Final Technical Report

GreatPoint Energy's V3.0 bluegas™ Hydromethanation Research Project

Innovative Catalytic Gasification Technology to Maximize the Value of Wyoming's Coal Resources

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Abstract

GreatPoint Energy, Inc. (GPE) has developed a proprietary, highly-efficient catalytic gasification technology, branded as bluegas™, for converting coal and petcoke into a pipeline-quality substitute natural gas (SNG). The heart of the bluegas™ process, termed "hydromethanation," is the catalytic production of methane-enriched synthesis gas in the gasification reactor resulting in significantly higher thermal efficiency and significantly lower capital investment per unit of SNG production formation.

The current process configuration, V3.0, involves the direct injection of oxygen into the bluegas™ hydromethanation reactor (HMR). The direct injection of oxygen into the HMR has raised three unique issues regarding scale-up to a commercial demonstration reactor:

1. Could the injection of oxygen into the HMR and the resulting exotherm from the very rapid partial oxidation reaction be managed without creating any local hot spots?
2. Would catalyst performance and reaction kinetics in the HMR be affected by exposure to oxygen?
3. Would that exposure to oxygen alter the catalyst and impact its recovery from spent char?

Bench scale testing at North Dakota University's Environmental Engineering Research Center (EERC) and at GPE's R&D laboratories in Chicago confirmed that oxygen, steam and coal could be fed to even these small reactors without creating local hotspots from the partial oxidation exotherm. The tests also confirmed that exposure to oxygen in the process has no adverse impact on catalyst activity or recovery. Follow on tests were conducted at EERC's continuous pilot reactor to validate the model developed for this process and confirmed bench scale findings. Results from the test program found that direct oxygen injection to the HMR in the V3.0 bluegas™ process poses no unusual or extraordinary scale-up risk.

A full economic analysis of this process was completed with the help of Jacobs Consultancy which concluded that GPE's V3.0 bluegas™ process economics are highly attractive and significantly better than other commercial gasification technologies.

Overall, this project successfully established the technical and economic feasibility of commercializing the GPE's PRB-based V3.0 bluegas™ process.

