NATIONAL ENERGY TECHNOLOGY LABORATORY

## Carbon Capture 2020 Workshop

***October 5-6, 2009***
***Univ. of Maryland***

# DOE/NETLs Existing Plants $CO_2$ Capture R&D Program

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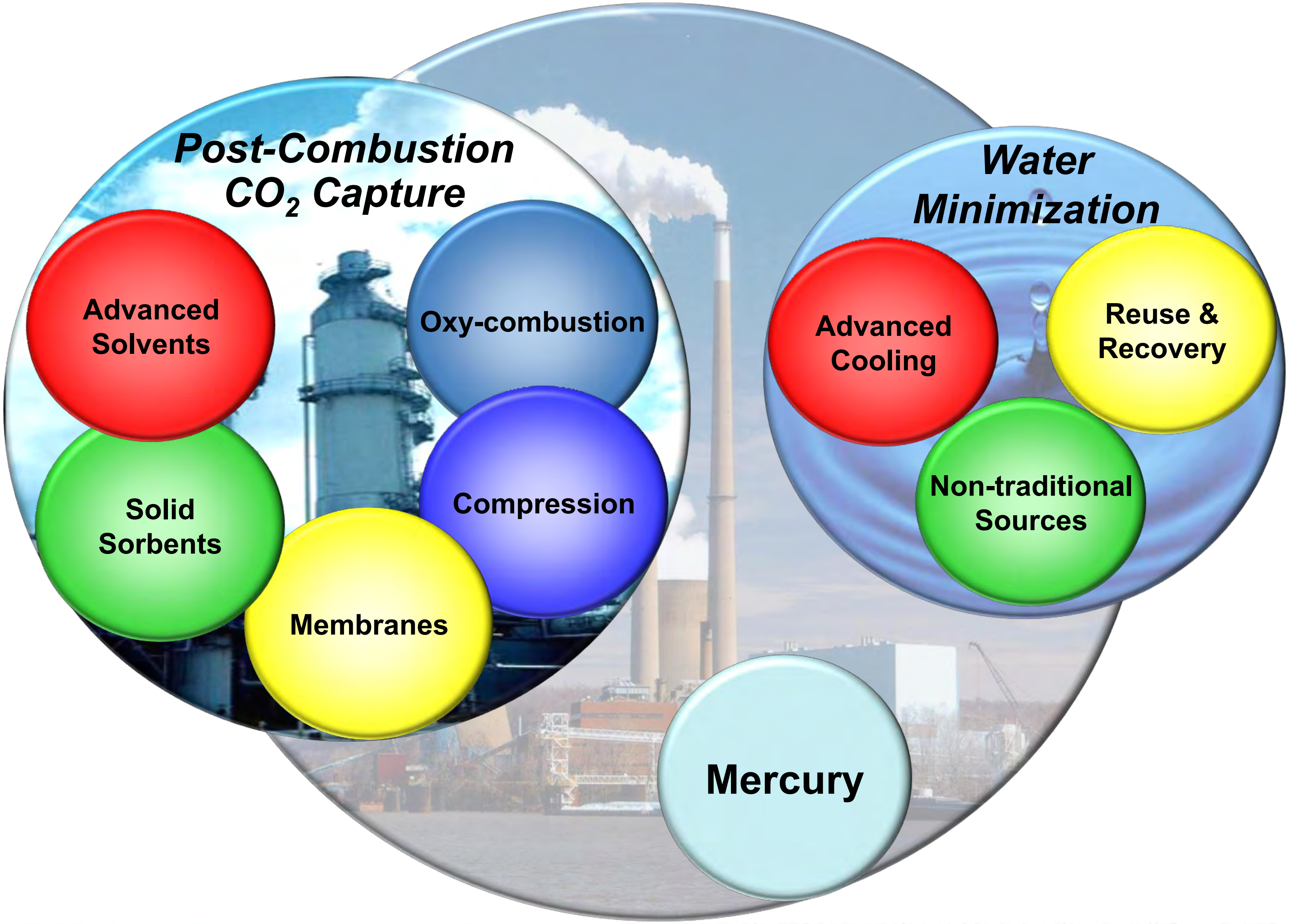
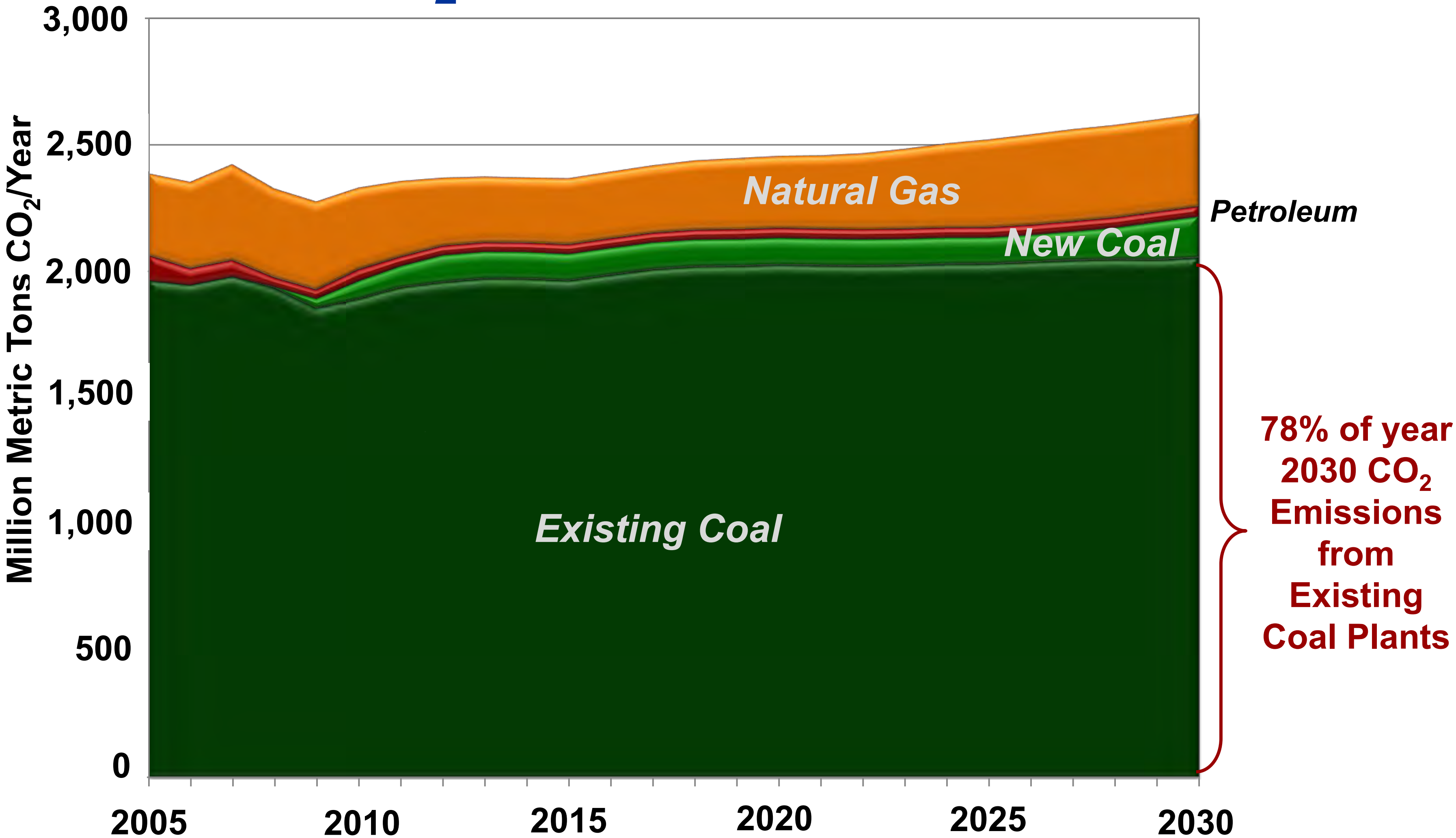
# Existing Plants Program Structure



