II.J.2 Purdue Hydrogen Systems Laboratory: Hydrogen Production*

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- National Renewable Energy Laboratory, Golden, CO
- University of Wyoming, Laramie, WY

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*Congressionally directed project

Objectives

- Investigate and evaluate initial processes for the production of hydrogen from various waste streams using anaerobic microbial fermentation.
- Investigate paths for implementation of the research as a modular energy source initially for application in remote locations.

Technical Barriers

This project addresses the following technical barriers from the Production section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan (Revision 2007) (see page 3.1-30 of Section 3.1.4):

(AR) H_2 Molar Yield
(AT) Feedstock Cost
(AU) Systems Engineering

Technical Targets

	2007	2010	2015
Hydrogen Concentration (volume %)	10	15	>25
Achieved to Date	9	14	

Accomplishments

- Testing of various combinations of microbial consortia was conducted with organic waste materials to determine parameters that maximize production. It was determined that pH, temperature and waste material concentration had the greatest influence on hydrogen production for the test conditions considered. A central composite design is being used to determine operating values that maximize hydrogen production.
- The automated testing system previously designed and constructed was used to determine optimal operating parameters. Fourth generation tests are now being completed.
- Tests of continuous production are ongoing for Purdue food waste and distiller's grain and innoculum samples.
- The initial design of a modular energy system for local energy production and waste treatment has been completed and is being used to optimize value.
- A 3 L batch/continuous fermentor is being implemented to enhance testing and consider scale up issues.
- The vacuum tube solar collector system is used for pre- and post-waste processing and consideration of other ancillary uses such as building heating and production of potable water.
- Steam generator tests demonstrated ability to distill water with maximum solar energy conversion efficiency of ~70%.
- Initial designs are being investigated for development of a prototype system with reduced substrate water concentration.
- Decreasing water concentration significantly increases the value for the modular energy system design. Water concentration has been decreased from 95% to 75% with little loss in hydrogen production rates.
- Significant hydrogen production was demonstrated using distiller's grain from ethanol production as substrate. Maximized operating procedure has shown significant increase in hydrogen production levels for second generation tests of distiller's grain.

- Two advisory board meetings were held in the last year to continue to gain input from industry. Advisory board members include: Cargill, INEOS Technologies, BP, Advanced Power Technologies, and Ajinomoto Food Ingredients, LLC.

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Introduction

This project allows the creation of a Hydrogen Research Laboratory in a unique partnership between Purdue University's main campus in West Lafayette and the Calumet campus. This laboratory is engaged in basic research in hydrogen production and storage and has initiated engineering systems research with goals established as per the U.S. DOE Fuel Cell Technologies Program. Hydrogen production research of this project is reported in Purdue Hydrogen Systems Laboratory: Hydrogen Production.

Bio-production of hydrogen is potentially an important renewable source of energy. Using organic wastes for bio-production of hydrogen not only has the potential to generate cost-effective and renewable energy but also can reduce pollution in the environment and provide a source of fertilizer for growing crops. The purpose of the current research effort is to investigate, obtain data, and evaluate initial processes for the production of hydrogen from various waste streams using microbial fermentation and investigate possible paths for implementation of the technology as a local electric and thermal energy source. This effort is targeted to assure that the developed technology will be applicable for integration into various current and future energy supply options including the Department of Energy Road Map. This effort is investigating ways to develop a modular anaerobic biological hydrogen production and energy system for applications initially in remote locations (Figure 1). It is realized that hydrogen production levels from conventional anaerobic processes are not as great as is desired in the long term perspective for bulk production systems.

