US-CHINA ACTC RESEARCH OVERVIEW

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Joint ACTC Activity Update

- Active collaboration since our last presentation to you in Beijing culminating in a joint meeting in California Jan 6-8, 2013 to summarize our accomplishments
- Developed joint summary of progress for annual report and plans for future research collaboration (see handout)
- Technical presentations by Dr. Yao and Dr. Friedmann will reflect depth of activities
- We expect collaboration to continue, develop and grow

Theme 1 – ADVANCED POWER GENERATION

- 1.1 - Increase Efficiency and Availability of Existing Coal-fired Power Plants
- 1.2 - Advanced Ultra-supercritical Boiler (A-USC) Development
- 1.3 -Upgrade Pulverizing System for Subcritical Power Plants

Theme Leads –Qiang Yao (THU)/ Matt Zedler(LP Amina)

- 1.1 – THU (Yao) and B & W (Mccauley)
- 1.2 – SJU (Zhang) and B & W (Mccauley)
- 1.3 – THU (Yao) and LP Amina (Zedler)

Accomplishments

- (Notable Publications)
  - J Zhuo, S Li, L Duan, Q Yao. Effect of Phosphorus Transformation on the Reduction of Particulate Matter Formation during Co-combustion of Coal and Sewage Sludge, Energy Fuels, 2012, 26 (6):3162–3166.
  - Z. X. Zhang, X. J. Wu, T. Zhou, et al. The effect of iron-bearing mineral melting behavior on ash deposition during coal combustion[J]. Proceedings of the Combustion Institute. 2011 (33), 2853-2861

Plans

- Next Year Plan
  - Organize joint workshop
  - Report on the plant interview results
  - Develop list of tools applicable to plant efficiency upgrades in China and U.S., respectively
  - Remainder of Project – Overall Goals

Theme 2 – Clean Coal Conversion Technology

- 2.1 - Co-generation System with Combined Pyrolysis, Gasification, Combustion and Poly-generation.
- 2.2 - Chemical Looping Gasification With CO2 Capture
- 2.3 - Direct SNG Production From Coal
- 2.4 - Coal To SNG By Catalytic Gasification
- 2.5 - Gasification Properties Of Coal DTL Residue
- 2.6 - Measurement, Modeling And Environmental Technologies For Unconventional Coal Gasification
- 2.7 - Coal/Biomass Co-conversion Processes

Theme Leads – Zhongyang Luo, Ismail Celik

2.1 – ZJU (Luo), WVU (Celik) and LPAmina (Targett)

- 2.2 – ZJU (Wang)) and WVU (Celik)
- 2.3 – CAS (Xiao) and WVU(Sun)
- 2.4 – ENN (Gan) and NETL (Lou)
- 2.5 – Shenhua(Chen) and UWY (Bell)
- 2.6 – ENN (Cheng) and LLNL (Friedman)
- 2.7 – CUMT (Liu) and WVU (Sun and Celik)

Accomplishments

- Coal co-generation technology combined pyrolysis, gasification and combustion is validated on 1MWt pilot plant and may be demonstrated in industry
- Studied feasibility of new coal gasifcation technologies include chemical looping gasification, direct SNG production, underground gasifciation, coal liquefaction residue gasification, co-gasification of biomass and coal, and achieved good progress.
- Constructed and operated an experimental setup that can reach 1500-2100C to study high temperature carbo-thermic reactions
- Published 17 papers, and 12 Chinese patents are applied or authorized.

Plan

Next Year Plan: research works will proceed according to the 10 point research plan

- Collaboration and academic exchanges between Chinese and USA partners will be enhanced.
- **Remainder of Project** –Further develop the new co-generation system with combined pyrolysis, gasification, and combustion, advanced coal gasification processes (Chemical Looping gasification with CO_2 capture, Direct SNG production from coal, Coal liquefaction residue gasification, underground gasification, coal/biomass co-conversion process.
- Design and build a very high temperature poly-generation reactor at lab scale and study fundamentals of calcium carbide production from coal
- Demonstrate part of developed technologies at pilot scale and industrial scale for development and sale in both countries.

Theme 3 – PRE-COMBUSTION CO_2 CAPTURE

- 3.1 - IGCC with CCS
- 3.2 - IGCC Knowledge Transfer

Theme Leads – Shisen Xu (HUANENG)/ David Julius (DUKE)

- 3.1 – Huaneng (Xu) , Duke (Julius)
- 3.2 – Huaneng (Xu) , Duke (Julius)

Accomplishments

- The Huaneng and Duke Energy reached an agreement on IGCC information will be exchanged. Information such as construction learnings, process learnings, availability issues, and environmental performance will look to be shared.
- GreenGen became commercial in 2012 and Edwardsport IGCC is expected to be commercial in early 2013
- Development of pre-combustion CO2 capture technology based on IGCC technology.
- Capture reagent and process development and evaluation.
- Mid-temperature adsorbents develop and PSA pilot rig set up.
- Screen existing chemicals and develop new formula for capture reagent.

