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April 28, 2010

Mr. Timothy Edman
Manager, Regulatory Administration
Xcel Energy, Inc.
414 Nicollet Mall
Minneapolis, MN 55401

Dear Mr. Edman:

Subject: Quarterly Progress Report Entitled "Indirect Liquefaction of Wood Waste for Remote Power Generation Fuel"; Contract No. RD3-66; EERC Fund 9968

Enclosed please find the subject report. If you have any questions, please contact me by phone at (701) 777-5159 or by e-mail at jhurley@undeerc.org.

Sincerely,

John P. Hurley
Senior Research Advisor

JPH/cs

Enclosure

Energy & Environmental Research Center, University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

Project Title: Indirect Liquefaction of Wood Waste for Remote Power Generation Fuel

Contract Number: RD3-66 Milestone Number: 5 Report Date: April 28, 2010

Principal Investigator: John Hurley Contract Contact: Tobe Larson

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Congressional District: Not Applicable

Congressional District: Not Applicable

MILESTONE REPORT

Executive Summary

During this milestone period, the 3-D drawings were completed for the overall layout of the mobile indirect liquefaction system, along with details of the gasifier component sizing. This layout has been optimized in order to accommodate all the necessary components while leaving space around the gasifier to allow for repairs and upkeep. The components have been designed to be installed in a modular fashion, with components kept on skids for easy installation and removal in case of repairs. The piping, structural supports, and catalyst reactor layouts for the gas-to-liquid system are currently still being designed. Construction of the gasifier section of the system was initiated during this quarter.

In addition, we have performed extensive modeling of the methanol production system in Aspen. Elements of the process model include the compressor, methanol reactor, water–gas shift reactor, hydrogen separation unit, and heat exchangers. A significant effort was devoted to developing an accurate kinetic model of the methanol reaction so that process changes could easily be analyzed. Several kinetic reaction expressions were found in the literature, and the model's predictions were compared to experimental results. The kinetic expression that best fits the experimental data was selected for use in the Aspen model. Several different process configurations were modeled in an attempt to optimize methanol production, maximize the use of heat, and minimize energy consumption. One promising concept that was explored in detail was recycling hydrogen. With the combination of a water–gas shift reactor and hydrogen separation membrane, the methanol production rate would nearly triple from the base case. The cost of gas compression increases by only 30%.

The programming language selected during this quarter for controlling the indirect liquefaction system is Labview®, is a graphical programming language developed by National Instruments® (NI). This language has been used in both academic and industrial control applications. The EERC has prior knowledge and experience using Labview for control applications.

Because of the delays reported in the last milestone report related to the testing of the new gasifier concept that will permit easy scale-up of the system, deployment of the system for field testing will be postponed for several months to June or July 2010.

Technical Progress

System Design: The 3-D drawings have been completed for the overall layout of the system, along with details of the gasifier component sizing. This layout has been optimized in order to accommodate all the necessary components while leaving space around the gasifier to allow for repairs and upkeep. The components have been designed to be installed in a modular fashion, with components kept on skids for easy installation and removal in case of repairs. The piping, structural supports, and catalyst reactor layouts for the gas-to-liquid system are currently still being designed.

Figure 1 shows the general 3-D design to date. The sizing of the gasifier, heat exchangers, and gas cleanup components is such that the system will extend beyond the trailer roof height and will require assembly in the field. The process begins with the gasifier toward the rear of the trailer from which the gas will flow through a set of heat exchangers and wet scrubbers to clean it.

After this stage, the gas will be ducted toward the middle of the trailer, where it goes through another cleaning process and then to the compressor. The compressor will pressurize the gas to 900 psi, and then the gas will flow through the gas-to-liquid reactor system, which is

