Overview of DOE/NETL RD&D Efforts to Develop Advanced Pre-, Post-, and Oxy-Combustion CO_2 Capture Technologies

http://www.netl.doe.gov/publications/index.html

NATIONAL ENERGY TECHNOLOGY LABORATORY

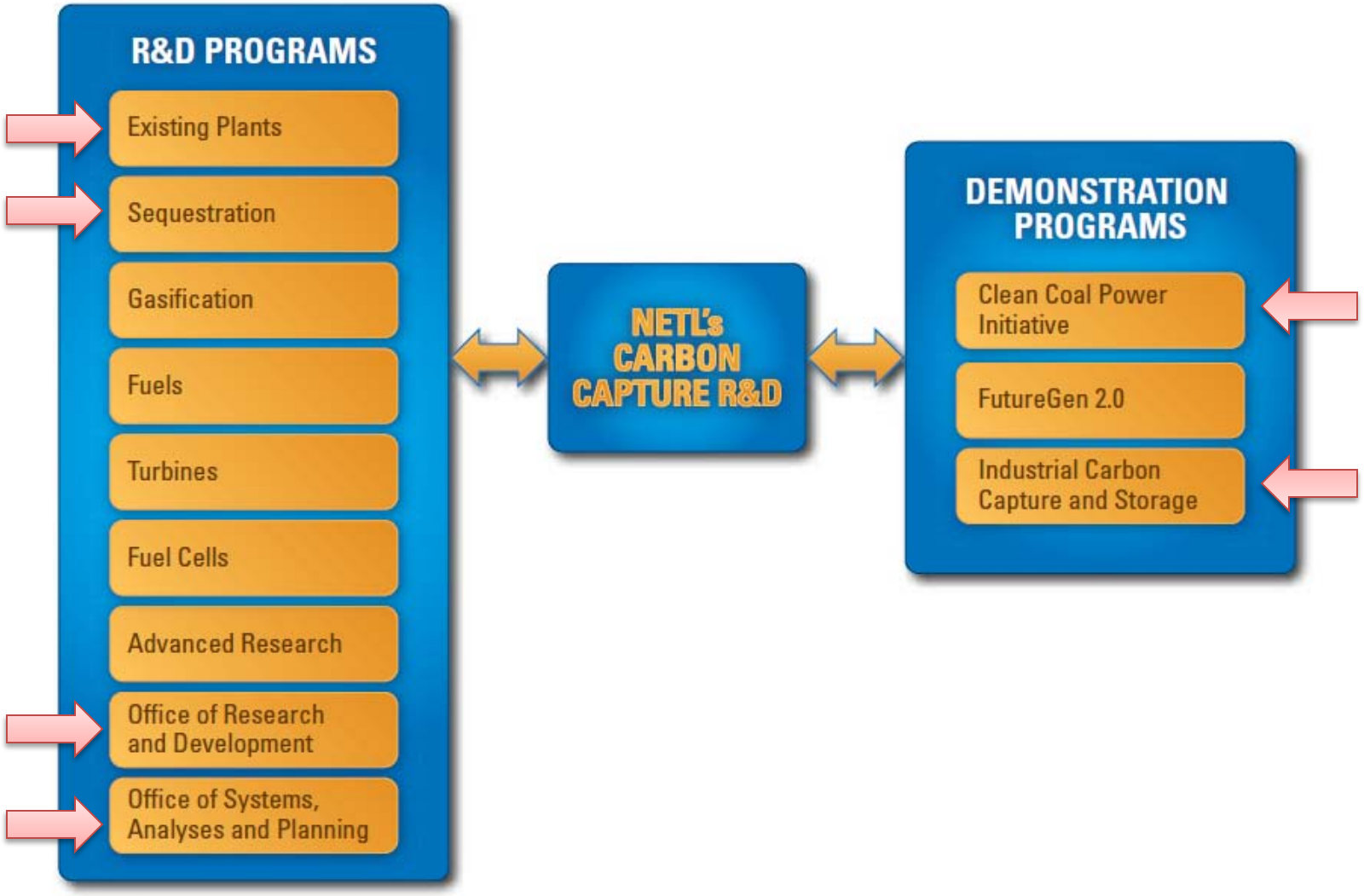
2010 NETL CO_2 Capture Technology Meeting

