Northern California Rice Field

Alcohol Fuels from Biomass – Assessment of Production Technologies

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Western Governor's Association
National Biomass State and Regional Partnership Report

www.westgov.org

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INTRODUCTION

The State of California has maintained for decades an active interest in the production and application of alcohol fuels for transportation energy. This has included efforts toward development of technologies for producing ethanol and other alcohol fuels from biomass. Past studies and projects conducted by the California Energy Commission (CEC), academic institutions and other California organizations have sought to advance the timetable for commercial projects in the state to produce alcohol fuels, along with electricity and other products, from cellulosic biomass resources.

The Western Governor's Association (WGA), through its Western Regional Biomass Energy Program, is also promoting the increased use of bioenergy and biobased products through the conversion of biomass residuals from forest health projects and commercial agriculture. In 2006, WGA engaged the CEC to study and report on the status and outlook for technologies under active development for conversion of cellulosic biomass feedstocks to ethanol or other alcohol fuels. This report contains the results of that study, which was conducted by TSS Consultants and CEC staff.

The purpose of this study is to further the understanding of the progress to date and development status of biomass-to-alcohol (bioalcohol) production technologies, and to help guide continued development activities in California, the Western region and elsewhere. Specific objectives outlined for the study are to:

(1) Review and evaluate candidate technologies for producing ethanol and other alcohols from cellulosic biomass feedstocks, describing development progress to date and future prospects for these technologies.

(2) Review and summarize relevant past bioalcohol production technology projects studied or proposed in California.

(3) Identify opportunities for new projects involving applications of candidate bioalcohol production technologies using California's cellulosic biomass resources.

(4) Identify remaining regulatory, economic and institutional obstacles to bioalcohol project development and describe state and federal government roles in addressing these challenges.

This study report presents the results of a wide-ranging investigation of bioalcohol production technologies under development worldwide. A survey conducted as part of the study is summarized in the form of individual profiles of 38 active technology developers in the U.S., Canada and several other countries. A number of these developers have operated pilot-scale and demonstration facilities, however, none have produced ethanol on a commercial scale.

The study’s key analysis involves application of a unique methodology, called “5E” assessment, to evaluate key features of the various categories of bioalcohol technologies under development. This approach was used to generally evaluate some of the principal technologies under development, using information compiled from developers and from publicly available reports and publications. The profiles of active developers of cellulosic biomass-to-alcohol technologies are presented in Appendix I.

EXECUTIVE SUMMARY

This report provides a perspective on the potential viability of various technological approaches for the production of alcohol fuels (bioalcohols) from renewable biomass (cellulosic) resources in California and the Western United States. Included is a historical review of several biomass-to-alcohol fuel projects that have been pursued in California. One reason such projects have yet to achieve commercial reality -- in California and elsewhere -- is that the principal conversion technologies underlying these ventures have not been adequately assessed for their scientific and engineering basis, energy efficiency, environmental impacts, economic viability, and socio-political effectiveness. Progress toward commercialization and deployment of such technologies requires more complete assessment of all these technology aspects, applying appropriate evaluation methodology to sufficient technical data.

To address the above need, a “5E” assessment approach (Schuetzle, 2007) was developed and applied to evaluate the potential viability of technologies under active development for the production of bioalcohol fuels from cellulosic biomass. The components of this 5E assessment methodology are: E1 – validation of technical performance and stage of development; E2 – estimation of energy efficiency; E3 – environmental impact assessment; E4 – economic analysis; and E5 – appraisal of socio-political effectiveness.

Hundreds of organizations worldwide have engaged in the development of technologies for the conversion of biomass materials to bioenergy, including electricity and process heat as well as various biofuels. The report separates these bioenergy technologies into fifteen different categories based on the technology characteristics and type(s) of bioenergy produced. Those technologies designed to produce ethanol or other alcohols, either as primary or secondary products, were selected as the focus for further study. Organizations that have concentrated their efforts on the production of bioalcohols were specifically identified and information on these organizations and their technologies was gathered directly from them and/or from other various sources of published information.

Results of the 5E assessment are provided generically for the technology categories where available data was found to be adequate to perform such an assessment. In many cases, technology developers have either not yet acquired some of this required data or keep this data confidential; thus the study does not comprise a complete or equally applied assessment of all candidate technologies. The report’s recommendations include further study needs in those cases where sufficient data for complete 5E assessment are not available.

