® minnesota power
AN ALLETE COMPANY

Allan S. Rudeck, Jr., Vice President – Strategy & Planning

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April 1, 2013

Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol
600 East Boulevard Ave., Dept. 405
Bismarck, ND 58505-0840

Re: North Dakota Industrial Commission Lignite Research Grant Request

Dear Ms. Fine,

I am an authorized officer of ALLETE and am submitting this grant application to you on behalf of ALLETE and our funding partners. We respectfully request that the Industrial Commission approve a matching grant for a project to advance the future use of North Dakota lignite through development of an innovative electric generation technology. Enclosed please find ALLETE's grant application submitted pursuant to North Dakota Administrative Code, Article 43-03.

ALLETE has been working with the technology provider, NET Power, to determine how best to further the development of NET Power's power system design and to specifically target the efficient use of lignite as the generating fuel. This $1,000,000 feasibility study is proposed to include a $150,000 matching grant request made with this application to leverage a five-fold private investment of about $850,000 of cash and in-kind services to complete this assessment of the NET Power system designed to utilize North Dakota lignite.

The future benefits of further research of this power system would be the ability to utilize North Dakota lignite for power generation with a step change in high efficiency, little-to-no emissions, and the ability to capture the carbon dioxide from the system. This opens up possibilities for not only the clean coal electric generation path for North Dakota lignite, but also for the continued viability of lignite as an electric generation fuel. ALLETE and its funding partners are confident that these benefits support the level of grant funds being requested.

As a part of this grant request and as described in our application, ALLETE and our funding partners commit to provide the matching $150,000 cost share and to manage the completion of the research project subject to Industrial Commission approval of the grant. On behalf of ALLETE and our funding partners, I hope that you will agree that this research is valuable for the future of the North Dakota lignite industry and approve the requested grant funds. If you have any questions regarding our project or this application do not hesitate to give me a call.

Sincerely,

Allan S. Rudeck, Jr.
Vice President – Strategy & Planning

Enc.

North Dakota Industrial Commission Grant Application

Project Title: Feasibility Assessment of the NET Power Electric-Generation Technology when fueled with North Dakota lignite

Purpose: A feasibility study assessing a clean-coal generation technology design for North Dakota lignite which could result in future lignite electric generation and which supports the future use of North Dakota lignite.

Proposal Submitted By:	ALLETE, Inc.
Project Manager:	Bill Sawyer, Minnesota Power Strategy and Planning
Principal Investigator:	NET Power, LLC., with subcontracts to Electric Power Research Institute (EPRI), Progressive Energy (Progressive), and CB&I (formerly The Shaw Group)
Project Co-funders:	Dakota Gasification Company (a subsidiary of Basin Electric Power Cooperative) (direct funding), & NET Power, LLC., Progressive Energy, and CB&I (in-kind services)
Submittal Date:	April 1, 2013
Total Project Cost:	$1,000,000 ($300,000 direct; $700,000 in-kind services)
Grant Funds Requested:	$150,000

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Abstract

The objective of this project ("Project") is the completion of a feasibility study assessing a clean-coal generation technology design for North Dakota lignite which could result in future lignite electric generation and which supports the future use of North Dakota lignite. The technology provider is a company named NET Power, LLC., and the technology involves an innovative, high-pressure, oxy-fuel, supercritical carbon dioxide electric generation cycle. The Project will focus on the system design for this technology that would be suitable for use of North Dakota lignite as the fuel, the anticipated performance characteristics of this system design, and the challenges to advancing further, more detailed development.

The expected results of the Project will be an optimized design of the technology system as fueled with North Dakota lignite including integration of key system components, identification of performance metrics and key development hurdles for the optimized design, identification of key processing requirements for North Dakota lignite, and the challenges with system design and performance utilizing North Dakota lignite.

The Project is expected to commence in June 2013 and be completed by October 2013. The total cost of the Project is set at $1,000,000, with $150,000 coming from the two industry funding partners of ALLETE and Dakota Gasification Company (DGC), $700,000 of in-kind services being provided by the technology developer NET Power and their team, and the remaining $150,000 being sought as grant funds from the North Dakota Industrial Commission.

The Project will be managed by ALLETE, and the work will be completed by NET Power with subcontracts to industry experts in the Electric Power Research Institute ("EPRI"), Progressive Energy (Progressive), and CB&I Power.

Project Summary

The technology developer for this innovative clean-coal technology has conceptually developed its power cycle design for application using either natural gas or coal for its primary fuel. The natural gas design is more straight forward, and has been developed more fully by the technology developer and other industry partners. The coal design is more complex and requires additional equipment within the power system, including a coal gasifier. This design needs further development to assess the challenges of integration of the system components and identify performance characteristics and key risks of the design. This Project will focus on the development of the power system when fueled with North Dakota lignite, and identify the system design, integration requirements, performance characteristics, and key challenges to further development.

The Project matches Lignite Research Council goals through the promotion of efficient and clean uses of lignite in order to maintain and enhance development of North Dakota lignite. Additionally, the ultimate development and application of generation technology for this power system would preserve jobs and potentially create new jobs involved in the production and utilization of North Dakota lignite as well as ensure economic stability and future growth in the lignite industry through continued utilization of North Dakota lignite.

Project Description

This Project will involve further assessment and design of the NET Power system generation technology fueled by North Dakota lignite. The NET Power system, as shown in confidential Appendix A along with a detailed white paper on the technology design, development path to date, and development path forward, has been conceptually designed to be fueled on coal. However, the current design has not had detailed development identifying the most effective system components to use, the integration of those components into a full-cycle design, the performance of that system design, and the challenges associated with fueling that design with North Dakota lignite.

This Project will accomplish each of these tasks, focusing on the development of the power system when fueled with North Dakota lignite, the identification of the system design, integration requirements, and performance characteristics when fueled with North Dakota lignite, and the key challenges to further development of this technology design.

The technology developer NET Power has partnered with three key industry experts in Toshiba, CB&I, and Exelon, to formulate a technology development team that will have the capabilities to design specific new materials and equipment needed to allow the technology design to be successful while also bringing engineering, site layout, and utility integration skills to the partnership. This team has initiated substantial actions to further the NET Power cycle development and push forward with a path to both natural gas and coal, and a natural gas pilot-scale implementation, which is described further in the white paper provided in Appendix A.

This project will utilize expertise from several of the technology development partners in NET Power's development team, in NET Power and CB&I, along with services from utility research expert EPRI and energy engineering and design firm Progressive Energy, which is working with NET Power on a study in the UK to identify design considerations for the NET Power cycle on bituminous coal. The project that is the subject of this grant application will focus on a design of the NET Power cycle fueled on lignite coal, providing a path forward for future lignite utilization, expansion, and power plant development.

Project Methodology:

The methodology to be utilized in this feasibility assessment is as follows:

- Identify the system components required to develop an operational power system design fueled using North Dakota lignite.
- Determine which current market components (gasifier, fuel handling, syngas cleanup) best fit the proprietary NET Power system components (combustor, turbine) and power cycle design.
- Run performance and economic modeling to determine expected performance characteristics and system design costs.
- Identify the key challenges associated with integrating and operating this power cycle using North Dakota lignite as the fuel (fuel handling, syngas properties, corrosion) where further development could be required.

Anticipated Results:

This Project will provide results in the form of a study report including information regarding the most feasible system design, the system performance characteristics from this design, the economic analysis of this technology performance, and a roadmap to achieve key developments of this technology fueled on North Dakota lignite.

Resources, Facilities, and Techniques:

The analysis will be performed by a team of industry experts with the primary services being provided by EPRI, utilizing their existing research facilities, modeling software, and electric generation analysis and coal gasification expertise, and additional services being provided both in-kind and on a fixed fee basis by the technology developer NET Power and their development partners CB&I and Progressive Energy.

NET Power and CB&I are partners on the development team for the technology, along with Toshiba and Exelon. Progressive Energy, a United Kingdom energy consulting and engineering firm, is currently providing detailed design services to NET Power on a study funded in part by the UK government. This study is assessing a design of the NET Power cycle on bituminous coal, which will provide a good platform for the lignite feasibility assessment to build on. The lignite assessment, which is the subject of this grant application, will utilize both data from the UK study, as well as the services of Progressive to assist EPRI with their analysis and utilization of the process design, heat balance, and economic modeling that will be completed for the UK study. The UK study is expected to commence in April 2013, and be finished by July 2013.

Technological and Economic Impacts:

The Project will result in furthering the technology development of a promising clean-coal generation technology. Development of a generation technology which could operate at substantially higher system efficiencies than present coal-based generation (see Appendix A for further information) not only allows for a more economical system, it also results in production of less ultimate emissions. Couple that with the fact that the technology offers no atmospheric air emissions and low water usage, and the technological and economic impacts of furthering this technology development for North Dakota lignite are substantial.

Environmental Impacts while the Project is Underway:

The Project will be a feasibility study to be completed by research and industry expert partners in their offices and research facilities. The Project will have no environmental impacts while it is underway.

Why is this Project Needed?

The Project is needed to provide additional pathways for the future use of North Dakota lignite and to provide alternative options for clean-coal electric generation using North Dakota lignite.

The Project also furthers the objectives of the North Dakota Industrial Commission (“NDIC”) and the goals of the Lignite Research Council (“LRC”) by:

1) Promoting economic, efficient, and clean uses of lignite and maintaining and enhancing development of North Dakota lignite utilization.

2) Preserving and potentially creating jobs in the production and utilization of North Dakota lignite.
3) Ensuring economic stability and growth through further future utilization of North Dakota lignite for electric generation.
4) Attracting private industry matching funds of at least 50% of the total project cost.

Standards of Success

The Project will be measured by the successful completion of the feasibility assessment and the final outcome of the study objectives to answer the questions of:

1) Identification of the system components required to develop an operational power system design fueled using North Dakota lignite.
2) Determination of which current market components (gasifier, fuel handling, syngas cleanup) best fit the proprietary NET Power system components (combustor, turbine) and power cycle design.
3) Completion of performance and economic modeling to determine expected performance characteristics and system design costs.
4) Identification of the key challenges associated with integrating and operating this power cycle using North Dakota lignite as the fuel (fuel handling, syngas properties, corrosion) where further development could be required.

