Advanced Coal Technologies for Power Generation

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National Energy Technology Laboratory

Full service DOE national laboratory

- Over 1,400 employees
- Dedicated to energy RD&D, domestic energy resources
- Fundamental science through technology demonstration
- Unique industry – academia – government collaborations

Oregon

Pennsylvania

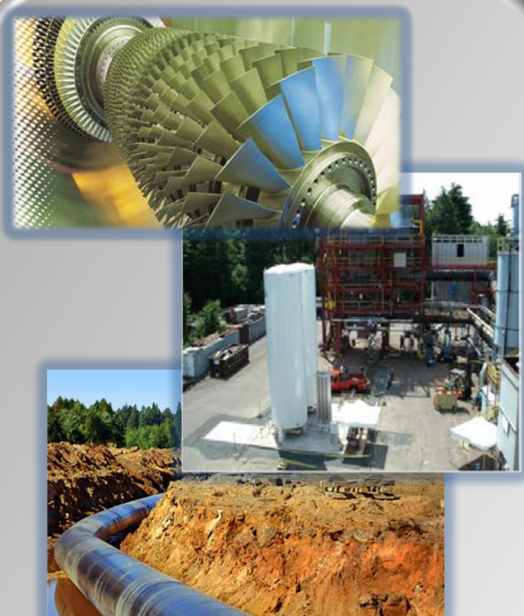
West Virginia

Strategic Center for Coal

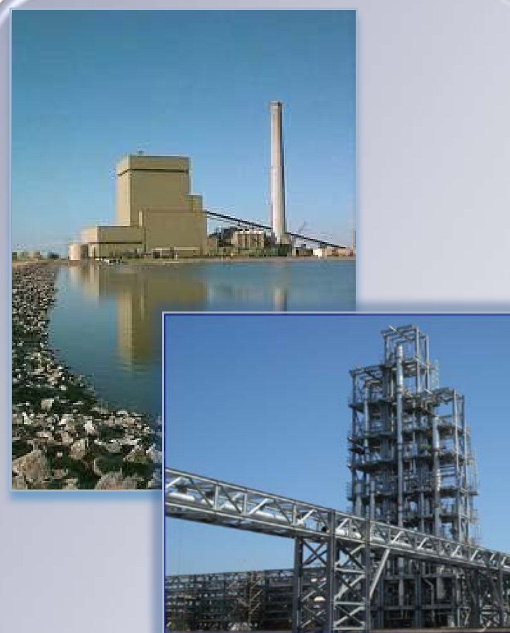
Advancing Technologies in Power Generation Utilizing Coal

~410 projects $14.5B Total ($5.7B DOE) *

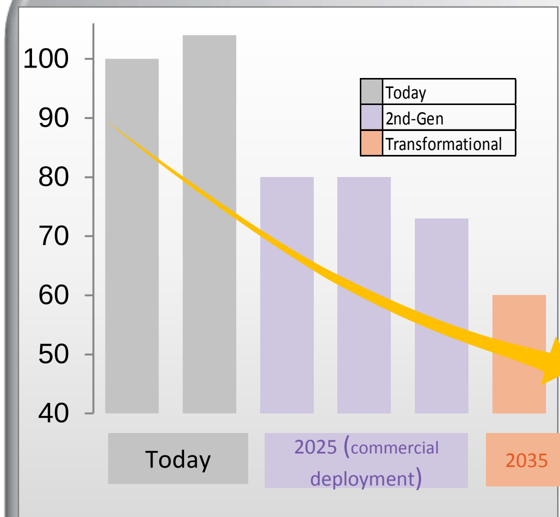
Relevance of R&D, Leverages, Promotes Commercialization



