Testimony
Prospects for Advanced Coal Technologies: Efficient Energy Production, Carbon Capture and Sequestration
U.S. House of Representatives
Committee on Science and Technology
Subcommittee on Energy and Environment

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Thank you, Mr. Chairman, Ranking Member Inglis, and Members of the Committee. I am Stuart Dalton, Director of Generation for the Electric Power Research Institute (EPRI), a non-profit, collaborative R&D organization. EPRI has principal locations in Palo Alto, California, Charlotte, North Carolina, and Knoxville, Tennessee. EPRI appreciates the opportunity to provide testimony to the Committee on the topic of "Prospects for Advanced Coal Technologies: Efficient Energy Production, Carbon Capture and Sequestration"

I want to focus my comments today on three subjects: (1) the technological challenges our country faces in limiting carbon dioxide (CO_2) emissions from power plants that use coal as an energy source through both efficiency gains and CO_2 capture and sequestration (2) policy and research gaps where we believe the federal government can do more to facilitate the reduction of CO_2 emissions from coal, and (3) highlights from recent EPRI analytical work that emphasizes the importance of advanced coal technologies as part of an overall low-cost, low-carbon portfolio of options to reduce greenhouse gas emissions associated with climate change.

Background

Coal is the energy source for over half of the electricity generated in the United States, and numerous forecasts of future energy use show that coal will continue to have a dominant share in our electric power generation for the foreseeable future. Coal is a stably priced, affordable, domestic fuel that can be used in an environmentally responsible manner. Over the past three decades, development and application of advanced pollution control technologies and sensible regulatory programs have reduced emissions of criteria air pollutants from new coal-fired power plants by more than 90%. And by displacing otherwise needed imports of natural gas or fuel oil, coal helps address America's energy security and reduces our trade deficit with respect to energy.

By 2030, according to the Energy Information Administration, the consumption of electricity in the United States is expected to be approximately 40% higher than current levels. At the same time, to responsibly address the risks posed by potential climate change, we must substantially reduce the greenhouse gas emissions intensity of our economy in a way which allows for continued economic growth and maintains the benefits that energy provides. This is not a trivial matter – it implies a substantial change in the way we produce and consume electricity. Because coal contains a higher percentage of carbon than other fossil fuels such as natural gas, and because this carbon is emitted as CO_2, coal presents a greater challenge to achieving reduced greenhouse gas emissions.

Technologies to reduce CO_2 emissions from coal will necessarily be one part of an economy-wide solution that includes greater end-use efficiency, increased renewable energy, more efficient use of natural gas, expanded nuclear power, and similar transformations in the transportation, commercial, industrial, and residential sectors of our economy. In fact, our work at EPRI on the impacts of climate policy on technology development and deployment has consistently shown that non-emitting technologies for electricity generation will likely be less expensive than technologies for limiting emissions of direct fossil fuel end uses in other sectors.

EPRI stresses that no single advanced coal generating technology (or any generating technology) has clear-cut economic advantages across the range of U.S. applications. The best strategy for meeting future electricity needs while addressing climate change concerns and economic impact lies in developing multiple technologies from which power producers (and their regulators) can choose the option best suited to local conditions and preferences. Assuring timely, cost-effective coal power technology with CO_2 capture entails simultaneous and substantial progress in research, development and demonstration (RD&D) efforts to improve capture processes and fundamental plant systems. EPRI sees the need for government and industry to pursue these and other pertinent RD&D efforts aggressively through significant public policy and funding support. Early commercial viability will likely come only through firm commitments to the necessary R&D and demonstrations and through collaborative arrangements that share risks and disseminate results.

Improvements and new development in several technology areas are required to achieve large scale reduction of CO_2 emissions from coal power plants. These needs can be described in three major aspects:

- Substantially increased thermodynamic efficiency of coal plants
- Cost-effective, efficient, commercially available technologies for capture of CO_2 from coal plants
- Cost-effective, commercially available technologies for storage of captured CO_2

Each of these areas presents substantial technology challenges requiring a sustained investment in RD&D.