Plans

- To complete the information exchange between Duke's Edwardsport plant and Huaneng's GreenGen IGCC in approximately the 2013 timeframe.
- Remainder of Project – Work through the IP issues between the two
- companies.
- Development of Techniques for Integration and Optimization of IGCC system.
- Study the operational impact with various WGS technologies and CO2 separation process on IGCC system performance.
- Screen existing chemicals and develop new formula for capture reagent that will have high working capacity and less energy consumption.

Theme 4 – POST-COMBUSTION CO_2 CAPTURE

- 4.1 - 1 M Tons / Year Post Combustion CO_2 Capture at Duke Gibson Station
- 4.2 - Development of Solvent for CO_2 Separation from Utility Flue Gas
- 4.3 - Development of Catalyst to Enhance CO_2 Capture Kinetics in Scrubber
- 4.4 - Membrane Development for CO2 Separation from Utility Flue Gas Stream
- 4.5 - Post CO_2 Scrubber Solvent Enrichment

Theme Leads – Gao Shiwang (Huaneng)/ Kunlei Liu(UKY)

- 4.1 - Huaneng (Gao), LLNL (Friedman)
- 4.2 - Huaneng (Gao), UKY (Remias)
- 4.3 - Huaneng (Gao), UKY (Lippert)
- 4.4 - NWU (Ma), LANL (Berchtold)
- 4.5 - THU (Wang), UKY (Landon)

Accomplishments

- Completed the conceptual simulation for 1 M tons / year post-combustion CCS project in Gibson-3
- Two phase solvent developed for CO_2 capture
- Development of new catalyst family with record activity (k_{cat} 10^5)
- Electrosorption capacity was nearly doubled with surface oxidation treatments
- Finished CO_2 absorption and desorption investigation in two advanced amine
- Complete the corrosion study for CPI proprietary solvent
- Ultra-thin selective layer deposition method developed for composite membrane fabrication
- *Journal of The Electrochemical Society* **2012,** *159* (11), A1861-A866.

Plans

- Refine ASPEN models of Gibson-3 to improve the simulation accuracy
- Continued development of 2 phase solvent and demonstration at pilot scale (0.1 MWth)
- Catalyst refinement, scale-up, and demonstration at the 1.5 ” mini-scrubber
- Continued optimize the system integration, and novel solvents development
- Carbon xerogel electrodes and asymmetric electrode configurations demonstrate economical amine solvent CO_2 enrichment with CDI
- Fabricate ultra-thin composite membranes with hybrid CO_2 selective materials

Theme 5 – OXY-COMBUSTION CO_2 CAPTURE

- 5.1 -Fuel Characterization and Emissions Study Under Oxy-Combustion Conditions
- 5.2 -Pilot-scale Oxy-Combustion Evaluation and Optimization
- 5.3 -Steady-state and Dynamic Process Modeling Simulations
- 5.4 - Feasibility Study for Large Scale Deployment

Theme Leads:

China: Zhaohui Liu (HUST)

US: Kevin McCauley and Shengteng Hu (B&W)

- Prof. Zheng Chuguang (HUST)
- Prof. Liu Zhaohui (HUST)
- Prof. Zhuo Jiankun (THU)
- Prof. Sun Shaozeng (HIT)
- Kevin McCauley (B&W)
- Dr. Shengteng Hu (B&W)

Accomplishments

- Research collaboration agreement was signed between B&W and HUST.
- Four US and four Chinese coals were characterized and CFD sub-model parameters were optimized.
- Selected test cases for both B&W SBS and HUST FCS were simulated using CFD codes (COMO and FURN).
- Preliminary development of Aspen steady-state and dynamic models for SBS and FCS were completed.
- A joint paper, “Char Burnout of U.S. and Chinese Coals under oxy-combustion Conditions”, was presented at the 2012 Pittsburgh Coal Conference

Plans

- Continue research on coal characterization, CFD and process modeling
- Evaluate need for new oxy-coal burner designs and pilot scale testing
- Knowledge sharing on feasibility study of a large scale demonstration plant
- Continue pursuing commercial demonstration opportunities

Theme 6 – Sequestration Capacity and Near-Term Opportunities

- 6.1 - Saline Formations at Basin Scale
- 6.2 - Geologic Storage and EOR
- 6.3 - Geologic Storage and ECBM
- 6.4 - Simulation and Modeling of Storage

Theme Leads – Li Xiauchun, Ren Xiangkun/Tim Carr, Ron Surdam, Phil Stauffer

- 6.1 – CAS (Li), WVU (Carr) and IGS (Rupp); SPIERCE (Zhou), UWYO (Surdam, Jiao)
- 6.2 – SPIERCE (Zhou), Yanchang (Gao) and UWYO (Jiao, Surdam)
- 6.3 – LLNL (Buschek)
- 6.4 – CUMT (Chu), LLNL (McNab) and LANL (Stauffer)

Accomplishments

- Assembled available information and data from Ordos Basin
- Inventoried the distribution of energy and CO_2 resources in Ordos Basin
- Delineated CO_2 sources and sinks in the Basin
- Explored the potential Ordos Basin analogs in Powder River, Greater Green River and Illinois Basins utilizing the latest performance and rock assessment simulation technology.

