Sustainable Biofuel Production: A DOE Perspective

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Biomass research has been a cornerstone of the Department of Energy's (DOE's) renewable energy research, development and deployment efforts over the last 25 years. In order to encourage the economic livelihood of a thriving biofuel industry, the Department of Energy's Office of the Biomass Program (OBP) supports research and development aimed at assessing the impacts of biofuels on the environment, including impacts to land, water, and air from energy production and use. Included in this mission is a goal to substantially reduce greenhouse gas emissions by accelerating the adoption of renewable energy technologies.

A clear driver of the OBP's activities is the President's goal to increase the use of biofuels and other alternative fuels in the transportation sector in order to replace 20% of the gasoline demand in the United States by 2017 (referred to as the "20 in 10" goal). Meeting this goal will require: significant and rapid advancements in biomass feedstock and conversion technologies; availability of large volumes of sustainable biomass feedstock; demonstration and deployment of large-scale integrated biofuels production facilities; and biofuels infrastructure development efforts. In addition, the existing agricultural, forestry and commercial sectors will be making decisions to invest in biomass systems—from shifting land use, to building capital-intensive biorefineries, to establishing the infrastructure and public vehicle fleet for ethanol distribution and end use—in the context of economic viability (including as it relates to environmental sustainability) and the needs of the marketplace.

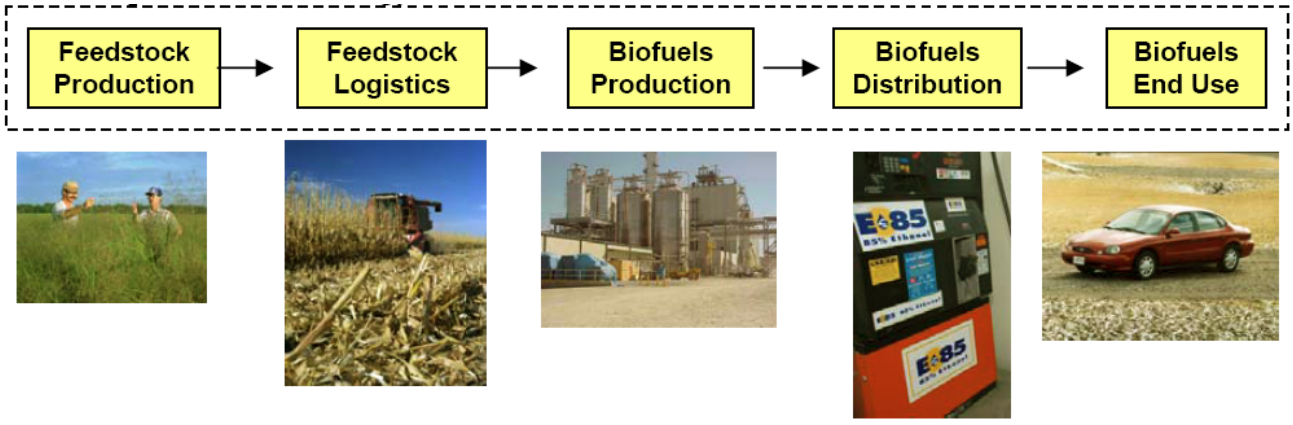

Figure 1. The Department of Energy's Biomass Program is researching the environmental impacts of biofuel production across the supply chain from feedstock production to end use in vehicles.

OBP's research and development (R&D) has led the effort to develop technology necessary to sustainably produce, harvest, and convert a variety of biomass feedstocks, as well as to deploy the resulting biofuels. Core R&D on feedstock production and logistics and biomass conversion technologies is conducted to develop the scientific and technical foundation that will enable the new bioindustry. OBP is looking to advance science in these areas through important collaborations with the DOE Office of Science Bioenergy Centers, the U.S. Department of Agriculture (USDA), land grant universities, and private industry. OBP has

developed Regional Feedstock Partnerships to begin to realize the sustainability of the resource potential outlined in the "Billion Ton Study"[1]. This approach facilitates the collaboration of industry, the agricultural community, state and local governments and USDA and is expected to accelerate the resource-readiness as the cellulosic fuels industry emerges.

