SUSTAINABILITY IN THE BIOFUELS INDUSTRY

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For

THE AGRICULTURAL CO-OPERATIVE DEVELOPMENT INITIATIVE (Ag-CDI)

March 31, 2009

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EXECUTIVE SUMMARY

Various interconnecting environmental, economic, and social facets affect the sustainability of biofuels. For example, while biofuels may offer opportunities for energy security improvement, rural development, and greenhouse gas (GHG) emissions reductions, they can also pose several risks, including negative environmental impacts on biodiversity, water, soil, and air; social issues surrounding food security, land rights, and employment; and economic problems of rising prices, cost-effectiveness, and market and trade distortions.

These types of trade-offs vary widely by the types of biofuels and where and how they are grown, and have led to an intense debate over how best to pursue biofuels development. On the one hand, some national governments, especially those in North America, have chosen to promote temperate biofuels, particularly liquid biofuels such as corn ethanol and soybean biodiesel for transport, by implementing incentive programs and blending mandates. In other countries, such as Germany, gaseous biofuels such as corn silage based biogas have been supported recently. Green power programs that use solid biofuels such as pellets are also becoming of interest as a means to displace coal-fired power generation. These largely domestically based programs are meant to increase energy independence, reduce eventual GHG emissions, and utilize surplus production capacity in the farm sector. On the other hand, however, the rapid scale up of temperate biofuels, especially of annual crops utilized widely for food and feed, is viewed to have significant negative impacts, especially on global food supply and on poor net food buying households, particularly the urban poor in developing countries. There is a significant effort by some organizations to stop completely all biofuel development from farmland. Others would suggest that only marginal farmlands that are less important for food crop production be utilized to grow energy feedstocks.

Additionally, perhaps the greatest controversy of biofuels development to date has surrounded the importation of liquid biofuels from the tropics. Palm oil, which is imported into some European countries for biodiesel production, has been particularly controversial due to its impacts on tropical deforestation (and subsequent carbon release) and on tropical bog destruction, which leads to methane release. The importation of ethanol produced from sugarcane from the tropics is also widely criticized, mainly due to impacts on food security in developing countries and to the potential for competition with land currently being used for cattle grazing or soybean production. Overall, there is much need to improve biofuels sustainability in both tropical and temperate regions.

The differences between the contexts, uses, sustainability implications, and policy structures of varying forms of bioenergy and bioenergy feedstocks are therefore complex, and controversy surrounding the proper nature, timing, and scale of biofuels development will likely remain pertinent well into the future. It is thereby important to evaluate and compare different bioenergy systems and their outcomes against various environmental, social, and economic criteria. It should be noted that while much is now known about the environmental sustainability of biomass feedstock production and bioenergy conversion processes, knowledge on the social sustainability of biofuel development is in its infancy.

This project compiles a current and relevant annotated bibliography on sustainability in the biofuels industry. It focuses on the diverse impacts of several biofuel feedstocks, conversion processes, and end-uses, and is made up of five sections, in accordance with the pertinent themes outlined below.

Section I addresses the environmental sustainability issues surrounding the production of various temperate biofuel feedstocks, including corn, soybeans, switchgrass, canola, and crop residues, as well as tropical feedstocks such as sugarcane. It highlights the cumulative energy required to produce these feedstocks and notes related environmental impacts on GHG emissions (particularly of CO_2 and N_2O), biodiversity, soil, and water.

Section II outlines different biofuel conversion systems and technologies and their associated environmental impacts. It reviews on a life-cycle basis the net energy gain, energy output-to-input ratios, and GHG mitigation potential of various biofuel feedstocks and conversion processes, including corn and wheat based ethanol, manure and energy crop biogas, soybean and canola biodiesel, and perennial grasses and crop residues for bioheat.

Section III examines the socio-economic issues stemming from bioenergy production, addressing impacts on food prices, livestock markets, rural economic development, employment levels, working conditions, and the structure of agriculture. In doing so, it explains the influence of economic efficiency, government support, shifting land-use, ownership, specific local economic context, and scale of technology on these social and economic impacts.