Office of Coal and Power R&D



Office of Major Demonstrations



Office of Program Performance & Benefits

* *Project Data as of June 10, 2013*

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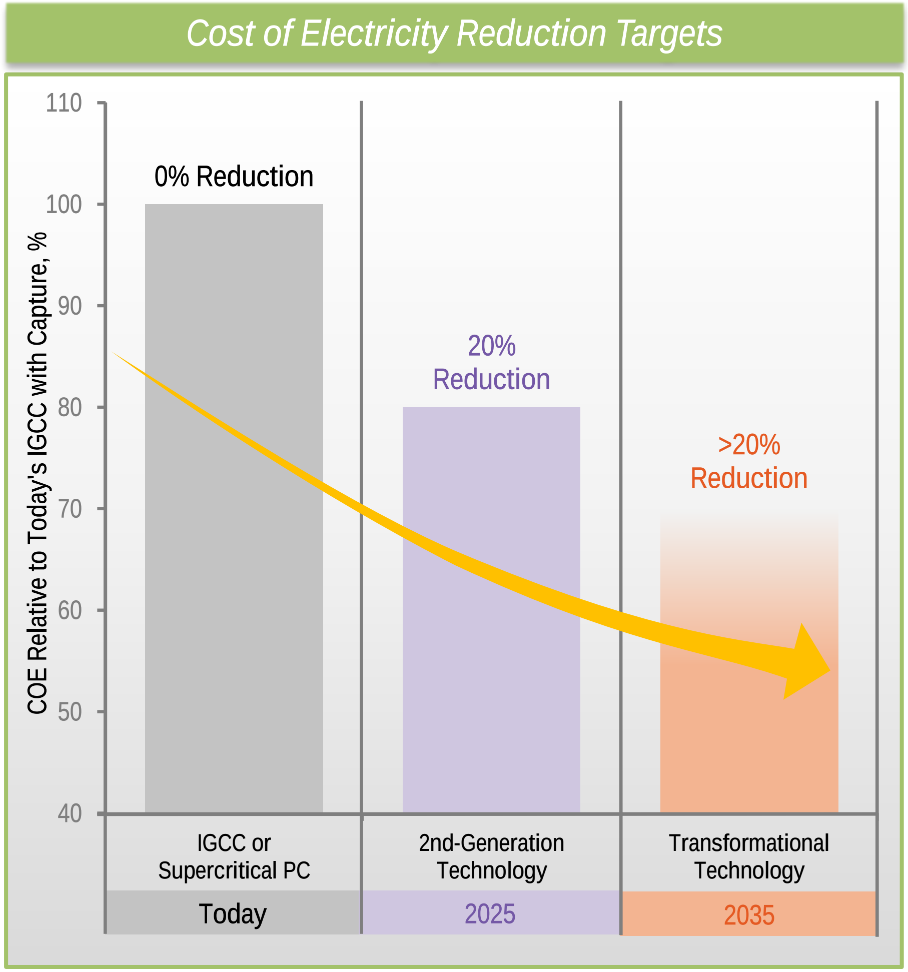
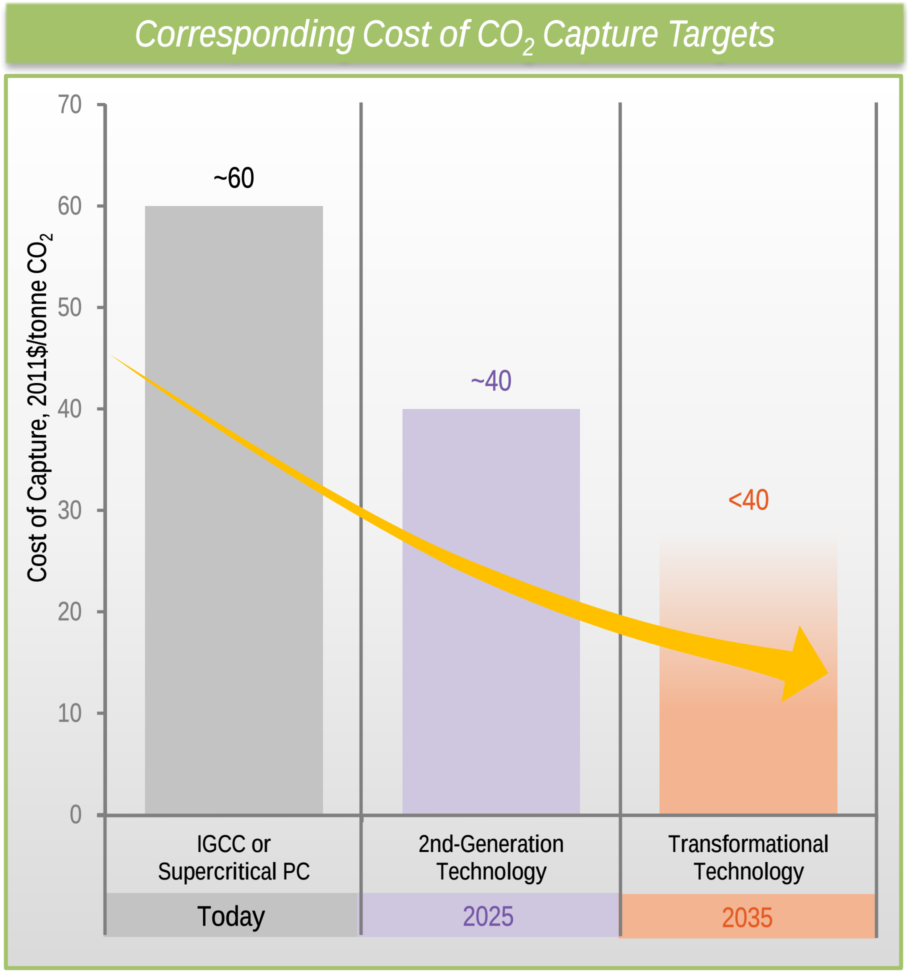
Clean Coal Research Program Goals

Driving Down the COE and Cost of CO_2 Capture of Coal Power with CCS





Goals shown are for greenfield plants. Costs are nth-of-a-kind, are for the first year of plant operation, and include compression to 2215 psia but exclude CO_2 transport and storage costs. Today's capture costs are relative to Today's SCPC without CO_2 capture. 2025 and 2035 capture costs are relative to an A-USC PC without CO_2 capture.

Advanced Coal Power Technologies

Aspects Applicable to Natural Gas

State-of-the-Art	2nd Generation	Transformational
Today's IGCC	Advanced IGCC Advanced Pre-combustion Capture	Integrated Gasification Fuel Cells (IGFC) Pulse Combustion 3100°F H_2 Turbine Transformational H2 Production
Today's Supercritical PC	Advanced Ultra-Supercritical (AUSC) PC Advanced Post-combustion Capture AUSC Oxycombustion	Transformational CO_2 Separation Chemical Looping Direct Power Extraction Supercritical CO_2 Cycles Pressurized Oxycombustion

