Process Modeling Results of Bio-Syntrolysis: Converting Biomass to Liquid Fuel with High Temperature Steam Electrolysis

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ABSTRACT

A new process called Bio-Syntrolysis is being researched at the Idaho National Laboratory (INL) investigating syngas production from renewable biomass that is assisted with high temperature steam electrolysis (HTSE). The INL is the world leader in researching HTSE and has recently produced hydrogen from high temperature solid oxide cells running in the electrolysis mode setting several world records along the way. A high temperature (~800°C) heat source is necessary to heat the steam as it goes into the electrolytic cells. Biomass provides the heat source and the carbon source for this process. Syngas, a mixture of hydrogen and carbon monoxide, can be used for the production of synthetic liquid fuels via Fischer-Tropsch processes. This concept, coupled with fossil-free electricity, provides a possible path to reduced greenhouse gas emissions and increased energy independence, without the major infrastructure shift that would be required for a purely hydrogen-based transportation system. Furthermore, since the carbon source is obtained from recyclable biomass, the entire concept is carbon-neutral.

Keywords: bio-syntrolysis, synfuel, greenhouse gas reduction

1 INTRODUCTION

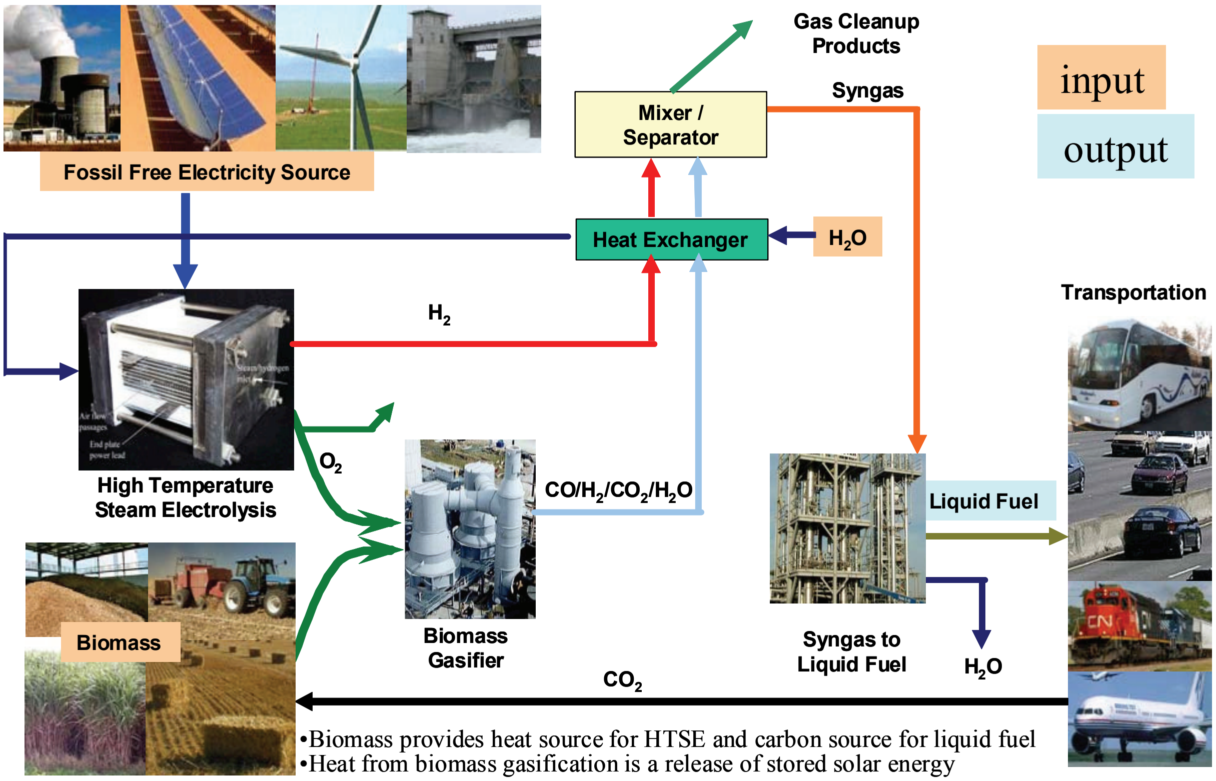
This paper provides a discussion of the process modeling results performed to understand issues of economic efficiency, viability, and areas of interest overall process efficiency. An economic discussion of the carbon neutral, Bio-Syntrolysis process of converting biomass to liquid fuels is presented in the accompanying 2010 Clean Technology Conference & Expo paper, #937, *Economic Assessment of a Conceptual Biomass to Liquids Bio-Syntrolysis Plant*, M.M. Plum, G.L. Hawkes.