On the basis of this assessment approach, technologies are identified that appear to have the most promising potential applicability for the conversion of biomass resources to bioalcohols in California and the Western region. Of these, it is

concluded that the thermochemical conversion technology with the highest probability for near-term success is an integrated pyrolysis/steam reforming process incorporating syngas to bioalcohol and electricity co-production systems. It is expected that the bioalcohols directly produced from these thermochemical processes will be comprised of an 80-85 % ethanol/10-15% methanol mix, with smaller percentages of other higher alcohols possibly present as well. Distillation can be employed to separate ethanol from such a mixed alcohol product if necessary. However, this adds to the costs, energy intensity and environmental impacts of the production facilities, and therefore is best avoided. Thus, steps to gain acceptance of mixed alcohol fuels by the automotive industry and regulatory agencies must also be pursued to fully realize the opportunity these technologies represent for bioalcohol fuel production.

The 5E assessment indicates that the above thermochemical process will be capable of producing bioalcohols in facilities using as little as 250 dry tons (DT) per day of biomass at a production cost of less than $1.50/gallon. Furthermore, this process should be able to produce ethanol at an average of $1.12/gallon for a 500 DTPD plant. Improvements in this thermochemical technology have the potential of reducing ethanol production costs to below $1.00/gallon by 2012, where biomass feedstock can be supplied at $35/ DT.

Other thermochemical conversion processes that incorporate air or oxygen typically produce syngas that has a low BTU value (<300 BTU/cubic ft.) and high concentrations of tars, particulate and other contaminants. Although these types of technologies have been used for over seventy years for the large scale production of fuels, electricity and chemical feedstocks from renewable and fossil biomass, it is not believed that these technologies are viable for bioalcohol fuel production in smaller-scale plants (200-1,000 DT/day).

Biochemical conversion processes that utilize enzymatic hydrolysis of lignocellulose, followed by fermentation of the simple sugars, are currently estimated to have the potential for producing ethanol at approximately $2.24/gallon for a 2,200 BDT/day plant. Simpler biochemical conversion processes have been studied for nearly 100 years that utilize acid hydrolysis for the conversion of cellulose to sugars, followed by the fermentation of the sugars to bioethanol. Projected improvements in biochemical conversion processes have the potential of reducing ethanol production costs below $1.50/gallon for 2,000 BDT/day or larger plants by 2012.

These thermochemical and biochemical technologies are expected to serve different needs and applications. Examples of prospective California applications include the conversion of forest biomass, agriculture waste, urban green waste and wastewater plant solids to bioalcohols, electricity and heat. Many different varieties of purpose-grown cellulosic energy crops could be used in the longer term.

Biochemical technologies appear most applicable where large volumes of a biomass feedstock of consistent quality are available. Examples include corn- and sugarcane-growing regions where residues from these crops are abundant and conventional ethanol production facilities already exist or are planned. Since thermochemical processes require much less biomass for economic viability, they are adaptable for the distributed production of bioalcohols and electricity. In addition, the thermochemical approach can be used for the conversion of nearly any biomass feedstocks.

Several novel technologies have also been under development for the conversion of biomass to bioalcohols. These include processes that employ specially-developed organisms (e.g., bacteria or yeasts) to produce alcohols, some using shallow pond systems capturing solar energy, some using syngas from a gasification process. These are examples of potential future technologies that require further research and scientific validation before their ultimate potential can be determined.

The U.S. Department of Energy (DOE) recently announced (February 2007) an investment of up to $385 million for the demonstration and deployment of six biorefinery projects incorporating both biochemical and thermochemical conversion technologies in California, Florida, Georgia, Idaho, Iowa and Kansas. The total investment in these six technologies is projected to total more than $1.2 billion over the next four years. The DOE grant program will provide a significant boost to the advancement of such conversion technologies. The technology developers represented by these six DOE grants (Abengoa, BRI, BlueFire, DuPont, Iogen, and Range Fuels) are among the 38 active technology developers profiled in Appendix I of this report.

Additional opportunities are summarized for the commercialization of technologies in California and the Western United States for alcohol fuel production from biomass feedstocks. The impact of high energy prices, geopolitical uncertainty, the growing focus on clean energy technologies and concern about global climate change are driving substantial increases in funding from the public and private sectors. There has never before been such a wide-ranging opportunity for technological advancements in the area of renewable and clean fuels and electricity.

Although U.S. government and private sector support has been increasing rapidly, much greater financial support for research, development, demonstration and deployment of renewable biomass to alcohol fuel and electricity production technologies will almost certainly be necessary to assure their commercial success. And, while the majority of active development projects identified by this study are in North America, growing interest in Asia, Europe and South America is also apparent. This suggests the likelihood of increasing worldwide competition for the lead in bioenergy technology development.

