Retrofitting of Coal-Fired Power Plants for CO_2 Emissions Reductions

An MIT Energy Initiative Symposium

Massachusetts Institute of Technology

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About the MITEI Symposium on the Retrofitting of Coal-Fired Power Plants for CO_2 Emissions Mitigation

The MIT Energy Initiative (MITEI) sponsored a symposium on the retrofitting of coal-fired power plants to capture CO_2 emissions. This report summarizes the views of symposium participants and identifies many key issues, opportunities, and possible "next steps" associated with retrofitting coal-fired power plants for carbon capture. The report represents a range of views from those at the symposium and where possible, includes consensus or general recommendations from the presenters and participants; *it is in no way intended to represent the views of all the participants, of specific participants, or of the rapporteur*.

Participants represented the range of stakeholders with expertise, equities, and interests in the topic and included 54 representatives of utilities, academia, government, public interest groups, and industry. This invitation-only event was designed specifically to elicit different perspectives and identify areas in which research, policy development, and analysis are needed to address this critical environmental concern.

The focus of the symposium was the retrofitting of existing pulverized coal plants, either through add-ons to existing plants, the rebuilding and upgrading of existing boilers to facilitate carbon capture, or increasing the thermal efficiency of existing boilers to reduce greenhouse gas emissions per unit of power output. Participants, however, also discussed a range of additional technology options, including the repowering of existing boilers with alternative fuels such as biomass or natural gas, rebuilding existing plants with more efficient coal technologies such as IGCC or oxy-combustion, and co-firing with low-carbon fuels.

To maximize time and to focus the discussion at the symposium, three topical white papers, commissioned from subject matter experts, were circulated to the symposium participants in advance of the event. These papers were designed to be thought-provoking and to provide participants with frameworks, data, points of view, and information on the issues to be discussed at the symposium. They were not intended to be comprehensive or definitive works and were a priori assumed to reflect the points of view and expertise of the individual authors only. Other symposium participants submitted papers for discussion purposes as well.

As several participants noted, this symposium provided the first major opportunity for stakeholders with extensive experience and knowledge to exchange frank points of view on the value and prospects for retrofitting coal-fired power plants in the U.S. The symposium was conducted under Chatham House rule so that participants could candidly discuss topics. Therefore, with the exception of the views of the symposium co-chairs and the authors of the white papers, there are no specific attributions in this report.

This report is intended to provide federal policy makers with insights on the importance and nature of the problem and a range of possible policies and research investments that will help mitigate CO_2 emissions from existing coal-fired power plants. The full texts of the discussion papers and some supporting slides are included in the appendices. As noted, additional papers were also submitted to inform the discussion. The texts of many of these papers are posted on the MIT Energy Initiative website (http://web.mit.edu/mitei).

The MIT Energy Initiative would like to thank all of the Symposium participants for sharing their time and expertise. We extend a special thanks to Entergy and its CEO Wayne Leonard who supplied the motivation for this event and made it possible through financial support. We would also like to thank those who submitted papers and allowed us to use information, slides, and tables in this report. Finally, we thank the Clean Air Task Force for allowing us to include their paper, Advanced Post-Combustion CO_2 Capture, authored by Howard Herzog, Jerry Meldon, and Alan Hatton and supported by the Duke Foundation, in this report.

FOREWORD

As CEO of Entergy Corporation, I have personally devoted a great deal of attention to the need for society to take effective action on the climate change issue. Entergy is a strong advocate for starting now on the path to significant reductions in greenhouse gas emissions by mid-century.

The impetus for this symposium was our conviction that an effective, sustainable response to climate change must include retrofit technologies to reduce CO_2 emissions from existing coal-fired electric power generating plants.

It is well known that coal-fired generation contributes over 80% of the CO_2 emissions from this country's electric power sector, and that the world's installed base of conventional coal plants is growing steadily as developing countries — China, in particular — increase their generating fleet to bring electricity to people who do not have what we consider a basic necessity.