# U.S. Electricity Generation $CO_2$ Emissions Forecast

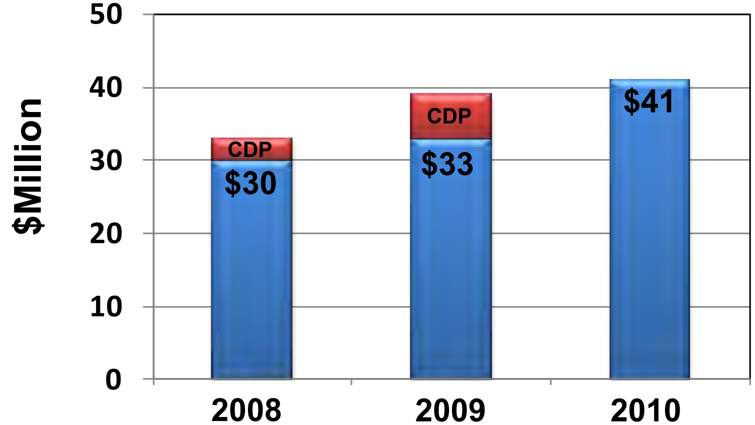




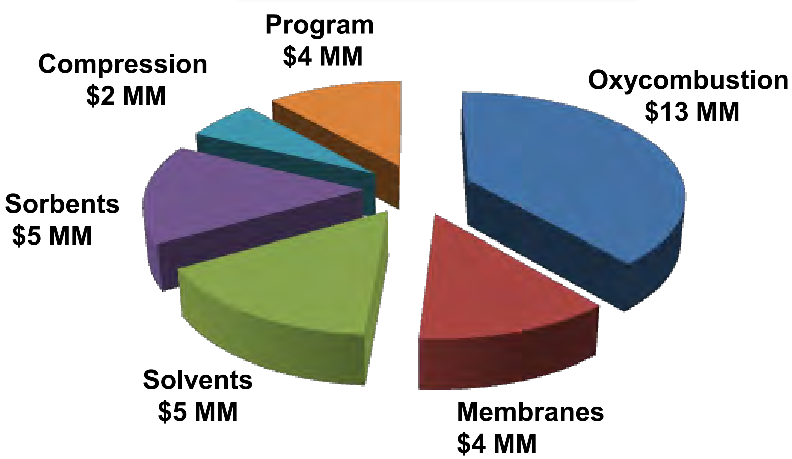

*Values Calculated from Energy Information Administration's Annual Energy Outlook ARRA Reference Case Scenario, AEO Does not consider PC with CCS*

# IEP Capture Program Budget & Partners

**IEP $CO_2$ Capture Annual Budget**




**FY09 Budget Allocation**




**Industry**

GE Research Corporation, Praxair, Air Products, Jupiter Oxygen, Alstom Power, Babcock and Wilcox, Foster Wheeler, UOP, ADA-Environmental Services, TDA, Reaction Engineering International

**Laboratory**

Lawrence Berkeley National Lab.

**University**

Ohio State
Georgia Tech.
University of Notre Dame
University of Akron
University of Pittsburgh
West Virginia University
Carnegie Mellon University
Penn State University

**Non-Profit**

Illinois St. Geological Survey
Research Triangle Institute
Southern Research Institute
SRI International
Southwest Research Institute



CDP = Congressionally Directed Projects
Program $--Systems Analysis, Program Planning

# Deployment Barriers for $CO_2$ Capture on <u>New</u> and <u>Existing</u> Coal Plants Today

1. **Scale-up**
   - Current PC capture ~200 tons/day
   - 550 MWe plant produces 13,000 tons/day
2. **Energy Demand**
   - 20% to 30% ↓ in power output
3. **Cost**
   - Increase Cost of Electricity (COE)
4. **Regulatory framework**
   - Transport — pipeline network
   - Storage

# Existing Plants $CO_2$ Capture Program Mission

***By 2020, have available for commercial deployment, technologies that achieve:***

***90% $CO_2$ capture***

***< 35% increase in COE****

## Set by Systems Analyses


1057

Availability analysis of post-combustion carbon capture systems: minimum work input

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*The manuscript was received on 27 June 2006 and was accepted after revision for publication on 5 June 2007.*

DOI: 10.1243/09544062JMES424

**Abstract:** This paper describes the availability analysis of a generic, post-combustion carbon capture plant. The analysis first establishes the minimum work input required in an ideal plant with a flue gas inlet temperature equal to the sink temperature. The analysis shows that the ideal work input is surprisingly low and that, roughly equal amounts of work are required to first separate and then compress the $CO_2$ contained in a typical flue gas stream. The analysis is then extended to include the effects of variable inlet temperature and extraction efficiency. This extended analysis shows that there is a considerable quantity of available energy in the flue gas of a normal power station. Indeed, in principle, carbon capture is theoretically possible without any external work input for fuels of low carbon/hydrogen ratio such as heavy fuel oil and natural gas. When burning coal, the minimum work input would be significantly reduced if the flue gases' availability were utilized.

The final section of the paper compares the actual work input of a variety of carbon capture schemes found in the literature, with the minimum work input for an ideal process. This comparison shows that the techniques presently found in the literature have a low second-law efficiency.

**Keywords:** carbon capture, post-combustion, availability, minimum work input, second-law efficiency

1 INTRODUCTION

Carbon sequestration has become an accepted part of a global effort to reduce man's augmentation of the greenhouse effect to sustainable levels. Substantial research programmes, sponsored by both government and industry, have shown that the technique is both technically and economically feasible and has advantages when compared with many of the alternatives [1]. Current research on carbon sequestration technology concentrates on broadly two main areas: carbon capture and carbon storage. Traditionally the storage technology is not considered critical from a thermodynamic perspective [2]; the process of separating $CO_2$ from the flue gas and its subsequent liquefaction (or compression) requires larger energy input.