The core R&D of OBP is organized around the integrated biorefinery concept. The biorefinery helps deliver sustainable and environmentally sound contributions to power, fuels, and products demand while supporting rural economies. Key barriers relevant to this area include ensuring resource sustainability at levels large enough to support large-scale production facilities and maximizing the efficiency of conversion facilities to minimize costs. Energy production from biomass on a large scale will require careful evaluation of U.S. agricultural resources and logistics, as these will likely require a change in paradigm that will take time to implement. Current harvesting, storage and transportation systems are currently inadequate for processing and distribution of biomass on the scale needed to support dramatically larger volumes of biofuels production. Evaluating the current feedstock resources on a national level as well as the potential for future feedstock production in light of environmental constraints is part of OBP's focus.

The primary program areas related to ecosystems services and sustainability within DOE OBP are (1) sustainable feedstock production, (2) sustainable harvest, and (3) sustainable biofuels production. The program is also committed to engaging in the international dialogue about sustainable biofuel production and providing outputs from our research investments to support the discussion when appropriate.

Sustainable feedstock production

Existing data on the environmental effects of feedstock production and residue collection are not adequate to support lifecycle analysis of biorefinery systems. It is difficult to assure that residue biomass will be collected in a sustainable manner due to the lack of decision support tools to predict the effects of residue removal as a function of soil type. There is an additional lack of a selective harvest technology that can evenly remove only desired portions of the residue. Until the residue issue is addressed, particularly with regard to corn stover, the full utilization of agricultural residue for bioenergy will be severely constrained. The production and use of perennial energy crops also raise a number of sustainability questions (such as water and fertilizer inputs, establishment and harvesting impacts on soil, etc.) that have not been comprehensively addressed. The Biomass Program at the Department of Energy strives to address some of these issues through our sustainability research and development portfolio.

A central focus of feedstock production efforts is to establish and maintain Regional Biomass Energy Feedstock Partnerships in collaboration with USDA, the Sun Grant Initiative universities, and other regional partners. Collaborating in this manner will be crucial to overcoming specific geographic issues of varying climatic conditions, soil types, water quality, and land usage. These regional partnerships are necessary for assessing and quantifying the feedstock resource base because of the diversity of regional feedstocks in terms of growth requirements, climatic differences, and infrastructure needs. Work is focused on:

[1] Biomass as a Feedstock for Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply, Robert D. Perlack, et al., USDA/DOE, DOE/GO-102005-2135, April 2005.

1) Genetic improvement of crops including yield per acre as well as traits desirable for conversion to biofuels, an effort conducted primarily by USDA, DOE's Office of Science, land grant universities, and private companies;
2) Regional resource assessments of the types of biomass feedstocks that can be sustainably grown in specific locations across the U.S., including the development of a National Bioenergy GIS;
3) Development of replicated field trials across regions to determine the impact of agricultural residue removal and to evaluate the feasibility of various energy crops; and
4) Analysis of the sustainability of producing specific biomass feedstocks, an effort being addressed by the Regional Feedstock Partnerships, USDA, and OBP analysis efforts.

