**Selected Outcomes**

**U.S.-China Clean Energy Research Center (CERC)**
**Advanced Coal Technology Consortium (ACTC)**

**November 2015**

## 1. Advanced Power Generation [Theme 1]

- ***First-of-a-kind experimental system:*** Power plants equipped with advanced ultra super-critical (A-USC) boilers have the potential to dramatically improve efficiency and reduce emissions compared to existing coal-fired power plants. A survey conducted by LP Amina and the Babcock & Wilcox Company (U.S.) and Tsinghua University (China) found that subcritical power plants accounted for 78% of China's coal-fired fleet in 2009, with super- and ultra super-critical units making up the remaining 22%. CERC researchers are targeting subcritical units in China and the United States with a capacity range of 300–600 MW to maximize system-wide impacts of plant efficiency improvements and emissions reductions potential. They also developed a toolbox of technologies to enable energy conservation and emissions reduction in coal-fired power plants. Separately, the development of improved A-USC boiler technologies was adopted as a national program in China. Tsinghua University and Huaneng CERI researchers also designed and constructed a unique experimental system to study pulverized coal combustion in counter-flow flames and used the system to investigate combustion characteristics of Xinjiang Houxun coal in A-USC boilers. (CERC AR 2012-2013, page E3, Appx E: ACTC research topic 1)

## 2. Clean Coal Conversion Technology [Theme 2]

- ***Validated co-generation technology at pilot plant:*** CERC researchers from the United States (LP Amina and West Virginia University) and China (Zhejiang University) jointly validated the modeling results of a 1 MW pilot plant for coal co-generation technology. The design combines pyrolysis, gasification, and combustion. The co-generation technology is expected to reduce maintenance costs and greenhouse gas emissions by more than 25% compared to conventional technology. Based on the validated model, researchers are now developing a co-generation system and advanced coal gasification process technology and will demonstrate the technologies at industrial scale for deployment in the United States and China. (AR 2012-2013, page E5, Appx E: ACTC research topic 2)

- ***Novel coal-to-chemicals polygeneration simulated and ready for testing:*** Researchers from China (ENN Group) and the United States (Lawrence Livermore National Laboratory and LP Amina) completed experiments and simulations of a coal-to-chemicals polygeneration scheme for LP Amina's calcium-carbide reactor. The simulation findings will be used to design and build a very high temperature polygeneration reactor at laboratory scale. The results set the stage for improved operation and commercialization, with potential for scale-up in China's coal-to-chemicals markets. New polygeneration technologies are

expected to dramatically reduce waste heat, water use, and greenhouse gas emissions, while improving thermal efficiency of power generation and chemical by-products production. (AR 2012-2013, page E5, Appx E: ACTC research topic 2)

## 3. Cross-cut Outcome: Advanced Power Generation and Clean Coal Conversion Technology [Themes 1 & 2]

- ***Demonstration of advanced coal-to-chemicals poly-generation technology:*** Gemeng International (China) cooperated with LP Amina (U.S.) in building a demonstration facility for coal-to-chemicals technology in China. LP Amina's 50 MW demonstration facility in Shanxi, China, is designed to co-produce electricity and 100,000 barrels/year of chemical intermediates. The groundbreaking design will allow the power plant to co-produce electric power and high-value byproducts, increasing revenues and cutting emissions. The LP Amina-Gemeng International Energy plant could reduce greenhouse gases by more than 25% compared to conventional technology. The demonstration is now underway.

## 4. Synthetic Natural Gas [New Theme 2]

- ***Direct synthetic natural gas (SNG) production from coal:*** ENN Group (China) and Lawrence Livermore National Laboratory (U.S.) built and tested a bench scale high-pressure constant-volume reactor. Coal gas with high-concentration methane was obtained, validating the possibility of direct SNG production from coal. The team is now constructing a circulating high-pressure, constant-volume reaction system for coal-to-SNG. If successful, this work will result in development of a new approach for direct SNG production from coal with high-efficiency, low-pollution, and low-cost.

## 5. Post Combustion $CO_2$ Capture [Theme 4]

- ***Further utilization of post-combustion simulations:*** Lawrence Livermore National Lab (U.S.) is modeling a solvent developed by Babcock & Wilcox Company (U.S.) to compare with Huaneng (China) and Duke Energy (U.S.) work performed earlier in the program. This research will generate additional data points on the cost of capture while leveraging existing work to yield further benefits that were not anticipated when the work was initially funded. In CERC–ACTC Phase II the model will be reconfigured to include Duke Buck Station (a 600 MW combined cycle gas turbine) and re-run to compare cost and performance data on a gas fired power plant.

