Technical Workshop Report

An Industry View: Advancing the Next Generation of Coal Conversion Technologies

A workshop convened by the Coal Utilization Research Council, with support from Alstom, American Electric Power, Arch Coal, Cloud Peak Energy, Consol Energy, Duke Energy, Peabody Energy, Southern Company, Tri-State Generation & Transmission Association, and the U.S. Department of Energy

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Summary

This report provides a record of a workshop convened to develop an industrial sector view of what is needed to foster advanced coal technologies, with a focus on technologies that are ready for pilot plant-scale demonstration.[1] Advanced coal-based power generation technologies and carbon capture and storage (CCS) technologies received the greatest emphasis. The workshop was hosted by the Coal Utilization Research Council (CURC), with the support of nine energy sector entities and the Department of Energy, and was held in Arlington, VA, on November 18-19, 2014.

Industry input was sought during three plenary session panel discussions, and four subsequent roundtable sessions conducted in parallel. A plenary summary session was held at the conclusion of the three panel discussions, and after the four roundtable sessions. The three panel discussions were organized by industry sub-sector:

- Potential next-generation technology customers (electric power generating companies, and a company involved in use of CO_2 for enhanced oil recovery (EOR))
- Technology developers and equipment manufacturers
- Financial experts and investors

General Themes from the workshop:

1. Future commercial coal markets in the U.S. are likely to derive from need for incremental power generation (load growth), which is expected to be a relatively small market; and the generation "gap" created by retiring coal and nuclear generators.
2. Advanced coal-based technologies are needed for domestic power diversity and reliability, as well as to meet global carbon goals. These technologies require "proof of concept" at the pilot scale – typically 10MWe, or 25-50MWe.
3. A number of technologies are ready for pilot scale development.
4. The private sector is willing to participate in development of pilot-scale projects, but the federal government must assume the bulk of the cost of pilot-scale projects.
5. Certain regulatory and government policy changes would also foster pilot-scale projects.

<u>Panel Sessions</u>

Panel discussions were led by a moderator and addressed questions related to potential commercial markets for advanced coal technologies, the status of advanced coal technologies, identification of technologies ready for demonstration at a pilot plant scale, barriers to demonstration of pilot scale projects, willingness of that particular industry sub-sector to support pilot scale projects, and government actions that could foster pilot scale projects.

[1] An Industry View: Advancing the Next Generation of Coal Conversion Technologies, Workshop held in Arlington, VA, by the Coal Utilization Research Council, on November 18-19, 2014.

During the panel sessions a number of general themes emerged, as well as a few issues on which panel members held divergent views. Regarding markets, panelists agreed that there are two major markets for advanced coal technologies: the market created by incremental increases in electricity demand over time (viewed to be a relatively small market, appropriate for relatively small capacity additions), and the market created by retiring coal and nuclear power plants (potentially requiring larger capacity units and characterized as the "gap" market). Panelists believed that part of the gap market is near-term and advanced coal technologies may not yet be sufficiently mature to impact that portion of the market. Also, for the near-term, panelists viewed EOR as the only pragmatic option for CO_2 storage for reasons of cost, regulatory complexity, and long-term liability exposure. Panelists said that a possible third technology market, retrofit CCS systems, would not likely extend beyond the most recently commissioned coal-fueled power plants.

In general, panelists saw a clear need for advanced coal technologies, driven both by evolving U.S. environmental policies and global objectives for limiting carbon emissions. New coal-fueled systems are unlikely to be built in the U.S. without CCS, but current CCS systems are not cost-competitive with the lowest cost power systems (currently NGCC without CCS). Panelists believed that pilot projects were a necessary step in the technology development process. Potential customers and technology developers both indicated a willingness to participate in such projects. However, for a range of technology-related and market-related reasons, both customers and technology developers expressed an inability to provide more than 10-20% of a pilot project's cost. Panelists indicated that the bulk of the cost for pilot projects would have to come from the federal government, although EOR revenues and polygeneration designs might offset overall costs via revenues that were additional to electricity sales, and international investors or State agencies might contribute part of a project's cost. Electric utility panelists expressed the greatest interest in pilot projects for "transformational technologies," defined to include pressurized oxy-combustion, chemical looping systems, and power cycles based on use of supercritical CO_2 as a working fluid (instead of water or steam).

Part of the cost challenge of developing pilot projects is the long lead time needed for completing the pilot project, a subsequent demonstration-scale project, and the initial phases of commercial deployment. A deployment-based financial return on a pilot plant investment could require 15-20 years, and depend on highly uncertain factors like changing public policy, future regulations, and possible development of lower cost competing energy sources. This timeline and uncertainty make building a positive "business case" for a pilot plant investment difficult. Financial panelists stated that uncertain returns made these technology development investments unattractive to market-based (private sector) financing.

The appropriate size of needed pilot projects was generally characterized as either 10 MWe, or 25-50 MWe although some participants expressed the opinion that pilot scale should be technology specific and risk specific without presuming a certain scale. Smaller pilot projects would likely be "tear-down" units, disassembled after the pilot testing had determined design and operational parameters for a commercial-scale demonstration unit, whereas larger pilot projects (25-50 MWe) would enable long-term operation and revenue generation from the pilot project. Pilot scale projects have significant cost, perhaps over $100 million for a 10 MWe integrated system, and such investments are difficult to justify if they lack any immediate production of revenue.

Participants viewed smaller "manufactured" commercial power plants as one approach to reduce the labor costs of traditional field-erected designs, while also better adapting to the emerging market for smaller capacity additions. Smaller commercial designs could impact the needed size of pilot scale projects. However, for this cost-cutting approach to be practical, equipment suppliers would need confidence in the future demand for a relatively large number of identical units.

Breakout Roundtables

On the second day of the workshop, four breakout roundtable sessions were conducted:

- Innovative financing mechanisms
- Technology readiness (for pilot projects)
- Change needed in government support approaches
- International collaboration

In general, the roundtable sessions explored issues from the previous day's sessions in greater detail and reinforced the themes developed during those initial plenary sessions. Financial roundtable participants discussed reasons that private sector financing would be difficult for pilot projects. They explained, for example, that venture capitalists seek opportunities where a relatively small investment can (although at considerable risk) provide a large payoff within a brief period of time. These characteristics are often found in the micro-electronics sector, but not in the electric power sector.

Possible sources of funds for pilot scale projects were identified to include energy extraction severance taxes and royalty fees, electricity "wire charges," international collaborators, and regulatory incentives paralleling renewable portfolio standards (RPS) that exist in many states to promote above-market renewable energy-based electricity. Participants recommended pursuit of niche markets for pilot projects, even if those markets might not be sufficient to support broad deployment of the technology being developed.

The technology readiness roundtable participants emphasized, as other workshop participants had, that pilot scale projects would generally not substitute for commercial scale demonstration projects. This was considered especially applicable to transformational technology projects that might seek a greater technical "reach" than evolutionary technology projects. Pilot projects are pursued primarily to establish the reliability of a technology in steady state or startup/shutdown modes, whereas commercial-scale demonstration projects establish the performance of a technology under all modes of operation expected for the mature technology, in a fully integrated commercial environment. However, this roundtable said that certain technology components, such as oxygen generators or a CO_2-based turbine system, could reach near-commercial demonstration in a pilot-scale project.

In addition to reinforcing views of the plenary discussions on the cost-share issue, the government roundtable suggested measures that could reduce regulatory barriers to pilot projects. These included establishing (by law) specific environmental requirements for pilot projects in lieu of currently applied case-specific permitting rules, and providing NEPA categorical exclusions for pilot plants. The panel also favored flexibility in (or removal of) requirements in DOE financial assistance programs regarding project location, project size, integration (or not with CCS), and domestic preference requirements including minimum U.S. labor content, and requirements for U.S. manufacture of products embodying new inventions.

