May 13, 2013

Responses to Reviewer Concerns on ALLETE feasibility study of NET Power system when fueled with North Dakota lignite

Question #2: Reviewer 13-7 concerns:

Medium potential to achieve the stated goals based on what was presented. No real solid presentation on the technical approach. What software platform will be used (ASPEN, ThermoFlow and etc.)? What unit operators will be modeled (some of these are mentioned in the proposal but they functionally are not described)? How detailed are the fundamentals for each unit operator? Without functions for unit operators that are well defined in terms of the fundamentals of temperature, pressure, mass and volume flow rates, combustion chemistry, and heat transfer there will be little chance of achieving the objectives.

Modeling for NET Power lignite feasibility study:
AspenPlus will be used to model the lignite gasification plant delivering cool syngas to the NET Power cycle which will be modeled by EPRI using IPSEPro.

The AspenPlus model will include all significant unit operations included in a coal gasification plant including lignite preparation/feeding, gasification, syngas cooling, syngas filtration, syngas cooling (and condensation), ammonia removal, acid gas removal, sulfur recovery, sour water, and any syngas humidification required before entering the Brayton cycle.

AspenPlus is an industry accepted rigorous heat and material balance simulator that is used for a wide variety of processes and has been used to model many IGCC facilities. It is capable of modeling solids and the conversion of coal to syngas. It will certainly produce a heat and material balance with all flows, temperatures, pressures, mass/molar/volume flows, etc. All physical properties required for gas/liquid phase heat transfer are modeled. In this level of study, ash chemistry and potential for fouling will not be modeled. The simulation will be very "granular" in the unit operations used. There will not be a "black box" for the gasification process. Every major unit operation will be modeled, and therefore, sensitivity studies can be performed.

Original Modeling Design for the NET Power system and Translation to Lignite Study:
The NET Power cycle for combustion of natural gas is well developed. As part of the demonstration program, the detailed process design for the demonstration and future commercial natural gas plants has been completed in ASPEN Plus, validated by NET Power's commercial partners and reflects the latest knowledge of component performance for all components of the system based on vendor-supplied data. These models have been completed in a sufficient level of sophistication to support a detailed Front-End Engineering Design (FEED) study for the demonstration and a pre-FEED study for the commercial facility that are currently underway for the natural gas system.

When transitioning from the natural gas based system to the coal fired system, additional consideration must be given to supply of a coal syngas to the cycle, rather than natural gas. In addition, processes for syngas cooling and cleanup must also be considered, as well as available heat generated from these processes that may be recoverable by the cycle. The goal of the UK Path to Coal study (that will generally precede but somewhat overlap the lignite study) is to *modify and optimize the current natural gas model for integration with a bituminous coal gasifier and associated equipment. A complete understanding of available gasification and associated equipment options will be developed, along with the unit operations of each technology for optimization in the NET Power coal model. Where possible, data will be obtained from OEM suppliers or from publically available sources. The major equipment additions will be specified and commercial quotes will be obtained where appropriate. Although the UK Path to Coal study will be focused on bituminous coal, much of the understanding of required modifications made to the natural gas cycle and how efficiency is optimized with gasifier integration are directly translatable to lignite. Additional considerations will be made for lignite, reflecting appropriate gasifier type (including handling and feed systems, waste handling and treatment, safety considerations, etc.) and changes the different syngas composition and impurities levels will have on downstream equipment. Data and unit operations for the process model for these equipment additions will be largely obtained from EPRI's existing database of gasification equipment. All of these will be incorporated within the base ASPEN model to understand performance tradeoffs in the system.*

Question #3: Reviewer 13-7:

The methodology is weak. System studies like these are very much dependent on what is in the "black box". If there are no first principle functions in the box then there is no chance of conducting a sensitivity study as a function of common parameters.

See above response to Question #2.

Cost studies can often be problematic when absolute values are discussed. One way to deal with this is to try and compare cost for different cases and hope that the errors in absolute numbers can be subtracted off and just difference examined. For instance what is the impact on cost for varying gasifier pressure or turbine firing temperature? The best result might be to conclude and order of magnitude understanding of how changing certain parameters effect cost (a sensitivity analysis).