Analysis and study results are expected to be completed within budget and within the schedule allocated to this Project to be considered successful.

Background

This Project will couple with an existing research effort being completed by the technology developer, NET Power, which will identify key system design parameters for their power cycle fueled on bituminous coal, but will not be specific to nor consider lignite coal. This study will be conducted utilizing other research partners in the United Kingdom, and will be funded in part by a grant from the UK government. This study will be initiated in April 2013 and completed in the July 2013 timeframe, and will provide the basis of information needed to move forward with the Project that is the subject of this grant application.

The UK study will identify any key flaws in the overall power cycle design when fueled by coal, which will then be incorporated into the more specific cycle design for our lignite application. The availability of this platform of design information for the NET Power cycle and the participation of NET Power and their development partners (Shaw and Progressive) will not only benefit, but will enhance the work to be completed under our lignite specific Project.

Qualifications

The applicant and project manager for this Project, ALLETE, Inc., is the parent company of Minnesota Power and of BNI Coal. ALLETE has had a presence in the North Dakota energy industry since it acquired BNI Coal in 1988, and has been a partner in electric generation utilizing North Dakota lignite since the Milton R. Young Station Unit 2 was constructed in 1977. ALLETE continues to be involved in clean-coal research and development, being a partner in the EPRI CoalFleet for Tomorrow consortium and a partner in the Energy and Environmental Research Center clean-coal research programs.

ALLETE has strong ties to the Lignite Energy Council and Lignite Research Council and seeks to continue to assess ways to further the beneficial use of North Dakota lignite for both electric generation and other potential alternatives. Past ALLETE research efforts have looked at using North Dakota lignite for emissions control applications, and in development of previous lignite-fueled clean-coal electric generation projects.

The principal investigator for this Project, EPRI, has a substantial amount of expertise in the utility and generation technology assessment universe and is looked at as one of the experts in completing generation technology feasibility and economic assessments. Members of the EPRI CoalFleet consortium have seen information over the past year on the NET Power technology and understand that EPRI considers it one of its top technologies to monitor over the next five years. EPRI will work under subcontract to the technology developer NET Power, along with two additional development partners of NET Power in CB&I (formerly The Shaw Group), and Progressive Energy. These partners are currently working with NET Power to further develop their technology cycle on both natural gas and coal. The coal assessment is focusing on bituminous coal in the UK and will provide a valuable platform for the lignite assessment to be completed in this Project.

NET Power is the developer of the technology, and holds the intellectual property on the technology and system design. NET Power will provide services to EPRI’s assessment in design and integration of system components and modeling and analysis of component and system performance. CB&I has expertise in energy system design, engineering, and site layout, and will be providing those services in assistance to EPRI for the work they will be completing. Progressive Energy is completing services related to assessment of the NET Power cycle on bituminous coal and will provide the expertise in stepping from their coal study into the lignite-specific study that is the subject of this Project. Progressive will assist with providing the research platform of system and component design to EPRI and building on the lessons learned from the UK coal study to ensure the lignite study will achieve success.

The services provided by EPRI and the other development partners are identified in Appendix B.

The other industry funding partner for this Project, Dakota Gasification Company (a subsidiary of Basin Electric Power Cooperative), also has substantial ties to the North Dakota lignite industry and to both electric generation utilizing lignite as well as gasification of lignite. This partner brings valuable experience which will help the Project through increasing understanding of what types of equipment and systems will work for a cycle design using North Dakota lignite, and what types will not work. This experience also extends to understanding of the challenges of operating a system such as this NET Power cycle, and what future considerations need to be addressed to further this technology design.

Value to North Dakota

This Project will provide value to North Dakota because it furthers the development of clean-coal generation technology that would utilize North Dakota lignite. The Project will result in identification of a technology design specific to the utilization of North Dakota lignite and the challenges that would be associated with furthering this design and development toward a future power plant installation.

The Project will further the potential for utilizing North Dakota lignite for future electric generation, resulting in the preservation of lignite mining jobs and the creation of new generation jobs. The Project promotes the efficient and economic utilization of clean lignite electric generation while offering economic stability and a growth opportunity for the lignite mining industry.

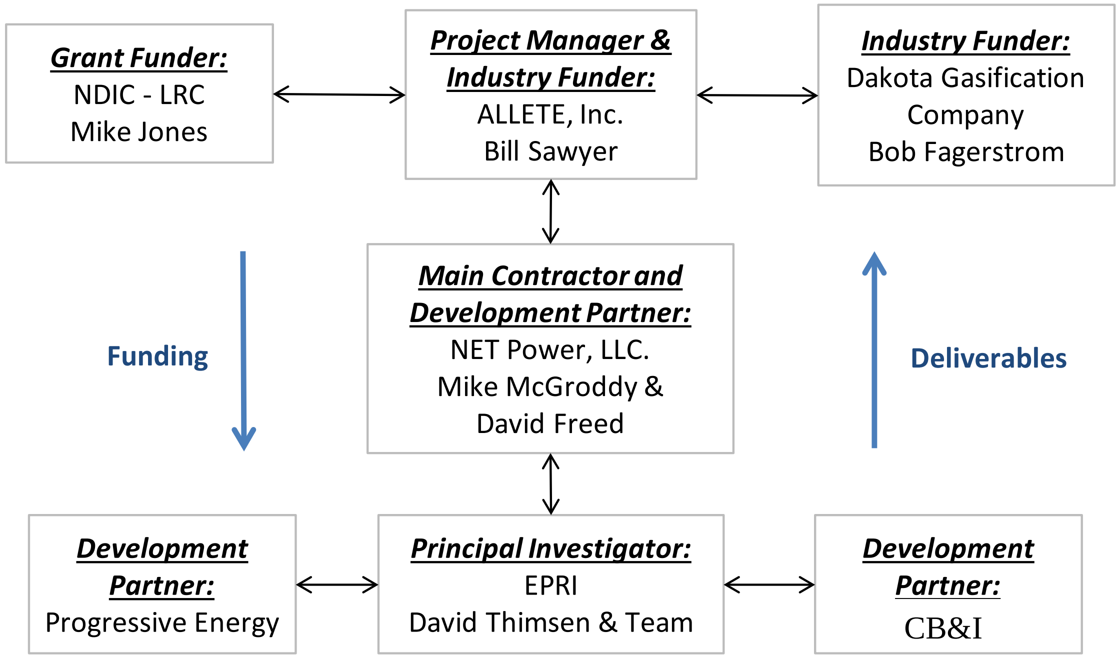
The public sector benefits from this Project are the continued economic viability of the lignite mining industry and the jobs it supports, as well as the future viability of a clean-coal, emission-free electric generation alternative to reduce carbon-dioxide emissions. An additional public benefit which could result from the successful development of this technology would be the establishment of more reasonable electric rates through a more efficient generation process, as compared to other alternatives for clean, baseload electric generation.

The likely use of the results of the Project would be from private industry and the application of the technology to electric generation for utility customers. Additional public application of the technology in the future could be for public locations such as universities and schools which generate their own electricity or heating requirements which could install this type of generation technology.

Management

The Project will be managed by both ALLETE, and the technology developer NET Power. The contracts to complete the feasibility assessment will be held between NET Power and the investigators EPRI, Progressive, and CB&I, for purposes of keeping the technology design and current intellectual property of NET Power confidential. ALLETE, on behalf of the NDIC, LRC, and the other industry funding partner will oversee the implementation of the Project to ensure that the scope is completed, the schedule is upheld, and the budget is adhered to. For purposes of the grant agreement between ALLETE and the State of North Dakota acting by and through its Industrial Commission, ALLETE will be the grantee and requests the ability to utilize the appropriate subcontractors (NET Power and their subcontractors in EPRI, Progressive, and CB&I) for completion of the required services.

A project management chart is provided as follows:



Periodic updates from EPRI, Progressive, and CB&I will be provided to both NET Power and ALLETE, and identification of progress towards key milestones for the assessment will be provided. The milestones established for this Project are as follows:

1) Completion of system component analysis for the cycle design – what is needed.
2) Completion of specific component specification for key system components outside the proprietary NET Power components – this includes the gasifier, fuel handling, and syngas cleanup components.
3) Completion of performance and economic modeling and determination of expected performance characteristics and system design costs.
4) Identification of the key challenges associated with integrating and operating this power cycle using North Dakota lignite as the fuel and areas where further development is required.

Timetable

The anticipated schedule for this project is as follows:

Task	Start Date	Completion Date
Power System Component Analysis	June 1	September 15
Component Specification for Lignite Specific Design	July 1	September 15
Performance and Economic Modeling	September 1	October 15
Identification of Key Challenges	September 1	October 15

A more detailed schedule is provided along with the Scope of Work for the Project in Appendix B.

A final report will be submitted to the NDIC and LRC by October 31, 2013, resulting in a project schedule for grant purposes as follows:

Project Start Date:	June 1, 2013 (or later based on the execution date of the NDIC grant agreement)
Project Completion Date:	October 15, 2013
Final Report Submittal:	October 31, 2013

Since this Project has a short duration of five months, periodic updates are not expected to be completed, however, the project has a specific list of tasks and milestones as provided above. If updates are needed during the five month timeframe of the assessment, they can and will be provided upon request.

In the event that NET Power's UK bituminous coal study is delayed, ALLETE will notify NDIC and alter the project timetable accordingly, if needed.

Budget

The budget for the Project is $1,000,000, which includes $300,000 of direct cash funding and $700,000 of in-kind services being provided. The cash portion of this budget is divided between: 1) the two industry partners providing a cash contribution of $150,000, and, 2) the subject of this grant request for a cash contribution of $150,000 from the NDIC/LRC.

The in-kind services will be provided by NET Power and their development partners, who will be bringing a substantial amount of technology development to the table with the UK coal study which provides the platform which this Project will build upon, as is described in the Scope of Work in Appendix B.

The cash funding will be used entirely for services performed by the subcontractors to ALLETE (NET Power and their subcontractors of EPRI, Progressive, and CB&I) sufficient to complete the Scope of Work for the Project. The Principal Investigator for the project will be EPRI. The Scope of Work for the services to be performed by EPRI, NET Power, Progressive and CB&I, is provided in Appendix B. The anticipated budget for the Project is identified below.

