

## **165 CO<sub>2</sub> Capture and Storage**

### **Program Overview**

#### **Program Description**

This program provides information about the expected cost, availability, performance, and potential risks of a range of flue gas CO<sub>2</sub> capture processes, as well as the permanence, safety, and environmental acceptability of long-term CO<sub>2</sub> storage from any source. Technical and economic assessments of staff-identified processes, followed by development and demonstration of those most promising, advance the availability of commercially mature carbon capture methods. Multiple, large, multi-year geosequestration projects provide the information and tools needed to gain public and regulatory acceptance of commercial-scale CO<sub>2</sub> storage. Topical studies – e.g., predicting and countering any environmental impacts of contact between injected CO<sub>2</sub> and potable aquifers – support the field injection demonstrations by addressing all the underlying geochemistry and structural interactions.

#### **Industry Needs and Issues Addressed**

- Robust, demonstrated post-combustion CO<sub>2</sub> capture processes, whose parasitic plant load is ≤ 10% and increase in busbar cost of electricity (COE) is ≤ 20%
- Affordable, socially-acceptable, secure removal and sequestration of CO<sub>2</sub> from boiler flue gases, including information and data needed to prepare approvable National Environmental Policy Act (NEPA) document (or state equivalent)
- Confidence in the ability to select suitable underground storage formations and to safely store large quantities of CO<sub>2</sub> in these formations with greater than 99% permanence over very long periods
- Ability to predict and monitor the movement of injected CO<sub>2</sub> in the underground formation, to ensure its permanence and non-contact with potable aquifers
- Information about purity requirements for CO<sub>2</sub> compression, transport, and injection locally, at a distance via a dedicated pipeline, or at a distance via an infrastructure pipeline
- Options for dealing with long-term liability for injected CO<sub>2</sub>, potential health and environmental effects of leaks, and permitting

#### **Impact**

- Information for credible asset planning through early understanding of the options, development timelines, costs, technical uncertainties, regulatory issues, and related issues
- Increased confidence that acceptable capture technologies and storage options will be available when needed
- Information for use in public dialog on the practical extent and timing of CO<sub>2</sub> reduction from U.S. power plants, using neutral third-party data and assessments from EPRI

#### **Key Accomplishments**

- Identified and provided early development of and support for the chilled ammonia capture process
- Created a partnership with a chilled ammonia commercializer to demonstrate the process on a large pilot slipstream, obtained a host site, successfully solicited more than 35 partners, and managed the development testing program. Provided guidance to the next, 10x scaled-up validation test.
- Identified compression options for a Department of Energy (DOE) capture and inject project, including new, less energy-intensive compressor designs

- Identified and evaluated the technical feasibility of as many as 50 CO<sub>2</sub> capture processes under development. Developed a quick screening method to determine feasibility, narrowing the candidate processes to fewer than 20
- Informed members about CO<sub>2</sub> capture and storage (CCS) developments worldwide through an international network of specialists
- Documented the process of finding, validating, and permitting injection sites through a management role in two DOE Regional Carbon Sequestration Partnerships and a supporting role in a third
- Developed health risk profiles on humans and animals of economic importance for use in risk assessments

**Current Year Objectives**

- Report on 1.7-MWe chilled ammonia slipstream pilot tests
- Summary of permitting experience and early injection results from DOE Regional Carbon Sequestration Partnership Phase II pilot injections
- Early progress on two to three promising capture processes via development accelerated using EPRI support
- Information about potential impacts on drinking water aquifers if contacted by CO<sub>2</sub> seeping from injection zone
- Information about legal status of underground injection by state
- Trial of new education and communications tool to gain public acceptance
- Methodology for selecting CO<sub>2</sub> transport and storage arrangements based on business factors
- Update on compressor options with reduced parasitic load.
- Scoping and initiation of multi-year projects to ensure the availability and effectiveness of measurement, monitoring, and verification (MMV) techniques to verify CO<sub>2</sub> permanence and traceability; assess caprock integrity; identify and test remediation techniques in case of CO<sub>2</sub> release from the intended storage formation; improve industry ability to predict the capacity and injectivity of CO<sub>2</sub> in geologic formations; and create a site-screening database

