WESTERN RESEARCH INSTITUTE RESPONSES TO REVIWERS (LRC-LXIX(69)-C)

Western Research Institute (WRI) would like to offer the following responses to the reviewers to clarify and expand on the information presented in the proposal. Additional information will be provided in the LRC Confidential Session. The reviewers asked for additional information about the Cost of Electricity (COE) of the proposed WRITECoal™ gasification/IGCC process compared to other technologies and selected technical process issues such as caking of particles in the gasifier and gas stream paths.

To set the stage of the proposal, WRI would like to point out that there are two different sets of plants that are of direct interest to the coal industry (1) retrofit of the existing fleet to include carbon capture and storage (CCS) and (2) new greenfield facilities that offer expansion of the coal industry and are also CCS-ready. This proposal addresses the greenfield IGCC plants. WRI has published costs for retrofit of lignite-fired subcritical plants with WRITECoal™ (described later).

Competing IGCC Technologies.

We agree that the proposed WRITECoal™ gasification/IGCC technology must be evaluated with respect to other gasification/IGCC technologies and other technologies such as supercritical and ultra-supercritical PC and oxy-fired plants. It is important to note that the proposed WRITECoal™ gasification/IGCC technology can be applied to nearly all currently proposed and commercially offered gasification/IGCC technologies (e.g., GE Energy (GEE), ConocoPhillips (CoP), Shell, etc.) within the proposed near-term commercial deployment timeframe of 5-8 years. The reason to look at the integration of the WRITECoal™ process with low-temperature fluidized bed or entrained flow gasification technologies (U-GAS® and Transport Reactor) is that it provides a higher increase in efficiency with these gasification technologies than with the higher temperature slagging type of gasifiers. Both the U-GAS® and the TRIG technologies are commercially ready, and as such the potential deployment of the WRITECoal™ IGCC technology will not be extensively delayed. WRI has had communications with other gasifier developers as well.

COE of Competing Technologies.

We agree that the COE is the ultimate parameter to assess the competitiveness of the WRITECoal™ gasification/IGCC technology. The Information presented in Table 2.1.1.1 and Figure 2.1.1.1 (page 10) of the proposal shows the estimated COEs for a variety of greenfield plants based on rather detailed estimates for bituminous coal-fired systems both without carbon capture and with carbon capture. The technologies shown include three gasification technologies (GEE, CoP, and Shell). These three gasification technologies represent higher temperature operation slagging technologies and a range of feeding among other items (Ciferno, 2007). When the three gasification technologies were compared the efficiencies were almost identical ranging from 31.7 (CoP) to 32.5 percent (GEE) with Shell at 32.0 percent. The capital costs with carbon capture were also similar $2,390 (GEE), $2,431 (CoP) and $2,668 (Shell) resulting in LCOE of 10.3, 10.6, and 11.0 cents/kWh. It should be noted that these costs were based on 2007 dollars and it is well-known that cost escalations over the last several years have occurred due primarily to material cost increases and other factors that have resulted in considerably higher recent published estimates for gasification projects, such as the Edwardsport project. Although these costs have varied with time, the

relative ratios of capital costs and COE for the different competing technologies with and without carbon capture remain essentially the same. As such, this data provide a relative comparison of the COE for gasification technologies.

In addition these three gasification technologies were compared to subcritical PC, supercritical PC, ultra-supercritical PC as well as supercritical oxy-combustion and ultra-supercritical oxy-combustion. Baseline subcritical with MEA and supercritical PC had an LCOE of 11.4 cents/kWh and supercritical oxy-combustion LCOE was 11.3 cents/kWh. Ultra-supercritical PC and ultra-supercritical oxy-combustion LCOE were slightly less at 11.0 and 10.7 cents/kWh respectively, even though the COEs represent a major increase in COE. Clearly, gasification/IGCC remains a low cost option (COE) for greenfield coal-fired plants, including lignite-fired units compared to supercritical pc and comparable to ultra-supercritical pc plants.

Comparison Between IGCC and Supercritical PC Technologies.

Specifically mentioned by one of the reviewers was additional information on the comparison of the COE between supercritical PC and IGCC. WRI would reference a specific cost and performance comparison performed by EPRI for subbituminous coals. Similar results can be reasonably expected for lignite.

EPRI (2007) in a study of the performance and costs for supercritical PC and Shell IGCC technologies with and without carbon capture for subbituminous PRB coal concluded that IGCC was much more cost-effective than similar technologies for removing CO_2 than technologies for removing CO_2 from supercritical PC flue gas. The major performance and economic impacts for 90% CO_2 capture are as follows.

Summary of the Performance and Costs of IGCC and Supercritical PC Using PRB Coal with CO_2 Capture.

	IGCC	Supercritical PC
Net plant output (pre CO_2 capture), MW	425	462
Heat rate increase, %	17	40
Total capital cost increase, %	47	73
Increase in Cost of Electricity, %	38	66
CO_2 capture cost, $/ton	24	35

Source: EPRI, 2007

The above clearly illustrates the cost and performance advantage of IGCC compared to supercritical PC with 90% CO_2 capture. One could expect a similar relationship for lignite coals as well.

In addition and as mentioned in the proposal, it is known that coal rank has a large impact on the IGGC efficiency and ultimate costs of IGCC systems. Booras (2008) pointed out the influence of coal rank on plant efficiency and plant costs (Fig. 3.2.4, page 13) that illustrated a 12% increase in the heat rate and capital costs between bituminous coal and subbituminous coal and 9-12% increase in heat rate and capital cost between raw lignite and subbituminous coals. As such, the WRITECoal™ process can have a significant impact on the ND lignite industry by reducing heat rate and capital costs and therefore making lignite perform even better than the coals referenced in the DOE study.

