Ecological Dimensions of Biofuels: Conference and Workshop Report

The workshop was held in Washington, D.C. on 11 and 12 March 2008. For a list of steering committee members, plenary speakers, workshop participants, and sponsors, see the Appendices at the end of the article.

Introduction

One of the major goals of the Ecological Society of America (ESA) is to provide unbiased scientific information about important environmental issues. ESA does not advocate for or against specific environmental policies, but rather strives to provide unbiased scientific information to help in the making of environmental policy. As part of this effort, ESA sponsored the Ecological Dimensions of Biofuels Workshop in Washington, D.C. on 11 and 12 March 2008 to discuss and evaluate the environmental effects of biofuel cropping systems within the United States. In attendance at the two-day workshop were 45 leading scientists with knowledge of biofuel production and the potential for environmental effects, including not only ecologists, but soil scientists, economists, engineers, and hydrologists. The workshop followed a one-day conference with open registration held at the Ronald Reagan Building in Washington, D.C., with over 300 in attendance.

The main goal of the conference and workshop was to synthesize the existing scientific information concerning the environmental impact of biofuel cropping systems in the United States. This article reports the findings of the workshop and includes feedback from conference attendees who were given the opportunity of a written response to the presentations given at the conference. ESA board members Drs. Pouyat and Parton were Co-Chairs of the meeting. They worked with an 11-member scientific steering committee to determine the speakers for the conference and to develop the workshop that followed the conference. See Appendix I for a list of steering committee members, Appendix II for the conference plenary speakers, Appendix III for a list of workshop attendees, and Appendix IV for organizations that cosponsored the conference and workshop with ESA.

Background

The Energy Independence and Security Act of 2007 (EISA) subsidizes the production of ethanol from corn and cellulose, with the goal of increasing ethanol production from biofuel cropping systems to 36 billion gallons within the next 10 years. During the last 20 years, the U.S. Government has subsidized the production of ethanol from corn grain with the stated purpose of: (1) reducing our dependence on foreign oil, (2) providing a fuel that reduces automobile air pollution (e.g., 10% ethanol gasoline is used in Colorado to reduce CO pollution during winter months), and (3) providing a renewable fuel that reduces greenhouse gas emissions. Current U.S. policies have been effective at achieving the first two goals, but there has been considerable uncertainty about the net greenhouse gas fluxes from corn grain ethanol production, ranging from 20% decreases in greenhouse gas emissions to 30% increases (Pimentel and Patzek 2005, Adler et al. 2007). Comparisons of the life cycle analyses used by the authors show that they used different approaches, assumptions, and values to calculate the efficiencies and co-products of the industrial processes associated with production of ethanol (Adler et al. 2007). Various studies have evaluated greenhouse gas fluxes (Sheehan et al. 1998, McLaughlin et al. 2002, Kim and Dale 2005) and energy balance (Shapouri et al. 2002, Farrell et al. 2006) for specific biofuel crops; however, there is a need to learn more about all of the biofuel crops currently being considered.

Fargione et al. (2008) have suggested the need to consider indirect effects of changes to land use in the United States and globally when calculating net greenhouse gas fluxes. The authors suggest that the current reduction in the amount of corn available to produce agricultural products (15% of corn is currently used to produce ethanol) has lead to an expansion of agriculture in countries such as Brazil and Argentina, which results in increased greenhouse gas fluxes. There is considerable uncertainty in the validity of the assumptions considered in the Fargione paper; however, it is clear that we need to better quantify the indirect effects of biofuel-caused land-use conversions.

