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Commercialization of Biomass Ethanol Technology

Feasibility Studies for Biomass-to-Ethanol Production Facilities

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ABSTRACT

With the recent commissioning of the National Renewable Energy Laboratory's (NREL) process development unit, through the support of the US Department of Energy (DOE) Biofuels Program, the technology to convert lignocellulosic biomass to fuel ethanol enzymatically has reached the pilot scale. The next step will be to construct precommercial-scale engineering demonstration units, which will probably be built at or near proposed commercial plant sites, to demonstrate this technology at selected biomass-rich locations in the US. Proper site selection can be critical to these units' long-term profitability, so DOE and NREL have begun a program to help industrial partners build sound business plans that include detailed siting studies. These studies examine biomass availability and cost projections, delineate site requirements, identify qualifying sites, examine environmental and community impacts, and provide detailed *pro forma* financial evaluations and projections. The DOE/NREL ethanol project currently supports several plans that help industry identify economically viable commercial opportunities for biomass ethanol.

Index Entries: Biomass; ethanol; production facilities.

INTRODUCTION

Technology for fuel ethanol production from biomass has been under development for more than 15 yr at the National Renewable Energy Laboratory (NREL) (formerly the Solar Energy Research Institute), with support from the Department of Energy (DOE) Biofuels Program. The technological improvements have been impressive and have reduced the projected cost of biomass ethanol from more than $1.22/L ($4.63/gal) in 1980 (P. W. Bergeron, personal communication, March 1995) to the current projected cost of about $0.32/L ($1.22/gal) *(1)* for ethanol produced in a 1814 metric ton (2000 t)/d plant. Historically, much of the cost saving has resulted from introducing superior cellulolytic enzymes—cost estimates attribute

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a savings of about $0.46/L ($1.75/gal). Cost savings have also been realized from better process designs. Changing from sequential hydrolysis and fermentation to a capital and operationally less complex process of simultaneous saccharification and fermentation (SSF) (combined with other process improvements) has permitted an additional saving of about $0.18/L ($0.70/gal). Finally, a new unit operation—pentose fermentation by a yeast—further reduced biomass ethanol's projected price by about $0.25/L ($0.95/gal). Since these cost estimates were made, basic technology has improved to reduce the cost even more. However, to realize these savings, this technology must be implemented on a commercial scale.

Because plant siting and investor support can be two of the most critical early activities for properly planning a commercial operation, a program has been undertaken to support industrial partners interested in locating both a profitable plant site and the necessary investor support. Ethanol project managers are convinced that a solid business plan that contains a siting study will address both needs for industrial partners.

BUSINESS PLAN STRATEGY AND CONTENTS

The objective of a business plan and feasibility study is to help an industrial/commercial organization or consortium identify and evaluate sites that have the greatest potential for operating a financially attractive biomass-to-ethanol production facility over the long term. Potential partners are identified via competitive solicitations or specific requests from commercial organizations. The business plan, which is completed by the commercial partner or its subcontractor, focuses on the following:

1. Ethanol marketing issues that would provide for the facility's long-term viability;
2. Feedstock production and delivery systems;
3. Preliminary engineering considerations for the facility;
4. Environmental and community-related issues; and
5. A *pro forma* financial analysis of the operation.

DOE supports the business plan, usually with a cost-shared subcontract, that includes a highly structured statement of work. The statement of work typically includes the following tasks.

Task 1: Assemble the Team

Usually, the subcontracting organization lacks some skills for completing a full business plan, so it assembles a team with the technical and business expertise to address the tasks in the statement of work successfully. NREL supports and guides the subcontractor, as needed, to develop a successful team.

Task 2: Determine Biomass Availability

A critical requirement for any biomass-based business is the biomass feedstock availability in the immediate area around the plant. Numerous biomass resource studies are typically used as a starting point for the analysis *(2,3)*. The business planning team must evaluate the feedstock production and delivery systems as follows:

1. Describe the biomass shed available to the ethanol facility, including location, number, concentration, and distribution of acres that produce the selected biomass.
2. Provide data that support anticipated biomass yield per acre, and assess the maximum potential for sustained biomass supply from the biomass shed. If the biomass is a waste material, determine the availability of that waste.
3. Ethanol production is a new use and will probably increase demand for the biomass; therefore, potential environmental benefits and hazards to a managed biomass shed intended for ethanol production must be identified.
4. Additional biomass sources, quantities, and characteristics must be identified, because many processes might be able to accept a variety of biomass sources.
5. Delivered feedstock costs must be determined within a specified distance from the site and must project future cost for expanded demand.