Section IV outlines the key drivers and limitations to international trade in bioenergy and presents specific import and export figures for Canada. This section also focuses on recent developments in, and the future potential of, biomass sustainability standards, which are meant to ensure that feedstocks and biofuels are produced in an environmentally and socially sustainable manner.

Section V provides a compilation of these diverse sustainability issues and puts forward various policy suggestions for the improved management of bioenergy production and use. It should be noted that it could be useful to read this section before consulting Sections I through IV, particularly to readers who seek a broad overview of the environmental, social, and economic sustainability issues facing biofuels development.

Overall, there is growing body of literature on biofuel sustainability that can help to provide a more solid basis for researchers, policy makers, and project developers to incrementally improve the sustainability of the biofuels industry from its early stages onwards.

I. Environmental Assessment of the Sustainability of the Use of Annual Grains, Oilseed Crops, Perennial Energy Crops, and Crop Residue for Bioenergy

SUMMARY

Section I addresses the environmental sustainability issues related to growing feedstock crops for use as bioenergy.

Part 1.1 looks at the overall energy balances and outputs and inputs of various biofuel feedstocks, including temperate feedstocks such as corn, alfalfa, soybeans, canola, rapeseed, switchgrass, and crop residues, and tropical feedstocks such as sugar cane and napier grass. It overviews the total cumulative energy produced through feedstock cultivation, as well as the energy required for this production. Examples of important external inputs that contribute to a feedstock's fossil energy requirements are nitrogen fertilizer, the fossil energy used for field operations, and the energy needed for crop drying. A major contributor to positive energy balance is the efficiency with which a crop converts solar energy into plant material. It is important to note that studies on this subject are often not directly comparable, due to the use of different units of measurement, system boundaries, and geographic regions. For example, one paper in this section measures energy requirements in terms of MJ of energy inputs per kg of feedstock, while the other calculates GJ of energy inputs per GJ of renewable energy feedstock produced. In addition, some studies include the energy spent on transport to a biorefinery, while others do not. Overall, estimates on energy requirements will vary depending on the technology, inputs, and hauling distance considered, amongst other factors, and there appears to be a lack of consistency in the manner with which energy analysis of biomass feedstock production is performed.

Part 1.2 assesses other environmental impacts associated with bioenergy feedstock production. These include impacts on N_2O emissions, water and soil quality, and biodiversity. Generally speaking, annual crops appear to have more serious environmental impacts than perennial crops grown as bioenergy feedstocks. Annual crop production tends to utilize more intensive farming practices, such as annual soil tillage and herbicide application and increased N fertilizer utilization, and often results in more field runoff of soil and nutrients. In addition, increased CO_2 emissions can occur when farmers worldwide respond to higher commodity prices and demand for biofuels by converting forest and grasslands to new cropland to replace the land diverted to biofuels. Less information is available on the impact of these land use changes on deforestation, however. Also, more substantial data on biodiversity changes, impacts of phosphorous fertilizers on the environment (through eutrophication, etc.), and Canada-specific impacts would be helpful.

Part 1.3 addresses the environmental sustainability issues related to using crop residues as energy feedstocks. It reviews the benefits that can be achieved by returning crop residues to the soils, including improved soil quality, CO_2 emissions offsets, and higher soil biodiversity levels.

The trade-offs between removing lignocellulosic residues of cereals for biofuel feedstock and returning them to the soil are thereby discussed. In general, using soil erosion as a sustainability parameter allows for higher rates of crop residue removal; however, it would seem that biomass removal is best governed by soil carbon sustainability.

1.1 Energy Requirements for Biomass Feedstock Production

Cumulative Energy and Global Warming Impact from the Production of Biomass for Biobased Products, by Dale and Kim, Journal of Industrial Ecology, volume 7, number 3-4, 2004, pages 147-162

This paper estimates the cumulative energy and global warming impacts associated with producing corn, soybeans, alfalfa, and switchgrass and transporting these crops to a biorefinery, with agricultural input data for each crop collected from Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. The study is meant to contribute to future comprehensive life-cycle analyses of biobased product systems.