Many commentators state that since the removal of $CO_2$ from gas streams is an established practice in the chemical industry, the application to the power industry is simply a matter of transferring a mature technology [3, 4]. There is undoubtedly logic in this position, however, the removal of $CO_2$ from flue gas in a power station still represents a major technical challenge. This is partly due to the low partial pressure of $CO_2$ in the flue gas, although, there are many techniques to deal with this situation [5]. However, another important factor is the economics of the power industry. The power industry does not have the luxury of producing a high value product. Additionally, it is increasingly one of intense competition and often subject to price shocks in one fuel sector and not another. Conversely, the chemical industry has the advantage that its products are generally of much higher value than energy, so there is less of an imperative for raising efficiency and minimizing capital cost. Additionally, in the chemical industry there is often a requirement for process 'robustness'. This can lead to

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NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL

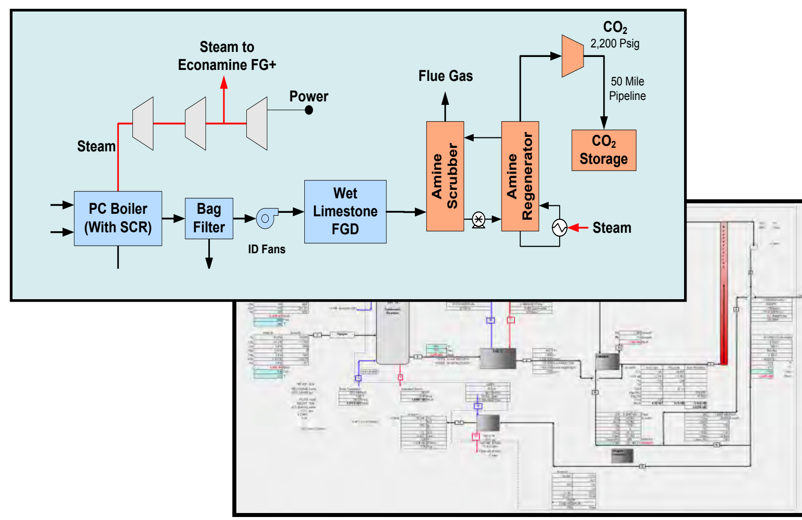
Existing Plants, Emissions and Capture – Setting $CO_2$ Program Goals