The expansion of biofuel cropping in the United States may have contributed to the recent dramatic increases in the price of agricultural crops. Higher corn prices are encouraging the expansion of this crop by reducing soybean production and increasing the conversion of Conservation Reserve Program (CRP) land into corn production. The use of CRP and undisturbed grasslands to plant biofuel crops can greatly reduce the net greenhouse gas benefits, compared to planting crops on previously cropped agricultural land. Expansion of agricultural land in the United States via plowing out of CRP and native grasslands can also lead to a loss of plant and animal biodiversity and a reduction in the wildlife benefits associated with the CRP land. Zah et al. (2007) have compared the net greenhouse budgets and overall environmental impact of different biofuel cropping systems and found that the net greenhouse gas impact of biofuel crops depends on the land use prior to conversion to biofuel crops, the specific biofuel crop (annual vs. perennial), and if the biofuel biomass is a waste product or a crop grown specifically for biofuel production. They suggest that the use of waste products to produce biofuels has substantially less negative environmental impact compared to growing biofuel crops on agricultural land, and that there are considerable differences in the environmental impacts of the different biofuel cropping systems.

Workshop objectives

Workshop participants were split into five topical breakout groups:

- Land-use change and landscape dynamics, including the interactions of population growth, urban sprawl, and increasing demands for a wider range of outdoor recreational uses, natural resource commodities, and ecosystem services on a finite land base.

- Disturbing biotic systems: conservation of biodiversity and identification of ecological thresholds for a wide range of ecosystems within which biomass extraction rates can be balanced with habitat needs so as to sustain native biota.

- Bioenergy production systems and economic opportunities and effects on ecological resources, for example, sustainability, best management practices, impacts on social networks, and trade-offs.

- Downstream effects, including unintended consequences and shadow effects on water and air quality and cumulative spatial and temporal effects.

- Role of global changes (climate, disturbances, etc.), including biofuels mitigating effects of fossil fuels; unanticipated carbon emissions (e.g., accelerated decomposition of organic matter) and/or actions that cause a decline of carbon fixation capacity, exacerbating climate change.

In each of these five topical areas, the charge was to focus on both the ecological opportunities and constraints to bioenergy development. Specifically, each breakout group was asked to address the following questions:

1) What is our current understanding of the environmental and ecological effects of biofuel production?

2) What are the basic principles of sustainable biofuel development?

3) What are the key knowledge gaps that need to be addressed for policy makers and environmental managers to be able to make sound decisions about biofuels production?

Other than the breakout groups, the workshop included plenary sessions for group reporting and discussion. At the onset of the workshop, the group felt the need to agree on a set of broad principles that would precede the more specific principles developed by each breakout group. The larger group of attendees agreed to recognize that:

1) bioenergy can be an important strategy to mitigate climate change, meet energy needs, and invigorate rural and urban economies of the United States;

2) many of the decisions related to the production of bioenergy will be determined by socio-economic-political factors; however, the trade-offs of the environmental and ecological effects of these decisions also need to be considered; and

3) bioenergy production alone will not achieve energy independence from the importation of foreign oil or natural gas.

Environmental and ecological principles of biofuels production

The breakout groups worked on their topics using the following definitions:

Biofuels. Solid or liquid fuel directly derived from recently living (nonfossil) life forms (including their waste). Although this definition recognizes that biofuels can potentially be produced through exploitative processes, efforts should be made to produce these fuels in a manner that is ecologically, economically, and socially sustainable in the long term.

Sustainability. Meeting the needs of the present without compromising the ability of future generations to meet their own needs (derived from *Our Common Future*, also known as the Brundtland Report, from the United Nations World Commission on Environment and Development (WCED 1987).

Each breakout group was asked to list a set of basic principles of sustainable biofuel development. Listed here is a summary of the principles listed by all five groups:

1. Biofuels are only part of the overall solution to energy independence.

    - A suite of diverse, cost-effective, and sustainable energy sources are needed for the country to reduce its reliance on the importation of fossil fuels and to reduce greenhouse gas emissions.

    - If all suitable land is devoted to biofuel feedstock production, it would account for only a fraction of the nation's energy needs.

    - Regardless of the nation's energy portfolio, reducing demand for energy through conservation is essential.

2. How we manage the production of biofuel crops is important.

    - Potential exists for biofuel production to both enhance and reduce ecosystem services.

    - Environmental trade-offs of management decisions occurring at local, regional, and global scales must be considered.