SECTION 10 - CONCLUSIONS AND RECOMMENDATIONS

Production of ethanol and other alcohol fuels from cellulosic biomass offers a promising means of supplying a significant part of future transportation energy needs using renewable resources. However, significant remaining research, development, demonstration and deployment (R3D) steps need to be successfully pursued before technologies for producing alcohol fuels from cellulosic biomass can be considered commercially available.

The impact of high energy prices, geopolitical uncertainty, the growing focus on clean energy technologies and concern about global climate change are driving substantial increases in funding from the public and private sectors. These factors have resulted recently in a substantial increase in biomass-to-alcohol research and development in the U.S. and several other countries. A number of new and expanded demonstration projects are under development and plans for several commercial-scale projects are being formulated. This increasing emphasis on development activities is encouraging, but still does not assure advancement of any of the various biomass-to-alcohol production technology options to the commercial stage.

For those technologies that appear to be promising, demonstration and commercial scale plants need to be built, tested, validated and improved. These plants need to be fully assessed applying a methodology such as the 5E approach described in this report – covering technical validation, energy efficiency, environmental impacts, economic viability, and socio-political effectiveness. A consistent method should be adopted as a tool by government, private and academic organizations to help evaluate the potential viability of emerging thermochemical and biochemical conversion processes. This type of process also has the value of identifying potential problems with candidate technologies, and it can help identify RD&D programs that should be carried out to help resolve those problems.

Although numerous biofuel and bioenergy reports and presentations have been published by public and private sector organizations during the past two decades, most of the information contained within these resources has not been published in peer-reviewed scientific and engineering journals, books, patents and other readily accessible resources. As has been the case with the rapid development and advancement of other technologies (e.g. information systems, software and automotive technologies), much more effort is needed to encourage the publication of such information in these peer-reviewed resources.

Government organizations should implement regulations, provide increased R3D support, and grant incentives that will help promote technological advancements and the implementation of production plants by the public sector. However, government should not mandate the type(s) of technologies that they believe will be the future winners, but support all promising technology approaches to the point where the most effective technologies prove commercially successful. The coordination of agencies with regards to siting and permitting could streamline the demonstration and deployment of these technologies. Governments can also assist on the market side through policies and regulations that assure adequate markets for bioalcohols and co-products and adequate returns on investments in production facilities.

The recently funded DOE projects are intended to produce several demonstration projects by at least 2012. Other technology companies are planning to build commercial scale plants by this time. These expectations appear to be realistic assuming that the level of interest and funding continues to increase substantially.

Among the 38 active technology developers profiled in this study are a number of promising candidates for potential commercial deployment. Included are both thermochemical and biochemical process approaches representing fundamentally different technology paths. Both approaches require and warrant further development emphasis and funding support, although most emphasis to date has been on the biochemical path. Thermochemical technology is the more emerging path, but appears to have certain advantages that suggest it deserves at least equal development attention.

Thermochemical processes have the ability to convert virtually any biomass feedstock to bioalcohols or other biofuels, a particularly important feature for California and other regions with a wide variety of biomass feedstock sources of different compositions and qualities. The energy efficiencies and environmental characteristics of facilities employing thermochemical technologies appear attractive as well. Also, the thermochemical processes require much less biomass for economic viability, making them better suited for the distributed production of bioalcohols and electricity.

The thermochemical technology with the highest probability for success is an integrated pyrolysis/steam reforming process. Current analysis suggests that a commercial plant utilizing this technology should be able to produce mixed alcohols at a cost of about $1.15/gallon for a 500 BDT/day plant, which would make this process competitive with traditional corn-based ethanol production. If market constraints to the use of mixed alcohols as transportation fuels prevail, then the further refinement of mixed alcohols to ethanol would add nominally to this production cost.

The biochemical conversion processes encompass two primary approaches – acid hydrolysis/fermentation and enzymatic hydrolysis/fermentation. Biochemical conversion processes that utilize enzymatic hydrolysis of lignocellulose, followed by fermentation of the simple sugars are currently estimated to have an ethanol production cost of approximately $2.24/gallon for a 2,205 BDT/day plant. Projected improvements in biochemical conversion processes have the potential of reducing ethanol production costs below $1.50/gallon for 2,205 BDT/day or larger plants by 2012.

Larger biochemical conversion plants can become viable when significant quantities (>2,000 tons/day) of biomass are available at feedstock costs below $35/BDT. An initial attractive application may be to co-locate these plants with large, traditional corn-to-ethanol production plants. Thermochemical processes can also be integrated with biochemical processes to supply electricity, heat (steam), cooling and the production of additional ethanol from waste materials. These integrated approaches are expected to increase plant energy efficiency, reduce emissions and increase economic benefits.