20 April 2009

DOE/NETL-2009/1366

U.S. DEPARTMENT OF ENERGY

## Evaluated by Systems Analyses

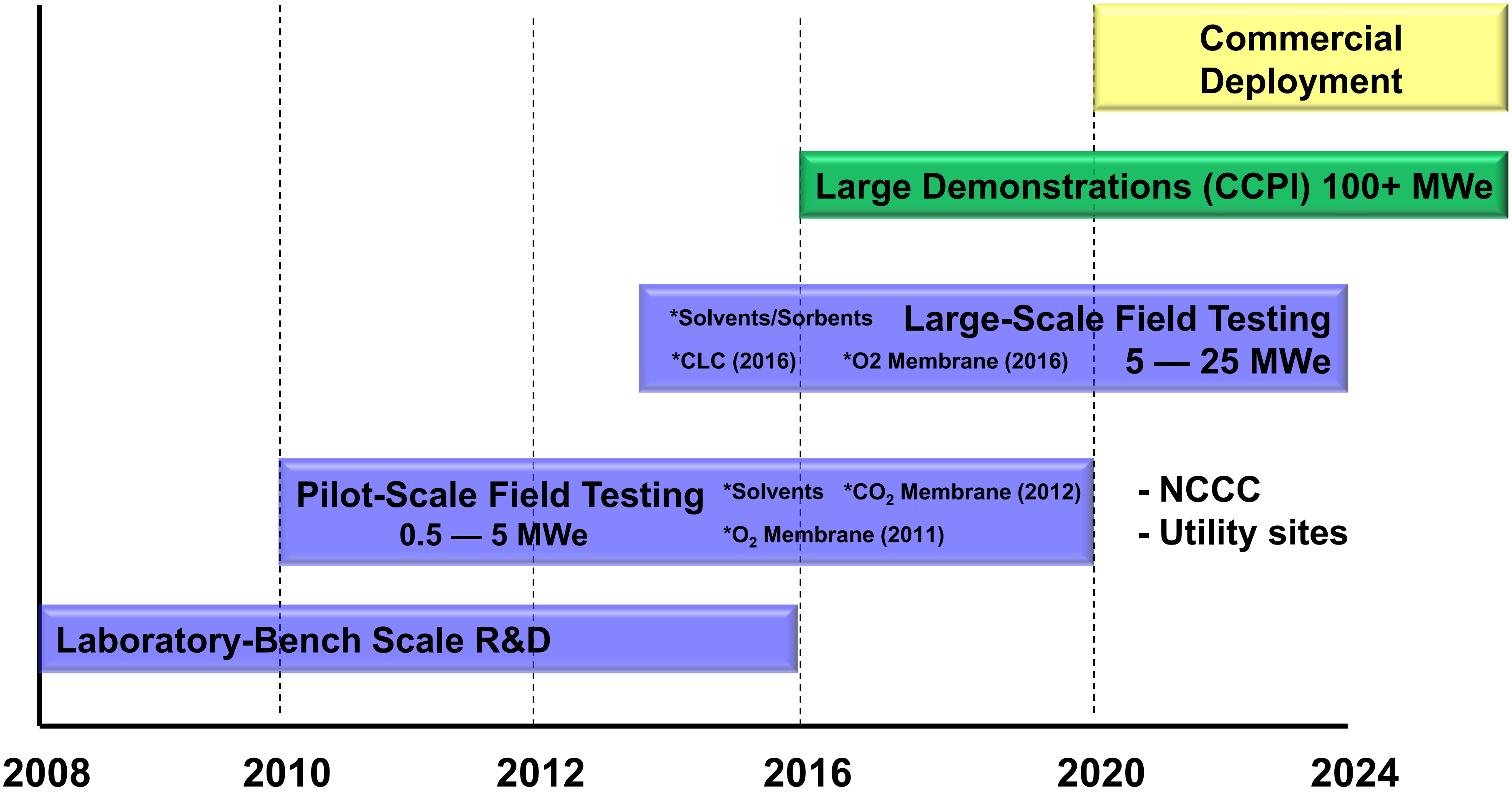



*Cost of Electricity includes 50 mile pipeline transport and saline formation storage, 100 years of monitoring



*Availability analysis of post-combustion carbon capture systems: minimum work input*, McGlashan, N.R., Marquis, A.J., Mechanical Engineering Science, Proc. ImechE Vol. 221 Part C, 2007
*Existing Plants, Emissions & Capture Program—Setting Program Goals,* U.S. DOE/National Energy Technology Laboratory, Final Report, April 2009

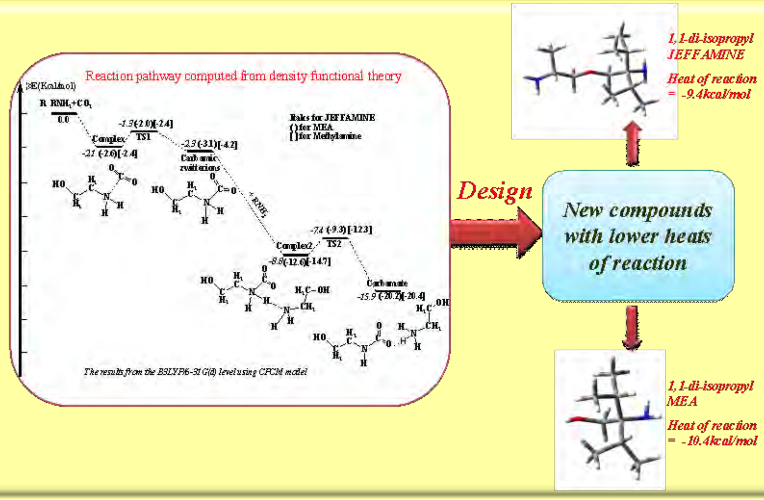
# RD&D Timeline to Commercial Deployment



# Advanced $CO_2$ Solvents

## Advanced Solvent R&D Focus

- High $CO_2$ loading capacity
- Minimize regeneration energy
- Fast reaction kinetics
- Non-corrosive
- No solvent degradation
- Low cost




Source: Novel High Capacity Oligomers for Low Cost $CO_2$ Capture, GE Global Research, GE Energy, University of Pittsburgh Annual NETL CO2 Capture Technology for Existing Plants R&D Meeting, March 24-26, 2009

## Project Types

- Ionic liquids
- Novel high capacity oligomers
- Potassium carbonate/enzymes
- $CO_2$ capture additives

***Solvent Screening and Synthesis***

***Recent chemical formulations show:***

- ✓ ***50% increase capacity vs. MEA***
- ✓ ***< 48% increase in COE***

**Laboratory-scale**



***Partners (5 Projects):*** *University of Notre Dame, Georgia Tech., Illinois St. Geological Survey, GE Research Corporation, Lawrence Berkeley Nat. Lab*

# Solid $CO_2$ Sorbents

## Advantages

- Low regeneration energy (no water, low heat capacity, low heat of reaction)
- High equilibrium capacity
- Fast kinetics

## Challenges

- System design
  - Pressure drop
  - Heat integration
  - Solid transport
- Durability (attrition, chemical stability)