- ***Development of low-cost, low-energy $CO_2$ sorbent:*** University of Wyoming (U.S.) researchers are developing a novel, solid $CO_2$ sorbent that shows early promise for a potential dramatic drop in $CO_2$ capture cost. This effort will be continued as a key collaborative effort in CERC-ACTC Phase II.

- ***Modeling of Huaneng Shidongkou post combustion capture system:*** Researchers from Lawrence Livermore National Laboratory (U.S.) and Huaneng CERI (China) used operational data from the 600 MW Shidongkou Power Plant to build and validate a simulation model for

the post-combustion capture mixed-amine absorption process. The model allows process performance assessments under varying decision-making environments. Researchers completed the conceptual simulation of a 1-million ton per year post-combustion $CO_2$ capture system in Duke Energy's Gibson-3 station using technology developed by China Huaneng and demonstrated at the Shanghai Shidongkou Power Plant. This effectively advances new capture and solvent technologies for the development of efficient $CO_2$ capture in existing coal plant retrofits. The simulation model revealed a number of design advances and suggested a cost of US$61–$68 per metric tonne, if the same system were installed at Duke's Gibson 3 plant in Indiana. Laboratory research conducted at the University of Kentucky (U.S.) and Tsinghua University (China) under this theme identified a two-phase solvent and new catalyst family with record activity levels. (AR 2012-2013 page E8, Appx E: ACTC research topic 4)

- ***Membrane fabrication:*** As a means to separate $CO_2$ from post-combustion gases, researchers at Los Alamos National Laboratory (LANL) (U.S.) fabricated a 100-nm thin $CO_2$-selective layer on commercially attractive support material, using LANL's Ultrasonic Spray Coating Technique (USCT). This resulted in the development of a novel polymer/ionic liquid (IL) hybrid-membrane that can achieve high-permeability in a mechanically robust platform. Such hybrid polymer/IL systems benefit from liquid-like $CO_2$ permeability and solubility in the IL, resulting in enhanced perm-selectivity. Polymer molecular manipulations were applied to dramatically improve IL additive retention and hybrid membrane permeability. The ultra-thin composite membrane fabrication method is now under continuous development and optimization. Large scale membrane fabrication appears to be readily achievable.

## 6. Oxy-Combustion $CO_2$ Capture [Theme 5]

- ***Development of pressurized oxy-combustor:*** Researchers from Washington University in St. Louis (WUSTL) (U.S.) have begun constructing a staged, pressurized oxy-combustor. The continued development of this combustor will be a centerpiece of the CERC-ACTC Phase II Oxy-Combustion program and is planned for joint work between WUSTL and Huazhong University of Science and Technology (China).

- ***Improved modeling capabilities for oxy-combustion:*** Researchers at Huazhong University of Science and Technology (China) and the Babcock & Wilcox Company (U.S.) characterized four U.S. and four Chinese coals and developed computational fluid dynamics (CFD) models for U.S. and China pilot-scale test facilities, leading to cost and performance improvements in oxy-firing combustion, which facilitates $CO_2$ capture. If policies encouraging $CO_2$ capture are in place, the computer models—once validated in larger scale demonstration projects—will facilitate and accelerate the rate of deployment of such technology in a variety of coal regions throughout the world. (AR 2012-2013 page E10, Appx E: ACTC research topic 5)

## 7. $CO_2$ Sequestration [Theme 6]

- ***Pre-feasibility work on saline aquifers near GreenGen:*** Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and West Virginia University (WVU) performed a pre-feasibility study on a saline aquifer adjacent to the Bohai Basin near Tianjin, China, using data supplied by Chinese researchers, and the results are promising. The purpose of the pre-feasibility study was to clear the way for a FEED and enhanced water recovery (EWR) project in conjunction with the $CO_2$ capture system currently being erected on the GreenGen project. The study led to discussions between U.S. and Chinese researchers on formation pressure management, which will be an important consideration when using saline aquifers for $CO_2$ storage. There is a high feasibility of useful water production and the ability to actively manage formation pressures. This has multiple positive outcomes for reducing risk in saline aquifer storage and in production of low-salinity water that could be utilized for municipal or agricultural use

