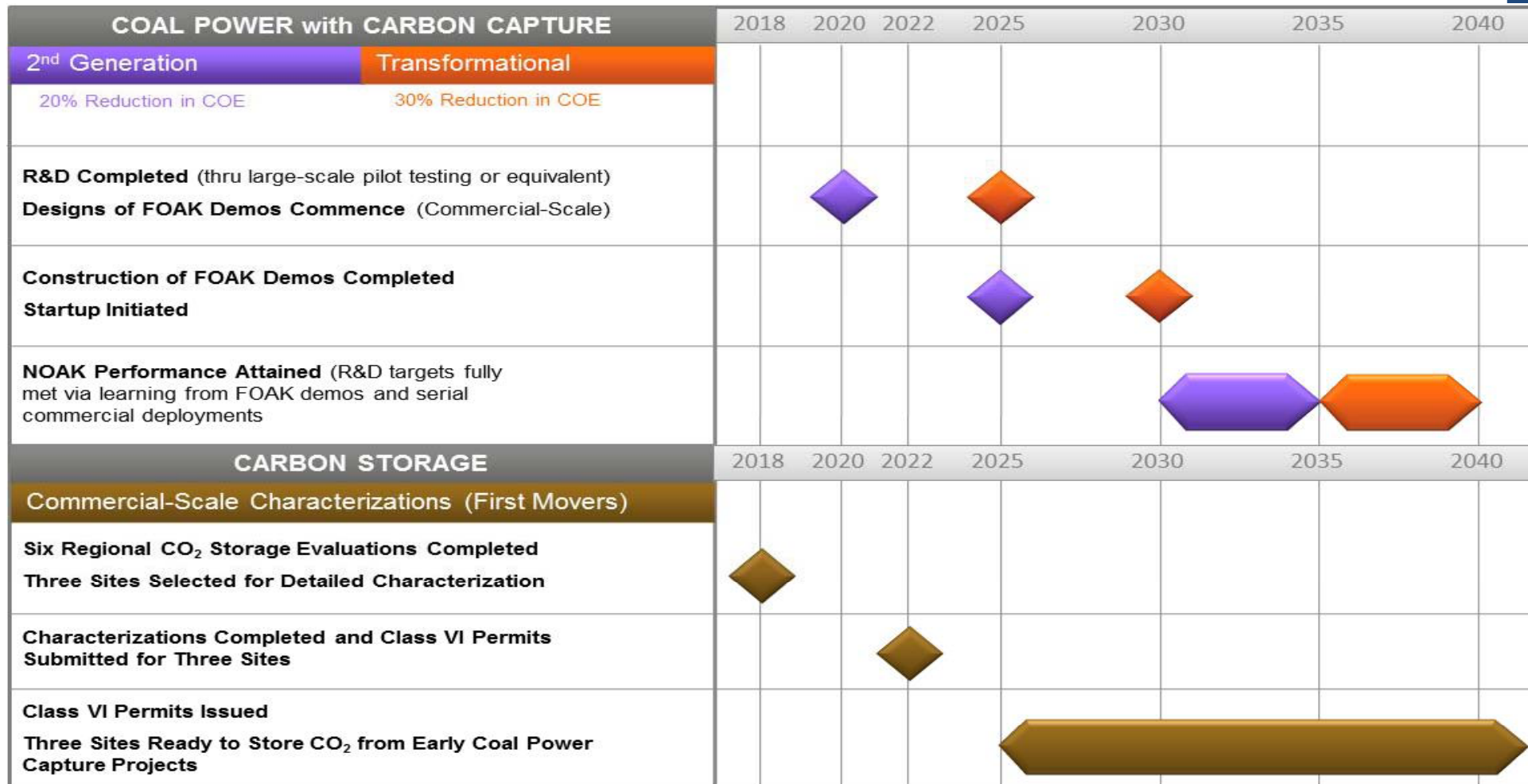
W.A. Parrish, TX: 1.4M tons/y CO₂ NRG/PetraNova project