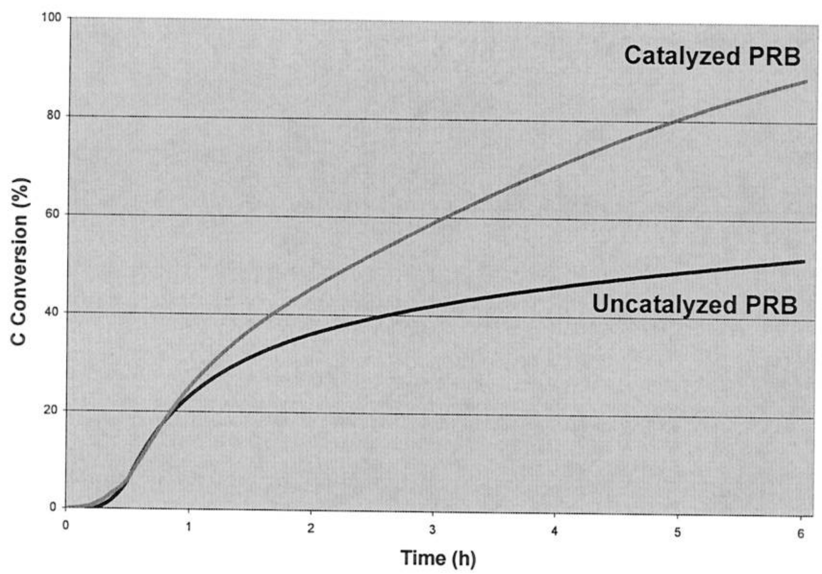
1. Introduction

GPE is the developer of a proprietary, highly-efficient catalytic gasification process, known as bluegas™, by which coal, petroleum coke ("petcoke") or biomass are converted directly into low-cost, pipeline-quality natural gas or hydrogen, while capturing nearly all of the carbon dioxide ("CO_2"). GPE's bluegas™ process, termed "hydromethanation," provides a cost of production that is lower than current prices of new drilled natural gas and imported liquefied natural gas and highly competitive with alternative means of producing hydrogen for refinery use. GPE plans to strategically locate production facilities at the intersection of low-cost feedstocks, outlets for its products and sites where CO_2 can be sequestered in enhanced oil recovery ("EOR") operations. GPE's integrated gas production and carbon capture and sequestration technology addresses America's energy security needs by providing an inexpensive source of CO_2 that can be economically captured and used to produce domestic oil, displacing foreign imports and reducing greenhouse gas emissions.

GPE's bluegas™ technology represents a new and innovative way to significantly improve the value-added use of sub-bituminous coal by producing high-value products while alleviating the constraints of high altitude that can limit the commercial application of gasification and power generation technologies in Wyoming. GPE's bluegas™ process is well suited for low cost feedstocks, such as coal from the Powder River Basin ("PRB"). GPE successfully demonstrated the techno-economic feasibility of converting PRB coal (Peabody Energy's North Antelope / Rochelle coal mine in Campbell County, Wyoming) to pipeline quality synthetic natural gas in 2007 pilot plant tests at GTI (Des Plaines, Ill).

The novel bluegas™ process developed by GPE uses a catalyst which allows the hydromethanation reaction to take place at a lower temperature compared to other non catalytic gasification processes. Figure 1.1. shows that GPE's proprietary catalyst achieves greater than 90% carbon conversion in 6 hours whereas the uncatalyzed coal only achieves about 40% carbon conversion—which is similar to the volatile content of the coal. This test was performed at 1300F which is well below the usual temperature range of 1800 F to 2600F for non-catalytic processes

Figure 1.1: Test Data Demonstrating High PRB Conversion under Hydromethanation Conditions



Carbon conversion under hydromethanation conditions is plotted in the figure against gasification time for Wyoming PRB Coal. It clearly indicates that GPE's bluegas™ catalyst formulations for the catalyzed PRB coal can successfully convert well over 90% of the carbon, significantly better than uncatalyzed coal showing that the catalyst is effective. Furthermore, GPE's bluegas™ hydromethanation technology's ability to capture a pure stream of CO_2 from the conversion process makes it an enabler of carbon capture and sequestration (CCS) technology – a technology critical for the advancement and adoption of clean coal technology in the USA on a large scale.

Wyoming's resources of coal are vast, particularly its sub-bituminous coal reserves, and continued responsible development of those resources provides vital economic development opportunities to the

State of Wyoming. Yet Wyoming sub-bituminous coal is lower rank coal with higher moisture fractions than Eastern coals and lower ash fusion temperatures, both of which negatively impact boiler performance, and when combined with significant transportation costs, put Wyoming coals at a pricing disadvantage. Furthermore, with the likely advent of future legislation regulating carbon emissions, continued coal use will face challenges and additional costs for CO_2 emissions, making innovation in coal gasification technology and CCS technology vital.

GPE's bluegas™ technology development program focuses on a novel way to utilize exactly the type of coal Wyoming possesses. GPE's bluegas™ hydromethanation process is a technological enabler to increase the realized value of Wyoming's coal resources by converting low-value coal resources into high-value natural gas that can be efficiently transported anywhere along the national pipeline infrastructure, or remain in the State to be used for power, home heating or industrial use.