The international roundtable echoed the government roundtable participants' views on reducing domestic requirements as a means to attract foreign participants in pilot projects. Additionally, although the international roundtable's participants viewed intellectual property issues to be manageable, they also stated that IP issues have arisen in past projects and should be addressed and resolved at project inception. On the issue of whether some U.S. funded pilot projects should be sited in other countries, participants said that foreign projects sometimes have the potential to be "better, faster, or cheaper" than domestic projects, but that there is substantial political opposition to U.S. government funding of large scale projects in other countries.

Introduction

In November 2014, the Coal Utilization Research Council (CURC), with the support of nine major energy companies and the U.S. Department of Energy (USDOE), convened a two-day workshop to obtain views of the private sector on how the next generation of coal-based technologies could be advanced.[2] The workshop focused on the role of pilot-scale projects: defined as projects using technologies that have passed "proof of concept" testing at bench-scale in laboratories, but that are not available for purchase at commercial-scale. This report is a record of that workshop.

Technologies capable of economically and reliably capturing and permanently storing CO_2 from the combustion of fossil fuels used in power and industrial applications are necessary for achieving stated climate change mitigation goals. The Cancun Agreements established in 2010 endorsed a goal of limiting the increase in global average temperature to 2 ^{o}C, relative to pre-industrial revolution (18th Century) temperatures. Such a temperature increase would be associated with a global average concentration of about 450 ppm of CO_2-equivalent, a level that has already been exceeded.[3, 4] An emission scenario compatible with achieving this CO_2-eq concentration was developed for use in the recent IPCC 5th Assessment Report (IPCC-AR5). Under this scenario, global CO_2 emissions would decrease from a 2010 level of 36 billion tonnes per year (BTPY), to 18 BTPY in 2040, and 0.43 BTPY in 2080.[5] The IPCC emission reduction needs are in stark contrast to projections that CO_2 emissions from fuel combustion will increase by 25% in 2025, and by 46% in 2040 under current policies.[6] These two projections cannot be reconciled in the absence of broadly deployed CCS technologies without incurring prohibitive mitigation costs. The IPCC-AR5 reported that only four of its many models for simulating future global CO_2 concentrations were able to achieve a 2 ^{o}C goal without CCS technologies, and those that could reach the goal without CCS did so only with a more than doubling of mitigation costs.[7]

The workshop agenda is provided as Appendix A. As indicated in the agenda, the heart of the workshop was a series of three plenary panel discussions (day 1), followed by four "breakout roundtable" discussions (day 2). A listing of the workshop's 75 participants is included as Appendix B.

The remainder of this report presents a summary of the panel sessions and breakout roundtable discussions, following their order in the Agenda, and concludes with identification of several themes that emerged during the workshop.

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[2] An Industry View: Advancing the Next Generation of Coal Conversion Technologies, Crystal Gateway Marriott, Arlington, VA, November 18-19, 2014.
[3] Fast facts & figures, United Nations Framework Convention on Climate Change, https://unfccc.int/essential_background/basic_facts_figures/items/6246txt.php .
[4] 400 ppm CO_2? Add Other GHGs , and It's Equivalent to 478 ppm, MIT, June 6, 2013, http://oceans.mit.edu/featured-stories/5-questions-mits-ron-prinn-400-ppm-threshold .
[5] RCP Database (Version 2.0.4), RCP2.6, April 15, 2010, http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=welcome .
[6] International Energy Outlook – 2013, World CO_2 emissions – Reference case, USDOE/EIA.
[7] Summary for Policymakers, Table SPM.2, IPCC WGIII, 2014.

Panels and Breakout Sessions

Appendix A (Agenda) identifies the topic and members of each panel and breakout roundtable, provides a brief statement of the objective of each panel, and identifies the facilitator for each breakout roundtable.

Introductory Remarks and The Need for Pilot Plants

The basic operational parameters for the workshop were stated, including:

- The overall goal of the workshop was to obtain information on what industry is willing to do to advance coal-based technologies, and what industry might require from government in a collaborative program targeted on pilot-scale technology development projects.
- All remarks in the panel sessions and breakout roundtables were "not for attribution."
- The intent was to gather information and ideas from various stakeholders' perspectives, and not to drive to consensus.
- No competitively-sensitive business information (e.g., related to prices, costs, and production decisions) would be discussed.
- Panel sessions would be directed by their Moderator and seek input primarily from the panel members, but an opportunity would also be provided for other workshop participants to provide input.

Background information on the role of pilot plants in technology development was presented as a means to set the stage for the overall workshop. Next-generation coal conversion technologies were defined as coal technologies:

- Not yet available for purchase at a commercial scale,
- Having preliminary or incomplete process-level design details, and
- Possibly having components or materials not yet manufactured or used at commercial scale.

Examples of innovative advanced systems included high-temperature oxy-power cycles (using natural gas or coal syngas), high-temperature topping cycles such as MHD or fuel cells, and enhanced efficiency cycles such as chemical looping, pressurized air-coal combustion, or pressurized oxy-coal combustion.

The process for commercializing new concepts was described as a non-linear progression with feedback from early adopters and initial deployment into the marketplace. Important elements were identified as: R&D, learning by doing, and learning by using. Under the typical technology development process, capital cost for a new technology initially increases before refinement and innovation facilitate cost reductions. Flue gas desulfurization and selective catalytic reduction were offered as examples of technologies that followed this iterative development process, over a period of 2-3 decades from sub-commercial unit to broad deployment. A table from an EPRI report was offered to define Pilot Plants as: Technology Readiness Level (TRL) 7, at least 5% of commercial scale, costing $10s to $100s of millions, and requiring 2-5 years (or longer) to complete a project.

Panel 1: Next Generation Technology Customers

Potential customers of next-generation coal-based power technologies identified two markets for advanced coal-based technologies. The first was the traditional market for new power plants, based on incremental growth in electricity demand. Given very low rates of projected demand growth, this market was seen as needing a limited number of relatively small new power plants.[8] The second market was associated with the expected retirement of existing coal and nuclear power plants, referred to by panelists as the "gap" market. The "gap" market will track the introduction of additional environmental regulations and longer term scheduled retirements of coal and nuclear units. This market is expected to accommodate larger capacity units, but utilities expressed aversion to new units that would potentially cost half of that utility's net value. The potential for advanced coal technologies to be retrofit on existing units was discussed as a possible third market, but panelists viewed such retrofits as more difficult to justify, with the possible exception of retrofits on newer assets. One participant offered that small coal units may not be compatible with CCS systems.

Several challenges were cited for advanced coal projects. Pilot scale projects and commercial scale demonstrations were viewed by potential customers as having significant cost and risk. Risk exposure included long-term liabilities associated with CCS systems and "brand exposure" to the participating customer for technologies that fail to meet expectations. They expressed significant interest in pilot projects involving transformational technologies, but only if supported by both cost-sharing and risk-sharing, and only if employing EOR for CO_2 storage. Potential technology customers (e.g., electric utilities) recognized that pilot scale projects were intended primarily to generate information, not electricity, but could not justify "tear-down" projects.[9] They noted that previous pilot scale projects had been denied inclusion in the rate base, meaning that their cost could not be recovered from electric utility rate payers. Moreover, recent capital investments for pollution control compliance hardware and investments in new capacity to replace aging coal units for which pollution control upgrades could not be economically justified meant that electric utilities could not support major additional investments for pilot plant projects. Any new utility project needs to have a "compelling value proposition." Additionally, for the near-term, power production using natural gas combined cycle (NGCC) technology without CCS was viewed as lower cost than advanced coal systems with CCS. Technology customers also cited state regulatory requirements to deploy more renewable energy power generation, and preference by some state electricity regulators for distributed generation systems.