The following R3D needs are identified for both thermochemical and biochemical technologies under development for producing alcohol fuels from cellulosic biomass:

Thermochemical Processes

The production of syngas from thermochemical conversion systems will need to meet certain compositional and purity standards to ensure acceptable catalyst efficiencies, selectivities and lifetimes for the efficient and economical production of bioalcohols.

Thermochemical conversion systems are needed that meet the following specifications:

- ~100% energy conversion efficiency of biomass to syngas, with external energy input of ~25% of natural gas and electricity (or)
- ~75% energy conversion efficiency of biomass to syngas, using the syngas as a heating source for the thermochemical conversion system)
- Syngas that has >350 Btu/SCF energy content at ambient conditions (STP)
- Syngas that meets or exceeds the following composition specifications:

H_2+CO:	>60 mole%
CH_4:	15-25 mole%
CO_2:	<15 mole%
N_2+O_2+Ar:	<2 mole%
C_6–C_{16}	<500 PPM
Tars/Waxes (>C_{16}):	<1 mg/M3
Sulfur and Chlorine:	<0.5 PPM
Particulate Matter (excluding Tar) :	<0.5 mg/M3

The following development efforts are recommended to help meet these syngas compositional requirements:

- Develop efficient, low-cost and robust syngas purification processes
- Develop thermochemical pyrolysis/gasification/steam reforming systems that produce low levels of contaminants, thus reducing the need for extensive and costly syngas purification processes

Thermochemical processes also require further catalyst development, including the following recommended efforts.

Develop catalysts for the conversion of syngas to bioalcohols that have the following capabilities:

- A one-pass catalyst conversion efficiency of greater than 30% (the current average conversion efficiency is ~18%)
- An ethanol/methanol catalyst selectivity of greater than 5/1
- A conversion efficiency for >2,000 hrs while maintaining greater than 80% of the initial catalyst specifications

Develop integrated systems for the co-production of bioalcohols, electricity and heat that:

- Reduce the number of unit processes needed to co-produce bioalcohol, electricity and heat, resulting in the reduction of capital and O&M costs
- Continuous syngas composition monitoring systems, integrated with real-time process control, for the optimization of bioalcohol, electricity and heat production

Biochemical Processes

Some R3D recommendations needed to develop efficient and low-cost methods for the production of ethanol via biochemical production technologies include:

- Separation of lignin and cellulose from sugars
- The development of lower-cost enzymes needed for the hydrolysis of cellulose
- Recovery and re-use of enzymes after the enzymatic hydrolysis of cellulose
- Recovery and re-use of acids after feedstock pretreatment and the acid hydrolysis of cellulose

- The development of fermentation organisms capable of co-fermenting C5 and C6 sugars
- The purification and recycling of wastewater with the objective of reaching a zero discharge system

APPENDIX 1 - TECHNOLOGY DEVELOPER PROFILES

This appendix summarizes the information gathered by the study on organizations engaged in active development of technologies for producing ethanol, or other forms of alcohol fuel, from cellulosic biomass feedstocks. Over fifty organizations worldwide were identified during the course of the study as possibly pursuing such technologies. Most of these organizations responded to a survey questionnaire developed and distributed by the project team requesting basic non-confidential information on their organizations, characteristics of their bioalcohol process technologies, and their technology development status and future plans.

Some survey respondents indicated they were not presently active in this field or that their technology development did not involve a complete process for producing an alcohol fuel from cellulosic biomass. A few organizations declined to respond to the survey and others indicated they prefer to keep most or all of their development progress confidential. Therefore, additional sources of information were used to supplement the survey, including websites, papers and presentations and direct contacts. Only publicly-releasable information supplied by technology developers or otherwise found in the public domain was used to compile these profiles. For the most part, the information is exactly as reported by the development organizations, with no attempt by the project team to screen or substantiate this developer-specific information.

Following in this appendix are profiles of 38 organizations that were found to be actively engaged in the development of a cellulosic biomass-to-alcohol production process. These profiles are grouped in various technology categories previously described in the report (and summarized in Table 1, page 9).

Of the organizations listed, 26 are headquartered in the U.S., 5 in Canada, 2 in Brazil, and one each in Sweden, Germany, Spain, Denmark and Japan. This list is believed to include most of the noteworthy entities currently active in this field, especially in the U.S. and Canada. However, there may very well be other organizations, especially outside North America, engaged in bioalcohol process development. There are also many other organizations (not listed) pursuing development of related components of bioalcohol production technologies, such as enzyme development for biochemical processes, catalyst development for thermochemical processes, etc.