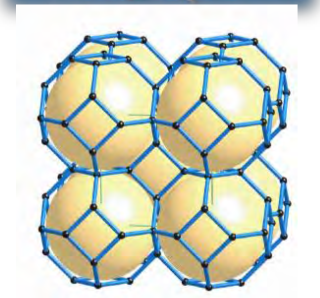
**Project Types**

- Sorbent systems development
- Carbonates
- Metal organic frameworks
- Metal zeolites

**Laboratory-scale**

## Advanced Sorbent R&D Focus

- **High $CO_2$ loading capacity**
- **Minimize regeneration energy**
- **Fast reaction kinetics**
- **Durable**
  - Thermally & chemically stable
- **Gas/solid systems**
  - Low pressure drop, heat management





**Partners (6 Projects):** ***RTI, UOP, University of Akron, ADA, SRI, TDA***

# $CO_2$ Membranes

## Advantages

- Simple operation; no chemical reactions, no moving parts
- Tolerance to high levels of wet acid gases
- Compact and modular with a small footprint
- Relatively low energy use; no additional water used (recovers water from flue gas)

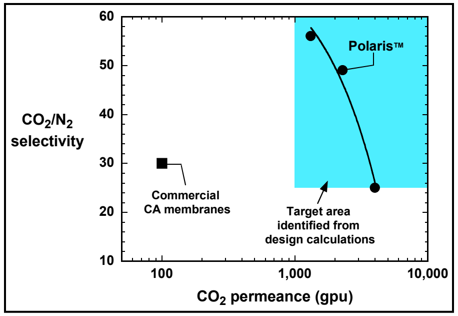
## Challenges

- Low flue gas $CO_2$ partial pressure
- Particulate matter and potential impact on membrane life
- Cost reduction and device scale-up
- Power plant integration (e.g. sweep gas)

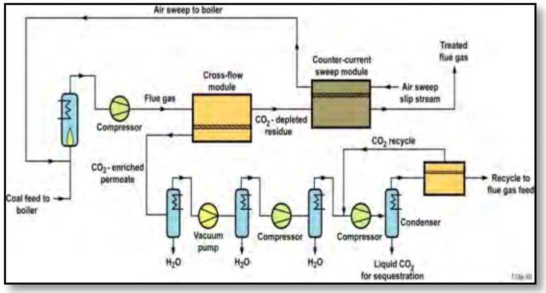
**Laboratory to Pilot-scale**

## Advanced Membrane R&D Focus

- High $CO_2/N_2$ selectivity & permeability
- Durability
  - Chemically ($SO_2$), thermally
  - Physically
- Membrane systems
  - Process design critical
- Low cost
  - Capital and energy penalty