Potential customers identified several possible solutions to these challenges, although most included a caveat. EOR storage was viewed as one possibility to reduce the cost of an advanced

[8] One participant stated that currently envisioned coal-based technologies have a practical lower size limit.

[9] A "tear-down" project is one which is designed to provide operational data for 2-5 years, after which the pilot plant would be removed.

CCS project and to avoid legal framework issues associated with storage of CO_2 in saline geologic formations. The Bakken tight oil production fields in North Dakota were cited as a potentially large consumer of CO_2 for EOR, given tight oil's extremely small oil recovery rate using existing conventional production techniques. But modified EOR techniques must be developed to enable use of CO_2-EOR with tight oil formations. In general, EOR revenues could be limited by the non-continuous operation of a pilot scale project, and by the existence of other energy resource contracts for oil producers.[10] Similarly, polygeneration (production of electricity and other products such as urea) was viewed as a possible source of revenue to offset part of the cost of an advanced coal technology, but polygeneration carries its own challenges such as technology risk and price uncertainty for the product. Panelists indicated that electric utilities are anticipating a value for carbon control after about 2020, although the amount is uncertain. Having a value on carbon is seen as offsetting part of the near-term price advantage of NGCC without CCS versus advanced coal with CCS. International partnerships were seen as a possible mechanism to mitigate both costs and risks, and major electric utilities have established relationships that would support such partnerships. Utilities said that generation diversity has a value, but current coal and nuclear systems are not valued as highly as other generating systems for meeting near-term incremental generation needs. However, the value of diversity for coal may increase in 10-15 years due to:

- Reduced coal-based generation resulting from age-related retirements and regulatory requirements.
- Reduced nuclear generation resulting from age-related retirements.
- Greater deployment of intermittent renewables under RPSs.
- Anticipated increases in the price of natural gas for NGCC systems.
- The need for dispatchable capacity, like coal-fueled systems, to assure grid stability considering reactive power needs and other reliability-based factors.
- The general "portfolio" value of reducing reliability risks via diversity in supply.

Large electric utilities expressed greatest interest in transformational technologies: Pressurized oxy-combustion, chemical looping, and supercritical CO_2 (working fluid) Brayton cycles.

The customers panel cited several general concepts favoring pilot scale projects:

- Global solutions to the challenge of climate change require affordable and effective CCS.
- All technology options that have the potential to be cost-effective should be pursued.
- Federal funds are crucial to offsetting the additional cost of these projects.
- Innovation often has a hidden or delayed value not anticipated at project inception.
- Although EOR was clearly the favored approach for CO_2 storage, it was noted that none of the saline storage projects undertaken by the Regional Partnerships has encountered an environmental performance problem.

[10] Regarding the latter point, it was suggested that oil and gas (O&G) producers may be unwilling to pay more for captured CO_2 than was typical for CO_2 recovered in O&G production contracts, due to the possible impact of a higher rate for captured CO_2 on those O&G contracts.

Panel 2: Technology Owners, Developers and Equipment Manufacturers

Technology developers had a slightly different view of markets than the view of potential customers. For example, all of the participating "Customers" (Panel 1) were U.S.–based and focused on U.S. markets; but technology developers have significant coal technology market opportunities overseas. Technology developers stated that the technologies in demand in China and India for example, which include advanced ultra-supercritical power without CCS, differ from the interests of U.S. customers who are seeking transformational technology incorporating CCS. Developers saw commercial U.S. markets shifting to smaller units, but one developer stated that some technologies have practical lower size limits. Like electric utilities, technology developers said that the limited size of anticipated U.S. markets for advanced coal technologies hurt the business model for R&D to develop those technologies. This is because the economic argument for investing in new technologies is based in part on expected earnings from deployment of the new technology. A smaller future market means smaller future earnings to credit against current RD&D investment.

Technology developers stated that both Canada and China could be collaborators on CCS technology development. In general, developers believed that intellectual property (IP) issues were manageable.

Similar to Panel 1, technology developers viewed polygen as a mixed package – offering potential cost offsets, but also introducing additional uncertainty to a project.

Technology developers see the primary purpose of a pilot scale project to be development of design information for a commercial scale demonstration project. They do not see this research function as compatible with the dispatching requirements associated with revenue generation via electricity sales from the pilot project. Hence, developers see the "tear-down" concept as the likely business model for projects of 10-20 MWe. In general, developers begin with a commercial concept and work backwards to define the fastest path to progress through pilot and demonstration phases in order to develop the commercial technology.

Additional input from technology developers included the following general concepts:

- Technology developers are businesses and their shareholders must at least breakeven on pilot scale projects.
- Coal competes with other sources of electricity generation – both for commercial markets and for R&D resources. Markets for commercial deployment of advanced coal systems may be 15 years away; this long delay for commercial sales make it difficult to build a business case for advanced coal R&D and pilot projects.
- Pilot scale projects aimed at components may be a partial solution to reducing development costs and risks because components could have applications with a range of advanced technologies, and the pilot project may be incorporated into an existing facility at relatively low cost.
- Manufacturing economies (producing smaller scale technologies that can be "manufactured" instead of field-erected, and deployed to a site as multiple identical units) may offset loss of economies of scale if markets continue trending to smaller units. Modularity also can help address the uncertainty of future electricity demand

growth. However, for this to be practical the market place must need many identical units.

- Loan guarantees can protect lenders and facilitate higher risk technology projects, but they do not address the operational risk of "first of a kind" projects. Grants are viewed by the private sector as the best mechanism to address technology risk. Nevertheless, financial incentives for early commercial deployment of an advanced technology can create R&D "pull" by expanding commercial markets.
- Money and time are not interchangeable, but additional funding could accelerate technology commercialization.

Panel 3: Financial Experts and Investors

The perspective from the financial panel was that neither "sub-commercial" pilot scale projects nor smaller "tear down" projects are generally conducive to market-based financing. Greater government support was seen as necessary in the early phases of technology development, with a shift to market mechanisms after risk has been reduced. It is possible for equity investments to support pilot projects, but only at high rates of return. Innovative financing mechanisms are possible for coal technologies, but application at pilot scale is uncertain.[11] Participants stated that the current risk tolerance policy of DOE's loan guarantee program does not make the program conducive to fostering needed higher risk technologies.

Participants said that regulatory uncertainty has a chilling effect on private investment. EPA's pending new source and existing source performance standards, and the potential for CO_2 storage projects to be transferred from "Class II" to more restrictive "Class VI" status under EPA's underground injection control program were cited as examples of regulatory uncertainty.

Factors fostering financing of advanced coal technologies include technology progression that reduces risk to acceptable levels, regulatory certainty, a stronger business case (perhaps augmented by EOR revenues), and a "carbon market" (placing a value on CO_2 reduction). Financial experts said that private sector financing would become more accessible as technologies progress in development and technical risk decreases.

Possible sources of funds for "sub-commercial" and tear-down pilot scale projects include government grants, other countries, state governments, equity markets at high rates of returns, rate recovery, and philanthropic investment. In contrast, "near-commercial" pilot scale projects and demonstration projects could be funded by government grants, loan guarantees, and tax credits, venture capital, debt, and project financing.

Additional input on Panels 1 – 3

A review session of the first day's panels provided an opportunity for clarifications and additional input by all workshop participants. The following concepts were offered:

[11] Participants stated that innovative financing concepts merit a more detailed discussion than was practical within the workshop's limited schedule.