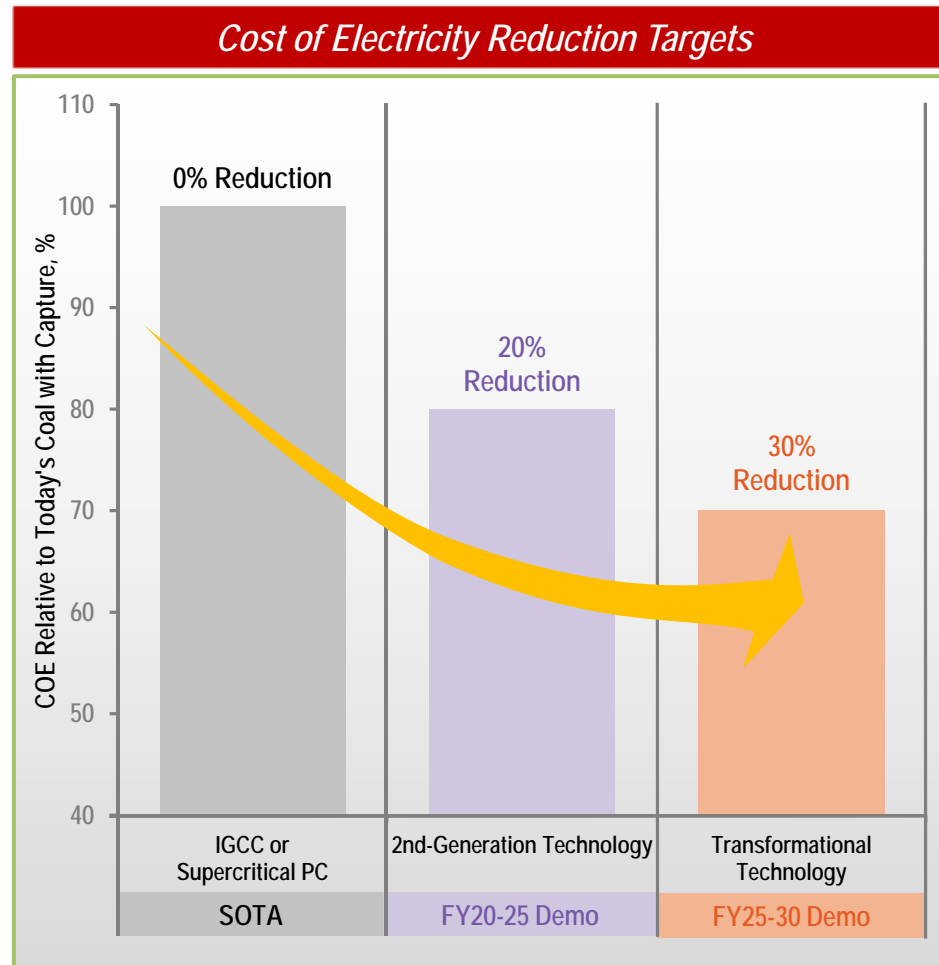
Broke Ground Sept. 5th! Operational in 2017

Must go farther and faster

2nd Gen and Transformational Technologies



DOE R&D Goals



Carbon Capture Program Objectives:

