EXPANSION ENERGY

www.expansion-energy.com

March 31, 2016

Attn: Karlene Fine
Lignite Research Council
North Dakota Industrial Commission
State Capitol
600 East Boulevard Ave., Dept. 405
Bismarck, ND 58505-0840

RE: Transmittal Letter for Lignite Research Council Funding Application of Expansion Energy LLC

Dear Ms. Fine,

Please accept the enclosed application package for funding support from the Lignite Research Council and the North Dakota Industrial Commission for Expansion Energy LLC's proposed Phase I Small Research Project for demonstrating our patented "VCCS™ Cycle" technology at a North Dakota lignite-fired power plant and utilizing ash derived from ND lignite coal.

Expansion Energy acknowledges that this Transmittal Letter sets forth a binding commitment from Expansion Energy to complete the project as described in the application if the North Dakota Industrial Commission makes the grant requested.

Sincerely,

David Vandor
Chief Technology Officer & Managing Director
Email: dvandor@expansion-energy.com
Tel.: 914-631-3197

Carbon Capture & Utilization Using "VCCS^{TM} Cycle" Technology – Phase I:

Mineralization of Acidic Flue Gas CO_2 via Chemical Reaction with Alkaline Lignite Fly Ash
+
Extraction of Marketable Minerals & Other Commodities from Lignite Fly Ash

Applicant:

Expansion Energy LLC
26 Leroy Avenue
Tarrytown, NY 10591

Principal Investigators:

David Vandor, Chief Technology Officer
Expansion Energy

Sandra Broekema, P.E., Manager of Business Development
Great River Energy

Christopher S. Brown, P.E., Vice President of Engineering
Zeton, Inc. Pilot Plant Technology

Rocky C. Costello, P.E., President
R.C. Costello & Assoc., Inc.

April 1, 2016

Amount Requested: $45,000

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Figures and Tables

Abstract

Expansion Energy LLC ("XE"), with participation and support from Great River Energy ("GRE"), proposes a Phase I project ("Project") to design and estimate the capital costs for a modular pilot plant ("Pilot Plant") utilizing XE's patented "VCCS™ Cycle" carbon capture & utilization technology, which neutralizes CO_2 from power plant flue gas by chemically reacting it with alkaline lignite coal ash, yielding marketable solid mineral materials, including high-value rare earth elements and metals. The VCCS technology also has the potential to reduce the need for SO_2 and particulate emissions control systems at lignite-fired power plants.

In a subsequent Phase II project, XE and Great River Energy would partner to deploy the Pilot Plant designed in Phase I for field demonstrations using flue gas CO_2 and lignite coal ash from Great River Energy's lignite-fired Coal Creek power plant near Underwood, ND, which would host the Phase II demonstration.

Successful Phase I & II projects would significantly enhance the value of lignite coal and the beneficial use of lignite ash by providing additional revenue streams from marketable lignite-derived commodities and by reducing CO_2 emissions from ND's lignite-fired power plants without relying on CO_2 emissions regulations.

In addition to advancing the VCCS Cycle's Technology Readiness Level ("TRL") for eventual commercial deployments, specific objectives and deliverables of the Phase I project will include:

- Pilot Plant process simulations using ChemCad software
- Pilot Plant process design & configuration using AutoCAD software
- Equipment selection for Pilot Plant
- Equipment vendor selection
- Capital cost estimation for Pilot Plant—equipment procurement + fabrication & assembly

This Phase I Project will result in a demonstration-scale process design & engineering package and capital cost budget for building the Pilot Plant in Phase II, which is a key objective for Phase I.

The duration of this Project is 4-5 months, including the reporting period.

Total estimated Project costs are $145,000, of which XE will provide $50,000 (34.5%) and Great River Energy will provide $50,000 (34.5%), covering a total of 69% of the total Project costs. Additional participants in this Project are Zeton, Inc. and R.C. Costello & Assoc., Inc., providing process simulation expertise and pilot plant design/build expertise.

Project Summary

XE, with participation and support from Great River Energy, proposes a Phase I Project to design, simulate (via ChemCad software) and estimate the capital costs for a modular Pilot Plant utilizing XE's patented "VCCS™ Cycle" carbon capture & utilization technology, which neutralizes CO_2 from power plant flue gas by chemically reacting it with alkaline lignite coal ash, yielding marketable solid mineral materials, including high-value rare earth elements and metals and other commodities. The VCCS technology also has the potential to reduce the need for SO_2 and particulate emissions control systems at lignite-fired power plants.

In a subsequent Phase II project, XE and Great River Energy would partner to deploy the Pilot Plant designed in Phase I for field demonstrations using flue gas CO_2 and lignite coal ash from Great River Energy's lignite-fired Coal Creek power plant near Underwood, ND, which would host the Phase II demonstration.

Successful Phase I & II projects would significantly enhance the value of lignite coal and lignite coal ash by providing additional revenue streams from marketable lignite-derived commodities and by reducing CO_2 emissions from ND's lignite-fired power plants without relying on CO_2 emissions regulations.

A main general objective of the Project is to advance the VCCS Cycle's Technology Readiness Level ("TRL") for subsequent demonstration-scale and eventual commercial-scale deployments. Material balance and energy balance estimates (from software-based process simulations) will also be part of the Phase I objectives.

Specific deliverables of the Phase I project will include:

- Pilot Plant process simulations using ChemCad software
- Pilot Plant process design & configuration using AutoCAD software
- Equipment selection for Pilot Plant
- Equipment vendor selection
- Capital cost estimation for Pilot Plant—equipment procurement + fabrication & assembly

Specific objectives for Phase I will be to determine the design and operating requirements of an appropriately scaled VCCS Pilot Plant, such as:

- Resolving main design issues through a Process Flow Diagram (PFD) generated by Zeton, Inc. with AutoCAD software

- Preparing a Process Simulation generated by R.C. Costello & Assoc. using ChemCad software
- Preparing piping and instrumentation diagrams (P&IDs); and
- Preparing major equipment specifications to establish a +/- 25% budget for the Phase II Pilot Plant

This Phase I Project will result in a demonstration-scale process design & engineering package and capital cost budget for building the Pilot Plant in Phase II, which is a key objective for Phase I.

Project Description

VCCS Cycle Technology Overview

XE's patented "VCCS™ Cycle" carbon capture & utilization technology neutralizes CO_2 (an acid on the pH scale) by reacting it with alkaline coal ash in a series of classic acid + base reactions, yielding precipitated, stable, solid carbonate mineral material (i.e., "mineralization") in a manner that requires very little additional energy input. The VCCS Cycle is a scalable, continuous process, where CO_2 binding reactions occur on a short timescale (measured in seconds), making the VCCS Cycle suitable for large-scale lignite-fired power plants. VCCS uses primarily basic process equipment which is in abundant supply at low capital cost and does not require long lead times, such as reaction vessels, blending equipment and augers, basic PLCs, standard piping, etc.

The VCCS technology uses processes and inputs that achieve marketable final products which are dry, flowable and easy to handle, store and transport. These byproducts can generate substantial revenues to support the deployment of VCCS plants adjacent to coal-fired power plants or coal ash pits.

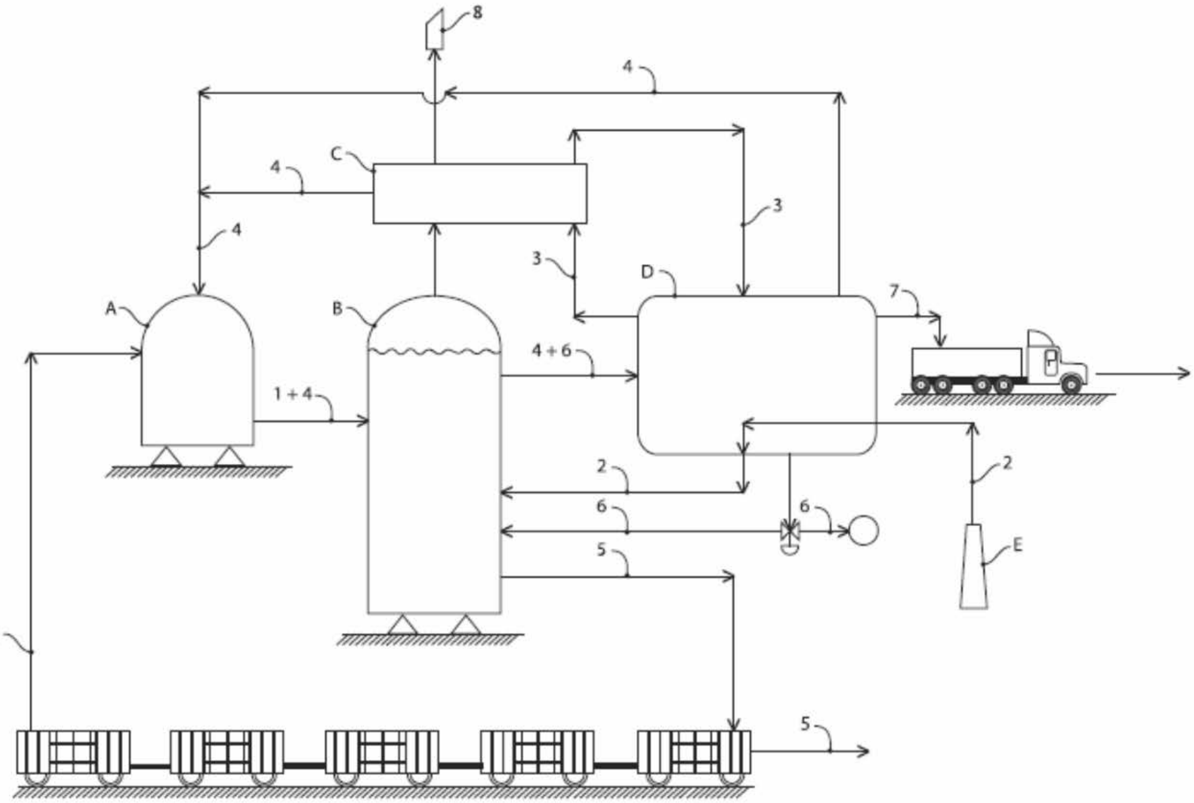
Whether VCCS captures 100% of the CO_2 emitted from any particular power plant or only a portion of such CO_2 is merely a matter of scale and material balance, which can be selected according to the user's needs or preferences, including the rate at which the user wishes to process coal ash and/or extract beneficial use commodities from the ash.

The VCCS technology provides multiple solutions for the challenges and opportunities related to lignite-fired power generation, including:

1. **Capturing and permanently sequestering a substantial portion of CO_2 emitted from lignite-fired power plants**, without having to sequester CO_2 underground and without involving expensive CO_2 pipelines and compressors, which are required by other carbon capture & sequestration systems. Instead, VCCS's outputs are marketable solid & liquid products that require no pipelines or underground sequestration.
2. **Treatment and beneficial use of coal ash** produced at lignite-fired power plants to the point that the ash's valuable and/or potentially harmful components can be separated out, leaving an environmentally benign residual material that can be further refined and marketed or safely landfilled.
3. "**Harvesting" valuable minerals** (such as rare earth elements, uranium, germanium, aluminum, nickel, iron oxide, etc.) **and other materials from coal ash**, which can generate substantial revenues via sale of those commodities to the market.
4. **Producing safe (treated) bulk materials for numerous industrial and construction applications.** Bulk byproducts, such as calcium carbonate, derived from the VCCS Cycle can be utilized as agricultural inputs (i.e., fertilizer); as a limestone substitute; for construction materials; for the treatment of contaminated soils; and for numerous other commercial applications.
5. **Augmenting (or eliminating the need for) electrostatic precipitators at coal-fired power plants** by inherently removing particulate ash matter from flue gas as that flue gas moves through the VCCS system. This would reduce capital costs, parasitic power losses and operating costs related to electrostatic precipitators deployed at coal-fired power plants today.
6. **Augmenting (or eliminating the need for) SO_2 removal systems at coal-fired power plants** by chemically reacting the acidic SO_2 with alkaline coal ash to neutralize SO_2 in substantially the same way that VCCS neutralizes CO_2. This would reduce capital costs, parasitic power losses and operating costs related to SO_2 removal systems deployed at coal-fired power plants today.

Thus, the VCCS Cycle technology has the potential to achieve carbon capture & utilization in a profitable, sustainable manner that does not rely on regulatory or legislative CO_2 reduction mandates for its economic viability.

Figure 1: VCCS Cycle – Process Schematic



KEY

MAJOR COMPONENTS
A - MIXING VESSEL
B - REACTION VESSEL
C - METHANOL CONDENSER
D - METHANOL REGENERATION + WATER DESALINATION
E - POWER PLANT FLUE

INFLOW STREAMS
1 - ASH + OPTIONAL ALKALI
2 - WARM FLU GAS: CO_2, N_2, AR, O_2...
3 - ABSORPTION REFRIGERATION
4 - METHANOL

OUTFLOW STREAMS
5 - DRY CARBONATES, IRON OXIDE, SAND...
6 - WATER
7 - SALTS + RARE EARTH COMPOUNDS
8 - REDUCED - CO_2 FLUE GAS

VCCS's reactions are hosted in a non-aqueous solvent, methanol, allowing the carbonates to precipitate out of the reaction without carrying water. **Key steps of the VCCS Cycle process** are as follows, referencing Figure 1 above:

1. Methanol is blended with the alkaline coal ash in a mixing vessel (A), producing a methoxide solution, and sent to a reaction vessel (B). Using methanol allows the carbonates to precipitate out of the reaction without carrying water. That innovation avoids a water-laden product stream and eliminates the need for energy-intensive separation of "salts" from saltwater.
2. The CO_2-carrying flue gas (and some moisture) from (E) is bubbled through the methoxide in reaction vessel (B), allowing for the acid + base reaction. Specifically, the acid CO_2 contained in the power plant's flue gas reacts with the alkaline calcium oxide and other basic metal ions in the coal ash, resulting in inert materials such as calcium carbonate (limestone), iron oxide and sand.
3. The wet (aqueous) methanol is continuously regenerated in (D), such that the water content in the reaction vessel is under certain limits. VCCS also includes a novel methanol regeneration step that uses refrigeration (but requires little external energy), which occurs in (D) before being sent back to (A) for further use. The recovered water from (D) can be used for power plant cooling or other industrial or agricultural purposes (after additional filtration).
4. The solid, dry carbonates that result from the acid + base reaction, plus the residual sand and iron oxide, are continuously removed from the reaction vessel (B), and are ready for use in the variety of industrial, construction and agricultural applications. Similarly, the continuous methanol regeneration process yields a wet byproduct that is a concentrated liquid, which contains metal salts, including significant proportions of rare earth elements. That recovered "liquor," which can be further processed at an off-site metals recovery facility, can be a source for valuable rare earth elements, helping the United States avoid the need to import critical rare earth elements from China (where ~ 95% of the world's rare earth elements are produced today).

Phase I Project Overview & Objectives

For this proposed Phase I Project, the Project participants will complete a basic design & engineering package for building a modular VCCS Pilot Plant in a subsequent Phase II project, which would be deployed at Great River Energy's lignite-fired Coal Creek power station near Underwood, ND. Following the successful completion of Phase I, XE and Great River Energy would partner on a Phase II VCCS demonstration effort, which would be to build and deploy the Pilot Plant at Coal Creek Station for demonstration purposes, using flue gas CO2 from Coal Creek and lignite coal ash from Coal Creek. Optionally, lignite coal ash from other ND power stations can also be tested with the Pilot Plant.

Specific deliverables of the Phase I project will include:

- Pilot Plant process simulations using ChemCad software
- Pilot Plant process design & configuration using AutoCAD software
- Equipment selection for Pilot Plant
- Equipment vendor selection
- Capital cost estimation for Pilot Plant—equipment procurement + fabrication & assembly

A main general objective of the Project is to advance the VCCS Cycle's Technology Readiness Level (TRL) for subsequent demonstration-scale and eventual commercial-scale deployments. Material balance and energy balance estimates (from software-based process simulations) will also be part of the Phase I objectives.

Specific objectives for Phase I will be to determine the design and operating requirements of an appropriately scaled VCCS Pilot Plant, such as:

- Resolving main design issues through a Process Flow Diagram (PFD) generated by Zeton with AutoCAD software
- Preparing a Process Simulation generated by Costello using ChemCad software
- Preparing piping and instrumentation diagrams (P&IDs); and
- Preparing major equipment specifications to establish a +/- 25% budget for the Phase II Pilot Plant

The P&IDs will be prepared showing all piping and valve requirements, instrumentation, control and safety requirements, and line sizing and line materials. The P&IDs will be issued by Zeton to XE and GRE for review and discussion, prior to the completion of the final Basic Engineering package. In addition, the following deliverables will be included:

- An Equipment List will be prepared listing all major equipment. The list will include materials, operating conditions and a recommended vendor(s).
- Equipment Datasheets will be prepared for major equipment, such as: vessels, reactors, columns, heat exchangers, pumps and mixers.
- Vessel datasheets will include required dimensions, operating conditions, material specifications, design temperature and pressure, and sketches as required.
- Heat exchanger datasheets will include performance requirements; operating conditions; physical properties of the fluids; materials; and design temperature and pressure.
- Pump and mixer datasheets will be provided and will include materials, operating conditions, and recommended vendor(s).
- An Equipment Layout will be prepared in a preliminary (3-D) format showing major equipment on the Pilot Plant modular skid.

The VCCS Cycle design that will be modeled in Phase I will rely on waste heat contained in the flue gas as the main energy source for the process, as well as the water content of the flue gas. More significantly, the Cycle will rely on a significant amount of calcium oxide in the ash. Lignite has especially high concentrations of calcium oxide, compared to other coal types, making lignite a good fit for successful VCCS deployments.

Following the successful completion of Phase I, a subsequent Phase II project would build, deploy and test the Pilot Plant per a set of protocols that will be elements of a subsequent Phase II application to the LRC.

Standards of Success

The standards of success for the Phase I Project include the following:

1. Design, a cost-effective, small scale (but scalable) VCCS Pilot Plant that will demonstrate the chemistry, thermodynamics and mass balance (flow rates) of the flue gas and lignite ash to the Pilot Plant, as well as the reduced CO_2 in the exiting flue gas, reduced alkaline metal content of the ash, and concentrated metals content of the "liquor" recovered from the ash.
2. With ChemCad computer simulations, demonstrate that the Cycle in the Pilot Plant will be in energy and mass balance, and that the Pilot Plant will be able to achieve the predicted outflow streams from the anticipated inflow streams of ash and flue gas specific to the Coal Creek lignite-fired power plant.
3. Using the Process Flow Diagrams and computer simulations derived as outlined above, prepare a preliminary Pilot Plant equipment list, vendor list, budget estimate, operating protocols and other such data that will generate a detailed construction, deployment and operating plan for the Pilot Plant to be built in Phase II.

The knowledge gained from Phase I will inform a Phase II LRC funding submission for the construction, deployment and operation/demonstration of an appropriately scaled VCCS Pilot Plant at Great River Energy's Coal Creek power plant, which XE plans to submit in partnership with Great River Energy. If successful, Phase II would, in turn, inform the potential commercial deployment of one or more full-scale VCCS Cycle plants at Coal Creek Station or at other ND lignite-fired power plants. The applicant understands that a positive decision by LRC to support this Phase I application does not guarantee that LRC will support the funding of Phase II.

Background

XE's objective in inventing and patenting the VCCS Cycle technology was to develop and eventually commercialize a carbon capture technology that can achieve meaningful reductions in CO_2 emissions from power plants (and other CO_2 emission sources) through processes that also provide substantial ancillary revenue streams, making these systems less reliant on public policies & regulations to achieve economic sustainability and widespread deployment. A related objective is to beneficially utilize and simultaneously remediate the abundant supplies of coal ash which exist in North Dakota and around the world, and to achieve greater economic value for this byproduct material by extracting valuable minerals and bulk commodity materials that can be sold to separate markets.

Under the direction of XE, laboratory testing of the VCCS Cycle using ND lignite coal ash has been previously performed by Wyoming Analytical Labs and analyzed by an independent chemical engineering consultancy: Thomas Schuster Consultants. This lab-scale work has validated the overall technical viability and efficacy of the Cycle, and provided important findings related to material balance and energy balance which will be instructive for the proposed Phase I Project. These tests and analyses have also confirmed that methanol is a superior "host" material for the CO_2 + alkaline chemical reaction. Utilizing methanol as the host material yields a dry, powdery (i.e., flowable and non-sticky) slate of resulting products (carbonates, iron oxide, sand, etc.), and the methanol is easily recovered for reuse in the Cycle. See the attached "VCCS Cycle Research Report.

In addition, that lab-scale work showed methanol to be an effective solvent for extracting a range of valuable minerals from lignite coal ash, thereby making such separated minerals marketable, and substantially reducing (or virtually eliminating) the heavy metals load of the carbonates and other byproducts produced by VCCS.

XE's completed lab-scale work is a strong foundation for further commercialization of the VCCS technology, beginning with the Phase I Project proposed herein and advancing further thereafter with the Phase II Pilot Plant field demonstration.

Qualifications

In addition to the qualification summaries below, please see the attached company Statements of Qualifications brochures and the bios of Key Personnel for the Project.

Company Qualifications

Expansion Energy LLC (Tarrytown, NY; www.expansion-energy.com) is a developer and licensor of breakthrough technologies (including the VCCS Cycle) related to the production, transport, storage and conversion of energy, as well as industrial-scale energy efficiency. XE's business model is largely to license its proprietary technologies to other companies, including end users in the energy industry as well as global energy equipment OEMs.

XE currently holds more than 30 granted US and global patents, with numerous additional patent applications currently being reviewed by various patent authorities globally. Most of XE's technologies rely on its deep expertise in the disciplines of gas processing, industrial process design, and cryogenics.

XE has successfully commercialized a portion of its technology portfolio, in partnership with corporate licensees of our technology, and is continuously commercializing its newer technologies, as they achieve patented or patent-pending status.

In addition to many projects for completed for private sector energy companies, XE has successfully completed multiple technical and economic studies for the New York State Energy Research & Development Authority (NYSERDA) related to the deployment of XE technologies in New York and related to third-party technologies and energy-related public policy. XE has also successfully completed projects for the California Energy Commission and the Gas Technology Institute.

Great River Energy (Maple Grove, MN; www.greatriverenergy.com) is one of the largest consumers of North Dakota lignite, operating several large lignite-fired power stations in ND. As such, GRE also has extensive experience with ash processing, disposal and beneficial use, as well as with flue gas emission control systems and processes. GRE is a national leader in energy innovation, and has successfully completed several prior studies for the Lignite Research Council in partnership with other ND lignite companies, including projects that have resulted in the full-scale commercialization of the technologies supported by LRC funding, such as the proprietary "DryFining" process.

Zeton, Inc. (Burlington, Ontario; www.zeton.com) is a world-leading designer and builder of innovative lab-scale systems, pilot plants, demonstration plants and small modular commercial plants. Zeton specializes in assisting clients to bring their new technologies and processes to market, faster, with less risk and lower cost. Zeton's engineering capabilities include multi-disciplined process, project, mechanical, control and electrical engineers.

Zeton serves the following process industries worldwide:

- Oil & Gas
- Polymers
- Chemicals
- Gas to Liquids/Synfuels
- Alternative Energy
- Bioenergy and Biofuels
- Pharma/Biotech
- Mining/Hydromet
- Fine Chemicals
- Environmental
- Sustainable Chemistry
- Process Intensification and other industries (e.g., Nuclear)

Zeton has successfully completed over 750 projects in 35 countries for clients such as:

- Dow
- DuPont
- BASF
- Bayer
- Solvay
- AkzoNobel
- Honeywell
- UOP
- Shell
- Chevron
- ExxonMobil
- Marathon Petroleum
- BP
- Total

Zeton has specific expertise with Hydrometallurgy Processing Pilot Plants. That experience is relevant to the VCCS Cycle's methanol regeneration step, where metals contained in the ash are concentrated in the water that is separated from the wet methanol. See Appendix A for a sampling of Zeton's Hydrometallurgy experience.

R.C. Costello & Assoc., Inc. (Redondo Beach, CA; www.rccostello.com) has over 25 years of experience in the chemical process industries, hydrocarbon processing and the hazardous waste business, and is a specialist in designing process plants of all scales. The firm has grown to include project managers, chemical process engineers, piping designers and support personnel, which, along with key strategic alliances (including with Zeton, Inc.), provide broad capabilities in all areas of chemical, process and environmental engineering. (See the attached Statement of Qualifications.)

Core areas of expertise and services include the following:

- Chemical Process Engineering
- Detail Design Engineering
- Process Intensification
- Bench-Scale Testing
- Commercial-Scale Testing
- Process Commercialization/Scale-Up
- Environmental Engineering
- Hazard & Process Safety
- Regulatory Compliance Support
- Professional Staffing and Outsourcing
- Due Diligence Services
- Project Management

A sampling of R.C. Costello's worldwide clientele includes:

- Akzo Nobel Chemicals Inc.
- Aramco
- Baxter Healthcare Corp.
- BP
- Bunge
- Chevron Products Company
- Corning, Incorporated
- FMC Corp.
- Flint Hills Resources
- Honeywell
- Kerr-McGee
- Southern California Gas Company
- Rhodia
- UNOCAL
- Valero Energy Corporation

<u>Key Project Personnel & Qualifications</u>

The following will be the Key Personnel for the Project, including its Principal Investigators. Bios and qualifications for key team members are included as appendices.