*1 TPD $CO_2$ , 6 month test*



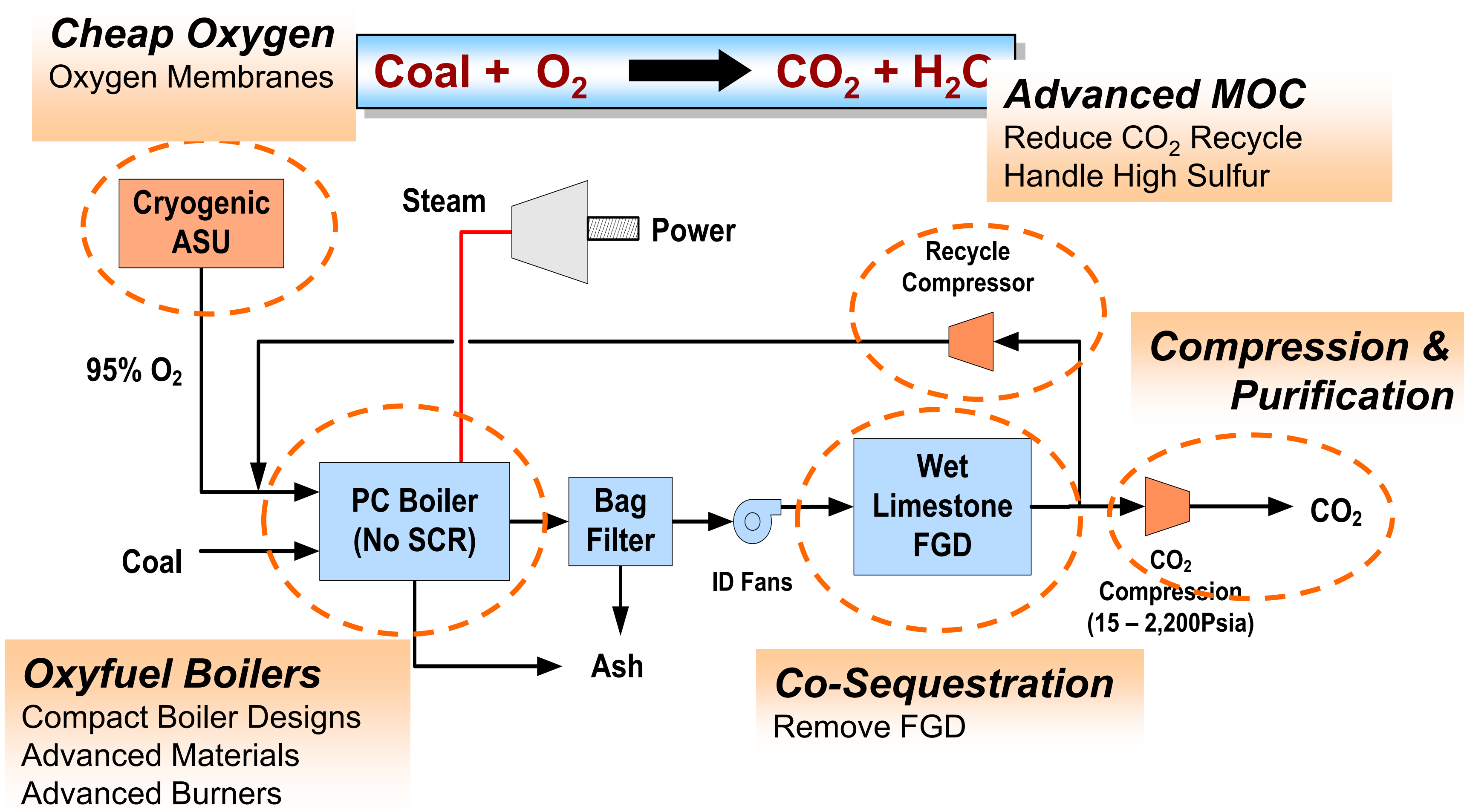





**Partners:** ***MTR, RTI***

# Pulverized Coal Oxy-combustion

## *Technology Opportunities*

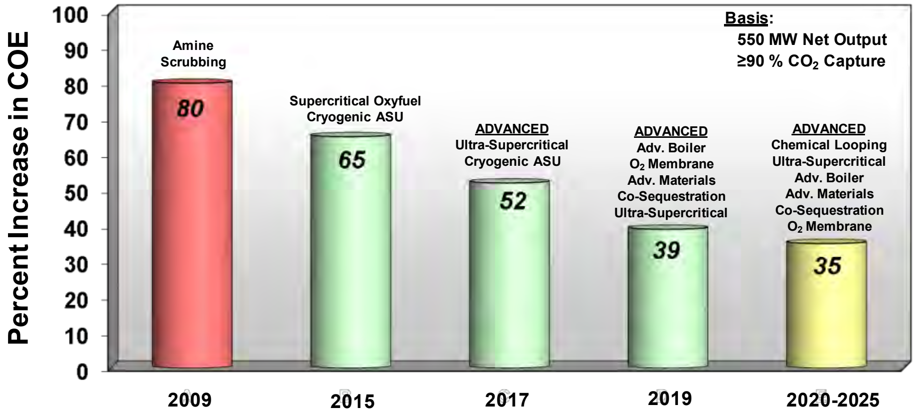



*MOC – materials of construction, FGD – Flue Gas Desulfurization, SCR – Selective Catalytic Reduction*

# Pulverized Coal Oxy-combustion

### Advantages

- Plant vs. unit operation—multiple cost reduction opportunities
- Existing technologies show slight economic advantage over scrubbing
- 1st generation plants can utilize existing technologies (e.g. boiler, cryogenic ASU)
- Co-sequestration options




### Challenges

- $O_2$ production → existing cryogenic ASUs are capital and energy intensive
- Excess $O_2$ and inerts ($N_2$, Ar) ↑ $CO_2$ purification cost
- Existing boiler air infiltration
- Corrosion and process control

### R&D Focus

- New oxyfuel boilers
  - Advanced materials and burners
  - Corrosion
- Retrofit existing air boilers
  - Air leakage, heat transfer, corrosion
  - Process control
- Low-cost oxygen
- $CO_2$ purification
- Co-capture ($CO_2$ + SOx, NOx, $O_2$)