Plans

- Improve maps of major stationary CO_2 emission sources in Ordos Basin and potential storage/EOR sites
- Initiate pressure regime study to determine distribution of anomalous velocity regimes in Ordos Basin
- Continue comparative sedimentologic, stratigraphic, petrophysical, rock/fluid and comparative well log study of the Madison/Majiogou and Lance/Yanchang Formations
- Refine numerical simulations (performance and risk assessments with much improved databases) for CO_2 storage and EOR in Ordos Basin
- Build optimal strategy for EOR projects in Ordos Basin
- Develop commercial-scale geologic CO_2 storage/surge tank capabilities in the Ordos Basin.

Theme 7 – CO_2 ALGAE BIOFIXATION AND USE

- 7.1 - Screening of Algae Strains
- 7.2 - Growth System Optimization
- 7.3 - Algae Post Processing
- 7.4 - Techno-economic Analysis

Theme Leads – Zhenqi Zhu, Mark Crocker

- 7.1 - ENN (Zhu) and UKY (Crocker)
- 7.2 -Duke (Durst), ENN (Zhu) and UKY (Crocker)
- 7.3 - ENN (Zhu) and UKY (Crocker)
- 7.4 - ENN (Zhu) and UKY (Crocker)

Accomplishments

- 6 high performance mutant strains were obtained; optimal native summer and winter strains for KY were identified
- Low-cost photobioreactor designed & constructed (Inner Mongolia and Kentucky)
- Optimized cultivation process for both closed photobioreactors and open ponds
- Demonstration facility constructed & operational at East Bend power plant
- 3 patent applications, 3 papers published, 4 under review, 11 conference presentations

Plans

- Evaluate productivity and tolerance of target mutants in outdoor environment
- Examine effect of recycle water on algal growth
- Optimize harvesting via flocculation, and optimize wet extraction approaches
- Operation of demonstration facility (East Bend) through 2013, with expansion to ca. 20,000 L
- Further upgrading and utilization studies for more complete techno-economic analysis
- Techno-economic modeling using process data generated at East Bend

Theme 8 – INTEGRATED INDUSTRIAL PROCESS MODELING AND ADDITIONAL TOPICS

- 8.1 - Power plant cycling and load-following operations
- 8.2 - Steady State and Dynamic Modeling of Post-combustion Carbon Capture Technologies
- 8.3 -Visualization and Operator Training Tools and simulations
- 8.4 - Modeling and Simulation of Post-combustion Power-plants with CO2 capture
- 8.5 - Design and Steady State Modeling of Coal-fired Power Plant with Total Carbon Capture, including Pre- and Post-Combustion
- 8.6 - Life Cycle Analysis of Coal-to-Chemical Systems with Pre-Combustion CO2 Capture

Theme Leads – Zheng Li , Richard Turton

- 8.1 - WVU (Turton) and NETL (Zitney)
- 8.2 -WVU (Turton) and LLNL (Friedmann)
- 8.3 - WVU (Turton)
- 8.4 - TU (Li)
- 8.5 - Huaneng, CPECC, CEP-CAS
- 8.6 - Shenhua

Accomplishments

- Dynamic Modelling and Simulation of CO_2 Capture using MEA
- Performances of Power Plants Retrofitted with a Throttle Valve, Sliding Pressure Operating Mode, and Back-Pressure Turbines capture
- Modelling of Functional Units of an IGCC System
- Performance of IGCC with ion transport membrane
- Dynamic modeling of multi-train CO_2 capture processes
- Implementation of 3D immersive training system
- Techno-economic evaluation of Gibson 3 CO_2 capture process

Plans

Next Year

- System identification and control structure for multi-train CO_2 capture processes
- Compute damage accumulation rates and dollar costs for cycling operation
- Determine the cost impacts of increasing ramp rates, MW load transient ranges, and shortened startup times
- Dynamic model of a power plant, and conduct dynamic analysis of the integration
- Study the control system of a CO_2 capture process and its coordination with a power generation plant
- Design of advanced/next-generation power plants with CO_2 capture
- LCA of coal-to-chemical plants with CO_2 capture

Long Term

Development and validation of:

- Dynamic models for CO_2 capture processes
- Robust control strategies for multi-train capture processes
- Dynamic models for plant-wide power system including CO_2 capture process
- Advanced/next generation power plants with CO_2 capture
- Life cycle assessment of coal-to-chemical plants with CO_2 capture