Figure 1 shows the overall process for converting biomass to liquid fuels via HTSE. A process model flow sheet has been developed with a biomass gasification system integrated with an HTSE system. Electrolytically produced oxygen from splitting water is fed to the gasifier and controls the amount of carbon monoxide and carbon dioxide produced. The gasifier products are cleaned and scrubbed and mixed with the electrolytic hydrogen to produce a very clean syngas [1] ready for the Fischer-Tropsch process. Various types of biomass such as corn stover, barley straw, bark, and switchgrass have been simulated in the process model flow sheet. Varying amounts of moisture content in the biomass was also investigated. High pressure and atmospheric pressure simulations were also performed. Low temperature electrolysis efficiency was compared to high temperature electrolysis. These parameters of moisture content, pressure, and electrolysis temperature are compared with base case observations for syngas production efficiency, and carbon conversion efficiency. Figure 3 shows syngas production efficiency for various types of biomass.

This paper will provide process model results of large scale biomass gasification with high temperature electrolysis and for the production of synthetic fuels. Bio-Syntrolysis converts 90% of the carbon in the biomass into liquid fuel. This is the highest conversion efficiency of any biomass to liquid process. It also uses the least amount of electricity because of the HTSE technology that uses 50% less than present-day alkaline electrolysis processes. With 1.3 billion tons of recyclable biomass available each year in the US, Bio-Syntrolysis can convert this into 12.5 million barrels per day of liquid transportation fuel and totally offset imported oil. A thorough economic analysis has been performed and is discussed in the already mentioned accompanying paper. This analysis forecasts diesel being produced at $3.50 per gallon. Figure 2 shows a regional Bio-Syntrolysis process where a centralized nuclear power plant provides electricity for Bio-Syntrolysis plants where the biomass is produced.

2 PROCESS MODEL / RESULTS

The process model was developed using the Honeywell UniSim [2] process modeling software. This commercial software is used in the oil and gas industry and can model thermo-chemical systems ensuring chemical, energy and mass balances. Four types of recyclable biomass were considered parametrically for this study. They are barley straw, wood bark, corn stover and switchgrass. The ultimate analysis of the dry, ash free, biomasses is based on



- Biomass provides heat source for HTSE and carbon source for liquid fuel
- Heat from biomass gasification is a release of stored solar energy

Figure 1. Depiction of Bio-Syntrolysis process

the PHYLLIS database of the Energy Research Centre of the Netherlands. Inputs from the biomass include the lower heating value. For example, the lower heating value of the barely straw is 18,460 kJ/kg. The dry ash is primarily silicon oxide with some potassium and calcium oxide. Both the ash and the dry, ash free, biomasses were modeled as hypothetical components. The composition and heating value of the biomasses are the only necessary components for the gasification process model. The gasifier uses a Gibbs reactor which minimizes the Gibbs free energy to determine the most likely products based on the composition, flow rates, pressure and temperatures of the barley straw, water, and oxygen.