Unit operations in the process model block will be derived from available data of commercially demonstrated systems. Process conditions (temperatures and pressures) of the major blocks (gasifier, and NET Power Cycle including turbine inlet temperature) are already known, and no substantive changes will be made in design of the optimum NET Power Lignite Cycle. This is because: 1) temperature and pressures of the NET Power cycle have already been optimized for maximum efficiency and adjustments will be made to BoP equipment to maintain these conditions when firing on a syngas fuel, and, 2) altering conditions of existing gasifiers will increase the cost and commercialization timeline, which is not the goal of the current study. Exploration of system performance sensitivities will primarily be focused on those process steps upstream and downstream of the gasifier, especially their effect on both system efficiency and overall cost.

Producing useful costs estimates is a challenge. A recent collaboration between EPRI, NETL and others has resulted in a more or less standard way to estimate and report costs. EPRI's report on this cost methodology is available to the public. We expect to conform to this methodology for reporting costs in the current project.

EPRI commonly does two types of cost analyses:

- *The most detailed is consistent with ACEE class 3 (EPRI Tag class 2) guidelines. The uncertainty in the resulting cost is in the range -15% to 30%. We acknowledge the difficulties associated with comparing cost estimates from different groups and our* *recent practice has been to have the folks preparing the cost estimate we seek also do a cost estimate for a standard specification ultra-supercritical PC power plant for which we have an extensive cost history. We typically spend between $300k and $700k on this level of cost estimate. The resources available for the current project are not sufficient to produce this level of cost estimate.*

- *The less detailed is consistent with ACEE class 4 (EPRI Tag class 1) guidelines. The uncertainty in the resulting cost is in the range ±30%. This is the quality of cost estimate that will be prepared for the current work. For many process parameters that might be varied, the sensitivity of costs is likely to be much lower than the overall uncertainty. For this reason, at this level of effort, only stochastic and/or ratio-type methods will be used to quantify the effect on costs of most variations in process conditions. Some reliance will be placed on the costing tools internal to AspenPlus.*

The cost portion of the study will be conducted as variations in gasification combined cycle plant costs previously reported by EPRI, and which are ACEE class 3 cost estimates. The current cost study will replace the syngas-fired combustion turbine combined cycle power plant with NET Power's technology.

Question #3: Reviewer 13-9:

The methodology in general is appropriate. However the use of information derived from bituminous coal regarding feasibility of a lignite-fired technology is likely to have limited value. The properties of lignite are significantly different than bituminous coals and work needs to be conducted that are specific to lignite.

When transitioning from the natural gas based system to the coal fired system, additional consideration must be given to supply of a coal syngas to the cycle, rather than natural gas. In addition, processes for syngas cooling and cleanup must also be considered. The goal of the UK Path to Coal study (that will precede the lignite study) is to modify and optimize the current natural gas model for integration with a coal gasifier and associated equipment. A complete understanding of available gasification and associated equipment options will be developed, along with the unit operations of each technology for optimization in the NET Power Coal model. Furthermore, the study will consider and model the performance of syngas within the base cycle including combustor, turbine, heat exchanger, water separation and corrosion questions which will be directly applicable.

Although the UK Path to Coal study will focus on bituminous coal, much of the understanding of required modifications made to the natural gas cycle and efficiency optimization with gasifier integration are directly translatable to lignite. The gasification block will supply the NET Power cycle with a coal syngas, and the understanding of how the cycle must be adjusted to accommodate this with bituminous coal will significantly contribute to further adjustments required for lignite. Additional considerations necessary for lignite will include selection of an appropriate gasifier type to handle higher ash and moisture content (including handling and feed systems, waste handling and treatment, etc.) and for changes the different syngas composition and impurities levels will have on downstream equipment. In the UK Path to Coal study, part of the gasifier screening process is an understanding of which gasifiers are appropriate for lignite in preparation for this study.

We agree that lignite gasification is significantly different than is gasification of bituminous or even subbituminous coal. EPRI has conducted a study that looks specifically at lignite gasification and the challenges associated with this high moisture content, low ash softening temperature *fuel which will serve as the basis to scope the work proposed for the current project. In addition, Howard Hendrix, EPRI Senior Project Manager who will conduct the gasification modeling effort proposed for this project was a senior design engineer for design of Southern's Plant Radcliffe which employs the TRIG gasification process for Mississippi lignite. The main challenges anticipated for lignite gasification include:*

- *Reduction of fuel moisture content prior to gasification*
- *Dry solids feed to the gasifier (No commercial offering for lignite based on slurry feeding)*
- *For Ft Union basin lignite, limiting gasification temperatures to avoid fouling associated with the high alkaline ash/low ash fusion temperatures.*

Question #4: Reviewer 13-9:

The potential for a significant contribution is great. The proposal did not provide a clear description of how the influence of lignite's unique properties will be considered regarding the unique design and operation.