    - Even with a careful accounting of the environmental trade-offs of biofuel production, not all decisions will have predictable environmental and ecological effects (i.e., there will be unintended consequences).

    - Potential for unintended consequences will require adaptive management strategies and environmental monitoring.

3. Sustainable landscape designs for biofuel production should include:

    - No net increase in working lands, but rather intensify biofuel production in highly productive sites using sustainable practices.

    - Considerations of spatial scale, e.g., proximity of biorefineries to feedstock production, surface waters, and other environmentally sensitive habitats

    - Promotion of biodiversity at local and regional landscape scales, through use of buffers, corridors, and targeted conservation approaches.

    - Consideration of the full range of demands on land resources and ecosystem services, including food production, forest products production, wildlife habitat, recreational use, human habitation and others.

- Ecosystem management needs to consider the design of high-performing landscapes—those with several ecosystem services and providing multiple benefits.

4. Sustainable feedstock production systems should consider the following:

- While optimizing ecosystem goods and services across the landscape is a goal, it must be understood that these goods and services will vary depending on the productive capacity of the land, the needs and desires of local practitioners and stakeholders, and on larger-scale social processes.

- Feedstock production systems should enhance or, at the very least, have a neutral impact on the environment while having a net positive energy balance. For example, feedstock production systems should use water and nutrients efficiently, be managed with reduced fossil fuel inputs, increase soil organic carbon, and minimize soil erosion and nutrient loss by utilizing cover crops, minimizing tillage, and reducing use of fertilizers.

- Feedstock production systems should fit the "fuelshed." For example, specific feedstocks for specific locations must be identified that provide adequate feedstock density, improve ecological outcomes over current cropping systems, promote long-term ecological function, and are adapted to different soils and landscape position.

- Recognize that the system of production will be a co-determinant of landscape characteristics and capabilities. For example, conversion systems must be appropriately located and sized to effectively utilize transportation, infrastructure, energy, water, co-products, appropriate location, emission controls, and human capital, and be cost effective. Therefore, feedstock production and conversion systems are intimately linked by feedstock type, characteristics, transportation mode, delivery systems, and landscape characteristics.

- Encourage development of conversion systems that can use multiple feedstocks.

- Biofuel production systems should be assessed using a Life Cycle Analysis (LCA) that includes all potentially significant factors, their effects at multiple scales, and the full range of potential responses or metrics, e.g., greenhouse gas emissions, water quality, water usage, soil organic matter, and ultimately, qualitative factors such as direct and indirect impacts on wildlife habitat and human quality of life.

5. Increase the use of perennial and native species as feedstocks

- The use of more local native species feedstocks are preferable, as they are likely to enhance structural, genetic, and functional diversity that will enhance nonfeedstock biodiversity. Such feedstocks have an additional benefit in that they are unlikely to become invasive.

- Producing biofuels from cellulosic material of perennial crops is likely to be less environmentally damaging and less socio-economically stressful than using feedstocks that are grain-based or otherwise a component of the human food chain.

6. Realize that large-scale biofuel production will be affected by and affect components of global environmental change

   - Examples include greenhouse gas emissions from biofuel production, atmospheric CO_2 effects on biofuel crop growth and soil carbon, and the effects of ozone on biofuel crop growth.

   - The nature and magnitude of these reciprocal effects per unit area are related to the production system used to grow biofuels (e.g., land preparation, soil management, use of perennial vs. annual crops)

Knowledge gaps

The participants in ESA's Conference on the Ecological Dimensions of Biofuels were given the opportunity to comment on gaps in the knowledge related to the sustainable development and use of biofuels; the social, biogeographic, land-use, and biodiversity considerations of biofuel development; and the ecological dimensions of the different alternatives for crops, harvesting methods, refining processes, and end products. More than 50 of the participants responded with suggestions about the gaps in knowledge, areas that raise some concerns, research that is needed, and approaches to systematically fill in identified gaps. In addition to the conference participants, a list of future research needs was derived from the two-day workshop. Research questions and knowledge gaps from both conference and workshop participant lists fell into several categories: crop selection, land use, social and economic factors, development of technology, integrated life-cycle assessment, and environmental effects.