Figure 3 is the process flow diagram for biomass

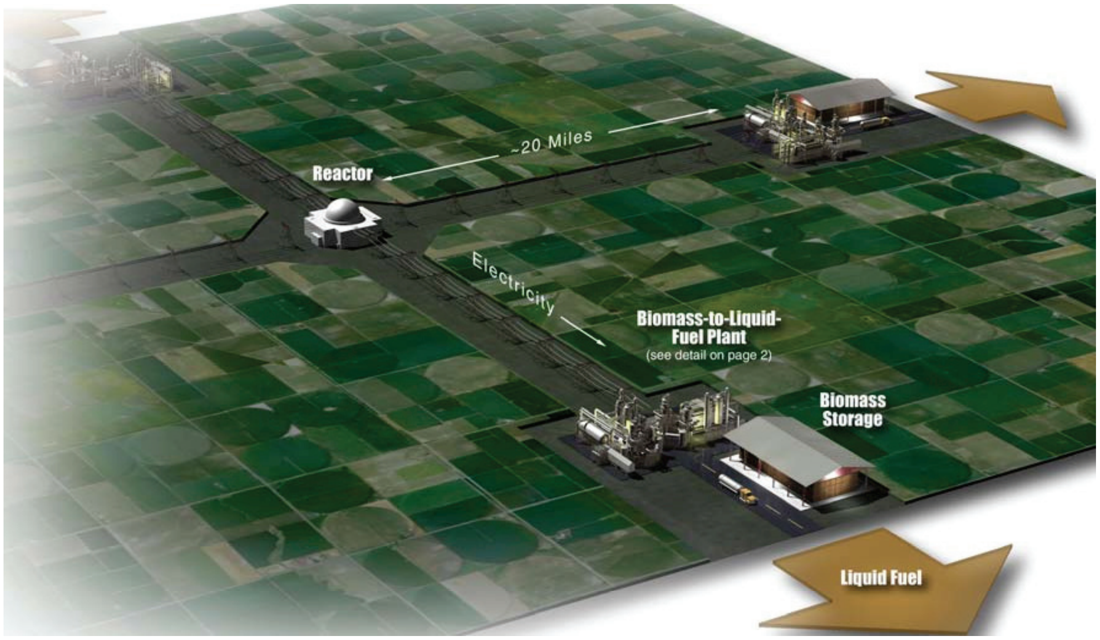


Figure 2. Regional concept of Bio-Syntrolysis

syngas production using high temperature electrolysis (HTE). The process is scaled to a biomass feed rate of 1 kg/s. The biomass is reacted with oxygen from the steam electrolyzer at a variety of gasifier temperatures ranging from 1500 K to 1900 K. Slagging of the ash will occur at those temperatures. Just enough oxygen is added to make the gasification process adiabatic.

The gasifier product stream and the hydrogen stream from the electrolyzer exit are cooled in the Heat Recuperator 1 heat exchanger to generate steam at 1073 K for the electrolysis unit. The water entering Heat Recuperator 1 is supplied by a make-up water source that is pumped to pressure and the water recycled from the electrolyzer outlet. Oxygen from the electrolyzer is sent to the gasifier in a controlled manner. Extra oxygen not needed goes through a cool down process. The gasifier product stream is quenched with water to the point of saturation for the purpose of modeling the energy loss due to particulate removal using a quenching process. The water contains some undesirable components from the gasifier including hydrogen sulfide and hydrogen chloride and therefore can not be recycled. The contaminants in this stream are removed in a contaminant removal process that is based on the Rectisol process. Methanol is refrigerated to 233 K and enters the top of an absorber. The gasifier product stream is cooled to remove excess water and enters the bottom of the absorber. The refrigerated methanol captures the hydrogen sulfide, some of the carbon dioxide, the ammonia, and the hydrogen chloride. The methanol is regenerated in a distillation column which is then recycled back to the absorber. Any losses of methanol are replaced. The contaminants exit the distillation column at the top of the column as a sour gas. The heat for the reboiler of the distillation column is provided by combusting a small stream of biomass at a feed rate of 0.025 kg/s. The energy used to pump and to refrigerate the methanol and the biomass burned to supply heat for the reboiler are taken into account in efficiency and carbon utilization analyses. Hydrogen from the electrolysis process is mixed with the gasifier stream to produce a syngas of hydrogen to carbon monoxide ratio of 2. This ratio is ideal for many synthetic fuel processes such as the Fischer Tropsch, FT.