See responses to Questions #2 and #3 above.

Question #5: Reviewer 13-9:

Research on the use of lignite in gasification systems has been conducted for decades and is in the open literature. The effects of lignite properties on the performance of gasification, gas cooling, and gas cleanup systems has been a key component of the research activities supported by the NDIC over the past several years. In addition, there are numerous publications and reports in the open literature. The value of the EPRI lignite study is unknown since it is not in the public domain.

See response to Question #3 above. The open literature will also be consulted during the proposed project. I have attached here the table of Contents for the Gasification of Lignite Coal report.

Overall Comments – All 3 Reviewers:

Reviewer 13-7: Funding is recommended.

Overall this would be a technically valuable piece of work with a budget that can be fully justified. However my experience with system models for this technology is that they need to be rigorous with significant technical detail.

Some general concerns include:

Heat exchangers and recuperators: What are the approach temperatures, what are the pinch point temperatures. Are there any cross over temperatures? What are the designs?

Designs for heat exchangers and recuperators will not deviate substantially from the well understood designs employed for the NET Power natural gas program, although additional considerations may be made regarding corrosion resistant alloys depending on the ultimate levels of impurities expected based on process design proposed. Additional considerations may be necessary for fouling and residual particulate matter. Approach temperatures for the heat exchanger train will be between 700 and 800°C on the hot end of the high temperature unit, and 50 and 70°C on the cold end of the low temperature unit. A pinch temperature for the cycle *occurs at roughly 110°C with approximately a 5°C pinch assumed for the HXs. No heat is transferred across the pinch.*

There are several companies capable of delivering the required HX systems, and the NET Power conditions are at the limit of what has been commercially demonstrated in power generation. Operational temperature and pressure have independently been verified in the oil/gas, process and maritime industries. Components will be fabricated from a suitable grade of stainless steel for the portion up to operating temperatures of 550°C to 600°C and from more specialized alloys, for the portion up to hot end temperatures. Engineering studies and tests show the suitability of those heat exchangers under consideration by NP for high pressure and temperatures in both stainless steel and high nickel alloys.

NET Power has worked closely with manufacturers to optimize HX unit count, layout and cut down on unit size to lower the usage and cost of specialized alloys and optimize temperature profiles and piping. This places the operational specifications required by these components further within the limits of available technology.

IGCC integration with the supercritical CO2 Power cycle: Benefits have been claimed with this integration but a full technical disclosure / explanation has not been completely forthcoming.

Reviewers are referred to page 21 of the NDIC grant application which contains the Energy Procedia paper presented at the GHGT-11 conference that describes the NET Power Coal cycle in detail. Further detail on specific and optimized designs and process conditions are currently being developed for bituminous coal in the UK Path to Coal Study, and for lignite as part of the proposed study in this grant application.

Gas stream cleanup will be a concern for this application along with the buildup of contaminants. How will the oxy-fuel (oxygen and Syngas) combustion be modeled, this is very high pressure, combustion could be an issue

Reviewers are referred to page 21 of the NDIC grant application which contains the Energy Procedia paper presented at the GHGT-11 conference that describes the NET Power Coal cycle, and handling of contaminants, in detail.

Detailed combustion kinetics for natural gas combustion are well understood by NET Power and its partners. Toshiba retains primary responsibility for development of the NET Power combustor and turbine. To date, a subscale (10MWt) combustor has been successfully tested, achieving ignition and stable combustion under the CO2-rich NP Cycle conditions. Several runs within the operational envelope of the combustor have been conducted.

Analysis of design changes required to the NET Power combustor for firing on a syngas fuel are outside the scope of this study. However, this study will inform what conditions the NET Power syngas combustor must be designed to in order to achieve optimum performance.

The general turbo machinery configuration needs to be established along with the overall efficiency of the turbo machinery.