Service Provider	Cost for Services to be Provided	In-Kind Services to be Provided	Total Budget
EPRI - Principal Investigator	$185,000	-	$185,000
NET Power - Power Cycle Development and Integration	$57,000	$400,000	$457,000
Progressive - System Design modifications from UK Study	$43,000	$200,000	$243,000
CB&I (Shaw) - Plant Design, Layout, Construction Expert	$15,000	$100,000	$115,000
Project Budget	**$300,000**	**$700,000**	**$1,000,000**

The $300,000 of cash funding identified in the table above will all be used for direct services provided to complete the scope of work. No capital equipment will be purchased as a part of this Project. The budgeted costs will cover labor, overheads, and indirect costs for each of the service providers in performance of the services required for the scope of work.

Of the costs identified for the project budget, the grant will support the completion of the work by the Principal Investigator, ERPI. The funding provided by the industry partners will support the supplementary work to be completed by the additional research partners, NET Power, Progressive, and CB&I, to ensure that the system design and integration work performed by the Principal Investigator can be successful.

The grant funding requested is necessary to achieve the project's objectives and fulfill the scope of work for this Project. Without the grant funding, the industry partners would not have sufficient funding available to complete this research. The magnitude of the funding required to secure the services of industry leading experts to provide the necessary research services would not able to be covered by the industry partners. If the grant funding was not available, or was only available at a lesser amount, the research would not be completed at this time and would be delayed until a future date when sufficient funds could be acquired through a public/private partnership.

Matching Funds

The matching cash funds for this project totaling $150,000, or 15% of the total project budget, have been secured from the industry partners identified in this application. The partners have committed funds as follows:

ALLETE	$100,000
Dakota Gasification Company	$50,000

A funding commitment letter from Dakota Gasification Company is attached to this application in Appendix C.

The in-kind services to be provided for this project, totaling $700,000, or 70% of the total project budget, will be completed by the technology developer NET Power, and their additional development partners. No industry partner in-kind (indirect) costs are used for the matching funds identified in this application.

The grant funds requested for this project total $150,000, or 15% of the total project budget.

Project Deliverables

This Project will provide results in the form of a study report including information regarding the most feasible system design, the system performance characteristics from this design, the economic analysis of this technology performance, and the key challenges to further development of this technology fueled on North Dakota lignite.

The final report will answer the questions of:

1) Identification of the system components required to develop an operational power system design fueled using North Dakota lignite.
2) Determination of which current market components (gasifier, fuel handling, syngas cleanup) best fit the proprietary NET Power system components (combustor, turbine) and power cycle design.
3) Completion of performance and economic modeling to determine expected performance characteristics and system design costs.
4) Identification of the key challenges associated with integrating and operating this power cycle using North Dakota lignite as the fuel (fuel handling, syngas properties, corrosion) where further development could be required.

The final report is the deliverable in which the State has the intellectual property rights provided in Administrative Code section 43-03-06-03. The technological information underlying the study cannot be subject to this code provision as that constitutes preexisting intellectual property of NET Power and was not developed with funding from this grant application.

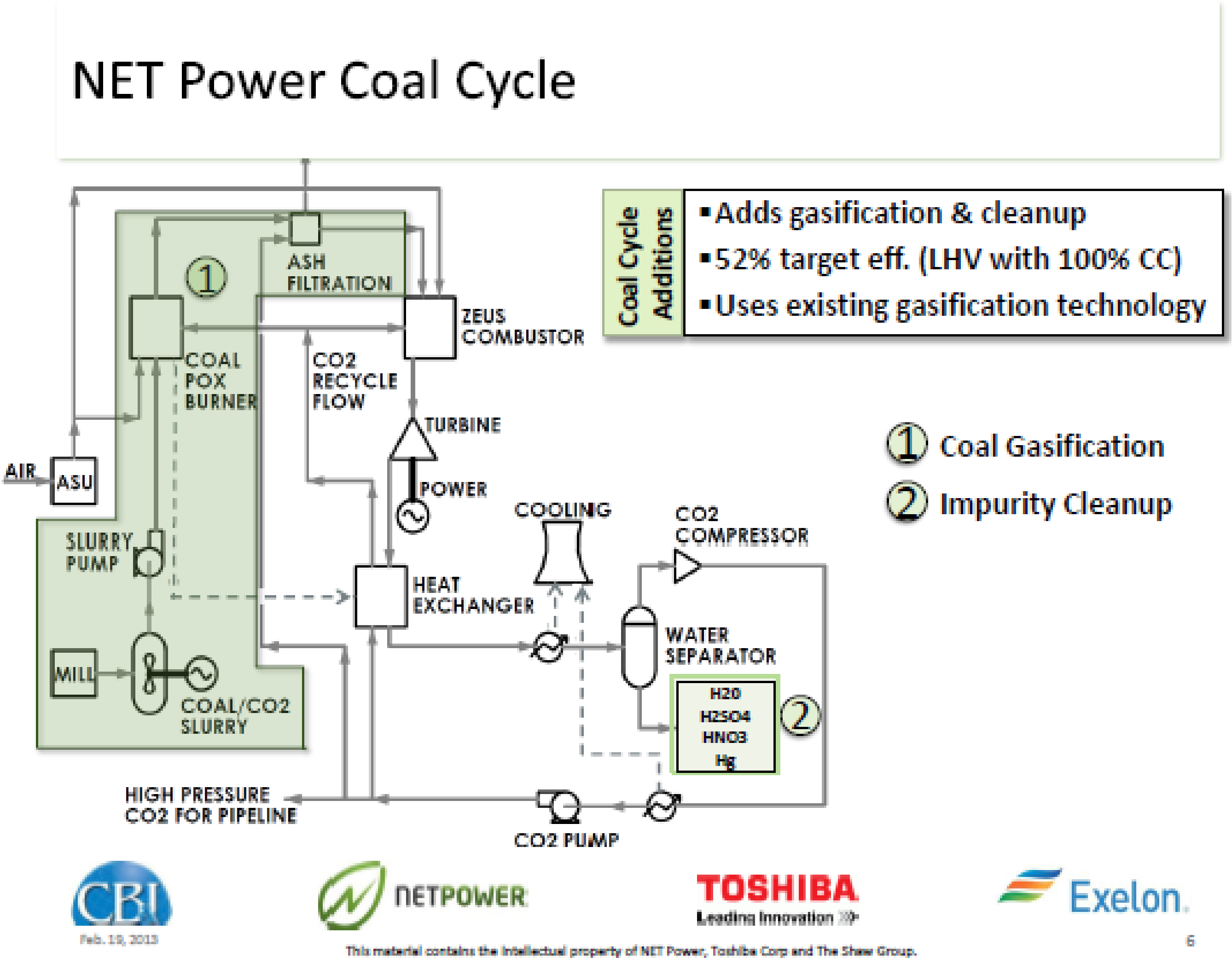
Tax Liability

Attached in Appendix D please find an affidavit stating that ALLETE does not have any outstanding tax liability owed to the State of North Dakota or any of its political subdivisions.

Manufacturing Waiver Requirement

ALLETE requests, as a part of this application, that the NDIC provide a waiver for the requirements listed in Chapter 43-03-06-04 of the North Dakota Administrative Code in reference to having all manufacturing of new technology or systems substantially occur in the state of North Dakota. Since this Project involves a feasibility study and design of a new power system, there will be no manufacturing that will occur as a part of this Project. However, if an additional phase of research and development occurs beyond this feasibility study to further the potential for application of this technology, ALLETE cannot commit on behalf of the technology provider that any manufacturing of equipment will be completed in North Dakota and asks for a waiver of this requirement to not hinder further development of this promising technology.

Appendix A: Technology Developer System Information



NET Power Coal Cycle

Coal Cycle Additions

- Adds gasification & cleanup
- 52% target eff. (LHV with 100% CC)
- Uses existing gasification technology

① Coal Gasification

② Impurity Cleanup

Feb. 19, 2013

This material contains the intellectual property of NET Power, Toshiba Corp and The Shaw Group.

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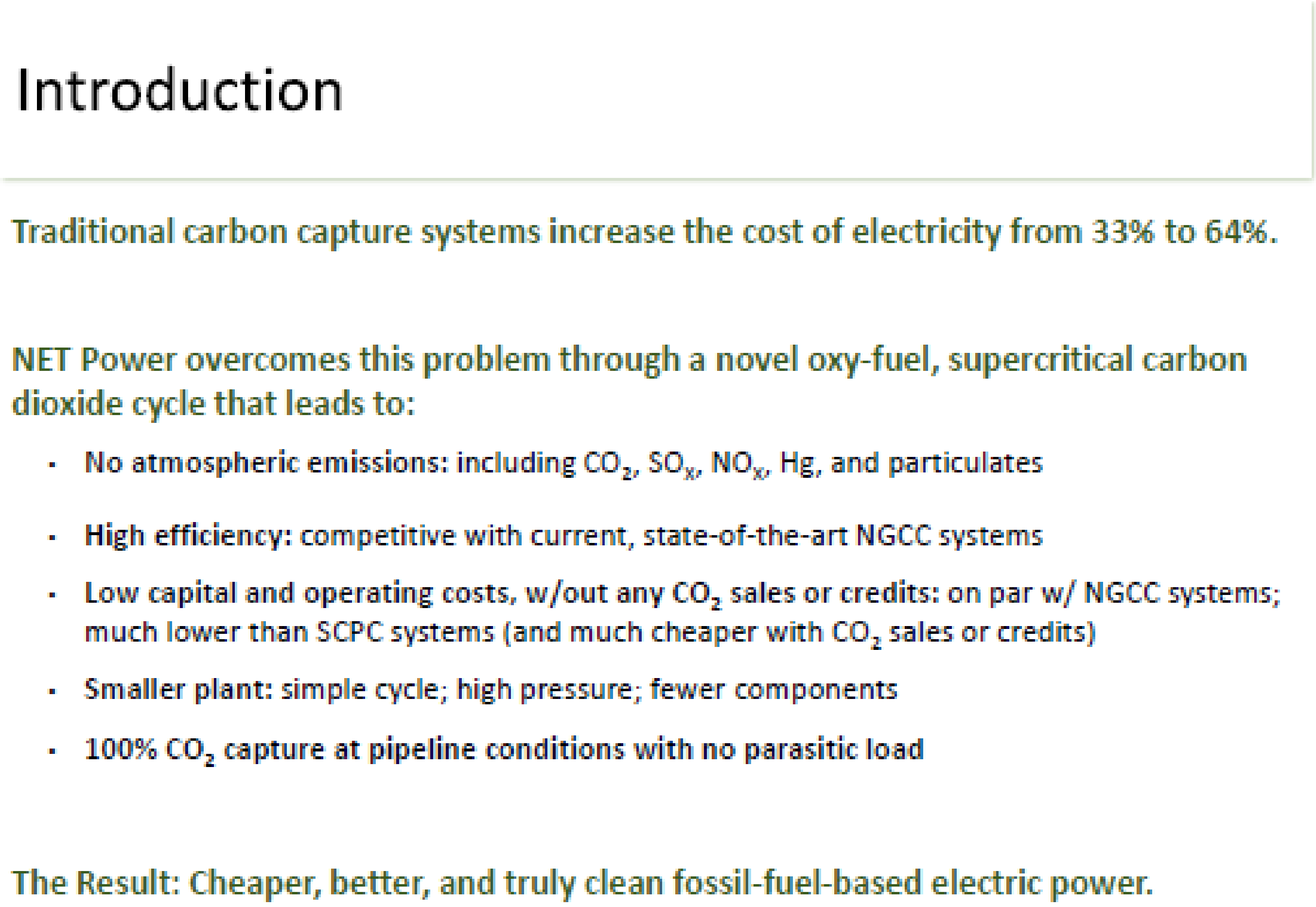