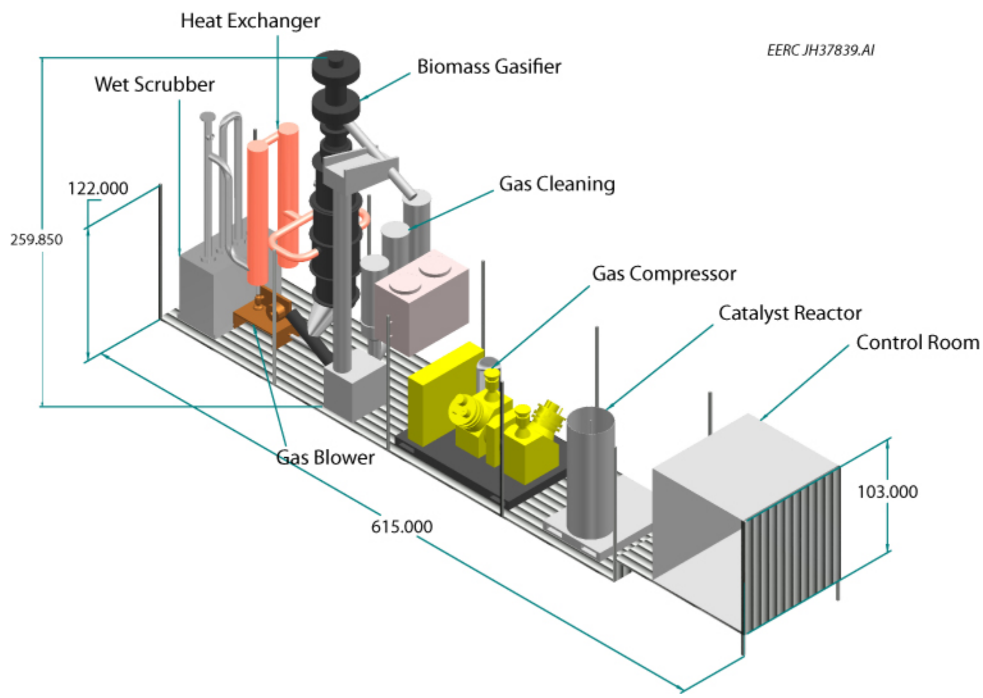

Figure 1. 3-D drawing of trailer-mounted gasification system. The trailer roof has been removed for this depiction only. Lengths are in inches.

still being designed. The control area is at the front of the trailer, shown by the enclosed box on the upper trailer. Construction of the gasifier section of the system was initiated during this quarter.

Gas-to-Liquid Conversion:

The past quarter of work has focused on modeling the methanol production system in Aspen. Elements of the process model include the compressor, methanol reactor, water–gas shift reactor, hydrogen separation unit, and heat exchangers. A significant effort was devoted toward developing an accurate kinetic model of the methanol reaction so that process changes could easily be analyzed. Several kinetic reaction expressions were found in the literature, and the model's predictions were compared to experimental results. The kinetic expression that best fit the experimental data was selected for use in the Aspen model.

Several different process configurations were modeled in an attempt to optimize methanol production, maximize the use of heat, and minimize energy consumption. One promising concept that was explored in detail was recycling hydrogen. As reported last quarter, the most important factor in optimizing methanol production rate is hydrogen partial pressure, which can be increased either by boosting total system pressure or increasing the concentration of hydrogen. Total system pressure is limited by the cost of gas compression and equipment, but the concentration of hydrogen can be increased if the unconverted hydrogen is separated and recycled back to the methanol reactor.

If a hydrogen membrane capable of separating 75% of the hydrogen was added to the system after methanol condensation and the hydrogen was recycled and recompressed, then methanol production would nearly double. The cost of gas compression would increase by 14.4%. In order to increase the partial pressure of hydrogen even further, a water–gas shift reactor could be installed immediately prior to the hydrogen separation unit. Unconverted carbon monoxide would react with steam to form additional hydrogen and carbon dioxide. With the combination of a water–gas shift reactor and hydrogen separation membrane, the methanol production rate would nearly triple from the base case. The cost of gas compression increases by only 30%.

A turboexpander was added to the model to evaluate the possibility of recovering mechanical energy from the high-pressure vent gas. Approximately 20 kW of electricity could potentially be recovered by expanding gas from 900 psi to atmospheric pressure. Significant cooling of the gas also occurs, and it may be possible to use the cold gas to chill the coolant in the methanol condenser loop. Unfortunately, turboexpanders are not commercially available in the scale for this application. Other means of exploiting the high-pressure mechanical energy are being investigated, such as vortex coolers.

Sensors and Controls:

The programming language selected during this quarter for controlling the indirect liquefaction system is Labview. This language has been used in both academic and industrial control applications. The EERC has prior knowledge and experience using Labview for control applications.

The indirect liquefaction control system can be broken into two parts, a real-time controller (RTC) and a human machine interface (HMI). The RTC controller utilizes a real-time operating system (RTOS) which is more robust for control systems than a general operating system (OS). Fail-safe logic and alarms will be located on the RTC and will be inaccessible to the user to prevent tampering. The RTC will also sort the various inputs and output controls and device communications. Signals will be converted into meaningful values and published for the HMI to view and change.