Two cases are utilized in this study: "case A," which represents the case for a low CO_2 nitrogen fertilizer production system, and "case B," signifying the case for a nitrogen fertilizer in which CO_2 is regarded as a waste in the fertilizer's production.

First, to produce 1 kg of corn, the total cumulative energy requirement equals 1.99 MJ in case A and 2.66 MJ in case B and the global warming impact equals 246 g CO_2 equivalent/ kg in case A and 286 g CO_2 equivalent/kg in case B. Nitrogen fertilizer and farm-based diesel use are the top contributors to these values.

Second, to produce 1 kg of soybeans, the total cumulative energy requirement is 1.98 MJ in case A and 2.04 MJ in case B and the global warming impact is 159 g CO_2 equivalent/kg in case A and 163 g CO_2 equivalent/kg in case B. Over 65% of these values stem from the liquid fuels (diesel and gasoline) used for producing and transporting the soybeans.

Third, to produce 1 kg of alfalfa, for both case A and case B the cumulative energy requirement is 1.24 MJ/kg and the global warming impact is 89 g CO_2 equivalent/ kg. Farm-based diesel use and the energy associated with transporting alfalfa to the biorefinery contribute most to these figures. There is no difference between the two cases because of the lack of nitrogen fertilizer used in alfalfa production.

Fourth, to produce 1 kg of switchgrass, the cumulative energy requirement is 0.97 MJ in case A and 1.34 MJ in case B and the global warming impact is 124 g CO_2 equivalent/ kg in case A and 147 g CO_2 equivalent/kg in case B. Diesel use is the primary factor in the cumulative energy requirement in case A, and nitrogen fertilizer is the primary factor in case B; in both cases, the energy associated with transportation to the biorefinery contributes about 20% of the cumulative energy requirement. GHG emissions come primarily from field emissions of N_2O and secondarily from diesel use (especially from transportation).

Overall, the study finds that growing perennial crops, such as alfalfa or switchgrass, has significantly lower fossil energy and CO_2 production than growing corn or soybeans. The authors note that the allocation of environmental burdens to the different functions delivered by the various crops should be the subject of further research, in order to be able to directly and properly compare one crop's cumulative energy requirement and global warming impact to another's.

Web-link available at:
http://mitpress.mit.edu/journals/JIEC/v7n3-4/jiec_7_3-4_147_0.pdf

The Potential of C_4 Perennial Grasses for Developing a Global Bioheat Industry, by Samson et al, Critical Reviews in Plant Science, volume 24, 2005, pages 461–495

This paper reviews the potential to cultivate and densify warm-season grasses for the development of a modern densified biofuel – or BIOHEAT – industry. For BIOHEAT to be a promising new renewable energy strategy for the world, crop production strategies must be developed that are as efficient as possible in capturing sunlight (solar energy) and storing it in plants (solar battery) at a low cost per gigajoule (GJ) of stored energy. Desirable characteristics for energy feedstocks thereby include: (1) efficient conversion of sunlight into plant material; (2) efficient water use; (3) sunlight interception during as much of the growing season as possible; and (4) minimal external inputs in the production and harvest cycle.

The authors note that C_4 perennial grasses exhibit these desirable characteristics. For example, when measuring the solar energy collection and fossil fuel energy requirements of crops in the province of Ontario, it is found that switchgrass consumes 0.8 GJ per oven dry tonne (ODT) of fossil energy (compared to grain corn's 2.9 GJ/ODT) and produces 163.8 GJ/ha of net energy (compared to grain corn's 98.3 GJ/ha). In addition, densified temperate warm-season (C_4) grasses such as switchgrass offer a 14.6:1 energy output: input ratio, while the net energy balances of other bioenergy sources are lower (1.21:1 for corn ethanol, 4.43:1 for switchgrass ethanol, and 1.47:1 for rapeseed biodiesel). C4 perennial grasses may also be developed as BIOHEAT feedstocks in tropical environments. Napier grass in Brazil, for example, provides an overall energy output: input ratio of 21.1:1.