Crop selection

There is a need to know which cropping systems will provide the greatest energy return with the least impact and the smallest energy inputs. Specifically, in what ways can feedstocks be grown with conservation tillage practices? What feedstocks provide a greater net energy output? What are the land requirements to support energy-efficient feedstocks?

There is a need to determine which crops are best suited in which ecoregion. No one plant species will be the best biomass producer in all climatic regions. However, at the present time, there is not a sufficient understanding from an energy efficiency perspective of which crops are appropriate for which ecoregion or production system. More comparative multispecies field trials and monitoring are needed at a range of climatic and soil conditions to fully understand the energy efficiency of various feedstock systems. Specifically, what are the geographical ranges, overall yields, and stabilities of feedstock species, preferably perennial species, as biofuel crops? Other questions on crop selection include:

- What value-added agricultural products have biomass as a by-product?
- How do the desirable plant characteristics for biofuels differ from traits that are available to breeding programs, and how will cropping systems and breeding programs need to be modified?
- How can energy crops be integrated into existing rotations?
- How will the environmental effects of these new cropping systems be assessed?

In addition, it is likely that crop systems will be developed for additional species and growing conditions; this may entail the use of genetic modification or the introduction of nonnative species. It is important that the negative effects of newly developed feedstocks for biofuel production be determined (e.g., soil erosion and sedimentation, water degradation from increased agricultural chemical applications, lower water tables from increased agricultural irrigation) and evaluated if they can be mitigated.

In addition, many of the plant characteristics being selected for dedicated biofuel feedstocks will increase the probability of these species escaping cultivation and becoming invasive species. A holistic screening system is needed that will quantify the risk of becoming invasive for each cultivar/genotype and ecoregion of production that is followed by risk analysis to determine if that level of risk if acceptable.

Land use

Research is needed on how to best design agricultural landscapes to deliver optimum environmental benefits while enhancing farm income through a mix of commodity and conservation revenue streams. As part of that research, the impact of conversion to biofuel crops on the conservation benefits of reserve programs and the impacts of changes in crop rotations on long-term soil productivity need to be investigated. The cost/benefit of moving marginal lands (including acreage that has been taken out of production of annual crops for conservation purposes) into production of perennial feedstocks needs to be assessed objectively. Specific questions include:

- What will be the impacts of loss of that conservation acreage?
- Would the growing of woody crop plantations on marginal agricultural land mitigate some of the pressure on natural forests?
- What are the economic and environmental consequences of growing biofuel crops on prime agricultural land?
- What are the aggregate effects on rates of change in land use attributable to various sets of subsidies and other policy incentives for the production of biofuels?

Research is needed to identify suites of conservation practices that could be widely implemented in biofuel production landscapes and verified by field experiments. In addition, a system of "payments for ecosystem services" need to be developed and implemented wherever possible.

Social factors

The development of cooperatives producing ethanol has had a very beneficial impact on many rural Midwest economies. Local ownership has economic, social, and environmental advantages that are not fully understood and need to be quantified. In addition, local and farmer ownership is rapidly being replaced with corporate and absentee ownership that often leads to the implementation of unsustainable practices. The impact of these ownership changes on the environment and economic sustainability of rural communities needs to be understood.

Production of biofuels from sustainable perennial feedstocks can benefit not only local communities but also reduce the environmental effects on "downstream" communities and rural communities in other countries. Therefore, there is a need to understand how incentives for crop-based biofuel production influence local and regional land-use decisions being made in this country as well as land-use decisions being made in other regions or continents, some of which may result in deforestation or a loss of crops being grown for fiber.