<u>Increasing Coal Plant Efficiency</u>

Although the United States was an early leader in developing high-efficiency coal plant designs, we have built very few new coal power plants in the last two decades and are now playing catch-up in the world race to achieve high-efficiency designs. In the 1950s and '60s, the United States was the world's pioneer in power plants using thermodynamically efficient "supercritical" and "ultra-supercritical" steam conditions. Exelon's coal-fired Eddystone Unit 1, in service since 1960, still boasts the world's highest steam temperatures and pressures. Because of reliability problems with some of these early units, U.S. designers retreated from the highest supercritical steam conditions until recently when international efforts involving EPRI and U.S., European and Japanese researchers concentrated on new, reliable materials for high-efficiency pulverized coal plants. Given the prospect of potential CO_2 regulations (and efforts by power producers to demonstrate voluntary CO_2 reductions), the impetus for higher efficiency in future coal-based generation units has gained economic traction worldwide. In fact, the majority of new pulverized coal (PC) plants announced over the last two years will employ high-efficiency supercritical steam cycles, and several will use the ultra-supercritical steam (USC) conditions with very high temperature, high efficiency designs heretofore used only overseas (aside from Eddystone).

EPRI is working with the Department of Energy, the Ohio Coal Development Office and major equipment suppliers on an important initiative to qualify a whole new class of nickel-based "superalloys," which will enable maximum steam temperatures to rise from an ultra-supercritical steam temperature of 1100°F to an "advanced" ultra-supercritical steam temperature of 1400°F.

Combined with a modest increase in steam pressure, this provides an efficiency gain that reduces a new plant's carbon intensity (expressed in terms of tons of CO_2 emitted per megawatt-hour [Tons/MWh]) by about 20% relative to today's state-of-the-art plants. Even modest increases in steam conditions can raise efficiency by several percent in the near term (a 2% increase in efficiency, for example, represents a roughly 5% reduction of CO_2 production and coal use). If capture of the remaining CO_2 is desired, improved efficiency will also reduce the required size of the capture equipment and the amount of coal mined and transported.

However, realization of this opportunity will not be automatic. In fact, it will require a renewed, sustained R&D commitment and substantial investment in demonstration facilities to bring new technologies to market. The European Union has embraced such a strategy and is midway through its program to demonstrate a pulverized coal plant with 1300°F steam conditions, which was realistically planned as a 20-year activity. Efficiency improvements will also be important for other coal power technologies. The world's first supercritical circulating fluidized-bed (CFB) plant is currently under construction in Poland. Many new units in China are being built with temperatures and efficiencies higher than recent U.S. units, as the cost of fuel and environmental pressures rise.

The greatest increase in efficiency for integrated gasification combined cycle (IGCC) units will come from increases in the size and efficiency of the gas turbines and improvements in their ability to handle hydrogen rich "syngas" that would be produced in IGCC plants designed for CO_2 capture.

A number of technologies are being developed that promise to decrease the amount of CO_2 per unit of power produced (e.g., pounds CO_2/kWh or Tons/ MWh). With today's technology, a modern pulverized coal plant and a modern coal-based IGCC plant would produce roughly the same amount of CO_2/kWh. Neither achieves CO_2 capture without significant operational and hardware modifications and some loss of efficiency. Both are expected to achieve efficiency advances and cost reductions based on research and development occurring worldwide. EPRI believes that both industry and the government should support the development, demonstration, and deployment of multiple high-efficiency technologies for the future, rather than picking technology winners.

CO_2 Capture Technology

Carbon dioxide capture and storage (CCS) technologies can be feasibly integrated into virtually all types of new coal-fired power plants, including IGCC, PC, CFB and variants such as oxy-fuel combustion. For those constructing new plants, it is unclear which type of plant would be economically preferred if it were built to include carbon capture. All can have relative competitive advantages under various scenarios.

A utility's choice between these technologies will depend on available coals and their physical-chemical properties, desired plant size, the CO_2 capture process and its degree of integration with other plant processes, plant elevation, the value of plant co-products, and other factors. For example, IGCC with CO_2 capture generally shows an economic advantage with low-moisture bituminous coals. For coals with high moisture and low heating value, such as sub-bituminous and lignite coals, a recent EPRI study (report 1014510 available publicly) shows PC with CO_2 capture as competitive with IGCC with CO_2 capture. However, no single set of costs can represent all conditions. In addition to such variables as coal type and plant design, the cost of electricity will also vary due to plant location and the type of financing of the facility receives.

Post-combustion CO_2 Capture

Although carbon dioxide capture appears technically feasible for all coal power technologies, it poses substantial engineering challenges (requiring major investments in R&D and demonstrations) and comes at considerable cost. However, analyses by EPRI and the Coal Utilization Research Council suggest that once these substantial investments are made, the cost of CCS becomes manageable and, ultimately, coal-based electricity with CCS can be cost competitive with other low-carbon generation technologies.