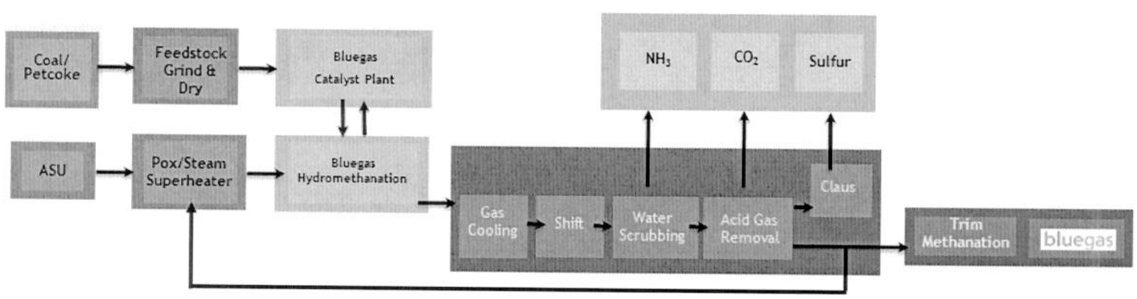
GPE has successfully simulated a previous generation bluegas™ hydromethanation process utilizing a partial oxidation unit (V2.5). A next-generation bluegas™ process based on direct oxygen injection into the bluegas™ hydromethanation reactor (V3.0) has been developed which improves operability and economics of the PRB based hydromethanation process. The focus of the R&D program is to generate the key information necessary to assess the viability and attractiveness of a commercial scale V3.0-based bluegas™ process using Wyoming coal. The proposed Hydromethanation Research Study project includes optimizing catalyst loading and recoverability; develop gasification kinetic parameters, continuous pilot plant scale testing and preliminary economic assessment.

1.1 Hydromethanation Overview

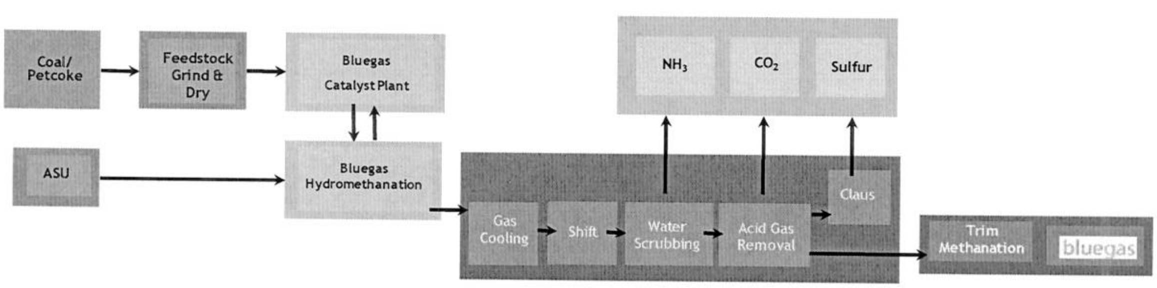
GPE's V3.0 hydromethanation process is a catalytic gasification technology that allows oxygen to be introduced directly in to the HMR increasing efficiency and lowering capital and operating costs. The general bluegas™ hydromethanation process consists of the feedstock receiving and preparation section, a fluid bed hydromethanation reactor ("HMR"), a catalyst loading and recovery section , a raw product gas cooler/steam generator and superheater, venturi scrubber, water gas shift, acid gas clean up and methanation unit. A methane compressor boosts the product pressure to pipeline operating pressure, assumed to be 1000 psig. Direct oxygen injection in the V3.0 bluegas™ process simplifies the process versus earlier versions (for example, by removal of recycle syngas) and improves thermal efficiency. The simple block flow diagrams for the earlier V2.5 version and the current V3.0 version of the bluegas™ process are depicted in figure 1.2 below:

Figure 1.2: bluegas™ catalytic hydromethanation process

Previous Version: V2.5



Current Version: V3.0



In the V3.0 bluegas™ process scheme, steam and oxygen are fed to the HMR in an amount sufficient to drive the catalytic gasification reactions, partially oxidize some of the carbon and offset heat losses in addition to generating steam while maintaining the reactor at process temperature. The steam-oxygen mixture is dilute in oxygen and generates the syngas (H_2 + CO) required for hydromethanation *in-situ*. This eliminates the recycle of syngas in to the reactor and increases the throughput of the facility. The nominal amount of oxygen injected in this process reduces the amount of steam required in the HMR. GreatPoint's catalyst, formulated from abundant, naturally-occurring minerals, is impregnated onto the feedstock. The catalyzed feedstock is then fed into the HMR and fluidized with pressurized steam to ensure optimal heat and mass transfer between the gas and solid phases. The major chemical reactions that take place in the reactor are described in Table 1.1. This process demonstrates a thermodynamically efficient reaction to convert carbon to natural gas.