- David Vandor, Chief Technology Officer and Inventor of the VCCS Cycle, Expansion Energy
- Sandra Broekema, P.E., Manager of Business Development, Great River Energy
- Charles W. Bullinger, Senior Principal Engineer, Great River Energy
- Christopher S. Brown, P.E., Vice President of Engineering, Zeton, Inc.
- Leisl Dukhedin-Lalla, Ph.D., P.E., Vice President of Operations, Zeton, Inc.
- Rocky Costello, P.E., President, R. C. Costello & Assoc., Inc.

Value to North Dakota

XE, with participation and support from Great River Energy, proposes to increase the total value of and demand for North Dakota lignite, and to contribute to the growth and longevity of North Dakota's lignite and lignite-fired power industries. In particular, successful commercial deployments of the VCCS Cycle technology (supported by the Phase I and Phase II projects discussed herein) could help extend the life of North Dakota's lignite-fired power stations under the proposed Clean Power Plan requirements (if ultimately implemented) for reducing CO_2, but doing so in a way that is technologically viable and economically sustainable. This will help preserve the jobs and economic activity in North Dakota (particularly in ND's lignite-producing counties) which are directly and indirectly related to the use of lignite for power generation.

If successfully deployed, the VCCS technology could provide multiple solutions for the challenges and opportunities related to lignite-fired power generation in North Dakota, including:

- Capturing and permanently sequestering a substantial portion of CO_2 emitted from lignite-fired power plants
- Treating coal ash produced at lignite-fired power plants so it can be utilized for numerous additional "beneficial use" applications.
- "Harvesting" valuable marketable minerals and other materials from lignite ash.
- Producing safe (treated) bulk materials for numerous industrial and construction applications.
- Augmenting (or eliminating the need for) electrostatic precipitators at coal-fired power plants.
- Augmenting (or eliminating the need for) SO_2 removal systems at coal-fired power plants.

Thus, the VCCS Cycle technology has the potential to achieve carbon capture & utilization in a profitable, sustainable manner that does not rely on regulatory or legislative CO_2 reduction mandates for its economic viability.

If the proposed Phase I (and subsequent Phase II) Project is successful, it could lead to the commercial deployment of the VCCS Cycle technology at one or more lignite-fired power plants in

North Dakota, generating meaningful ancillary "beneficial use" revenue streams from the production/extraction of high-value metals and other commodity materials from lignite coal ash streams.

Such commercial VCCS deployments could eventually create dozens or hundreds of additional, well-paying, stable jobs for North Dakotans and substantial increases in general economic activity in North Dakota, particularly in ND's coal-producing counties. New jobs would be for employment at the VCCS plant(s) itself; jobs related to the transportation and storage of the commodity materials produced; and potential new value-added manufacturing of construction materials, fertilizer materials, and other products produced from the commodity materials coming from the VCCS plant(s). A significant number of additional nearby indirect jobs would also be expected from the deployment of a VCCS plant(s).

The proposed Phase I work will specify the scope and configuration of the Phase II Pilot Plant, which will demonstrate the ability of flue gas CO_2 to be neutralized by alkaline lignite ash, producing calcium carbonate and yielding a concentrated stream of valuable rare earth elements and other marketable minerals contained in ash, adding to the value of lignite as a feedstock material. Commercial-scale VCCS deployments would therefore elevate ash reclamation/recycling programs toward more and higher-value beneficial uses of lignite coal ash.

The value of North Dakota lignite will be further enhanced by the use of lignite ash to mitigate the CO_2 produced during combustion at lignite power plants. That reduction in CO_2 emissions will help North Dakota create a viable path forward in its State Implementation Plan (SIP) if the federal Clean Power Plan is ultimately enacted.

Management

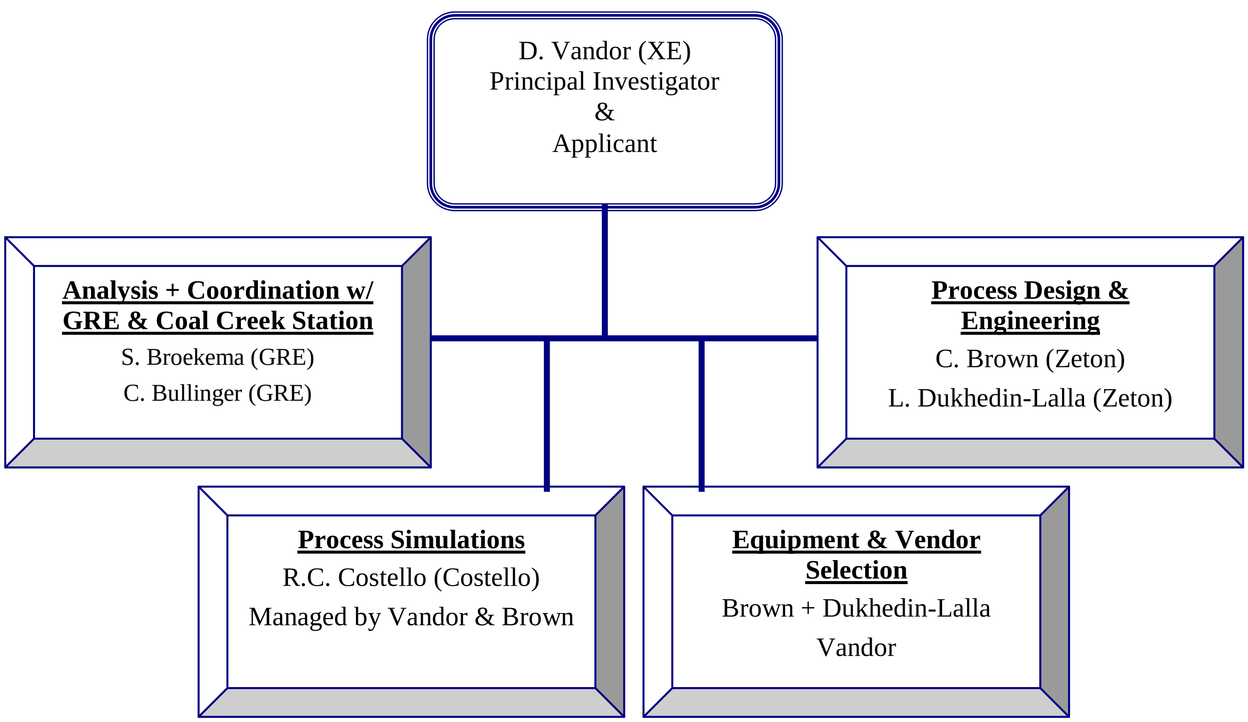
The proposed Project will be co-managed and coordinated by Mr. David Vandor (XE) and Ms. Sandra Broekema (Great River Energy). XE will act as the primary applicant and contract coordinator. Vandor will serve as the contact point for the LRC & ND Industrial Commission. David will also coordinate technical matters with Zeton.

Broekema will coordinate managerial, technical and logistical matters related to Great River Energy and its Coal Creek Station, including the involvement of GRE Senior Principal Engineer, Charlie Bullinger.

Zeton, Inc. and Vandor will jointly oversee the process simulation work to be completed by R.C. Costello & Assoc., Inc.

The following organizational chart summarizes the management structure that will be used for the Project:

Figure 2: Project Management



The team identified in the above organizational chart is composed of the Key Personnel listed in the "Qualifications" section of this application. The Project team will meet as needed, primarily via teleconferencing, and otherwise communicate on a regular basis to stay coordinated and keep everyone apprised of relevant progress and developments. These meetings and communications will serve as the basis for the interim reports to LRC. The Project's Final Report will be created as a joint effort of the Project team, but primarily led by XE.

Timetable

The following are the proposed milestones and dates for completing the Phase I Project:

Week 1 - Arrange and complete "kick off" conference call with full Project team

Weeks 2-3 - Transfer pertinent data from XE and GRE to Zeton and Costello

Weeks 3-6 - Costello to complete process simulations with ChemCad

Weeks 3-8 - Zeton to conduct process design & engineering

Weeks 8-9 - Interim report to LRC

Weeks 9-10 - Zeton and Costello to complete draft of Preliminary Engineering Report to XE

Weeks 10-12 - XE and GRE to review and comment on Zeton and Costello's draft report

Weeks 12-16 - Drafting of Final Report for LRC

Week 16 - Delivery of Final Report to LRC

Budget

Figure 3 is a summary of the Project budget. The total budget for the Phase I Project is $145,000. This Project will not require any materials or construction, and therefore the Phase I budget comprises only professional labor costs.

Figure 3: Budget Summary

Description	Professional Labor	Contribution	$ Source
GRE Technical, Project Mgmt. and Admin. (1)	$50,000	$50,000	GRE
XE Project Management & Technical Input (2)	$50,000	$50,000	XE
Zeton & R.C. Costello & Assoc. Engineering	$45,000		LRC
Total Budget	**$145,000**	**$100,000**	
Total Budget Request from LRC	**$45,000**		

Notes:
(1) 250 hours of professional time at $200/hr
(2) 250 hours of professional time at $200/hr

This Project is a technology development project and, therefore, in itself has no immediate return on investment. However, this Project is being undertaken with the intention of demonstrating and subsequently commercializing technology which will significantly improve the value of North Dakota lignite by multiple means. Therefore, the payback for this Project will come from the eventual commercialization of this technology. The North Dakota Industrial Commissions participation in this Project is critical for the project to be completed in its entirety. However, if additional process simulation runs from R.C. Costello are required to successfully complete the Project, XE will pay Costello in cash for such additional work.

Matching Funds

As summarized in the table below, XE has agreed to provide a total contribution of $50,000 to the Phase I Project. Great River Energy has agreed to provide a total contribution of $50,000 to the Phase I Project. In addition to the above in-kind contributions, XE will make a cash contribution to the Project if any additional process simulation runs need to be completed by Costello, above the number of runs outlined in the attached Zeton + Costello work quotation. We are requesting that the North Dakota Industrial Commission join us in supporting this Project by committing an additional $45,000 to this Project through the Lignite Research Council.

Contributor	Contribution Type	Contribution Amount	Contribution %
Expansion Energy	In-Kind Services	$50,000	34.5%
Great River Energy	In-Kind Services	$50,000	34.5%
NDIC/LRC	Cash Grant	$45,000	31%
TOTAL		**$145,000**	**100%**

XE and Great River Energy's in-kind contributions will be primarily related to technical & design services and knowledge, but will also include managerial and administrative services. XE and Great River Energy will also provide technical information & data from their current knowledge bases relevant to the topics & objectives of the Project. (The dollar value of such information has not been included in the above table.) In-kind contribution hourly rates for the Principal Investigators from XE and Great River Energy are $200/hour. This equates to 250 hours of professional time from XE and 250 hours of professional time from Great River Energy.

This Project will provide valuable information and improve the prospects of commercializing the VCCS technology for enhancing the value and competitiveness of North Dakota lignite by accessing new revenues from ND lignite and lignite coal ash and by reducing ND lignite's "environmental footprint." This will help ensure ND lignite's continued use for affordably priced power, even under tighter federal environmental/emissions constraints. More specifically, the Project will provide valuable process simulations, design parameters, and cost estimates for a Phase II VCCS Pilot Plant program, which will improve the prospects of commercializing a new carbon capture and ash mitigation/beneficial use technology that will enhance the value and competitiveness of ND lignite.

Tax Liability

XE does not have any outstanding tax liability owed to the State of North Dakota or any of its political subdivisions. See the attached Affidavit.

Appendices

Please see the attached appendices supporting this application.

Appendix A - Sample of Zeton, Inc.'s Hydrometallurgy Experience

1. Multi-Skid High Pressure Acid Leach Pilot Plant (HPAL), including pressure oxidation, as well as filtration, neutralization, sulfide precipitation and numerous downstream processing operations, Falconbridge Limited, Canada. Slurry throughput: 65 L/hr. Design Pressure/Temperature: 1500 psig/315 C
2. Versatile Laterite Slurry Preheater Unit – add-on for Laterite HPAL autoclave included stirred pre-heater vessel with internal and external heating and pressurized feed system.
3. Laterite Ores Processing Pilot Plant, including High Pressure Acid Leaching, followed by neutralization, CCD and other downstream processing steps, Queensland Nickel, Australia, Slurry throughput: 95 L/hr. Design Pressure/Temperature: 1500 psig/315 C
4. Selenium-Tellurium Removal Unit – Proprietary continuous process involving pumps and several mix tanks.
5. Multi-Skid Hydrometallurgy Processing Pilot Plant, including pressure oxidative leaching (POL), CCD thickeners, precipitation and filtration, solvent extraction, neutralization, sulfide precipitation, and electrowinning, Inco, Canada. Slurry throughput: 0.1 T/day (Dry Solids Basis). Design Pressure/Temperature: 550 psig/225 C
6. Flash Cooling Unit – Add-on cooling and let down system to Inco 0.1 T/day POL autoclave.
7. Multi-Skid Hydrometallurgy Processing Demonstration Plant, including pressure oxidative leaching (POL), with flash cooling and a pressure let down system, Inco, Canada. Slurry throughput: 8.3 T/day (Dry Solids Basis). Operating Pressure/Temperature: 200 psig/200 C

Appendix B: Affidavit of No ND Tax Liabilities

EXPANSION ENERGY

www.expansion-energy.com

March 31, 2016

Attn: Karlene Fine
Lignite Research Council
North Dakota Industrial Commission
State Capitol
600 East Boulevard Ave., Dept. 405
Bismarck, ND 58505-0840

Affidavit of No North Dakota Tax Liabilities

Through my signature below, I, David Vandor, Chief Technology Officer and Managing Director of Expansion Energy LLC with offices at 26 Leroy Avenue, Tarrytown, NY 10591, attest and confirm that Expansion Energy LLC has no outstanding tax liability with the State of North Dakota or any of its political subdivisions.

David Vandor   3/31/16
Date

Appendix C: Great River Energy Letter of Support

GREAT RIVER ENERGY™

12300 Elm Creek Boulevard
Maple Grove, Minnesota 55369-4718
763-445-5000
greatriverenergy.com

March 30, 2016

Lignite Energy Council
1016 E. Owens Avenue
Bismarck, ND 58502

RE: Letter of Support for Phase I Engineering Preparation - Expansion Energy VCCS™ Cycle Pilot Project

Great River Energy believes that carbon capture and utilization may provide a pathway to maintaining and extending the viability of our base load lignite fired generating units in North Dakota under the proposed Clean Power Plan regulations.

Prior research has indicated that carbon capture and sequestration is too energy intensive and costly to be practical anytime soon. Expansion Energy's "VCCS™ Cycle" has some interesting characteristics that may make it much less energy intensive and potentially more cost effective.

Great River Energy has agreed to collaborate with Expansion Energy toward developing a pilot scale plant to validate these characteristics. Phase I will include secondary research and some engineering analysis to prepare for a future Phase II small scale pilot in North Dakota. Great River Energy will provide my services as a co-Principal Investigator and determine specific plant modifications needed to facilitate the pilot test, instrumentation required and establish the test protocols. We will also participate in evaluating the opportunity for mineral recovery and use.

Great River Energy will offer in-kind PI and engineering support for Phase I, estimated at $50,000.

We believe that this project will benefit the lignite energy industry in North Dakota while contributing to Great River Energy's mission of providing our owner-members with affordable, reliable energy in harmony with a sustainable environment.

Sincerely,

GREAT RIVER ENERGY

Sandra Broekema, P.E.
Manager, Business Development
(763) 445-5304

Cc: Mark Fagan
John Weeda
David Farnsworth
Charlie Bullinger
David Vandor, Expansion Energy

EXPANSION ENERGY

www.expansion-energy.com

March 31, 2016

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Lignite Research Council
North Dakota Industrial Commission
State Capitol
600 East Boulevard Ave., Dept. 405
Bismarck, ND 58505-0840

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David Vandor

3/31/16
Date

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Sincerely,

GREAT RIVER ENERGY

Sandra Broekema, P.E.
Manager, Business Development
(763) 445-5304

Cc: Mark Fagan
John Weeda
David Farnsworth
Charlie Bullinger
David Vandor, Expansion Energy

Quotation

Preliminary Engineering Study

CO2 Removal System

Zeton Quotation Number 280-1A

For: Expansion Energy LLC
Tarrytown, NY

By: Zeton Inc.
740 Oval Court
Burlington, ON L7L 6A9
Phone: 905-632-3123

1 Objectives

The objectives of Preliminary Engineering are to develop the design of the plant, and estimate the cost of detailed design, procurement and fabrication. This includes working with the customer to determine design and operating requirements, resolving main design issues, preparing process flow diagrams (PFDs), and preparing major equipment specification sheets.

2 Scope of Work

The scope of work of the project is defined by the generic block flow diagram of the plant as outlined on page 22 of the research report "Chemical Analysis and Laboratory Testing of Expansion Energy LLC's Patented "VCCS™ Cycle"" provided by Expansion Energy. This estimate is based on the assumption that main process lines will be sized to allow the use of tubing.

3 Deliverables

The following deliverables will be prepared during the Preliminary Engineering Study:

3.1 Process Flow Diagrams

Expansion Energy, Zeton, and R.C. Costello & Associates will work collaboratively to prepare a PFD for the VCCS™ Cycle Technology process. The PFD will reflect a reduced scope of work that does not match US patents 8,252,242 or 8,501,125, but does provide proof of concept. It will show major equipment, critical electronic instrumentation and control philosophy. They will be issued to the customer for review and discussion during this phase, prior to issue with the final Preliminary Engineering package. PFDs will be prepared in AutoCAD version 2012.

3.2 Process Simulation

The PFDs will be used to prepare a process simulation in ChemCad for the plant. Key process information will need to be provided to R.C. Costello in order to have the system modelled correctly. The estimate includes one process simulation. Additional process simulations will cost US$10,000.00 per simulation. Since Zeton does not develop, own or license process technology, the model will be provided without a process guarantee. The customer is responsible for reviewing and approving the simulation results.

3.3 Datasheets

3.3.1 Equipment List

- An equipment list will be prepared listing all major equipment. The list will include materials, operating conditions and recommended vendor.

3.3.2 Equipment Datasheets

- Will be prepared for major equipment: vessels, reactors, columns, heat exchangers, pumps and mixers.
- Vessel datasheets will include required dimensions, operating conditions, material specifications, design temperature and pressure and sketches as required.
- Heat exchanger datasheets will include performance requirements, operating conditions, physical properties of the fluids, materials, and design temperature and pressure.

- Pump and mixer datasheets will be provided and will include materials, operating conditions and recommended vendor.

Equipment list and equipment datasheets will be prepared in MS Excel format, and will be issued in Adobe PDF format for customer approval before soliciting vendor quotes.

3.4 Customer Specifications

In pricing the study, Zeton has assumed that no corporate and/or site standards and specifications will apply to this project beyond the information already provided.

3.5 Cost Estimate

A final cost estimate will be prepared for the plant. The accuracy of this estimate will be within +/- 25%. In order to develop a firm quotation for the pilot plant, basic engineering will need to be completed. A basic engineering quotation will be provided near the conclusion of Preliminary Engineering.

4 Design Review Meetings

Design review meetings with the customer will be scheduled as required during this phase. Meetings can take place at Zeton's facility in Burlington, Canada, and at the customer's facility.

Zeton has allowed for a single, weekly project meeting by telecon between all parties (customer, Zeton, OSBL contractor, etc.). Project meeting minutes, if required, will be taken by the customer, and circulated to Zeton for comment.

5 Delivery

The Preliminary Engineering Study will be completed approximately 6 – 8 weeks after receipt of order. This is based on Zeton's workload at the time of quotation, and shall be reconfirmed at the time of order.

Assuming receipt of purchase order within 30 days of this quotation, Zeton will begin to assign engineering resources to the study. We ask that customers allow up to two weeks for this mobilization phase to be completed.

6 Estimated Cost: Preliminary Engineering Study US$ 45,000.00

The estimated cost for the Preliminary Engineering Study is based on the above scope of work and deliverables. Local taxes and duties are not included.

The estimate is based on the following clarifications:

- Travel and living costs associated with attending off-site meetings are not included, and will be billed separately if travel is necessary.
- Time for Zeton's engineers to participate in meetings off site from Zeton has been excluded.
- Time for Zeton's engineers to participate in a Hazop has been excluded.

6.1 Payment: Preliminary Engineering Study

The cost for Zeton's services will be paid on reimbursable basis for actual hours spent on the project plus travel and living expenses as incurred. Travel time incurred on the project to attend meetings will be billed up to a maximum of 8 hours per day. The hourly labour rates are stated below. Invoices will be submitted for services on a monthly basis. Invoices are payable within thirty (30) days of the date thereof.

A retainer of $ 20,000 is to be paid upon commencement of work. Retainer amounts received will be deducted from the final invoice.

Bank Information:

Bank of Montreal
Walkers Place Branch
3505 Upper Middle Road
Burlington, ON, L7M 4C6
Contact: Lynnette Valencia (905-336-1286)

Zeton US$ Account Information
Beneficiary: Zeton Inc.
Bank: 001
Transit: 38712
Account: 4600-713
SWIFT: BOFMCAM2

<u>2016 Engineering Labour Rates</u>

The following are the labour rates that will be charged to perform the engineering tasks:

R.C. Costello:

Engineering	US$ 185.00/hr
Drafting	US$ 85.00/hr

Zeton Inc.:

Senior Project Manager	US$ 130.00/hr
Project/Lead Engineer	US$ 115.00/hr
Control Engineer	US$ 115.00/hr
Electrical Engineer	US$ 115.00/hr
Senior Mechanical Designer	US$ 105.00/hr
Senior Engineering Technologist	US$ 100.00/hr
Electrical Technologist	US$ 100.00/hr
Assistant Engineer	US$ 85.00/hr
Drafting/CAD	US$ 85.00/hr
Administration	US$ 70.00/hr

Please note that it is not Zeton's practice to charge separately for computer use, CAD equipment use, telephone and facsimile costs, reproduction and photocopying and similar expenses on the project. These costs are included in the above hourly billing rates.

7 Study Package

On completion of the Preliminary Engineering Study, Zeton will create a final study package in a binder with hard copies of all drawings and documents. As a back-up to the hard copy version, a CD will be included with the binder with electronic versions of all drawings and documents in Adobe PDF format.

Should the project proceed into detailed design, procurement and fabrication with Zeton, a full set of as-built documentation will be issued at the end of the project, along with electronic copies in their original format (e.g. XLS, DWG, DOC etc.).

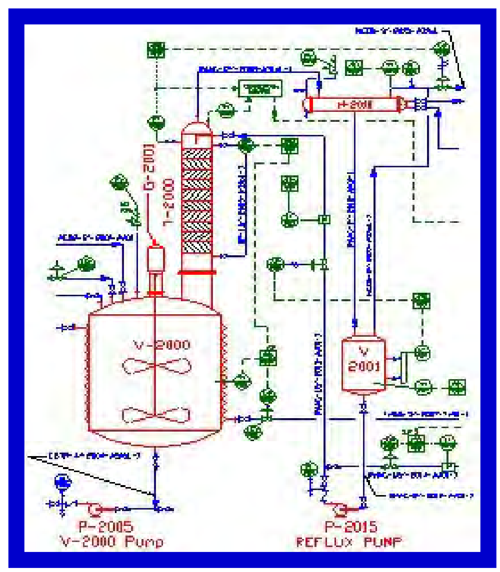
8 Standard of Performance and Limited Liability

Zeton's responsibility is to provide engineering services to the customer. In providing these services, Zeton undertakes to perform them in accordance with generally accepted engineering standards of practice and they will reflect competent professional workmanship. In the event any part of Zeton's work fails to comply with this undertaking, and the customer so informs Zeton in writing, Zeton will correct such deficiencies at its own expense. The remedy set forth herein is the sole and exclusive remedy of the customer for any failure of Zeton to comply with this obligation.

Except for the limited express warranty herein, and other than any wilful act of omission or gross negligence, neither Zeton nor any director, officer, employee or representative of Zeton shall be liable to pay any losses, damages, claims or demands whatsoever arising out of the services performed hereunder. In no circumstances whatsoever shall Zeton or any director, officer, employee or representative be liable for consequential or indirect damages, or loss of use or loss of profit.

COSTELLO

— CONSULTING ENGINEERS —



R.C. COSTELLO & ASSOC., INC.
- CONSULTING ENGINEERS -

STATEMENT OF QUALIFICATIONS

R.C. Costello & Assoc., Inc.
www.rccostello.com

Corporate Office Contact:

Rocky C. Costello, P.E.
1611 S. Pacific Coast Highway, Suite 210
Redondo Beach, CA 90277
v: (310) 792-5870 fax: (310) 792-5877
e-mail: rcca@rccostello.com

TABLE OF CONTENTS

OVERVIEW

Introduction

R.C. COSTELLO & ASSOC., INC. (COSTELLO) was founded by Rocky C. Costello, P.E., a chemical engineer, who has over 25 years experience in the hydrocarbon processing, chemical process industries and the hazardous waste business. With over 15 years at Rhodia, his diverse background includes process engineering, project engineering, plant operations & troubleshooting, plant management, project management and sales management.

His extensive background includes specialty chemicals, pharmaceutical intermediates, ethylene dichloride, chlorine and caustic, sour gas processing, 4-ethoxysilicon, benzyl chloride, thiophene-2 acetyl chloride, titanium trichloride, high purity hydrogen peroxide, hydrogen sulfide, powdered metal processing and many others.