Biofuel production systems need to be developed that link energy, food, and fiber production, and natural-resource objectives. These systems should be designed to support the cultural transition needed to shift from corn/ethanol to the predicted future of perennial and cellulosic systems. Specifically, research needs to focus on the following questions:

- Are higher agriculture commodity prices driving crop-shifting and deforestation in other regions or continents?
- What incentives are needed to move producers into the low-environmental-impact biofuel crop production?
- How do current property-rights regimes and local institutional frameworks affect conservation practices, and how do they influence transitions to other crop production systems?
- What are the impacts of implementing a certification process that supports the sustainable production of biofuel crops?
- What are the potential impacts of demands for biofuels on the acreage of lands maintained in the USDA's Conservation Reserve Program?

Economic factors

An overarching question is how much land and economic incentives are needed to produce cellulosic biofuels at a national level, and similarly, how much of the overall energy needs of the nation can be satisfied by this production? In addition, the economic issues of biofuel production's impact on food prices, international grain markets, production of other crops, and aid to other countries need to be assessed. Moreover, the expansion of biofuel production could significantly impact other energy sources, e.g., wind-generated energy, industries depending on abundant water supplies, and recreation-related uses of land or water, which needs to be assessed.

A fundamental problem is how to balance economies of scale of production (field and industrial) with local environmental and national economic needs. The optimum scale of biofuel production systems needs to be determined, taking into account the local environmental, ecological, and economic impacts. Specifically, how does scaling affect communities and what are the benefits of small-scale, decentralized energy production? In addition, when technologies are scaled up, what are the potential impacts on deforestation and other land-use conversions that are considered externalities and not built into the cost of production?

Development of technology

Foremost, technological increases in the economic efficiency of biofuel production systems should result in less overall environmental impact of these systems. For example, technological advances could lead to fermentation processes to make hydrophobic products, such as high-order alcohols and alkanes. Such products would likely have greater energy content, would avoid the need for distillation, and would obviate some of the need for road transport because they could be transported through extant petroleum-distillate pipelines. Therefore, plant-improvement research is needed to develop perennial biofuel crops that provide value-added co-products (extractable enzymes, nutrients, food proteins, etc.), improve the efficiency of conversion to fuels, and/or reduce the need for purchased inputs. In addition, the development of source-specific equipment for planting, cultivating, harvesting, and processing could be a major economic hurdle for adopters of sustainable biofuel crop production techniques. Engineering processes will need to be designed to accommodate the interchangeability of crops for multiple-resource usage. Moreover, research is needed to assess the use of waste materials, higher-efficiency feedstocks, and future-generation biofuel sources, such as algae as potential substitutes of food resource feedstocks.

Integrated life cycle assessments

To determine the conditions under which biofuel production systems are a net energy benefit, transparent, flexible, and spatially explicit life cycle assessments at local, regional, and global scales are needed. Specifically, life cycle assessments are needed that calculate the net energy production, greenhouse gas footprints, and environmental degradation of renewable energy systems. To accomplish a more integrated life cycle assessment, there needs to be:

- A complete accounting of various biofuel production options that includes technology, economics, net energy, and environmental impacts such as soil degradation, biodiversity, water use, and pollution.
- An energy budget for each crop production system to determine which causes fewer negative "side-effects."
- A clear assessment of the carbon balance related to the conversion from fossil fuels to biofuel production systems.
- A full accounting of the impacts on greenhouse-gas emissions and soil carbon losses from land-use change at local, regional, and global scales.

These assessments can be integrated if, among other steps:

- Sustainability criteria are defined.
- Methods for estimating water use and consumption are standardized.
- A full suite of indicators is developed and maintained to account for direct ecosystem impacts of land-use transitions (e.g., habitat area and quality, nutrient leakage to waterways, soil quality, production of ecosystem goods and services, biodiversity, etc.).
- Indirect land-use implications of biofuel production systems are investigated, measured, and accounted for with an approach that is integrated with the food supply chain.