This research is focusing on a process that has multiple products and associated values. Value streams include hydrogen, waste disposal function, heat for buildings, drinking water, and possibly a marketable chemical product produced from process carbon dioxide. After it is proven, it is anticipated that the technology will be leveraged to larger applications in continuing research efforts. We have performed preliminary cost analysis studies, but factors such as the water content greatly influence the design and consequently the cost. It is also necessary to consider aspects such as the value of waste disposal, sanitized fertilizer, and ancillary energy. These aspects depend on the details of the process currently being developed. Preliminary estimates indicate that when all costs and benefits are considered, the technology has advantages over other alternatives for this application. The carbon dioxide capture portion of the process is intended principally for gas conditioning. Carbon dioxide is a co-product and hydrogen purification is usually necessary. The potential for utilization of the captured carbon dioxide in the production of chemical products is under investigation as a part of maximizing the utility of the proposed self-contained system.

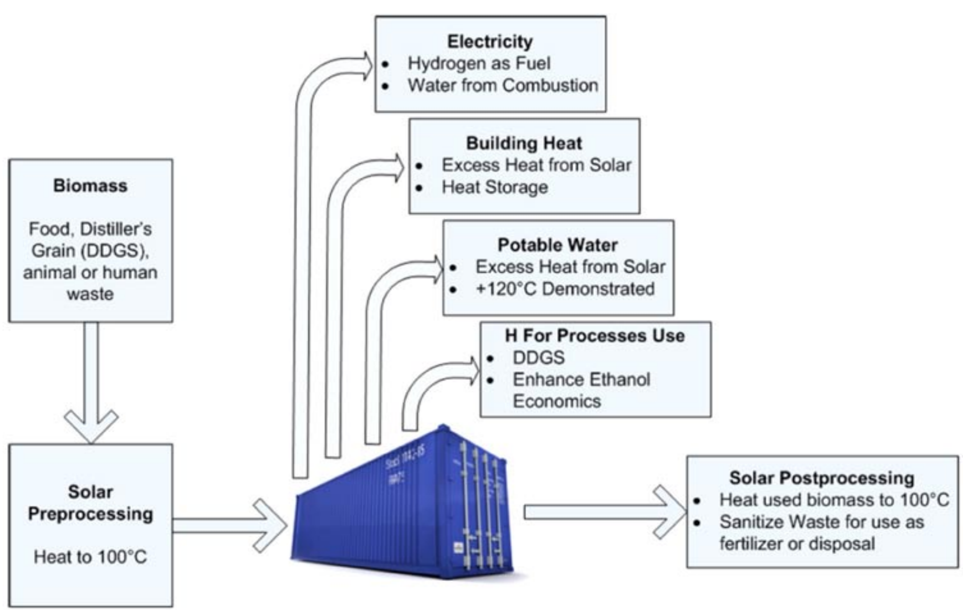

FIGURE 1. Modular System Overview

Approach

We are considering methods to optimize hydrogen production from waste through the use of a fermentation process (Figure 2). The optimization procedure is being used to form the foundation for the subsequent development of a modular device that will use various waste streams, including garbage, animal or human waste, and distiller's grain for the production of hydrogen. This hydrogen will be separated from the biogas stream by use of nanocatalyst or a membrane for use in a fuel cell or reciprocating engine to produce electricity locally. Methods to sequester carbon dioxide as part of the process are also being considered. Energy for the pre- and post-processing of feed streams is being obtained from a solar collector system. The steam generator of the solar system is currently producing potable water. Computer simulations of the process indicate that the system can be installed in a shipping container and used to provide local electric and thermal energy. Initial efforts have reduced the amount of water in the processed waste material from 98% to 75% with minimal decrease in hydrogen production. By reducing the fraction of water it will be possible to reduce the volume and weight of the bio reactor and increase the system efficiency.

Results

Additional inoculua have been tested and the concentration of hydrogen in the produced gas has been correlated with the experimental variables: pH, temperature, and substrate concentration. We have preliminary indications that a new procedure for producing hydrogen with distiller's grain may show considerable higher hydrogen production levels than any observed to date. We are currently investigating this approach. If verified, this may provide a new alternative for increasing hydrogen production levels with distiller's grain and provide a potential enhancement to the energy balance for ethanol production. Considerable interest in these results has been shown by the Industrial Advisory Board for the project since it could be of value for multiple industrial processes.