**Partners (11 projects):** ***Praxair, Air Products, Jupiter, Alstom, B&W, Foster Wheeler, REI, Southern Research***

# Chemical Looping Combustion

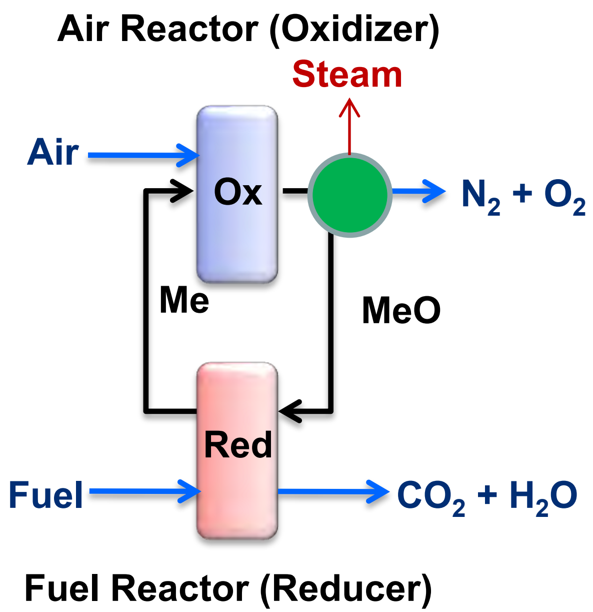
**Chemical Looping Advantages:**

- Oxy-combustion without an $O_2$ plant
- *Potential* lowest cost option for near-zero emission coal power plant <20% COE penalty
- New and existing PC power plant designs

**Key Challenges**

- Solids transport
- Heat Integration

**Oxy-Firing without Oxygen Plant**




- **Solid Oxygen Carrier** circulates between **Oxidizer** and **Reducer**
- **Oxygen Carrier:** Carries Oxygen, Heat and Fuel Energy
- **Carrier picks up $O_2$** in the Oxidizer, leaves N2 behind
- **Carrier Burns** the **Fuel** in the Reducer
- **Heat** produces **Steam for Power**

**Status**

2010 Alstom Pilot test (1 MWe)

- ✓ 1000 lb/hr coal flow
- ✓ 1st Integrated operation
- ✓ 1st Autothermal Operation



**Key Partners (2 projects):** ***Alstom Power (Limestone Based), Ohio State (Metal Oxide)***

# For More Information About the NETL Existing Plants Program

- **NETL website:**
  - [www.netl.doe.gov](http://www.netl.doe.gov)

**Reference Shelf**

- **Annual CO2 Capture Meeting**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- **Office of Fossil Energy website:**
  - ww.fe.doe.gov

**Innovations for Existing Plants**
$CO_2$ Emissions Control

Capturing Carbon from Existing Coal-Fired Power Plants (Apr 2009)
Annual NETL $CO_2$ Capture Technology for Existing Plants R&D Meeting Presentations - March 24-26, 2009
DOE/NETL's Monthly Carbon Sequestration Newsletter

- Program Goals and Targets
- Post-Combustion $CO_2$ Control
- Oxy-Combustion $CO_2$ Control
- $CO_2$ Compression
- $CO_2$ Beneficial Use
- Systems Analysis
- $CO_2$ Emissions Control Reference Shelf

Welcome to the Innovations for Existing Plants (IEP) Program's $CO_2$ emissions control R&D homepage. In FY08, the IEP Program redirected its focus to include $CO_2$ emissions control for existing coal combustion-based plants, e.g. conventional pulverized coal-fired plants. The focus on $CO_2$ emissions control technology – both post-combustion and oxy-combustion – and related areas of $CO_2$ compression and $CO_2$ beneficial reuse is in direct response to the priority placed on advancing technological options for the existing fleet of coal-fired power plants for addressing climate change. In addition to funding R&D projects conducted externally, DOE/NETL also conducts in-house research to develop new breakthrough concepts for carbon capture that could lead to dramatic improvements in cost and performance relative to today's technologies. The IEP $CO_2$ emissions control R&D activity also sponsors systems analysis studies of the cost and performance of various carbon capture technologies. The program goal is to develop advanced $CO_2$ capture and separation technologies for existing power plants that can achieve at least 90% $CO_2$ removal at no more than a 35% increase in cost of energy services.

Use the hyperlinks located in the adjacent blue box to find detailed information on the IEP $CO_2$ emissions control R&D activities. Information on pre-combustion $CO_2$ emissions control technology applicable to coal gasification-based (e.g. integrated gasification combined cycle) plants is located at the $CO_2$ Capture webpage of DOE/NETL's Carbon Sequestration Program website.

Prior to FY08, DOE/NETL's $CO_2$ emissions control R&D effort was conducted under the Carbon Sequestration Program. With responsibility for existing plant $CO_2$ emissions control R&D now being conducted under the IEP Program, the Carbon Sequestration Program continues to focus on pre-combustion $CO_2$ emissions control and geological sequestration. Since its inception in 1997, the Carbon Sequestration Program has been developing both core and supporting technologies through which carbon capture and storage (CCS) will become an effective and economically viable option for reducing $CO_2$ emissions from coal-based power plants. Successful R&D will enable CCS