- The traditional utility business model is not conducive to funding R&D or pilot projects for advanced technologies.
- RPSs have provided a regulatory incentive for renewable energy-based electricity generation. A properly designed Clean Energy Standard that included CCS-based electricity generation could similarly assist in early deployment of advanced coal systems with CCS.
- Greater levels of government support – beyond 50:50 cost sharing – may be necessary for pilot scale coal/CCS projects. 80% government funding was cited as a possibility. Others noted that the National Institutes of Health often provide 100% funding of projects.
- In general, pilot-scale projects should not be viewed as adequate to enable commercial deployment. Both technology suppliers and financing stakeholders view commercial-scale demonstration projects as necessary to reduce technical risk to manageable levels. Even large scale pilots cannot be viewed as "replacements" for commercial-scale demonstration projects. However, today's "commercial-scale" demonstration projects may be smaller than previous 500 – 600 MWe demonstrations. Additionally, pilot-scale projects focused on a technology component may be a sufficient basis for proceeding directly to commercialization.
- One approach to reduce the capital cost of demonstration projects is to perform less than 90% capture.
- The time needed to cycle through the multiple steps of technology development can be compressed to some degree by overlapping the separate phases of development.
- Venture capital investors typically pursue relatively small investments with the potential for rapid advancement to commercial markets for successful technologies. This is not compatible with the investment scale and development timetable associated with advanced coal-based technologies.
- States may be willing to provide financial incentives for pilot scale projects.

Breakout Roundtable 1: Innovative financing mechanisms[12]

The session focused on low CO_2 emitting coal-based technologies that could be profitable under "reasonably" expected CO_2 prices. An example might be a technology with capture costs of $40 per tonne CO_2, under a scenario in which EOR could provide revenue of $25-35 per tonne CO_2, tax credits might total $10 per tonne, and a carbon trading price was $10-20 per tonne.[13]

Additionally, the discussion focused primarily on financing initial small commercial units (SCUs), perhaps 25-50 MWe. This capacity range was considered the smallest capable of long term operation and serving as a source of data for a "full commercial demonstration." Such a unit could provide useful variable cost data for commercial designs; generate some offsetting

[12] This review of the Breakout Sessions includes the subsequent plenary discussion of findings, led by the facilitator of each Breakout Session.
[13] This example assumes that the base coal technology, without CCS, is competitive with the alternative least cost electricity supply option.

revenue from sale of power (allowing multi-year operation); use commercial components such as turbines, pumps, compressors; and be large enough to interest a commercial power supplier and (EOR) CO_2 consumer. In contrast, the group defined "pilot" as being about 5 MWe, a capacity too small to jump to commercial scale in one step, and unlikely to be sufficiently efficient to justify long term operation. Funding for such small pilots was likely to come from grants or "angel investors."

Finance experts stated that advanced coal technologies were fundamentally different from other high-tech markets like computer chips. Individual coal technologies differ from one another, are relatively costly, and have a lengthy time period for commercialization.

One view expressed by workshop financing representatives is that private markets are properly functioning with regard to current CCS technologies. They are avoiding low carbon technologies like coal-based generation with CCS because they are not commercially viable today, and will not be viable until carbon prices reach $60 per tonne CO_2. The long lead time for developing and deploying a lower cost coal-based system is a deterrent to private sector financing.

Another view is that global efforts on coal-CCS technologies are fragmented by country because of each country's desire to develop domestically profitable technologies. The result is that efforts tend to be both duplicative and inadequate to develop the needed technologies. The suggested solution was greater integration into multi-nation programs to make better use of limited resources.

Sources of funds for SCUs (25-50 MWe) were discussed at length and the group recommended consideration of the following:

- Industry sources
    - A federally imposed levy (possibly a "wire charge" per MWhr of fossil-based electricity generation), to provide a fund administered by industry for mutually beneficial projects.
    - State pooled severance tax (new, or redirection of part of an existing levy, collected from coal producers) to fund coal technology projects. This approach would have to comply with practices in some states that prohibit contracts based on future year tax revenues.
    - A similar levy (royalties) on coal produced from leased federal lands.
- DOE sources
    - Current budget is insufficient to fund multiple projects at 25-50 MWe scale – estimated at $250 - 500 million each for an integrated power-CCS system, and perhaps half that amount for a CCS system retrofit.[14]

[14] The financial group estimated pilot plant costs at about $5 million/MWe, for a 50MWe capacity. Other figures offered at the workshop included $20 million/MWe for 1MWe scale projects at the National Carbon Capture Center, and over $10 million/MWe for FOAK demonstration projects (100 – 550 MWe scale) such as the Kemper County and Boundary Dam projects. Costs are expected to vary significantly for fully integrated power-CCS systems, versus CCS projects applied to a slipstream of an existing power plant.

    - DOE could fund multiple FEED studies (e.g., in FY2016), and down select to physical projects in subsequent years. However, a source of funds for the selected projects would still need to be found.
    - The group suggested that DOE might fund the <u>difference</u> between the capital cost per MW of the SCU and the anticipated cost per MW of commercial technology – still a substantial amount of money per project.
    - DOE might retain an equity interest in the technology that could be recycled into future SCUs.[15]
- International sources
    - Some countries (e.g., Japan, S. Korea) interested in CCS lack EOR opportunities and are not likely to overcome political opposition to saline CO_2 storage.
    - Those countries may provide support to early U.S. SCUs because of the large EOR-CO_2 revenue stream possible for projects located in the U.S. (reducing the cost of these technology development projects and accelerating the availability of commercial CCS technologies).
    - Technology developers in these countries already participate to some degree in the DOE RD&D program.
- State sources
    - State RPS programs generally exclude coal-CCS projects. A broader low-carbon program – "Low Carbon Portfolio Standard" (sometimes cited as a "Clean Energy Standard") would target the same low emission goal, but be open to coal-based technologies.
    - The group noted that Michigan's RPS (10% by 2015) includes coal-fired generation with CCS as an eligible technology.[16]
- Other ideas
    - Consider financing by private market mechanisms in niche markets. These markets would not support full deployment of a technology, but may be sufficient to finance a few large scale pilot plants.
    - Consider ways of integrating multiple national efforts to develop CCS and reduce duplication.

<u>Breakout Roundtable 2: Technology readiness for pilot projects</u>

The general scale of pilot projects was postulated to be 10 to 50 MWe capacity, and it was assumed that bench-scale work is completed but the technology is not ready for a commercial-scale demonstration project. The group's discussion followed five basic questions:

- What technologies are ready for large pilot plant testing?
    - Ready technologies include supercritical CO_2 Brayton cycles, advanced ultra-supercritical (AUSC) component testing (sometimes cited as "com-test"), chemical looping combustion, pressurized oxy-combustion, oxygen transport

[15] New legislation could be required to allow DOE to take an equity stake in a coal technology project.
[16] <u>Clean, Renewable, and Efficient Energy Act</u>, Public Act 295, Michigan, October 2008.

    - membranes, and possibly ion transport membranes. Several technologies currently operating at 1-3 MW scale are ready for moving to the large pilot plant stage, recognizing that the actual pilot plant may require several years planning, design & construction.
    - 1st Generation CO_2 capture systems are already being demonstrated, or are ready for demonstration. These technologies may not meet industry's long term needs, but experience with these technologies is needed to enable the next generation of technology development. However, these 1st Generation technologies do not require further pilot plant experience. We are now developing "1.5 Generation" systems.
- Would a large pilot project be "commercial" (i.e., provide or enable meaningful revenues)?
    - This was considered possible for components, such as oxygen producing technologies and AUSC components, although pilot plants were not seen as a general substitute for commercial-scale demonstration plants, as explained below.
    - It was also considered possible for certain integrated systems, such as SC-CO_2-Brayton cycles, and some forms of chemical looping technology.
    - Some integrated pilot plant systems could produce revenues (from sale of electricity or steam) which could offset some of the pilot plant cost.
- How do large pilot projects differ from commercial demonstration projects?
    - An obvious difference is size. Pilot plants are smaller than demonstration plants.
    - Pilot plants provide a proof of concept in a realistic operating environment (versus in a laboratory), show reliability under steady state operation and startup/shutdown, provide cost information, and provide operational data to facilitate a commercial-scale design.
    - Pilot plants do not, but commercial demonstration plants do, provide system integration at scale, show load-following performance (ramp rates for each major component) and performance characteristics over the full range of operating conditions, and provide balance-of-plant information. Commercial-scale systems may have components with different designs than pilots, e.g., steam turbines.
    - A pilot plant is generally a necessary prerequisite to a commercial-scale demonstration unit.
- What is the role of computer modeling in technology development?
    - In general, computer modeling does not allow technology developers to "skip steps", i.e., jump directly from a large pilot to commercial deployment.
    - However, modeling can improve pilot plant designs, accelerate the timeline for deployment, improve the confidence of scale-up and operation at varying conditions, and evaluate uncertainties.
- Who should pay for large pilots?
    - The group believed that public sector/private sector collaboration is essential for pilot plants, and that the government share of costs should be approximately 80%, industry share approximately 20%.