Task 3: Assess the Market

Assessing the market for the facility's ethanol product is important to the business plan, owing primarily to the cost for transporting ethanol to the market. Fortunately, the market for ethanol is well established *(4)*. The team must:

1. Analyze the price trends for conventional ethanol sources and assess the potential product pricing impact of existing and planned regulations;
2. Develop a preliminary marketing plan for ethanol, and assess the effect of existing and proposed federal and state tax incentives; and
3. Define ethanol product distribution costs and sales prices, associated with different market options.

Task 4: Fulfill Technical Requirements

A proper technical conversion approach is critical to any feasibility study and has been the subject of critical technical reviews *(5–7)*. As part of this screening study, the business planning team must:

1. Create preliminary process flow diagrams to identify the technology that will be used to convert the biomass to ethanol;
2. Specify any technical requirements, including pilot plant tests and demonstration unit operations at smaller scales, that lead to the construction of a large-scale biomass-to-ethanol production facility; and
3. Develop and report cost evaluations and schedules for any identified requirements.

Task 5: Select a Site

A critical part of the business plan is assessing and identifying the preferred site for the biomass ethanol plant. This activity is divided into five subtasks.

Subtask 5.1—Establish Processing Facility Requirements

The subcontractor must define the minimum facility requirements needed for the site screening evaluation, including:

1. Minimum feedstock supply quantities and expected quality mix;
2. Ethanol production rate and solid byproduct rate;

3. Environmental emission characteristics;
4. Area requirements (acres) and preferred shape;
5. Utility and chemical requirements (water, steam, fuel, power, chemicals);
6. Special transportation requirements (truck, water, rail); and
7. Special storage requirements for feedstock, byproducts, and chemicals.

Subtask 5.2—Screen Available Sites for a Match with Facility Requirements

Once the team has identified the minimum acceptable requirements, it must screen sites within the specific region to find preferred sites that meet or exceed the minimum requirements defined in subtask 5.1.

Subtask 5.3—Develop Budgetary Capital and Operating Costs Based on Process Considerations

The team will probably identify several sites. One way to select superior locations is to analyze the production costs at the sites. The team must develop annualized budgetary capital and operating costs for the island of process equipment, and definitions of feedstock quality and cost assumptions used in the analysis.

Subtask 5.4—Evaluate Site-Specific Issues Relative to Site Zoning Restrictions and Community Interests

Even with superior economics and feedstock availability, a new plant will have a definable impact on the surrounding community and environment, so the team must define the plant's potential effects on the area. Typical environmental and community-related issues include:

1. Required environmental permits and their availability;
2. Known competing uses for the site;
3. Site zoning restrictions;
4. Current mix of heavy industrial, light industrial, and business parks in the surrounding area;
5. Residential density near the sites;
6. Project development time (permitting time, ownership);
7. Natural resource (wetlands, wildlife) issues;
8. Availability and quality of nearby existing roads, rail lines, and waterways; and
9. Sensitive nearby facilities (schools, churches, parks).

Subtask 5.5—Evaluate and Rank Final Sites

The previous subtasks provide a solid set of criteria to evaluate and rank the sites fully. The business planning team is required to use the economic, environmental, and community issues information described in subtasks 5.3 and 5.4 to rank the top sites. Once the ranking is complete, the team completes tasks 6 and 7 on the top-ranked locations only. Ideally, that will be two locations.

Task 6: Refine Budgetary Capital and Operating Costs for Both Sites

The site-specific, detailed budgetary information must verify that one or both sites are economically viable. Therefore, the team must:

1. Review and refine the capital and operating costs defined in subtask 5.3;
2. Prepare a list of major process equipment specifications to allow the budgetary capital costs to be estimated;
3. Devise a capital cost estimate with an eventual accuracy of ± 30%; and
4. Prepare an anticipated specific operating cost estimate for the preferred sites with an eventual accuracy of ± 30%.

Task 7: Prepare Financial Evaluation for Preferred Sites

Subtask 7.1—Prepare Financial Pro Formas

The team must use the capital and operation cost estimates and other information to answer the critical question: Is a plant at this site likely to be economically viable in the short and long term? The team must:

1. Prepare financial *pro formas* for constructing and operating biomass-to-ethanol facilities on both sites;
2. Clearly identify all assumptions in the *pro formas*;
3. Incorporate the site-specific capital and operating costs as determined in Task 6, and determine the feedstock cost and market value of the ethanol and other byproducts that provide for a financially attractive return on equity; and
4. Perform a sensitivity analysis for varying ethanol prices and feedstock costs to provide anticipated best and worst case scenarios.