What is less well understood, I believe, is that these coal plants are going to continue to operate for decades, even as our industry turns to carbon-free electric power generating technologies such as solar, nuclear, biomass, geothermal, and others. Once built, coal plants are, in most cases, the cheapest source of base load power generation and will not be phased out absent very high CO2 prices. It's basic economics. The great majority of costs for a plant are sunk at the time it starts operation; only the "to go" costs matter in deciding whether to continue running the plant.

Thus, our view is that an effective strategy for achieving significant and cost effective reductions in CO_2 emissions requires the deployment of new technologies to retrofit existing coal plants and reduce their CO_2 emissions. If we are to sustain an effective climate program and grow our economy, we can't kill coal; we have to save it. That may seem strange to hear from a CEO of an electric company with less than 10% of its capacity in coal-fired generation — but it is the inescapable conclusion of our analysis.

We also concluded that not enough is being done to commercialize this technology on a timeframe consistent with the climate change goals. That is why we asked the MIT Energy Initiative (MITEI) to bring together the nation's leading experts in this field to assess the current issues surrounding retrofit technologies and to formulate a concrete action plan to move forward quickly.

In my view, the symposium fills a major void in the climate change policy debate. This report provides the most comprehensive and up-to-date analysis of retrofit technology issues. Now it is up to policy makers to provide the requisite focus and sense of urgency to get this technology developed.

There are no guarantees that the entire world will sign on to CO_2 reduction or stabilization. There is no panacea that will make a solution quick or "cheap." What does appear certain is that carbon capture and sequestration is an absolutely necessary technology — albeit insufficient by itself — to address the greatest challenge our generation may ever face.

I want to express my thanks and appreciation to Ernie Moniz and Melanie Kenderdine of MITEI, Professor John Deutch, and all the symposium participants.. We look forward to working with you to implement these excellent recommendations.

Wayne Leonard
CEO, Entergy Corporation
Symposium Co-Chair

SUMMARY FOR POLICY MAKERS

On March 23, 2009, the MIT Energy Initiative (MITEI) sponsored a symposium on *Retrofitting Coal-fired Power Plants for CO_2 Emissions Reductions* to investigate different pathways for CO_2 emissions reductions using current technology, identify promising RD&D for cost reduction, and discuss policy and institutional barriers to CO_2 emissions reductions in the United States. The deliberations were informed by three commissioned white papers and from additional contributions submitted by workshop participants. These documents are available at www.mit.edu/mitei.

We summarize for policy makers the key points from the lively discussions among the diverse group of participants. **We stress that the observations here are those of the authors and are not offered as a consensus view of the participants**.

- ***There is today no credible pathway towards stringent GHG stabilization targets without CO_2 emissions reduction from existing coal power plants, and the United States and China are the largest emitters.***

  The United States and China account for about 40% of global anthropogenic CO_2 emissions and for over half of global coal use. Both countries have immense reserves of relatively low cost coal. In the United States, almost half of all electricity is supplied by coal power plants that average 35 years of age and produce about a third of U.S. CO_2 emissions. China has brought on line in the last five years a coal electricity production capacity about equal to the total US installed capacity. Coal will continue to be used for power generation from existing plants in both countries, so mitigation of CO_2 emissions from these plants is a high priority for research, development, demonstration, and deployment (RDD&D).

  Workshop discussions focused mainly on options and actions for the United States. However, the dominant contribution of China in coal-based emissions highlighted the importance of developing more economical CO_2 emissions mitigation technologies. *There is a "China Test" about whether CO_2 emissions mitigation can be accomplished at a sufficiently small incremental cost that China and other emerging economies can afford to implement it.* Passing this test is a critical RD&D goal for the next decade.

- ***There are multiple pathways to reduce CO_2 emissions from existing coal plants.***

  For existing coal plants, post-combustion capture followed by long-term, large-scale, sequestration is the most direct pathway to avoiding nearly all CO_2 emissions. The workshop discussion focused in large part on this path, addressing which plants are amenable to capture retrofits.