**Industry Involvement**

- Estimated 2009 funding: \$1.8M

**Program Technical Lead**

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**Summary of Projects**

<b>Project Number</b>	<b>Project Title</b>	<b>Value</b>
P165.001	Technology Watch: Developments and Trends in Carbon Capture and Storage	Participate in IEA Greenhouse Gas R&D Program and associated networks, work-shops, and the Massachusetts Institute of Technology's (MIT's) Carbon Sequestration Initiative. Attend conferences. Prepare newsletters to update members on current worldwide CCS RD&D and use insights gained to inform EPRI RD&D program.
P165.002	Assessment of "Add-on" CO <sub>2</sub> Capture Systems for Combustion-Based Fossil Power Plants	Maintain database of CO <sub>2</sub> capture processes, with in-depth assessments of selected technologies. Conduct process simulations of most promising technologies to seek further improvements through optimized design and thermal integration with the power plant. Promote accelerated development of promising new technologies.

<b>Project Number</b>	<b>Project Title</b>	<b>Value</b>
P165.003	CO <sub>2</sub> Disposal/Storage and Utilization Issues Assessment	Participate in technical leadership roles in multi-partner collaborations addressing storage issues: leakage risk, MMV, well integrity, and data needs to select an injection formation. Assess potential impact on drinking water if injected CO <sub>2</sub> migrates into potable aquifer. Complete studies on state-by-state legal status of underground injection, methods of better educating the public on CCS issues, and business determinants in selecting CO <sub>2</sub> transport and storage arrangements.
P165.004	Integrated Direct Carbon Sequestration Economics and Technology Development	Continue participation in DOE Regional Carbon Sequestration Partnerships, with expanded role in storage to ensure power industry needs are addressed. Assess industry experience transporting CO <sub>2</sub> of different purities in pipelines. Continue to co-produce economic studies of post-combustion CO <sub>2</sub> capture with different technologies and scenarios with the CoalFleet for Tomorrow Program (Program 66).

## **Project Descriptions**

### **P165.001 Technology Watch: Developments and Trends in Carbon Capture and Storage (062056)**

#### **Issue**

Post-combustion CCS from any power generation source involves very complex and costly issues with substantial uncertainty. RD&D to find economically and environmentally acceptable solutions is an expensive enterprise, but because these issues have concerned many nations and nongovernmental organizations (NGOs) for several decades, researchers worldwide are seeking solutions. To maximize the value of their RD&D investment, avoid unnecessary duplication, and benefit from the world's best expertise in the area, power companies need access to this research community.

#### **Description**

EPRI provides a link to the worldwide CCS RD&D community through its participation in the IEA Greenhouse Gas Program and MIT Carbon Sequestration Initiative, as well as by attending numerous conferences and workshops. Periodically, EPRI prepares a newsletter that summarizes the latest findings and R&D directions reported at these venues. EPRI also informs the research community about power generators' operability issues, helping guide their research.

#### **Value**

- Basis for credible asset planning through early understanding of the options, development timelines, costs, uncertainties, and regulatory issues.
- Dialog about the practical extent and timing of CO<sub>2</sub> reduction from U.S. power plants.

#### **How to Apply Results**

Environmental compliance specialists and strategic planners can stay abreast of the latest issues and progress in CCS by reading the newsletters and, if desired, following up with EPRI staff. They can use this information to support planning exercises and communications with policymakers, shareholders, the media, and the public.

## 2009 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Newsletter on Developments in CCS: Newsletter on Developments in CCS:</b> Periodic news/notes and briefs on technical advances, issues, policy changes, and related issues, as heard and observed in meetings attended by EPRI staff or received in newsletters and reports provided by the organizations to which EPRI belongs or has access.	12/31/2009	Technical Resource
<b>Evaluation Reports: Evaluation Report(s):</b> If a new issue arises, EPRI will investigate it and issue an informal report describing the issue, EPRI's assessment of its technical or socio-political basis, actions to address it, possible outcomes, and potential impact on power generation companies.	12/31/2009	Technical Update

## Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Newsletters on Developments in CCS:</b> Ongoing activity with newsletters issued two to four times per year as determined by the availability of significant new information. End date may be sooner or later, depending on continued member interest.	2012	Technical Resource
<b>Issue Evaluation Report(s):</b> Annual, topical reports, similar to description under 2009 deliverable, on issues that may arise during each year.	2012	Technical Update

## P165.002 Assessment of "Add-on" CO<sub>2</sub> Capture Systems for Combustion-Based Fossil Power Plants (062057)

### Issue

Commercial post-combustion CO<sub>2</sub> capture technologies used in nonpower applications impose a severe energy penalty on the power plant (up to 30% of plant output) and are very complex, resulting in high capital costs. Processes under development (e.g., ammonia-based or advanced amines) might require much less plant energy, but it is still too early to guarantee their success. Nor are they expected to achieve the ultimate goal of less than 10% parasitic load and less than 20% increase in cost of electricity (COE). More than 50 emerging processes were investigated in 2008, with some suggesting advances, but no breakthroughs. However, it is reasonable to believe one or more will be lower cost/energy penalty than current developments, and further investigation will uncover possible breakthroughs. The power industry must be able to procure and operate such systems in time to meet regulatory requirements.

### Description

Under this project, EPRI is participating (with highly leveraged funding) in the development of three alternatives to current amine-based CO<sub>2</sub> capture processes: chilled ammonia, solid carbonate (with Program 66 -- CoalFleet for Tomorrow), and a university-developed carbon-based sorbent. EPRI will continue to seek and evaluate novel technologies, supporting any that appear to offer significant advantages (lower parasitic load, and cost or the production of a solid product to avoid the uncertainties of geosequestration). This support may consist of seed funding or co-funding, proof-of-concept tests,

process simulations to help inventors move their invention from concept to practical system, or detailed process analyses aimed at improving the process's predicted performance. As new processes are found and information on them becomes available, EPRI will post them on the program's website in a database with downloading and searching flexibility. If promising new early-stage processes are found under a supporting major Technology Innovation thrust, EPRI will conduct proof-of-concept tests under this proposed project.

#### Value

- Reduce COE increase due to post-combustion carbon capture from the current estimate of 60–80% down to 20% or less.
- Reduce parasitic energy demand from approximately 30% to 10% or less.
- Potentially find a viable approach to capturing CO<sub>2</sub> as a solid.

#### How to Apply Results

Environmental compliance specialists and strategic planners can stay abreast of the latest progress in CO<sub>2</sub> capture technologies by attending advisory meetings, participating in webcasts, and viewing and searching the web-based technology review. They also can follow up with EPRI staff. Members can use this information, backed by first-hand knowledge of promising developments, to support planning and communicate with policy makers, shareholders, the media, and the public.

#### 2009 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Assessment of CO<sub>2</sub> Capture Options Currently Under Development:</b> Web-based, database-format compilation of all known CO <sub>2</sub> capture processes with process description, developer, status of development, actual or expected performance and cost, and assessment of feasibility and performance/cost projections. Document will be updated quarterly, if merited by new information.	12/31/2009	Technical Resource
<b>Pilot Tests of Chilled Ammonia CO<sub>2</sub> Capture Process – Summary of Results:</b> Nonproprietary results of 6-9-month test of Alstom 1.7-MW chilled ammonia pilot R&D plant at We Energies' Pleasant Prairie Power Plant, especially CO <sub>2</sub> separation, energy penalty, and cost. Also will assess reliability/robustness, ammonia slip and make-up requirements, purity of CO <sub>2</sub> stream, and transient response.	9/30/2009	Technical Report
<b>Pilot Tests of Solid Sorbent CO<sub>2</sub> Capture Processes:</b> Summary of results from laboratory and pilot slipstream tests of RTI's carbonate and University of Wyoming's carbon-based solid CO <sub>2</sub> sorbents, especially CO <sub>2</sub> separation, sorbent attrition rate, and predicted energy penalty and cost. Will include conceptual designs of full scale-ups of each of these technologies.	12/31/2009	Technical Report
<b>Advanced CO<sub>2</sub> Capture Processes – Feasibility of Technologies X, Y:</b> Proof-of-concept tests, probably in laboratory on simulated flue gas or behind pilot combustor at DOE or EPA. Depends on finding <u>more than one</u> process that appears very promising (i.e., breakthrough technologies), but is in early stages of development and requires external support for timely development.	12/31/2009	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<b>CO<sub>2</sub> Capture Research Center</b> Support of, and active participation in, the DOE (80% funding) Carbon Research Center at Alabama Power's Plant Gaston. Five-year program designed to test new CO <sub>2</sub> capture concepts for all generation technologies at appropriate scales (multiple bays ranging from 0.1 to 10 MWe equivalent flue gas flow). Program to fund testing of emerging post-combustion CO <sub>2</sub> capture processes. 2009 deliverable will be test center designs and R&D plans.	12/31/2009	Technical Resource

### Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Design-to-Properties: Theoretical Analysis of Ideal Solvent, Sorbent, and Membrane Properties:</b> Process simulation trials to identify "ideal" solvents, sorbents, and membranes, with goal of challenging chemists to develop materials with these properties.	2010	Technical Report
<b>Proof-of-Concept Tests of CO<sub>2</sub> Ideal Separation Media:</b> Laboratory and pilot tests of designer solvents, sorbents, and/or membranes based on design-to-properties results.	2013	Technical Report
<b>CO<sub>2</sub> Capture Research Center:</b> Final report in series of annual test reports of emerging technologies tested at this research center.	2013	Technical Report
<b>Demonstration Tests of Advanced CO<sub>2</sub> Capture Processes – Annual Updates:</b> Final report in series of annual reports on test results from large-pilot CO <sub>2</sub> capture processes. Continued pilot testing beyond 2013 to be decided by members and availability of processes meeting program cost and energy penalty goals by mid-2012.	2013	Technical Report
<b>Proof-of-Concept Tests of Advanced CO<sub>2</sub> Capture Processes – Annual Updates:</b> Final report in series of annual reports on proof-of-concept tests of advanced, potential breakthrough CO <sub>2</sub> capture processes. Continued testing beyond 2012 to be decided by members and availability of processes meeting program cost and energy penalty goals.	2013	Technical Report

### P165.003 CO<sub>2</sub> Disposal/Storage and Utilization Issues Assessment (052326)

#### Issue

CCS is central to the electricity generation industry's response to expected limitations on CO<sub>2</sub> emissions. Although as much as 80% of the cost of CCS is due to the capture process, most of the uncertainties and risks surround the means of permanently storing CO<sub>2</sub>. The industry and public need confidence in the ability to safely inject and store CO<sub>2</sub> in underground formations with greater than 99% permanence over very long periods and with no undesirable side effects. Essential supporting technical needs include assessments of how to mitigate any CO<sub>2</sub> impact to public health, environment, and natural resources (groundwater); demonstrations of the ability to monitor the fate and movement of injected CO<sub>2</sub> in the underground formation to ensure its permanence; and purity requirements for CO<sub>2</sub> compression,

transport, and injection. Socio-political issues include legal or regulatory procedures for dealing with long-term liability for injected CO<sub>2</sub>, potential health and environmental effects of leaks, and permitting.

### Description

EPRI is addressing the needs for CCS through its participation in several of the DOE's Regional Carbon Sequestration Partnerships and, potentially, continuation of its role in the oil-company-led, multi-million-dollar Carbon Capture Project Phase 2 (CCP2). Topics include expedited certification of injection plans and selected storage formations; well integrity; measurement, monitoring & verification (MMV) approaches suited for CO<sub>2</sub> underground flow management using surface measurements; and models that correctly simulate the CO<sub>2</sub>-formation geochemistry, the CO<sub>2</sub> plume, possible leakage pathways, and related issues. In complementary efforts, EPRI will assess the potential for injected CO<sub>2</sub> to contact and affect aquifers containing potable groundwater and begin to study caprock integrity; potential induced seismicity; monitoring techniques to ensure permanence of CO<sub>2</sub>; remediation techniques in case of release from the intended storage formation; and the ability to predict the capacity and injectivity of CO<sub>2</sub> in geologic formations. EPRI also will begin to create a national site-screening database, starting with guidelines for site selection.