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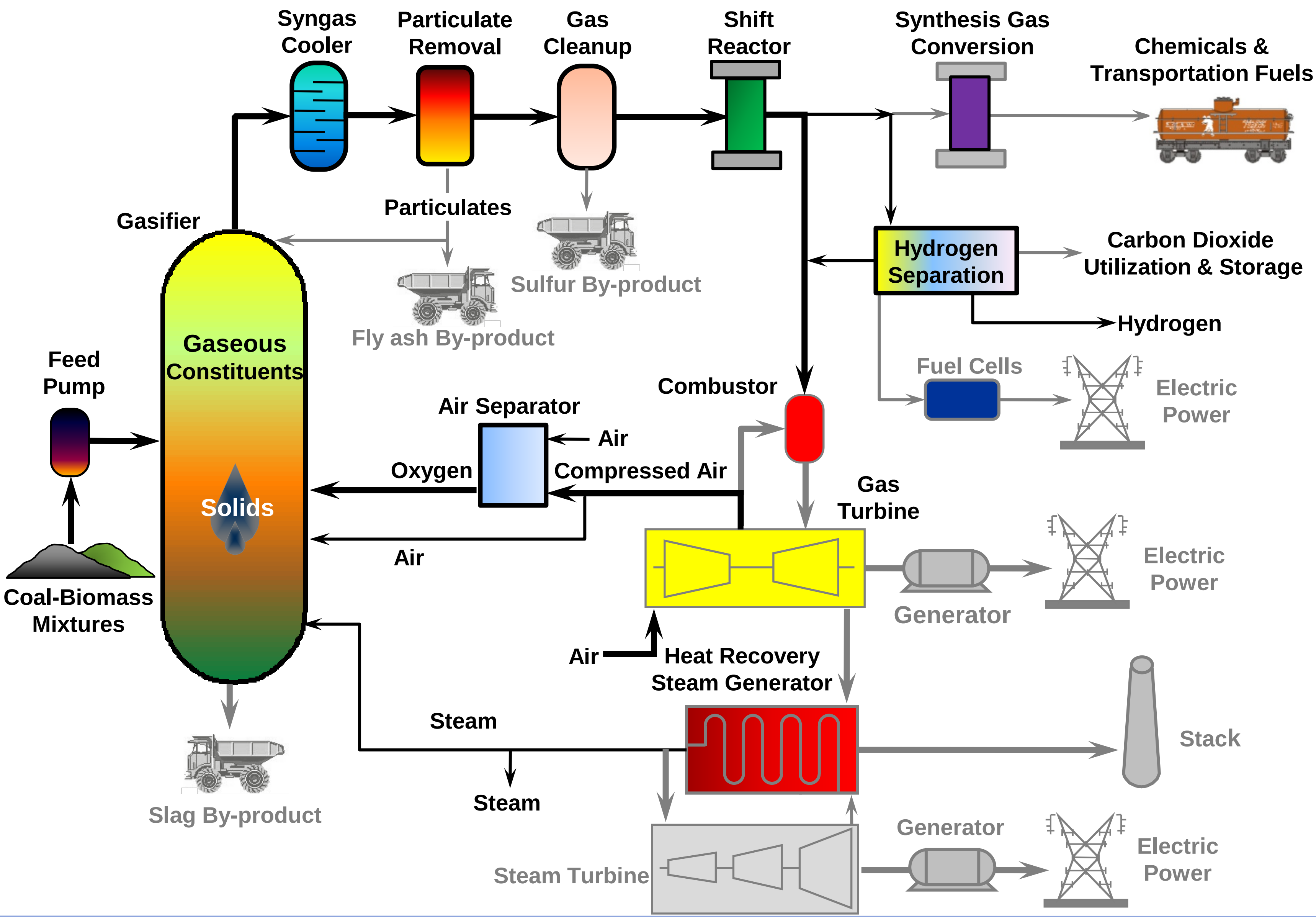
Advanced Coal Gasification Options



Warm Gas Cleanup – RTI

Eastman Gasification Facility

High Temperature Desulfurization

Direct Sulfur Recovery

Multi-contaminant Control System

Kingsport, TN

250 MW Tampa Electric IGCC Power Plant

50 MW demonstration under construction near Tampa, Florida

- Operates at high temperatures
- Cleans multiple contaminants while creating pure sulfur product
- 99.9 % removal of both H_2S and COS
- > 3,000 hours of operation at 0.3 Mwe