His background in environmental technologies includes hazardous waste incineration, spent sulfuric acid processing, hydrocarbon vapor incineration, various waste water treatment and air pollution control processes.

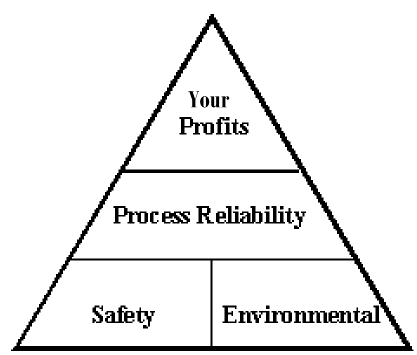
The firm has grown to include project managers, chemical process engineers, piping designers and support personnel, which, along with key strategic alliances, provide broad capabilities in all areas of chemical, project and environmental engineering.

The firm leads the way in Process Intensification and Advanced Process Control using ChemCAD 5.5 as an interface to excel.

Mission Statement

R.C. COSTELLO & ASSOC., INC. is dedicated to providing industry on a world wide basis with quality chemical and environmental engineering services, advanced and emerging process technologies, and regulatory technical/compliance support services that optimize client expenditures and manpower requirements.

You benefit from our ability to design and construct process plants, and obtain the necessary environmental permits to make them operational. We fully integrate the engineering design and permitting functions. We provide full engineering, procurement, and construction services.



Strategic Alliances

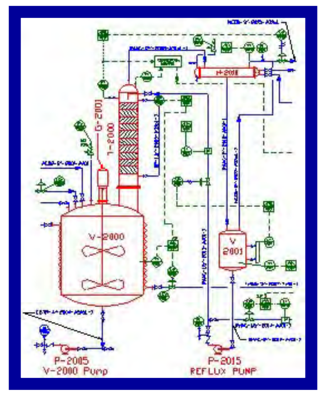
COSTELLO has entered into strategic alliances, which have enhanced the expertise/services of our company. These alliances were designed to increase our ability to offer technical expertise in highly specialized segments of the process industries, provide expanded turnkey services for our customers, or to offer a local presence in global markets.

SERVICES PROVIDED

COSTELLO routinely provides the following types of services to industry:

Chemical Engineering Services

- Complete turn-key plant design, procurement, and construction (E/P/C)
- Process modeling/simulation using ChemCad 5.5 and custom computer applications
- Preparation of Process Flow Diagrams, including Heat and Material Balances.
- Preparation of Piping & Instrument Diagrams
- Plant modifications, optimization and troubleshooting
- Equipment specification and selection
- Process control and instrumentation
- Fluid flow and heat transfer
- Distillation and evaporation
- Process technologies available:
    - Pipco, Inc. Sulfur Recovery Technology
    - Ecofluid biological waste water treatment for refineries and chemical plants
- Process Intensification technologies available (see Process Intensification section)
- Specific areas of **expertise** include: (see next page)



Detail Design Engineering Services

- Civil/Structural Design
- Piping Design
- Electrical Power
- Process Automation using PLC's and PCs with Wonderware or Intellution
- Construction Bid Packages

- Specific areas of **expertise** include:

Bulk Industrial Chemicals

- Chlorine / Caustic (Cl_2 / NaOH)
- Sulfur
- Sulfuric Acid (H_2SO_4)
- Sodium Bicarbonate (Na_2HCO_3)
- Titanium Tetrachloride ($TiCl_4$)
- Titanium Dioxide (TiO_2)
- Hydrogen Sulfide / Sulfur (H_2S / S)
- Aqueous Ammonia (NH_4OH)
- Anhydrous Ammonia (NH_3)
- Phosphoric Acid (H_3PO_4)
- Hydrochloric Acid (HCl)
- Nitric Acid (HNO_3)

Specialty Chemicals

- Vanadium Oxytrichloride ($VOCl_3$)
- Vanadium Tetrachloride (VCl_4)
- Antimony Trichloride ($SbCl_3$)
- Titanium Trichloride-Aluminum Trichloride Complex ($TiCl_3$* $3AlCl_3$)
- Ethyl Silicate and Polymers of Ethyl Silicate ($Si(OC_2H_5)_4$)
- Dichloro Benzyl Chloride ($C_6H_3Cl_2CH_2CL$)
- Hydrogen Peroxide (High Purity 90% H_2O_2)
- Sulfur Chlorides
- Lubricating Oil Additives (Sulfonates Used As Detergent Additives)
- Powdered Metal Processing

Pharmaceutical Intermediates

- Thiophene-2-Acetyl Acid (For semisynthetic Penicillin Production)
- Thiophene-2-Acetyl Chloride (For semisynthetic Penicillin Production)
- Benzyl Chloride ($C_6H_5CH_2CL$)
- Benzyl Alcohol ($C_6H_5CH_2OH$)

Plastics and Resins

- Unsaturated Polyester Resins
- Phenolic Resins
- Halar (Ethylene-Chlorotrifluoro Ethylene Co-Polymer)
- Polyethylene

Agricultural Chemicals

- Captan
- Folpet
- Difolatan
- Orthene

Fertilizer

- Ammonium Nitrate
- Diammonium Phosphate

Renewable Energy

- Biodiesel
- Biogas

Sour Gas & Biogas Processing

- Amine Units for the Removal of Carbon Dioxide and Hydrogen Sulfide
- Sulfur Recovery Plants
- Sour Water Strippers

Petrochemicals

- 1,2-Dichloroethane
- Vinyl Chloride Monomer
- Styrene
- Ethylene
- Benzene
- Cumene
- Poly-Alpha-Olefins
- Normal-Alpha-Olefins

Petroleum Refining

- Crude and Vacuum Distillation
- Hydrotreating
- Reforming
- Coking
- Hydrogen Plant
- Selexol Process to remove Carbon Dioxide
- Fluid Catalytic Cracking Unit (FCCU)
- Lo-Cat Sulfur Recovery Process
- Selexol Sulfur Recovery Process
- AquaClaus Sulfur Recovery Process
- Pipco Sulfur Recovery Process
- Sulfimol Process for the removal of Hydrogen Sulfide and Carbon Dioxide
- Beavon Stretford Tail Gas Unit
- Merox Process

Process Intensification

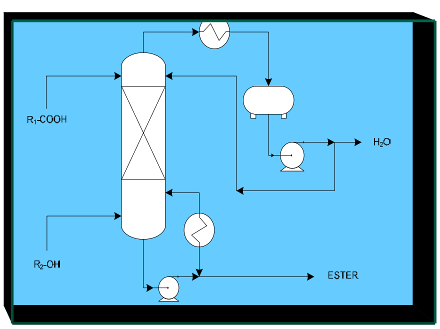
Process technologies available:

- The Spinning Tube In a Tube STT^{TM} process helps substantially improve profits in chemical, petrochemical, pharmaceutical and bio-chemical operations through a paradigm leap from volume-based to area-based reaction systems. This reaction system can dramatically reduce residence time in the range of 2-4 orders of magnitude resulting in a much more compact reaction system

- Härröd Research of Sweden's Supercritical Single-Phase Hydrogenation Technology achieves extremely high reaction rates in a small continuous unit. It improves the product quality to levels that were impossible to reach using the traditional multiphase technology and it reduces the investment costs and the operating costs. It can be used for the hydrogenation of organic compounds, fats, oils and polymers.

- COSTELLO's unique continuous flow reactor features a modified static mixer with a jacket for the cooling or heating media. These reactors:
    - Enhance Reaction Rates
    - Perform better than plug flow reactors
    - Jacketed for heat removal
    - Scale up
    - Economical

- **Reactive Distillation**



offers a reduction in equipment by combining a reactor and a distillation column into one unit. This combination can drive some chemical reactions to a level of completion that is not achievable with traditional equipment.

R_1-COOH + R_2-OH → Ester + H_2O
R_2-OH is more volatile than R_1-COOH

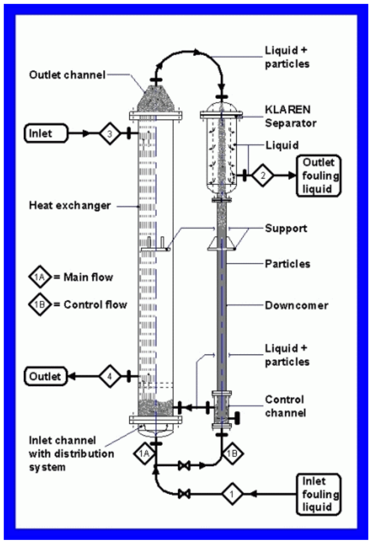
- Microwave technology is able to reduce chemical reaction times from hours to minutes, reduce side reactions, increase yields and improve reproducibility. This technology uses microwave heating to increase the speed of organic reactions. In case of microwaves, the energy transfer does not occur by conduction or convection as in conventional heating, but by dielectric loss.

- Micro channel reaction technology is offered through an ongoing relationship with Velocys. The benefits are as follows:

  Liquid Phase Reactions:
    - Increased product yield & selectivity
    - Eliminates need to recover catalyst
    - Rapid, in-line heating & cooling
    - Modular
    - Small, inexpensive reactors

Gas Phase Reactions:
- Increased product yield & energy efficiency
- Decreased capital costs
- Enhanced catalyst productivity
- Cost-effective plant siting, debottlenecking & expansion
- Reduced pollutant emissions

- Novel extraction technologies utilize low boiling point, inert refrigerants as extraction solvents. These provide extensive savings in both installed and operating costs. These processes replace super critical CO_2 and operate at 75 psig vs. super critical's 2,000 psig.



- Klarex Technology self-cleaning Fluid Bed Heat Exchanger is receiving worldwide interest for a variety of severely fouling heat exchange applications. This technology can be applied to the following applications:

  1. Forced circulation evaporators and reboilers
  2. Chemical processes where heating or cooling causes polymerization fouling or resinous deposits.
  3. Cooling crystallization applications.
  4. Heating of hard scaling well waters or biologically fouling surface waters. Heat recovery from wastewaters, etc.

Services available:

- Feasibility Studies (Technical Audit & Report)
  We review your process, sort through the process data, review technical information, and gather specific data to your chemical reactions including kinetics. We then recommend suggestions where Process Intensification (PI) would be beneficially applied. This includes reactors, distillation units, extraction units and heat exchangers. We perform audits on both new and existing processes.

- Pilot Plant and/or Process Testing
  We work with you and our licensors to develop a pilot or test program for your process. This testing should identify the degree of intensification that can be reached.

- Front End Engineering Design
  We prepare intensified Process Flow Diagrams, Piping & Instrument Diagrams, equipment specifications and detailed process descriptions.

- Cost Estimates
  After the Front End engineering package has been completed, a Cost Estimate of the intensified process can be provided.

- Equipment Supply
  Equipment supply is usually provided by our licensors and this includes bench scale, pilot plant and full size equipment.

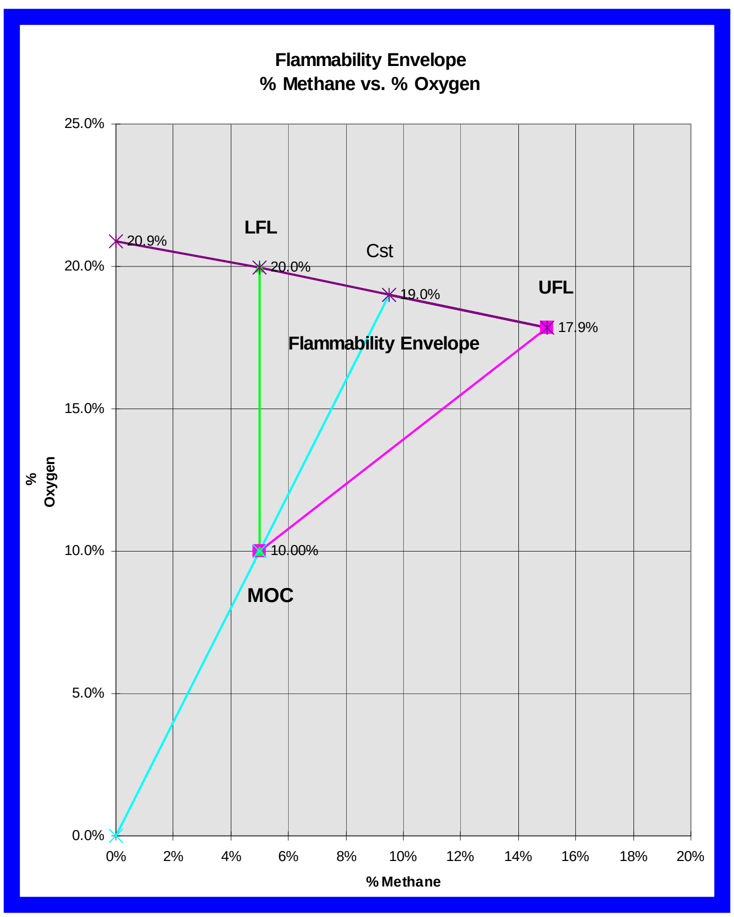
Bench Scale Testing Services

- Reactive Distillation
- Distillation
- Continuous Process Intensified Chemical Reaction Systems

Testing Services

- Measurement of temperature
- Measurement of liquid and gas flow rates
- Measurement of LFL (lower flammability limit)

Hazard & Process Safety Services



- Hazardous and Operability (HAZOP) Reviews
- Process safety studies including computer modeling (flammability studies)
- Explosion Investigations for refineries and chemical plants
- Our custom ChemCAD 5.5 /Excel applications are used to determine if and when a process is operating in the flammable envelope
- Explosion prevention Engineering and Design
- Equipment surveys, reviews, and process redesign
- DIERS calculations for sizing relief valves and rupture disks

Environmental Engineering Services

- Design and construction of air pollution abatement equipment including industrial ventilation.
- Design and construction of water treatment processes. This includes neutralization, precipitation of metals, cyanide oxidation, hexavalent chromium reduction, ion exchange, filtration, carbon absorption, electrochemical technologies, membrane technologies, and biotreatment.
- Evaluation of air pollution and water pollution technologies
- Troubleshooting
- Process selection studies and economic evaluation
- Treatment of contaminated groundwater and effluent from underground vapor extraction wells
- Air emission testing
    - Stationary Source Testing
    - Ambient Air
    - Title V
    - CEMS
    - BIF compliance
    - Trial Burns
- Design of air and water remediation systems, with specific expertise in the following technologies:
    - Water technologies: Air Stripping, Steam Stripping, UV Oxidation, Activated Carbon
    - Air technologies: Catalytic Oxidation, Vapor Phase UV Oxidation, Activated Carbon with or without on-site regeneration, Incineration
- Types of chemicals "remediated" include:
    - Chlorinated Organics
    - BTEX Compounds
    - Pesticides

Regulatory Compliance Support Services

- Regulatory compliance interpretation and guidance
  (All Federal, State, and Local environmental, health, and safety regulations)
- Sanitation District Pretreatment permit applications / NPDES permit applications
- Air Quality Management District air permits / Federal Title V air permit applications
- California EPA Department of Toxic Substance and Control Tiered permit application for wastewater treatment
- Waste minimization
- RCRA permit applications

- Spill prevention plan preparation
- Preparation of Material Safety Data Sheets and Management Systems
- OSHA / EPA regulatory compliance audits and environmental assessments
- Guidance for federal labeling, packaging and shipping compliance
- Interpretation and guidance on regulations applicable to the development and commercialization of new products (environmental, health, and safety issues)
- Emergency response planning / RMPP and RMP preparation
- Regulatory compliance interpretation and guidance

Professional Staffing and Outsourcing

As a professional service firm, we provide chemical engineers, mechanical engineers, project managers, piping designers, and AutoCAD operators to the refining and chemical industries.

In addition, our staff in the office can provide technical assistance as needed to the people in the field. This can be as simple as reviewing a report prior to delivery to the client, advice on calculation methodologies, advice on problem solving, or advice on control loop strategy. Or, it can be as complex as providing detail engineering services, process simulation, or P&ID development.

We are also members of the Los Angeles Area Clean Card Program.

Engineering Disciplines Provided:

- Civil
- Construction Management
- Control Systems
- Cost Control
- Electrical
- Mechanical
- Piping
- Process
- Programmers
- Project Management
- Schedulers and Planners
- Structural

Due Diligence Services

R.C. COSTELLO & ASSOC., INC. offers due diligence for chemical plants, petro-chemicals plants, and biofuels plants. Our step wise approach includes:

1. Review of PFDs,
2. Review of P & IDs,
3. Review of plant assets based on visual observation,
4. A listing of plant deficiencies,
5. A review of plant utility systems.

The due diligence also may encompass some or many of the following key determinants:

Markets

- Assessment of historic and forecast global, regional or local supply/demand situation and trade flows
- Forecast feedstock and product price
- Assessment of target company's economic competitiveness within industry
- Review impact of anticipated structural or regulatory changes in market

Physical Assets

- Assessment of historic downtime and analysis of unplanned outages
- Plant inspection and asset condition check
- Assessment of plant operating performance
- Maintenance program and implementation of maintenance program
- Inspection and operating reports for major equipment items
- Schedule for catalyst replacements and turnarounds

Business Operations

- New project assessments
- Human resource issues
- Validation of client's financial model for target facility and proposed projects
- Key contractual documents and obligations
- Safety performance and safety procedures
- Environmental compliance with applicable state, province, country or World Bank regulations
- Status of operating permits

PARTIAL LIST OF CLIENTS

AG Fluoropolymers
Akzo Nobel Chemicals Inc.
AOC, L.L.C.
Aramco
Baxter Healthcare Corp.
Beal Aerospace Technologies, Inc.
BP
Bunge
Cal-Nevada Pipeline Company
Chevron Products Company
Corning, Incorporated
EdeniQ
Edfu Pulp and Paper Company, Egypt
FMC Corp.
Flint Hills Resources
GAF Materials Corp.
Honeywell
Kerr-McGee
Kreido Biofuels
Microgy
Nalco Company
The Norac Company
Onyx Environmental Services
Southern California Gas Company
Reichhold Chemicals, Inc.
Rhodia
Southdown Inc.
Trojan Battery Company
UNOCAL, Indonesia
Valero Energy Corporation

INSURANCE CERTIFICATES

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 03/14/2016

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

IMPORTANT: If the certificate holder is an ADDITIONAL INSURED, the policy(ies) must be endorsed. If SUBROGATION IS WAIVED, subject to the terms and conditions of the policy, certain policies may require an endorsement. A statement on this certificate does not confer rights to the certificate holder in lieu of such endorsement(s).

PRODUCER	CONTACT
NOREEN KOSMAS INSURANCE 4030 W. 168th Street Lawndale, California 90260	CONTACT NAME: Noreen Kosmas PHONE (A/C, No, Ext): (310) 542-9946 FAX (A/C, No): (310) 542-9952 E-MAIL ADDRESS: noreenkins@yahoo.com

	INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A :	Liberty Mutual	
INSURER B :	Lloyds of London	
INSURER C :		
INSURER D :		
INSURER E :		
INSURER F :		

INSURED

R.C. COSTELLO & ASSOC. INC
1611 S. Pacific Coast Hwy #210
Redondo Beach, California 90277

COVERAGES **CERTIFICATE NUMBER:** **REVISION NUMBER:**

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	COMMERCIAL GENERAL LIABILITY ☐ CLAIMS-MADE ☐ OCCUR ☒ Business Owners GEN'L AGGREGATE LIMIT APPLIES PER: ☐ POLICY ☐ PRO-JECT ☐ LOC OTHER:			BZS (16) 56 70 68 43	05/26/2015	05/26/2016	EACH OCCURRENCE	$ 2,000,000
							DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 50,000
							MED EXP (Any one person)	$ 5,000
							PERSONAL & ADV INJURY	$ 2,000,000
							GENERAL AGGREGATE	$ 4,000,000
							PRODUCTS - COMP/OP AGG	$ 4,000,000
								$
a	AUTOMOBILE LIABILITY ☐ ANY AUTO ☐ ALL OWNED AUTOS ☐ SCHEDULED AUTOS ☒ HIRED AUTOS ☒ NON-OWNED AUTOS			BZS (16) 56 70 68 43	05/26/2015	05/26/2016	COMBINED SINGLE LIMIT (Ea accident)	$ 2,000,000
							BODILY INJURY (Per person)	$
							BODILY INJURY (Per accident)	$
							PROPERTY DAMAGE (Per accident)	$
								$
	UMBRELLA LIAB ☐ OCCUR EXCESS LIAB ☐ CLAIMS-MADE DED ☐ RETENTION $						EACH OCCURRENCE	$
							AGGREGATE	$
								$
	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y / N ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? ☐ (Mandatory in NH) If yes, describe under DESCRIPTION OF OPERATIONS below	N / A					PER STATUTE / OTH-ER	
							E.L. EACH ACCIDENT	$
							E.L. DISEASE - EA EMPLOYEE	$
							E.L. DISEASE - POLICY LIMIT	$
B	PROFESSIONAL LIABILITY			PGIARK04391-01	12/10/2015	12/10/2016	Aggregate	$2,000,000
							Each claim	$2,000,000

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)

engineers or architects - consulting, not engaged in construction supervision
Professional Liability is a claim basis policy with $10,000 deductible per claim

CERTIFICATE HOLDER	CANCELLATION
INSURED'S COPY	**SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.** AUTHORIZED REPRESENTATIVE

RCCOS-1 OP ID: H1

ACORD

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 05/05/2015

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PRODUCER
Grosslight Insurance, Inc.
License # 0247283
1333 Westwood Blvd.
Los Angeles, CA 90024
Gil Grosslight

CONTACT NAME: Gil Grosslight
PHONE (A/C, No, Ext): 310-473-9611 FAX (A/C, No): 310-312-4993
E-MAIL ADDRESS:

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A : Preferred Employers Ins Co	10900
INSURER B :	
INSURER C :	
INSURER D :	
INSURER E :	
INSURER F :	

INSURED
R. C. Costello & Assoc, Inc.
Bonnie Hahnel
1611 S.Pacific Coast Hwy #210
Redondo Beach, CA 90277

COVERAGES **CERTIFICATE NUMBER:** **REVISION NUMBER:**

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INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
	COMMERCIAL GENERAL LIABILITY; CLAIMS-MADE; OCCUR; GEN'L AGGREGATE LIMIT APPLIES PER: POLICY; PRO-JECT; LOC; OTHER:						EACH OCCURRENCE	$
							DAMAGE TO RENTED PREMISES (Ea occurrence)	$
							MED EXP (Any one person)	$
							PERSONAL & ADV INJURY	$
							GENERAL AGGREGATE	$
							PRODUCTS - COMP/OP AGG	$
								$
	AUTOMOBILE LIABILITY; ANY AUTO; ALL OWNED AUTOS; SCHEDULED AUTOS; HIRED AUTOS; NON-OWNED AUTOS						COMBINED SINGLE LIMIT (Ea accident)	$
							BODILY INJURY (Per person)	$
							BODILY INJURY (Per accident)	$
							PROPERTY DAMAGE (Per accident)	$
								$
	UMBRELLA LIAB; OCCUR; EXCESS LIAB; CLAIMS-MADE; DED; RETENTION $						EACH OCCURRENCE	$
							AGGREGATE	$
								$
A	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y / N; ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH); If yes, describe under DESCRIPTION OF OPERATIONS below	N / A		WKN10239116	05/26/2015	05/26/2016	PER STATUTE / OTH-ER	
							E.L. EACH ACCIDENT	$ 1,000,000
							E.L. DISEASE - EA EMPLOYEE	$ 1,000,000
							E.L. DISEASE - POLICY LIMIT	$ 1,000,000

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)

CERTIFICATE HOLDER

PROOF-5

"Proof of Coverage Only"

CANCELLATION

SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.

AUTHORIZED REPRESENTATIVE

Gilbert F. Grosslight

RESUMES OF KEY INDIVIDUALS

Rocky C. Costello, P.E.

President

SUMMARY OF EXPERIENCE:

Twenty-five years in the Chemical, Oil & Gas and Hazardous Waste industries assuming a variety of roles in engineering and management. Positions include Process Engineer, Production Engineer, Senior Design Engineer, Plant Manager, Sales Manager, and Project Director. Currently the principal in R.C. Costello & Assoc., Inc., an engineering consulting firm conducting business in the U.S., Mexico, Asia & Europe. Extensive hands-on operating experience, chemical process design and project management expertise. Currently company is focused on biofuels with emphasis on biodiesel and biogas.