2.1 Syngas Production Efficiency

The syngas production efficiency is defined as the thermal value of the syngas divided by the sum of thermal value of the biomass and the thermal equivalent value of the electricity used in the process as shown in Eq. 1. The thermal values of the syngas and the biomass are calculated by multiplying the lower heating values of each with their respective molar flow rates. The thermal value of the electricity is found by summing the electric power of the system and dividing it by the thermal efficiency of the electric power cycle providing the electricity. The heat for the gasification process is not included in this efficiency because the process is adiabatic. The molar flow rate of the biomass is the biomass entering the gasifier and the biomass that is combusted to provide heat for reboiler in the methanol regeneration column. The refrigerator compressor power and the methanol recycle pump power are also included in this efficiency.

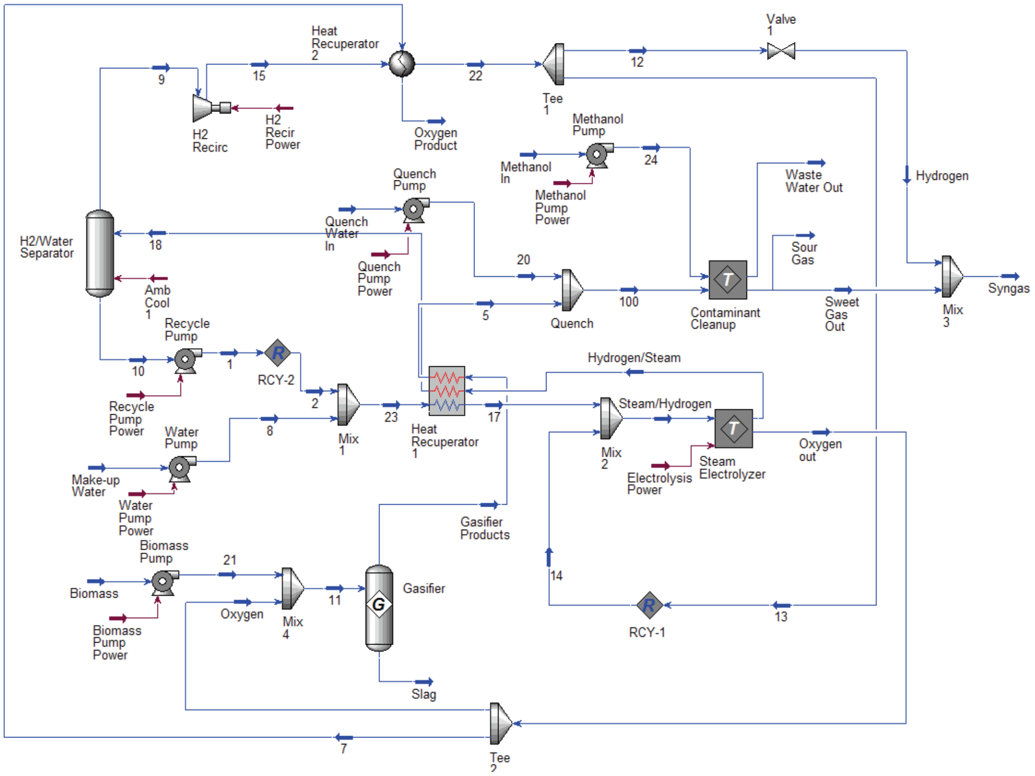


Figure 3. Process flow diagram of biomass gasification with high temperature electrolysis.