Developing and Demonstrating Technology

National Carbon Capture Center

Wilsonville, AL

- Gasifier and systems research
- Slip stream component testing

Mississippi Power's IGCC Power Plant

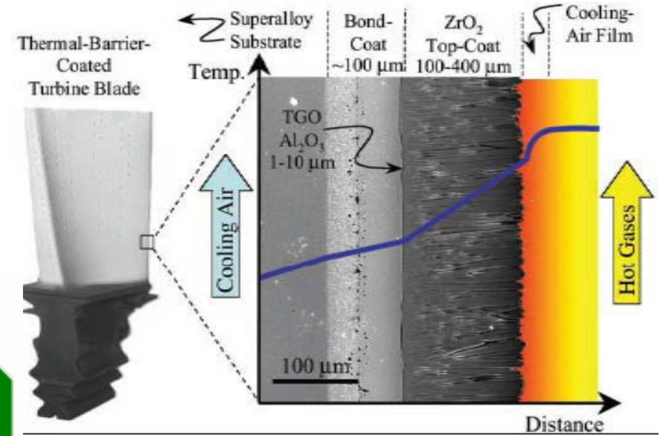
Kemper Co., MS

- 582 MW IGCC with CCS
- TRIG™ technology & lignite coal

Advanced Turbine R&D Areas

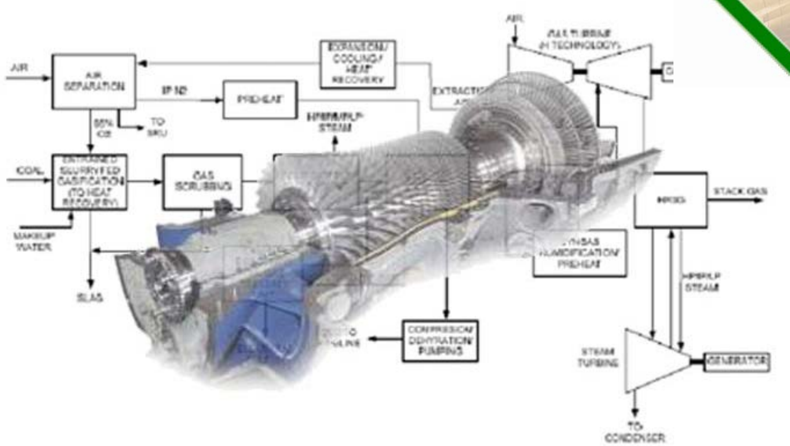
Combustion

Materials

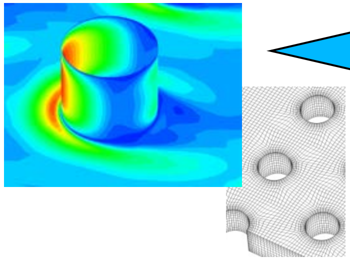


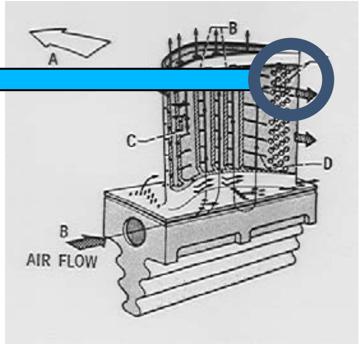
Cost
Power
Efficiency
Emissions

System Design



Aerodynamics & Heat Transfer





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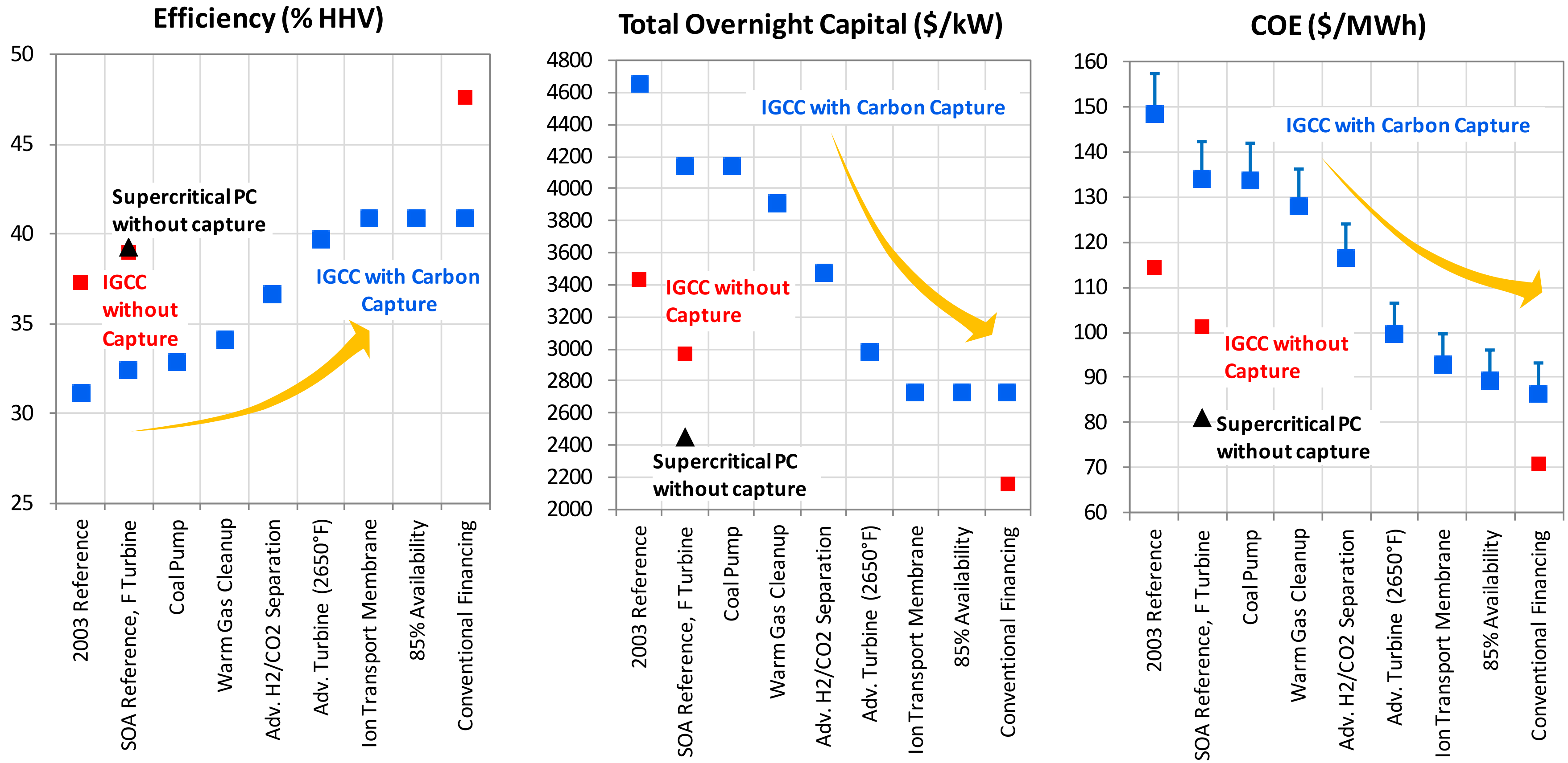
Advanced IGCC Systems