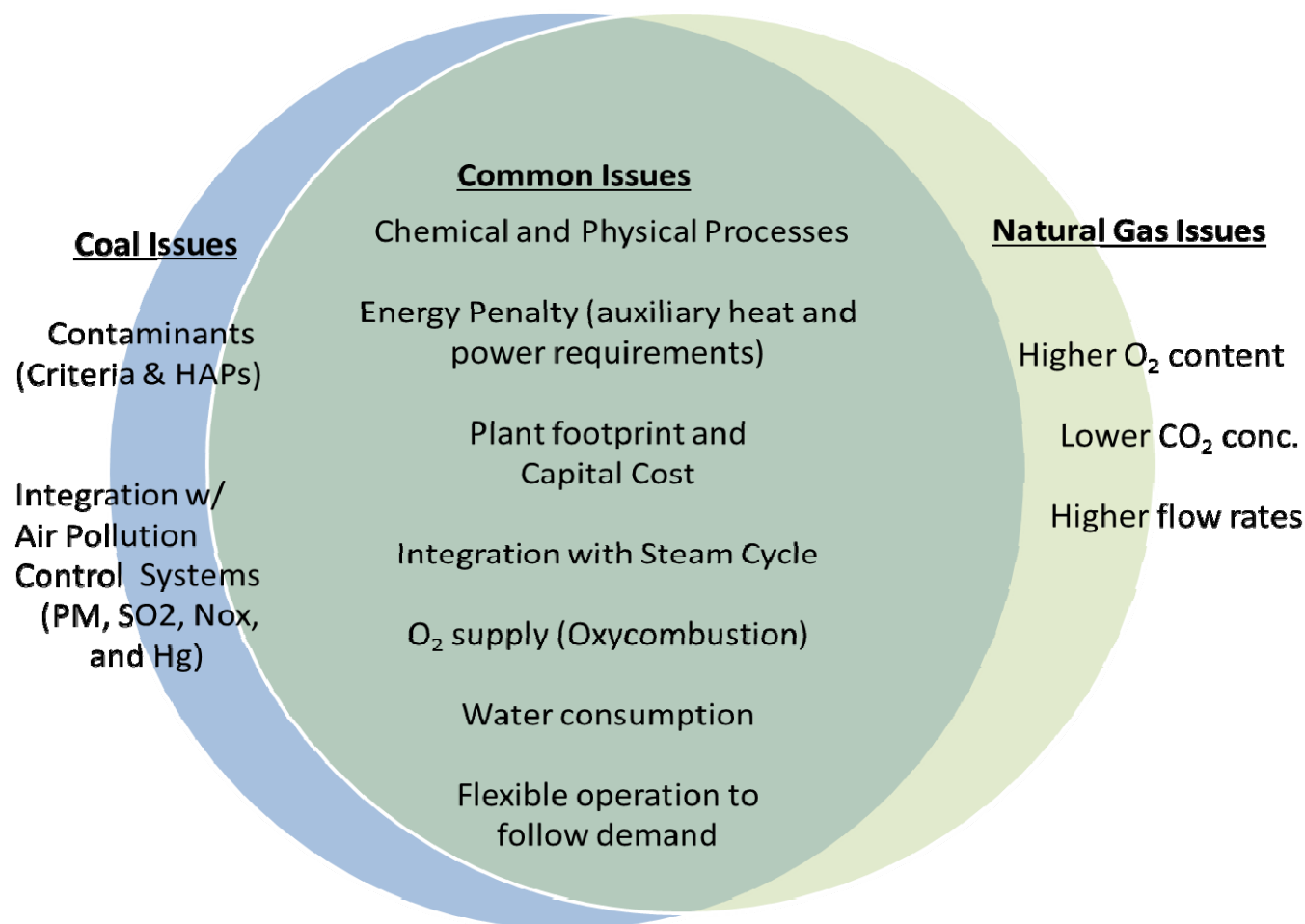
- Large-scale pilot validation
 - 2nd generation by 2020
 - Transformational by 2025
- Demonstration 5 years after each large pilot phase
- Meet 20% reduction by advanced solvents and systems; membranes, and sorbents
- Meet 30% goal through disruptive research in novel materials, advanced manufacturing, process intensification, electro chemical, and other advanced processes

DOE Carbon Capture Budgets

- FY2015 Appropriations
- \$88M
 - \$76M for post combustion
 - \$12M for pre combustion
- **Focus on coal**
- Additional funding to support pilot and bench scale projects
- FY16 Request
- \$116M
 - \$104M for post combustion
 - \$12M for pre combustion
- **Primary focus is Coal**
- **Integrate Natural Gas into R&D portfolio**
 - Leverage existing bench and large pilots to test on NG
 - All future projects must consider gas

CCS for Coal and Natural Gas

Integration of R&D Efforts



R&D Areas: CO₂ Capture

FY15 - \$12MM

Pre-Combustion

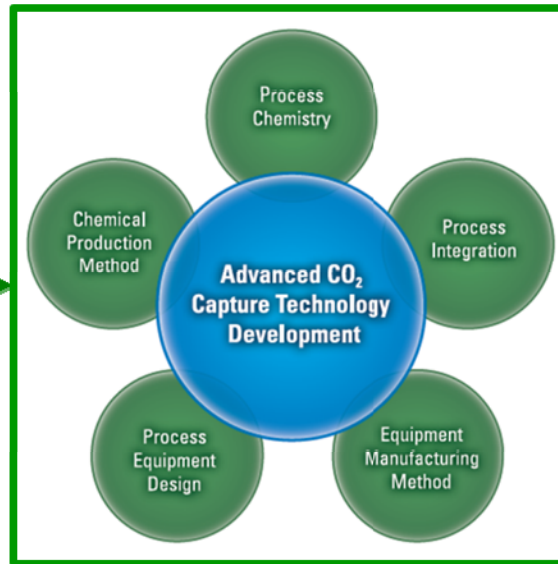
- ☐ *Solvents*
- ☐ *Sorbents*
- ☐ *Membranes*
- ☐ *Hybrid processes*
- ☐ *Water-gas shift reactor*