Densified grass biofuels are therefore increasingly seen as a sustainable means of meeting heating requirements at less cost than other energy alternatives. The energy efficiency and cost-effectiveness of densified grasses as fuel results from: (1) efficient use of low cost marginal farmland for solar energy collection; (2) minimal fossil fuel inputs during field production as well as energy conversion, leading to an excellent energy balance; (3) minimal biomass quality upgrading, which acts to limit energy loss from the feedstock; and (4) efficient and convenient combustion for heating, cooking, and industrial purposes.

The authors conclude by stating that commercialization of densified herbaceous plant species has been slow due to relatively high alkali and chlorine levels in the feedstocks, which lead to clinker formation and the fouling of boilers. This challenge could be met through improvements in biomass quality with advances in plant breeding and cultural management to reduce the chlorine, alkali, and silica content, and with new combustion technologies. The authors thereby suggest that future research and agronomic practices in both tropical and temperate regions focus on developing warm-season grasses that have: low chlorine content, low response to potassium fertilization, low alkali levels, improved stem-to-lead ratios, biological nitrogen fixing abilities, and reduced silica content.

Web-link available at:

http://www.reap-canada.com/online_library/feedstock_biomass/15-The%20Potential%20of%20C4%20Perennial%20Grasses%20for%20Developing...%20_Samson%20et%20al.,%202005_.pdf

1.2 Environmental Impacts (N_2O, Carbon, Soil and Water Quality, Biodiversity)

N_2O Release from Agro-Biofuel Production Negates Global Warming Reduction by Replacing Fossil Fuels, by Crutzen et al, Atmospheric Chemistry and Physics Discussions, volume 8, 2007, pages 389-395

This paper re-examines the relationship, on a global basis, between the amount of nitrogen (N) fixed by chemical, biological, or atmospheric processes entering the terrestrial biosphere, and the total emissions of nitrous oxide (N_2O). It addresses to what extent the reduced global warming ("saved CO_2") achieved by using biofuels is counteracted by this release of N_2O.

The authors estimate a global conversion factor of 3-5% for the past, present, and future yield of N_2O from fixed N inputs, particularly from synthetic N fertilizer production. According to their calculations, the amount of extra N_2O entering the atmosphere as a result of using N to produce crops for biofuels is about three to five times greater than the amounts generally estimated in current life cycle analyses. The extra N_2O emissions from biofuel production are calculated in "CO_2-equivalent" global warming terms and compared with the quasi-cooling effect of "saving" emissions of fossil fuel derived CO_2. The outcome is that the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn (maize), can contribute as much as or more to global warming from N_2O emissions than to emissions abatement from reduced fossil fuel use. Crops with less N demand and subsequently lower N_2O emissions, such as perennial grasses and woody coppice species, plus future enhanced efficiency of the uptake of nitrogen fertilizer by plants, could have more favourable climate impacts.

The authors conclude that relatively large emissions of N_2O exacerbate the already huge challenge of getting global warming under control. They also suggest several areas to be focused on in further research. First, as this particular study does not take into account climate impacts associated with the input of fossil fuels to biomass production on the one hand or the creation of useful co-products on the other, full life cycle assessments should be carried out to determine how these factors interact and to what degree they compensate each other. Second, life cycle assessments should be sure to fully account for N_2O emissions, by focusing on the nitrogen cycle and sources of N_2O. Third, future research should attempt to estimate the degree to which the high percentage of N-fertilizer that is not taken up by the plants, and the organic N in the harvested plant material, may stimulate CO_2 uptake from the atmosphere.

Web-link available at:
http://www.atmos-chem-phys.net/8/389/2008/acp-8-389-2008.pdf

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change, by Searchinger et al, Science, volume 319, 2008, pages 1238-1240

This paper addresses the carbon emissions that occur as farmers worldwide respond to higher commodity prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. It estimates land-use changes through the use of a worldwide model that projects increases in cropland for all major temperate and sugar crops by country or region (as well as changes in dairy and livestock production) in response to a possible increase in U.S. corn ethanol of 56 billion liters above projected levels for 2016.