PROFESSIONAL HIGHLIGHTS:

- Project Manager for the design and construction of a 28 LTPD sulfur recovery plant and a 100 GPM diethanolamine natural gas sweetening unit. Later operated the plant as plant manager responsible for operations from well head to gas production line.
- Engineering design and support for a biogas processing plant in Texas
- Designed oily wastewater treatment plant, crankcase oil rerefining plant, antifreeze redistillation plant and thinfilm evaporator. Plant contains various distillation columns, including vacuum tower, glycol distillation tower, and solvent recovery tower. Construction pending Cal. EPA approval.
- Audit leader for a North American Soybean Processor to find methods to modify and modernize their soybean processing and oil refining operation.
- Saudi Arabian refinery preheater replacement project.
- Troubleshooting for vacuum tower in Texas refinery.
- Engineered, designed, and constructed a hydrochloric acid byproduct plant.
- Provided engineering support to an aluminum sulfate (alum) production facility
- Engineered and designed a 150,000 gallon silicon tetrachloride tank farm. Material is reactive with water.
- Engineered, designed, and constructed, a heavy metals waste water treatment plant. Also prepared wastewater discharge permit.
- Project Manager for the design of a grassroots hazardous waste incineration plant utilizing a rotary kiln.
- Project Manager for the preparation of a RCRA part B permit for an organic and heavy metals wastewater treatment facility. This included the engineering section, emissions section and waste analysis plan.
- Project Manager for the design of a dichloro-benzyl chloride specialty chemical plant.
- Upgraded process instrumentation for a continuous ethyl silicate monomer plant

- Column modifications for ethyl alcohol / ethyl silicate continuous distillation system.
- Design of a continuous ethylene dichloride distillation column with heart cut product takeoff. This was a 10-foot diameter unit with approximately 100 theoretical plates for an overall height of over 150 feet.
- Design of a propylene glycol / water and ethylene glycol / water distillation columns in an unsaturated polyester resin operation. Prepared enthalpy concentration diagrams for the distillation of propylene glycol and water.
- Design of a batch distillation system to obtain pure dichlorotoluene from a mixture of toluene, monochlorotoluene, and dichlorotoluene. Design of a batch distillation system for the production and purification of dichloro benzyl chloride.
- Troubleshooting for boron trichloride operation using ChemCad III software package.
- Debottlenecking for a thiophene-2-acetic acid and thiophene-2-acetal chloride pharmaceutical operations.
- Debottlenecking for a sodium bicarbonate plant
- Debottlenecking for a chlor-alkali plant utilizing DeNora mercury cells.
- Startup and troubleshooting for vanadium oxytrichloride and vanadium tetrachloride continuous fluid bed reactors.
- Designed a batch reactor system for the production of phenol-formaldehyde copolymer.
- Redesigned various thermal oxidizers that had exploded.
- Completed hydrocarbon tank truck safety study.
- Completed asphalt tank farm explosion investigation study and redesigned the tank farm.
- Prepared waste minimization study.
- Prepared business development studies for client in Mexico.
- Served as project manager on hazardous waste tank farm and hazardous waste drum shredding operation.
- Designed a phenol formaldehyde binder bending and application system for a fiberglass insulation plant.

PROFESSIONAL EDUCATION:

B.E. in Chemical Engineering, Youngstown State University, 1974. Completed two years of additional graduate chemical engineering courses at the University of Toledo and Manhattan College. Attended numerous professional seminars on RCRA, management, engineering, instrumentation and finance.

Currently have two (2) patents and three (3) invention disclosures.

Licensed Professional Engineer in New York #58268.

Member of the American Institute of Chemical Engineers.

RECENT PUBLICATIONS:

Chemical Processing, February 1996, Improving performance and safety of thin film evaporators, Configuration and control enhancements boost effectiveness

Chemical Engineering, August 1996, Pipeflow - A Pressure Drop Calculator

Chemical Processing, January 1997, Flashback prevention helps cure thermal oxidizer explosions, System redesign improves safety and productivity

Innovations in Pharmaceutical Technology June 2002, Process Intensification: Think Small

Chemical Engineering April 2004, Process Intensification: Think Small

Getting Serious about Safety, Biodiesel Magazine, September 2006

Reflux and Recovery Biodiesel Magazine, November 2006

Tiny reactors aim for big role, Chemical Processing Magazine, December 2006

David A. Cheuvront, P.E.

Project Manager

SUMMARY OF EXPERIENCE:

Over 26 years in the petroleum refining, petrochemical and hazardous waste industries, assuming a variety of roles in engineering and project management. Positions include Project Manager for a grass roots 30MMSCFD sour gas treating facility, Regional Manager and Technical Specialist for hazardous waste treatment equipment manufacturer and Lead Design Engineer on a 60,000 BPSD Atmospheric Residual Desulphurization Unit.

PROFESSIONAL HIGHLIGHTS:

- Project Manager for $2.5 MM Hydrogen Peroxide Concentration Facility. Managed a team of engineers responsible for the technical process development, P & ID=s, equipment specifications, detailed engineering design, purchasing and project scheduling.

- Represented owner as project manager for $120MM sour gas treating facility. Supervised selection of proprietary amine process, coordinated engineering efforts of amine and sulfur plant engineering contractors, selected and monitored construction contractor. Managed a team of engineers of various disciplines who reviewed the contractors design efforts, assisted in negotiating construction permits, managed start-up training and assisted in negotiating contract for sale of natural gas liquids and sulfur.

- Developed construction bid packages and supervised mechanical and electrical installation of safety related emergency vent shut-off valves for asphalt tank facility.

- Provided consultation for metals etching and plating facility, which involved securing wastewater discharge permit and various air quality permits. Also provided design of an air ventilation network for the various rinse tanks, printing and plating machines.

- Provided troubleshooting services for a metal plating facility. Developed as-built P&ID's and operating instructions for on-spec treatment.

- Provided numerous hydraulic studies to an offshore oil company investigating plant modifications using proprietary software.

- Provided start-up training and on-site supervision for numerous groundwater remediation systems, with capacities ranging from 15 to 400 gpm, some of which treated nuclear waste. Responsibilities included process design, local permitting, and construction contractor selection and supervision.

- Supervised preparation of process studies and preliminary designs related to offshore oil processing.
- Provided process and P&I engineering for the upgrade and feedstock change of a synthetic natural gas production facility.
- P&ID engineer for a grass roots 50,000 ton/ year titanium dioxide plant
- Responsible for supervising the engineering and design of tank farm modifications and expansions.
- Supervised process safety reviews of both offshore and onshore gas and oil treating facilities in Santa Barbara County.
- Supervised P&ID engineers for the design of a 60,000 BPSD ARDS unit.
- Provided project management and engineering design services for construction and start-up of a turnkey 400 gpm wastewater treatment facility.

PROFESSIONAL EDUCATION:

BSChE Purdue University (1973)

Licensing: CA Chemical Engineer - No. 3471

Member: American Institute of Chemical Engineers.

RECENT PUBLICATIONS:

Groundwater Treatment with Zero Air Emissions, Environmental Progress, Volume 9, No. 3, August 1990.

Innovative Groundwater Treatment Technologies with Zero Air Emissions, presented at Hazmacon – 1988, Anaheim.

A New Process for SNG Manufacture, presented at the 1984 annual AGA meeting, San Francisco.

Michael F. Delamore
Project Manager

SUMMARY OF EXPERIENCE:

40 years of experience managing projects in the design and construction industry including heavy industrial petrochemical, oil & gas, power, and manufacturing plants and facilities. Positions include individual project management responsibilities, team task force management, and company ownership and CEO positions managing a three division company including field design and construction, ASME code shop and process skid manufacturing, and a proprietary process design product line for refinery crude oil desalter equipment.

PROFESSIONAL HIGHLIGHTS (partial list):

- Managed a design/build project to revamp a complete storm water collection and treatment system for a major Texas Gulf Coast chemical complex.
- Managed multiple petrochemical plant grass roots, revamp, and plant addition projects for a wide variety of major chemical producers.
- Managed the design and fabrication for 32 individual industrial centrifuge process skid modules to treat crude oil on board a large FPSO for a major US oil company and the national Chinese oil company.
- Managed the design and fabrication of multiple custody metering skids and meter prover skids for an international pipeline company operator.
- Managed the detail design and fabrication of a skid based 38.5 million gallon per year bio-diesel plant.
- Managed the detail design and fabrication of a pilot plant for a major chemical company to verify an improved chemical process.
- Managed the detail design and fabrication for a custody meter skid and prover loop for a South American oil producer's FPSO.
- Managed many projects to fabricate various topsides equipment skids for multiple off shore oil production platforms.
- Managed many projects to fabricate various surface equipment packages for natural gas well production.
- Participated in multiple HAZOPS reviews on projects with the project owners and consulting engineers.
- Managed a three division company for 27 years consisting of the following:
    - Heavy industrial field construction company licensed in TX, LA and OK specializing in the petrochemical and power industries.
    - ASME code vessel [U, S, R, NB] shop and engineered process skid manufacturing.
    - Crude oil desalter product line design and manufacturing utilizing a proprietary design.

PROFESSIONAL EDUCATION:

BArch, University of Arkansas (1972)

Mark A. Piersante, R.E.A.

Senior Project Manager Safety & Environment

SUMMARY OF EXPERIENCE:

Twenty years in the chemical and oil refining industries assuming a number of roles in process engineering and safety, environmental, and management. Positions include Process Engineer, Design Engineer, Environmental Engineer, Environmental & Safety Manager, and Senior Environmental Engineer. Certified HAZOP leader.

PROFESSIONAL HIGHLIGHTS (Process Engineering):

- Designed automated backwash filtering system for highly reactive sulfur chlorides intermediate manufacturing process with feed neutralization and downstream storage systems. Project size: $300,000.

- Designed a 150,000 gallon silicon tetrachloride tank farm. Material is reactive with water. Project size: $1,000,000.

PROFESSIONAL HIGHLIGHTS (Environmental, Health & Safety):

- HAZOP leader for over 25 projects in Petrochemicals, refining and chemicals. Certified leader under the Chevron HAZOP Program.

- Project Manager for preparation of a California Risk Management and Prevention Program (RMPP) for a large fertilizer manufacturing facility. Project size: $400,000

- Obtained permits and managed removal of two underground fuel oil storage tanks, and subsequent soil removal at large lubrication oil additive manufacturing plant. Project size: $250,000

- Project manager for preparation of a hazardous waste incinerator RCRA Part B permit at pesticide manufacturing plant. Project size: $500,000

- Environmental Manager at fertilizer manufacturing plant for 5 years. Responsible for all aspects of environmental compliance, permitting, auditing and inspection, hazardous waste disposal, training, and regulatory agency negotiations.

- Wrote guidelines and implemented procedures for wastewater disposal. Authored legislation allowing land application.

- Environmental and Safety Manager at lubricating oil additives manufacturing plant for three years. Maintained total responsibility for emergency response, hazardous waste management, air pollution control and permitting, wastewater treatment, groundwater monitoring, and plant/lab/personnel health and safety issues.

- Developed complete environmental, emergency response, hazard communication, and other health and safety training programs. Conducted routine and specialized training including hypothetical drills for plant and lab personnel, and outside emergency first responders (police, fire, etc.).

- Supervised wastewater technician, industrial hygienist, and environmental operations personnel.

- Responsible for reducing OSHA-recordable accident frequency to zero from 14 through development of trust and aggressive, direct interaction with plant operating personnel.

- Served as first industry representative on EPA Superfund Amendment and Reauthorization Act (SARA) Title III Local Emergency Planning Committee for the five-county Los Angeles region from 1986-1988.

- Served on California Office of Emergency Services interdisciplinary committee established to develop guidance document for preparation of Risk Management and Prevention Programs (1988).

- Prepared numerous NPDES and city/county sewer discharge permits for industrial facilities.

- Senior Environmental Engineer on Corporate Environmental staff at Chevron for six years. Responsible for all aspects of company compliance with Federal Clean Air Act and EPA Superfund emissions and release reporting. Provided compliance guidance and technical assistance to Chevron manufacturing plants around the world.

- Provided compliance and legal guidance on all aspects of Federal air toxics and operating permits regulations to U.S. chemical manufacturing plants.

- Developed Company-wide programs to prioritize and implement air emissions reductions and implement pollution prevention measures.

- Provided technical assistance on all environmental issues to individual facilities and assisted in selection of consultants and equipment suppliers.

- Provided counsel to senior management on Company policy and strategy decisions involving air pollution and emissions reduction.

- Provided compliance, legal and technical guidance on all aspects of Federal and California emergency planning and response regulations. Responsible for preparation of California facilities' Risk Management and Prevention Programs.

- Project Manager in charge of site investigation and remediation for 10 sites within Chevron's Richmond Refinery. Developed and managed budget of $6 million/year, and $20 million project total. Directed and supervised work activities of site geologists, hydro geologists and project engineers.

- Responsible for negotiations with regulatory agencies and development of regulatory approval and permitting strategy.

- Managed clean-up, treatment and safe disposal of hazardous wastes.

- Directed development of soil and groundwater investigations and reports.

- Selected remedial solutions, issued corresponding work plans and proposals, directed risk assessments, investigations and remedial actions. Participated in development and construction of refinery-wide groundwater extraction system.

- Responsible for all aspects of project health and safety compliance. Directed/supervised work activities of Project Health and Safety Officer and Site Safety Officers.

- Directed/supervised work activities of permit specialists to obtain Army Corps of Engineers, Bay Conservation and Development Commission, State Lands Commission and City permits.

PROFESSIONAL EDUCATION:

BSChE University of Michigan (1979)

Alfred L. Lay, P.E.
Senior Process Engineer

SUMMARY OF EXPERIENCE:

Over 35 years of well rounded "hands-on" experience in the process engineering, detailed design, PSM, project management, construction management, permitting, start-up, and operation, of petroleum refinery and chemical plant projects. Projects have ranged from small revamps to large grass-roots facilities, and have included turn-key, lump-sum, fixed-fee, and cost-plus contracts. Extensive experience in distillation.

PROFESSIONAL HIGHLIGHTS:

- Hydro Area Process Team Leader for major refinery; responsible for the process engineering of all projects in five hydrotreaters, three reformers, hydrogen plant, and hydrocracker.
- Performed study to expand mid-barrel capacity, and reduce energy usage, by swapping services of three hydrotreaters. Project was approved for $30,000,000.
- Eliminated 30 year problem of a unicracker's hydrogen make-up compressors breaking down monthly due to liquids and solids entering the cylinders, by troubleshooting, recommending, and designing corrective actions that solved the problem. These changes allowed the unit to run continuously at capacity and negated the need for a proposed $18,000,000 new compressor project.
- Debottlenecked and eliminated corrosion problems in a hydrogen plant's Selexol unit by troubleshooting, recommending, and designing corrective actions that solved the problem.
- Brought non-functioning refinery groundwater recovery system ($6,000,000 cost) into service by troubleshooting, recommending, and designing corrective actions that solved the original design problems.
- Member of team that developed plan for revising major refinery to meet RFP requirements.
- Process representative for RMPP/Hazop review of three hydrotreater/reformer units.
- Troubleshooting, design, project and construction management of revisions to a refinery's flare and fuel gas systems to correct safety and operating problems.
- Process/Project Engineer on a refinery's expansion including crude unit, FCC, gas oil HDS, SWS, Lo-Cat sulfur plant, new steam system, new flare and fuel gas systems.
- Conceptual design of a system for exporting a refinery's excess fuel gas to two other refineries, plus the design/management of the installation of the on-site portions.
- Energy saving analysis for an oil refinery to reduce fuel consumption.

- Developed fired heater safety standard (fuel gas controls, etc.) for independent refinery.

- Project Manager for the design of Sandia Laboratories Solar Group's thermochemical (reformer/methanator) closed loop pilot plant including design of the reactors.

- Project Manager for the design and installation of a tank farm thermal oxidizer system.

- Heat exchanger ratings, network analyses, and fouling studies.

- Environmental permitting. Troubleshooting and correction of regulatory violations.

- Design of oil patch shipping terminal and steam flood enhanced oil recovery system.

- Manager of Engineering for new west-coast division of this engineering/construction company headquartered in Kansas. Created fifty-man multi-discipline engineering division from scratch and handled projects, which included two crude unit revamps, new FCC unit, and refinery expansion offsites.

- Project Manager for very profitable, lump-sum turnkey engineering/construction project at a local refiner. Project included new tank farm, cooling tower, Naphtha HDS revamp, and relocated TEL facility.

- Project Manager for very profitable, lump-sum turnkey engineering/construction project for an alkyd/polyester resin manufacturer. The plant was expanded by adding four new mixing tanks on load cells, new tankage, new truck loading rack, and new drum loading facility.

- Unit Leader for new FCC unit, and shale oil recovery project for a major engineering/construction firm.

- Senior Project Engineer on coker revamp, sulfur/sulfuric acid plant offsites, etc.

- Process Engineer, Area Project Engineer, and Start-up Engineer for the sulfuric acid, phosphate rock grinding, and phosphoric acid portions of two fertilizer complexes built in Korea.

- Process Engineer, Plant Engineer, and Chief Chemist for fertilizer producer in Illinois. Units included sulfuric acid, phosphoric acid, and diammonium phosphate.

- Assistant Plant Manager for merchant sulfuric acid producer in Illinois.

PROFESSIONAL EDUCATION:

B.S. Chemical Engineering - Purdue University, West Lafayette, Indiana (1959)

Registered Professional Chemical Engineer - California

Robert J. Bugiada, P.E.

Senior Process Engineer

SUMMARY OF EXPERIENCE:

Chemical Process Engineer with many years of diverse experience. Provides solutions to the nation's energy challenges through the optimal selection, design, and operation of large facilities in the energy industry. Ability to simulate process systems, perform engineering calculations, size and select equipment, make presentations to clients, and to manage others.

PROFESSIONAL HIGHLIGHTS:

- Experienced in the Engineering & Construction, Aerospace, and Valuation industries.
- Process engineering skills include simulation, hazard analysis; preparation of heat & material balances, Process Flow Diagrams, Piping & Instrumentation Diagrams (P&IDs), equipment specifications; definition of utility consumption, and instrumentation & control requirements; and supervision of other engineers.
- Project-management skills include utilizing PERT/CPM in project planning, logistical analyses in hardware transportation & testing, linear & dynamic programming in optimization studies, and effective presentations.
- Implemented flare-gas and flare purge & pilot flow-measurement requirements with the installation of ultrasonic GE Panametrics and vortex flowmeters.
- Met flare-gas analysis requirements with the installation of total sulfur and higher heating value analyzers.
- Modeled pyroscrubber air-flow distribution and evaluated NOx-reduction options for the Wilmington calciner.
- Installed steam-assisted ultra low NOx burners on the Naphtha Hydrodesulfurization process heater.
- Upgraded a flare pilot-detection system and installed a new flame-front generator system at BP's FCC flare.
- Updated and validated the simulation model of BP's FCC Main Fractionator and Gas Plant, and generated a new heat & material balance.
- Modeled a boiler flue-gas recirculation system and wrote the AQMD permit application.
- Defined the requirements for a new high-pressure hydrogen pipeline into the BP refinery from Air Products.
- Appraised a 496-MW gas-turbine power plant. Regularly appraised numerous machinery & equipment items.
- Appraised various types of assets for mergers and acquisitions.
- Applied benchmarking studies to estimate excess operating costs for functional obsolescence calculations.
- Highlights include a 155,000-barrel/day (b/d) N.J refinery with its lube base oil plant, and a 129,500 b/d CA refinery, 71 hydroelectric facilities totaling 661 MW, and seven fossil-fueled plants totaling 2,614 MW.
- Traveled internationally to appraise wire & cable-making facilities, and lube-oil blending plants.
- Prepared initial P&IDs for crude distillation units and delayed-coker gas plant of a 165,000-b/d upgrader.
- Designed the silica-catalyst preparation unit of a 512,000-metric-ton-per-year polyethylene plant.
- Performed conceptual studies for converting an existing NH_3 plant to an 800-ton/day MeOH plant by re-rating synthesis gas compressors, reactors, and other equipment items, and generating appropriate material balances.
- Coordinated the maintenance and update of P&IDs, checked hydraulics and revised pump-system designs, and verified electrical loads for two 350 MW combined-cycle modules of the Rabigh Steam Power Plant Extension.

- Developed heat and material balances for a facility to process 10,000 lb/day of liquid agent containing VX nerve gas using Molten Metal Technology's catalytic extraction process.
- Wrote process descriptions, feasibility design reports, and programmatic environmental impact statements (PEIS) for highly enriched uranium and plutonium storage facilities, and wrote PEIS for a tritium supply plant.
- Prepared an exhaustive comparative analysis of cooling methods (air vs. evaporative) and reactor types (heavy vs. light water vs. modular high temperature gas cooled), based on cost, plot space, and resource consumption.
- In charge of the design and testing of the deployable radiator, which collects heat from the batteries and power electronics, and radiates 10 kW to space using 1,500 lb/hr of liquid ammonia.
- Managed and coordinated the design, procurement, manufacture, and test, in accordance with military standards, of all fidelities of radiator hardware and support equipment.
- Managed the development of the Ni-H2 batteries, each with a capacity of 81 Amp-hr, with 76 cells per battery.
- Operated an air heater experiment with a throughput of 1,800 lb/hr of coal and limestone to determine metallurgical degradation of heat-exchanger tube test specimens.
- Collected and reduced test data, and directed unionized mechanics when problems arose at the plant.
- Spent the better part of ten years at a test facility for 70 MW (thermal) sodium-heated steam generators.
- Coordinated the upgrade of the circulating cooling water and chemical leak detection systems.
- Conducted the conceptual economic trade studies when a steam turbine was first being considered.
- Tracked the technical and financial progress of DOE-funded geothermal projects.
- Verified equipment selection, analyzed power cycles, and performed studies for future expansions.
- Modeled financial statements for DOE, financial institutions, and subcontracted accountants and consultants.
- Modeled the life-cycle costing of potential retrofit projects, new building designs, and other solar-energy systems. Considering regional fuel costs and local climactic conditions enabled rapid computer evaluations of candidates for DOE funding and project selection.
- Assisted state energy agencies in evaluating the technical and economic merits of applications for federal grants to schools and hospitals for Energy Conservation Measures. Evaluated technical data packages at the state energy offices around the US.
- Established a database used for screening later projects based on historical simple-payback ranges.

PROFESSIONAL EDUCATION:

M.S. in Chemical Engineering - University of Southern California (2005)
B.S. in Chemical Engineering and Chemistry - Syracuse University, Syracuse (1979)
M.B.A. Pepperdine University (1983)
Certification: Project Management, West Coast University (1989)

LICENSURE AND AFFILIATON:

- Registered Professional Engineer, California and Washington, Chemical Engineering
- American Institute of Chemical Engineers, Southern California Section

RICHARD A. POTTS

Senior Project Manager

SUMMARY OF EXPERIENCE:

Over thirty years of experience in managing projects in an industrial plant environment. Development and design of both new and existing facilities, including land acquisition, and extensive experience in managaing both environmental, health and safety systems, including air, storm, water, wastewater, hazardous waste and solid waste compliance systems.

PROFESSIONAL HIGHLIGHTS:

- Coordinated facility process layout for a $50 million, greenfield, pilot plant to produce ethanol from corn cobs or switch grass. Also managed the plant structural design, including supports for the processing equipment.

- Responsible for design improvements in proprietary process to recover up to 90% of municipal solid waste and convert up to 60% into a filler for use in plastics. General process flow modifications and specific changes to the drying, pelleting and electron beam sterilization processes will result in increased operational efficiency and additional processing capabilities of the system.

- Managed the design, major equipment procurement, construction and start-up of a $13.5 million expansion and modernization project at a hazardous waste prtocessing facility. The project included new buildings, material handling systems, liquid handling and storage facilities, integrated, multriple PLC control system and regenerative thermal oxidizer emission control system. The project included modifications to existing buildings and tank farms, and was completed while maintaining existing production.

- Coordinated the facility major equipment layout for a new off-raod radial tire manufactoring plant ($320 million + equipment by owner). Managed the structural design of all concrete structures, including the machine foundations and pits to accommodate the lard curing vessels.

- Managed the major reorganization of a sporting goods manufactoring facility. The manufactoring process was reagganged in order to incorporate finished goods warehousing and distriburtion into an existing facility.

- Developed and managed a new group utilizing proprietary technology to provide on-site procesing of petroleum refinery K-Waste into fuel for cement kilns. Efforts included process design, equipment design, procurementr, operations and marketing.

- Coordinated the establishment of a team of environmental management professionals and technicians who conducted hazardous materials incidents. Served as Resonpsible Managing Officer for General Engineering Contractor License.

- Responsible for the design, procurement, installation and start-up for anew $1.5 million solvent system at an existing facility. In addition to the new thin film solvent recovery system, the project included a new 350’ rail spur with spill control and containment, new warehouse and processing building for corrosives, new truck unloading facility, new tank farm systems, and provisions for future expansion.

- Devoloped a new facility to provide industiral plant services and hazarous waste treatment. Secured Conditional Use Permit, Air Control Device Permits, Industrial Wastewater Discharge Permit, and Hazardous Waste Facility Permit. Completed site design, including provisions for initial fill & grade for compaction, final grading, utilities, storm water management, vehicle management and landscaping.

- Developed site plan for a proposed solid waste processing facility. Plan inculded plant process layout, building layout, site grading plan, and site utilities plan. Prepared and secured a permit to contruct for the required air control system.

- Provide corporate leadership for the engineering and maintenance efforts at six regional hazardous waste management facilities, including the development and implementation of preventive and predicitve maintenance systems.

- Responsible for the complete conversion of a hazardous waste facility production control, nventory tracking, data and reporting systems. The new hardware and software systems handle Waste Approval, Receiving and Sampling; Analysis and Conformation; Bar Code Tracking and Inventory Control; Production Planning and Process Control; and Customer Billing.

- Developed a Process Safety Management System and Standard Operating Procedures System for a group of hazardous waste processing facilities. The facilities' operations included: pre-approval of materials, receiving, sampling, analysis, storage, processing, packaging and shipping of hazardous wastes.

- Directed the development and implementation of policies and operating procedures to assure compliance with facility permits and government regulations at a hazardous waste treatment and storage facility. Conducted a review of past practices and events which resulted in a reduction of $500,000.00 in proposed fines for previous violations.

- Responsible for establishing systems for ensuring compliance with environmental regulations and permits (air, storm, water, wastewater ad hazardous waste) for multiple regional processing facilities. Assisted in the development and implementation of companion health and safety policies and procedures.