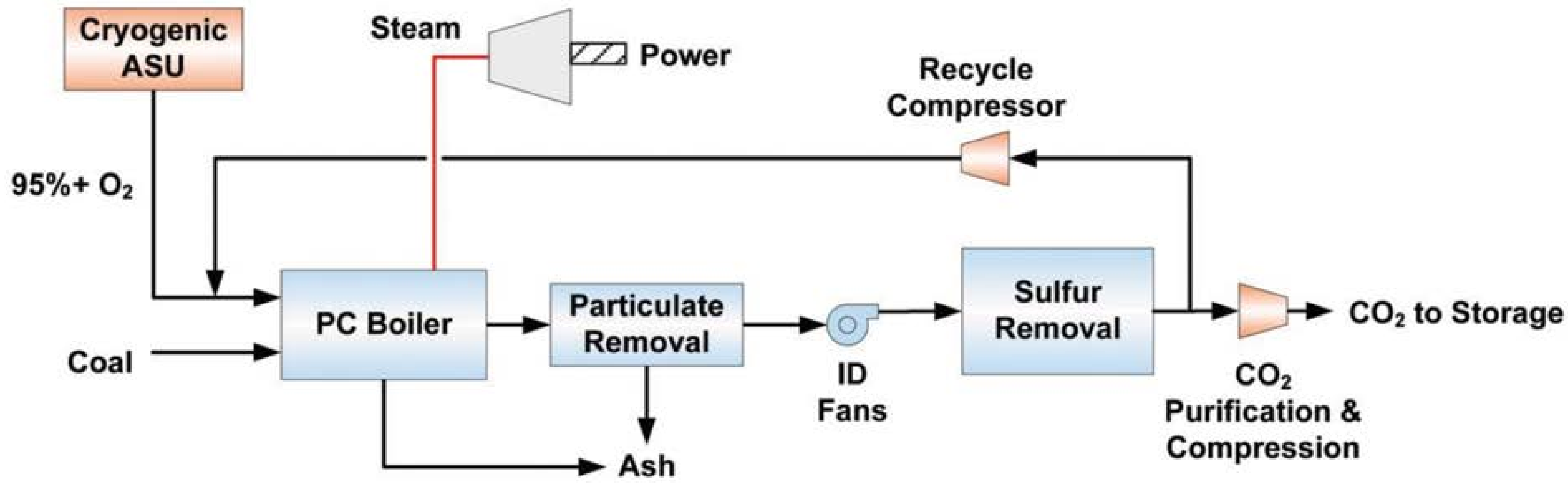


Advances in hydrogen turbines, gas cleanup, CO_2 separation, oxygen production, gasifier feed systems and plant availability show potential for:

- Efficiency improvements of 8.5 percentage points
- Capital cost reduction of 34% or $1,400/kW
- Cost of electricity (COE) reduction of 35%

Above relative to state-of-the-art (SOA) IGCC. An additional 1.3 %points in efficiency, 7% reduction in capital cost and 7% reduction in COE are due to turbine R&D progress-to-date
Ref: Current and Future Technologies for Gasification-Based Power Generation Volume 2: A Pathway Study Focused on Carbon Capture Advanced Power Systems R&D Using Bituminous Coal, Revision 2, 2013 DRAFT, DOE/NETL-2009/1389

Oxy-combustion Overview



Alstom's 5 MW Pilot Plant

Windsor, CT

Oxy-combustion Goal

Develop technology to provide commercially attractive CO_2 capture solutions and to accelerate commercialization for retrofit of existing pulverized coal power plants.

World-wide Oxy-Combustion Status

US focusing on Transformational Concepts

1st Generation

2nd Generation

Transformational

U.S. Oxy-combustion

Design/Lab Testing under Phase I FOA
Pressurized Oxy

- Unity Power Alliance[1]

Pilot Scale

- Pratt & Whitney (Aerojet) Rocketdyne[2]
- Washington University[1]
- Praxair OTM[3] – 1 MWe
- Jupiter Oxy-comb[1] – 5 MWe
- Alstom Oxy-comb[1] – 5 MWe

Demonstration Scale

- FutureGen 2.0[1] – 170 MW

Worldwide Oxy-combustion

Pilot Scale

- CANMET[1] Canada – 300 kWth
- Schwarze Pumpe Vattenfall[1] Germany – 10 MWe
- Compostilla[2] ENDESA/CUIDEN Spain – 10 MWe
- Callide-A Oxy-fuel CS Energy[1] Australia – 10 MWe
- HUST[1] China – 12 MWe

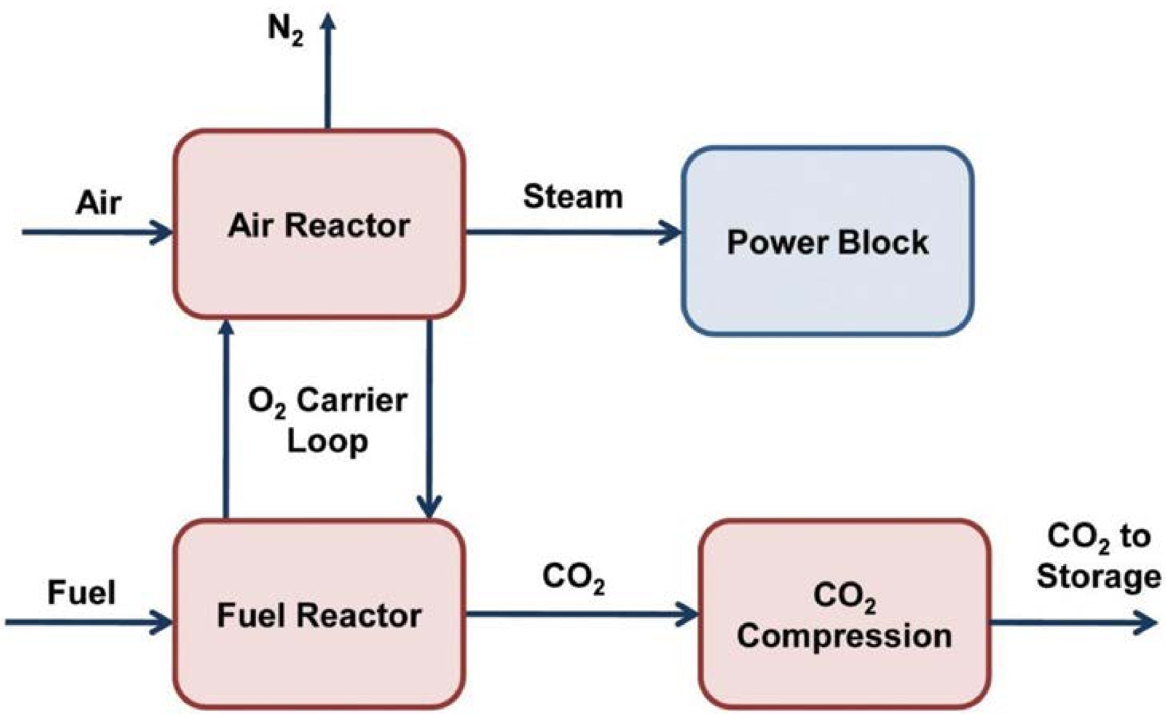
Proposed Demonstration Scale

- Young Dong[1] Korea – 100 MWe
- Taiyuan SIEG[1] China – 250 MWe
- Compostilla[2] ENDESA/CUIDEN Spain – 323 MWe
- Daqing Datang[1] China – 350 MWe
- White Rose CCS[1] UK – 426 MWe
- Korea CCS-2[1] Korea – 500 MWe
- Dongying CCS Project[1] China – 1000 MWe