Subtask 7.2—Identify Business Interests

The team needs to identify—from the financial community, from feedstock suppliers, and from end product users—parties with compatible business interests who can support a biomass-to-ethanol project in the area. The team also needs to contact local, state, and federal officials to determine their interest in using ethanol for their vehicular fleets, and verify those contacts with letters of interest or other evidence.

Task 8: Write a Final Report

Finally, the team must write a final report that describes the results of each task in this study. It should include present conceptual designs and cost evaluations for the sites under consideration. The team must define and outline any additional supporting or mitigating factors it discovers during the course of the study that affect site selection.

ONGOING NREL ETHANOL PROJECT BUSINESS PLAN STUDIES

NREL Letter of Interest Biomass Systems Integration Projects

The ethanol project began supporting business plan and siting studies in FY 1993 with its participation in the letter of interest titled "Economic Development Through Biomass Systems Integration" (LOI RCA-3-13326) issued July 1, 1993. After competitively evaluating 24 proposals, 12 were selected as having merit for funding. Eight addressed biomass power generation; four targeted either biomass ethanol or a combined biomass power and biomass ethanol production. The four projects involving ethanol that are supported by the DOE/NREL Biofuels Programs are reviewed. The members of each project are as follows:

1. "Biomass Systems Integration Program for the Island of Hawaii" (referred to as the PICHTR/Brewer project), with the Pacific International Center for High Technology Research (PICHTR), Amoco Corporation, Cargill Company, C. Brewer, Hawaii Electric Light Company, Hawaiian Electric Company, County of Hawaii, state of Hawaii Department of Economic Development and Tourism, the University of Hawaii, Hawaii Natural Energy Institute, and Hawaiian Sugar Planters' Association.
2. "New Bern Advanced Biomass-to-Energy Project" (referred to as the Weyerhaeuser project), supported by Weyerhaeuser Company, Amoco Corporation, Carolina Power and Light, and Stone & Webster Engineering Corporation.
3. "Economic Development Through Biomass Systems Integration in Central Florida" (referred to as the Florida project), with the University of Florida, Bartow Ethanol, BioEnergy International, Kenetech, W. V. McConnell, Sarvant Vincent, Wheelabrator Technologies, and Decker Energy International.
4. "Feasibility of Reducing Costs of Liquid Fuels and Electricity from Dedicated Biomass Feedstocks and Waste Resource Management in California" (referred to as the WICO project) with Wood Industries Company (WICO), Appel Consultants, the University of California at Davis, State of California Food & Agriculture, Lane Engineers, BSK & Associates, Parallel Products, Kenaf International, and Ultrasystems.

Each project is cost-shared, that is, financially supported by DOE/NREL and the team. All projects are now under way. The first project to be completed is the Weyerhaeuser project. A brief synopsis of the project goals and objectives is included below.

The PICHTR/Brewer Biomass Systems Integration Program

DOE, industry, and many state and local government agencies are interested in establishing a dedicated feedstock supply system (DFSS) to produce liquid fuels, electricity, and related byproducts. Hawaii is a natural location for such a system, because it has an abundance of agricultural land, a year-round growing season, and a dependence on high-cost imported fuel that creates conditions favorable to the success of such a project. PICHTR has assembled a team to investigate all aspects of the proposed DFSS implementation. The team will evaluate the Ka'u Agribusiness and Hilo Coast Processing Company sites on the east coast of the island of Hawaii for producing and processing biomass products, and will use production projections based on previous studies in this area and on site-specific small-plot plantings to estimate the yield and cost of biomass at this and other sites in Hawaii. The engineering demonstration units and future commercial scale-up activities may be carried out at this site.

The team will evaluate sugar cane species and hybrids, sorghum, napiergrass, tree crops (eucalyptus and leucaena), green waste, and the lignocellulosic components of municipal solid waste, and will consider other crop sources. It will document DFSS production economics.

PICHTR and its partners will examine the enzymatic, concentrated acid hydrolysis, and fermentation processes for ethanol production. The team will compare each process and use the optimal production concept to design and estimate the facility's capital and operating costs. In addition, it will evaluate three options for electricity production:

1. Directly combust biomass;
2. Segregate high BTU-containing materials from the transportation fuels stream to produce electricity; and
3. Redirect all organic wastes from options 1 and 2 to anaerobic bioconversion to methane for electricity production.