Post-combustion CO_2 separation processes (placed after the boiler in the power plant) are currently used commercially in the food and beverage and chemical industries, but these applications are at a scale much smaller than that needed for power producing PC or CFB power plants. These processes themselves are also huge energy consumers, and without investment in their improvement, they would reduce plant electrical output by as much as 30% creating the need for more new plants.

EPRI's most recent cost estimates suggest that for PC plants, the addition of CO_2 capture using amine solvents (the most highly developed technical option currently available), along with drying and compression, pipeline transportation to a nearby storage site, and underground injection, would add 60–80% to the net present value of life-cycle costs of electricity (expressed as levelized cost-of-electricity, or COE, and excluding storage site monitoring, liability insurance, etc.). With coal providing ~50% of U.S. electricity generation, this translates into a potentially significant increase in consumers' electric bills.

Oxy-firing

For PC plants, the introduction of oxy-fuel or oxy-coal combustion may allow further reductions in CO_2 capture costs by allowing the flue gas to be compressed directly, without any CO_2 separation process while also allowing the size of the supercritical steam generator to be reduced. Boiler suppliers and major European and Canadian power generators are actively working on pilot-scale testing and scale-up of this technology. AEP has recently announced plans to study use of this "oxy-coal" technology for retrofitting an existing plant, and SaskPower (Saskatchewan Power) has announced that, Babcock & Wilcox Canada (B&W) and Air Liquide will jointly develop the SaskPower Clean Coal Project.

Pre-combustion CO_2 Capture

CO_2 separation processes suitable for IGCC plants are used commercially in the oil and gas and chemical industries at a scale closer to that ultimately needed, but their application necessitates deployment of modified IGCC plant equipment, including additional chemical process steps and gas turbines that can burn nearly pure hydrogen.

The COE cost premium for including CO_2 capture in IGCC plants, along with drying, compression, transportation and storage, is about 40–50%. Although this is a lower cost increase in percentage terms than that for PC plants, IGCC plants initially cost more than PC plants. Thus, the bottom-line cost to consumers for power from IGCC plants with capture may be comparable to that for PC plants with capture, depending on the types of coal used, elevation of the plant and other site-specific factors.

It should be noted that IGCC plants (like PC plants) do not capture CO_2 without substantial plant modifications, energy losses, and investments in additional process equipment. As noted above, however, the magnitude of these impacts could likely be reduced substantially through aggressive investments in R&D. Historical experience with the development of environmental control technologies for today's power plants suggests that technological advances from "learning-by-doing" will likely lead to significant cost reductions in CO_2 capture technologies as the installed base of plants with CO_2 capture grows. An International Energy Agency study led by Carnegie Mellon University suggested that overall electricity costs from plants with CO_2 capture could come down by 15% relative to the currently predicted costs after about 200 systems were installed.

Furthermore, despite the substantial cost increases for adding CO_2 capture to coal-based IGCC and PC power plants, their resulting cost-of-electricity is still usually less than that for natural gas-based plants at current and forecast natural gas prices.

Engineering analyses by EPRI, DOE and the Coal Utilization Research Council suggest that costs could come down faster through CO_2 capture process innovations or, in the case of IGCC plants, fundamental plant improvements—provided sufficient RD&D investments are made. EPRI pathways for reduction in capital costs and improvements in efficiency are embodied in two companion RD&D Augmentation Plans developed under the collaborative CoalFleet for Tomorrow program. The IGCC plan (Report No. 1013219) is publicly available, and the PC plan will be available later this year. Efforts toward reducing the cost of IGCC plants with CO_2 capture will focus on adapting more advanced and larger gas turbines for use with hydrogen-rich fuels, lower-cost oxygen supplies, improved gas clean-up, advanced steam cycle conditions and other activities.

CO_2 Transportation and Geologic Storage

Geologic sequestration of CO_2 has been proven effective by nature, as evidenced by the numerous natural underground CO_2 reservoirs in Colorado, Utah and other western states. CO_2 is also found in natural gas reservoirs, where it has resided for millions of years. Thus, evidence suggests that depleting or depleted oil and gas reservoirs, and similar "capped" sandstone formations containing saltwater that cannot be made potable, are capable of storing CO_2 for millennia or longer. Geologic sequestration as a strategy for reducing CO_2 emissions is being demonstrated in numerous projects around the world.