Several hardware options exist for the RTC. These options include a general personal computer (PC), a programmable automated controller (PAC), and a programmable logic controller (PLC). PC control is very flexible for programming but uses a general, less robust OS. A PLC has a RTOS but is much less flexible. A PAC bridges the gap between PC controller and PLC, offering flexible control with a RTOS. NI has two PAC hardware systems which are viable candidates for the system, compact fieldpoint (cFP) and compact reconfigurable input/output (cRIO).

The HMI allows an operator to monitor and control the system. This includes device control, data-logging, real-time data-trending, and system status and alarms. Noncritical system logic will be located on this device. The HMI may also host any external communication desired for the system.

The HMI needs to have a significant amount of computing power. The computing power is needed to perform system control and data capturing. An industrial PC or control panel with an embedded OS would be suitable. Several companies including NI design industrial PCs and control panels. The EERC has had success working with Windows XP embedded. On April 27, Windows Embedded Standard 7 will be released.

A final selection of the RTC, HMI, and HMI OS will be made when input, output, and control devices are finalized. A visual description of the proposed architecture is shown in Figure 2.

Particulate Filter: A diesel particulate filter (DPF) system is being ordered for low-pressure syngas cleanup. This system is used on diesel engines to remove soot (fine particulate matter) from the exhaust. DPFs help diesel vehicles reach increasing U.S. Environmental Protection Agency (EPA) standards for lowering particulate emissions. This soot would negatively impact the compressor’s performance. Gasification tests of wet wood at the EERC have shown small amounts of soot present in the syngas stream even after existing cleanup methods.

A DPF is a microporous ceramic media which collects particulate matter (PM) in a gas stream. Eventually, the soot plugs the filter and the filter needs to be replaced and/or regenerated. Regeneration is signaled by a rise in the differential pressure across the filter. The filter temperature is increased to combust the soot. Regeneration can be accomplished both online or offline and can be active or passive. Passive regeneration requires a catalyst to be applied to the filter. The catalyst reduces the combustion temperature of the soot to normal exhaust temperatures. Active regeneration heats the filter either with electricity or a fuel burner.

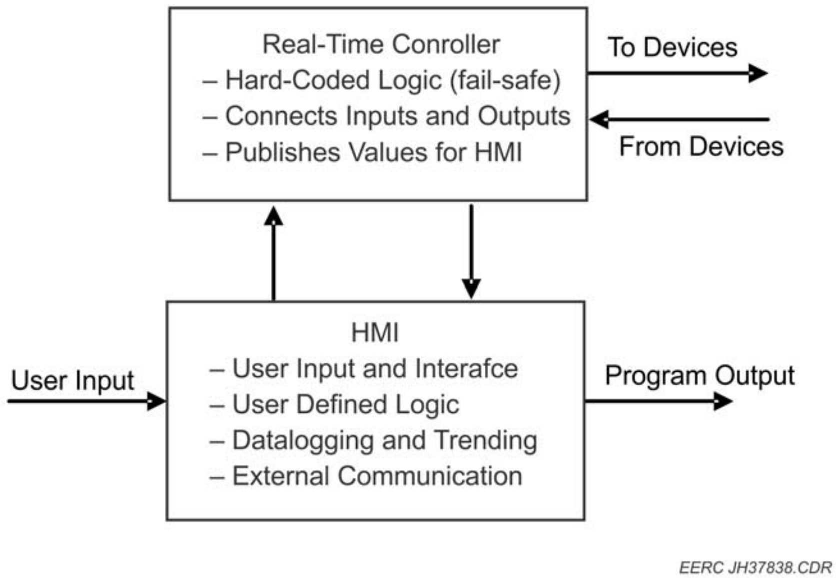

Figure 2. Basic control architecture.

Several companies were contacted to determine the type of system appropriate for the indirect liquefaction system. Since carbon monoxide (CO) and hydrocarbons (HC) are present and necessary in the syngas, passive regeneration was not an option. Active regeneration times range anywhere from 1 to 8 hours. Therefore, regeneration must be performed offline to prevent downtime. Unlike diesel engines, the indirect liquefaction system does not have a supply of diesel. Consequently, electrical regeneration was recommended. Of the companies contacted, only Engine Control Systems (ECS) has a system that meets the process requirements. A brief summary of the ECS unit is provided in Table 1.

Table 1. ECS DPF System Performance Summary

Syngas Flow Rate	150	scfm
Particulate in Syngas after Initial Cleaning	45	mg/min
DPF Volume	18	L
DPF Loading Limit	6	g/L
	108	g
Time to Full DPF	40	hr
DPF Regeneration Time	8	hr
DPF Regeneration Type	Offline active (electrical)	

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