FY15 - \$76MM

Post-Combustion

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



Advanced Compression

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



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National Carbon Capture Center

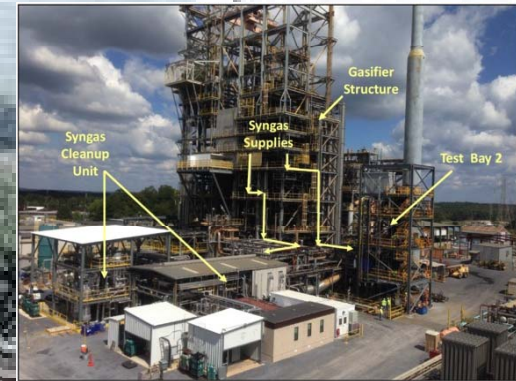


Pilot Solvent Test Unit

Post Combustion

- ☐ PC4 Facility – 4.3MWe
- ☐ Real PC flue gas
- ☐ Bench through pilot scale
- ☐ ~25,000 hours of testing
- ☐ 15 Technologies tested
- ☐ “Tech-Flexible”

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



TRIG Gasifier

Pre Combustion

- ☐ 6.3MWe Trig gasifier
- ☐ Air- or O₂ fired syngas
- ☐ Bench through pilot scale
- ☐ ~20,000 hours of testing
- ☐ 13 gasifier runs
- ☐ “Tech-Flexible”



– World Class Carbon Capture Technology Test Facility –

Current DOE's Carbon Capture Small Pilot Projects

Performer	Scale	Planned Construction Complete
Post-combustion Solvents		
Linde, LLC	1 MWe	Complete
Neumann Systems Group, Inc	0.5 MWe	Complete
Southern Company Services	25 MWe	Complete
University of Kentucky	0.7 MWe	Complete
General Electric	0.5 MWe	Late 2015
ION Engineering	0.7 MWe	Mid 2015
Post-combustion Sorbents		
ADA-Environmental Solutions	1 MWe	Complete
TDA Research, Inc.	0.5 MWe	Late 2016
SRI International	1 MWe	Late 2015
Post-combustion Membranes		
Membrane Technology & Research	1 MWe	Complete
Gas Technology Institute	1 MWe	Early 2016
Pre-combustion		
SRI International	0.1 MWe	Mid 2015
TDA, Inc.	0.1 MWe	Late 2015

1 MWe Slipstream: Low Pressure Membrane Contactors

Membrane Technology & Research

Project Summary

Approach

Develop and test a spiral-wound membrane process on a 1 MWe slipstream at the National Carbon Capture Center

Status

Operational – January 2015 NCCC
Moving Unit to integrated test facility

Advantages

- Smaller footprint
- Efficient scale-up 20-25x larger than current modules
- Capital cost reduction
- Reduced process complexity

Challenges

- Overcoming sweep side pressure drop
- Effective use of all membrane area
- Maximizing packing density while minimizing pressure drop



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1 MWe Slipstream: Novel Amine-Based Post-Combustion Process

Linde, LLC

Project Summary

Approach

Test BASF's advanced amine-based solvent process technology and Linde's novel equipment and process innovations on a 1 MWe slipstream at the National Carbon Capture Center

Status – Operational since Jan 2015

Advantages

- Solvent more stable, higher capacity, faster kinetics and ~30% lower energy demand than MEA
 - Projected up to 60% lower electrical energy load
 - Novel intercooler
 - Integrated absorber/wash unit
 - High pressure regeneration
 - Low cost MOC (projected ~30% capital savings)
-

Challenges

- Sustaining performance projections through scale



0.7 MWe Slipstream: Process Integration to Reduce Capture Costs

University of Kentucky Center for Applied Energy Research (CAER)