Syngas coproduced with methane in the HMR is shifted to produce a H_2 to CO ratio of 3:1, after which the shifted syngas is treated for acid gas removal. The resulting sweet gas is converted in a trim methanator to SNG using conventional catalytic methanation technology. Heat recovered downstream of the HMR including the trim methanator generates superheated steam, which is used as feed to the HMR along with oxygen.

Table 1.1: bluegas™ Hydromethanation Process Reactions

Process	Chemical Reaction	
Steam Carbon	$2C + 2H_2O \rightarrow 2CO + 2H_2$	Endothermic
Water Gas Shift	$CO + H_2O \rightarrow H_2 + CO_2$	Mildly Exothermic
Methanation	$CO + 3H_2 \rightarrow CH_4$ (methane) + H_2O	Exothermic
Overall	**$2C + 2H_2O \rightarrow CH_4$ (methane) + CO_2**	**Thermally Neutral**

This catalytic process reduces the operating costs and capital costs for coal conversion compared with other gasification technologies, such as those marketed by ConocoPhillips, GE, Siemens and Shell, due to its lower operating temperatures and increased process efficiency. In addition, the bluegas™ technology is polygenerational because it allows coal to be converted to either methane or hydrogen depending on the best end-use product market.

Furthermore, the bluegas™ process effectively addresses coal's most challenging issue: environmental impact. Under the reducing conditions of the HMR, sulfur and nitrogen that may be present in coal are converted to H_2S and NH_3, and ultimately recovered as elemental sulfur and ammonia, both of which are valuable commodities used in agriculture and industry. Ash and trace metals are also removed and either safely disposed of or used as raw materials for other products.

GreatPoint has fundamentally shifted the economics of gasification with its bluegas™ hydromethanation technology, which has six key advantages over conventional gasification technologies:

(1) A major portion of the SNG (~70%) is produced in the HMR. This gives the bluegas™ process a clear advantage over conventional noncatalytic gasification where only syngas is produced in the gasifier;

(2) Overall conversion efficiency is significantly higher than conventional processes, due to the direct "capture and utilization" of the exothermic heat of methanation inside the reactor;

(3) Hydromethanation occurs at much lower temperatures than conventional non-catalytic processes, resulting in lower maintenance and capital costs in the reactor, gas cooling and heat recovery systems;

(4) Hydromethanation yields no waste residues such as tars or oils, and the residual char can be marketed as fuel blendstock, soil supplementsand even activated carbon;

(5) Hydromethanation is a catalytic process that operates under reducing conditions and therefore, does not produce the nitrogen oxide (NOx), sulfur oxide (SOx) and particulate emissions typically associated with the burning of carbon feedstock;

(6) Hydromethanation produces a capture-ready stream of high purity CO_2, which can be compressed and transported by pipeline to be sold for use in EOR, geological sequestration, or for other commercial applications.

1.2 Objectives and Methods

As part of this study, GreatPoint developed a comprehensive scope of work to mitigate the risks and maximize value, with the results yielding data on how best to tailor the application of GreatPoint's bluegas™ technology to Wyoming's unique sub-bituminous coal. The total R&D bench-scale program, pilot plant tests, associated modeling and economic assessment took approximately one year to complete and were conducted in parts at GreatPoint's laboratory facility in Chicago, Illinois and in the EERC facilities in North Dakota. The R&D program consisted of four major tasks:

1. Hydromethanation Process Parameters Development - Conduct laboratory scale experiments using existing GreatPoint equipment and understanding gained from laboratory testing, to determine catalyst performance, yields, selectivity, and kinetics over a range of catalyst compositions, impregnation methods, pressure, temperatures, residence times and particle size distributions.