- After a FEED study, market risks and regulatory risks become better understood, and technology developers would be willing to accept more cost burden.
- CCS technologies are unusual in the sense that: a) their market is driven by evolving government regulatory policy; and b) the timeframe for technology development is lengthy, so there is a high probability that policy (and markets) will change prior to commercialization of the technology. These factors combine to create genuine risk that a pilot plant technology investment may never have a commercial deployment stage to enable recovery of the pilot plant investment, or that the recovery may be beyond the planning horizon of the technology developer. Hence, a large government cost share is needed for these pilots.

An additional point raised by a participant was that if one assumes that we are seeking to advance transformational technologies (defined as technologies with much more favorable performance and lower cost than currently available technologies), then the pilot plant "step" becomes even more important than for technologies based on incremental improvements.

<u>Breakout Roundtable 3: Changes needed for more effective Government support</u>

Roundtable 3 discussed challenges posed by current federal programs intended to support advanced coal technology development, and how these challenges could be overcome by modifying those federal programs.

Cost sharing requirements were a major issue addressed by the group. Current law was characterized as requiring at least 20% cost sharing (non-federal share) for R&D, and at least 50% cost sharing for demonstration projects; but also allowing the Secretary to reduce or waive these percentage requirements.[17] Additionally, DOE financial assistance rules define "demonstration" projects to include pilot projects.[18] Roundtable participants said that a cost share approach that was appropriate in 2005 (i.e., EPACT-05 provisions) is no longer workable for coal-CCS technology. They expressed the view that even a 20% cost share requirement was too high for coal-CCS pilot projects because:

- The time required for developing these technologies was 10 years or greater, and
- The market for these technologies is highly uncertain because it is strongly influenced by future regulations, other changeable government policies, and competing fuel forms with unknown future costs.

These factors make it difficult to construct a business case for technology investment without major federal support, particularly for smaller companies. Some members of the group believed that 90% federal cost sharing should be considered. However, the closer a technology project came to commercial status, the greater the appropriate industry share. Timing was also considered a key factor, with greater federal support being appropriate during the early stages

[17] See EPACT-05, Section 988 (Public Law 109-58).
[18] 10CRF600.30 and .302. "*Demonstration* means a project designed to determine the technical feasibility and economic potential of a technology on either a pilot plant or a prototype scale."

of a project. The group also thought that the level of private sector cost sharing in a project (above an eligibility floor) could be used as an evaluation factor in competitive solicitations.[19]

The group also discussed structural issues related both to the pilot plant and to a solicitation seeking private sector development of a technology. Regarding pilot plant eligibility criteria, participants said that the government should emphasize whether a pilot project can meet the government's program objectives, and be flexible regarding:

- the size of the project,
- whether it includes both CO_2 capture and storage, and
- whether it is located in the U.S. or in another country.

Past technology development programs that were phased, with down-selection to later phases, have proven to be workable from the developers' perspective. The Industrial CCS program was cited as an example. Phase 1 of such a program should focus on developing an understanding of techno-economics of the technology, risks and risk mitigation, financing options, teaming, and potential pilot project sites. Criteria for the down-select should be explicit and transparent. In some cases, the early FEED stage provides information that persuades the technology developer that the technology is not ready to advance to the construction phase of development, which should not be viewed as a research failure. Roundtable participants stated that some DOE solicitations provided relatively brief periods (e.g., 2 months) to prepare and submit proposals, whereas assembling a team of participants in a project could require much longer (e.g., 6 months), making a quick submittal impractical. A possible solution was to delay the teaming requirements until Phase 2 of a project.

Regarding the overall size and timing of a government-assisted pilot plant program, the roundtable predicted that a larger program, by its nature, took longer to begin and execute.

Government environmental requirements were seen as problematic in some respects. For example, current permitting and environmental review periods were not seen as conducive to large scale pilot plants. Larger pilots could trigger New Source Review requirements and lengthier NEPA reviews that can require 3 years. The Industrial-CCS program selected projects in 2009, but none has yet received an EPA Class VI injection well permit. The group believed that improved legal and policy options (which would ensure environmental protections) should be developed. One option cited was to establish fixed environmental performance criteria for pilot plants. Another was to provide Categorical Exclusions (under NEPA) for pilot scale environmental projects like coal-CCS. Some types of environmental streamlining would likely require legislation.

The group believed that current policies regarding intellectual property (IP) rights were workable. However, U.S. Preference provisions that require U.S. manufacturing of new inventions developed with government support were viewed as a barrier to international

[19] The subsequent Plenary discussion of this session's findings acknowledged a tension between the market economics or "business plan" approach to defining a worthy pilot plant project, and the "public interest" valuation of a project that might not meet business investment criteria. One participant stated that, ultimately, one needs a business justification for developing a technology, although that justification may be based on a very long (e.g., 20 year) time horizon. Such a business case includes the commercial technology expected to evolve from the pilot.

participation in pilot projects, as was the 75% U.S. labor requirement. Some in the roundtable cited current difficulties in obtaining patent waivers for cost-shared technologies and recommended that patent waivers be approved for pilot plant projects. Other participants said that they had obtained waivers, but it was a time consuming procedure.

Breakout Roundtable 4: Effectiveness of international collaboration

International collaboration on pilot plant projects offers opportunities and challenges. The discussion cited some of these opportunities and suggested approaches for addressing the challenges.

Roundtable members said that international collaboration and pooling of funds is cumbersome, but cited some examples of successful programs. For example, Saskatchewan established a carbon capture test facility that, after an initial year of use by a major funding company, will be available for evaluating ideas from others, regardless of country of origin. Alberta uses carbon tax revenues to fund the Climate Change and Emissions Management Corporation (CCEMC), which cost shares adaptation, CCS, renewable energy, and energy efficiency projects.[20] "Grand Challenge" (which awards a grant to projects that address a specified CCEMC objective) is also administered by CCEMC. The U.S.-China Clean Energy Research Center (CERC) was cited as a successful approach to collaboration on CCS technologies.[21] Roundtable participants suggested that pooling concepts include enabling opportunities for international funding of projects that have already been selected for support (versus pooling funds and then soliciting for projects).

The U.S. private sector has successfully pursued technology development in foreign countries, but there are also examples of efforts that have been stymied until assisted via DOE discussions with foreign government counterparts. U.S. government funding for overseas projects is more difficult than encouraging cooperation in privately funded projects. Pilot project funding may be possible, but U.S. funding for large demonstration projects in other countries is considered unlikely. DOE solicitations on CCS demonstrations have included a 75% "domestic content" requirement. Canada supports international projects, but only if there is a compelling case that the technology has broad applicability to Canadian facilities. One participant suggested that an investment overseas supported by a clear justification (e.g., infrastructure, expertise, or capital that exists outside the U.S.) could ease restrictions on U.S. funds. Another suggested that the key criteria necessary to support an international project could be characterized as "better, faster, cheaper."