Three relatively large projects – the Sleipner Saline Aquifer CO_2 Storage (SACS) project in the North Sea off of Norway; the Weyburn-Midale Project in Saskatchewan, Canada and the In Salah Project in Algeria – together sequester about 3 to 4 million metric tons of CO_2 per year, which approaches the output of just one typical 500 megawatt coal-fired power plant. With 17 collective years of operating experience, these projects suggest that CO_2 storage in deep geologic formations can be carried out safely and reliably. Furthermore, CO_2 injection technology and subsurface behavior modeling have been proven in the oil industry, where CO_2 has been injected for 35 years for enhanced oil recovery (EOR) in the Permian Basin fields of west Texas and Oklahoma and in other U.S. fields. Regulatory oversight and community acceptance of injection operations are well established in those contexts.

Within the United States, DOE manages an active R&D program, the Regional Carbon Sequestration Partnerships, that is mapping geologic formations suitable for CO_2 storage and conducting pilot-scale CO_2 injection validation tests across the country. These tests, as well as most commercial applications for long-term storage, will compress CO_2 to a liquid-like "supercritical" state to maximize the amount that can be stored. Virtually all CO_2 storage will be at least a half-mile underground, where the CO_2 will be injected into a porous sandstone-like material saturated with salty water. CO_2 will be stored in locations with geologic seals to minimize the likelihood of any leakage to the atmosphere (which would defeat the purpose of sequestering the CO_2 in the first place).

DOE's Regional Carbon Sequestration Partnerships represent a broad collaboration of public agencies, private companies and non-profits; they would be an excellent vehicle for conducting larger "near-deployment scale" CO_2 injection tests to prove specific U.S. geologic formations, which EPRI believes to be one of the keys to commercializing CCS for coal-based power plants. Evaluations by these Regional Partnerships and others suggest that enough geologic storage capacity exists in the United States to hold several centuries' worth of CO_2 emissions from coal-based power plants and other stationary sources. However, the distribution of suitable storage formations across the country is not uniform: some areas have ample storage capacity whereas others appear to have little or none.

Thus, CO_2 captured at some power plants would require pipeline transportation for several hundred miles to reach suitable injection locations, which may be in other states. While this adds cost, it does not represent a technical hurdle because CO_2 pipeline technology has been proven in oil field EOR applications. As CCS is applied commercially, EPRI expects that early projects would take place at coal-based power plants near to sequestration sites or to existing CO_2 pipelines. As the number of projects increases, regional CO_2 pipeline networks connecting multiple sources and storage sites would be needed.

There is still much work to be done before CCS can implemented on a scale large enough to significantly reduce CO_2 emissions into the atmosphere. In addition to large-scale demonstrations at U.S. geologic formations, many legal and institutional uncertainties need to be resolved. Uncertainty about long-term monitoring requirements, liability and insurance is an example. State-by-state variation in regulatory approaches is another. Some geologic formations suitable for CO_2 storage underlie multiple states. For private companies considering CCS, these various uncertainties translate into increased risk.

The Promise of CCS

Recent EPRI work has illustrated the urgent necessity to develop CCS technologies as part of the solution to satisfying our energy needs in an environmentally responsible manner. Our recently released "Electricity Technology in a Carbon-Constrained Future" study suggests that with aggressive R&D, demonstration and deployment of advanced electricity technologies, it is technically feasible to slow down and stop the increase in U.S. electric sector CO_2 emissions, and to then eventually reduce them over the next 25 years while simultaneously meeting the increased demand for electricity. Of the technologies that can eventually lead to reductions in CO_2 emissions, the study indicates that the largest single contribution would come from applying CCS technologies to new coal-based power plants coming on-line after 2020.

Many other U.S. and international climate models and reports have stressed that CCS is a vital part of the needed technology mix in any carbon-constrained future. We believe action is needed now to assure we can meet these technological and cost challenges.

R&D Gaps

A gap in the policy and RD&D area that EPRI believes needs to be addressed by the U.S. industry and government is the funding of multiple capture, transport, and storage demonstrations at large scale (>1 million metric tons per year of CO_2). These demonstrations should encompass a variety of coal technologies and capture processes, and should be conducted in multiple regions, using varying geologic formations. Monitoring will need to be conducted to assure long-term storage effectiveness.

Engineering analyses by EPRI, DOE and the Coal Utilization Research Council suggest that costs could come down faster through CO_2 capture process innovations or, in the case of IGCC plants, fundamental plant improvements—provided sufficient RD&D investments are made. Combined with EPRI's past experience in transforming science into deployed technologies, these analyses clearly indicate that a sustained and substantial RD&D investment will be necessary to assure the availability of CCS and levels of coal plant performance compatible with potential CO_2 policies.