Introduction

Traditional carbon capture systems increase the cost of electricity from 33% to 64%.

NET Power overcomes this problem through a novel oxy-fuel, supercritical carbon dioxide cycle that leads to:

- No atmospheric emissions: including CO_2, SO_x, NO_x, Hg, and particulates
- **High efficiency:** competitive with current, state-of-the-art NGCC systems
- Low capital and operating costs, w/out any CO_2 sales or credits: on par w/ NGCC systems; much lower than SCPC systems (and much cheaper with CO_2 sales or credits)
- Smaller plant: simple cycle; high pressure; fewer components
- 100% CO_2 capture at pipeline conditions with no parasitic load

The Result: Cheaper, better, and truly clean fossil-fuel-based electric power.

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GHGT-11

High efficiency and low cost of electricity generation from fossil fuels while eliminating atmospheric emissions, including carbon dioxide

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Hideo Nomoto[b], Masao Itoh[b], Nobuo Okita[b], Charles Jones Jr.[c]

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[c]*The Shaw Group Inc., 4171 Essen Lane, Baton Rouge, LA 70809, USA*

Abstract

NET Power has developed a novel, oxy-fuel thermodynamic power cycle [1] that uses hydrocarbon fuels, captures 100% of atmospheric emissions, including all carbon dioxide, and has a cost of electricity that is highly competitive with the best current systems that do not have CO_2 capture. The proprietary system achieves these results through a closed-loop, high-pressure, low-pressure-ratio recuperated Brayton cycle that uses supercritical CO_2 as the working fluid. The cycle exploits the special thermodynamic properties of carbon dioxide as a working fluid by eliminating the energy losses that steam-based cycles encounter due to the heat of vaporization and condensation. The compelling economics of the system are driven by high target efficiencies – 59% net LHV for natural gas and 51% net LHV for coal – and low projected capital and O&M costs, which are the result of utilizing only a single turbine, having a smaller plant footprint, and requiring fewer, smaller components than comparable fossil-fuel systems.

NET Power, Toshiba Corporation, Exelon Corporation, and the Shaw Power Group are partnering to commercialize this system by developing a 50MWt facility that is scheduled to begin testing in 2014. This facility will generate electricity from natural gas and capture 100% of emissions, including all CO_2. The initial design for a commercial system with an electrical output in the range of 200MWt to 500MWt is also under development. The turbine for the 50MWt plant is being designed at the 500MWt level and then scaled down for the demonstration plant to facilitate rapid development of the large-scale turbine in the future. The demonstration plant will test all components and control systems and the operability of the cycle, including 100% capture of carbon dioxide and other impurities, using a range of fuel gas compositions.

The NET Power cycle will have an important impact on the power industry's ability to control and limit greenhouse gas emissions. Driven by its competitive cost when compared to state-of-the-art technologies without CO_2 capture, the authors believe the NET Power cycle will remove economic barriers to the deployment of 100%-carbon-capture, fossil-fuel-based electricity generation technology. This will enable both the developed and developing world to produce cheap electricity that does not contribute to CO_2-based climate change.

Selection and/or peer-review under responsibility of GHGT

Keywords: CO_2 capture; carbon capture and storage; carbon capture and sequestration; supercritical carbon dioxide; carbon dioxide cycle; enhanced oil recovery; zero emissions; power generation; thermodynamic cycle; supercritical carbon dioxide; oxy-fuel.

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1. Introduction

In the face of rising atmospheric CO_2 levels and a continued reliance on fossil fuel-based power generation, new technological solutions are needed [2][3][4]. Renewable energy technologies – based mainly on solar, wind, hydro-electric, and biomass systems – still face difficult cost and reliability challenges [5]. Growth in nuclear power usage has been compromised by recent accidents, the shutdown of old power stations and continued concerns over the storage of nuclear waste. Current greenhouse gas reduction technologies for fossil fuel systems face a difficult future as well. High capital costs, high parasitic energy requirements, and additional environmental concerns over scrubbing chemicals have combined to limit the viability of CO_2 capture systems for fossil fuel power plants [6].

Coupled with these challenges, there has been a dramatic increase in global recoverable natural gas resources and rapid growth in energy usage in the developing world, where coal in particular is a dominate source of energy. Because of these realities, fossil fuels will continue to be relied upon heavily in the immediate future, leading to even greater production of atmospheric CO_2. The result is an accelerating need for technological advancements to achieve low-cost, clean fossil-fuel-based power generation. Broadly, there have been three primary systems proposed and studied extensively for the production of electric power from fossil fuels with CO_2 capture:

- The IGCC system, in which coal is partially oxidized with pure oxygen at high pressure, the produced CO is converted to CO_2 and H_2 by the shift reaction, the H_2 fuel gas is purified with CO_2 capture and the hydrogen fuel is burned in a gas turbine combined cycle power unit.
- Flue gas scrubbing using an amine solvent applied to both coal fired boilers and natural gas combined-cycle power systems.
- Oxy-fuel combustion of a fossil fuel with pure oxygen, producing CO_2 and water plus fuel and combustion-derived impurities followed by separation of pure CO_2. This process has been studied and applied to conventional coal-fired boilers, gas turbine combined cycles, and high pressure steam-based systems.

These systems all face a similar critical problem: they cause significant increases in their cost of electricity over traditional systems, ranging from 33% to 64%, which severely limits their global implementation [7].

NET Power directly addresses this problem by producing fossil-fuel-based electricity without emitting CO_2 to the atmosphere and at a cost that is competitive with current power generation systems that do not have CO_2 capture. This novel cycle separates virtually all of the CO_2 from the other combustion products, producing a sequestration-ready CO_2 byproduct that is at pipeline quality and pressure without degrading the economic performance of the overall power generation system. This is accomplished with a new high-pressure, closed-loop, oxy-fuel power cycle that utilizes a supercritical CO_2 working fluid, a single high-temperature turbine, an economizer heat exchanger and a novel combustor. The cycle exploits the special thermodynamic properties of carbon dioxide as a working fluid by eliminating the energy losses that steam-based cycles encounter due to the heat of vaporization and condensation. This system achieves very high efficiencies with low capital costs and does not require additional equipment, processes, or costs to capture, purify, and compress produced CO_2.

2. Cycle Process Description

The proprietary NET Power cycle utilizes CO_2 as the working fluid in a high-pressure, low-pressure-ratio Brayton cycle, operating with a single turbine that has an inlet pressure in the range of 200 bar to 400 bar and a pressure ratio of 6 to 12. The cycle includes a high pressure oxy-fuel combustor that burns a fossil fuel in a pure oxygen stream to provide a high pressure feed stream to a power turbine. Figure 1 is a simplified flow scheme for a unit burning natural gas. An economizer heat exchanger transfers heat from the high temperature turbine exhaust flow to a high pressure CO_2 recycle stream that flows into the combustor, diluting the combustion products and lowering the turbine inlet temperature to an acceptable level. The turbine exhaust flow is cooled to a temperature below 70°C in the economizer heat exchanger and then further cooled to near atmospheric temperature in an ambient air cooler or with cooling water. Liquid water derived from water or hydrogen in the fuel is separated, and the remaining stream of predominantly CO_2 is compressed to the required high pressure. The recycle stream is then reheated in the economizer heat exchanger before returning to the combustor. The net CO_2 product derived from the combustion of fuel with pure oxygen in the combustor is removed from the high pressure stream recycle at a high purity and pressure for delivery to an export CO_2 pipeline.

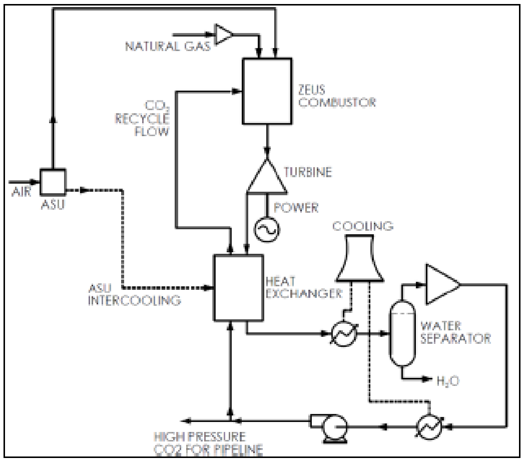

Figure 1: Proprietary NET Power Natural Gas Cycle

The optimum high pressure for operation of the system is between 200 bar and 400 bar, while the optimum pressure ratio is in the range of 6 to 12. This means that the CO_2 recycle compressor inlet pressure will be below the CO_2 critical pressure of 73.9 bar. In the recycle CO_2 compression system, a conventional single- or two-stage compressor first raises the pressure to about 80 bar. The supercritical CO_2 is then cooled to near ambient temperature in the compressor after-cooler. Its density at this point will be above 700kg/m3. The CO_2 can now be pumped to the high pressure required using a multi-stage centrifugal pump.