The Carbon Capture Leadership Forum (CCLF) is a multi-national organization that supports 26 CCS projects. The question was posed: is this the correct approach for international collaboration? Participants stated that CCLF was more of a communications vehicle for RD&D, rather than a process for initiating CCS projects. The Asia Pacific Economic Cooperation (APEC) organization was cited as a multilateral organization that, among other things, does capacity building for CCS.

[20] See www.ccemc.ca .
[21] See www.us-china-cerc.org . CERC funds building efficiency and "clean" vehicles, as well as CCS.

There are several reasons why international collaboration on advanced coal pilot plant projects would be constructive:

- The cost of these projects is large; attracting international support may be necessary as a practical matter. Collaboration also reduces risk.
- Climate change is an international issue and can be addressed effectively only with an international approach.
- International scope expands the slate of existing facilities that could be configured with control technologies. High growth rate economies offer more new facility sites.
- Once a technology is developed, it can be used anywhere.
- International collaborative frameworks already exist.
- Projects conducted overseas may be executed faster.

Nevertheless, international collaboration raises new issues and challenges to technology development, including:

- In general, U.S. policy discourages international projects through requirements to build in the U.S., use largely U.S. labor or content, etc.
- Conflicting requirements of multiple governments can impede a project. Government funding is viewed as essential, but government direction of projects is viewed as a problem.
- Different nations have different funding cycles.
- Intellectual Property (IP) issues are more problematic in an international context.
- Some potential participants have limited EOR opportunities, which increases project costs in those countries, and may limit interest in CCS.
- Some previous large projects with international collaboration (FutureGen and Mongstad) have not fully met expectations. Others, such as Weyburn, are viewed as very successful.

A broad range of possible government and private sector approaches for facilitating international collaboration were cited by participants, including:

- U.S. "content" requirements could be relaxed. For example, the 75% domestic content requirement could be applied only to U.S. government funding.
- As with domestic projects, international projects should be focused and have well defined goals.
- Multiple governments should be involved in an advanced coal technology pilot program.
- It may be easier and faster to build on existing programs and site projects at existing facilities.
- Some participants suggested that the coal industry should take more of a leadership role in CCS RD&D, although the group recognized that the industry is currently under an economic strain.
- Projects must recognize the politics and culture of the host country and participating organizations.
- A lesson learned from FutureGen is the value of siting projects where they are embraced by the local community.

- Regulatory drivers may be needed to justify project economics (e.g., a carbon price or tax, or a carbon emissions cap). However, one participant stated that a carbon tax could serve as a facilitator for CCS (if it effectively created a revenue stream that made CCS economically attractive), or as a barrier to CCS (if it created cost advantages for other technologies leading to reduced use or closure of coal-based systems). As an example of the latter, the European carbon tax was seen as encouraging biomass cofiring rather than CCS.
- Regulatory frameworks for carbon storage may be needed, particularly for countries that have limited oil and natural gas production. Countries with developed O&G resources tend to have more experience with underground resource property rights, environmental issues related to protection of drinking water, and geological expertise.
- Technology developers may need a "roadmap" that shows an economic return on investments in domestic or foreign technology development (pilots, demonstration projects), through ultimate commercial deployment.
- IP issues must be addressed at project conception.
- Consolidation of current international funding mechanisms is appealing due to the established frameworks, but may also be procedurally cumbersome.

Dominant Themes

The purpose of the workshop was to elicit a private sector perspective on what measures are necessary to foster a series of pilot plants using advanced coal-based technologies, including CCS, and what actions the private sector was willing to take to support such pilot plants. Although the intent of the workshop was not to reach a consensus of views, a number of themes emerged during the workshop and are presented in this section.

The Role of Pilot Plants in Technology Development

Workshop participants appeared to hold a common view that coal technology development followed a progression of steps:

- Basic research leading to "proof of concept" at a laboratory or bench scale.
- Pilot plant operation of technologies successful at bench scale, in order to obtain design parameters for commercial scale demonstration.
- Commercial scale demonstration.
- Commercial deployment.

Each step in this process is considered critical to commercial deployment, and the process can include iterative feedback loops in which one set of technologies feeds the next generation of those technologies. For example, certain 1st Generation CCS technologies are now at the commercial demonstration stage, and 2nd Generation technologies are moving through the basic research stage. R&D, "learn by doing," and "learn by using" were all considered part of the process of moving to a mature advanced technology. Coal-related technologies like flue gas desulfurization and selective catalytic reduction have followed this pattern and are now fully commercial. An important conclusion was that, although pilot plant projects are essential, they generally are not an alternative to commercial-scale demonstrations.

The basic purpose of pilot plants is to establish proof of concept in a realistic operating environment and to provide design information to enable demonstration at the larger "commercial" scale. Pilot plants show that a technology works under steady state conditions and during startup and shutdown. But they generally do not involve full system integration or operate under all modes likely to be encountered by a commercial unit.

Markets, Types of Pilot Plants, and Timing

Workshop participants focused primarily on the historically dominant market for coal in the U.S.: electric power generation. Low carbon applications of coal were the major technology development focus, particularly CCS. Two major markets for advanced coal technologies were identified: the market created by electricity demand growth, which is expected to be relatively small over time and be met with new units in the 200-300 MWe capacity range; and the market created by retiring coal and nuclear units, sometimes characterized as the "gap" market, which may reflect both aging units and units for which additional capital investment to meet new environmental requirements cannot be justified. This latter market could accommodate larger new coal units than the incremental growth market. Several participants stated that the potential market for CCS retrofits to existing coal-fired power plants was limited to relatively recently commissioned units, and is not as significant as the other two markets.

Participants considered the most likely candidates for pilot scale projects to be transformational technologies, including chemical looping, pressurized oxy-combustion, supercritical CO_2 (Brayton) power cycles, and related key components such as advanced oxygen production technologies or ultra-supercritical components. In contrast, 1st Generation technologies were deemed to already have progressed beyond pilot scale testing, and 2nd Generation technologies were generally deemed to be more appropriate for evaluation at the National Carbon Capture Center at ~ 1 MWe scale. The participants generally viewed the appropriate size of the needed pilot plants at either about 10 MWe (for units that might be disassembled after completion of pilot testing), or 25-50 MWe (for units that might generate significant revenue, and operate for an extended time period, e.g., 20 years or more). Certain advanced technology components were viewed as appropriate for pilot scale projects at a much smaller size. Workshop participants considered the technologies listed above to be ready now to enter the pilot project "process" which typically includes a period of time to solicit project proposal, respond with preliminary designs, selection of projects for funding, and detailed design, permitting, and construction.

Willingness of Industry to Support Pilot Plant Projects

Workshop participants included potential technology customers (such as electric utilities), technology developers, and coal companies. All indicated an existing presence in coal technology development, and said that they would participate in pilot plant projects under certain conditions. However, all indicated that their ability to support such projects financially is limited due to several factors, including:

- Near-term commercial markets for coal-CCS technologies are considered limited and that makes large investments in new technology difficult to justify. Markets are limited because currently available coal-CCS technologies are relatively costly, growth in electricity demand is small, and CCS faces regulatory barriers.
- Past electric utility coal-CCS pilot projects have been refused "rate base" inclusion, meaning that the utility could not recover the expense from ratepayers.
- The coal industry is experiencing a difficult economic period, as evidenced by falling stock exchange prices.

Potential government-based or sanctioned funding sources were identified to include: traditional energy RD&D appropriations, wire charges, resource extraction royalty payments, severance taxes, and contributions from foreign governments.

In general, financial experts at the workshop felt that market financing was appropriate for commercial scale demonstration projects, and commercial deployment of technology, but is not appropriate for the relatively high risk and uncertainty of pilot projects.