The authors calculate that the ethanol increase of 56 billion liters diverts corn from 12.8 million hectares (ha) of U.S. cropland and in turn brings 10.8 million ha of additional land into cultivation (including 2.8 million ha in Brazil, 2.3 million ha in China and India, and 2.2 million ha in the U.S.). Subsequent greenhouse gas (GHG) emissions depend on the type of lands converted and would average at about 351 metric tonnes per converted ha (CO_2 equivalent). Therefore, corn ethanol, instead of producing a 20% savings in GHGs, nearly doubles them over 30 years and increases them for 167 years. Even if corn ethanol caused no emissions except those from land-use change, overall GHGs would still increase over a 30-year period. Overall, then, the potential emissions per ha of land conversion greatly exceed the annual greenhouse reductions per ha of biofuels.

This study notes that, to avoid land use change altogether, biofuels must use carbon that would reenter the atmosphere without doing useful work that needs to be replaced, such as municipal waste, crop waste, and fall grass harvests from reserve lands. Algae grown in the desert or feedstocks produced on lands that generate little carbon today might also keep land-use change emissions low. Effective policy should thereby guarantee that biofuels use a feedstock, such as a waste product, or carbon-poor lands that will not trigger large emissions from land-use change.

The authors conclude that proposed environmental criteria that focus only on direct land-use change would have little effect, because emissions from land-use change are likely to occur indirectly. For example, barring biofuels produced directly on forest or grassland would encourage biofuel processors to rely on existing croplands, but farmers would replace crops by plowing up new lands. Such use of good cropland for biofuels would probably exacerbate global warming in a manner similar to directly converting forest and grasslands. Overall, to generate greenhouse benefits, the carbon generated on land to displace fossil fuels (the carbon uptake credit) must exceed the carbon storage and sequestration given up directly or indirectly by changing land uses (the emissions from land-use change).

Web link available at:
http://www.sciencemag.org/cgi/reprint/319/5867/1238.pdf

Effects of Agricultural Beneficial Management Practices (BMPs) on Conservation and Restoration of Biodiversity in Agricultural Regions, by ERIN Consulting Ltd and REAP-Canada, for Environment Canada, 2006, 309 pages

This paper provides a thorough analysis of the effectiveness of Beneficial Management Practices (BMPs) and agricultural guidelines for conserving and restoring biodiversity and ecosystem health. It defines a BMP as any agricultural management practice that ensures the long-term health and sustainability of land related resources used for agricultural production; positively impacts the long-term economic and environmental viability of the agricultural industry; and minimizes negative impacts and risks to the environment.

Agriculture has reduced biodiversity through large-scale conversion of native habitats to agricultural cropping, intensification of production, and specialization of agricultural activities. Intensification practices often lead to: monoculture; removal and degradation of small wetlands and watercourses from the landscape; pollution and poisoning of water and soils by organic and inorganic compounds; and introduction of exotic invasive plants, animals, and diseases. These biodiversity issues can also be associated with planting of biofuel feedstocks.

To analyze these problems, the authors present in-depth analysis for the management of (1) terrestrial habitats, (2) soil, (3) riparian areas and water, (4) nutrients, and (5) species. For example, in presenting the BMPs for terrestrial habitat management, the authors highlight the considerable biodiversity gains to be realized through the increased use of perennial crops and agroforestry systems on farms in Canada. Compared to annual systems, perennials tend to have greatly reduced rates of soil erosion, decreased levels of nitrate pollution to groundwater and phosphorus loss to surface water, low energy inputs, and reduced pesticide use. Perennials also store significantly larger volumes of soil carbon and provide habitat and food for some species throughout a greater part of the year. Late season perennial grasses grown as energy crops, such as switchgrass, offer these benefits and may also enhance species diversity as it is not absolutely necessary to maintain pure monocultures. This is in stark contrast to corn production, which provides low biodiversity benefits, due to increased rates of soil erosion and nutrient off loading, and low food resources for butterflies, wild pollinators, and birds because of low weed biomass.