Sept. 13 – Sept. 17, 2010
Pittsburgh, PA

The U.S. Department of Energy's Carbon Dioxide Capture RD&D Program

Jared Ciferno, Technology Manager
Existing Plants Program

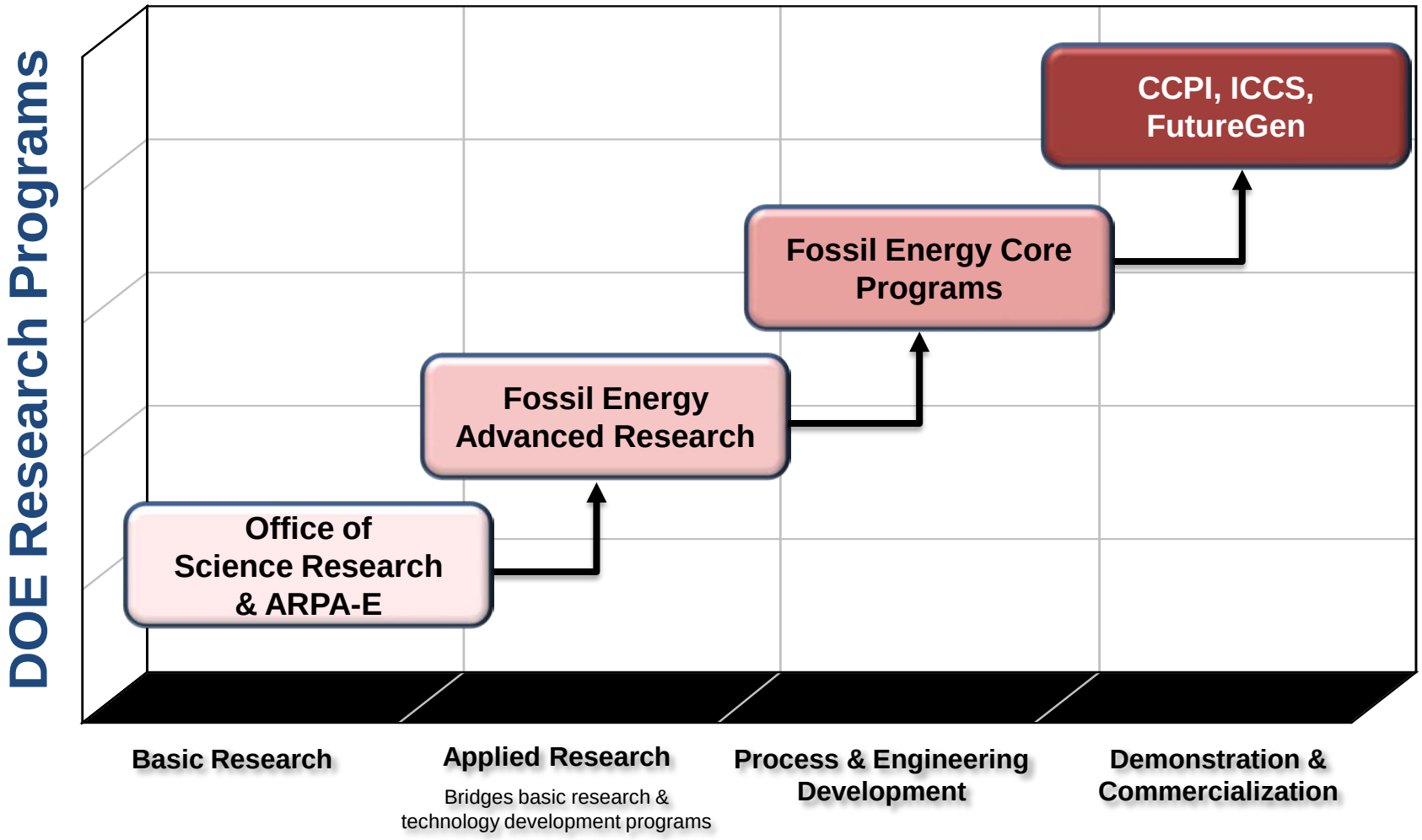
DOE/NETL CO_2 Capture RD&D Program



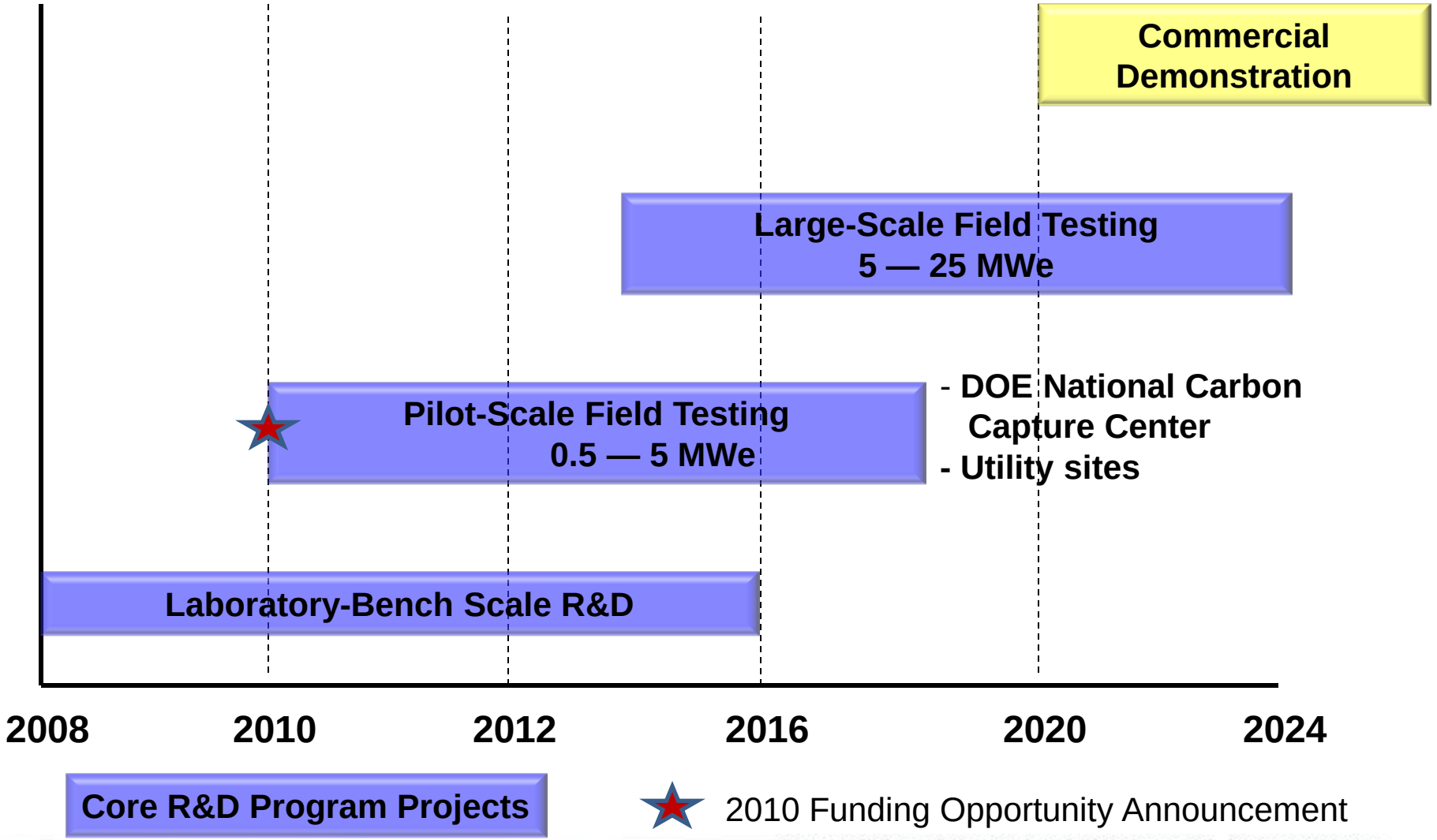
Conference Overview

Monday	Post-Combustion Sorbents
	Post-Combustion Solvents
Tuesday	Post-Combustion Membranes
	Oxy-Combustion
	ARPA-E Projects
Wednesday	Chemical Looping