Test samples and data are being exchanged between Purdue Calumet and Lafayette and trials to test repeatability continue. A micro gas chromatograph is used to determine gas composition. The testing is based upon a central composite experimental design. We are currently completing the third iteration for the optimization of the hydrogen production levels. This process identifies combinations of operating variables that maximizes hydrogen production. Figure 3 depicts the third generation optimization of hydrogen concentration using the Simplex methodology with an optimum point at 36.9°C, starting pH 5.9 and 1.2 g/25ml concentration. The multiple testing devices are fully operational and is being used to generate data (Figure 4). This device provides the capability to conduct multiple simultaneous tests with automated data processing and monitoring. Continuous production testing is currently being conducted at Purdue Lafayette and initiated at Purdue Calumet with the addition of a batch fermentor (New Brunswick). Initial approaches to a dry substrate design are being investigated at Purdue Calumet and Lafayette. The computer simulation model for the modular energy system was updated based upon new experimental values. Efforts using a catalyst process for capture of carbon dioxide have been initiated.

Conclusions and Future Directions

The biological hydrogen production work to develop optimal hydrogen production cultures for different substrates, reduce the water content in the substrate, and integrate results from the vacuum tube solar collector pre and post processing tests into an enhanced energy system model and modular energy system design will continue this year. The automated testing device developed will continue to be used to consider optimal hydrogen production conditions using statistical testing procedures. Testing with the