PROFESSIONAL EDUCATION:

Loyola University of Los Angeles, Los Angeles, CA
B.B.A. degree-Management and Finance-1972

University of California – Berkely, Berkely, CA
Chemical Engineering

FRANK KEARNEY, P.E.
Senior Process Engineer

SUMMARY OF EXPERIENCE:

Over 35 years experience in ammonia plants, petroleum refining, and petrochemical industries, assuming a variety of roles in engineering and project management.

PROFESSIONAL HIGHLIGHTS:

- Process Engineer for a refinery upgrade Project for Chevron's Richmond Refinery. Worked on the revamp of three sulfur recovery units. The main segments of the SRU upgrade are new burners in the main reaction furnaces, new sulfur condensers with steam drums, new refractory lining as required, and a new deaerator in the SRU BFW Plant. My responsibilities included P&ID development, hydraulics, instrument specs, and coordination with technical groups in other locations.

- Process Engineer on a Refinery upgrade Project for Chevron's El Segundo refinery. Worked on the FCC unit. The FCC revamp consisted of designing and installing a new deethanizer, a new depropanizer, and a new main air blower. Up until now only the new deethanizer has been installed. I was responsible for all the P&ID work, hydraulics, and tie-ins to the existing refinery. I also provided the process data for new equipment and instrumentation and assisted with the technical supervision of the project.

- Process Engineer at Shell's Martinez refinery. Worked on a number of small projects and environmental projects. The projects included installing a number of control valves in high pressure let down service to reduce leakage, installing new interconnecting feed lines between units to reduce contamination, adding variable speed motors on various air coolers for winterization, and rerouting a number of drains in the hydrogen plant for environmental compliance. I was responsible for all process engineering on these projects including process calculations, P&ID development, hydraulics, tie-ins, new equipment and instrument specifications, and coordination with refinery personnel.

- Process Engineer on a Refinery upgrade Project for ConocoPhillips' Ferndale, Washington refinery. I worked on the FCC unit, evaluating the capacity of existing lines and pumps for the increased flow rates.

- Process Engineer on a clean fuels project for Chevron's Salt Lake City refinery. The major components of the project are a new VGO unit, an HDS upgrade, and new and revamped tankage and offsites. Worked primarily at the refinery accessing the capability of existing lines and equipment to handle the new requirements after the revamp, and coordinating with refinery operations on tie in points and the routing for new lines.

- Process Engineer on an HDS upgrade at BP's Carson refinery. The project consisted of adding a parallel reactor, revamping the existing heater to handle the parallel trains, and the related piping and instrumentation work. Responsibilities included P&ID's, hydraulics, checking existing equipment for the new conditions, and studying the existing refinery DEA and stripped sour water systems to be sure they could handle the increased loads.

- Process Engineer for small projects at BP's Carson Refinery. Did the process engineering for a number of small projects at BP's Carson refinery. The projects included several sulfur plant revamps and upgrades, installing a new condensate collection system, and adding a recovered water system. Responsible for all process engineering work on these projects.

- Lead Process Engineer on a NOx reduction project for TOSCO in Rodeo, California. Project consisted of installing low NOx burners, SCRs, and ammonia injection facilities in a number of process furnaces at the refinery. Responsibilities included process calculations, P&IDs, hydraulics, and helping to prepare equipment and instrument specifications.

- Process Engineer on a FCCU NOx reduction project for BP's Carson Refinery. Project consisted of adding an SCR and ammonia injection facilities to the flue gas discharge from a fluid cat cracker unit, and some minor revamp work. Responsibilities included process calculations, hydraulics, and equipment specifications.

- Lead Systems Engineer for ammonia plant in Trinadad. Developed as-built P & IDs for existing plant as well as P & IDs for revamp work and hydraulics. Prepared equipment specifications.

- Supervised P & ID and instrument checkout of ammonia plant and a 1200-ton/day urea plant in Alaska.

- Process unit leader for entire ammonia plant in Georgia. Included reforming, shift conversion, carbon dioxide removal, ammonia synthesis section, refrigeration, and carbon dioxide compression.

- Designed front end for a methanol plant in Canada.

- Designed new ethylene plant being built in Saudi Arabia. Process design of gasoline hydrotreater and two PSA units. Responsibilities included P & ID development, hydraulics, equipment specifications, vendor coordination, and some technical supervision.

- Redesigned ethylene vaporizers and boil off gas compressors for an ethylene plant expansion in Saudi Arabia. Developed equipment specifications for new PSA unit and assisted with technical supervision.

- Project engineer responsible for all engineering on a refinery improvement project in California. The project major segments included upgrading the refinery instrument and control system, including a new control room and DCS; installing a new process water stripper unit; revamp the sulfur plant; install a new flare and upgrade the existing relief system; replace the existing coker steam out system; and add a tank vapor recovery system.

- Designed flare gas recovery unit and completed a study to upgrade the refinery fuel gas system for a refinery in Algeria.

- Responsible for the process design of a 144 MMSCFD hydrogen plant and a gas handling plant in a refinery in Kuwait. The hydrogen plant included feed gas compressor and central hydrogen makeup compressions facilities. Responsible for all process design work including P & ID development, hydraulics, equipment specifications, and writing the operating manual.

- Unit leader for hydrogen plant and diesel hydrogenation unit of a billion-dollar refinery in Canada which processes synthetic crude from tar sands.

- Designed crude and vacuum unit for a refinery expansion in Louisiana.

- Designed hydrogen sulfide recovery unit and refinery expansion flare system for a refinery in California.

PROFESSIONAL EDUCATION:

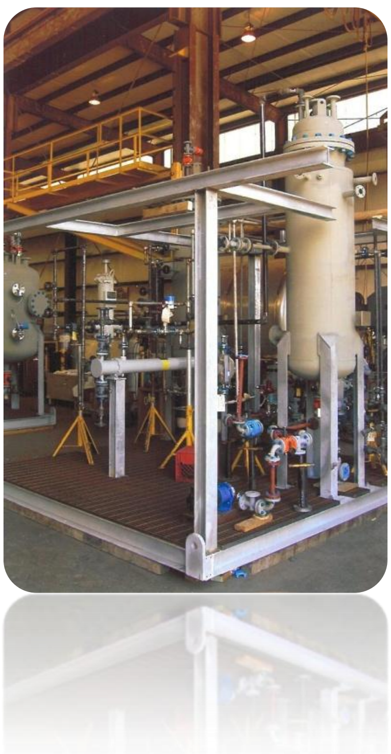
BSChE Newark College of Engineering, Newark, NJ

Registered Professional Engineer in California

P R O J E C T   L I S T

Chemical Projects

Project: Skid Mounted Plant for the Production of PXTS, a new polymeric wood preservative
Client: Akzo-Nobel
Location: Axis, Alabama
Skid Construction: Certified Technical Services
Description: Utilized proprietary reactor designed by Costello and client for a liquid/ liquid reactor that produced a liquid product and a byproduct gas.



Project: Skid Mounted Plant for the Production of a Water Treatment Chemical
Client: Nalco
Location: Chicago, Illinois
Skid Construction: Koch
Description: Plant utilized reactive distillation. R.C. Costello brought this technology to the client. Three distillation columns were eliminated in the final design.

Project: Feasibility Study for Conversion of a Specialty Chemical to an Intensified Process
Client: Penn Specialty Chemicals
Location: Memphis, Tennessee
Skid Construction: None
Description: Consulted with Jeff McDaniels on applying Velocys Microchannel Technology, but client stayed with existing technology.

Project: Skid Mounted Plant for the Production of High Purity Hydrogen Peroxide
Client: Beal Aerospace
Location: McGregor, Texas
Skid Construction: By Client
Description: Plant produced 90% H_2O_2 for rocket fuel oxidant when used with JP5. Safety was a big factor in the design of this facility.

Fisher-Tropsch Liquids Projects

Project: Natural Gas to F-T liquids Feasibility Study with cost estimate
Client: Proprietary – Major U.S. Coal Producer
Location: SW US
Skid Construction: None
Description: Plant utilized the FT technology from Emerging Fuels of Tulsa, Oklahoma.

Project: Waste to F-T liquids Feasibility Study with cost estimate
Client: Sierra Energy
Location: California
Skid Construction: None
Description: Plant utilized the FT technology from Velocys of Plainville, Ohio.

Project: Natural Gas to F-T liquids
Client: Proprietary
Location: SW U.S.
Skid Construction: Yes
Description: Biomass to FT liquids utilizes Emerging Fuels FT Technology.

<u>Biofuels Projects</u>

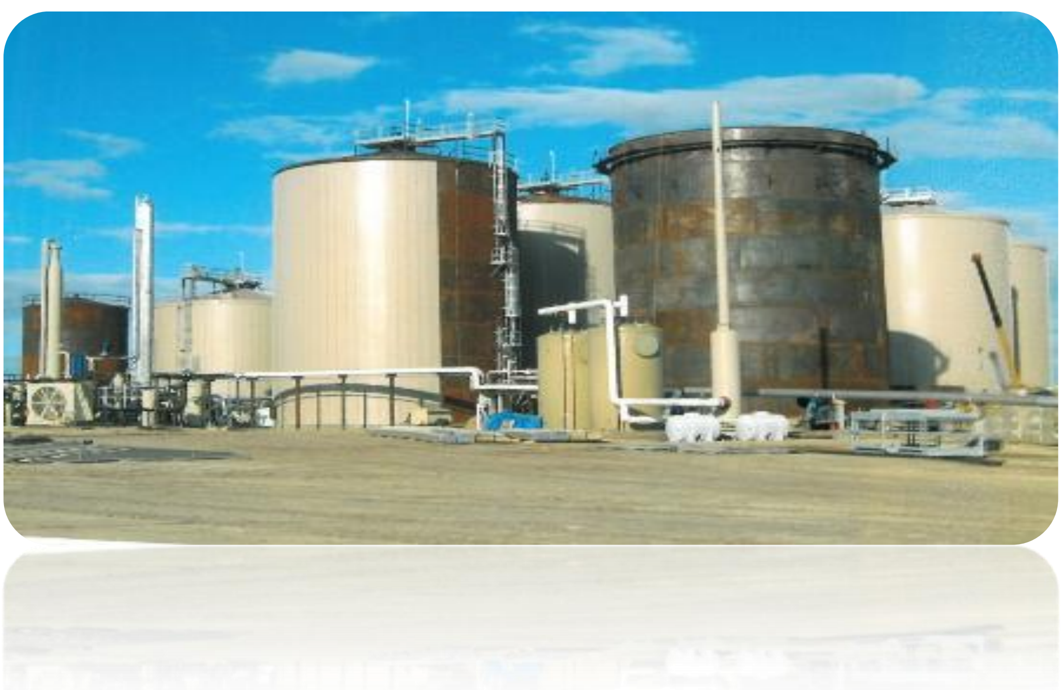
Project: Skid Mounted Plant for the Production of Biodiesel
Client: Kreido Biofuels
Location: Calabasas, California
Skid Construction: Certified Technical Services
Description: Plant utilized the clients Spinning Tube in a Tube (STT®) Reactor Technology. Plant under construction. Skid mounted plant shipped from Pasadena, TX to Newton, IL. Startup 2013.

Project: Front end Engineering Design Package for a Cellulosic Ethanol Pilot Plant
Client: EdenIQ
Location: Visalia, California
Skid Construction: Yes Modular Design
Description: Plant utilized client’s proprietary technology.

Project: Front-End Engineering Design Package for 50 MGY Biodiesel Plant
Client: Northwinds
Location: Pittsfield, Massachusetts
Skid Construction: Never built for lack of funds
Description: Plant utilized the Shockwave Power® Reactor in the transesterification section of the plant. This is a proven PI reactor for liquid/ liquid reactions. The esterification section used a solid catalyst from Lanxess. Also included was a degumming section.

Project: Front-End Engineering Design Package for 25 MGY Biodiesel Plant
Client: EarthFirst Technologies, Inc.
Location: Channahon, Illinois
Skid Construction: Never built for lack of funds
Description: Plant utilized the Shockwave Power® Reactor in the transesterification section of the plant.

Project: Engineering Design & Support
Client: Microgy
Location: Stephenville, Texas
Skid Construction: SouthTex Treaters
Description: This is the largest Biogas plant in the world. Client bought a skid mounted amine unit built from used equipment. We troubleshot and helped to modify the plant until it operated properly. This encompassed extensive changes to the facility and repairs to a large reciprocating compressor. All operating personnel were trained by our firm. Plant produces 2.2 MMSCFD of pipeline grade BioMethane.



Project: Engineering Design & Support
Client: Element Markets (Formerly Microgy)
Location: Texas
Skid Construction: None
Description: Feasibility study for three separate anaerobic digestion sites that flow to one gas processing plant.

a. Preliminary PFD from CHEMCAD
b. Process Description
c. Detailed equipment specification sheets that encompass molecular sieves, compressors, amine units and glycol units.
d. Cost Estimate

Project: Engineering Design & Support
Client: Element Markets (Formerly Microgy)
Location: California
Skid Construction: None
Description: Feasibility study for three separate anaerobic digestion sites and related gas processing plant.

a. Preliminary PFD from CHEMCAD
b. Process Description
c. Detailed equipment specification sheets that encompass molecular sieves, compressors, amine units and glycol units.
d. Cost Estimate

Project: Engineering Design & Support
Client: Element Markets (Formerly Microgy)
Location: Stephenville, Texas
Skid Construction: None
Description: Provided design work to heat integrate the amine unit with the anaerobic digesters so that excess heat from the amine unit heats the digesters in the winter but rejects heat in the summer.

Project:	Distillation Unit
Client:	D'Aquino Bond
Location:	Australia
Skid Construction:	None
Description:	Production of beverage grade ethanol by distillation

Project:	Computer simulation of a corn ethanol plant
Client:	Bibb Engineering
Location:	Louisiana
Skid Construction:	None
Description:	Prepared Computer Simulation in ChemCad Software

Project:	Ethanol Plant Optimization and Troubleshooting
Client:	Parallel Products
Location:	Louisville, KY
Skid Construction:	None
Description:	Improved ethanol distillation column operation

Project:	Design Ethanol Distillation Column
Client:	E-Fuel Corporation
Location:	Multiple
Skid Construction:	None
Description:	Design Ethanol Distillation Column for mini Ethanol plamt

Executive Biography – David Vandor

David Vandor is the Co-Founder & Chief Technology Officer of Expansion Energy LLC, which develops and owns innovative, patented and patent-pending energy-related technologies. David is the inventor or co-inventor of each of Expansion Energy's technologies. His Bachelor of Science degree was obtained from the City College of New York (CUNY) in 1969, followed by a Bachelor of Architecture in 1970. Through 1985, he achieved positions of increasing responsibility at the New York City Planning Commission, dealing with public policy and environmental issues. That was followed by several years of consulting, including for entities seeking cost-effective solutions for deploying alternative fuel vehicles (AFVs). By the mid-1990's, David's work focused exclusively on energy-related matters, through which he developed extensive expertise in the science of cryogenics, which is at the core of many of Expansion Energy's innovative energy & environmental technologies. His work during this period has included the following:

- Co-wrote the New York State "Alternative Fuel Vehicle Act of 1997", establishing incentives for the production and deployment of AFVs in New York State.

- Through 1998, was a member of the New York State Energy Research and Development Authority's (NYSERDA) LNG Study Group.

- In 1999, completed a study for US DOE's Brookhaven National Lab regarding the technical and economic issues associated with producing Liquid Natural Gas (LNG) from Landfill Gas (LFG).

- In 2001, completed NYSERDA PON 559, which offered "An Innovative Liquid Natural Gas (LNG) Storage Model."

- In 2002, completed NYSERDA PON 519-99, which focused on off-pipeline uses of LNG for heating and refrigeration; and quantified the value of "cold recovery" where LNG is vaporized prior to its use as a fuel.

- Also in 2002, with NYSERDA and Praxair co-funding, co-wrote a "Technology Evaluation of Small-Scale LNG Plants."

- From 2002 through 2005, served as a consultant to NYSEG and KeySpan Energy (now National Grid), regarding protocols for LNG systems.

- Through 2006, was a member of NYSERDA's LNG Steering Committee, helping to frame policy for LNG production, storage, transport, and dispensing in New York State.

- Also in 2006, began work on the invention of a cost-effective Small-Scale LNG Production System, which became Expansion Energy's patented "VX Cycle" technology.

- From 2004 through 2006, David completed "The Storage of Cold Compressed Natural Gas (CCNG) in Solution-Mined Salt Caverns," an in-depth R&D study which was co-funded by NYSERDA. The team included Geocomp, a world-renowned geotechnical consulting firm, which confirmed David's hypothesis that solution-mined salt caverns can be used to store cryogenic natural gas.

- Project Director for NYSERDA Contract #18814, examining the feasibility of deploying Expansion Energy's patented utility-scale power storage system, called the "VPS Cycle" at a steam-generating facility operated by Con Edison in New York City. The project team also includes equipment suppliers such as Dresser-Rand, Cameron and Chart Industries as contributors and peer reviewers.

David's R&D work focuses on developing innovative, patentable technologies that have demonstrable commercial value and address a known market need. The following is a sampling of Expansion Energy's patented technologies invented or co-invented by David Vandor:

U.S. Patent No. 7,464,557 B2, a "System and Method for Cold Recovery", granted on December 16, 2008. -- Cold Compressed Natural Gas (CCNG) is a supercritical phase of natural gas, achieved by moderate refrigeration (-116º F and colder), and moderate pressures (700 psig and greater), achieving approximately 85% of the density of LNG. The invention focuses on "cold recovery" during the "shift" from CCNG to CNG.

U.S. Patent 8,020,406, for a "Method and System for the Small-Scale Production of Liquid Natural Gas from Low-Pressure Pipeline Gas" (Granted in the U.S. and in Australia, and pending in other international jurisdictions.) A method and system (called the "VX Cycle") for the small-scale production of LNG using an innovative version of a methane expansion cycle, which does not require a high-pressure feed gas stream or a low-pressure outflow gas "sink". The VX Cycle uses natural gas as both the "product" and the "refrigerant".

U.S. Patent No. 7,821,158 B2, a "System and Method for Power Storage and Release", the "VPS Cycle", granted October 26, 2010. -- The VPS Cycle stores off-peak, low-value electricity as dense, liquid air (L-Air) in aboveground cryogenic vessels. The energy is released by pumping the L-Air to pressure, warming the now-compressed air by waste exhaust heat, and sending the hot, high-pressure air to the combustion chamber of a generator-loaded hot gas expander. During "send-out" the cold energy of the stored L-Air is recovered in a smaller "power loop(s)" that drives one or more additional generators.

U.S. Patent Application No. 12/247,902, for a "System and Method of Carbon Capture and Sequestration", the "VCCS Cycle". (Patented under "fast track" review by USPTO, per its Green Technology Pilot Program.) The VCCS Cycle captures CO2 in a non-aqueous solvent to which an alkali has been added. That alkali can include the alkaline ash (fly ash) that is produced at coal-fired power plants. The reaction between the acidic CO2 (as carbonic acid) and the alkali yields carbonates, water and heat. The non-aqueous solvent allows the carbonates to precipitate out of solution, yielding a dry powder that is non-toxic and has many post-production uses, while avoiding the need for energy intensive water removal (drying) of the carbonate. VCCS also provides for the recovery of valuable rare earth elements, other minerals, and bulk construction materials, while "detoxifying" the fly ash.

U.S. Patent 8,342,246, for "Fracturing Systems and Methods Utilizing Metacritical Phase Natural Gas" (Granted in the U.S. on 1/1/13, and pending internationally.) Vandor's Refrigerated Gas Extraction (VRGE) process uses locally available natural gas to fracture shales and tight hydrocarbon formations and to deliver the proppants used to allow the released hydrocarbons to flow to the surface. The core concept of VRGE is to use "like with like," i.e., to use natural gas (NG) to release and bring to the surface the hydrocarbons trapped in the formation, avoiding the use of large quantities of water "imported" to the well site and avoiding the need to bring costly fracturing fluids such as nitrogen, carbon dioxide or propane to the well site.

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Maple Grove, Minnesota 55369-4718
763-445-5000
greatriverenergy.com

Bio - Sandra Broekema, P.E.

Sandra Broekema is currently Manager of Business Development for Great River Energy. She brings more than 20 years of experience in the energy industry focusing on R & D and new product commercialization in solar, wind and power generation. Sandra has a Bachelor's degree in Mechanical Engineering from the University of Minnesota - Institute of Technology and a Master's in Business Administration from the University of St. Thomas. She holds a Professional Engineering license in the State of Minnesota.

Sandra leads the commercialization initiative for DryFining™ fuel enhancement process and business development for Spiritwood Energy Park Association to secure additional tenants and steam partners for Spiritwood Station combined heat & power plant in North Dakota.

Great River Energy is a not-for-profit electric cooperative owned by 28 member distribution cooperatives. We generate and transmit electricity for members located in the upper Midwest.

Contact:
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Maple Grove, MN 55369-4718
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Cell: (612) 280-8689
E-mail: sbroekema@GREnergy.com
www.greatriverenergy.com

Christopher S. Brown, P. Eng.
Vice President of Engineering, Senior Project Manager

Education
B.A. Sc. Chemical Engineering, University of Waterloo

Summary of Experience and Qualifications

Mr. Brown has been responsible for the engineering design of many of Zeton's pilot plants, and has successfully acted as Project Manager on some of Zeton's key projects. He has been with Zeton since its inception in 1986, and he has been involved in pilot plant related work for 30 years most of which have included dedicated to computer controlled systems for the petroleum, petrochemical, chemical and bioenergy industries, and particularly hydroprocessing technologies, for Zeton Inc.

His experience with Zeton has principally involved systems for Hydroprocessing, FCC, Catalytic Reforming, Catalyst Deactivation and Cyclic Metals Impregnation, including Fixed bed, Fluidized bed and Circulating Fluidized Bed reactors, and alternative energy systems such as Coal Liquefaction, Coal Gasification, Gas to Liquids processes, Biomass Pyrolysis and Biodiesel. He was also responsible for an Ebullating bed system to simulate thermal hydrocracking to upgrade oil sands bitumen. In addition, he has been responsible for systems to test polyolefins reactions and to measure resin viscosity, and other specialty polymer applications.

Mr. Brown has also acquired special experience in commercializing new technology in converting biomass to food chemicals and clean fuel products. He has been with the company in a senior capacity since it was established.

Experience

Successfully completed under budget all projects on which he was directly responsible for project management, design, procurement, manufacture, installation, commissioning and start-up, including:

- a major Hydrocracker/Fractionation pilot plant with flexibility to study multiple operating options and to simulate conditions in 6 refineries world-wide, for BP Oil Research in Britain.

- a specialty polymer pilot plant including cryogenic processing, for one of the Bayer AG group of companies.

- Dual Mode Hydrotreater, for CANMET.

- Catalytic Reforming pilot plant for a research institute, Beijing, China.

- Polyolefins Resin viscosity test unit, for Dow Benelux, The Netherlands and a Polyolefins pilot plant, with two interchangeable reactors, for testing reactions with temperatures ranging from -30^{o}C to 300^{o}C, for Davison Division of W. R. Grace.

- Ebullating Bed Hydrocracker for simulating technology for upgrading oil sands bitumen, Alberta, Canada

- A 40% Coal/60% Vacuum Bottoms Hydroprocessor and Delayed Coker for coal liquefaction co-processing, using an adaptation of German technology.

- Design of a Coal Slurry Pressurized Gasification pilot plant for Texaco.

- High Purity electronic chemical production plant, Cyanamid, USA.

- Two Fluid Catalytic Cracking pilot plants (Davison Circulating Riser) for FCC catalyst testing, for BP of Britain and Repsol Petroleo of Spain.

- a custom Catalyst Steam Deactivation Unit for Shell Research BV, The Netherlands.

- Design and construction supervision of commercial plant to produce Food Chemicals by rapid pyrolysis of biomass.

- Fixed Fluid Bed FCC catalyst pilot plant, a Grace Davison design for which Zeton is sole licensee, to pretreat FCC catalyst, for BP.

- Multi-reactor pilot plant with various combinations of Fixed Bed and CSTR reactors, for Yukong Ltd., S. Korea

<u>Professional Affiliations</u>

Professional Engineers of Ontario.

Leisl Dukhedin-Lalla, Ph.D., P.Eng.
Vice President, Operations

Education

Ph.D., Chemical Engineering, University of Toronto
M.A. Sc., Chemical Engineering, University of Toronto
B.A. Sc., Chemical Engineering, University of Toronto

Summary of Experience and Qualifications

Ms. Dukhedin-Lalla joined Zeton in 2002 with seven years of experience in process development, process and detailed design, construction and commissioning for specialty chemicals production facilities, pilot scale experimental test programs for heavy water production in connection with nuclear power generation. During the last 12 years at Zeton she has worked on several mini-plant projects for Gas-to-Liquids technology and Fischer-Tropsch products processing. In 2013, Ms. Dukhedin-Lalla became the engineering manager at Zeton Inc.

Prior to joining Zeton, she researched, developed and designed a new process for purification of silicon tetrafluoride, and was responsible for design, construction and commissioning of facilities for other products including germane, alkylsilanes and alkylborons, and diborane.

Leisl's experience also extends to HAZOP and safety reviews, which is valuable to Zeton's clients in the design of pilot and production scale modular plants. While with Zeton, Leisl has been involved in project managing, engineering design, equipment specification and selection and coordination with fabrication of Zeton modular mini-plants for technologies such as Fischer-Tropsch product upgrading for the production of clean liquid fuels.