The authors thereby suggest that new efforts to incorporate more perennial species into agricultural landscapes, such as through the planting of adapted mixtures of warm-season grass varieties near natural areas, be made. There is a strong possibility that significant amounts of Canadian farmland could be diverted into biofuel production systems, with 65% of Ontario's agricultural landscape potentially convertible to energy crop production. Cooperation between various actors is necessary to achieve such reduction of agricultural risks to biodiversity. Ultimately, however, the most critical part of the biodiversity conservation program rests at the individual farm level.

Web-link available at:
http://www.reap-canada.com/online_library/feedstock_biomass/Pepper%20et%20al.,%202006.pdf

1.3 Crop Residue Sustainability

Crop Residues as Soil Amendments and Feedstock for Bioethanol Production, by Lal, Waste Management, volume 28, issue 4, 2008, pages 747-758

This paper addresses whether crop residues should be used for carbon (C) sequestration and soil quality improvement or for producing energy. In doing so, it questions whether this decision should be determined by short-term economic considerations or by the long-term sustainability of natural resources, and whether or not the need for renewable fuels overrides the urgency to achieve global food security.

The paper notes that the return of crop residues to the soil yields several important benefits, as the rate of improvement in indicators of soil quality (i.e. infiltration rate, soil organic carbon [SOC] concentration, aggregation, nutrient concentration, earthworm activity, microbial biomass carbon, etc.) increases with increases in the quantity and quality of crop residue returned to the soil. Overall, residue retention helps to strengthen nutrient recycling, enhance soil fertility, and improve agronomic productivity; offset CO_2 emissions through improved SOC concentrations; and enhance biodiversity by providing food substrate and habitat for soil organisms. Subsequent enhanced food production could be of great importance to alleviating global food insecurity.

Other strategies for using crop residues in order to decrease CO_2 emissions include: sequestration in the ocean, cofiring with coal, and conversion to ethanol. However, these processes entail removal of residues from soils, and excessive (>25%) and continuous (>10 yr) removal of crop residues can jeopardize soil quality, reduce agronomic productivity, accentuate soil erosion, increase non-point source pollution, and exacerbate the problem of hypoxia in coastal ecosystems. Thus, the authors argue that lignocellulosic residues of cereals (i.e. corn, wheat, barley, oats, rice, etc.) must be used for enhancing soil quality rather than for biofuel or other competing uses, because the long-term benefits of improved soil quality will outweigh any short-term economic gains to be made from selling residues for ethanol production.

The authors present several grasses, including switchgrass, big bluestem, Indian grass, bluejoint grass, and cord grass, as potential alternative feedstock sources for biofuel production and SOC sequestration. Species such as guinea grass, elephant grass, molasses grass, and andropogan also have a high biomass production potential and can be grown in tropical environments. These grasses, as well as short rotation woody perennials, could be established on agriculturally marginal/surplus lands, degraded soils, or disturbed lands, and ancillary benefits could include erosion control, water quality improvement, wildlife habitat, and restoration of degraded soils and ecosystems. Biofuel feedstock could also be derived from other biosolids such as animal waste, food industry waste, and municipal solid waste. Overall, the authors emphasize that crop residues must be retained for soil quality and suggest that other diverse biofuel feedstocks be used to strongly impact the global C cycle and reduce net emissions of CO_2 into the atmosphere while meeting global energy demands.

Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply, by Wilhelm et al, Agronomy Journal, volume 99, 2007, pages 1665-1667

This paper presents estimates of the amount of corn stover needed to maintain soil organic carbon (SOC), which is responsible for favorable soil properties, as well as levels of corn stover necessary to avoid wind and water erosion.

When returned to the land, crop residue helps replenish SOC, which has typically been reduced to 30-50% of pre-cultivation levels through crop production activities. SOC retains and recycles nutrients, improves soil structure, enhances water exchange characteristics and aeration, and sustains microbial life within the soil. In addition, crop yield and the value of environmental services (such as carbon and nitrogen sequestration) may be greater for soils with greater SOC.