### Value

- Demonstrate that acceptable methods exist for storing CO<sub>2</sub> in underground formations.
- Create precedence for the regulatory and legal framework for underground CO<sub>2</sub> storage, guidelines on characterizing a formation before injection to satisfy permit writers and risk managers, and technologies to monitor the underground migration of injected CO<sub>2</sub>, saving future storage permit applicants several years and up to millions of dollars in permitting costs at each of the first several sites.
- Avoid the need to purchase allowances—assuming a power company does not have permitted injection sites and allowances are available—that could cost a 2,000-MW plant \$500 million over five years (using conservatively low allowance prices of \$20/ton CO<sub>2</sub>).

### How to Apply Results

Power company personnel at all levels and all branches (planning, asset management, environmental engineering, environmental policy, risk management, legal) and management can use the results of the work packages conducted under this project to assess their options and guide the implementation of their strategies.

### 2009 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Methodology for Developing Local Public Acceptance:</b> Assessment of a coordinated education and survey methodology developed by Carnegie Mellon University to obtain more informed responses to questions about CCS. This project will test the hypothesis that better public education will led to more informed responses.	9/30/2009	Technical Report
<b>Assessment of Sequestration Options:</b> Summary of experiences up to publication date, including preliminary guidelines for obtaining drilling and injection permits. Includes descriptions of CO <sub>2</sub> storage projects identified and investigated by EPRI through networks; lessons learned; ability to predict and monitor CO <sub>2</sub> migration; and guidance on engaging the public and regulators.	12/31/2009	Technical Update

Product Title & Description	Planned Completion Date	Product Type
<b>Understanding Legal Implications of Geosequestration:</b> Complete survey of legal status of underground CO <sub>2</sub> injection in each state. Primary focus will be on determining who “owns the pore space” into which the CO <sub>2</sub> is injected. Supporting work will discuss liability if injected power plant CO <sub>2</sub> causes (or is perceived to cause) concerns to property owners beyond the boundaries of the injection site. A parallel effort will investigate any regulatory issues associated with interstate transport of coal-derived CO <sub>2</sub> via pipelines.	6/30/2009	Technical Report
<b>Potential Impact of Injected CO<sub>2</sub> on Drinking Water Aquifers:</b> Assessment by team of experts of likelihood of CO <sub>2</sub> reaching and affecting potable water in aquifers, based, in part, on EPRI 2008 state-of-knowledge survey. Begin lab tests on water quality after contact with CO <sub>2</sub> and ability of CO <sub>2</sub> to mobilize metals out of solution in reservoirs and organics out of shale caprock.	12/31/2009	Technical Update
<b>Scoping Study for Additional Projects on Reservoir Integrity:</b> Plans for studies of caprock integrity, monitoring CO <sub>2</sub> permanence, remediation techniques in case of CO <sub>2</sub> release from the intended storage formation, predicting and optimizing the capacity and injectivity of CO <sub>2</sub> in geologic formations, and the development of a site-screening database.	8/31/2009	Technical Resource

#### Future Year Products

Product Title & Description	Planned Completion Date	Product Type
<b>Guidelines for Site Selection and Permit Applications – 1st Update:</b> Update of 2009 assessment of sequestration options based on DOE Phase 3 and private-sector demonstrations, plus supporting technical studies (e.g., CO <sub>2</sub> /potable water interactions and caprock integrity) and anticipated EPA regulations for injection (under Underground Injection Control [UIC] program).	2011	Technical Report
<b>Guidelines for Site Selection and Permit Applications – 2nd Update:</b> Update on 2011 assessment of sequestration options based on two more years of injection and monitoring at DOE Phase 3 and private-sector demonstrations, plus supporting technical studies (e.g., further definition of drinking water concerns, caprock integrity, mobilization of metals and organics) and findings on legal and liability issues.	2013	Technical Report

### P165.004 Integrated Direct Carbon Sequestration Economics and Technology Development (062058)

#### Issue

Given the importance of CCS to the electricity generation industry and the uncertainties associated with the underground storage of 1 to 2 billion tons of CO<sub>2</sub> annually, the industry needs successful long-term demonstrations of **coal-derived** CO<sub>2</sub> injection. To select generation options for load growth in a carbon-constrained environment, asset planners need credible cost information for generation technologies—pulverized coal, circulating fluidized bed, and integrated gasification combined cycle—when equipped

with the CO<sub>2</sub> capture processes most appropriate for that generation technology, the given site, and the coals it burns.