Project Summary

Approach

- Design, build and install an integrated CO₂ capture system into an existing PC power plant at a 0.7 MWe slipstream scale (~15 TPD CO₂) E.W. Brown Generating Station

Status – Construction Complete

Currently conducting MEA baseline testing

Advantages

- Two-stage air stripping increases solvent working capacity; CO₂-laden air sent to boiler to increase flue gas P_{CO₂}
- Integrated cooling tower uses regenerated CO₂ waste heat to dry liquid desiccant which dries cooling tower air for improved steam turbine efficiency

Challenges

- Proving air stripping at slipstream scale
- High O₂ environment may increase solvent oxidation



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Mixed Organics Solvent System

ION Engineering

Project Summary

Approach

Demonstrate solvent CO₂ capture using mixtures of amines and organic solvents

Status

Currently testing at NCCC

Considering testing at TCM 13 MWe system

Advantages

- Higher CO₂ loading capacities
 - Reduced corrosion and solvent losses
 - Less make-up water used by the process.
 - Ability to use lower-quality steam in regeneration
-

Challenges

- The current performance levels need to be demonstrated at the 0.5- to 1.0-MW slipstream level for longer test runs
- Solvent stability, degradation, and corrosion under coal-fired slipstream test conditions



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CO2 Capture by Sub-Ambient Membrane Operation

American Air Liquide

Project Summary

Approach

Demonstrate performance and verify mechanical integrity of commercial-scale membrane operating at sub-ambient temperature in a bench-scale test skid

Status

100KWe skids constructed Feb 2015

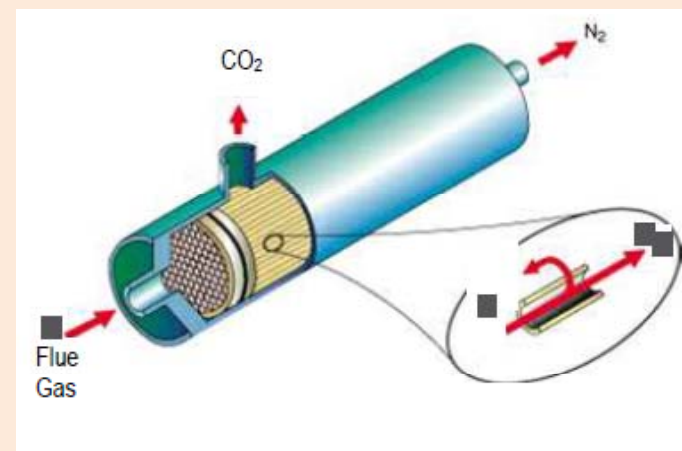
Bench-scale testing at NCCC commencing in 2015

Advantages

- Improved membrane performance
- Partial recovery of the flue gas compression energy
- Optimal operation without external refrigeration

Challenges

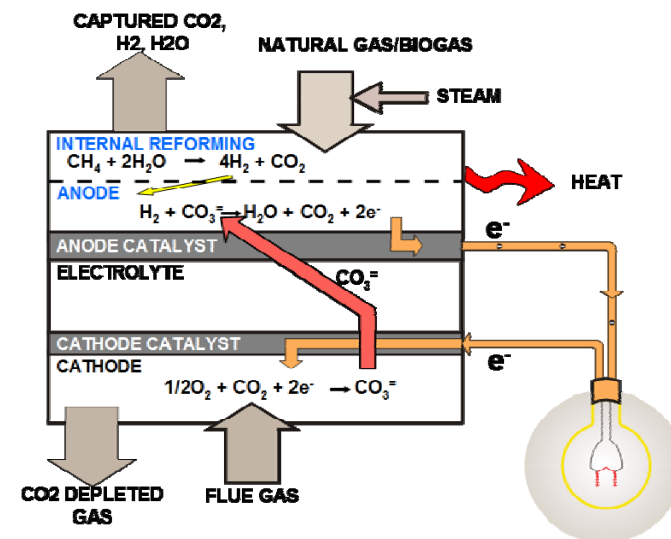
- Development of membrane materials operating at sub-ambient temperatures (i.e., permeance, selectivity, stability)
- Integration of sub-ambient membrane process (e.g., energy integration with the power plant heat transfer compression and turbo-expansion schemes)



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Pilot Test (3MWe) of Novel Electrochemical Membrane System for Carbon Dioxide Capture and Power Generation

- **Goal:** Design, fabricate, and test a 3 MWe Combined Electric Power and Carbon-Dioxide Separation (CEPACS) system.
 - Previous bench-scale (10 kW) results
- **Benefits:** The system is anticipated to capture 90% of CO₂ with 95% purity for \$40/tonne with ≤35% increase in the COE.
- Does not impact base plant
- The ECM produces power while capturing CO₂, reduces NO_x emissions



Electrochemical membrane (ECM) technology

FuelCell Energy, Inc.