International Collaboration

Participants saw value in using international collaborations to support advanced coal pilot projects. However, past USDOE technology assistance solicitations have included provisions that discouraged other countries from providing financial support and foreign based companies from participating in a U.S. project, and discouraged use of U.S. funds for a project located in another country.

Protecting intellectual property rights (IP) was viewed by participants as more difficult for a project involving other countries, and should be addressed in the initial stages of planning a pilot plant project.

Potentially Beneficial Actions to Encourage Pilot Plant Projects

1. In general, participants stated that it is important for the private sector to have "skin in the game," or a direct financial commitment in pilot plant projects. However, market, policy, cost, and technology risk associated with development of advanced fossil energy technology at pilot scale suggests that higher public sector contribution – greater than the levels generally applied under federal law and regulation – is needed to drive these projects.[22] Federal law allows the Secretary of Energy to deviate from traditional cost share levels, and the group recommended doing so for near-term pilot plant projects.
2. Grants were viewed as the most effective funding mechanism to address the levels of market, policy, cost, and technology risk encountered in pilot plants.

[22] Participants generally cited federal support levels of 80% or 90% as appropriate, given the risks associated with these technologies at the pilot stage of development.

3. Participants concluded that it was counterproductive for small environmental technology development projects to be delayed for years by environmental protection regulations. Government could address and reduce certain regulatory barriers to coal-CCS pilot projects by:
    a. Providing coal-CCS pilot projects with categorical exclusions under NEPA.
    b. Eliminating the potential for migration of pilot projects from Class II to Class VI regulation under the EPA UIC program.
    c. Ensuring any CO_2 storage monitoring and reporting requirements measured the creditable amount of CO_2 storage, and did not serve as "reopeners" for CO_2 injection permits.
    d. Specifying environmental performance requirements (emission limits) in pilot program authorizing legislation – to replace ambiguous and litigious elements of permitting regulations for subject pilot plants.
    e. For those units electing saline storage, accelerate the UIC permitting process. Participants stated that industrial CCS projects selected in 2009 have yet to obtain Class VI permits under the UIC program.
4. A regulatory "driver" for CCS technology could be created by expanding State RPSs to include CCS (as Michigan does), or by creating a "Clean Energy Standard" that would function like an RPS, but include CCS as a compliance option.
5. Attracting international collaboration in pilot projects would be facilitated by modifying U.S. requirements for project location, U.S. content and labor, and expected manufacturing location.

Appendix A – Agenda

An Industry View: Advancing the Next Generation of Coal Conversion Technologies

November 18-19, 2014 • Crystal Gateway Marriott
Arlington, VA • 22202

DAY ONE • NOVEMBER 18th • PLENARY SESSION• SALON J	
7:30 am to 8:30 am	*Continental Breakfast* • ***Salon J***
8:30 am to 8:50 am	**Introductions and Opening Remarks** (Ben Yamagata**,** Executive Director, CURC) **Setting the Stage: The Need for Pilot Plants** • **Dr. Ed Rubin**, Department of Engineering and Public Policy, Carnegie Mellon University
8:50 am to 10:30 am	**Panel 1: Next Generation Technology Customers** • **Matt Greek**, Senior Vice President of Generation, Basin Electric Power Company • **Mark McCullough**, Executive Vice President-Generation, AEP • **David Mohler**, Vice President and Chief Technology Officer, Duke • **Dwight Peters**, President, Schlumberger Carbon Services Objectives of the Panel: Address the criteria that will be considered by electricity generators in making a decision to use advanced coal-fueled generation technology, including costs; performance; commercial readiness; size; ability to prevent or control emissions especially carbon dioxide; preservation of power generation options and timeframe for adoption. Comment upon the circumstances under which a technology customer might be willing to support or facilitate the construction or operation of a pilot plant designed to further the development of a next generation technology.
10:30 am to 10: 45 am	*Break*
10:45 am to 12:30 pm	**Panel 2: Technology Owners, Developers and Equipment Manufacturers** • **Kip Alexander**, Vice President of PGG Technology, Babcock and Wilcox Power Generation Group • **Bill Brown**, CEO, NET Power ; Co-Founder, 8 Rivers Capital • **Bob Hilton**, Vice President, Power Technologies for Government Affairs, Alstom Power

	Inc. • **Sharon Sjostrom**, Chief Technology Officer, ADA-ES • **Don Stevenson**, Senior Director, Energy Advanced Programs , Aerojet Rocketdyne Objectives of the Panel: Comment upon what is required to further develop next generation coal power generation technology, including the role of pilot plant projects prior to commercial offering of the technology; the degree and nature of risk that can be assumed to pursue development at the pilot scale and beyond; the amount, form and duration of support, from both the public sector and from potential customers and others, needed to undertake a pilot scale project; the criteria for determining the degree of readiness necessary to proceed to a large scale pilot plant and the steps needed thereafter before a commercial offering is made; and discussion of other barriers to rapid development and opportunities for international participation.
12:30 pm to 1:30 pm	***Lunch and Special Guest Speaker: Dr. Julio Friedmann**, Deputy Assistant Secretary, Office of Clean Coal and Carbon Management, U.S. Department of Energy*
1:30 pm to 3:15 pm	**Panel 3: Financial Experts and Investors** • **Ronald Bertasi**, President & CEO, Sparus Holdings, Inc. • **John MacWilliams,** Senior Advisor to the Secretary-Financial, U.S. Department of Energy • **Bill Schoelwer**, U.S. Finance Director, Alstom Power Inc. • **Harrison Wellford**, Founder & President, Wellford Energy Group Objectives of the Panel: Discuss the criteria considered in making investments in next generation coal power generation technology at the pilot scale level, at the larger commercial demonstration scale level (if necessary) and at commercial scale, including the availability of conventional or innovative financing; address circumstances under which debt or equity funding could be available to support a facility that is constructed and operated to validate technology maturity and readiness after which the project might be dismantled or alternatively continued to operate and generate revenues.
3:15 pm to 3:45 pm	*Break*
3:45 pm to 4:45 pm	**Summary of Discussions and Key Findings** Facilitators: Doug Carter and Tom Russial
5:00 pm	*Reception • **Sky View at the Crystal Gateway Marriott***

DAY TWO • NOVEMBER 19th • BREAKOUT ROUNDTABLES • ***After breakfast please proceed to your designated breakout room (final summary discussions to take place in Salon J)***	
7:00 am to 7:45 am	*Continental Breakfast* • ***Salon J***
8:00 am to 9:45 am	**Breakout Roundtable 1:** Financing Pilot Scale Projects and Exploring Innovative Financing Mechanisms *(Salon H)* **Facilitator: Jeff Brown, Senior Vice President-Finance/Corporate Strategy, Summit Power Group, Inc.** • Walker Dimmig, Principal, 8 Rivers Capital • John Harju, Associate Director for Research, EERC • Walter Howes, Managing Partner, Verdigris Capital, LLC • Rob Hurless, Interim Director, Enhanced Oil Recovery Institute • Darren Mollot, Director, Office of Advanced Fossil Technology Systems, Office of Fossil Energy, U.S. Department of Energy • Satish Tamhankar, Technology Expert, Clean Energy & Innovation Management, Linde LLC **Breakout Roundtable 2:** Technology Readiness *(Manassas Room)* **Facilitator: Ed Rubin, Department of Engineering and Public Policy, Carnegie Mellon University** • Tom Alley, Vice President of Generation for the Electric Power Research Institute • David Julius, Emerging Technology Director, Duke Energy • John Marion, Director Technology and R&D- Boiler Line, Alstom Power Inc. • Riley Moore, Generation Engineering Manager, Tri-State G&T • Karen Parysek, Director, Technology Relations, Praxair Inc. • Matt Usher, Director - New Technology Development, American Electric Power **Breakout Roundtable 3:** Modifications to Federal Programs *(Alexandria Room)* **Facilitator: Tom Russial, Independent Consultant** •Jason Begger, Government Affairs Manager, Cloud Peak Energy •Tom Sarkus, U.S. Department of Energy, National Energy Technology Laboratory •David McCarthy, Director External Technologies, Air Products and Chemicals, Inc. •Steve Moorman, Manager Business Development - Advanced Technologies, The Babcock & Wilcox Company •Frank Morton, Consulting Engineer, Southern Company •Dwight Peters, President, Schlumberger Carbon Services •Don Stevenson, Senior Director, Energy Advanced Programs, Aerojet Rocketdyne, Inc. •Dick Winschel, Director of Research & Development, CONSOL Energy Inc.