Costs of WRITECoal™ Process Additions.

WRI and URS with input from Foster Wheeler (2009) completed an assessment of the capital costs and COE impact of the WRITECoal™ process on retrofitting both subbituminous and lignite coal-fired pc power plants. Key features of the integration included mercury and NO_x reduction, potential beneficial uses of activated carbon-free ash and increased power production. The capital and operating costs for a 600We subcritical lignite coal-fired plant were estimated via EPRI's PCCost model. The Present Worth Revenue Requirements (PWRR) advantage for a WRITECoal™ retrofitted lignite plant was 26.3% and 11.7% compared with the same plant with ACI and TOXECON, respectively. Retrofitting with the WRITECoal™ process reduces COE 1.1 cents/kWh from 6.7 cents to 5.6 cents/kWh.

Although there are clearly differences with integration of the WRITECoal™ process in gasification, similar results on capital and COE are expected. Preliminary estimates by WRI for the WRITECoal™ gasification technology, following NETL protocol, projects COE costs at up to 30% increase in COE compared to new lignite subcritical COE without carbon capture and a reduction in estimated COE of 24% compared to COE for a subcritical lignite plant with MEA carbon capture. A second major patent pending technology modification not discussed in the proposal, allows for reduced parasitic power, which contributes to the economic benefit (lower COE) described above. WRI, Etaa Energy, GTI and URS are in the process of completing an analysis of the WRITECoal™ process for a carbon capture IGCC configuration under the Phase I effort for PRB coals and a similar evaluation will be undertaken as part of the proposed Phase II effort for the North Dakota lignite with UGAS and TR gasifiers.

Performance of ND Lignite in Transport Reactor Specifications.

We agree that the early tests (2003/04) of ND lignite in the TR gasifier at the PSDF had issues with caking/bed and fines agglomeration resulting in the use of dolomite and in a lower carbon conversion. However, later tests (2006/07) resolved to a degree these issues, by using a meta-kaolin additive. Other techniques have also been deployed for alkali gettering. The general rule has been to limit coals with Na_2O ash contents of <5.0% in this reactor. Although some of the North Dakota lignite has alkali contents above this amount (e.g., Freedom Mine), these coals have been processed successfully in the past. For example, GTI has used their U-GAS® reactor with these high sodium Freedom Mine coals (tested up to 5.9% Na_2O coal) without either caking or agglomeration problems. A large proportion of potentially commercially developable ND lignite reserves fall within the 5-6% Na_2O ash content above. Another, but parallel, resolution pathway is to limit alkali build up in the bed via operational modifications in bed inventory maintenance as has been successfully carried out by members of this research team. In addition, the WRITECoal™ product has been shown in Phase I with PRB coals to be twice as reactive based in the residence time for near 100% char carbon conversion (pg 56), thereby helping to mitigate possible low carbon conversion operational regimes.

WRITECoal™ Process Operation and Water Usage.

WRI agrees with the general comments as to how the proposed proprietary process operates as described by the one reviewer. The process described in the application is only a part of the proprietary process that allows for

significantly enhanced power output. WRI is willing to share with parties upon signing an appropriate NDA the remaining process modification that allows for this increased power output.

In addition, WRI would like to point out that the utilization of water as described covers only a few of the possible options. There are other places that recovered water can be used in the WRITECoal™ gasification process. Other proprietary process configurations use the recovered water with minimal treatment within the overall process that also represents equally valuable uses.

Other Comments.

With respect to other comments, WRI points out that they will test both North Dakota lignite and subbituminous PRB coals in both the TR gasifier at EERC as well as the GTI UGAS gasifier (page 4).

- WRI also welcomes the participation of Michael Jones and any other representatives from LRC and the North Dakota lignite industry as appropriate to any and all of the meetings on the project.
- For clarification, the WRITECoal™ process removes <2.5% volatiles, mostly from the decarboxylation of the coal and the release of CO_2.
- The 'FB gasifier' technology referenced in Figure 4.1.1 (pg 58) is the U-GAS® gasifier without carbon capture (Nexant, 2005) and with carbon capture (from the Phase I effort) which showed a 3.3% increase in efficiency to 35.4% with carbon capture.

Summary and Benefits to the Coal Industry of North Dakota.

In conclusion, WRI would like to reiterate that the proposed WRITECoal process has a track record that shows a high likelihood of successful deployment, both technically and economically, with a range of gasifier types.

- Although simple drying processes have had a mixed track record for North Dakota lignite coals, the unique integration of the WRITECoal™ process with IGCC and the associated changes in operation and performance can make the WRITECoal™ IGCC the highest performance (emissions, efficiency, water recovery and parasitic power demand) and lowest COE option with carbon capture for the lignite industry in the deployable timeframe;
- The projected COE for the WRITECoal™ technology can make it a significant game-changing technology option for the ND lignite industry if and when CO_2 emissions are regulated; and
- Although it is expected that the lignite industry will deploy a number of retrofit options for carbon capture for the their existing fleet, it is also expected that, depending on future growth demand for power, the lignite industry will consider their coal reserves for new greenfield lignite-fired plants and that deployment will require low COE, such as can be provided in large part by the proposed WRITECoal IGCC process.

As such, we strongly believe that the successful demonstration of the WRITECoal™ gasification/IGCC technology can have a 'significant' impact on the ND lignite industry's future.