EPRI pathways for reduction in capital cost and improvement in efficiency for IGCC plants are embodied in an RD&D Augmentation Plan developed under the CoalFleet for Tomorrow program. This figure shows how efficiency can be increased over the next two decades as costs are decreased in constant dollar terms. The detailed plans for this have been developed in our collaborative efforts with firms form five continents and over 60 participants. A similar figure appears for combustion processes and shows equally impressive efficiency and cost gains. Neither of these can be realized without a strong commitment to research development and demonstration.

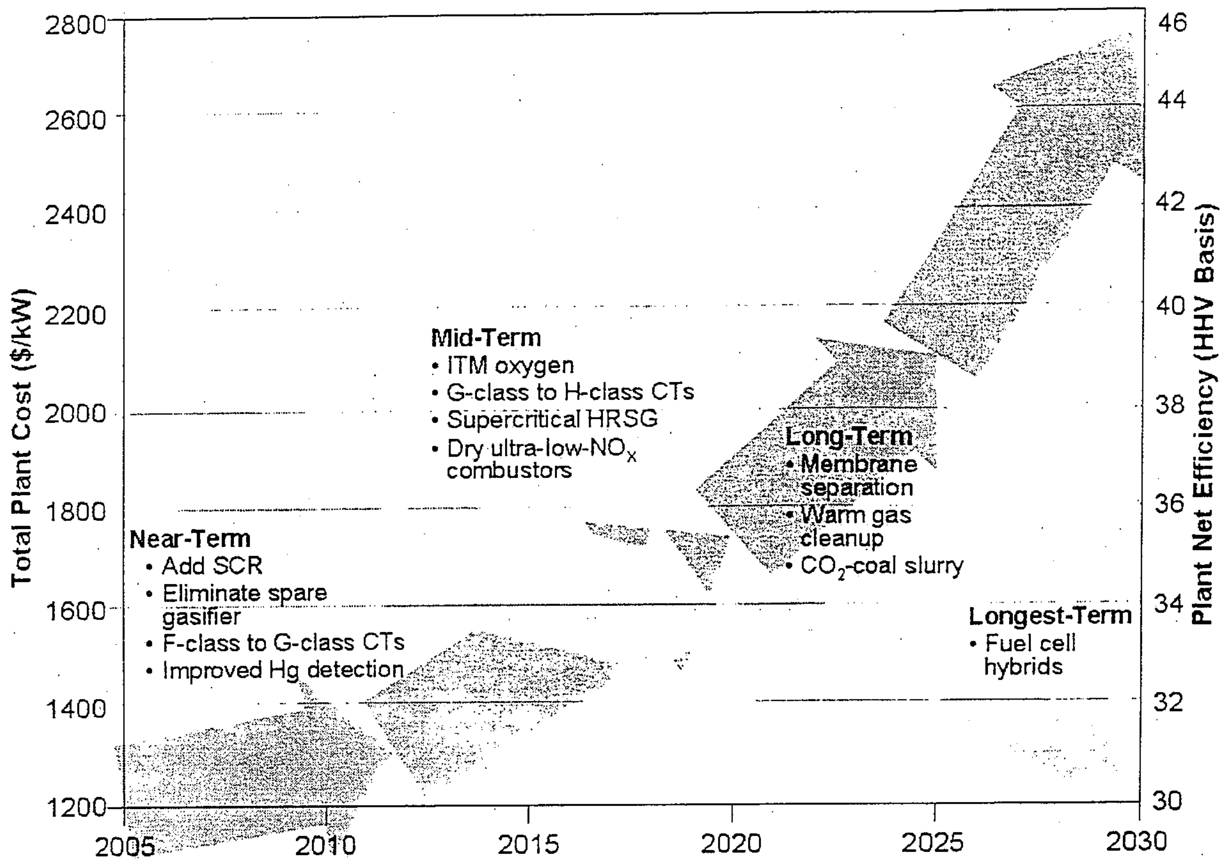


Figure 1: Forecast Reduction in Capital Cost and Improvement in Efficiency Through Implementation of the EPRI CoalFleet IGCC RD&D Augmentation Plan
(Slurry-fed gasifier, Pittsburgh #8 coal, 90% availability, 90% CO_2 capture, 2Q 2005 U.S. dollars)

Efforts toward reducing the cost of IGCC plants with CO_2 capture will focus on adapting more advanced and larger gas turbines for use with hydrogen-rich fuels, lower-cost oxygen supplies, improved gas clean-up, advanced steam cycle conditions, and more.