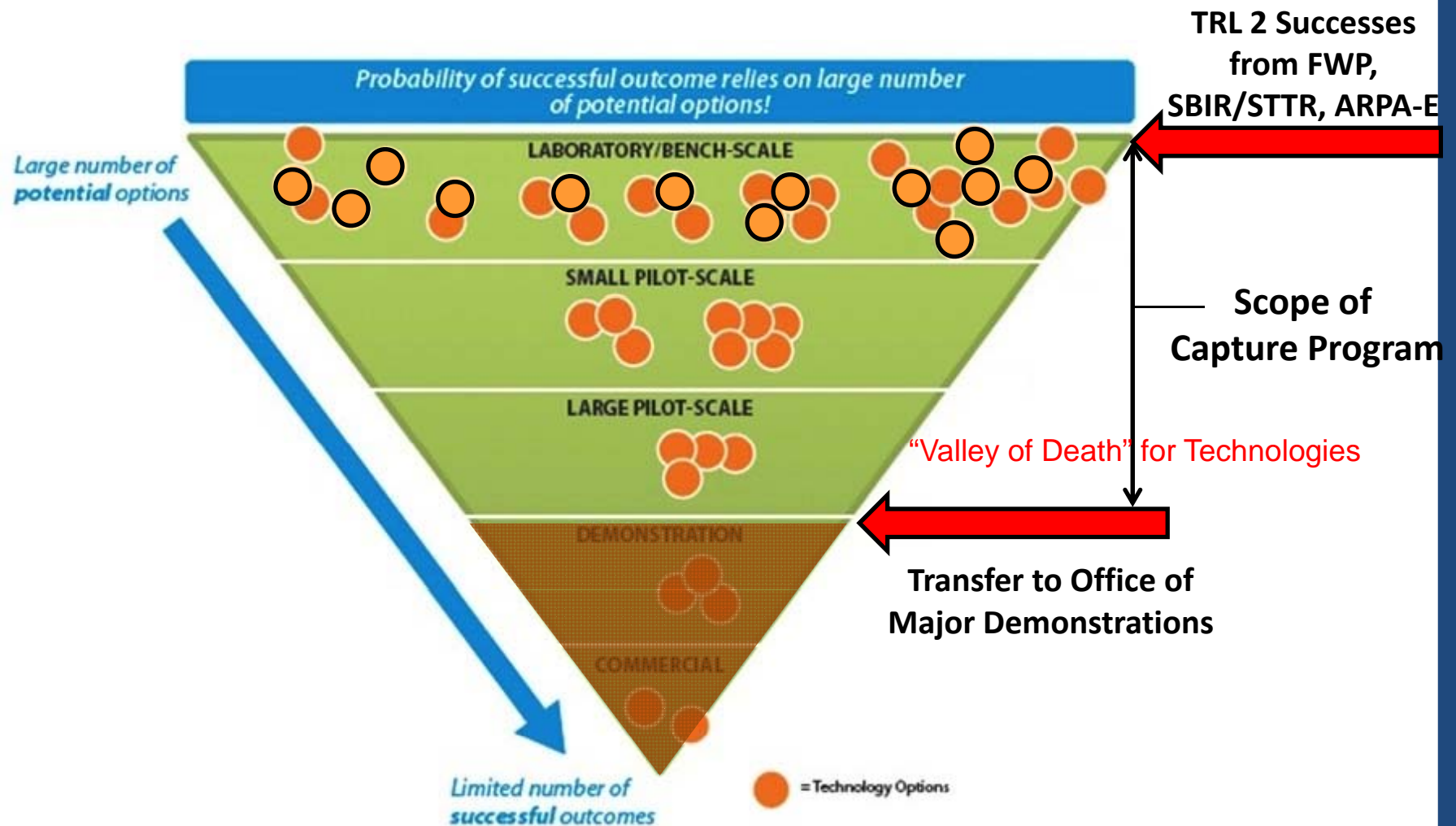
Performance Period: 10/01/2015 – 12/31/2018

Project Budget

<u>Total</u>	<u>DOE</u>	<u>Participant</u>
\$23,728,906	\$15,000,000	\$8,728,906

[Hyperlink to Fact Sheet](#)

Pathway for Technology Commercialization



We need more 2nd generation pilots!