Crop management practices greatly impact the rate of organic matter decomposition and erosion. Therefore, the authors derive from a recent US study the following estimated amounts of corn stover needed to maintain SOC content: 12.50 Mg ha^{-1} for moldboard plow tillage in a corn-soybean (C-S) rotation, 7.90 Mg ha^{-1} for no till or conservation tillage in a C-S rotation, 7.58 Mg ha^{-1} for moldboard plow tillage with continuous corn, and 5.25 Mg ha^{-1} for no till or conservation tillage with continuous corn. In addition, the estimated amount of corn stover needed to limit water erosion ranges from 0.65 Mg ha^{-1} for no till or conservation tillage with continuous corn to 7.98 Mg ha^{-1} for moldboard plow in a C-S rotation, and the estimated amount of corn stover needed to limit wind erosion ranges from 0.14 Mg ha^{-1} for no till or conservation tillage with continuous corn to 2.74 Mg ha^{-1} for moldboard plow tillage in a C-S rotation.

Sustainably harvestable corn stover also varies widely with cropping practice. For example, stover would be sustainably harvestable starting at a grain yield of approximately: 17 Mg ha^{-1} under moldboard plow tillage in a C-S rotation, 11 Mg ha^{-1} under no till or conservation tillage with a C-S rotation, 10 Mg ha^{-1} under moldboard plow with continuous corn, and 6.5 Mg ha^{-1} under no till or conservation tillage with continuous corn.

Overall, these estimates indicate that stover needed to maintain SOC, and thus productivity, is a greater constraint to environmentally sustainable cellulosic feedstock harvest than that needed to control water and wind erosion. An extensive effort is needed to develop advanced cropping systems that greatly expand biomass production to sustainably supply cellulosic feedstock without undermining crop and soil productivity. The authors conclude that it is necessary to address these needs in a timely manner, because of the great speed with which U.S. government policy and the broader energy industry is pursuing cellulosic-based fuels and the slow speed with which SOC increases in response to improved management.

II. Environmental Assessment of the Sustainability of Bio-Energy Conversion Systems

SUMMARY

Section II addresses the environmental sustainability issues stemming from a variety of bio-energy conversion systems.

Part 2.1 outlines technology options for the biofuels sector, with a focus on the different conversion processes and end-uses for bioethanol, lipid derived biofuels, Biomass to Liquid (BtL) fuels, biomethane, and biohydrogen. The possible impacts, as well as potential future developments, of processing these and other biofuels are also characterized.

Part 2.2 reviews on a life-cycle basis the net energy gain, energy output-to-input ratios, and GHG mitigation potential of various biofuels, including starch-, sugar-, and lignocellulosic-based ethanol; manure and energy crop biogas; soybean and canola biodiesel; rapeseed and sunflower methylester; and perennial grasses and crop residues for bioheat. Some of the summarized studies also address economy considerations such as cost-effectiveness and issues of human and environmental health. However, critical gaps remain, particularly with regards to the life-cycle impacts of biofuels on the environment (i.e. soil erosion, deforestation, acidification, biodiversity, eutrophication, etc.) and on humans (i.e. impacts to food supply, air pollution, human toxicity, etc.). In addition, life-cycle based studies often utilize different system boundaries, with some considering co-products and/or food energy consumed by workers and/or avoided reference uses, and others not. Life-cycle analysis (LCA) that is truly cradle-to-grave should therefore be the focus of future work. Further research that focuses on lignocellulosic and sugar ethanol, as well as Canada-specific biofuels options, would also be useful.

Part 2.3 includes analysis of land requirements and hauling distances for the production of commercial sized biofuel conversion facilities, with a focus on sugarcane bioethanol in Brazil. Once again, it would be helpful to fill the gaps in Canada-specific data on this subject. For example, comparisons between the land-base requirements and hauling distances of grain-based and cellulosic ethanol plants, biogas facilities, and pelleting and briquetting conversion facilities would be useful for the Canadian context.