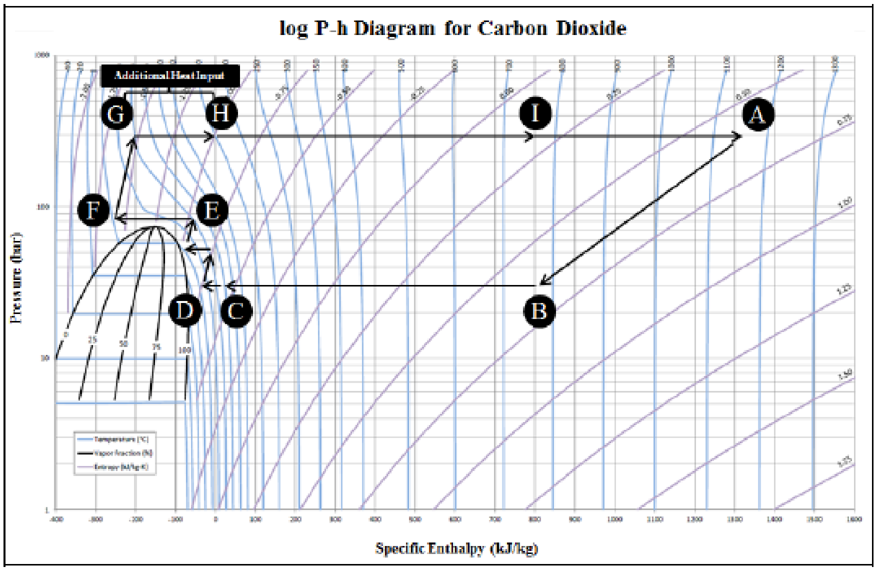

Figure 2: Pressure-Enthalpy Diagram for pure carbon dioxide and the proprietary NET Power natural gas cycle

The operating points for the CO_2 power cycle are shown on a pressure-enthalpy diagram for pure CO_2 in Figure 2. This diagram illustrates a system that uses pure methane as a fuel and has a turbine inlet condition of 300 bar and 1150°C and an outlet pressure of 30 bar. Note that the presence of water, inert nitrogen, argon and oxygen plus fuel and combustion-derived impurities will modify the physical properties slightly. The turbine inlet is at point A and the outlet is at point B, which is also the inlet to the economizer heat exchanger. The heat input to the combustor is equivalent to A-I. The heat transferred from the turbine exhaust to the high pressure recycle stream is B-C. Following ambient cooling from points C to D and water separation, the cooled turbine exhaust enters a two stage CO_2 compressor with an intercooler at point D and is compressed to point E, which is above the critical pressure of the predominantly CO_2 stream. The compressor after-cooler then cools the supercritical CO_2 stream to near ambient temperature at point F. A multi-stage centrifugal pump then raises the CO_2 pressure to the needed high pressure of the recycle stream at point G. The net product CO_2 is removed at or before this point and the remaining stream enters the economizer heat exchanger at point G. The heated recycle CO_2 flow leaves the economizer heat exchanger and enters the combustor at point I, where it mixes with the combustion products from a methane stream burned with oxygen.

To achieve high overall power generation efficiency, a close temperature approach is required at the hot end of the heat exchanger. It can be seen that there is a very significant imbalance between the heat liberated by the low pressure turbine exhaust (B-C) and the heat required to raise the temperature of the high pressure recycle stream (G-I). This imbalance is due to the very large increase in the specific heat of CO_2 in the high pressure recycle stream at the low temperature end of the economizer heat exchanger (see Table 1)[8].

Table 1: Specific Heat of CO_2 at Various Pressures

Temperature (°k)	CO_2 at 30 Bar (kJ/kg)	CO_2 at 300 Bar (kJ/kg)
300	1.18	1.95
350	1.05	2.00
400	1.02	1.90
450	1.03	1.63
500	1.06	1.47
600	1.10	1.31
750	1.17	1.23
1000	1.24	1.28

The imbalance can be corrected by adding a significant quantity of the heat required to raise the recycle CO_2 temperature at the low temperature end of the heat exchanger in a temperature range of 100°C to 400°C. This is done by heating a portion of the recycle CO_2 at point G against an externally generated, low temperature heat source, heating the stream from point G to point H. A very convenient source of heat can come from the air compressors of the cryogenic air separation plant that produces the oxygen stream used in the oxy-fuel combustor. These compressors can be operated adiabatically with no inter-cooling. Although this increases the compressor power, the overall effect on the cycle is very positive since most of the total adiabatic power input to the compressors is matched by an equivalent drop in the fossil fuel energy input needed by the system due to the reduction in the economizer heat exchanger hot end temperature difference.

An important factor in achieving high net cycle efficiency is to use a high turbine inlet temperature. This temperature, however, is limited by the maximum allowable temperature of the low pressure turbine exhaust that flows directly into the heat exchanger. This maximum allowable temperature depends on the operating pressure selected and the allowable stress levels for high nickel alloys, such as Alloy 617, which is approved for ASME rated pressure vessels, including the economizing heat exchanger (see Figure 5) [9]. The operating temperature at the hot end of the heat exchanger is in the range of 700°C to 750°C. This leads to a typical turbine inlet temperature constraint in the range of 1100°C to 1200°C.

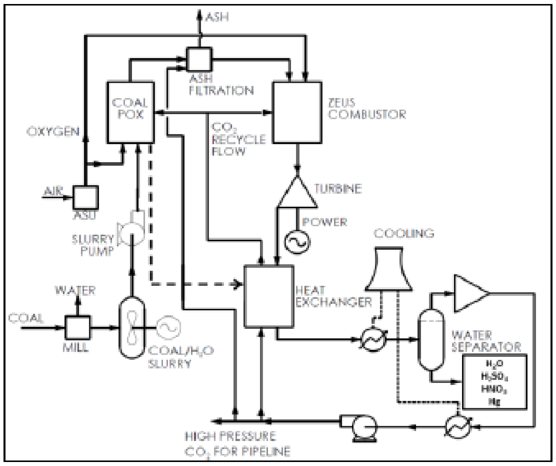

Figure 3: Proprietary NET Power Coal Cycle

Figure 3 shows a coal-fired NET Power system. In this configuration, coal must first be gasified using a conventional partial oxidation water quench gasifier with a water/coal slurry feed. All the coal- and POX-derived impurities will be present in a reduced form in the synthesis gas product that contains a major quantity of steam and will be in the temperature range of 250°C to 300°C. The water quench, plus the additional water scrub and an addition of a final fine particle filtration, will remove all slag and inorganic material from the steam/fuel gas mixture. The filtered gas stream is then cooled to near ambient temperature in a heat exchanger, which condenses the steam content, cools the fuel gas portion, and transfers the low grade heat released to the low temperature region of the high pressure CO_2 recycle where it is used to heat a side stream from the economizer heat exchanger. There is very little heat loss due to the use of a direct water quench gasifier, since this low grade heat input derived from the sensible heat in the partially oxidized coal-water slurry prior to water quench is available in the NET Power system at close to the same heating value as combusted fuel gas. Condensed water is separated from the fuel gas that is then compressed to the high pressure required for the fuel gas feed to the combustor. The coal-derived fuel gas is combusted and the impurities, such as H_2S, COS, CS_2, NH_3, and HCN, are converted to their oxidized forms: SO_2, NO, H_2O, N_2. The predominant impurities in the low pressure turbine exhaust stream are SO_2 and NO/NO_2. These will be converted to H_2SO_4 and HNO_3 mostly within the cold-end passages of the heat exchanger in the presence of condensed liquid water and excess oxygen. Table 2 shows the reaction sequence. The pressure of the turbine exhaust stream, in the range of 16 bar to 66 bar, ensures that the reaction kinetics are fast. This is particularly true for the NO oxidation reaction, which is accelerated by the relatively high partial pressures of the NO and the excess O_2 present after combustion. This process step has been demonstrated in several locations, including Vattenfall's Schwarze Pumpe pilot plant in Germany. The concentration of H_2SO_4 will depend on the ambient cooling temperature and the sulfur content in the coal used. It should be in the range 10% to 40% by weight. The nitric acid present will largely remove mercury contaminant. The H_2SO_4 can be converted directly to $CaSO_4$ by reaction with a limestone slurry in a simple stirred tank reactor. $Ca(NO_3)_2$ is highly soluble in water and can be separately recovered if desired [10].

Table 2: Impurities Reaction Sequence

$NO + \frac{1}{2} O_2$	→	NO_2	(1) Slow
$2\ NO_2$	→	N_2O_4	(2) Fast
$2\ NO_2 + H_2O$	→	$HNO_2 + HNO_3$	(3) Slow
$3\ HNO_2$	→	$HNO_3 + 2\ NO + H_2O$	(4) Fast
$NO_2 + SO_2$	→	$NO + SO_3$	(5) Fast
$SO_3 + H_2O$	→	H_2SO_4	(6) Fast

3. Turbine

3.1. General description

The turbine and combustor are new equipment items for this cycle, and their development includes combining gas turbine and steam turbine technologies. The turbine inlet temperature of the cycle is not a high for gas turbines, but it is very high for steam turbines. Similarly, the pressure of this cycle does not surpass that of advanced steam turbines, but it is extremely high for gas turbines. Toshiba has experience with 1300°C gas turbines and combustors, so the NET Power cycle temperature is well within their work experience. Toshiba is also a major developer and manufacturer of steam turbines, having a cumulative production of 170GW to date. In particular, in the area of high pressure and high temperature turbines – USC (Ultra Super Critical) or A-USC (Advanced Ultra Super Critical) – Toshiba has been at the forefront of manufacturing and investment in future technology R&D. The highest pressure achieved to date is 31Mpa (310 bar) for two 700MW turbines in the early 1990s, which continue to be safely operated and whose pressure is still the highest in the world for commercial turbines.