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FY2015 Funding Opportunity Announcements

Transformational Capture Technologies

- Selected 14 new technologies for negotiation
- Disruptive technologies
 - Hybrid processes
 - Electrochemical
 - Advanced materials (Sorbents, solvents, membranes)
- >\$25M invested in new lab and bench scale technologies (11 post, 3 pre)
- Integration of algae into power plants (2)

FY2015 Funding Opportunity Announcements

Large Scale CO₂ Capture Projects (10+MWe)

- Final scale before full scale demonstration (100+Mwe)
- Need several pilots to support 2020 demonstrations
- Necessary for
 - Validation of capture technology
 - Integration of advanced capture system components
 - Optimization of capture system for full scale demo
- Phase I – Design (6 awards) (2015-2016)
- Phase II – Construction and operations (2016-2020)

Large Scale Pilots –Phase I

- **Univ of Illinois** - Testing of Linde/BASF Post-Combustion CO₂ Capture Technology at the Abbott Coal-Fired Power Plant, 25MWe
- **NRG CO₂NCEPT**– VeloxoTherm™ solid sorbent capture system, 10MWe
- **Southern Co. Services** – Process improvements/advanced solvent at Plant Barry Pilot Facility, 25 MWe

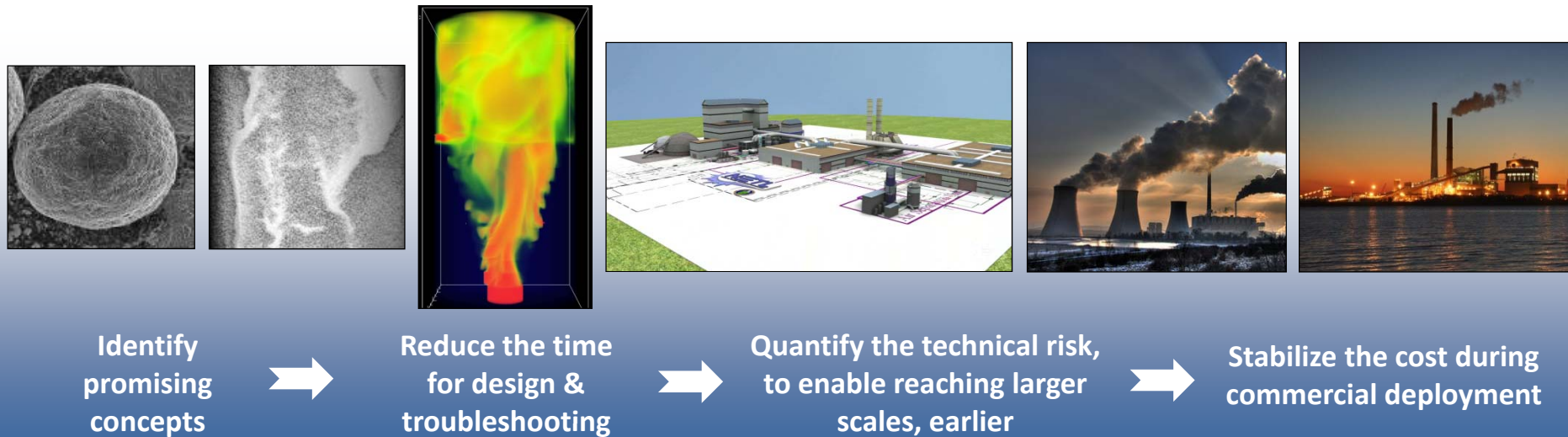


Large Scale Pilots –Phase I

- **Alstom** – Improvements to Chilled Ammonia Process, 15MWe
- **GE** – Amino Silicone capture process, 10MWe+
- **Univ of KY** – Heat Integrated Capture System, 10MWe+



CCSI: Accelerating Technology Development



National Labs



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