### Description

EPRI participates in three of DOE's Regional Carbon Sequestration Partnerships. Starting in 2007, EPRI also began to arrange integrated CO<sub>2</sub> capture and large-tonnage injection pilot programs (100,000–1 million ton/yr) with industry partners, DOE, and others. In collaboration with the CoalFleet for Tomorrow™ Program (Program 66), this project sponsors engineering and economic studies of various coal-fueled options for generating electricity with CO<sub>2</sub> control. The study option for 2009 will be selected in late 2008, jointly with the advisors of the two programs; it is likely to be further process simulations seeking optimum thermal integration and fluid properties for solvent-based absorption systems – advanced amine or ammonia. Detailed economic analyses also might be made of new CO<sub>2</sub> capture processes if significant technical advances occur.

### Value

- Increase the probability that CO<sub>2</sub> underground storage will be available (i.e., the industry and regulators will have the necessary experience and tools to engineer and permit such projects) and accepted when needed (e.g., 2020 or sooner).
- Reduce the chance of “unpleasant surprises” during continuous operation of integrated CO<sub>2</sub> capture and storage systems.
- Understand future power generation options with CCS, including the most recent, credible costs.

### How to Apply Results

Engineers and planners responsible for developing climate change compliance plans can use the economic assessments of different integration options as guidance and benchmark data for their own system planning studies. They can use the demonstration results to determine realistic costs and consider the impacts of the options, as well as design features that they should include or avoid in their specifications.

### 2009 Products

Product Title & Description	Planned Completion Date	Product Type
<b>Economic Assessment of Integrated CO<sub>2</sub> Capture, Transportation, and Storage – Status Report on CO<sub>2</sub> Compression Options:</b> Review of CO <sub>2</sub> compression options for minimum energy penalty, based on experience in DOE Regional Carbon Sequestration Partnership projects and designs by separate industry-EPRI integrated capture-transport-inject demonstrations	12/31/2009	Technical Update
<b>Opportunities to Optimize Capture System Designs and Thermal Integration with Power Plant for Minimum Parasitic Energy:</b> Process simulations of retrofit CCS to existing plants, with variants based on thermal integration. Possible integration analysis of another process (solvent, such as chilled ammonia or Powerspan® ammonia, or solid adsorbent such as RTI carbonate) similar to 2007-8 study on monoethanolamine (MEA) and advanced MEA. Might include assessment of heat sources for regeneration other than steam, or other approaches to reduce parasitic load and capacity loss.	12/31/2009	Technical Report

Product Title & Description	Planned Completion Date	Product Type
<b>Business Arrangements for Managing Powerplant CO<sub>2</sub>:</b> Review of business arrangements under consideration for storing CO <sub>2</sub> captured from a power plant. Known options range from self-management (e.g., injection on-site) to total responsibility by third party. Report to include identification and description of options under consideration, analogous experience to date, and expert assessments of these options.	6/30/2009	Technical Report

**Future Year Products**

Product Title & Description	Planned Completion Date	Product Type
<b>Integrated CO<sub>2</sub> Capture and Storage Demonstration – Interim Report:</b> Interim report (two years out of anticipated four- to five-year operation) documenting the nonproprietary results from a 20-MWe CO <sub>2</sub> capture, injection, and storage project. Pending continued, broad industry support and consistent DOE funding, parallel reports could document two to five other demonstrations. Annual technical updates are planned during the project, and a final report is expected by 2015.	2012	Technical Report
<b>Economic Assessment of Integrated CO<sub>2</sub> Capture, Transportation, and Storage:</b> Economic analyses of power generation with CO <sub>2</sub> capture and storage in underground formations for a range of locations and fuels. An interim report is anticipated in 2010, based on the economics at that time.	2012	Technical Report