Firing Mode
[1]Conventional PC
[2]CFB
[3]Other

Chemical Looping Combustion

General Process Description



Products

1. Steam for power
2. Nitrogen
3. Concentrated CO_2

Key Features

- Separate oxidation and reduction reactions
- Metal oxide or other compound carries oxygen from combustion air to fuel
- Carrier releases oxygen reacting with fuel
- Carrier recycled back to air reactor and reoxidized with air
- Raise steam for power through heat exchangers

Chemical Looping Combustion

Key Attributes

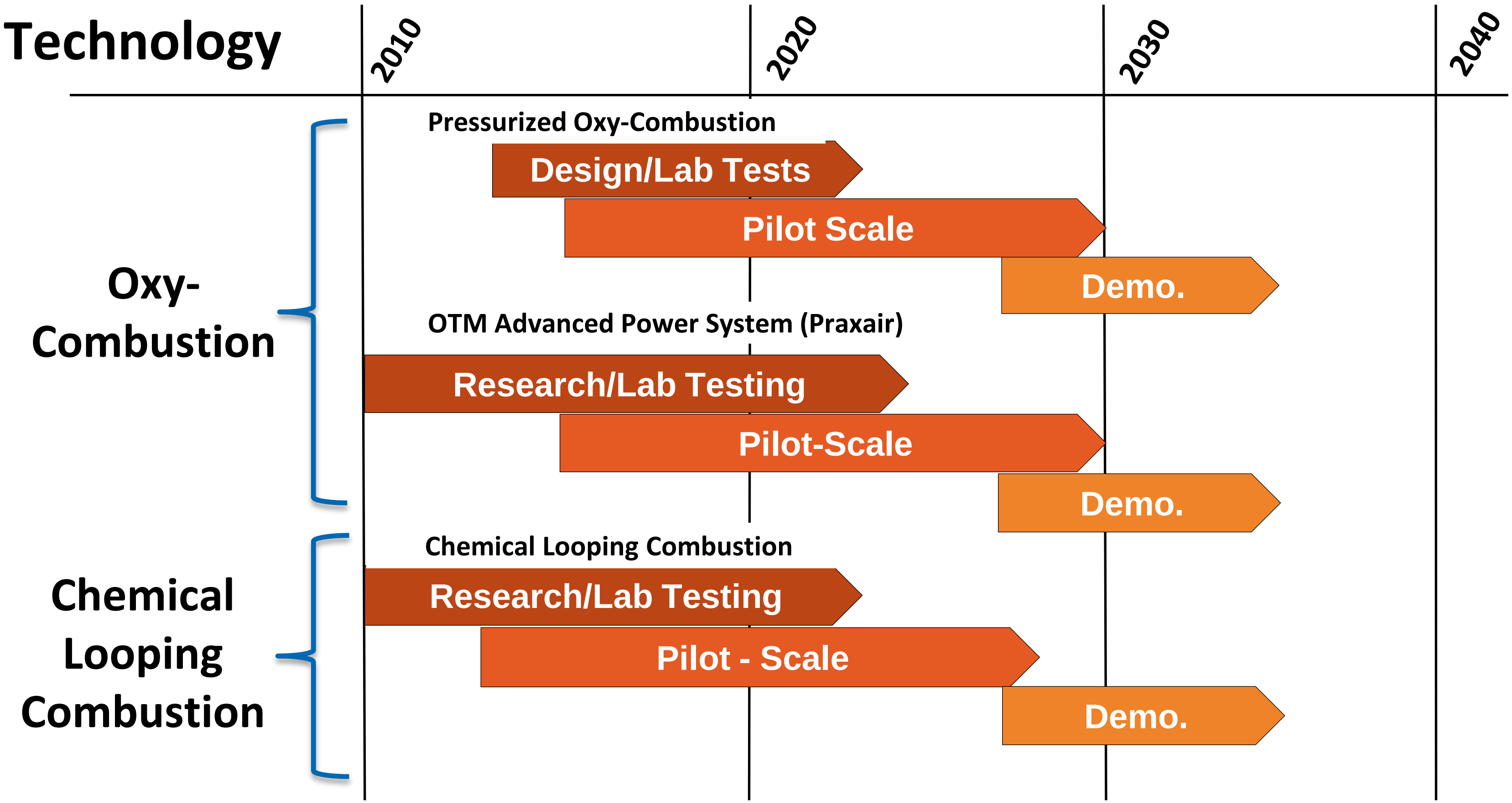
- **Advantages**
  - Air separation unit (ASU) not required for oxygen production
  - CO_2 separation takes place during combustion
  - Builds off commercial Circulating Fluidized Bed Combustion (CFBC) experience
- **Challenges**
  - Scale-up issues
  - Solids handling and transport
  - Oxygen carrying and reactivity
- **Maturity:** Pilot-scale
  - Auto-thermal operation at 3 MWth (Alstom)
  - US has largest unit (Alstom)
- **Unique Feature**
  - Alternate process configurations can be applied for both combustion and gasification