Experience

- senior project manager on a large technology demonstration unit for fine chemicals involving several unit operations including fixed bed reactors, distillation and purification.

- project engineer on a large demonstration scale plant for the processing of Fischer-Tropsch products into clean low sulfur fuels, designed for the use of shut-in natural gas as feed stock.

- project manager and lead engineer on a 10 bpd pilot scale plant for the Fischer-Tropsch synthesis and product upgrading (hydrotreating and hydrocracking) into clean low sulfur fuels

- project manager on study team for a preliminary engineering and capital cost study for a Gas-to-Liquids mini-plant to test new catalyst, for a US location.

- project manager for a 2 bpd pilot plant for a heavy oil upgrading process.

- project manager and lead engineer for basic engineering and cost estimation of a novel 100 bpd heavy oil upgrading demonstration unit

- co-author for 12 published papers on topics such as heavy oil processing and mixtures, behaviour of organic fluids at elevated temperatures and pressures, coal-oil coprocessing and liquefaction, and phase behaviour of complex hydrocarbon mixtures.

- Leisl's Ph.D. thesis was related to complex phase behaviour of heavy oil mixtures using x-ray imaging as applied to Athabasca bitumen, n-dodecane and hydrogen, as well as effects on micelles, waxes and colloids present in asphaltenes.

- modified, reassembled and commissioned a pilot plant for a 4500 l/day heavy water (deuterium) pilot plant at Chalk River laboratories of Atomic Energy of Canada Limited (AECL), the developers of the CANDU nuclear power generation technology

- wrote, compiled and updated calculation data for the chemical processes and design factors associated with heavy water production by catalytic exchange.

- as a senior engineer for Voltaix, Inc., New Jersey, researched, developed and designed a process for purification of silicon tetrafluoride, including being project manager on the scale up program from pilot to production scale. Also responsible for production capacity increase and process improvements for germane (GeH_4) production facilities.

Professional Affiliations

Professional Engineers of Ontario

Research Report

Chemical Analysis and Laboratory Testing of Expansion Energy LLC's

Patented "VCCS™ Cycle":

The Behavior of a Coal Fly Ash Sample Toward Carbon Dioxide Species In Methanol, Water, and Aqueous Methanol

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Abstract

Chemical and process analysis was conducted to validate the core concepts of Expansion Energy LLC's patented "VCCS™ Cycle" technology for fly ash management/remediation and carbon capture and sequestration. Testing and analysis was designed to investigate VCCS's efficacy with respect to two key measures: (i) carbon dioxide binding; and (ii) the extraction (leaching) of representative trace materials from the fly ash.

A fly ash sample from a power plant utilizing lignite coal (North Dakota, USA) was investigated for carbon dioxide binding as well as the leaching of representative trace metals under three slurry carbonation conditions: (i) water; (ii) methanol (5% water); and (iii) "wet" (aqueous) methanol (~50% water). The resulting samples were analyzed by Thermogravimetric Analysis (TGA) for CO_2-loading and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for metals. The results indicate that:

(i) The fly ash sample was able to bind 0.28 tons of CO_2 per ton of fly ash;

(ii) Leachable metals were extracted during the slurry process

(iii) Carbonated fly ash samples derived from methanolic slurries have better handling characteristics than the samples originating from water slurries or aqueous methanol slurries

Notably, leaching and carbonation was accomplished on a 15-minute time scale, and the resultant carbonates were dry, powdery and easily handled (i.e., not "muddy") when derived from methanol slurries. These findings demonstrate the chemical and technical feasibility of the VCCS Cycle technology, and lay the foundation for further work. Future studies will focus on using other types of alkaline materials (instead of coal ash), metals leaching and metals recovery, to gain further insight into the design and economic parameters of the process. The extraction of hazardous and/or economically useful metals from the fly ash into the methanol solvent is an attractive feature that allows for the proper disposal of hazardous waste in concentrated form and/or for further processing to recover marketable elements/minerals—including valuable rare earth minerals plus "bulk" commodities for industrial, construction and agricultural applications.

Introduction

The generation of carbon dioxide (CO_2), fly ash and bottom ash from the combustion of coal and other fuels in thermal power plants presents significant environmental challenges. (Note: The term "fly ash" in this paper refers to both fly ash and bottom ash, including but not limited to coal ash.) Carbon dioxide is produced on a scale affecting global atmospheric chemistry and acidifying all major bodies of water, affecting aquatic species.

In addition, the fly ash that results from the combustion of coal represents a significant solid waste challenge, as experienced from the breaching of coal ash storage reservoirs at the Tennessee Valley Authority's Kingston Fossil power plant in December 2008. That breach caused acute environmental and health concerns, and will cost as much as $1.2 billion for clean-up and other liabilities.[1]

While fly ash can (for now) be utilized in road construction, cement manufacture and other building applications, much of it goes to landfills. Also, the waste lagoons (and dry piles) that store fly ash at its production source (e.g., at power plants) are sources of potential surface and groundwater contamination due to metals leaching out of storage, and from pH effects on the soil and groundwater.

As a result of the above factors, fly ash is facing the threat of increased regulation, including attempts to regulate this material as hazardous waste and to require more stringent methods for its disposal and treatment. Thus, there is a need for a cost-effective and ecologically and technologically feasible strategy to address the substantial volumes of fly ash generated by combusting coal (and other combustion fuels) and CO_2 emissions—and to economically extract the valuable materials contained in fly ash.

Carbonation of fly ash (such as occurs in the VCCS Cycle) has been correlated with reduced leaching of heavy metals and other salts from the ash into the environment, and often is referred to as "fly ash stabilization", with the product sometimes referred to as "stabilized fly ash".[2] The term "stabilization" or "stabilized" refers to the reduced hazard level of carbonated fly ash. In addition, fly ash loses a considerable amount of its fluidity when it is carbonated ('calcified') *in situ*. Predominant theories involve clogging of the microcrystalline pores, metal immobilization due to metal carbonate formation, and changes in the ash product pH profile.[3]

A main objective of Expansion Energy LLC's patented VCCS™ Cycle is to extract CO_2 from the effluent flue gas stream (e.g., from power plants) by reacting the acidic flue gas with the alkaline fly ash in the presence of a suitable (and novel) non-aqueous solvent, which results in the formation of an artificial limestone material—i.e., "mineralization"—thus reducing CO_2 emissions from power plants, incinerators and the like. The resulting materials are expected to find a variety of commercial uses while mitigating the hazardous and non-hazardous waste properties of the effluent gas and fly ash waste streams. In the VCCS Cycle, the fly ash is slurried in methanol and subsequently reacted with flue gas in a reaction vessel. Under these conditions, the CO_2 in the flue gas reacts with the calcium oxide (CaO) present in the fly ash to form calcium carbonate ($CaCO_3$). The essentially dry and flowable carbonated fly ash product resulting from the chemical reaction is separated, while the methanol is reused for further fly ash + CO_2 treatment. In applications at thermal power plants, the energy to drive the VCCS Cycle is derived from waste heat from the power station and supplementally from the heat generated by the chemical reaction itself.

The study described and discussed below represents the proof-of-concept for the VCCS Cycle, and is based on laboratory tests specifically designed to validate its chemistry. The stabilized fly ash product derived from the VCCS Cycle can be utilized in a variety of ways, such as:

- Fill material for road construction and building materials
- Agricultural inputs and artificial limestone
- Soil treatment / de-contamination
- Ocean de-acidification
- To extract rare earth minerals and other valuable materials (e.g., uranium, germanium, etc.)

Background

Coal predominantly consists of combustible organic matter with varying degrees of minerals dispersed throughout. The types and amount of these minerals depend on the grade of the coal and its geographic origin. The organic matter in coal is converted to CO_2 during the combustion process. The carbon dioxide-forming reaction of carbon with oxygen is the source of the heat that generates the steam for the production of electricity. Eq. 1 below shows the two elementary steps of the CO_2-forming process. Thermodynamically, most of the energy is freed in the first elementary step (Eq. 1a).

$$(1a)\ 2\,C + O_2 \longrightarrow 2\,CO$$

$$(1b)\ 2CO + O_2 \longrightarrow 2\,CO_2$$

It is during combustion that the minerals are concentrated in the fly ash product and some of the minerals are converted to their oxides. At this point, calcium oxide (CaO) becomes available and the sulfur and nitrogen oxides are formed as well. Nitrogen oxides are derived not only from the combustion of nitrogen-containing matter in the coal, but also by combustion of the nitrogen present in air. The primary sources of sulfur are the coal's organic components and, to a smaller extent, its mineral content. Mitigation of nitrogen oxide formation can be accomplished through the control of combustion conditions. Sulfur oxide production is determined by the coal itself as an intrinsic property, and it can be addressed by the application of sulfur "scrubbing" technologies.

The mineral composition of coal is caused by several factors. First, the mineral content roughly reflects the average abundance of the chemical elements in the earth's crust, which means that the likelihood of finding a certain element is proportional to its natural abundance in the earth's crust. Examples would be magnesium, titanium and aluminum. Since coal is derived from formerly living matter, certain elements are present above their natural abundance level in the earth's crust as they become enriched in plant or animal matter, such as calcium and sulfur. It is the presence of calcium, as CaO, that gives fly ash its potential for neutralizing CO_2 in flue gas. A third factor is the geochemistry of the region the coal originates from. Notable examples of this variation are the extent to which uranium and germanium are present. Uranium, in particular, is enriched in coal from phosphate bedrock, such as found in the Appalachian Mountains. The presence of uranium in fly ash, at quantities that add an extra degree of "hazard," also offers potential opportunities for uranium recovery. Metals recovery from fly ash will be the subject of a follow-up analysis in a subsequent paper.

For this report, Thomas Schuster Consultants (TSC) evaluated chemical data available in the public domain for North Dakota lignite coal, and the results are given in Appendix 1, which shows the average distribution of chemical elements in coal for the North Dakota coal basins. Data for 205 coal samples reported in the Coal Quality Database of the US Geological Survey was evaluated.[4] The largest variations for the predominant elemental species within the data base are for sulfur, silicon, iron and calcium, and the trace elements for barium.

The basic (alkaline) properties of fly ash are derived from the presence of alkaline metal oxides. Typically the primary alkaline is calcium oxide (CaO). Depending on coal composition, varying amounts of alkaline metal oxides such as sodium oxide (Na_2O), potassium oxide (KO), or barium oxide (BaO) contribute to the alkalinity of the fly ash. It is these alkaline metal oxides which give fly ash its carbonating properties, and thus its potential to capture and sequester CO_2. One key factor of carbonation is the aqueous chemistry of CO_2 (Eq. 2). Eq. 2 plus the additional equations that follow represent the carbonation portion of the VCCS Cycle.

Water sources for VCCS include the flue gas itself and the chemical reaction, so that water from external sources will not be required for VCCS. In fact, VCCS will produce water. VCCS requires that the ratio of liquid water to methanol in the reaction vessel be kept within certain limits.

$$(2)\ CO_2^{gas} \rightleftharpoons CO_2^{aq} + H_2O \rightleftharpoons HCO_3^- \rightleftharpoons H_2CO_3 \text{ or } CO_3^{2-}$$

The first step shown in (Eq. 2) is the physical dissolution of carbon dioxide gas by a given aqueous solvent system. This dissolution is reversible and the equilibrium is driven by the partial pressures of CO_2 in the gas and solvated forms. The bidirectional arrows indicate the reversibility of these processes. High partial pressures of gaseous CO_2 drive the dissolution and the equilibrium to the solution side (the left side). In general, the VCCS Cycle is enhanced by flue gas above atmospheric pressure.

The second step is the capture of the solvated CO_2 by water or a base to form carbonate in the free form (carbonic acid) or as an ion (carbonate itself). Ion formation depends on the alkalinity of the solution. The reaction is reversible as a whole, and the position of the equilibrium is governed by the alkalinity and acidity of the solvent and the partial pressure of gaseous CO_2.

Hydroxylic solvents—such as water or methanol—also play a role in making the alkaline oxides available for carbon capture. The fundamental reaction of water with CaO is given in (Eq. 3), and the equation for methanol (MeOH) given in (Eq. 4).

$$(3)\ CaO + H_2O \longrightarrow Ca(OH)_2 \rightleftharpoons Ca^{2+} + 2\ OH^-$$

$$(4)\ CaO + MeOH \longrightarrow Ca(OH)(OMe)$$

In methanolic solution, the following equilibria (Eqs. 5(a) and 5(b)) describe the principle behavior of the Ca^{2+}/CO_2 system after the initial solvolysis of the CaO.

$$\text{(5a)}\quad 2\,Ca(OH)(OMe) \rightleftharpoons 2\left\{Ca^{2+} + OH^- + OMe^-\right\} \rightleftharpoons Ca(OH)_2 + Ca(OMe)_2$$

$$\text{(5b)}\quad CO_2 + Ca(OR)_2 \rightleftharpoons (RO)CaCO_3R^1 \longrightarrow CaCO_3$$

R = H or Me (for R = R^1 = H)

The choice of a solvent for the process is quite important. Water has a high boiling point and a significant latent heat of evaporation so it would be difficult to remove from a solidifying wet product and would result in a more cement-like, sticky product with poor handling properties. By contrast, a solvent like methanol (as used by the VCCS Cycle) is a better choice, since methanol is easier to remove and yields a dry, more powdery and easier-to-handle material.

The VCCS™ Cycle

Expansion Energy LLC's patented VCCS™ Cycle is illustrated by a Schematic Diagram (Appendix 2), which shows several major components of the continuous process. This section of the report offers a brief overview of the Cycle as illustrated by the Schematic Diagram.

The primary inflow streams to the Cycle are the alkaline ash stream from a coal-fired power plant, stream 1, (which may be augmented or replaced by alkalis from other sources), and the CO_2-containing flue gas, stream 2, produced by the power plant. Stream 1 is shown "arriving" by rail car because the original coal that produced the ash likely arrived by rail car, and any significant quantity of additional alkalis from off-site sources would also likely arrive by rail car. Stream 2 is shown to exit the power plant's flue (E) at some pressure and still warm, and possibly having been treated for contents other than its CO_2 content (e.g., SO_2, NO_2, etc.), but still containing trace amounts of moisture.

The ash stream (1) and any supplemental alkalis enter mixing vessel (A), which also receives pure methanol, as stream 4. Most of the methanol used in the Cycle is regenerated and sent back to the mixing vessel (A) for reuse as the primary solvent. However, some will be lost, requiring a make-up stream of methanol, which is not shown on the Schematic Diagram. Stream 1 becomes a suspension in stream 4, and is sent on to the reaction vessel (B) where the CO_2 contained in the flue gas from stream 2 (after having given up its heat content in subsystem (D)) reacts with the alkalis delivered by stream 1 + 4 to form carbonates, water and heat. Some components of stream 1 + 4, such as sand, remain unchanged and, along with the carbonates formed by the acid + base reaction, will precipitate to the bottom of the reaction vessel, to be mechanically removed as stream 5, returning to the railroad cars (or other means of transport) for delivery to off-site customers. Additionally a relatively small amount of water (6) derived from the methanol regeneration process may need to be added to the reaction vessel (B), augmenting the water produced by the acid + base reaction. However, the water content in the reaction vessel is strictly controlled, so that the methanol delivered by stream 1 + 4 is substantially the "host" solvent, offering a relatively "non-aqueous" medium in which the acid + base reaction occurs. That non-aqueous environment is the key to the “dry” precipitation of the sand, iron oxide and newly formed carbonates that leave the reaction vessel as stream 5.

In order to maintain the mostly non-aqueous conditions in the reaction vessel, wet (aqueous) methanol is removed from the top of the vessel as stream 4 + 6. That stream is sent on to subsystem D where the methanol, water and any salts carried by stream 4 + 6 are separated. (Less than 5% of the solids in the reaction vessel will travel with the 4 + 6 stream.) The regenerated methanol is returned to the mixing vessel as stream 4.

Those components of the flue gas (N_2, Ar, O_2) that do not react with the alkaline components of stream 1 will exit the reaction vessel as stream 8, and be vented or sent for further processing. To the extent that the alkaline content of stream 1 does not match the CO_2 flow rate in the flue gas (2), some CO_2 will also exit as part of stream 8. Up to 100% of the coal-fired power plant’s daily ash stream can constitute stream 1, and up to 100% of the CO_2 content of the flue gas (2) produced daily can be neutralized, if enough alkali is added to stream 1.

The treated flue gas exiting the top of the reaction vessel (B) will carry some methanol vapor with it. That methanol is mostly recovered by condensation in a heat exchanger (condenser C), which is cooled by a flow of refrigerant. The condensed methanol (4) joins the larger regenerated methanol stream that arrives from subsystem D, with the combined methanol stream returned to the mixing vessel (A). The refrigeration (illustrated by stream 3) used in condenser C and in subsystem D is produced by absorption refrigeration (not shown), which is driven by several waste heat sources, including heat in the flue gas, heat produced during the mixing of the methanol with the alkalis in stream 1, and by the heat produced in the reaction vessel (B). That integration of the various heat sources and the absorption chiller is not shown on the Schematic Diagram.

The vast majority of the chemistry occurs in the reaction vessel (B), yielding almost as much solids in stream 5 (by weight) as entered the Cycle as stream 1. The function of subsystem D is to comprehensively treat the continuous but smaller wet methanol (plus salts) stream, separating it into regenerated methanol, water and solids (7) that are subsequently removed by truck (or other means of transport). This proprietary separation process yields separate liquid streams of methanol and water, and a separate stream of solids, stream 7, which will include various compounds (including those that contain valuable rare earth elements), which can be further processed for “byproduct” recovery and/or for treatment as toxic waste. In other words, unlike other CO_2 and fly ash treatments, the VCCS Cycle produces only a modest liquid waste stream, diverting some 95% of the solid products of the reaction vessel as a dry (non-aqueous) stream 5, and, significantly, the Cycle includes a viable deionization component suitable for cost-effectively treating the relatively modest liquid waste stream.

Study Design

The study was approached as a slurry process. The scale of a commercially deployed VCCS Cycle would accommodate the fly ash stream of a standard 500 MW coal fired power plant. A plant of that size produces approximately 400 to 450 tons of fly ash per day. Implementation of this process as a continuous flow process, as opposed to a batch process, would result in the turnover of roughly of 16 t/hr. of ash, which is a reasonable size for a single-reactor slurry process. This mass-over-time consideration determined the experimental time basis for the laboratory tests, which was set to the order of 10 to 20 minutes as an assumed residence time for ash in the reaction vessel.

The reaction conditions were chosen to show differences between water and methanol. In addition, carbonation experiments were conducted under two conditions. The first condition used aqueous sodium bicarbonate solution to simulate an indefinite CO_2 supply, and in the second set of experiments a simulated flue gas (80% nitrogen, 15% CO_2 and 5% O_2) was utilized to mimic power plant conditions. (The simulated flue gas condition is referred to throughout this report as the “purge gas” condition.)

It should be noted that the methanol used in this study was 95% methanol with 5% water. In the bicarbonate experiments, the final water content of the methanolic solutions was on the order of 50% due to the nature of the reagent. These high-water-content solutions are referred to as aqueous methanol in this report. The goal was to establish exhaustive carbonation data through the use of a carbonate reagent to serve as a reference point for the gas purge (simulated flue gas) experiments. Other data to be collected and reported were changes in the pH profile, weight and temperature changes. The temperature change data are necessary information for possible heat recovery opportunities from the reactor. The pH data might serve a possible basis for the development of process control strategies. An aliquot of the fly ash sample was separated crudely into ferromagnetic and non-ferromagnetic constituents. The idea was to see if trace metals and carbonation behavior move accordingly. The inclusion of indium in the determinations was based on its rareness and value, but also because of its routine use as an internal standard in ICP-MS. This use of indium often precludes its routine detection in samples unless unexpected results are investigated. The Test Plan submitted to the laboratory is reproduced in Appendix 3.

Laboratory

Laboratories for bidding were selected according to several criteria: technical capability, experience in the area of the study, reputation, and length of time in business. The study was granted to Wyoming Analytical Laboratories (WAL) based on those factors and pricing.

Discussion

Physical Descriptions

Sample

The fly ash sample was provided by Expansion Energy LLC, which is the developer and owner of the patented VCCS Cycle. The sample was a fine powder of blackish appearance. It was electrostatically charged, suggesting dryness. The sample was split by TSC into two samples in a 2:1 proportion. The lesser portion was magnetized and the magnetic particles crudely removed with a permanent needle magnet. The three resulting samples where submitted to WAL for laboratory testing and analysis. The sample with the original composition was labeled L8444, the magnetically enriched sample L8445, the magnetically depleted sample L8446.

Laboratory Observations

The laboratory communicated that the samples derived from highly aqueous solutions behaved poorly. They were difficult to filter, stuck to the laboratory equipment and were difficult to dry. By contrast, samples derived from methanol handled well, did not stick excessively to laboratory equipment and air-dried easily, yielding a manageable powder.

Instrumental Analysis

Carbon Load

The carbonated fly ash samples were submitted to TGA in order to establish the amount of carbon loading. The measurement principle is that the weight of a sample is monitored while it is heated and weight losses are noted. In this case, weight loss in temperature ranges above 450° C is attributed to the thermal loss of CO_2. Figures 1 and 2 at the end of this paper give example TGA curves in Time (s) *vs.* Loss representation. The loss of CO_2 is well defined in the data and starts at approximately 1500 s (450° C). The curves return to baseline after the transition, indicating completeness of decarboxylation. Tables 1 through 3 summarize the results of the analyses and predictions.

Table 1: Carbon Dioxide loading in Weight Percent.

Sample	Water (Gas Purge)	Water (Bicarbonate)	Methanol (Gas Purge)	Methanol (Bicarbonate)
Bulk Fly Ash	28.37	33.63	28.52	31.85
Magnetic Component	25.64	29.26	22.06	27.33
Non-Magnetic Component	27.19	33.22	28.72	31.42

Table 2: Error estimate (in %) for weight loss data.

Sample	Loss 1	Loss 2	Error
Methanol (Gas) Bulk Fly Ash	28.52	28.61	0.28
Water (Bicarbonate) Non-Magnetic	33.22	34.75	4.40

Table 3: Theoretical ranges for CO_2 loading for ashes originating from this power station (Weight %).

Carbon Dioxide Ranges	Maximum	Minimum
Unadjusted	25.18	14.02
Steinour	38.58	2.85
Steinour (No Sulfur)	41.12	17.13

The data in Table 1 show that the carbon dioxide loading of the CFA samples is on the order of 30% regardless of the solvent selected. (However, as discussed below, the methanol solvent yields carbonates that are more workable and less cementitious.) On the basis of our own analyses, the

Steinour formula (Eq. 6) predicts approximately 27% carbonation for the actual sample we investigated, which is in good agreement with the factual findings. The Steinour formula is designed to provide a quick assessment tool for the total carbonation potential of an ash sample and a loading of approximately 20 to 30% for this work was expected on the basis of this formula. The Steinour formula attempts to account for carbonation antagonizers such as the acidic sulfur oxides.[5] Other species interfering with carbonation are the acidic oxides of phosphorus and possibly nitrogen.

$$(6)\quad CO_2\,(\%) = 0.785\,(CaO - 0.7\,SO_3) + 1.09\,NaO + 0.93\,K_2O$$

With respect to the degree of carbonation, there are no substantial differences between water and methanol visible in the data and the likely reason is that the samples were carbonated exhaustively. The difference between the bicarbonate and the simulated flue gas numbers is attributed to the presence of residual bicarbonate reagent in the former. Comparison of the curves (Figures 1 and 2) shows that the respective CFA materials are different and the loss of fine structure in the weight loss profiles supports the presence of residual reagent in the final product. As a consequence, this demonstrates that it needs to be considered which supplemental reagents/bases can be added to the fly ash mix as there will be carry-over into the final product. There is a small difference between the magnetically enriched, the initial, and the magnetically depleted samples with respect to carbon loading. It appears that the magnetically enriched sample has a slightly lesser capability of CO_2 binding. While small, the difference is consistent throughout all conditions and suggests a reduction of binding capability of approximately 15% and indicates that iron oxides are not available for carbon binding. Iron oxide removal can be considered for high-iron-content ashes.

Based on verbal descriptions by laboratory personal, the samples changed appearance dramatically and substantial amounts of a grayish powder appeared during the exposure of the samples to CO_2. These observations suggest that the reaction of the ash with CO_2 was extensive and effective. The observations also indicate that the metal base was available outside of the sample particulate and that the pore limitations and surface effects observed in dry carbonations do not necessarily apply to slurry processes. Rephrased, in a dry carbonation process, the carbonation is limited to the accessibility of the alkaline metal oxide by the CO_2 through the particulate matrix, while in a slurry process the alkaline metal oxides are dispersed throughout the particulate and liquid components of the slurry.

In summary, these experiments establish that the carbonation of fly ash is readily and exhaustively affected in slurries on short time scales. However, a critical innovation of VCCS is the non-aqueous solvent, methanol, which plays an important role in the "workability" of the carbonated product, with methanol yielding a dry, workable product. In contrast, using water as a solvent yields a wet and cement-like carbonate product that is difficult to work with.