$$\eta_{\text{syngas}} = \frac{\dot{n}_{\text{syngas}}\ \text{LHV}_{\text{syngas}}}{\left(\dot{n}_{\text{biomass}}\ \text{LHV}_{\text{biomass}} + \sum \text{Pwr}_{\text{elec}} \big/ \eta_{\text{th}}\right)} \qquad (1)$$

2.2 Carbon Utilization

The carbon utilization is the mass flow of carbon in the syngas divided by the mass flow of carbon in the biomass as shown in Eq. 2. Only the carbon in the carbon monoxide component of the syngas is considered because all components except for hydrogen and carbon monoxide are considered contaminants or inerts.

$$U_c = \frac{Mass_{C,Syngas}}{Mass_{C,Biomass}} \qquad (2)$$

Figure 4 shows the syngas production efficiency and carbon utilization for the four types of biomass as a function of gasifier temperature. Both parameters decrease as the temperature increases. This occurs since more oxygen is added to the process to make more heat in the form of CO2. Syngas production efficiency is near 95%, while carbon utilization is near 72%.

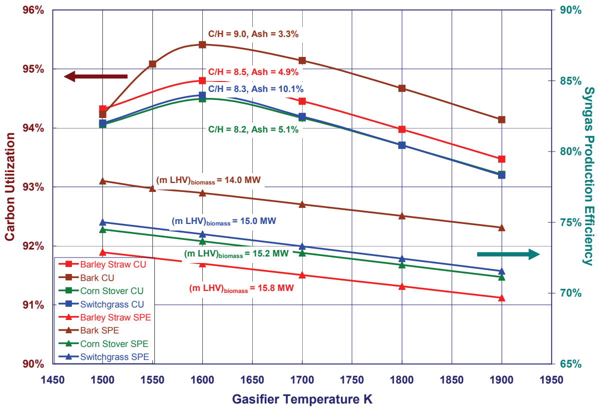


Figure 4. Carbon utilization and syngas production

3 CONCLUSIONS

This evaluation suggests a credible outcome for an integrated nuclear Bio-Syntrolysis synfuels plant. Moreover, the risk of this outcome seems minimal as a majority of the cost inputs are well known. At risk is the predicted operation of a computer simulated yet unproven technology. The prospect of this potential outcome suggests that efforts be made to understand this technology better.

A process model was developed to simulate the generation of syngas by gasification of biomass and high temperature electrolysis of steam for the process known as Bio-Syntrolysis. Biomass provides the heat source for the HTSE and the carbon source for the syngas. The carbon utilization is affected only slightly by gasifier temperature as the utilization varies between 94% and 95%. The syngas production efficiency is closely tied to the power cycle efficiency. At a power cycle efficiency of 50%, the syngas production efficiency varies from 70% to 73%.

Parametric studies were shown for carbon utilization and syngas production efficiency varying with gasifier temperature, system operating pressure, HTSE versus LTE, biomass moisture content, and four biomasses (barley straw, corn stover, bark, and switchgrass).

An economic analysis was performed for this process showing liquid fuel production at $3.50 per gallon. Although the analysis looks promising, other biomass inputs would change the configuration. If large concentrations of sodium, potassium or phosphorus compounds are found in the ash, the gasifier temperatures would need to be much lower to prevent slagging.

4 COPYRIGHT STATEMENT

This work was supported by the Idaho National Laboratory, Laboratory Directed Research and Development program and by the U.S. Department of Energy, Office of Nuclear Energy, Nuclear Hydrogen Initiative Program.

5 REFERENCES

[1] O'Brien, J. E., McKellar, M. G., Harvego, E. A., and Stoots, C. M., "High-Temperature Electrolysis for Large-Scale Hydrogen and Syngas Production from Nuclear Energy – Summary of System Simulation and Economic Analyses," International Journal of Hydrogen Energy, in press, 2009.

[2] UniSim Design, R360 Build 5, Honeywell International Inc., Copyright 2005-2006