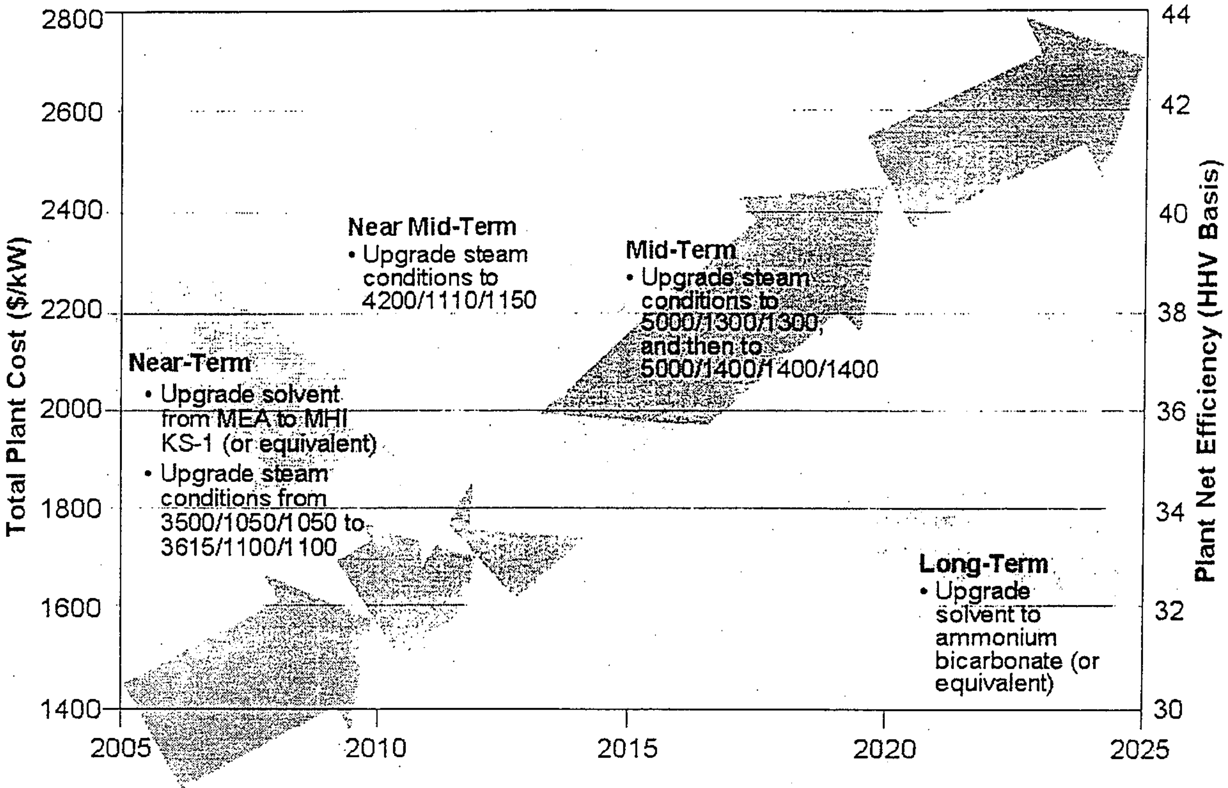
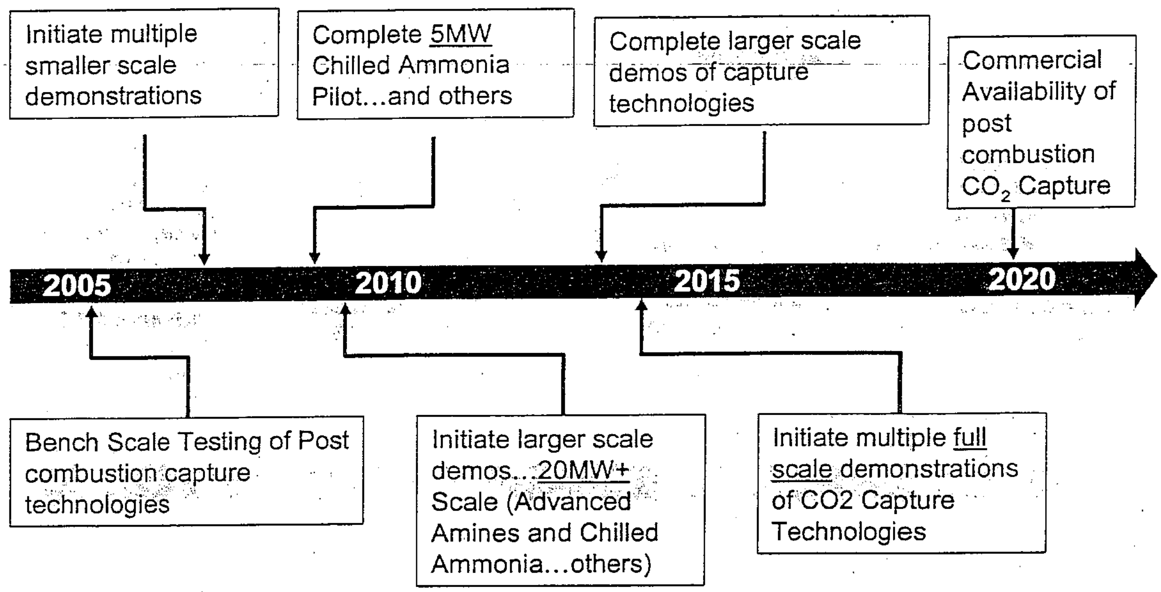