2. Pilot Plant Testing - Conduct short duration continuous fluidized bed tests in the 3" diameter pilot plant set up at EERC to study the effect of oxygen exposure to the catalyst under commercial conditions and generate adequate amounts of char for conducting catalyst

recovery studies. In addition, examine the impact of O_2 injection on the temperature profile of the reactor.

3. Hydromethanation Process Modeling - Validate existing GreatPoint reactor and catalyst recovery models with laboratory-measured performance characteristics of PRB coal in the bluegas™ V3.0 hydromethanation process. Perform rigorous mathematical modeling incorporating hydrodynamics and chemical kinetics to simulate and predict pilot and commercial reactor performance.

4. Economic Assessment - Perform preliminary engineering, process optimization studies, and estimate capital and operating costs of a commercial scale plant in order to quantify the plant's financial and environmental performance.

This report will discuss the work done, the results obtained, and will summarize the conclusions reached in each of the four tasks set forth above.

Project Conclusions

The project work completed successfully studied the bluegas™ V3.0 hydromethanation process developed by GPE in bench scale and pilot scale with Wyoming's sub bituminous PRB coal. The study clearly demonstrated the operability of the process in both batch and continuous modes. The following conclusions were drawn from the work done in this project:

Scale-up Issues:

With the validation of the model, good process operability, absence of any significant exotherm with oxygen injection, and no detectable impact of oxygen exposure on catalyst activity several key concerns pertaining to the scale up of HMR have been successfully addressed so far.

a. No hot spot observed

The pilot plant tests soundly established that oxygen injection into the reactor can be managed without causing uncontrolled hot spots and the fluidized bed of well mixed solids can effectively dissipate the heat generated by the oxidation reactions.

b. Catalyst Activity not impacted by oxygen exposure

Several tests done with the oxygen exposed catalyst containing char showed conclusively that the catalyst activity is not affected by oxygen in the process. This was reinforced by the modeling work that showed non-oxygen kinetic parameters were applicable to the direct-oxygen-injection environment.

The EERC facilities worked well at both the laboratory and pilot scale. The tests conducted in the laboratory scale and pilot plant scale clearly showed that direct oxygen injection in EERC test facilities works well. Both the laboratory and pilot units were started up and shut down several times and the process was reproducible. The pilot plant fluidized bed reactor operated for several hours with continuous feed under stable lined out conditions. The stable operation allowed collection of good quality steady state data.

c. Model validated

Consistent with all prior laboratory and pilot testing, the tests done at EERC the laboratory and the pilot plant successfully validated the GPE bluegas™ design model. The model was tested in the laboratory under batch mode and in the pilot plant in the continuous feed mode. In both cases the model successfully predicted the test results. This lends great credibility to the results predicted by the model for the commercial unit.

Economic Assessment:

The GPE process economics were assessed by Jacobs Consultancy as part of a study to compare different gasification technologies. The economic analysis clearly established not only the economic viability of the GPE bluegas™ V3.0 hydromethanation process, but also showed that its process economics is far superior to other known gasification technologies on a relative basis. The specific competitive advantages identified by the Jacobs study are:

- Lower capital costs
- High thermal efficiency (operates at a higher efficiency than all other gasifiers in this study)
    - Lower oxygen use
    - Less CO_2 produced
- Catalytic activity that promotes the formation of methane in the gasifier
- Lower operating temperature (600 – 700°C) and thus, reasonable probability of higher reliability & availability, and lower maintenance costs
- Lower overall feedstock consumption per unit amount of SNG produced
- No tars and oils produced

Overall, this project successfully established the operability and confirmed the feasibility of commercializing the PRB-based bluegas™ V3.0 hydromethanation process. In addition, it showed that that the economics of the bluegas™ V3.0 hydromethanation process is not only attractive but also is best in class when compared to other known gasification technologies.