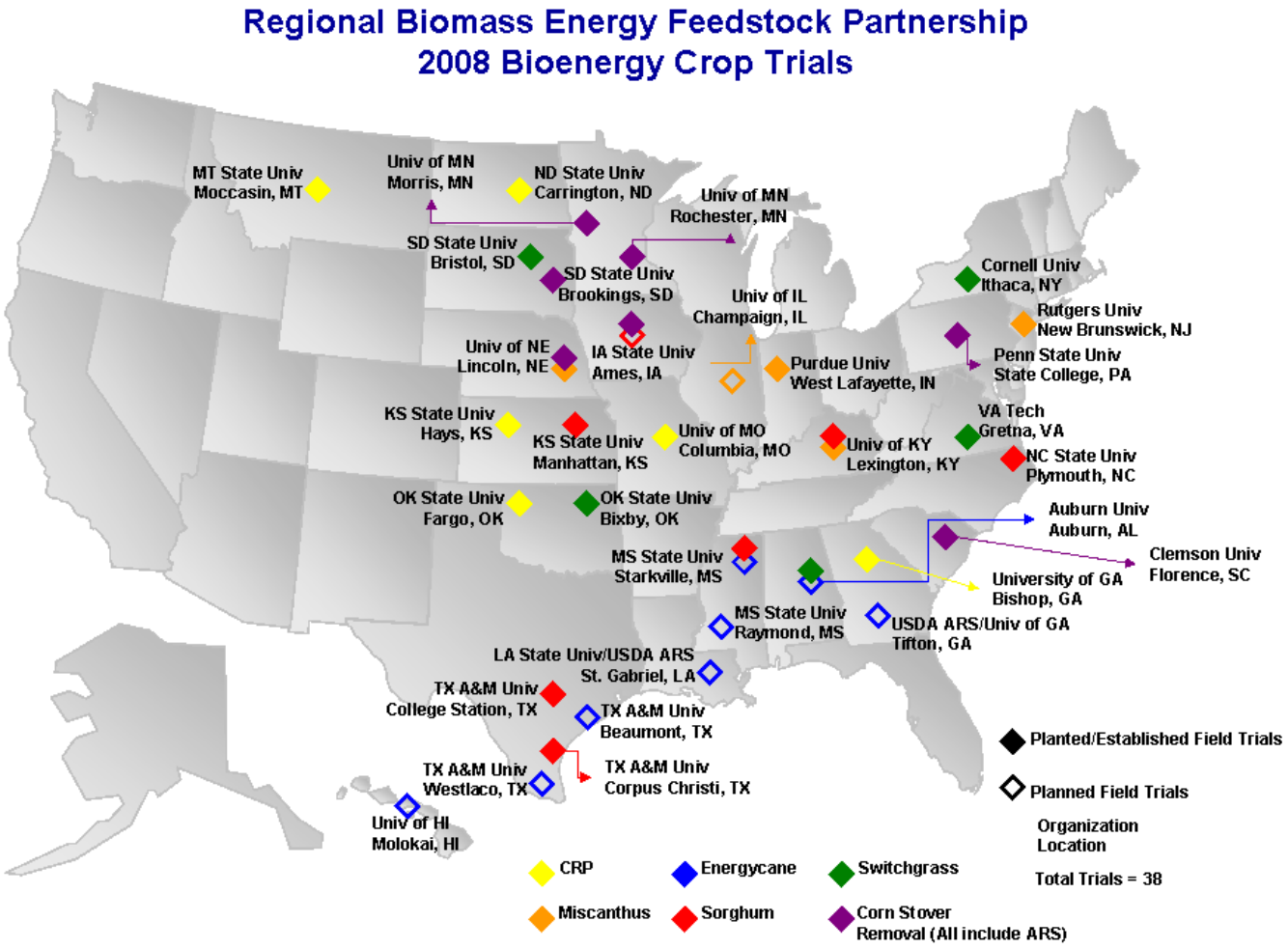

Figure 2. Several of the Regional Biomass Energy Feedstock Partnership Field Trials are focused on evaluating the impact of growing energy crops on soil carbon, water use and nutrient cycling.

One focus of the Regional Feedstock Partnership trials is evaluating the impact of switchgrass production on hydrology and water quality and on soil carbon sequestration. The hydrological and water quality impacts of land conversion to grow switchgrass have not been sufficiently studied. In particular, there is a need for studies that use the small watershed as the

experimental unit. Test sites have been established in South Dakota, Oklahoma, Alabama, and New York to capture a wide potential distribution of switchgrass production. In regards to soil carbon sequestration, the relationship between it and residue removal is a potential area of concern with wide-scale production of bioenergy feedstocks. The objective for focusing on this area would be to apply the soil carbon balance model "CQESTR" to analysis of advanced agriculture residue removal scenarios for ethanol production, and implement the model as part of an enterprise level case study analysis of a proposed residue removal tool framework.

Additionally, the National Bioenergy GIS tool being developed by Oak Ridge, Argonne and Idaho National Laboratories and partnering universities, will serve as a spatially referenced database of current and potential feedstock availability and associated environmental and industrial variables to be used in the analysis of future economic and environmental sustainability related to feedstocks. This tool will also serve as a decision support system to inform the location of new feedstock production and processing facilities and to evaluate the resulting contribution potential of biofuels to the "20 in 10" goal (and beyond) that will sustain air and water resources of quality and availability for desired uses.