The basic concept of the NET Power turbine is as follows:

- Use well-known, proven technology as much as possible in order to make the R&D scope as minimal as possible.
- Scale down the demonstration turbine from a design of the future commercial plant turbine.

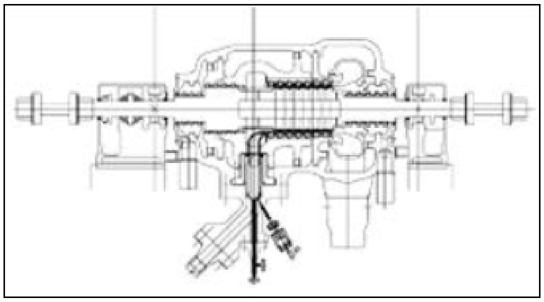

Figure 4: Cross-section of the Toshiba NET Power 50MWt Demonstration Plant Turbine

3.2. Material selection

When designing innovative high pressure and/or high temperature turbo-machinery, material R&D is a key focus. For the NET Power turbine, the R&D that Toshiba has conducted for A-USC systems can be effectively utilized. The turbine for the 50MWt demonstration plant of this cycle, depicted in the cross-sectional drawing in Figure 4 above, has a double shell structure (outer casing and inner casing), which is a steam turbine technology that serves to contain the system's high pressure. The space between the inner casing and outer casing will be filled with a carbon dioxide cooling flow extracted from the lower temperature end of the plant. The cooling technology enables the outer casing and first inner casings to be designed using CrMoV casting. Ni-based material is used for the smaller, second inner casing that encloses the exhaust area, where temperatures are higher than 700°C and moderate cooling is applied to the outer surface. As for the rotor, two kinds of materials are being used. The central portion of the rotor uses Ni-based forging. The ends of the rotor, where the temperature is lower and where no moving blades are assembled causing smaller centrifugal force, can utilize CrMoV forging. These two materials will be welded together. In general, very large Ni-based forgings are very difficult to manufacture and require a long R&D period. Additionally, the final product will typically be very expensive because of the high cost of the material and because of its machining difficulty. Welding the Ni-based forging with the CrMoV forging is a very practical approach that limits the need for Ni-based forging. Toshiba has experience combining Ni-based and CrMoV materials from the R&D of A-USC systems. Figure 5 below shows a comparison of the creep rupture strength of various materials. Conventional materials, including 1% CrMoV in this figure, are used in steam turbine technology. Alloy 617 and Alloy 625 are commercial Ni- based materials. "TOS1X" and "TOS3X" are materials developed by Toshiba; the former is used for forging and the latter is used for casting. It should be noted that Ni-based materials have far stronger characteristics in high temperature regions and that both "TOS1X" and "TOS3X" have even higher creep rupture strength than commercial Ni materials. (NOTE: Product names mentioned above may be trademarks of their respective companies.)

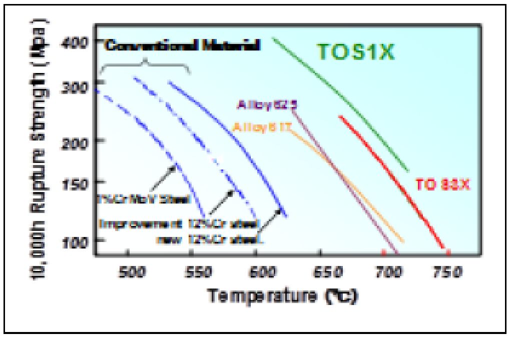

Figure 5: Comparison of Creep Rupture Strength

3.3. Cooling design and thermal barrier coating

In addition to using a welded rotor, the turbine design calls for the use of cooling technology. First, cooling CO_2 is supplied to the center bore of the rotor. This cooling flow is distributed to each stage through radial holes machined in the rotor, which protects both the blade fixation and the moving blade. Figure 6 shows the typical temperature contour of a moving blade in the NET Power turbine; it has been carefully analyzed and takes into account outer heat transfer, inner heat transfer, and thermal conductivity of both the metal and thermal barrier coatings. Film cooling that is generally used for high temperature gas turbine is not necessary in this design because the inlet temperature is not extremely high, as compared to existing gas turbines, and because the heat transfer coefficient of the cooling flow is very high, making simple convection cooling very effective.

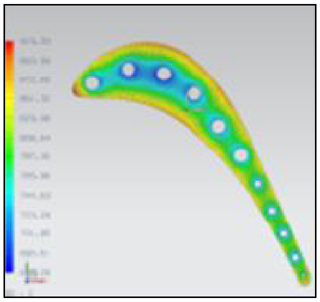

Figure 6: Turbine Blade Temperature Contour

3.4. Combustor

The combustion process in this cycle is of critical importance because the working fluid and pressure is different from typical heavy duty gas turbines. Major characteristics of this combustor are:

- Little to no NOx emissions because of the use of oxygen as opposed to air.
- The temperature is not as high as existing combustors for heavy duty gas turbines.
- The pressure is much higher than existing combustors.

Recent developments in combustors for heavy duty gas turbine have been focused on decreasing NOx emissions. This effort has led to the use of "pre-mixed combustion," in which fuel is mixed with air before combustion to enable lower temperature combustion. The disadvantage of pre-mixed combustion, however, is that it causes system vibrations, called "dynamics," due to flame instability. In this regard, the present NET Power system is advantageous for combustion because it eliminates NOx while enabling adoption of simpler and more stable diffusion combustion. The system is also able to use proven cooling technology, such as back side convection cooling, due to the moderate temperature of combustion and the high cooling capability and high availability of carbon dioxide. Toshiba is planning to conduct a high pressure rig test of a NET Power combustor, scaled down by 1:5, at the end of 2012. That test system, shown in Figure 7, will reveal combustion characteristics during simulations of ignition, load-up and operation in order to confirm combustion stability performance, combustion dynamics, temperature distribution, blow-out and other features.

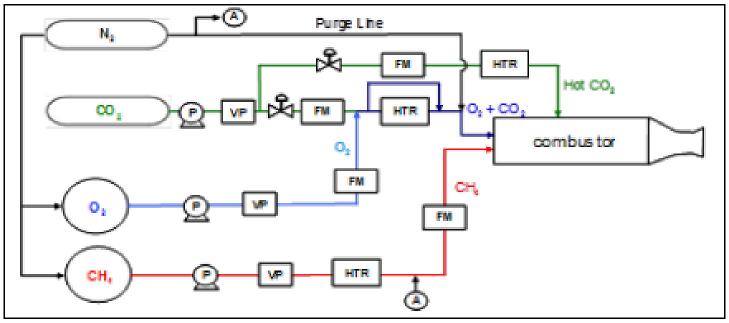

Figure 7: Combustor Test System Design

4. Air Separation

The oxygen required for fuel gas combustion is provided from an industry standard pumped LOX cycle cryogenic air separation unit. An oxygen production rate of approximately 3000 tonne/day at 99.5% purity is required for a 250 MWe NET Power system using natural gas fuel. The oxygen is diluted with a portion of the CO_2 recycle stream before entering the combustor in order to moderate the adiabatic flame temperature. Oxygen concentrations between 15% and 30% by mole-fraction are suitable. The cryogenic air separation system can be designed to produce oxygen at pressures between 30 bar and 80 bar so that it can be blended with CO_2 streams from the suction, inter-stage, or delivery of the CO_2 compressor. A separate O_2/CO_2 compressor delivers the oxidant mixture to the combustor at the required high pressure. It will not be necessary to produce high pressure oxygen directly from the air separation system at pressures above 200 bar. The oxidant mixture is preheated in the economizer heat exchanger before entering the combustor. An oxygen purity of 99.5% results in a net CO_2 product containing about 1% argon and up to 2% oxygen. The main air compressor will be a simple axial flow unit with a discharge pressure of between 5.5 bar and 6 bar. The booster compressor will be a multi-stage centrifugal compressor with a discharge pressure of about 60 bar with the first 2 or 3 stages operated without inter-cooling. The heat of compression from both compressors is transferred to the CO_2 recycle stream using a closed cycle heat transfer fluid. When using coal as the primary fuel, part of the pure oxygen product will be passed directly to the coal gasification reactor.

5. Economizer Heat Exchanger

The NET Power cycle's high efficiency depends on the use of an economizer heat exchanger to recover the sensible heat content of the turbine exhaust, which will be in the range of 700°C to 775°C at 30 bar pressure. The high pressure recycle CO_2 must be heated to a temperature in the range 675°C to 750°C. The very high flows of CO_2 coupled with the large temperature range from 50°C to 750°C require a heat exchanger with a very large specific surface area.

This can be provided by a compact multi-channel plate-fin heat exchanger. This must be fabricated from a suitable grade of stainless steel for the portion up to operating temperatures of 550°C to 600°C and from high nickel alloys, such as "617," for the portion up to 750°C. Heat exchangers with these characteristics are available commercially in stainless steel. The technology for production of the high temperature nickel alloy section can be provided based on development work currently in progress on optimum fabrication techniques.

There are two main types of heat exchanger configuration that can be used for ultra-high pressure service. The first uses passages fabricated from flat metal sheets which are shadow masked with a pattern of the required passages on one side of the metal surface, chemically etched to form the passages, stacked to form a heat exchanger block and diffusion bonded in a heated chamber. The resulting complete heat exchanger block is essentially one continuous metal element with no boundaries present between the passages. This form of construction is well suited to the requirement for high strength and a large surface area per unit of block volume. The necessary nozzles are welded to the blocks and to headers that allow the blocks to be assembled into a battery. High pressure heat exchangers fabricated from stainless steel with this type of construction have been used extensively in the oil industry and recently for experiments in CO_2 heat transfer in nuclear reactor studies.

The second type of surface consists of separately fabricated sections of corrugated sheet metal that forms a finned surface when used in heat exchanger passages. The low pressure passages in the economizer heat exchanger can be fabricated from formed fins that are sandwiched between the high pressure passages. As an alternative to chemical milling to form the high pressure passages, fins held between plain parting sheets can be used. This method of fabrication has been used for gas turbine economizer heat exchangers fabricated from stainless steel. Engineering studies and tests show the suitability of this type of heat exchange fabrication for high pressure and temperatures in both stainless steel and high nickel.