The long-range objective is to demonstrate technology and production methods to cost-effectively produce ethanol and electricity from sustainable biomass sources. To accomplish this, the team must select and demonstrate on a small scale the optimal feedstock and plant design, with an emphasis on integrating the most cost-effective approaches to the production process. This will minimize uncertainties in the technologies and economics for planting areas and processing plants.

Weyerhaeuser's New Bern Biomass-to-Energy Project

DOE is promoting the development and commercialization of biomass energy systems. One specific area involves integrating biomass production and conversion technologies. This was a unique and significant opportunity for evaluating both a biomass gasification combined cycle (BGCC) and a biomass-to-ethanol process using a specific mill site (Weyerhaeuser's New Bern, NC facility) and sized to satisfy mill steam, power, and integration needs.

The primary reasons for selecting this site for a high-efficiency, biomass-fueled power plant were that the New Bern plant currently cannot burn residual hog fuel (primarily bark) generated at the adjacent sawmill and chip export facility. To use the existing bark boiler, New Bern would have to spend significant capital on flue gas treatment. It currently purchases 470,000 barrels/yr of fuel oil to meet process steam demands (natural gas is not available).

Weyerhaeuser Company and its industrial partners have determined the conditions under which biomass-derived power and liquid fuels production can be practiced in an environmentally supportive and economically sound manner. The partners performed a project feasibility study on a 43-MW energy BGCC power facility to assess the economic merits of expanding biomass use to produce electric power or liquid fuels, or both. In addition, the partners evaluated an attending project that incorporates an ethanol plant to assess the relative economic merits of liquid fuels and power.

The team evaluated alternatives at each stage and develop an integrated program that will result in the most cost-effective production of electricity and ethanol from sustainable sources of biomass. The team identified feedstock streams and projected the levels of material available that could be converted to biogas for electricity production. This information was used to formulate a production concept and detailed costs to define the economics of a commercial plant.

Based on the information developed in this study and parallel evaluations performed by Weyerhaeuser and others, biomass gasification for use in power production appears to be technically viable. At the New Bern mill, options exist that would allow commercial-scale demonstration of the technology while serving the practical energy requirements of the mill. A staged project development plan has been prepared for review. The plan provides for a low-risk and low-cost demonstration of a biomass gasifier as an element of a boiler modification program, and then allows for timely expansion of power production by adding a combined cycle cogeneration plant.

Although ethanol technology is at an earlier stage of development, there appears to be a set of realizable site and market conditions that could provide for an economically attractive woody-biomass-based ethanol facility. The market price of ethanol and the cost of both feedstock and enzyme have a dramatic impact on the projected profitability of such a plant. Additional process and project development work is required to reduce uncertainties and perceived risks before proceeding with future work.

The University of Florida Biomass Systems Integration in Central Florida Project

The University of Florida proposes an integrated systems analysis approach to scale up a DFSS. It will assess biomass cropping alternatives, conversion strategies, and environmental considerations. Because four private sector partners will participate, the university will have some flexibility in evaluating multiple products and strategies. The team has identified four conversion strategies:

1. Press sugar cane and convert the extracted juice to ethanol, and then burn the press-cake (bagasse) to generate electricity;
2. Extract the juice and ferment it and the bagasse to ethanol;
3. Ferment the whole plant (elephantgrass, sugar cane, or woody material) to ethanol in an SSF process; and
4. Directly combust the whole plant biomass to electricity.

The feasibility study will draw on several years of research and practical experience to identify various critical components and processes for a DFSS. It will include the input and output from each component of an integrated biomass system from crop planting through ethanol, electricity, and chemical byproduct production.

Four specific objectives have been established for the project:

1. Estimate biomass production costs by estimating the costs of establishing, maintaining, and harvesting biomass crops by using a computer model called AGSYS (developed by the University of Florida Food and Resource Economics Department);
2. Use computer modeling to predict physical and economic relationships for each system;
3. Perform laboratory testing on selected feedstocks. Conversion coefficients for selected feedstocks used for specific processes, such as converting sugar cane press-cake, elephantgrass, and leucaena to electricity by direct burning, are not known; and
4. Expand the stock of planting material Expanding the available seed stock of the tall grasses is important if feedstock is to be available in the future to pursue feasible options. Similarly, new superior clones of eucalyptus have been identified that need to be expanded by rooting cuttings or micropropagation. Leucaena can be propagated by seed; however, seed orchards need to be established.