	Systems Studies & Modeling
	CO_2 Compression
	New Post-Combustion Projects
Thursday	New Post-Combustion Projects, cont'd
	CCPI & ICCS Demonstrations
	Pre-Combustion Projects
Friday	Pre-Combustion Projects, cont'd

Stages of Energy RD&D



Advanced CO_2 Technology Timeline



Adv. Post- and Oxy-Combustion CO_2 Capture Goals

By 2020, have available for <u>demonstration</u>, advanced CO_2 capture technologies that achieve:

90% CO_2 capture

< 30% increase in COE^2

Set by Systems Analyses

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.

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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 realistic 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 large 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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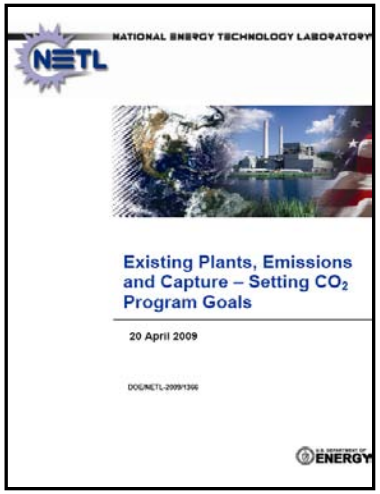
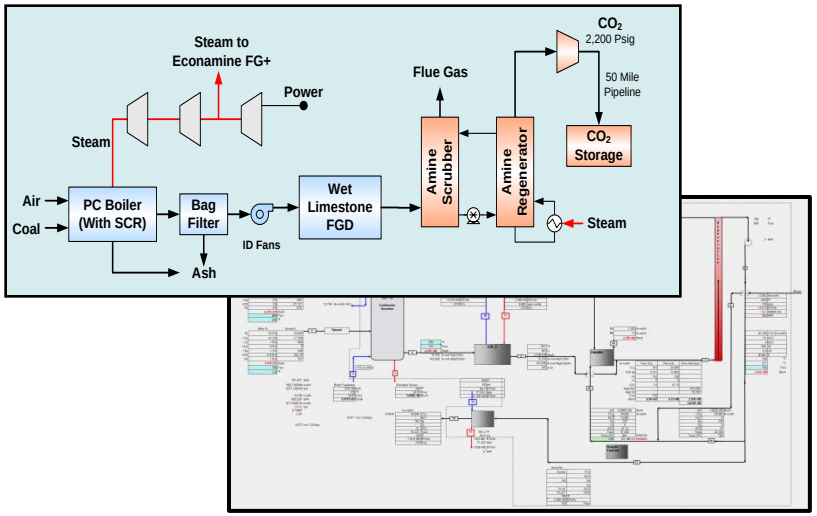