6. Cycle Performance

6.1. Efficiency

Table 3 and Table 4 provide the performance summary and targeted overall efficiency of the NET Power natural gas and coal cycles. The NET Power natural gas system performance is based on pure CH_4 at 40 bar pressure to simulate natural gas fuel. The NET Power coal system is based on Illinois No. 6 coal with 12% water content and a heating value of 22.4 MJ/kg using a conventional partial oxidation water quench gasifier with a water/coal slurry feed. The results demonstrate that NET Power's targeted natural gas efficiency is competitive with current NGCC technologies and the target coal efficiency is superior to that of traditional supercritical pulverized coal and IGCC technologies.

Table 3: NET Power Natural Gas Cycle Target Performance

Natural Gas Target Efficiencies (100% CO_2 Capture at 300 bar)		
Energy Components	**HHV**	**LHV**
Gross Efficiency	74.65%	82.70%
CO_2 Compressor Power	-10.47%	-11.60%
Plant Parasitic Power	-11.01%	-12.20%
Net Efficiency	**53.17%**	**58.90%**

Table 4: NET Power Coal Cycle Target Performance

Coal Target Efficiencies (100% CO_2 Capture at 300 bar)		
Energy Components	**HHV**	**LHV**
Gross Efficiency	71.12%	74.91%
CO_2 Compressor Power	-10.25%	-10.78%
Plant Parasitic Power	-11.99%	-12.69%
Net Efficiency	**48.88%**	**51.44%**

The turbine inlet and outlet temperatures for the NET Power system are controlled by the temperature and pressure rating for the economizer heat exchanger material at its hot end based on ASME pressure vessel code requirements. The cycle will realize efficiency gains as these temperatures are increased beyond their current level of 1150°C. Recently, alloy 740 with a higher temperature capability has been approved for both piping and pressure vessel use. Future developments in high temperature alloys allowing increases in turbine inlet and outlet temperatures will follow. Additionally, efficiency gains for the air separation plant and compressors, the two largest parasitic loads for the system, will enable overall system efficiency increases.

6.2. Capital cost

Several features of the NET Power system suggest that it will have capital costs that are comparable to or lower than conventional combined cycle or pulverized coal plants. The NET Power cycle eliminates all of the steam elements of a combined cycle system, including the Heat Recovery Steam Generator, main steam piping, reheat steam piping, steam headers, and the entire three stage (HP, IP, LP) steam turbine block. NET Power does include components that are not included in standard combined cycle plants, though, including most notably a heat exchanger and air separation unit. Because of its high pressure, NET Power's cycle is able to utilize smaller components and an overall smaller footprint than plants with a similar power output. Preliminary designs suggest that a NET Power natural gas plant will have a footprint about 1/3 the size of an NGCC plant with a similar power output, and NET Power coal plant will have a footprint about 1/6 the size of a supercritical pulverized coal plant with a similar power output. Additionally, because of its closed-loop, oxy-fuel characteristics, NET Power is able to avoid many of the expensive emissions control systems and components required by conventional fossil fuel plants. The major components of a full-scale commercial NET Power natural gas plant will also be prefabricated, leading to lower site erection costs and a shorter construction schedule compared to existing systems of a similar size.

Capital costs for the NET Power system have been preliminarily evaluated on a rough order of magnitude basis by compiling costs that the system shares with existing, similarly-sized NGCC, IGCC, and Supercritical Pulverized Coal systems, using as a reference the 2010 NETL report: "Cost and Performance Baseline for Fossil Energy Power Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity" [11]. For components not included in similarly sized systems but existing elsewhere (e.g. the heat exchanger and air separation unit), estimates and quotes were compiled from industry reports, design studies, and vendors. This preliminary capital costing analysis resulted in a targeted capital cost of \$800-\$1000/kW for the NET Power natural gas system and a targeted capital cost of \$1500-\$1800/kW for the NET Power coal system. Further granularity and certainly about NET Power's capital costs will be obtained following the completion of a FEED study of the 50MWt NET Power natural gas demonstration plant and a pre-FEED study of a 250MWe natural gas plant, both of which are in progress and being performed by The Shaw Group.

7. Cycle Commercialization

7.1. Development partnership

NET Power LLC, the Shaw Group, Toshiba Corporation, and Exelon Corporation have partnered to commercialize the NET Power system through the development of a 50MWt natural gas power plant. This plant has a final operational goal of continuous operation with no performance degradation. Following initial startup, the plant will go through extensive testing to include demonstration of all components; establishment of start-up and shut-down procedures, ramp rates, and safety and control systems; and measurement of flow stream chemistry and temperatures for future system optimization. Once converted to commercial operation, the plant will generate revenue through sales of electricity and CO_2 for enhanced oil recovery.

The Shaw Group will provide engineering, procurement and construction services to the project. Responsibilities include the development of pre-FEED and FEED studies of the 50MWt demonstration plant and a pre-FEED study of a commercial scale 500MWt NET Power plant. Toshiba is utilizing their experience in both high pressure steam turbines and high temperature gas turbines to develop the NET Power turbine and combustor. Exelon is siting, permitting, and commissioning the facility. NET Power is responsible for management of the project, overall system engineering and integration, and coordination between the partners.

7.2. Development plan, schedule, and progress

NET Power's commercialization will take place in four phases. Phases 1 and 2 include site selection, pre-FEED and FEED studies for the 50MWt natural gas demonstration plant, a pre-FEED study for a 500MWt plant, and a combustor rig-test. These phases are underway and are expected to be completed by the end of 2012. Figure 8 depicts a preliminary layout of the 50MWt demonstration plant. Phase 3, expected to be completed by the end of 2014, involves the delivery of the turbine and other equipment and the construction, commissioning, and testing of the 50MWt plant. In phase 4, the plant will be transitioned to full commercial operation. The development and site selection of the first full-scale commercial natural gas plant in the planned range of a 250MW net electrical capacity is expected to commence in 2014.

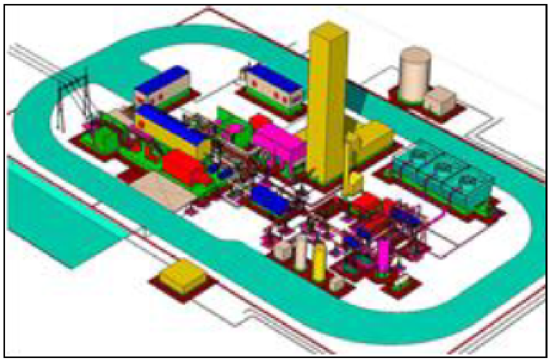

Figure 8: 50MWt Preliminary Plant Layout

7.3. Future development plans

The NET Power cycle is a platform technology with a number of applications beyond the basic natural gas-fired and coal-fired configurations. NET Power will pursue a parallel coal development plan that will involve integration with currently available commercial gasifiers. Other important applications of the NET Power cycle will include:

- Integration with Liquefied Natural Gas regasification.
- Integration with existing steam turbine power systems, where the cycle can superheat steam from an existing power station with a coal fired boiler to a temperature of 700°C to 750°C, increasing the overall plant efficiency and power output without increasing net CO_2 emissions.
- Direct integration with Enhanced Oil Recovery facilities.
- Solar-Natural Gas combined cycle plants that utilize concentrated solar power as a heat input to the NET Power system, enabling significant reduction in fuel consumption and near baseload solar power production.

8. Conclusion

The NET Power cycle presents an important opportunity for the power generation sector. In the face of growing climate change impacts from CO_2 emissions, utilizing abundant fossil fuels cleanly without raising the cost of electricity is a critical yet substantial challenge that requires innovative new approaches. By relying on new applications of well-understood technologies, the NET Power cycle can provide a significant breakthrough in oxy-fuel power generation in the near future by offering the first system that eliminates atmospheric CO_2 emissions while competing on all levels with conventional technologies that do not employ carbon capture. The authors believe the technology has the opportunity to make carbon capture an economic choice, even in the absence of carbon regulations, and can enable the widespread adoption of substantially cleaner, low-cost fossil-fuel-based power generation much sooner than previously thought possible.

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Appendix B: Project Scope of Work

Statement of Work
for
Feasibility Assessment of the NET Power Electric-Generation Technology when fueled with North Dakota lignite

"«Oxy-Lignite Syngas Fueled Semi-Closed Brayton Cycle Process Evaluation»"

A. Background, Objectives and New Learnings:

NET Power (Durham, NC) is developing a novel oxy/gas-fired semi-closed Brayton power cycle for co-production of bulk power and CO_2 suitable for enhanced oil recovery or other geological storage. Initial deployments of the power cycle are expected to be fueled with natural gas, but, in the longer term, NET Power expects that a coal syngas-fueled version of the power cycle will be an option.

NET Power has a study underway which will evaluate the expected performance of their technology when integrated with a bituminous coal syngas plant. The work proposed here will be to conduct a similar analysis for plant performance when integrated with a lignite syngas plant taking into account the unique characteristics of lignite as compared to bituminous coal. In these applications, the NET Power technology would replace the combustion turbine combined cycle plant normally included in an integrated gasification combined cycle (IGCC) plant design.

The work conducted under this agreement will exploit EPRI's experience in assessing the engineering and economic factors for lignite-fueled IGCC plants.

B. Benefits

At the beginning of the 21st century, increasing political and technological focus is being given to minimizing carbon dioxide (CO_2) emissions to the atmosphere. A significant source of CO_2 entering the atmosphere is from combustion of coal to generate electric power. The technology being developed by NET Power produces storage-quality CO_2 as a by-product of normal operations and has the potential for low CO_2 capture cost and lower levelized cost of electricity compared to gas-fired and coal-fired power plant designs to which CO_2 capture technology must be added. The work under this agreement will provide an initial assessment of the benefits and costs of the proposed technology when fueled by lignite, a low-cost fuel resource abundant in North America.