At a regional scale, we are studying the economic, energetic, logistic and environmental benefits of integrating the growth of short rotation woody crops into the current agricultural production areas. This effort would result it marginal land and water that are utilized to maximize the supply of additional woody lignocellulosic feedstock in parallel to corn ethanol or other crops, with concurrent optimization of water resources and environmental benefits. We have configured our study format to match existing ongoing work in OBP to examine feedstock growth potentials and water requirement implications for biofuel production. Within this framework, we are addressing a specific set of problems by addressing the potential use of impaired water and land that could be leveraged to meet OBP feedstock production goals.

We are integrating our research with an understanding of larger water utilization issues instead of a specific focus on impaired water and land use, along with examining the potential advantages of a more practical approach on yield potentials and on the minimization of the environmental footprint of current and future feedstock cropping.

Through a pilot assessment at the regional scale focused on the availability of marginal land and non-point nitrate pollution in groundwater and surface water, future work will include: determining quantitative estimates of potential growth of biofuels in "marginal land" by category; efficiency and usefulness of using impaired, nitrate-contaminated water to grow bioenergy crops, the logistic feasibility of this approach, with an analysis of the potential economic, environmental and energy gains; and impacts on surface and groundwater resource inventories, both clean and impaired.

Sustainable harvest

Current crop harvesting machinery is unable to selectively harvest desired components of biomass and address the soil carbon and erosion sustainability constraints. Biomass variability places high demand and functional requirements on biomass harvesting equipment. Current systems cannot meet the capacity, efficiency, or delivered price requirements of large cellulosic biorefineries, nor can they effectively deal with the large biomass yields per acre of potential new biomass feedstock crops. In addition, feedstock specifications and standards

against which to engineer harvest equipment, technologies, and methods, do not currently exist.

A key to success is the ability to convert a wider variety of regionally-available biomass feedstocks and agricultural waste. The DOE is working to establish Regional Biomass Energy Feedstock Partnerships that will identify local opportunities for feedstock development and ethanol production. Part of this work is the development of a number of different core models that examine the impacts of farming, residue/crop harvesting and supply system practices on previously identified agronomics indicators such as soil organic carbon, erosion and water usage. These models develop basic relationships between crop types, soil types, land allocation and cropping schemes to determine the impact on these indicators. This task focuses on capturing the relationships in the core models for a systems level analysis of the biomass sustainability system based on potential growth scenarios of biomass demand. It is aimed at evaluating the current models and databases that will be combined into resources assessment models with the capability to analyze the feedstock supply systems to ensure that the sustainable resources are not stranded from the biorefineries and that the sustainable biomass production is sufficient to meet Federal goals. The next step will be to couple the Idaho National Laboratory-developed Feedstock Supply System model with the aforementioned National Bioenergy GIS to allow for a comprehensive assessment of the cost of a biomass feedstock that includes the feedstock supply system costs.

The output from this research will be a system of models that will make it possible to do a comprehensive analysis of the entire Feedstock Supply Logistics system. By linking the INL Feedstock model with the National Bioenergy GIS, it will be possible to assess the impacts of the supply systems on the cost basis for the various feedstocks, an assessment that is missing in the current analyses. The outcome should include economic cost analysis and sustainability indexes for the various feedstocks under consideration.

Future work includes developing the capability to analyze the cost impacts of the supply systems based on variability in feedstock access. This analysis will help to identify potential sources of constraints on growth and help mitigate impacts of those constraints. The final analysis will determine the sustainability of the biomass supply system and what the constraining factors will be for growth.

Sustainable biofuels production

While perhaps the greatest sustainability challenges to biofuel production lie within the feedstock production sector of the biomass-to-bioenergy supply chain, existing projects within OBP extend beyond feedstock production and harvest. Currently, a life cycle assessment (LCA) of the Advanced Energy Initiative is being performed for the 60 billion gallon 30x30 scenario (a scenario for supplying 30% of 2004 motor gasoline demands by 2030). The analysis covers the entire biofuels supply chain from feedstocks to vehicles. The four main areas addressed in the LCA are: land use and soil sustainability, water use impacts, air quality impacts, and greenhouse gas (GHG) emissions impacts.