Figure 2: Forecast Reduction in Capital Cost and Improvement in Efficiency through Implementation of the CoalFleet USC PC RD&D Augmentation Plan

(Pittsburgh #8 coal, 90% availability, 90% CO_2 capture, as-reported data from various studies [not standardized])

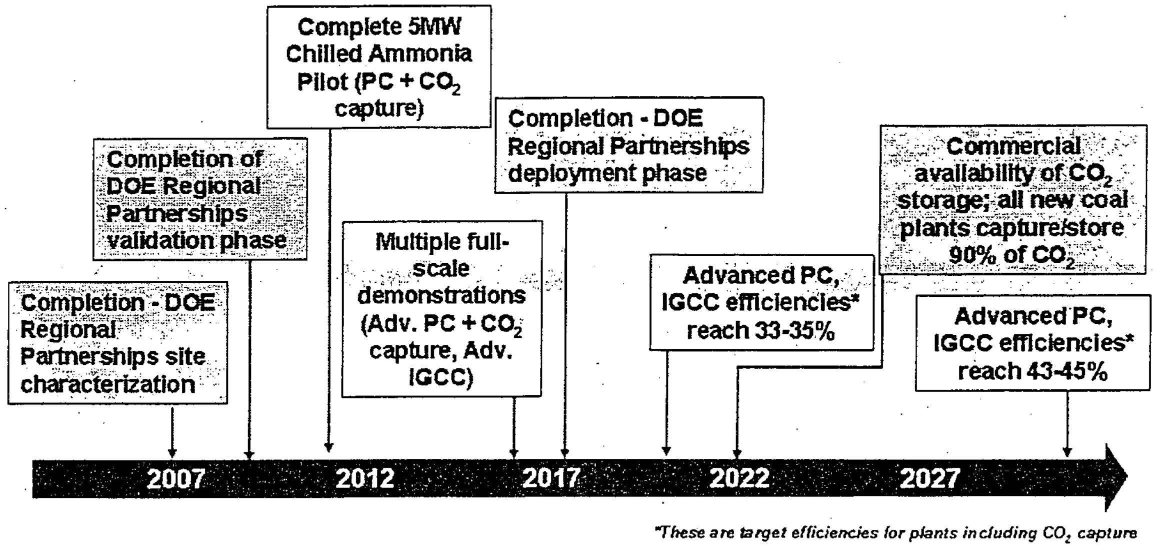
For PC plants, the progression to advanced ultra-supercritical steam conditions will steadily increase plant efficiency and reduce CO_2 production. Improved solvents are expected to greatly reduce post-combustion CO_2 capture process. EPRI is working to accelerate the introduction of novel, alternative CO_2 separation solvents with much lower energy requirements for regeneration. Such solvents—for example, chilled ammonium carbonate—could reduce the loss in power output imposed by the CO_2 capture process from about 30% to about 10%. At present, a small pilot plant (5 MW-thermal) for chilled ammonia is being designed for installation at a power plant in Wisconsin later this year; success there would warrant a scale-up to a larger pilot or pre-commercial plant. An EPRI timeline (compatible with DOE's timeframe) for the possible commercial introduction of post-combustion CO_2 capture follows.



The introduction of oxy-fuel combustion may allow further reductions in CO_2 capture costs by allowing the flue gas to be compressed directly, without any CO_2 separation process and reducing the size of the supercritical steam generator. Boiler suppliers and major European and Canadian power generators are actively working on pilot-scale testing and scale-up of this technology.

Assuring timely, cost-effective coal power technology with CO_2 capture entails simultaneous and substantial progress in RD&D efforts on improving capture processes and fundamental plant systems. EPRI sees the need for government and industry to pursue these and other pertinent RD&D efforts aggressively through significant public policy and funding support. Early commercial viability will likely come only through firm commitments to the necessary R&D and demonstrations and through collaborative arrangements that share initial risks and disseminate results.