  Efficiency retrofits of existing coal plants can result in modest reductions of CO_2 emissions per unit of electricity produced. This is especially attractive for older, less-efficient plants. There is a range of approaches from boiler to control system improvements. A rough estimate is that 4–5% emission reduction could be realized relative to business as usual if efficiency improvements were introduced at less efficient coal plants. This action has the highest benefit/cost ratio for CO_2 mitigation.

  Bio-mass co-firing is another retrofit option for net CO_2 emissions reduction, if the feedstock is available. Indeed, if biomass use is combined with CCS there are negative net CO_2 emissions.

  Major rebuilds of existing coal plants are another option. There is a range of possibilities for such rebuilds, starting from capturing substantial value from use of an existing site and its infrastructure, and perhaps from its existing permits as well. Rebuilds are likely to be expensive, but will include large efficiency gains, for example, rebuilding an old subcritical unit to a high

efficiency supercritical (SCPC) or ultra-supercritical (USCPC) unit, with or without CCS. More extensive rebuilds include conversion to oxygen-driven combustion or to an IGCC plant with CCS. Additional options discussed in the background papers include co-generation and, for gasification plants, poly-generation of fuels and electricity.

Finally, repowering (biomass, natural gas) at coal plant sites is an option when CO_2 emissions charges are high and retrofit and rebuild are not attractive. Use of some elements of existing infrastructure (e.g., grid connections) can reduce project costs.

- ***The US government must move expeditiously to large-scale, properly instrumented, sustained demonstration of CO_2 sequestration, with the goal of providing a stable regulatory framework for commercial operation.***

  Obviously, without sequestration, CO_2 capture has no purpose. A substantial sequestration demonstration program should include several sites with storage of one to several megatons per year scale. EOR projects provide some useful information about geological storage, if properly instrumented and monitored, but neither the EOR regulatory framework nor the potential for EOR is adequate for CO_2 mitigation from coal fired generating units at a scale that will be material for climate change risk mitigation. The primary focus of the government program for the long-term sequestration at scale should be deep saline aquifers. Since a major source of CO_2 emissions is the existing coal fleet, *the DOE CCS demonstration program should include projects at existing plants.* The Clean Coal Power Initiative (CCPI) is placing increased emphasis on retrofits, but it has neither sufficient funds nor project management resources to support the large-scale projects called for here, certainly not in sufficient numbers.

  A robust R&D program should include exploration of *advanced sequestration technology options*. Examples are enhanced biological sequestration and beneficial uses of CO_2 in materials.

- ***Relatively large (300MWe or greater), high efficiency coal plants with installed FGD and SCR capability are the best candidates for CCS retrofit.***

  Such plants make up less than half of the existing fleet. With current and evolutionary amine-based capture technology, *estimates of the capture cost were generally in the $50-70/ton of CO_2 range for the Nth-plant.* This estimate of the cost of CO_2 emissions abatement is significantly higher than is generally recognized in the United States, but is not dramatically higher than the costs experienced in Europe (at current exchange rates).

  China has a significant number of recently built supercritical plants because of its aggressive deployment of coal power plants in this decade. Consequently there may be many opportunities for retrofit of Chinese coal plants when CO_2 emissions are priced, assuming that the incremental cost for CCS for air-driven combustion units is reduced substantially through RD&D.

  By contrast, retrofit is not attractive for old, lower efficiency, smaller, subcritical units. Rebuilding or repowering are options depending on significant CO_2 prices being in place.

  Extensive modifications require both retrofit and rebuild. An important option is oxy-combustion modification to the existing coal fleet to replace an air fired combustion system with an oxygen fired combustion system. This modification requires both significant retrofit and rebuild, so there many challenges. For example, infiltration into existing air fired older boilers may be acceptable for current operation, but the retrofit oxy-combustion system is likely to require plugging the leaks, which is an expensive undertaking.

- ***"Real world" retrofit decisions will be taken only after evaluation of numerous site-specific factors. Some of the key screening factors include:***

    - Proximity to geologic sequestration or EOR site and/or CO_2 pipeline
    - Available space: space constraints may make carbon capture retrofit impossible, or limit the amount of capture that is possible
    - Access to increased water supply
    - Existence of FGD and SCR capability
    - Practicalities of heat and power integration
    - Implication of a retrofit for dispatch in the regional system.