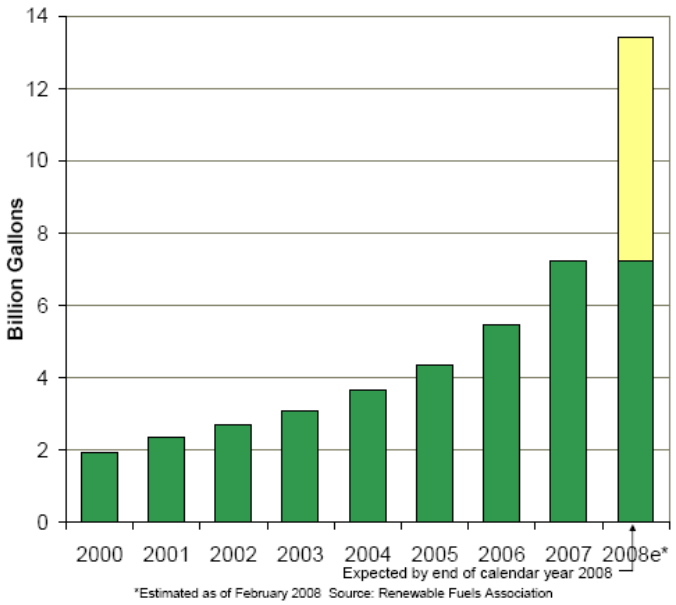

Figure 2. As U.S. ethanol production capacity increases, potential impacts to water use, air quality and greenhouse gases must be assessed.

Also, the GREET model (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) is being utilized for an analysis of water demand for biofuel production, energy and GHG emission benefit of biofuels. Included in this project is an expansion of the existing model to include corn ethanol, sugarcane ethanol, and flex-fuel vehicle (FFV) test results. As part of GREET model development, a focus on indirect land use change is underway. Land-use practices that support biofuel feedstocks and are sustainable cannot be adequately defined due to the lack of documentation of indirect effects of bioenergy and the integration of land use into LCA models. The Biomass Program is engaging with its national lab and university partners to enhance existing analytical tools and develop new predictive models of land use implications of biofuel production. This will include preparing and updating databases on land use change, productivity, inputs, and carbon flows. These tasks will also include testing models with empirical data for validation and the identification of weaknesses and/or areas of improvement related to estimates of carbon loss and storage under different feedstock production systems.

International work

Through a partnership with the nonprofit environmental organization, Conservation International, the DOE is completing an in-depth analysis of potential areas for biofuel crop expansion and overlaying this information with regions with high value for biodiversity conservation, carbon storage, protection of water resources, or other ecosystem services. This work enables the identification of areas that should be avoided during biofuels expansion, as well as opportunities for growth onto abandoned or degraded lands. The development of industry-wide sustainability standards, as well as comprehensive national policies and regulatory frameworks for biofuel crop expansion will help ensure that producers follow recognized best practices by limiting market access to those that do not comply. This project is designed to help give policy makers, industry experts, and producers the tools they need to generate the socioeconomic benefits of biofuels while mitigating the potential negative impacts on biodiversity.

Projects such as that with Conservation International are further enabling DOE to provide data and analysis to inform a variety of international and domestic discussions on sustainability standards including the Roundtable on Sustainable Biofuels and the Global Bioenergy Partnership's working groups on Greenhouse Gas Accounting and Sustainability. In partnership with the State Department, DOE is working to address global sustainability issues with international partners, including environmental organizations, industry, and others.

Through the International Biofuels Forum (IBF) Brazil, China, India, South Africa, and the European Commission have joined the US in an international discussion to promote the sustained use and production of biofuels around the globe. We believe that global standards for sustainable development would promote adherence to best practices in developing biofuels industries.

Conclusions

Through its focus on the entire biomass to biofuel lifecycle, the Biomass Program at the US Department of Energy is committed to developing biofuels that minimize or eliminate the negative environmental impacts associated with conventional fuels and have less carbon emissions throughout their lifecycle—from biomass production to end use in vehicles. To produce these biofuels, we are developing the resources, technologies, and systems needed to *sustainably* produce, harvest, transport, and convert a variety of biomass feedstocks.

For more information, visit: http://www1.eere.energy.gov/biomass/