Ohio State University

Process Development Unit

25 kW_{th}

Transformational Combustion



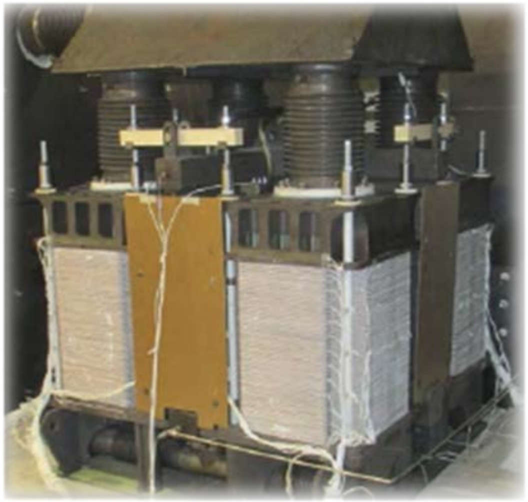
Cumulative Benefits

Advanced Combustion + Power Cycles + CO_2 Compression + Materials =

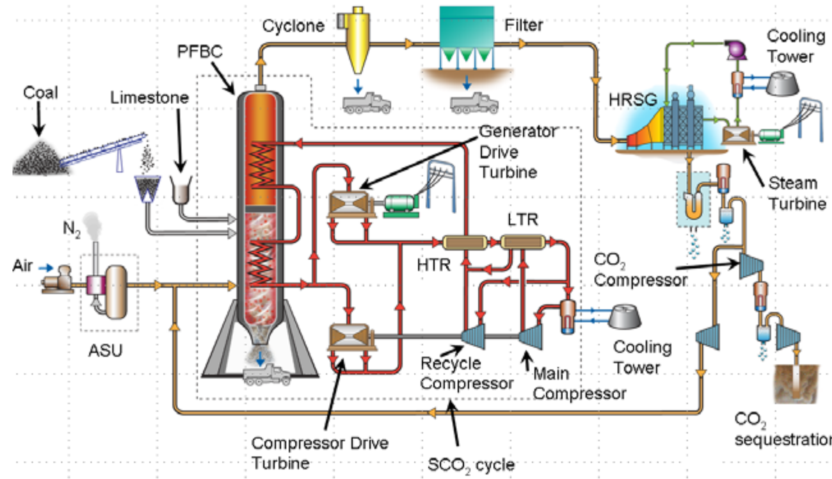
Today ~$60/tonne → less than $40/tonne CO_2 Removed

Additional Highlighted Technologies

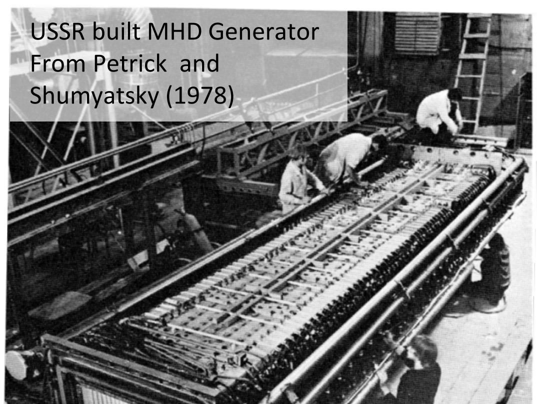
Solid Oxide Fuel Cells



Supercritical CO_2 Power Cycles



Direct Power Extraction



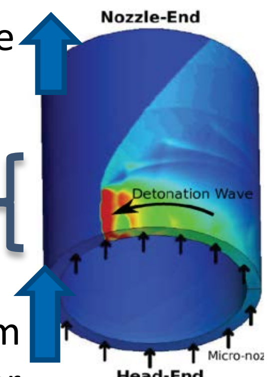
Magnetohydrodynamic (MHD) Power Generator

Rotation Wave Detonation Combustion

Higher pressure,
~ steady flow
to turbine

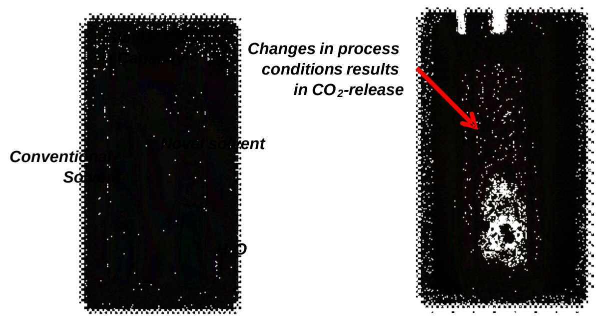
Rotating Detonation

Inlet from
compressor



Advanced CO_2 Capture
R&D Areas & Status

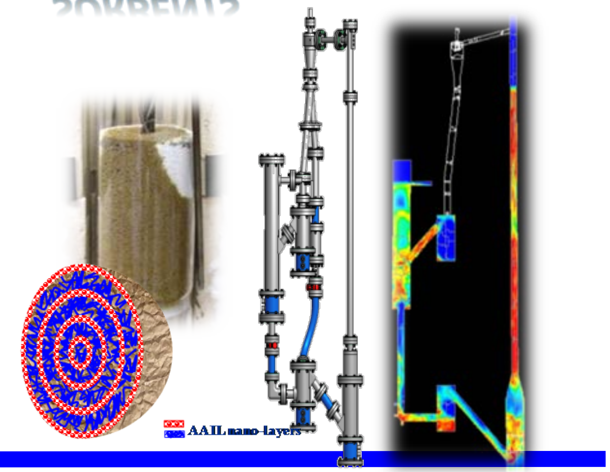
SOLVENTS



- ❑ Ionic Liquids
- ❑ Carbonates
- ❑ Amines
- ❑ Enzymes

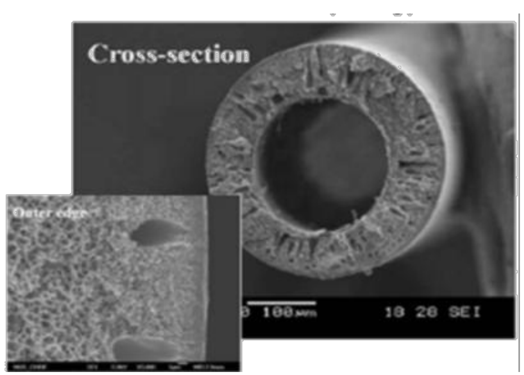
SORBENTS

- ❑ Amine-based
- ❑ Carbon
- ❑ MOFs*



11 Projects at Pilot Scale 0.1 to 25 MWe

MEMBRANES



- ❑ Polymer
- ❑ Metal
- ❑ Catalytic
- ❑ Hollow Fiber
- ❑ Spiral Wound
- ❑ Cryogenic

ADVANCED COMPRESSION

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

MOFs: Metal Organic Frameworks

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Major CCS Demonstration Projects

Significant Integrated Carbon Storage

CCPI

ICCS Area 1

FutureGen 2.0

FutureGen 2.0

Large-scale Testing of Oxy-Combustion w/ CO_2 Capture and Sequestration in Saline Formation