Environmental effects

Since the conference and subsequent workshop focused on the environmental and ecological effects of biofuel production, this section received the most interest, and discussions were the most wide-ranging. The following overall questions were raised:

- What are the large-scale biodiversity impacts of various biofuel production scenarios?
- What are the ecological implications and agricultural viability of biofuel production from fertilized monoculture crops vs. perennial crop systems?
- If transgenic biofuels plants are grown in diverse agro-ecosystems, what would their impact be on surrounding natural lands, agricultural lands, and other habitats if they escape cultivation?
- What are the large-scale water and air quality impacts of various biofuel production scenarios?
- What is the long-term sustainability of differing cellulosic biomass management scenarios?

These questions arise because we know little about the impacts of biofuel production on ecosystem services and need to know more about the environmental impacts associated with increased agricultural inputs (i.e., disservices) and the loss of native vegetation associated with crop expansion, and subsequent effects on biodiversity. Current methods to measure and evaluate the ecological and human-health impacts of biofuel production are inadequate.

Specifically, the overall impacts of biofuel production on the nitrogen cycle are not well understood, including the extent to which different energy crops and production practices increase or decrease N_2O emissions and NO_3 runoff. Also poorly understood are the impacts of crop residue (e.g., corn stover) removal on soil chemistry and soil structure, with implications for carbon sequestration, soil fertility and soil erosion, and the implications of woody biomass removal for forest health. Beyond some "threshold," removal of forest and agricultural residues risks damage to soil health and productivity, nutrient cycling, stand structure, and water quality. However, the level of these thresholds and the factors that cause them to vary from field to field or woodlot to woodlot are not well understood. In addition, impacts of removing biomass from forest ecosystems on any wildlife or plant group (especially terrestrial insects, fungi and mycorrhizal associations, smaller animals low on the forest food chain, and rare plant communities) are not well understood.

More specific questions or needs were identified:

- Research based on simulation modeling, meta-analysis of the literature, and field experiments in different agro-ecosystems is needed to evaluate the environmental and ecological impacts of crop rotations, such as different combinations of grass–legume rotations, double crops, winter cover crops, etc.

- Research is needed on soil and nutrient cycling characteristics and carbon sequestration levels across a continuum of biomass removal levels.

- Floral and faunal community compositional and structural responses to differing levels of biomass removal/retention need to be examined.

- The productivity and yield of crops, botanical composition of high-diversity mixtures, nutrient requirements to maximize yield, and benefits of monocultures vs. polycultures need to be measured.

- The emission of nitrogen oxides and the ecosystem services of diverse production systems, such as hay meadows, need to be studied.

- In many areas, expanded biofuels production will necessitate an increase in irrigated agriculture, with attendant impacts on shallow aquifers; research is needed on the potential impacts of water withdrawals on stream baseflows.

- Ethical and scientific guidelines for the use of genetically modified organisms in biofuel production need to be developed.

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Appendix II (list of plenary speakers, and titles of presentations)

Marilyn Buford
Sustainable Biofuels and Bioproducts from Our Forests

Virginia Dale
Interactions between Biofuel Choices and Landscape Dynamics and Land Use

Otto Doering
The Rush to Biofuels and Ecological Perspectives in the Policy Process

Jose Goldemberg
Environmental and Ecological Dimensions of Biofuels

Robin Jenkins
Field to Fuel - Developing Sustainable Biorefineries

Catherine Kling
Biofuels and Water Quality in the Midwest: Corn vs. Switchgrass as Feedstocks

Jerry Melillo
A Global-Scale Biofuels Program and its Environmental Consequences

William Parton
Environmental Dimensions of Biofuel Cropping Systems: Introduction

Donna Perla
Municipal Solid Waste as Supplemental Feedstocks

G. Philip Robertson
The Biogeochemistry of Bioenergy Landscapes: Clean Water, Clean Air and Climate Mitigation vs. Business as Usual

John Sheehan
Defining Sustainable Biofuels – or, "It isn't Easy Being Green"

Linda Wallace
Is Rangeland Biofuel Feedstocks Ecologically Sustainable?

John Wiens
Biofuels and Biodiversity

W.W. Wilhelm
Production of Biofuels Feedstock on Agricultural Land and Grasslands

Appendix III (list of workshop participants)

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