Because the same core cycle is employed between the NET Power natural gas and coal systems, no changes are expected to occur in general turbo machinery configuration. Additional considerations for required changes to metallurgy, blade coatings, etc. will be informed by the results of the proposed lignite study based on the optimized process conditions developed. As part of the natural gas system Toshiba will be performing an oxidation test to consider constituents likely in natural gas and applicable for coal systems.

Estimates of current natural gas and coal system efficiencies are based on the latest data available from Toshiba for their turbine, and taken from vendor-supplied data for the remainder the of turbo machinery.

How will trace amounts of O2 in the working fluid be dealt with or is it not a concern?

Reviewers are referred to page 21 of the NDIC grant application which contains the Energy Procedia paper presented at the GHGT-11 conference that describes the NET Power Coal cycle, and handling of contaminants, in detail. In this description the value of the excess O2 to the processing of sulfur, NOX and heavy metal contaminants is explained in detail.

Trace oxygen is only a concern for meeting pipeline specifications for CO2 provided for Enhanced Oil Recovery. Several industrial methods exist for removal of O2 to meet these specs.

Reviewer 13-8:

The weaknesses of this proposal include:

1. the limited published and available technical and economic detail provided in the proposal (The limited basic technical information is a significant weakness in this proposal)

   See responses to Questions #2, #3, and #5 above, as well as the responses to Reviewer 13-7's overall comments.

2. an explanation why the use of lignite could be technically desirable or economically advantageous,

   The use of lignite is both technically desirable and economically advantageous. The higher oxygen content of lignitic coals reduces the load on the air separation plant, which contributes significantly to overall system efficiency.

   Lignitic coals represent over half of estimated global reserves and are available at lower costs than more traditional coal types. Achieving commercialization of the NET Power system integrated with combustion of lignite with 100% carbon capture would enable NET Power to deliver truly clean and lower cost energy from this underutilized resource to the broadest markets possible.

3. uncertainty with regard to the marketability of sequestrated CO_2 in ND, and

   In addition to sequestration, CO2 can be utilized for both Enhanced Oil Recovery and as a substitute for water in hydraulic fracturing of shale gas deposits[1]. Existing projects in ND already supply significant quantities of captured CO2 for conventional EOR operations in Saskatchewan (Dakota Gasification Facility). Significant research is also being conducted on the viability of CO2 injection to promote enhanced recovery from oil shale deposits in the Bakken formation, which would require large amounts of CO2 to support.

   However, in the event the owner were to vent the CO2, the amount of other emissions and CO2 would be substantially less than any other available technology. Furthermore, the venting would add another 1-1.5% to the efficiency of the plant, achieving economics that are far and above any other generation plant on the market today or on the horizon.

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[1] Tsuyoshi Ishida et al. Acoustic emission monitoring of hydraulic fracturing laboratory experiment with supercritical and liquid CO_2. *Geophys. Res. Lett.* 39 (16): L16309

4. any reference to the potential of a future demonstration project.

A demonstration project for the NET Power natural gas system is currently underway. A key outcome of the proposed lignite study will be to assess the feasibility of the NET Power Lignite system and identify those key developments required to progress to demonstration. Due to the similarities between the coal and natural gas cycles, this demonstration could be conducted on the current facility under development, with only minor equipment required to convert to syngas firing. In addition, given the choice to pursue only commercial gasifiers in this study, a full demonstration plant may not be needed with only subsystems being initially tested.

<u>Reviewer 13-9:</u>

The major flaw of the proposal was the lack of discussion and reference to literature that would demonstrate an understanding of the influence of lignite properties on the design/operability of a gasifier, gas cooling, and gas cleanup system.

See responses to Questions #3 and #5 above.

It is a primary focus of this proposal to determine which of the commercially available gasification systems are suitable for both gasification of lignite, and optimal integration with the NET Power cycle. Relative to the study of bituminous fuel sources, additional considerations will have to be made for the higher ash content, higher water content, higher oxygen content, lower density and higher levels of alkali metals and chlorine. These characteristics may alter technology selections made for bituminous coals, particularly when considering the difficulties in lignite storage and gasifier slurry.

For expertise on lignite and lignite gasification, the research team is engaging EPRI, LRC, and DGC, each of which have significant experience in the gasification of lignite.