Trace Metals and Metal Leaching

Figures 3 through 6 at the end of this report give graphical representations of the trace metal data. Appendices 4 and 5 show the data in detail in tabulated form. What is clear from the data is that both purge gas and bicarbonate are extremely efficient in leaching metals from the ash on the allotted time scale of 15 minutes, thus confirming the metals extraction potential of the VCCS Cycle. In contrast, the current British standard method requires a two-stage leaching test of combined duration of 24 hrs for leachables of particulate solid wastes, including ashes. In essence, the time constraints suggested in the literature and in standard laboratory protocols for leaching are not relevant for the slurry process investigated herein. This is an extremely favorable outcome.

As expected, there is some preference among the metals toward specific solution conditions. Figure 7 shows the preferences for leaching under purge gas conditions with regard to the two investigated solvents and, in this data set, methanol exhibits better metal salt solvation as compared to water.

Overall, this study was effective in determining the fate of species during slurry carbonation and provided some answers to the leaching behavior of several metals during the VCCS process. Separate work is needed to show trends in a wider series of carefully selected metals. Once trends are identified, conditions can be modified to optimize the leaching profile of a slurry process leveraging the partitioning properties of methanol.

Future Work and Considerations

The results from this work demonstrate the feasibility of the VCCS Cycle in general, and therefore additional work to advance the Cycle toward commercialization is justified. Two items require particular attention: 1) the potential supplementation of the fly ash substrate by suitable materials to increase carbon dioxide removal from the flue gas; and 2) the exploitation and management of valuable metals contained in the fly ash as well as in supplemental substrates.

Additional sources of substrate for the Cycle will be identified and investigated. This might include the salvaging of existing waste piles of fly and bottom ash at the power plant, the pooling of ashes from multiple facilities, use of alkaline waste materials from water desalination, aluminum production, or mining and/or caustic soda production. Each possible supplemental substrate will be reviewed for suitability within the VCCS Cycle on the basis of chemical, ecological and economical aspects. For example, a power plant in close proximity to an aluminum production site may add alkaline aluminum production waste to the VCCS reactor to increase carbon capture from the power plant while providing a waste management solution for the aluminum production waste stream. Alkaline waste from other production processes may be considered as well, but clearly a review of alkaline waste sources is required. The key aspects are: What generates the waste? Where is the waste generated? What is it? Is it suitable for the Cycle? How does it affect the properties and application of the CFA? This is not an overwhelming task, but rather demonstrates the flexibility of the Cycle to provide solutions in addition to carbon remediation and fly ash management at the power station, and many such applications may be identified on a case-by-case basis.

Recovery of hazardous and/or valuable metals from the fly ash is a second, but important, consideration. At this point, tests need to be performed to gain a better understanding of metals recovery using a broader list of elements. When properly designed, such a study will provide the basis for predicting the metals recovery capacity of VCCS. In general, the usefulness of metals removal is twofold: 1) the generation of a more environmentally benign CFA material; and 2) the potential use of the concentrated metals waste in the recovery of rare and important metals.

It is possible that VCCS may also be effective for removing sulfur and mercury from flue gas, which would add to the total value of VCCS deployments. Expansion Energy plans future work to investigate the efficacy of VCCS for those applications.

Conclusions

The laboratory results demonstrate that the proposed VCCS Cycle is feasible. The methanolic slurry process will produce completely carbonated fly ash and is effective in removing leachable metals from the ash particulate. The recovery of certain trace metals is remarkably good—including many rare and valuable metals. This process will also remove the theoretically possible amount of CO_2 from the flue gas depending on CaO content, in this example 0.28 tons of CO_2 per 1 ton of fly ash. The data and observations to date also validate the selection of methanol as the slurry solvent. The actual minimum amount of water required for the process needs to be determined in an additional investigation.

Once metals are removed from the particulate, further enrichment and subsequent purification can be accomplished quite readily with existing industrial processes. Economic considerations will determine the application of the process. The conversion of the fly ash stream from a waste stream to a revenue stream, and the possibility of revenue from valuable metals, will offset some or all expenses of the VCCS process on the whole. General criteria for process deployment might include the hazard level of fly ash, waste disposal options at the power plant location, the pending categorization of coal-based fly ash as "hazardous waste" by the US EPA (or other regulatory body), and the original source and composition of the coal.

Extending the scope of the VCCS Cycle to the treatment of the ashes from municipal waste incineration would be an intriguing application as well, in part because levels of environmentally relevant metals are high in municipal waste streams, and because emission and landfill directives are more stringent for such facilities. This treatment allows for the reduction of leachable metals from the fly ash substrate and allows for the safe disposal of the hazardous components.

In addition to carbon capture & sequestration plus fly ash management applications, VCCS may also find applications as a clean-up process for the feed gases utilized by natural gas processing plants, LNG liquefaction plants, anaerobic digester gas (ADG) facilities, landfill gas (LFG) facilities, and plants that produce industrial gases. VCCS can remove large concentrations of CO_2 and water (and possibly H_2S) from feed gases. VCCS may be especially valuable for feed gas that is particularly "dirty," such as untreated field gas (e.g., at wellheads), ADG and LFG, and where traditional clean-up systems such as molecular sieves or membrane systems may be too expensive or not robust enough to handle high levels of impurities.

Further Materials and Discussion

Appendix 6 is a worksheet for reference and planning purposes for further investigation and analysis. Appendix 6 is a nearly comprehensive alphabetical listing of chemical elements in coal. Its purpose is to provide a basis for screening regarding hazardous and high-value metals that may be recovered in the VCCS Cycle—thereby increasing the economic value of coal and coal ash, while reducing its environmental impact. The “Typical” Coal, Bottom Ash (BA) and Fly Ash (FA) columns reflect the concentration level of an element a laboratory would calibrate analytical equipment for on the basis of industry-standard test methods and empiricism. As an implication, these numbers are a good guideline for what to expect from a coal or fly ash sample, but regional or coal origin variations need to be investigated. The columns headed “Literature” contain values from a variety of literature sources compiled for this report and do not represent an exhaustive effort underlining the significance of regional variations. These values do not necessarily match the values reported in other columns as they are of different background and source.

The “This Study” columns show chemical element levels obtained in this study for leached metals and carbonated fly ash. For the purpose of further discussion and planning, columns titled “’Green’ Metal”, “Energy Metal” and “Worthwhile” were included. The “green” metals are generally “rare earth elements” that are critical raw materials for advanced energy saving, energy storage and energy generation technologies, such as hybrid cars, solar panels, wind turbine components/electronics, and electricity storage (e.g., advanced batteries). The Energy Metal category marks elements utilized in the nuclear energy sector for power generation. “Worthwhile” elements represent a collection of metals that have high economic value in general, but were not grouped into the two other categories. These columns are comprehensive, but entries will require project-based updating from further investigations. It should be realized that Appendix 6 is a true worksheet.

Figure 1: Example TGA Curve Shown as Differential Plot of Time (s) *vs*. Loss. [i]

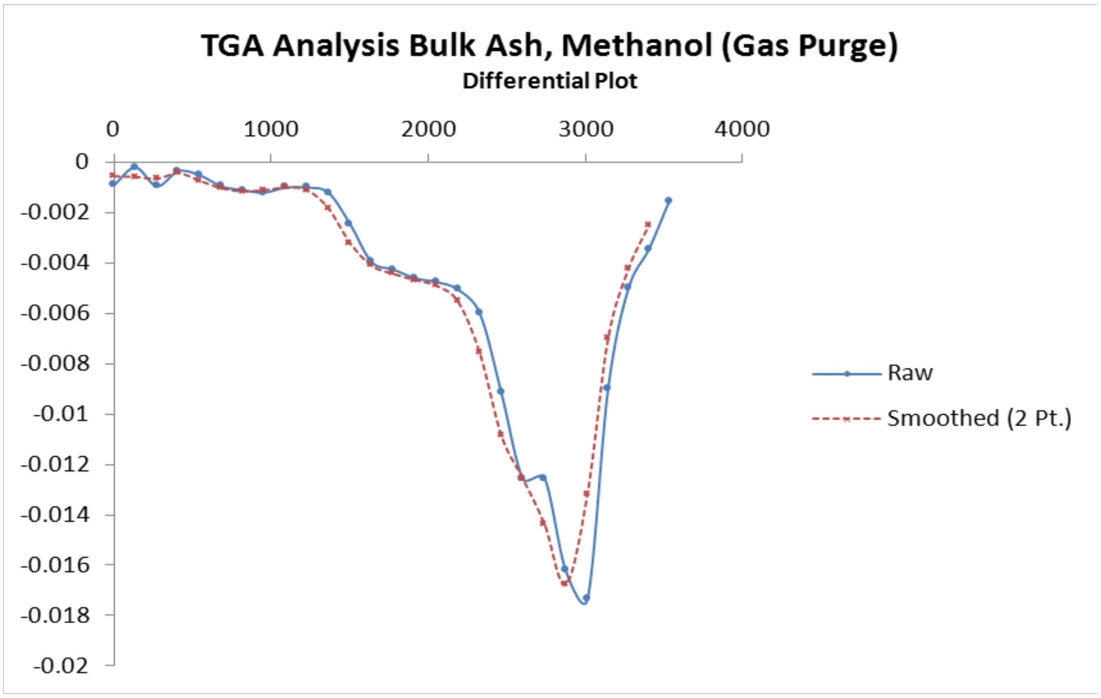
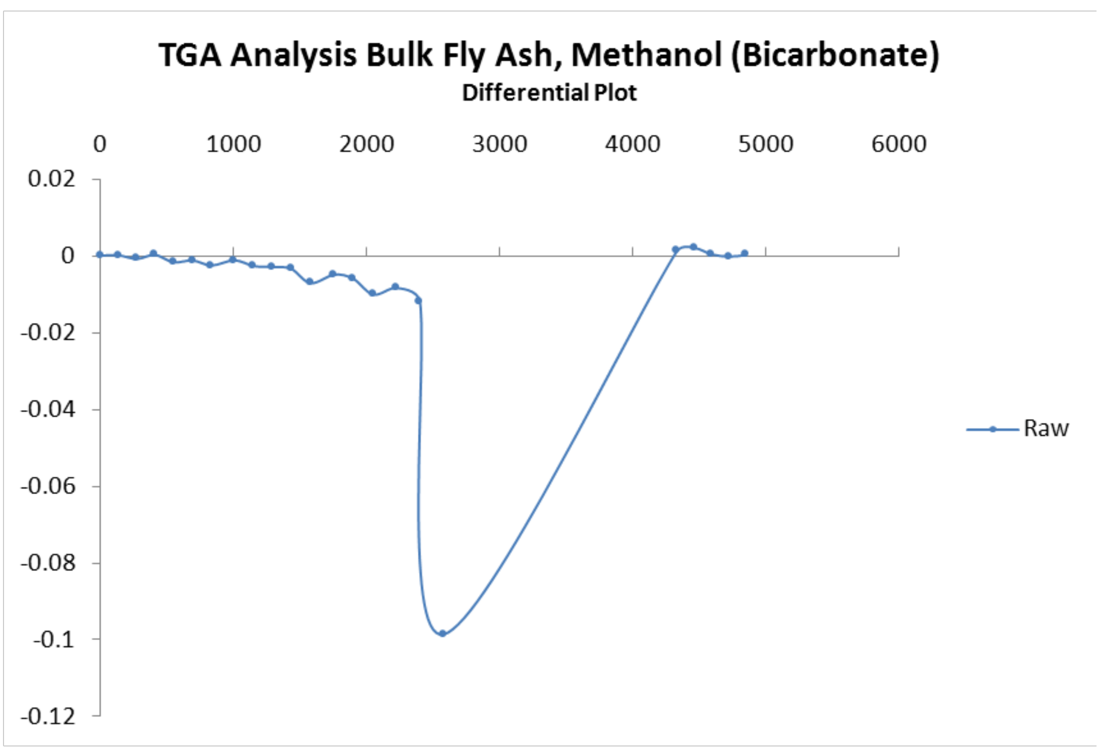
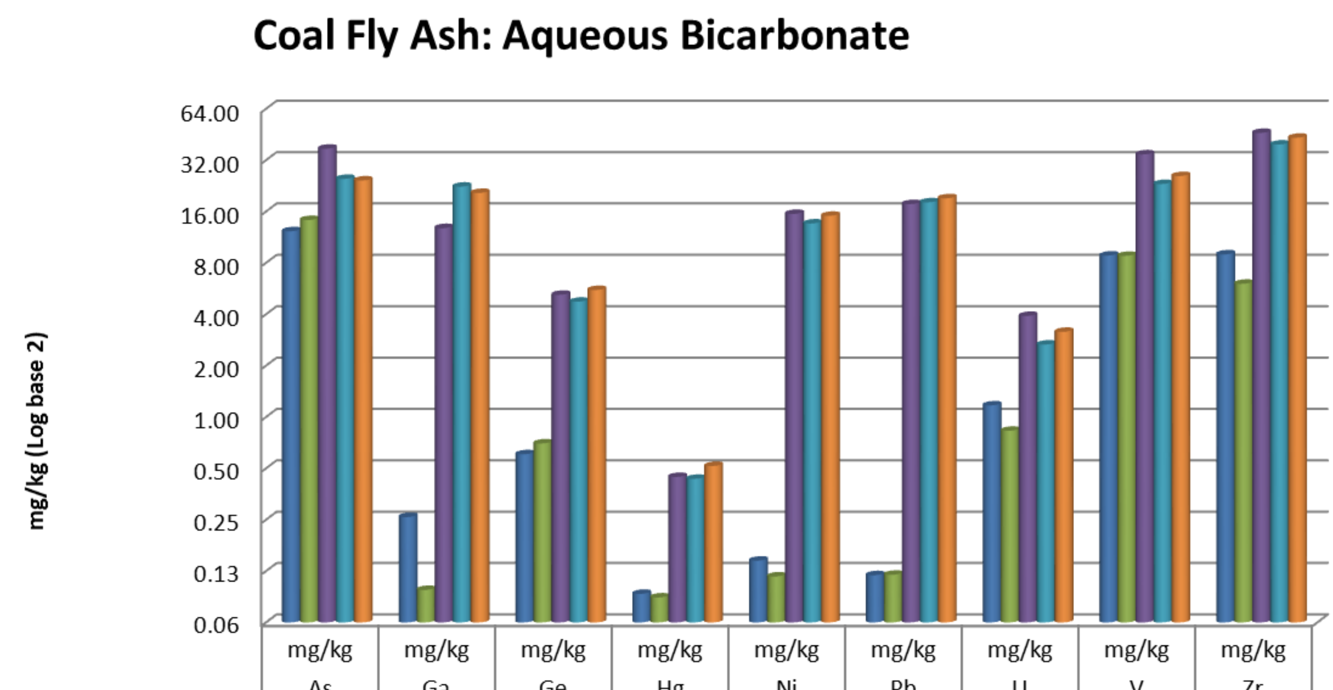


Figure 2: Example TGA Curve Shown as Differential Plot of Time (s) *vs*. Loss.



[i] Differential determined as Value (Time 1) – Value (Time 2); smoothed data curve is 2-point moving average.

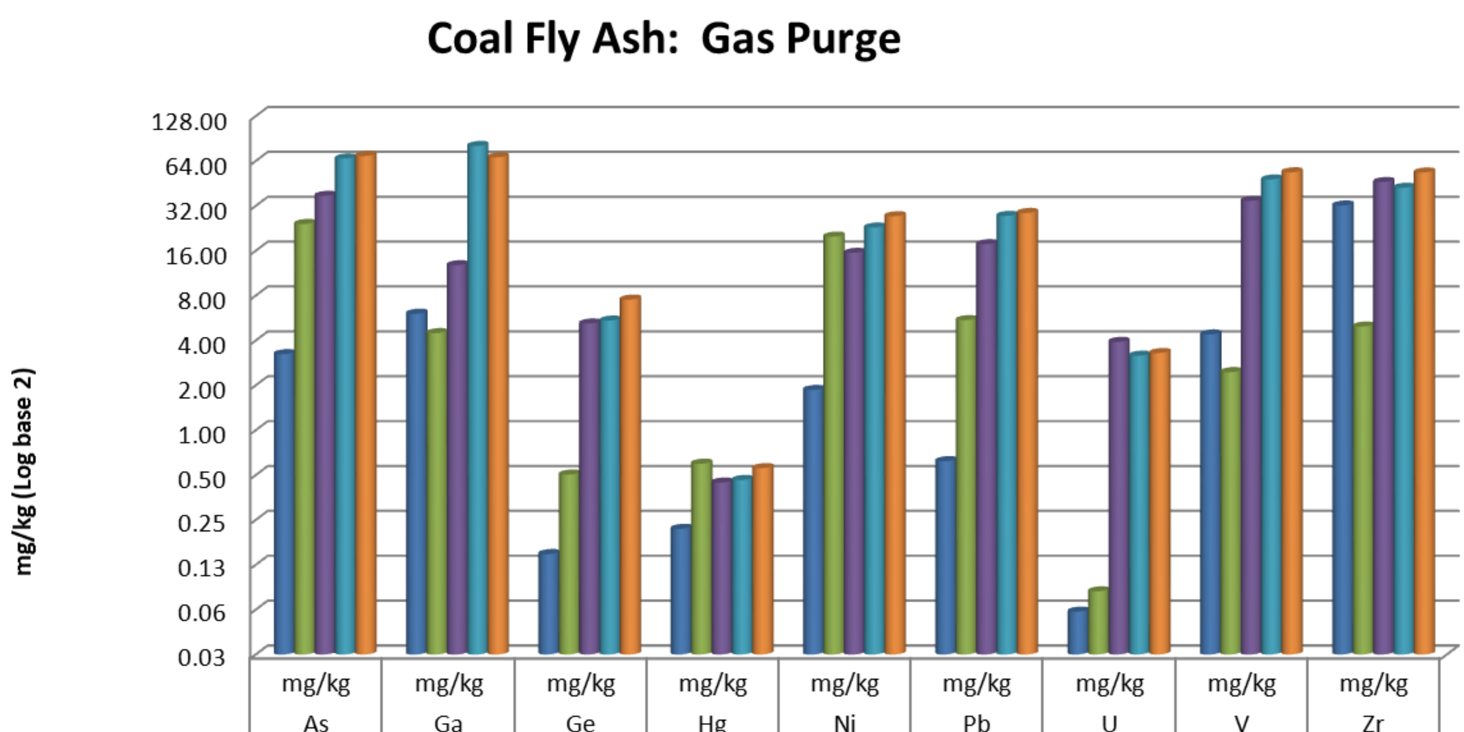
Figure 3: Representation of ICP-MS Data for Trace Metals Distribution under Bicarbonate Conditions as Log Base 2 Plot.[i]



	mg/kg As	mg/kg Ga	mg/kg Ge	mg/kg Hg	mg/kg Ni	mg/kg Pb	mg/kg U	mg/kg V	mg/kg Zr
Bicarbonate, Water, Filtrate	12.3	0.3	0.6	0.09	0.1	0.1	1.2	8.8	9.0
Bicarbonate, Methanolic, Filtrate	14.3	0.1	0.7	0.09	0.1	0.1	0.8	8.8	6.0
Fly Ash	37.4	12.8	5.2	0.45	15.5	17.7	3.9	34.6	46.2
Bicarbonate, Water, Precipitate	24.9	22.4	4.7	0.43	13.6	18.1	2.7	23.2	39.5
Bicarbonate, Methanolic, Precipitate	24.3	20.6	5.6	0.52	15.1	19.1	3.2	25.8	43.3

[i] In this chart, "Filtrate" refers to the solvent containing the leachable, and "Precipitate" refers to the carbonated fly ash.

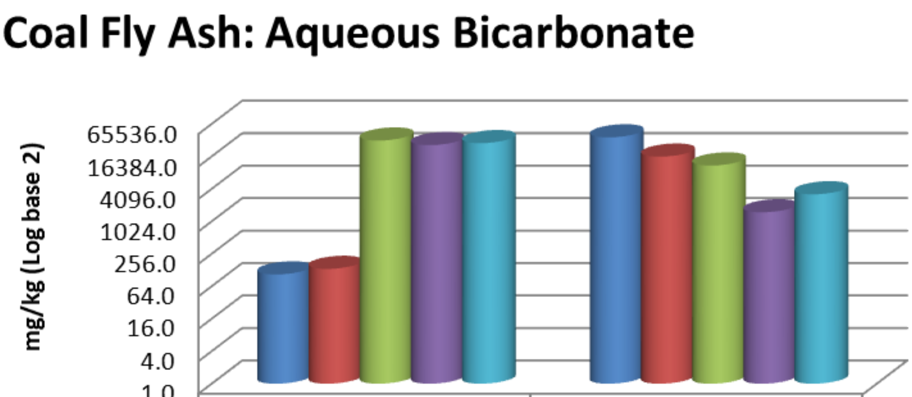
Figure 4: Representation of ICP-MS Data for Trace Metals Distribution under Purge Gas Conditions as Log Base 2 Plot.[i]



	mg/kg As	mg/kg Ga	mg/kg Ge	mg/kg Hg	mg/kg Ni	mg/kg Pb	mg/kg U	mg/kg V	mg/kg Zr
Purge, Water, Filtrate	3.2	6.1	0.1	0.22	1.9	0.6	0.1	4.4	32.2
Purge, Methanolic, Filtrate	24.2	4.5	0.5	0.60	19.9	5.5	0.1	2.5	5.0
Fly Ash	37.4	12.8	5.2	0.45	15.5	17.7	3.9	34.6	46.2
Purge, Water, Precipitate	66.5	80.7	5.4	0.46	22.9	27.4	3.2	48.1	42.4
Purge, Methanolic, Precipitate	69.2	67.8	7.5	0.56	27.3	28.7	3.3	53.8	53.6

[i] In this chart, "Filtrate" refers to the evaporated solvent containing the leachable, and "Precipitate" refers to the carbonated fly ash.

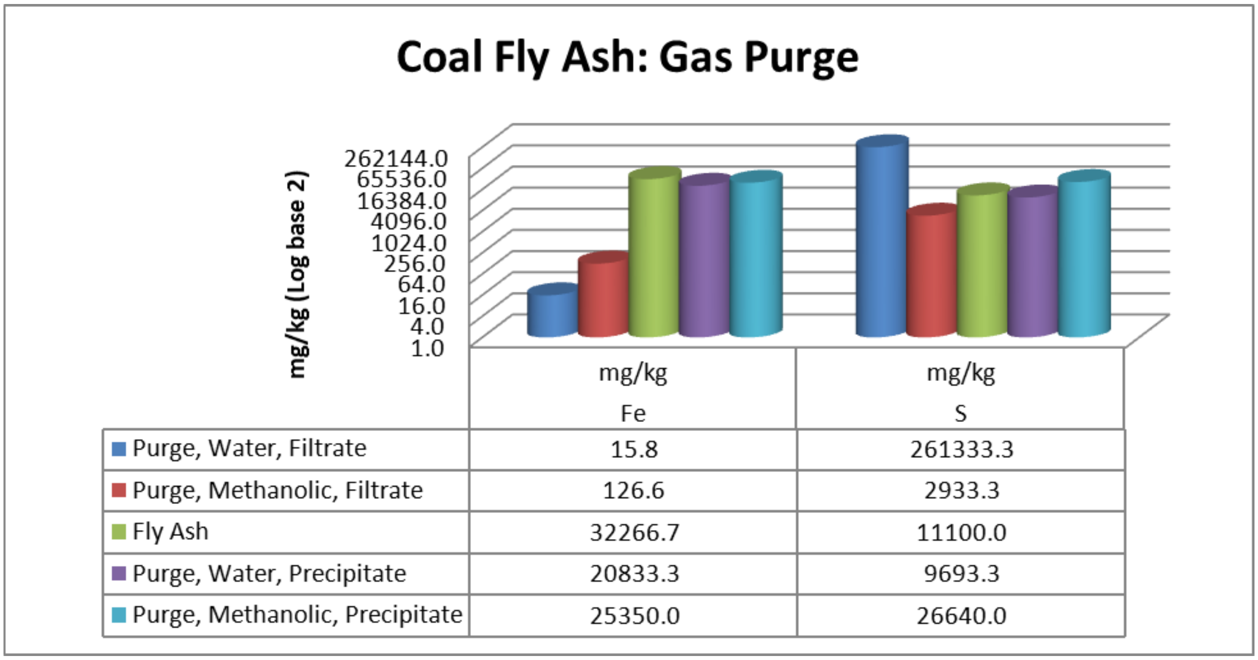
Figure 5: Representation of ICP-MS Data for Iron and Sulfur Distribution under Bicarbonate Conditions as Log Base 2 Plot.[i]



	mg/kg Fe	mg/kg S
Bicarbonate, Water, Filtrate	106.3	36950.0
Bicarbonate, Methanolic, Filtrate	134.7	16233.3
Fly Ash	32266.7	11100.0
Bicarbonate, Water, Precipitate	26533.3	1510.0
Bicarbonate, Methanolic, Precipitate	28900.0	3250.0

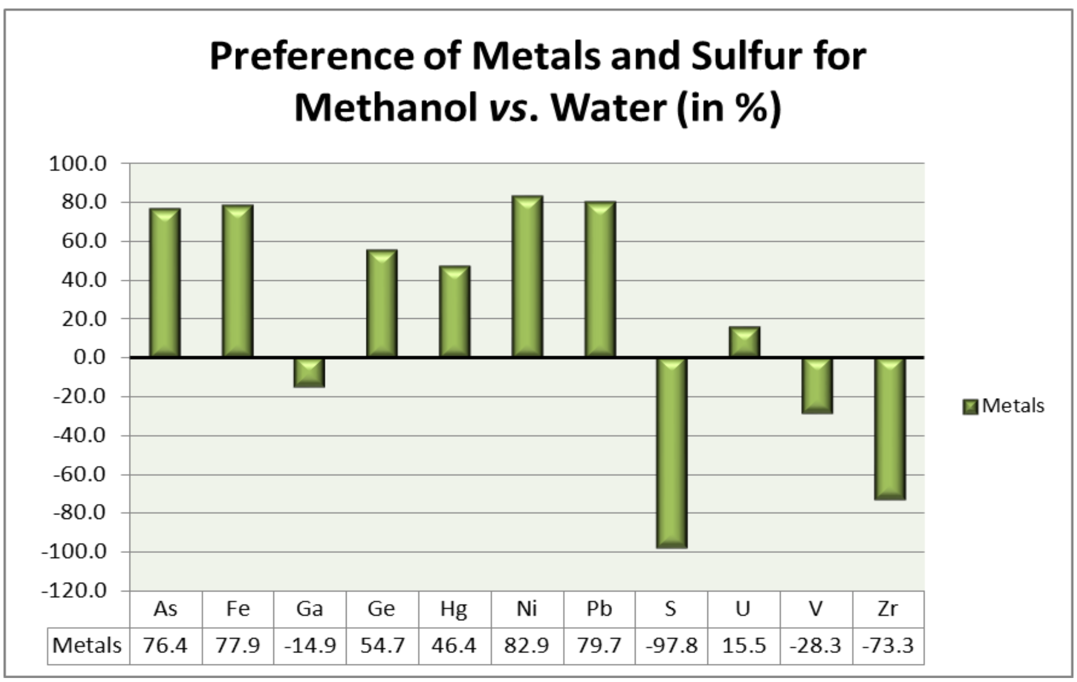
[i] In this chart, "Filtrate" refers to the solvent containing the leachable, and "Precipitate" to the carbonated fly ash.