Project: ~$1.78B – Total; ~$1.05B – DOE

SALINE – 1 MM TPY 2017 start

Archer Daniels Midland

CO_2 Capture from Ethanol Plant

CO_2 Stored in Saline Reservoir

$208M – Total, $141M – DOE

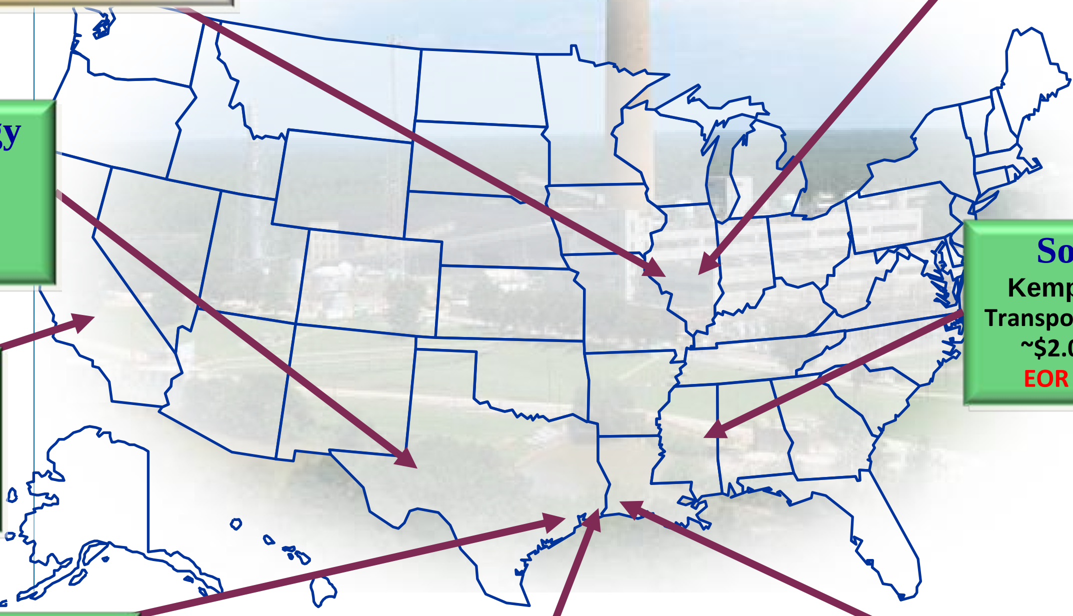
SALINE – ~0.9 MM TPY 2015 start

Summit TX Clean Energy

Commercial Demo of Advanced IGCC w/ Full Carbon Capture

~$1.7B – Total, $450M – DOE

EOR – ~2.2 MMTPY 2017 start



Southern Company

Kemper County IGCC Project

Transport Gasifier w/ Carbon Capture

~$2.01B – Total, $270M – -DOE

EOR – ~3.0 MM TPY 2014 start

HECA

Commercial Demo of Advanced IGCC w/ Full Carbon Capture

~$4B – Total, $408M – DOE

EOR – ~2.6 MM TPY 2019 start

NRG

W.A. Parish Generating Station

Post Combustion CO_2 Capture

$775 M – Total

$167M – DOE

EOR – ~1.4 MM TPY 2016 start

Air Products and Chemicals, Inc.

CO_2 Capture from Steam Methane Reformers

EOR in Eastern TX Oilfields

$431M – Total, $284M – DOE

EOR – ~0.93 MM TPY 2012 start

Leucadia Energy

CO_2 Capture from Methanol Plant

EOR in Eastern TX Oilfields

$436M - Total, $261M – DOE

EOR – ~4.5 MM TPY 2017 start

Summary

- **2nd generation technologies on the horizon**
  – Targeting 20% COE reduction and $40/tonne of CO_2 captured
  – Enables economical deployment of coal power with CCS when coupled with EOR revenues
- **Transformational technologies will decrease costs further by 2035 to support wide-spread market competiveness of coal with CCS**
  – Not dependent on EOR revenues for market viability
- **2 paths to achieve goals: gasification and combustion**
  – Many promising technologies under development
  – Demonstrations at commercial scale in integrated applications
- **Many technologies partially or fully applicable to natural gas applications**

Thank You

Office of Fossil Energy

www.fe.doe.gov

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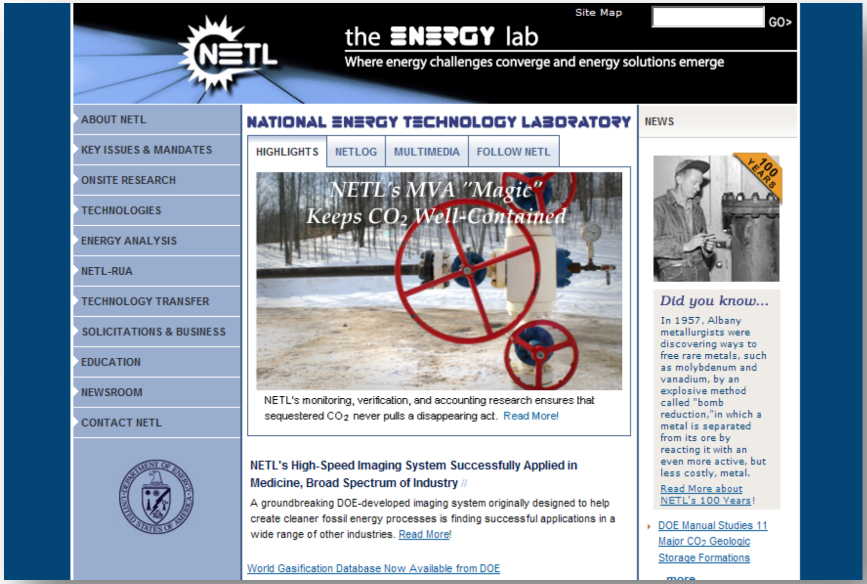

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