    It is unclear at the moment how restrictive these criteria will be for the existing fleet. EPRI is carrying out five site-specific case studies to help inform the discussion. It is quite possible that these site-specific screens will substantially limit that part of the existing coal fleet in the US for which retrofit or rebuild is attractive or result in partial capture solutions tailored to the current plant configuration.

- ***CO_2 capture cost reduction is important.***

    CO_2 capture costs are large because both the capture and release step is expensive and because the capture process conditions influence other steps in the conversion process. Accordingly, CO_2 capture technology deserves significant R&D support as part of a balanced retrofit program.

- ***A robust US post-combustion capture/oxy-combustion/ultra-supercritical plant R&D effort requires about $1B/year for the next decade.***

    A balanced R&D effort includes advanced simulation and analysis, exploratory research, proof of concept, pilot plants, leading to large scale demonstrations. Such an R&D program should be pursued with urgency. There are many important directions for research of intermediate term and "over-the-horizon" technologies. Near term R&D opportunities that are being pursued include a chilled ammonia capture project and exploration of new amine chemical solvents for binding CO_2. Longer-term opportunities included ionic liquids, membrane separations, and perhaps use of algae or other biomaterials to capture and convert the CO_2.

    Exploratory research could lead to a major breakthrough relevant to the "China test". It should be noted that some of the advanced capture approaches are appropriate only for oxygen driven systems. Oxygen separation cost reduction would be a critical enabler for both oxy-combustion retrofit and for various rebuild options, including gasification. Advanced materials research is important for ultra-supercritical plants.

    In addition there are R&D opportunities directed principally at new builds based on advanced gasification or novel approaches such as chemical looping.

- ***The Federal government should dramatically expand the scale and scope for utility-scale commercial viability demonstration of advanced coal conversion plants with CO_2 capture. The program should specifically include demonstration of retrofit and rebuild options for existing coal power plants. New government management approaches with greater flexibility and new government funding approaches with greater certainty are a prerequisite for an effective program.***

    Symposium participants discussed the range of desirable demonstration projects for retrofit of pulverized coal combustion including oxy-combustion, re-powering, and poly-generation. The estimated cost range for these projects to be borne by industry and government was $12-15B over the next decade, in addition to the research budget.

Given the urgency of establishing CO_2 emissions reduction options for the existing coal fleet, and the likelihood that there will not be a strong CO_2 emissions price signal for several more years, a Federal utility-scale cost- and risk-shared demonstration program needs a clear near term focus on commercial viability within the electricity market structure reasonably anticipated over the next 10-15 years, rather than technology-forcing requirements. The financial assistance agreements with the private sector should be based on commercial terms and conditions rather than government procurement restrictions. Multiple demonstrations will be needed in parallel, requiring substantial outlays, experienced management, and careful evaluation.

Such a strategy can be begun under the current DOE Clean Coal Power Initiative (CCPI) demonstration program, if it is expanded and has enhanced flexibility for speeding up the government process and for private sector project management and financial accounting.

However, new legislation should be considered in parallel with the CCPI program solicitation and implementation. An expanded commercial viability utility-scale demonstration program should be established through a quasi-government corporation. The authorities of the new corporation should be designed with a broader mandate than that of the CCPI program, encompassing the full range of low-carbon electricity technologies and fuels and financed from a multi-billion dollar annual small electricity line charge (as has been under consideration in the Congress).

Time is of the essence.

The retrofit, rebuild, or re-powering of the existing coal fleet, in the US and in China, to reduce CO_2 emissions dramatically is a necessary step towards achieving GHG stabilization targets. Practical options that will justify the vast investments needed over the next decades require validation from demonstration, development and research. Failure to do so will both drive up CO_2 prices (and the cost of electricity) and leave us with a continuing dearth of appropriate technology options.

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