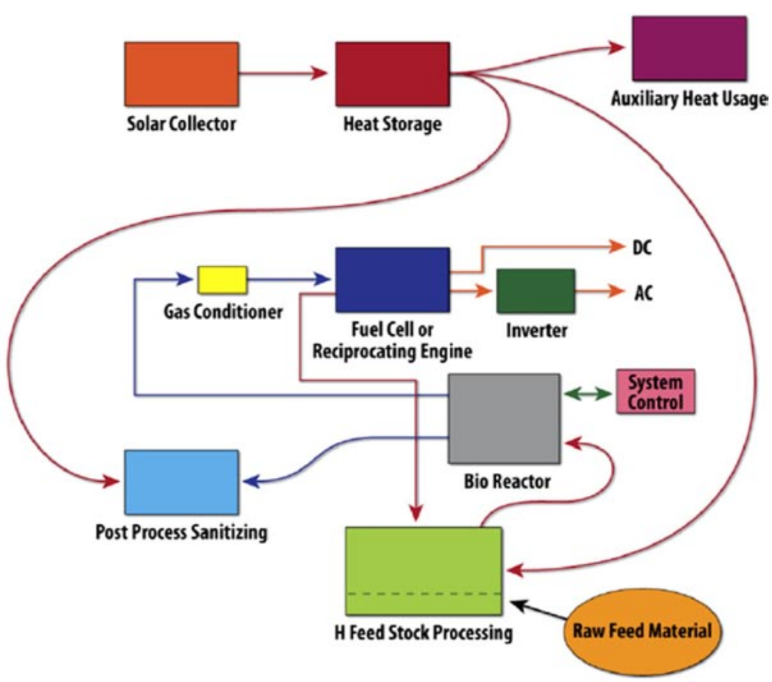

FIGURE 2. Process Overview

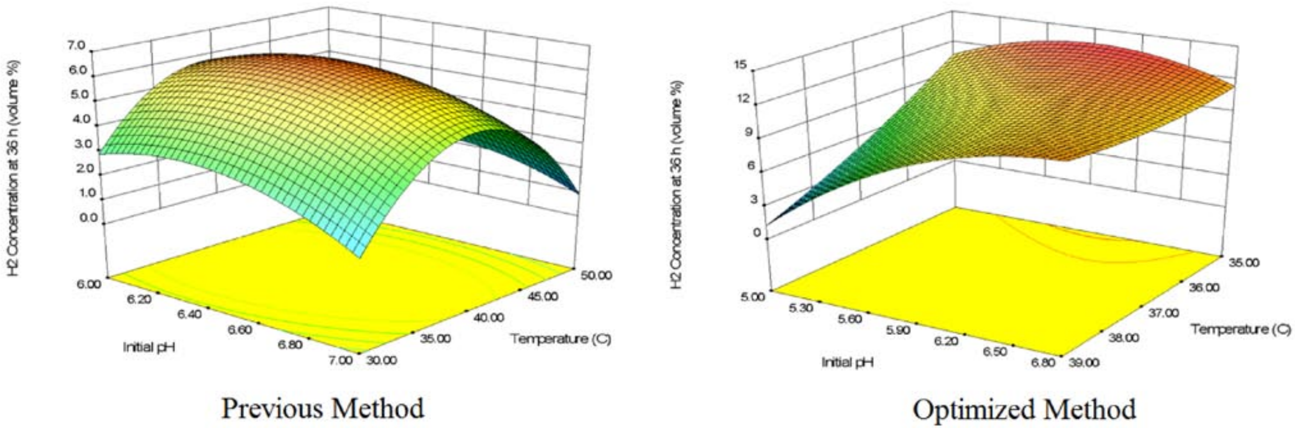

FIGURE 3. Increase in Hydrogen Concentration with New Process

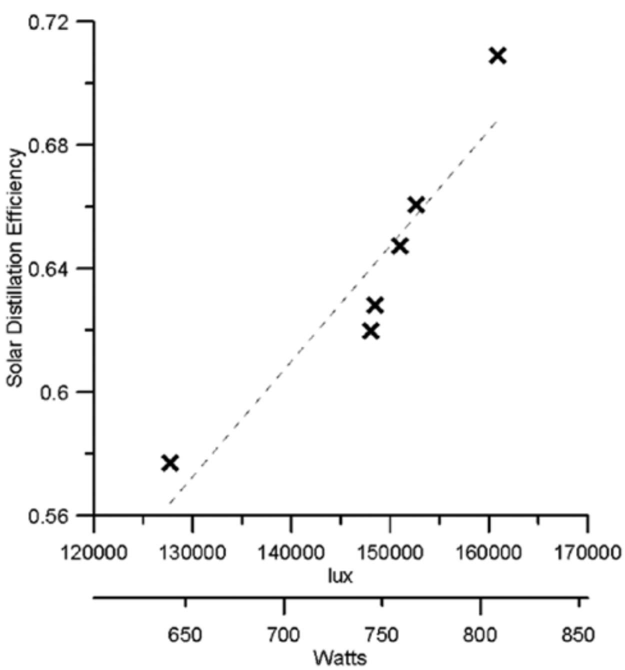

FIGURE 4. Steam Generator Efficiency vs. Solar Luminance

continuous fermentor will be expanded to consider issues associated with continuous feed of substrate and scale up of the process. A mass flow meter will continuously measure hydrogen production levels from the fermentor. We will also explore existing catalytic methods including nanocatalysts for capture of carbon dioxide from the fermentation process. The next phase of the research will involve the construction a bench top reactor based on these designs that will operate with dryer waste material and use solid material handling techniques. Funding is currently not available for the actual construction of the dry bench top test unit. This research considers hydrogen production, but also considers the leveraging of other value streams to overcome design issues that have arisen in the past. We consider this process to have significant value for waste processing and heat production as well as hydrogen production. The use of catalysis to condition the biogas stream also adds value to the process that has not been considered in the past for this application.

FY 2010 Publications/Presentations

1. Brockman, A., Basu, S., Gagare, P., Diwan, M., Shafirovich, E., Zheng, Y., Ramachandran, P., Varma, A., Gore, J., Kramer, R., Patterson, J., Ting, B., Pelter, L., and Maness, P., "Purdue Hydrogen Systems Laboratory," *2010 Annual Merit Review & Peer Evaluation*, Washington, D.C.

2. Kramer, R., Patterson, J., Pelter, L., Branch, R., Liu, W., Martin, R., Kmiotek, K., "Utilization of Solar Heat for Processing Organic Wastes for Biological Hydrogen Production", submitted for publication, Energy Engineering.