These activities drive the site assessment study. Because these objectives are so extensive, the full business analysis and siting study are not included in the scope of this work.

WICO's Feasibility Project for Reducing Costs of Liquid Fuels and Electricity from Dedicated Biomass Feedstocks and Waste Resource Management in California

WICO is a wood waste management, composting, and fuel supply company in Visalia (Tulare County), CA. It has a 40.5-ha (100-acre) "demofarm" in the heart of a rich agricultural region, and is interested in investigating the production of transportation fuels from dedicated feedstocks grown in the central valleys of California. WICO's resources and current involvement in biomass management provide a unique opportunity to investigate the potential for an economical biomass-to-energy system. This project (and others like it) could strengthen local economies.

The objective of this project is to develop a plan for integrating biomass production and conversion technologies for liquid fuels and electricity production. The study of cost-reduction strategies includes selecting a site to optimize production, transportation, and marketing; performing integrated studies of biomass crops for highest end use; assessing the markets for high-value (nonfuel) biomass products; using residues for fuel conversion feedstock; and integrating waste resource management into the DFSS, e.g., using set-aside and damaged farmland, municipal and agricultural processing waste water for irrigation, and compost from municipal, agricultural, waste products, manure, and biomass ash for fertilizer.

The WICO team has determined the conditions under which biomass-derived power and liquid fuels production can be practiced in an environmentally and economically sound manner. It is assessing the economic merits of expanding biomass use at an independent power producer in the Visalia area to produce electric power and liquid fuels.

Additional Ethanol Project Business Plan/Siting Study Projects

Since July 1993, the NREL ethanol project has been helping parties with business plans, and is now helping the following groups complete business and siting plans:

1. New York City and State Siting Study titled "Screening Study for Waste Biomass-to-Ethanol Production Facility in the State of New York." This is funded largely by the New York State Energy Research and Development Authority and cofunded by DOE/NREL, Amoco Corporation, NYNEX, Champion International, and Stone & Webster Engineering Corporation.
2. Belcan Engineering Group, Inc. (Cincinnati, OH) is conducting a feasibility study for a biomass sawmill waste ethanol facility in the "tristate" region of Ohio, Kentucky, and West Virginia.

FUTURE DIRECTIONS

In addition to the business plans and siting studies outlined, the NREL ethanol project has joined in a solicitation aimed at joining DOE in partnership with state energy offices to support commercialization of DOE technology. The program, called Sustainable Technology Energy Partnerships, or STEP, will solicit potential industrial partners and their state energy offices to send proposals that outline projects aimed at commercializing biomass ethanol, among other topics. The ethanol project portion of the solicitation will address business plan and siting studies,

biomass availability studies, and related projects whose goal is to facilitate starting the biomass-to-ethanol industry. Multiple deployment and commercialization projects will likely result from this solicitation (issued in January 1995) and should result in additional DOE-funded projects aimed at biomass ethanol in the summer of 1995.

Eight business plans and siting studies are now being pursued that involve 11 states and about seven feedstocks. Each will contain unique opportunities and specific deficiencies that will be outlined in the final plan. With this number of business opportunities being defined, there will likely not be enough resources, either financial or personnel, to provide additional assistance to all business partners. Therefore, a set of evaluation criteria is now under development to help determine the relative merit of any submitted plan. Plans that have a high probability of success will be given a high priority for additional DOE assistance.

The DOE ethanol projects will continue to facilitate the commercialization of biomass ethanol technology by offering specific enterprises technical and financial assistance. For example, NREL's new 0.9 metric ton (1 t)/d biomass ethanol pilot plant offers a unique opportunity for industry to work with DOE to examine its process on a large scale. Additionally, NREL's engineering expertise may be included in specific projects to help industrial partners finalize process designs for biomass ethanol demonstration units or full commercial plants. Finally, DOE may participate in a heavily cost-shared arrangement to design and construct a demonstration unit for biomass ethanol, thus buying down the risk for the first few production plants in a new industry. This new biomass ethanol industry, which will directly decrease a portion of the US petroleum imports (now >50% is imported oil), is viewed as critical for the nation's strategic and economic well-being. These biomass ethanol siting studies and business plans are vital first steps in the commercialization process. DOE is pleased to be able to help start this new industry.

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