Figure 6: Representation of ICP-MS Data for Iron and Sulfur Distribution under Purge Gas Conditions as Log Base 2 Plot.[i]



	mg/kg Fe	mg/kg S
Purge, Water, Filtrate	15.8	261333.3
Purge, Methanolic, Filtrate	126.6	2933.3
Fly Ash	32266.7	11100.0
Purge, Water, Precipitate	20833.3	9693.3
Purge, Methanolic, Precipitate	25350.0	26640.0

Figure 7. Relative Partitioning of Selected Trace Elements and Preference for Methanol.[i]



	As	Fe	Ga	Ge	Hg	Ni	Pb	S	U	V	Zr
Metals	76.4	77.9	-14.9	54.7	46.4	82.9	79.7	-97.8	15.5	-28.3	-73.3

[i] Positive values indicate preference for methanol.

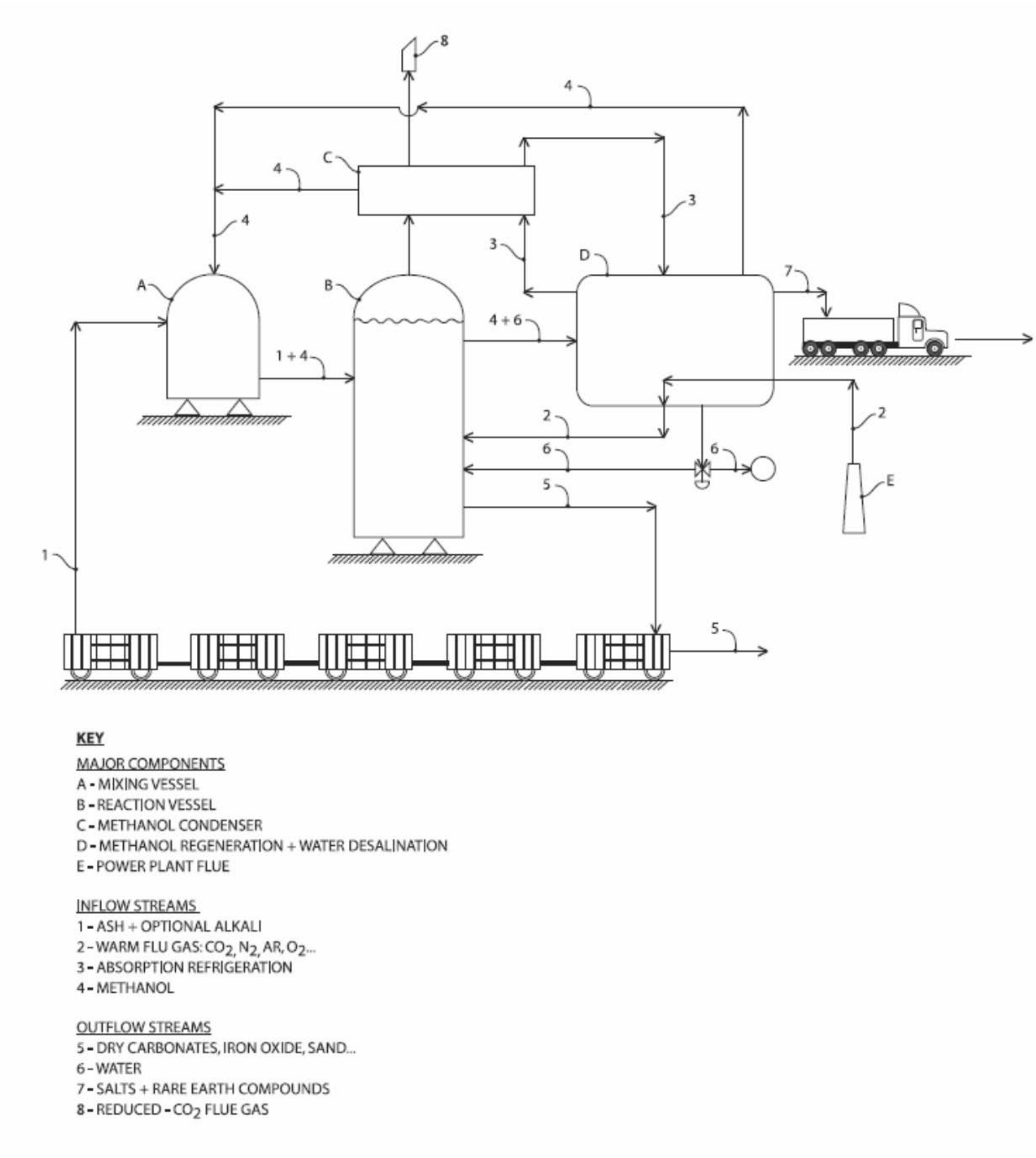
Appendix 1: Statistical Evaluation of North Dakota Coal (USGS Data) and Comparison with Fly Ash Data (ppm, this report).

Element	Si	Al	Ca	Mg	Na	K	Fe	Ti	S	Ag	As	Au	B	Ba	Be
USGS[i]	23.0[ii]	9.1[ii]	15.4[ii]	5.5[ii]	5.2[ii]	0.5[ii]	8.6[ii]	0.6[ii]	17.1[ii]	0.08	8.42	0.60	129.55	680.25	0.92
FA[iii]	23.8[ii]	10.4[ii]	25.4[ii]	6.8[ii]	5.9[ii]	0.6[ii]	7.3[ii]	0.4[ii]	14.6[ii]		37.2				
Element	Bi	Br	Cd	Ce	Cl	Co	Cr	Cs	Cu	Dy	Er	Eu	F	Ga	Gd
USGS	1.05	0.00	0.11	11.42	110.00	2.69	6.78	NR[iv]	6.95	2.69	0.49	0.17	32.99	3.11	2.20
FA														4.8	
Element	Ge	Hf	Hg	Ho	In	Ir	La	Li	Lu	Mn	Mo	Nb	Nd	Ni	Os
USGS	2.55	6.15	0.13	0.88	3.17	3.27	7.38	3.53	1.31	84.39	3.83	2.40	7.85	3.98	1.93
FA	5.2		0.45		ND[v]									15.5	
Element	Os	P	Pb	Pd	Pr	Pt	Rb	Re	Rh	Ru	Sb	Sc	Se	Sm	Sn
USGS	1.93	293.31	3.66	0.11	8.95	0.64	NR	3.01	0.23	0.64	0.58	1.98	0.79	3.01	0.52
FA			17.7												
Element	Sr	Ta	Tb	Te	Th	Tl	Tm	U	V	W	Y	Yb	Zn	Zr	
USGS	334.37	43.16	4.16	NR	2.23	0.77	0.49	1.53	11.93	3.27	6.49	0.64	10.90	22.40	
FA								3.9	34.6					46.2	

[i] USGS data based on coal except as noted.
[ii] Data in % based on ash.
[iii] FA: Fly ash, this study. Values in % extrapolated from data communicated by Expansion Energy LLC.
[iv] NR: Not Reported
[v] ND: Not Detected

Appendix 2. Schematic Diagram of the VCCS™ Cycle

US Patents No. RE 45,309 (7,947,240); 8,252,242 and 8,501,125
Japan Patent No. 4880098
Canada Patent No. 2,739,743 and 2,836,239
Australia Patent No. 2009302737 and 2012256278
China Patent No. 200980149295.6
+
Additional International Patents Pending



Appendix 3: Study Protocol for Fly Ash Analysis.

Test Plan:

a. Materials:

   i. Fresh fly ash (lignite North Dakota)

   ii. Magnetic fly ash components

   iii. Non-magnetic fly ash components

   iv. 95% methanol

   v. di-Water

   vi. Sodium bicarbonate (Metal Analysis grade)

b. Reagents:

   i. Reagent R: 1 L of a 5 w% solution of sodium bicarbonate in di-water.

   ii. Reagent S: 1 L of aqueous carbonate solution (pH = 5.6).

c. Titration parameters:

   i. Potentiometric pH determination of aqueous and methanolic slurries:

   Starting at time t = 300 s, every 30 s are added 2.5 mL of R to the samples C and D. Temperature is determined within 5 sec after addition and the pH is determined 25 s after addition. Additions are continued every 30 s to time point 1200 s. The last temperature is determined at t = 1205 s and the last pH is determined at t = 1225 s.

d. Experiments (titration):

   i. 20 mL of 95% methanol (Sample A) and separately 20 mL of di-Water (Sample B) are placed in a suitable glass vessel and the pH(pS) and the solution temperature are determined and recorded. Subsequently, 50 mL of R are added to each and the pH(pS) and the solution temperature are determined and recorded. Also, any visible changes to the solutions are to be documented.

   ii. At t = 0 sec, 5 g of fly ash are slurried in 20 mL of 95% methanol (Sample C) and the pH(pS) and temperature of the solution are determined and recorded. Titrate according to c.i. The mixture is filtered and the filter cake washed with 20 mL of 95% methanol. The filtrate and washings are combined and reduced to dryness. The weight of the residue is recorded. The filter cake is allowed to air dry overnight and the weight is recorded.

iii. At t = 0 sec, 5 g of fly ash are slurried in 20 mL of di-water (Sample D) and the pH and temperature of the solution are determined and recorded. Titrate according to c.i. The mixture is filtered and the filter cake washed with 20 mL of di-water. The filtrate and washings are combined and reduced to dryness. The weight of the residue is recorded. The filter cake is allowed to air dry overnight and the weight is recorded.

iv. A 2 g sample of each of the filter cakes (d.ii. and d.iii.) are slurried in 20 mL of pH 5.6 water for 5 minutes, filtered and subsequently washed with 20 mL of di-water. The filtrate and washings are combined and the pH is determined. The filter cake is allowed to air dry overnight and the weight is determined.

v. Samples of the filter cakes (d.ii. and d.iii.) are dried at 105 °C for 5 hours. These samples are submitted to TGA. Temperature range ambient to 850 °C. Details will be discussed with the testing laboratory.

e. Experiments (gassed)

i. 20 mL of 95% methanol (Sample A) and separately 20 mL of di-Water (Sample B) are placed in a suitable glass vessel and the pH(pS) and the solution temperature are determined and recorded. Subsequently, simulated flue gas is purged through the solutions for 10 min. pH(pS) and temperature are determined again within 1 min of the end of gas flow.

ii. At t = 0 sec, 5 g of fly ash are slurried in 20 mL of 95% methanol (Sample E) and the pH(pS) and temperature of the solution are determined and recorded. Simulated flue gas will be purged through the solution from t= 300 to 900 s and the flow rate is monitored. pH(pS) and temperature readings will be acquired every 30 s. The mixture is filtered and the filter cake washed with 20 mL of 95% methanol. The filtrate and washings are combined and reduced to dryness. The weight of the residue is recorded. The filter cake is allowed to air dry overnight and the weight is recorded.

iii. At t = 0 sec, 5 g of fly ash are slurried in 20 mL of di-water (Sample F) and the pH and temperature of the solution are determined and recorded. Simulated flue gas will be purged through the solution from t= 300 to 900 s and the flow rate is monitored. pH and temperature readings will be acquired every 30 s. The mixture is filtered and the filter cake washed with 20 mL of di-water. The filtrate and washings are combined and reduced to dryness. The weight of the residue is recorded. The filter cake is allowed to air dry overnight and the weight is recorded.

iv. A 2 g sample of each of the filter cakes (e.ii. and e.iii.) are slurried in 20 mL of pH 5.6 water for 5 minutes, filtered and subsequently washed with 20 mL of di-water. The filtrate and washings are combined and the pH is determined. The filter cake is allowed to air dry overnight and the weight is determined.

v. Samples of the filter cakes (e.ii. and e.iii.) are dried at 105 °C for 5 hours. These samples are submitted to TGA. Temperature range ambient to 850 °C. Details will be discussed with the testing laboratory.

f. Metals Panel

i. The filtrate residues (d.ii., d.iii., e.ii. and e.iii.), filter cakes (d.ii, d.iii., e.ii., and e.iii.), and fly ashes (a.i., a.ii., a.iii.) are submitted to a metals panel by ICP/MS. Target metals are Fe, Ni, V, Pb, Hg, U, Ge, As, Ga, In, and Zr. Elements to include are S.

Appendix 4: Compiled ICP-MS Data for Bicarbonate Conditions. Data Shown for Completeness.

	As	Fe	Ga	Ge	Hg	Ni	Pb	S	U	V	Zr
Sample ID	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
L8444-DI-R-F (residue)[i]	12.5	114	0.301	0.737	0.098	0.129	0.085	36,300	1.17	9.08	9.35
L8445-DI-R-F (residue)	12.3	76.9	0.232	0.485	0.091	0.151	0.118	37,700	1.15	8.93	8.27
L8446-DI-R-F (residue)	12.0	128	0.245	0.593	0.087	0.152	0.152	36,850	1.19	8.49	9.31
L8444-MeOH-R-F (residue)	13.2	84.6	0.080	0.628	0.083	0.112	0.071	18,000	0.934	8.70	7.69
L8445-MeOH-R-F (residue)	14.8	233	0.122	0.761	0.091	0.130	0.128	15,400	0.773	8.61	4.98
L8446-MeOH-R-F (residue)	14.8	86.4	0.089	0.71	0.089	0.107	0.158	15,300	0.783	9.09	5.44
L8444-initial	39.2	28,000	10.6	4.16	0.405	15.7	17.9	10,800	3.94	36.6	44.3
L8445-initial	38.3	45,000	14.9	6.73	0.441	17.0	17.3	11,600	3.97	34.3	49.9
L8446 initial	34.6	23,800	12.9	4.72	0.491	13.8	17.9	10,900	3.83	32.9	44.5
L8444-DI-R-C1 [ii]	24.0	23,000	23.0	4.07	0.424	13.0	17.4	1,540	2.63	22.3	40.0
L8445-DI-R-C1	27.2	36,300	20.7	5.84	0.435	14.7	18.8	1,400	2.81	24.2	40.9
L8446-DI-R-C1	25.6	29650	21.85	4.955	0.4295	13.85	18.1	1470	2.72	23.25	40.45
L8444-MeOH-R-C1	23.9	25,400	21.9	4.99	0.5	14.4	18.6	2,830	2.99	24.7	40.2
L8445-MeOH-R-C1	26.0	37,400	20.6	6.81	0.587	16.9	19.9	3,520	3.41	27.1	47.1
L8446-MeOH-R-C1	23.1	23,900	19.2	4.85	0.462	14.0	18.9	3,400	3.07	25.7	42.7

[i] "residue" refers to the dissolved matter in the solvent. This is where the leachables are.
[ii] Entries ending in "-R-C1" identify carbonated fly ash.

Appendix 5: Compiled ICP-MS Data for Purge Gas Conditions. Data Shown for Completeness.

	As	Fe	Ga	Ge	Hg	Ni	Pb	S	U	V	Zr
Sample ID	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
L8444-DI-P-F (residue)[i]	3.23	16.6	12.1	0.171	0.230	1.98	0.84	245000	0.018	4.79	31.1
L8445-DI-P-F (residue)	4.32	16.5	4.15	0.164	0.266	1.34	0.55	301400	0.15	7.52	39.9
L8446-DI-P-F (residue)	2.16	14.2	1.90	0.108	0.158	2.27	0.47	237600	0.014	0.87	25.5
L8444-MeOH-P-F (residue)	35.5	93.8	3.04	0.224	0.620	15.7	5.78	3856	0.076	2.84	3.97
L8445-MeOH-P-F (residue)	23.0	173	4.95	0.902	0.518	22.0	5.16	1723	0.093	2.36	6.13
L8446-MeOH-P-F (residue)	14.1	113	5.46	0.386	0.650	22.0	5.5	3221	0.08	2.16	4.79
L8444-initial	39.2	28,000	10.6	4.16	0.405	15.7	17.9	10,800	3.94	36.6	44.3
L8445-initial	38.3	45,000	14.9	6.73	0.441	17.0	17.3	11,600	3.97	34.3	49.9
L8446 initial	34.6	23,800	12.9	4.72	0.491	13.8	17.9	10,900	3.83	32.9	44.5
L8444-DI-P-C1 [ii]	59.0	16300	77.1	4.67	0.47	21.1	27.9	6718	3.10	47.6	37.8
L8445-DI-P-C1	67.8	28700	86.4	7.64	0.47	25.3	27.6	7722	3.22	47.9	42.7
L8446-DI-P-C1	72.8	17500	78.6	4.00	0.45	22.3	26.8	14640	3.16	48.9	46.6
L8444-MeOH-P-C1	70.3	23100	82.5	5.82	0.46	23.8	27.2	11181	3.19	48.4	44.65
L8445-MeOH-P-C1	78.2	36200	77.4	10.8	0.66	26.1	29.8	27750	3.20	54.1	58.1
L8446-MeOH-P-C1	62.2	19300	60.8	6.33	0.56	26.0	27.8	27500	3.30	54.1	50.3

[i] "residue" refers to the dissolved matter in the solvent. This is where the leachables are

[ii] Entries ending in "-R-C1" identify carbonated fly ash.

Appendix 6: Element Worksheet for Coal with Metal Value/Use Designations

Method	Element	Cont.	Typ. Coal	Typ. BA	Typ. FA	Coal Literature Ranges	Ash Literature Ranges	This Study - Filtrate	This Study - FA	"Green" Metal	Energy Metal	Worth-while
NAA	Aluminum (Al)	%	3.53	8.58	13.1							
NAA	Antimony (Sb)	ppm	0.68	0.8	3.5	10 - 30	100 - 3000					
NAA	Arsenic (As)	ppm	2.3	2.7	14.2	0.8 - 500	280 - 10000	24.2	37.4			
NAA	Barium (Ba)	ppm	761	1580	3320	2 - 257	18 - 2200					
ICPMS	Beryllium (Be)	ppm	1.1	1.9	3.2	0.1 - 40	1 - 4000					
ICPMS	Bismuth (Bi)	ppm	0.19	0.12	0.7	0 - 100	0 - 2000					
PG	Boron (B)	ppm	48	143	353	15 - 356	52 - 10000					
NAA	Bromine (Br)	ppm	0.9	1	1.1							
ICPMS	Cadmium (Cd)	ppm	0.09	0.06	0.32							
NAA	Calcium (Ca)	%	1.37	3.49	7.41							
NAA	Cerium (Ce)	ppm	32	73	134					X		
NAA	Cesium (Cs)	ppm	0.6	1.4	2.7							
NAA	Chlorine (Cl)	ppm	<28	<45	<61							
NAA	Chromium (Cr)	ppm	6	30	28	<0.1 - 50	<0.1 - 7400					
NAA	Cobalt (Co)	ppm	2.2	5.4	9.9	0.4 - 34	5 - 2000					
ICPMS	Copper (Cu)	ppm	5.6	16	22	2.6 - 85	10 - 1200					
NAA	Dysprosium (Dy)	ppm	2.1	4.7	7.6					X		
	Erbium (Er)									X		
NAA	Europium (Eu)	ppm	0.41	0.9	1.6					X		
	Gadolinium	ppm								X		
NAA	Gallium (Ga)	ppm	11	17	32	1.2 - 100	10 - 3200	4.5	12.8			X
ICPMS	Germanium (Ge)	ppm	0.4	0.6	2.4	0.4 - 50	9 - 47000	0.5	5.2			X
NAA	Gold (Au)	ppb	<1	<3	<5							X
NAA	Hafnium (Hf)	ppm	2.5	6.1	10.8					X		

Appendix 6: Element Worksheet for Coal with Metal Value/Use Designations (cont.)

Method	Element	Cont.	Typ. Coal	Typ. BA	Typ. FA	Coal Literature Ranges	Ash Literature Ranges	This Study - Filtrate	This Study - FA	"Green" Metal	Energy Metal	Worth-while
	Holmium (Ho)										X	X
NAA	Indium (In)	ppm	<0.04	<0.06	0.09					X		X
NAA	Iodine (I)	ppm	<1	<2	3					X		X
NAA	Iridium (Ir)	ppb	<1	<3	<4					X		
NAA	Iron (Fe)	%/ppm	0.48	1.7	2.48			126.6	32266.7			
NAA	Lanthanum (La)	ppm	20	43	75	1.5 - 40	<30 - 700			X		
ICPMS	Lead (Pb)	ppm	12.9	15.5	49	25 - 3000	200 - 31000	5.5	17.7			
ICPMS	Lithium (Li)	ppm	12.1	25.4	6.4					X		
NAA	Lutetium (Lu)	ppm	0.17	0.39	0.71					X		
NAA	Magnesium (Mg)	%	0.1	0.25	0.57							
NAA	Manganese (Mn)	ppm	71	286	388	9 - 5000	100 - 22000					
NAA	Mercury (Hg)	ppm	0.08	<0.1	<0.2	<0.1 - 300		0.60	0.45			
NAA	Molybdenum (Mo)	ppm	2.1	15	8.2	<0.7 - 200	<5 - 6000					
NAA	Neodymium (Nd)	ppm	10	25	45					X		
ICPMS	Nickel (Ni)	ppm	5.1	13	15	0.42 - 60	5 - 16000	19.9	15.5			
ICPMS	Niobium (Nb)	ppm	4.7	14	22					X		
	Palladium (Pd)											X
ICPMS	Phosphorus (P)	ppm	67	230	310							
	Platinum (Pt)											X
NAA	Potassium (K)	%	0.14	0.31	0.65							
NAA	Rubidium (Rb)	ppm	6	15	33							X
NAA	Samarium (Sm)	ppm	2.3	5.6	9.9					X		
NAA	Scandium (Sc)	ppm	3	6.6	13.1		60 - 400			X		

Appendix 6: Element Worksheet for Coal with Metal Value/Use Designations (cont.)

Method	Element	Cont.	Typ. Coal	Typ. BA	Typ. FA	Coal Literature Ranges	Ash Literature Ranges	This Study - Filtrate	This Study - FA	"Green" Metal	Energy Metal	Worth-while
NAA	Selenium (Se)	ppm	0.5	<1	2							
	Silicon (Si)											
NAA	Silver (Ag)	ppm	<0.3	<1	<1	0 - 3	0 - 60					X
NAA	Sodium (Na)	%	0.38	0.64	1.81							
ICPMS	Strontium (Sr)	ppm	155	385	713	0 - 100	0 -1000					
NAA	Tantalum (Ta)	ppm	0.61	1.5	2.5							X
ICPMS	Tellurium (Te)	ppm	<0.06	<0.05	0.15							X
NAA	Terbium (Tb)	ppm	0.3	0.7	1.2					X		
ICPMS	Thallium (Tl)	ppm	0.09	0.1	0.58							X
NAA	Thorium (Th)	ppm	7.99	18	31						X	
	Thulium											X
NAA	Tin (Sn)	ppm	<15	<50	<67	0.1 - 300	0.4 - 6000					
NAA	Titanium (Ti)	%/ppm	0.091	0.22	0.38	95 - 2300	100 - 35000					
NAA	Tungsten (W)	ppm	1	1.8	3.1							
NAA	Uranium (U)	ppm	3.3	7.7	14	0 - 24000	6 - 1650	0.1	3.9		X	
NAA	Vanadium (V)	ppm	13	26	60	<1.4 - 100	10 - 25000	2.5	34.6			X
NAA	Ytterbium (Yb)	ppm	1.1	2.6	4.6					X		
ICPMS	Yttrium (Y)	ppm	9.5	20	36	0.1 - 49	10 - 2000			X		
NAA	Zinc (Zn)	ppm	23	16	46	7 - 2000	115 -21000					
NAA	Zirconium (Zr)	ppm	<35	70	110	0 - 140	0 - 7000	5.0	46.2			

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