C. Tasks:

1. Design Review of Lignite-fueled IGCC power plants:

EPRI	EPRI has previously conducted numerous Engineering and Economic Evaluations of IGCC power plants. A study specifically focusing on the unique constraints associated with lignite gasification has also been conducted[1]. In this task, EPRI will provide to NET Power the lignite design study as well as a concise, referenced, design review of lignite gasification plant producing syngas suitable for firing in NET power technology including: fuel handling, fuel preparation (sizing and drying), air separation plant, suitable gasification technology, syngas filtration, syngas clean-up systems, ash handling, and syngas compression to combustor pressure. The non-confidential design and performance characteristics of suitable lignite gasifiers and syngas filtration/clean-up technologies will be detailed.
NET Power/ PEL	As part of previous investigations into suitability of available gasification and syngas treatment technology options, NET Power and Progressive Energy have performed a similar design study of these components for the combustion of hard coals. A major focus of this study was an investigation of key technology attributes and their effect on the performance of the NET Power Cycle, independent of fuel type. As these effects on overall plant performance are unique to any previous studies of IGGC-type technology, NET Power will provide EPRI with background details of this study, including any available background data on performance and cost implications of technology options. NET Power and Progressive Energy will work with EPRI to refine the design review, optimizing for integration with the NET Power Cycle, as well as combustion of a lignite fuel. Progressive Energy will also interface with the relevant vendors for candidate systems to ascertain how combustion of a lignite fuel will affect commercial guarantees for the system, a key consideration for eventual deployment of the technology. This is expected to take the form of an initial, interim and final design review of EPRI's work, as well as work required to interface with vendors.

2. Optimized Design of NET Power Cycle and Integration with lignite gasification plant

EPRI	EPRI will conduct process modeling to optimize the integration of a prototype semi-closed, direct-fired Brayton power cycle, supplied by NET Power, with a candidate lignite gasification plant, the scope of which will be developed in cooperation with NET Power. The integrated process model(s) developed will be used for the cost study in Task 6 below.
NET Power	NET Power will provide EPRI with all background information and data required for detailed process modeling of the NET Power Cycle. NET Power will contribute work developed previously for combustion of hard coals and work with EPRI to assist development of their model. It is expected that NET Power will assist in optimization of the model and perform several, iterative design reviews throughout the process. Validation

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[1] *Gasification of Lignite Coal.* EPRI, Palo Alto, CA: 2009. 1018137.

	of the results will also be iteratively performed and compared against previous work on hard coals.
PEL	Progressive Energy will provide background information generated from previous work on an optimized NET Power model for the combustion of hard coal, input on detailed models of gasification, input on available vendor data for the operation of specific components (or interface with vendors to assist in any required data gathering for the same) and provide comment on the suitability of the optimized system for commercial operation. PEL will also investigate optimal integration of those systems identified in Task 4 for the pre-treatment and processing of lignite coal. This is expected to take the form of an initial and final design review meeting in addition to work required for interface with vendors and optimization for preprocessing.

3. Technology Gap Assessment

EPRI	EPRI will assess the technical maturity of the components of the integrated power plant(s) developed to identify technology gaps and how the associated technical uncertainties might be reduced to acceptable levels by detailed design studies and/or pilot plant work.
NET Power	NET Power will provide background information on technical maturity of the optimized NET Power Cycle for the combustion of hard coals, as well as mitigation plans already identified and detailed from previous work. Results of EPRI's analysis of components unique to the combustion of lignite will be reviewed. This is expected to take the form of initial and final review iterations.
PEL	Progressive Energy has already conducted a detailed analysis of technical maturity of those components required for the combustion of hard coals. They have solicited the opinion of experts in relevant fields for a study to identify required developments for commercialization, as well as details of required studies for mitigation, possible partners, funding requirements and expected timelines for the same. Progressive will utilize these partners to provide similar detail to the design studies and pilot plant work identified by EPRI

4. Lignite pre-processing requirements and additional safety concerns for handling

EPRI	EPRI will review design studies and field experience for lignite handling/preparation focusing on lignite drying, a process requirement likely to be critical to overall process performance. The study will also identify any extra-ordinary safety concerns associated with handling/preparation of lignite (as compared to normal coal handling concerns).
NET Power	NET Power will review results of EPRI's analysis and seek comments from its partners on optimization of the pre-processing requirements for performance and cost. This is expected to take the form of initial and final review iterations.

5. Materials Assessment

EPRI	EPRI will conduct a review of materials suitable for the lignite gasification/gas clean-up processes as well as the NET Power cycle components. This assessment will focus on corrosion effects as well as strength of materials that might be used for high pressure, high temperature components.
NET Power	NET Power will provide input on material reviews conducted to date for prevention of corrosion for various components unique to the NET Power system. This is expected to take the form of initial and final review meetings.
CB&I	CB&I provide input on materials under consideration for the NET Power Cycle for the combustion of both natural gas and hard coals. Knowledge of design and procurement information for components unique to the NET Power cycle will be provided. Results of EPRI's analysis will be reviewed and cost implications of material selections (based on rough quantities of piping, etc.) will be added.

6. Cost Study

EPRI	EPRI will conduct an economic evaluation of the full lignite syngas-fueled NET Power technology according to commonly accepted cost estimating procedures[2] and using economic parameters mutually developed with NET Power. The cost study will estimate major component cost, installation and start-up costs as well as non-fuel and fuel operating costs using common costing tools. The results of the cost study will include: total plant cost, levelized cost of electricity, cost of CO_2 captured/avoided compared to baseline plants with pre-combustion CO_2 capture and IGCC and pulverized coal power with post-combustion CO_2 capture. EPRI will rely on NET Power to provide costs for the components of the semi-closed Brayton cycle technology which they are developing.
NET Power	NET Power will provide information on equipment costs for those components unique to the NET Power Cycle and any information generated from previous studies for the combustion of hard coals.
CB&I	CB&I will provide information on BoP component costing performed to date and review capital costs estimated by EPRI. Where possible, CB&I will provide increased certainty on capital cost estimates to aid EPRI's analysis of LCOE and expected cost of CO_2.

D. Deliverables:

Task 1 – EPRI will provide to NET Power the proprietary report: Gasification of Lignite Coal[3].
Tasks 1-6 – EPRI will provide informal reports of all findings.
At the end of the project, a final report will be submitted to NET Power, who will then provide the report to the Project Manager, ALLETE.

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[2] *Toward a Common Method of Cost Estimation for CO_2 Capture and Storage at Fossil Fuel Power Plants.* EPRI, Palo Alto, CA: 2013. 3002000176.

[3] *Gasification of Lignite Coal.* EPRI, Palo Alto, CA: 2009. 1018137.

E. Estimated Cost:

EPRI – $185,000
NET Power – $57,000
PEL – $43,000
CB&I – $15,000
Total – $300,000

In addition to the costs directly incurred for this program, NET Power, PEL and CB&I will be contributing significant in-kind work to generate designs, layouts, equipment lists, models and experimental data for both gas- and coal-fired NET Power systems that will serve as the basis from which to conduct the current study. All required information, including information generated specifically for the effects of coal combustion on the NET Power system, will be provided for use in this current study. The value of this in-kind effort will be:

Commercial NET Power Natural Gas Pre-FEED Study: $500,000
NET Power "Path to Coal" UK Study (estimate of private cost share): $200,000

F. Estimated Period of Performance / Estimated Schedule:

The Period of Performance for this effort is 19 weeks from completion of the contract. The schedule for individual tasks:

	Week																		
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	**X**	**X**	**X**	**X**	**X**	**X**													
EPRI	X	X	X	X	X														
NP	X		X		X	X													
PEL	X		X	X	X	X													
2					**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**					
EPRI					X	X	X	X	X	X	X	X	X						
NP					X	X	X	X	X	X	X	X	X	X					
PEL					X				X		X	X	X	X					
3														**X**	**X**	**X**	**X**	**X**	**X**
EPRI														X	X	X	X	X	
NP														X				X	X
PEL														X				X	X
4								**X**	**X**	**X**	**X**	**X**	**X**						
EPRI								X	X	X	X								
NP								X				X	X						
5					**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**				
EPRI					X	X	X	X	X	X	X	X	X						
NP					X								X	X					
CB&I					X									X	X				
6														**X**	**X**	**X**	**X**	**X**	**X**
EPRI														X	X	X	X	X	
NP														X		X		X	X
CB&I														X			X	X	X

Appendix C: Project Partner Funding Commitment Letter

DAKOTA GASIFICATION COMPANY
A BASIN ELECTRIC POWER COOPERATIVE SUBSIDIARY

1717 EAST INTERSTATE AVENUE
BISMARCK, NORTH DAKOTA 58503-0564
PHONE: 701-557-4400 FAX: 701-557-4450

Great Plains
SYNFUELS

April 1, 2013

William J. Sawyer
Supervisor - Project Development
Minnesota Power
Strategy and Planning Department
30 West Superior Street
Duluth, MN 55802-2093

Re: NET Power Cycle Project Feasibility Study

Dear Mr. Sawyer:

Please consider this letter the commitment of Dakota Gasification Company (DGC), a subsidiary of Basin Electric Power Cooperative, to participate as a funding source for the feasibility study of using lignite to fuel the NET Power cycle, a high-pressure, oxy-fuel, supercritical carbon dioxide cycle to produce electricity (the Project). We are committing to provide this project up to $50,000, based upon the total amount of funding required to complete the work and the total number of funding partners involved in the project.

You have advised us that ALLETE, Inc. intends to apply for a grant from the State of North Dakota acting by and through the North Dakota Industrial Commission (the Grant) for the project and that one of the Grant application requirements is to demonstrate the commitment of private matching funds for at least fifty percent of the project's total cost. We consent to ALLETE, Inc. submitting this letter with the Grant application to identify DGC as a private funding source for the project in the amount referred to above.

The funding commitment described in this letter is contingent upon the project being awarded a Grant.

Sincerely,

Mark Foss
Acting Vice President &
Chief Operating Officer

bf/las

Appendix D: Affidavit for Tax Liability

ALLETE

Statement Regarding Outstanding Tax Liability

March 26, 2013

ALLETE does not have an outstanding tax liability owed to the State of North Dakota or any of its political subdivisions.

Jamie Jago

Jamie L. Jago
Manager – Taxes
ALLETE

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