The urgent need to establish an enhanced RD&D program for developing advanced coal and carbon capture and storage technologies is further increased by the likelihood that, as is typical for research, unexpected technical challenges will surface and require additional time, effort and funding to resolve.



Policy Gaps

Without incentives or regulatory requirements, or a market for CO_2, CCS will not be chosen based on economics. In addition to incentives to encourage use of CCS, the state and federal governments will need to deal with the issues of land use, ownership, and liability for CO_2. This is perhaps the biggest unknown. No company can take on unlimited liability – options will be needed to allow firms to make long-term commitments to the technology. Such options may include special insurance provisions, state or federal liability provisions, and must include clarity in regulatory requirements for long-term storage of CO_2. Models and current analogies lead us, and many in the industry, to believe that the risk should be manageable, but the unknowns of long-term liability makes this risk difficult to manage.

Conclusions

Our country does face significant technology challenges in limiting CO_2 emissions from coal and it will require multiple technological approaches for capture and multiple storage demonstrations to prove the cost, efficiency, and effectiveness of CO_2 capture and storage. These must be pursued in the near future to provide options for CO_2 capture and storage on timeframes compatible with potential policies.

Our research indicates that with proper support and an RD&D program sustained over the coming decades, the technology for CCS can play a significant role in reducing CO_2 emissions from the power industry to meet future national requirements.

Summary of Testimony to the Subcommittee on Energy and Environment, Committee on Science and Technology, of the U.S. House of Representatives "Prospects for Advanced Coal Technologies: Efficient Energy Production, Carbon Capture and Sequestration"

Stuart Dalton, Director of Generation, Electric Power Research Institute
May 15, 2007

Coal is a stably priced, affordable, domestic fuel that can be used in an environmentally responsible manner. It is the workhorse of the U.S. electricity grid, accounting for more than half of all the power generated. Forecasts of future U.S. energy needs envision the continued predominance of coal in the electric power sector. Thus, technologies to reduce CO_2 emissions from coal-based power plants must be part of the set of solutions to climate change concerns. For the electric sector, that portfolio will also include improved efficiency in transmission and end use, increased renewable energy, more efficient use of natural gas, and expanded nuclear power. Analogous low-carbon transformations must occur in the economy's transportation, commercial, industrial, and residential sectors. Even within the subsector of coal-based electricity, EPRI stresses that a portfolio of advanced coal technologies is needed. No single technology has clear-cut economic advantages across the range of U.S. applications. The best strategy for reducing CO_2 emissions lies in developing multiple technologies from which power producers (and their regulators) can choose the option best suited to local conditions and preferences.

An often-cited step is improving the efficiency of new coal power plants. This can achieve CO_2 reductions of up to 20% per megawatthour of electricity before the addition of any dedicated CO_2 controls. The MIT "Future of Coal" report and a forthcoming report by the National Coal Council endorse this fundamental measure. Realization of this opportunity will require a sustained R&D commitment and substantial investment in demonstration facilities. EPRI, DOE, Ohio Coal Development Office, and equipment suppliers have a program in place.

EPRI and others believe that CO_2 capture and sequestration (CCS) technologies for coal-based power plants will be an indispensable technology for achieving the deep cuts in man-made CO_2 emissions needed to stop, and ultimately reverse, atmospheric build-up. CCS technologies can be feasibly integrated into all types of new coal power plants, including integrated gasification combined cycle (IGCC), pulverized coal (PC), circulating fluidized-bed (CFB), and variants such as oxy-fuel combustion. No advanced coal technology is economically preferred for adopting CCS, and the field of CO_2 capture technology options is evolving quickly at small-scale, but large demonstrations are vital. Sites for long-term geologic storage of CO_2 are regionally available throughout much of the United States. Yet, there are major challenges to be overcome—both technically and in terms of public policy—before geologic storage of CO_2 can be applied at the broad scale needed. Specifically, multiple large-scale (>1 million tons) demonstrations need to commence as soon as possible. Legal and regulatory frameworks need to be established, particularly with respect to long-term ownership and liability.

RD&D pathways to success have been established collaboratively by EPRI, DOE, and industry groups. The RD&D funding needs are a significant step up from current levels, but within historical percentages for government agencies and private industry. Given the long technology development and deployment leadtimes inherent in capital intensive industries like energy, investment and policy decisions must be made now or we risk foreclosing windows of opportunity for technology options that we expect will prove tremendously valuable in a carbon-constrained future.