Evaluated by Systems Analyses



**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

2010 FOA: Bench-scale Project Selections

- **2 Membranes**
  - **American Air Liquide:** Sub-Ambient Membrane Operation
  - **Gas Technology Institute:** Hybrid Membrane/Absorption Process
- **5 Solvents**
  - **3H Company, LLC:** Self-Concentrating Amine Absorbent
  - **Akermin:** Enzyme Catalyzed Solvent
  - **ION Engineering:** Amine/Ionic Liquid Solvent
  - **University of Illinois:** Hot Carbonate Absorption Process
  - **URS Group:** Concentrated Piperazine Solvent

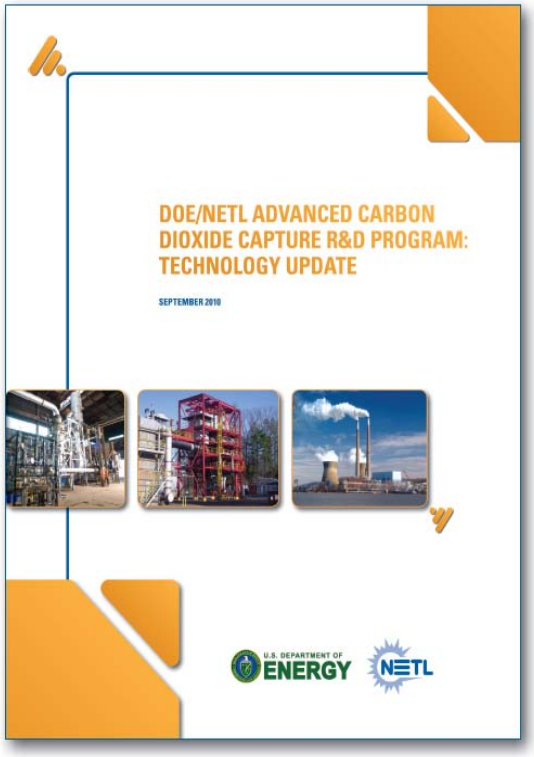
2010 FOA: Pilot-Scale Project Selections

3 Pilot-scale

- **Solvents**
  - **Siemens Energy (2.5 MWe):** Siemens POSTCAP Amino Acid
- **Sorbents**
  - **ADA-ES (1 MWe):** Advanced Solid Sorbents
- **Membrane**
  - **Membrane Technology Research (1 MWe):** Membrane CO_2 Capture

DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)

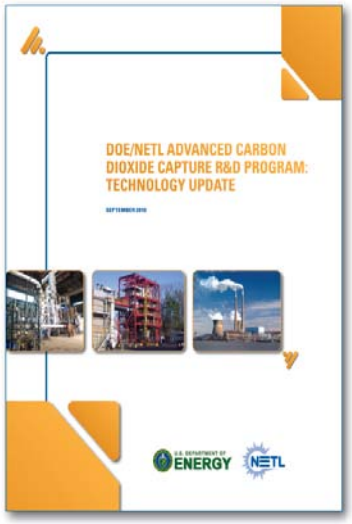
- Just published and available for download
- This comprehensive handbook provides an update on DOE/NETL R&D efforts on advanced CO_2 capture technologies for coal-based power systems.
- Prepared by the Existing Plants and Sequestration R&D Programs, the report tracks the progress of DOE/NETL pre-combustion, post-combustion, and oxy-combustion technologies for CO_2 capture.
- The handbook is available for download on the NETL website at these two locations:



http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

http://www.netl.doe.gov/technologies/carbon_seq/index.html

DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)



- Chapter 1: Introduction stressing the importance of developing cost-effective advanced CO_2 capture technologies.
- Chapter 2: Description of DOE/NETL's CO_2 capture R&D program.
- Chapter 3: Overview of the three basic configurations for CO_2 capture − pre-combustion, post-combustion, and oxy-combustion.
- Chapter 4: Provides some of the basic scientific principles and important operating parameters for the various CO_2 capture technologies.
- Chapters 5 through 10 report on the status of DOE/NETL's R&D efforts for pre-combustion capture; post-combustion capture; oxy-combustion; oxygen production; chemical looping; and advanced compression, respectively.
- Chapter 11: Review of DOE/NETL's CO_2 capture R&D collaborations.
- Appendix: Provides detailed information on the status and results of the current portfolio of DOE/NETL's CO_2 capture R&D projects.

DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)

Project Title:
CO_2 Capture from IGCC Gas Streams Using AC-ABC Process

Technology Area:	**Technology Maturity:**
Pre-Combustion Solvents	Pilot-scale using actual syngas

Primary Project Goal:

SRI International is developing, for integrated gasification combined cycle (IGCC)-based power plants, a carbon dioxide (CO_2) capture technology based on the use of a high-capacity and low-cost aqueous ammoniated solution containing ammonium carbonate (AC), which reacts with CO_2 to form ammonium bicarbonate (ABC).

Technical Goals:

- Test the technology on a bench-scale batch reactor to validate the concept.
- Determine the optimum operating conditions for a small pilot-scale reactor.
- Design and build a small pilot-scale reactor capable of continuous integrated operation.
- Perform pilot-scale tests to evaluate the process in a coal gasifier environment.
- Perform a technical and economic evaluation on the technology.

Technical Content:

The technology is based on the use of an aqueous ammoniated solution containing AC, which reacts with CO_2 to form ABC.

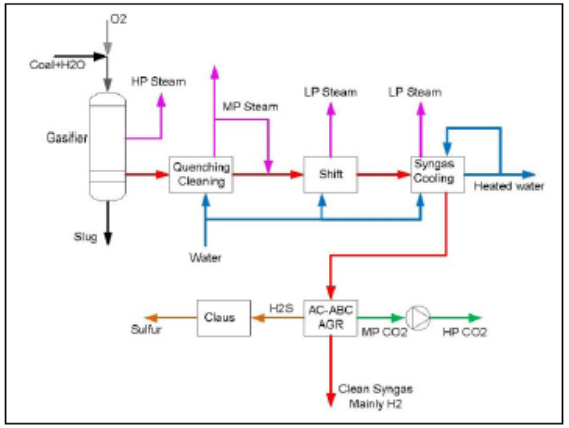


Figure 1: AGR in Gasification System

The concentrated ammoniated solution is used to capture CO_2 and hydrogen sulfide (H_2S) from synthesis gas (syngas) at high pressure. This technique reduces the size of the CO_2 stripper and operates at high pressure, reducing CO_2 compression needs. Both reduce electric power consumption. AC has high net

A technical and economic analysis will use Aspen modeling to generate the equipment sizing and heat and material flows, DOE cost models, and a base case, 750-MW nominal IGCC plant without CO_2 capture to compare the AC-ABC process with a similar-size plant using CO_2 capture with a Selexol subsystem.

Table 1: Solvent Parameters

	Parameter	Current R&D Value	Target R&D Value
Solvent Properties	Type of solvent	Aqueous ammoniated solution	Aqueous ammoniated solution
	Molecular weight	Nominal 18	Nominal 18
	Boiling point (°C)	Varies with pressure; 100°C at 1 atm	Varies with pressure; 100°C at 1 atm
	Heat of reaction (kJ/mole CO_2)	40 to 60 depending on the NH_3/CO_2 ratio	40 to 60
	CO_2 loading/working capacity*, wt.%	10	20
	Solvent concentration to stripper (mol/liter)	6 M NH_3	8 M NH_3
	Heat capacity of solution (kJ/K/kg)	3.5	3.5
	Viscosity, cP	1	1
Operating Conditions	Absorption temperature, °C	25	25 to 40
	Absorption pressure, atm.	20	50
	CO_2 capture efficiency, %	>90	>90
	Regeneration method	Heating with steam	Heating with steam
	Regeneration temperature, °C	N/A	150
	Regeneration pressure, atm.	N/A	50
Heat Integration	Required regeneration steam temperature, °C	120	170
Miscellaneous	Solvent make-up rate, kg/kgCO_2	N/A	N/A
Product Quality	CO_2 purity, %	>98%	98.1
	N_2 concentration, %	N/A	1.9
	Other contaminants, %	N/A	0.01
Process Performance	Electricity requirement, kJ/kgCO_2	N/A	17.7
	Heat requirement, kJ/kgCO_2	N/A	620.6
	Total energy (electricity equivalent), kJ/kgCO_2	N/A	638.3