- ***New evaluation of saline aquifer storage and enhanced oil recovery (EOR):*** Researchers from China (Shaanxi Provincial Institute for Energy Resources and Chemical Engineering, Northwest University, Yanchang Oil Company, and Sinopec North China Co.) and the United States (University of Wyoming Carbon Management Institute, Indiana Geological Survey, and Los Alamos National Laboratory) collaborated on an assessment of aquifer storage and enhanced oil recovery potential in the Ordos Basin in China. The team assembled the geologic, petro-physical, structural, and stratigraphic frameworks of the Ordos Basin and compared evaluation methodologies for Ordos with the Wyoming and Illinois Basins in the United States. Shenhua (China) provided detailed sub-surface coding information to LANL to allow accurate modeling of areas in the Ordos Basin. This model will be useful for a number of collaborations, including exploring the potential of EWR and EOR projects with Yanchang Petroleum and EOR demonstrations with Shenhua. (AR 2012-2013 page E12, Appx E: ACTC research topic 6)

- ***Advances in simulation modeling lead to new optimal designs for $CO_2$ source-sink matching in Chinese and U.S. basins:*** Researchers in the United States (Los Alamos National Laboratory (LANL) and the Indiana Geological Survey (IGS)) and China (Institute of Rock and Soil Mechanics, Chinese Academy of Sciences (IRSM)) have built the first ever cost surface for linking $CO_2$ sources to geologic sinks for the Ordos Basin. The cost surface was combined with data gathered to generate candidate pipeline networks from existing $CO_2$ sources to a set of nine potential reservoir regions provided by the Chinese. $CO_2$ source data, including industry type and emission quantity, were used to optimize storage schemes for targeted capture ranging from 10 MT/yr to more than 250 MT/yr. Similar system analysis, including enhanced oil recovery potential, is underway for the Illinois basin in the Gibson region in cooperation with Duke Energy (U.S.). LANL, IGS, and the University of Wyoming, working in both the Illinois basin and the Rock Springs Uplift, have demonstrated that inclusion of reservoir parameter uncertainty is key to allowing realistic estimates of storage capacity and injectivity. Results from this work are already being examined by local and regional

leaders in China who are planning for implementation of carbon capture, utilization, and storage (CCUS).

- ***New cross-theme collaborations will advance fully integrated CCUS projects:*** Theme 6 ($CO_2$ Sequestration) is closely collaborating with post-combustion research in Theme 4 (Post Combustion $CO_2$ Capture), linking potential $CO_2$ capture from the Gibson Generating Station with enhanced oil recovery and saline aquifer storage within the Illinois Basin. This includes developing a specific transport and storage plan for the Gibson capture project. Theme 6 is also leveraging pre-combustion $CO_2$ capture work from Theme 3 (Synthetic Natural Gas) and applying this to the Edwardsport Integrated Gasification Combined Cycle (IGCC) project. Close collaboration with Theme 6 partners in China will promote similar results for the Ordos Basin.

## 8. $CO_2$ Utilization [Theme 7]

- ***Design configurations assessed for $CO_2$ utilization with microalgae:*** Researchers in the United States (Duke Energy and University of Kentucky) and China (ENN Group) examined $CO_2$ utilization in algal growth systems using a range of U.S. and Chinese strains and different reactor designs. The researchers are developing and demonstrating technology for $CO_2$ utilization with microalgae and transformation of algal biomass into a sustainable source of energy or other high-value products. A mutant algae strain developed by ENN shows a 15% faster growth rate than the corresponding wild type algae. Moreover, the new strain is tolerant of aggressive environments, including high temperatures. Further assessments are ongoing at Duke Energy's East Bend power plant. The accumulated data will be incorporated in a techno-economic model that will identify potential areas for improvement and economies of scale. Collaborative research and data sharing is enabling the comparative advantages of a number of process configurations, ranging from open pond cultivation to closed-loop photobioreactors. The success of the reactor and the research results encouraged Duke Energy to work with Algenol Biofuels (U.S.), where both parties are currently in negotiations to capture and use $CO_2$ from Duke Energy's Polk River CCGT facilities. (AR 2012-2013, page E14, Appx E: ACTC research topic 7)

## 9. Simulation and Assessment [Theme 8]

- ***Reduced energy penalty from post-combustion $CO_2$ capture:*** Researchers from Tsinghua University (China) and West Virginia University (U.S.) simulated a steady-state scenario for $CO_2$ capture from a super-critical pulverized coal power plant using a monoethanolamine (MEA) solvent. Optimizing the design and operating parameters, researchers were able to reduce the simulated net energy penalty by 2.5%—from 12.7% to 10.2%. Application of advanced modeling and simulation tools enable improvements in technology and systems integration not otherwise possible, due to the complex nature of the many interacting processes present in large-scale power generators with carbon capture. Such improvements are expected to guide designs that will decrease cost and improve performance of $CO_2$ capture technologies. (AR 2012-2013, page E15, Appx E: ACTC research topic 8)