	Breakout Roundtable 4: International Collaboration*(Mt. Vernon Room)* **Facilitator: Dick Bajura, Director, West Virginia University National Research Center for Coal and Energy** •David Butler, Executive Director, Canadian Clean Power Coalition •Patrick Frye, Director, Business Development, Aerojet Rocketdyne •David Mohler, Vice President and Chief Technology Officer, Duke Energy •Ron Munson, Principal Manager, Carbon Capture, Global CCS Institute •Scott Smouse, Senior Management & Technical Advisor – International, U.S. Department of Energy National Energy Technology Laboratory •Thomas Weber, President, Jupiter Oxygen Corporation
9:45 am to 10:15 am	*Break*
10:15 am to 12:00 pm	**Summary of Discussions, Key Findings and Concluding Remarks • *Salon J***

Appendix B – Registered Attendees

Name	***Job Title***	***Company / Organization***
Mr. Kip Alexander	Vice President of Technology	The Babcock and Wilcox Power Generation Group, Inc.
Mr. Tom Alley	VP - Generation Sector	Electric Power Research Institute (EPRI)
Ms. Shannon Angielski	Principal	Coal Utilization Research Council
Dr. Richard Bajura	Director	WVU NRCCE
Mr. Jason Begger	Government Affairs Manager	Cloud Peak Energy
Mr. Ronald Bertasi	CEO/Operating Partner	Sparus Holdings/Source Capital
Mr. Brian Brau	Director Project Development Btu Conversion	Peabody Energy
Mr. Jeff Brown	SVP, Finance & Corporate Strategy	Summit Power Group, LLC
Mr. Bill Brown	CEO	8 Rivers Capital and NET Power
Mr. David Butler	Executive Director	Canadian Clean Power Coalition
Mr. Doug Carter	Independent Consultant	L.D. Carter
Mr. Mike Casper	Sr. Manager	NRECA
Mr. Ray P Chamberland	Manager, Contract Boiler R&D	Alstom Power Inc.
Mr. Tom Dennis	Executive Vice President	Cassidy and Associates
Dr. Victor Der	Executive Advisor	Global CCS Institute
Mr. Walker Dimmig	Principal	8 Rivers Capital
Dr. Julio Friedmann	Deputy Assistant Secretary for Clean Coal and Carbon Management	Office of Fossil Energy, U.S. Department of Energy
Mr. Patrick Frye	Director, Business Development	Aerojet Rocketdyne
Mr. Matthew Greek	Sr. VP, Engineering & Construction	Basin Electric Power Cooperative
Ms. Stuart Hall	Director of Membership Services	Coal Utilization Research Council
Mr. John Harju	Associate Director for Research	Energy & Environmental Research Center
Ms. Marianne Helms	Director, Governmental Issues	Van Ness Feldman
Mr. Robert Hilton	Vice President	Alstom
Mr. Shintaro Honjo	Research Manager	Mitsubishi Hitachi Power Systems Americas, Inc.
Mr. Walter Howes	Managing Partner	Verdigris Capital, LLC
Mr. Rob Hurless	Deputy Director	School of Energy Resources
Mr. Revis James	Director, Generation R&D	Electric Power Research Institute

Mr. David Julius	Emerging Technology Director	Duke Energy Corp.
Ms. Alison Kerester	Executive Director	Gasification Technologies Council
Mr. Michael Knaggs	Director, Office of Major Demonstrations	DOE-NETL Strategic Center for Coal
Mr. John Litynski	Carbon Capture Program Manager	U.S. Department of Energy
Mr. John Lowell	Director, Strategy and Technology	Arch Coal, Inc.
Mr. George Luke	VP, Business Operations	Neumann Systems Group
Mr. John MacWilliams	Senior Advisor to the Secretary	U.S. Department of Energy
Mr. John L Marion	Director Technology & R&D, Boiler Line	Alstom Power Inc.
Mr. Michael Matuszewski	Technology Manager	U.S. DOE - NETL
Mr. David McCarthy	Director External Technologies	Air Products
Mr. Mark McCullough	Executive Vice President	American Electric Power
Mr. David Mohler	Vice President Emerging Technology	Duke Energy
Ms. Nancy Mohn	Director, Strategic Marketing	Alstom
Mr. Darren Mollot	Director, Office of Advanced Fossil Technology Systems	Office of Fossil Energy, U.S. Department of Energy
Mr. Riley Moore	Generation Engineering Manager	Tri-State Generation & Transmission
Mr. Steve Moorman	Mgr, Business Development Advanced Technologies	Babcock & Wilcox
Mr. Frank Morton	Consulting Engineer	Southern Company
Mr. Ronald Munson	Principal Manager Carbon Capture	Global CCS Institute
Mr. Ram Narula	Chief Technology Officer	Energy Industries of Ohio
Mr. Neil O'Brien	Business Develpment Manager, Government Contracts	Air Products and Chemicals, Inc.
Ms. Karen Parysek	Director of Technology Relations	Praxair, Inc.
Mr. Dwight Peters	President	Schlumberger Carbon Services
Dr. Sean Plasynski	Director, Strategic Center for Coal	National Energy Technology Laboratory
Mr. Robert Purgert	President	Energy Industries of Ohio
Mr. Richard Reavey	VP Public Affairs	Cloud Peak Energy
Dr. Edward Rubin	Professor	Carnegie Mellon University
Mr. Thomas Russial	Attorney	Thomas J. Russial
Ms. Christina Sadorf	Executive Assistant	Coal Utilization Research Council
Mr. Thomas Sarkus	Division Director	U.S. DOE - NETL
Ms. Katy Sartorius	Special Assistant, Office of the Secretary	U.S. Department of Energy

Mr. Hamid Sarv	Discovery Leader	Babcock & Wilcox
Mr. Bill Schoelwer	U.S. Fiance Director	Alstom Power Inc.
Dr. Vijay Sethi	Sr. Vice President	Western Research Institute
Ms. Sharon Sjostrom	Chief Technology Officer	Advanced Emissions Solutions
Mr. Scott Smouse	Senior Management & Technical Advisor	U.S. Department of Energy
Mr. Donald Stevenson	Director, Advanced Energy Programs	Aerojet Rocketdyne
Mr. Gary Stiegel	Division Director	U.S. Department of Energy
Dr. Satish Tamhankar	Technology Expert	Linde LLC
Mr. Matt Usher	Director - New Technology Development	American Electric Power
Mr. Martin Webler		National Energy Technology Laboratory
Mr. Thomas Weber	President	Jupiter Oxygen Corporation
Mr. William Wellford	Chairman	Wellford Energy Group
Mr. Steven Winberg	Program Manager	Battelle
Mr. Richard Winschel	Director, Research & Development	CONSOL Energy Inc
Mr. James Wood	Director, U.S.-Chine Clean Energy Research Center	West Virginia University
Mr. Jon Wood	President	CoalBlue Project
Mr. Alex Wormser	CEO	Wormser Energy Solutions, Inc.
Mr. Ben Yamagata	Executive Director	Coal Utilization Research Council