*Working capacity is the loading difference CO_2 rich solution before and after it is regenerated.

Equations Describing Chemical Reaction:

$NH_4OH + CO_2 = NH_4HCO_3$

$(NH_4)_2CO_3 + CO_2 + H_2O = 2NH_4HCO_3$

$NH_4(NH_2CO_2) + CO_2 + 2H_2O = 2NH_4HCO_3$

$NH_4HCO_3 = NH_4HCO_3$ (precipitate)

Solvent Reaction Kinetics:

The absorption of CO_2 by the ammoniated solution is proportional (1st order) to the CO_2 partial pressure. Preliminary experiments confirm this behavior. The kinetics of CO_2 absorption is expected to be rapid at the elevated pressures and high CO_2 concentrations expected in the IGCC gas stream downstream of the water gas shift (WGS) reactors.

Solvent Heating/Cooling Method:

During regeneration, the liquid is heated by steam using a reboiler. In the absorber, the liquid is cooled using a heat exchanger and a coolant from a direct contact cooler.

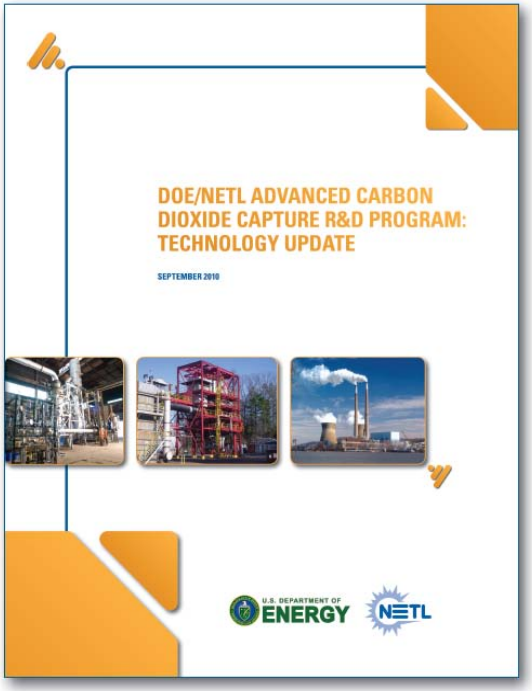
Solvent Contaminant Resistance:

The solvent is expected to be resistant to several contaminants nominally present in an IGCC gas stream. Hydrogen sulfide reacts with the solvent, but it can be removed during the regeneration. The ammonia

DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)

- Special request to our Project Principal Investigators:

We need your help in updating and improving the format and content of this handbook for next year's publication.



- For questions or comments regarding the handbook, please contact:
  - Jared P. Ciferno, Technology Manager, Existing Plants R&D Program (post-combustion and oxy-combustion technologies) jared.ciferno@netl.doe.gov
  - Sean I. Plasynski, Technology Manager, Sequestration R&D Program (pre-combustion technologies) sean.plasynski@netl.doe.gov

DOE/NETL Advanced CO_2 Capture R&D Program: Technology Update (September 2010)

- Special thanks to:

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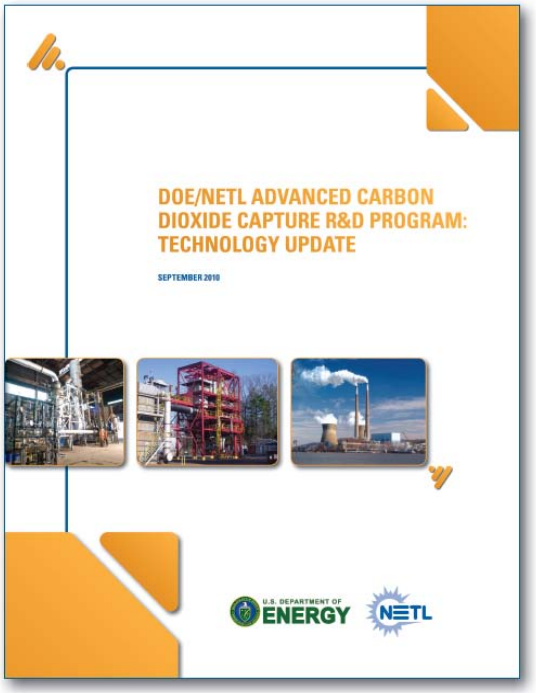


Looking Forward

FY2011 Post-Combustion Capture Solicitation

- *"Carbon Dioxide Capture Technology Development and Scale-up for Application to Existing Pulverized Coal Power Plants"*
- October 2010 - FOA scheduled for release
- Spring 2011 - Project selections
- Total funding available - ~$60 - $70 million

- **Areas of Interest**

Bench/laboratory-scale
- Membranes
- Solvents
- Sorbents

10 - 15 awards

Pilot-scale (0.5 - 5 MWe)
- Solvents
- Sorbents

2 – 3 awards

Thanks for Participating!!

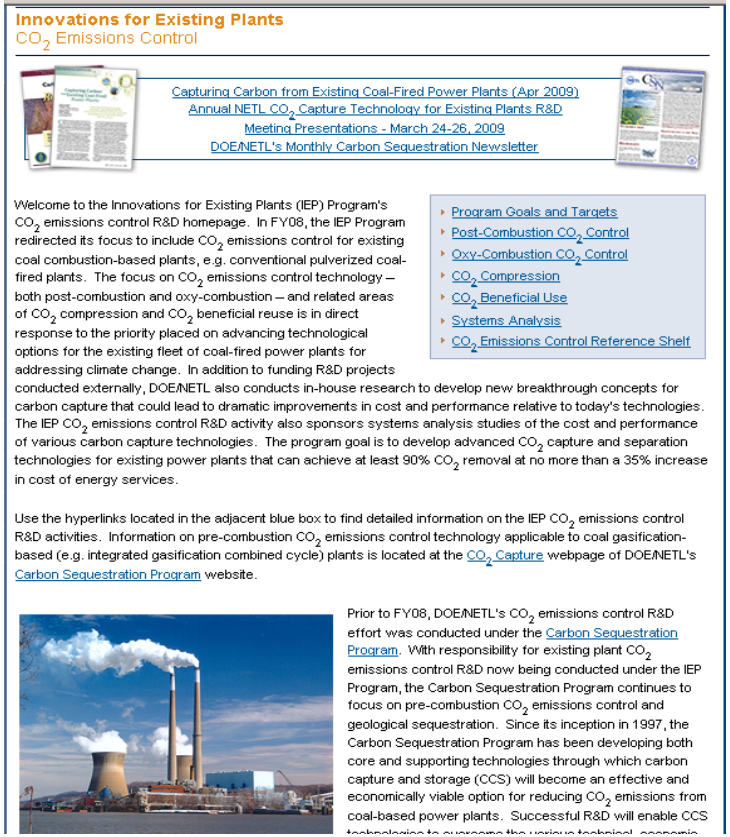
For More Information About the NETL Existing Plants Program

- NETL website:
  - www.netl.doe.gov

Reference Shelf

- Annual CO2 Capture Meeting

- Office of Fossil Energy website:
  - www.fe.doe.gov



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