Overall, the impact of biofuels on GHGs and the environment varies dramatically according to feedstock use, geographic location, agricultural practice, and conversion technology.

2.1 Technology Options

Biofuel Technology Handbook, by Janssen and Rutz, for WIP Renewable Energies, Munich, 2008, 152 pages

This handbook describes in detail various biofuel feedstocks and conversion technologies, with an emphasis on first generation biofuels such as bioethanol, biodiesel, pure plant oil, and biomethane. It also looks at second generation biofuels such as Biomass to Liquid (BtL) fuels and bioethanol from lingo-cellulose as well as biohydrogen. The entire life cycle of each biofuel is assessed under technical, economical, ecological, and social criteria.

Part A of the handbook discusses the common characteristics of biofuels, including the potential of biomass feedstock sources; biofuel policies (i.e. market barriers, standardization, and international trade) and their impacts on biofuel market penetration; and basic biofuel life cycles, touching on energy balance, emissions, sustainability, economy, and co-products.

In Part B, characteristics and applications of biofuels for transport purposes are demonstrated and evaluated. The specific feedstocks; production processes; properties; technology applications; standardization aspects; energy balance; emissions; and sustainability and economy characteristics of the following biofuels are addressed: bioethanol, lipid derived biofuels, BtL-fuels, biomethane, and biohydrogen. GHG calculation methods are presented and potential impacts of biofuel production are characterized, including damage to rainforests and wetlands, loss of biodiversity, water pollution, and changes to human health and labor conditions.

Part C outlines future developments in the biofuel sector. The authors note that the future of biofuels hinges on the following technical development issues: (1) first vs. second generation biofuels, (2) integrated biorefinery concepts, and (3) strategies for new vehicle technologies. First, while both first and second generation biofuels carry with them distinct advantages and disadvantages, the authors state that the creation of a sustainable transport sector in the foreseeable future will depend upon the successful promotion and development of both types of biofuels. Second, the integrated refining concept is seen as a holistic approach for the production of biofuels, whereby so called "biorefineries" produce both biofuels and high value co-products, which are further processed in the same refinery in order to add value. Similar to fossil fuel refineries, biofuels would represent the majority of total production in a biorefinery, while chemicals and other materials would generate most profits. Third, the authors note different strategies being pursued to modify conventional engine technology and to promote the use of biofuels. For example, in the short term, today's combustion engine is being further developed to present an efficient and sustainable option that requires no additional infrastructure, while for the long term the development of electric engines driven by fuel cells and high efficient batteries that produce no emissions is being looked at (although numerous technical and economical challenges to this technology remain).

Web-link available at:
http://www.compete-bioafrica.net/publications/publ/Biofuel_Technology_Handbook_version2_D5.pdf

2.2 Energy Security and the GHG Benefits of Biofuels

A Review of Assessments Conducted on Bio-Ethanol as a Transportation Fuel from a Net Energy, Greenhouse Gas, and Environmental Life Cycle Perspective, by von Blottnitz and Curran, Journal of Cleaner Production, volume 15, issue 7, 2007, pages 607-619

This paper reviews 47 life cycle based studies, published between 1996 and 2004, on bio-ethanol made from varying feedstocks for use as a transportation fuel.

Results are discussed in three categories of special interest to the question of environmental sustainability: (1) reducing dependence on fossil fuels through energy balance assessments; (2) reducing emissions of greenhouse gases (GHG); and (3) reducing health and environmental impacts throughout the life cycle.

The bulk of the studies report moderate to strong replaced fossil energy (GJ/ha.a) effects for bio-ethanol systems. Sugar crops are the most land-efficient in replacing fossil energy, with tropical sugarcane (at 250 GJ/ha.a) significantly outperforming sugar beet in temperate regions. Starch crops, such as corn, potatoes, wheat, and rye, replace significantly less fossil energy (35-50 GJ/ha.a). Ethanol from lignocellulosic feedstock brings results of a similar magnitude to ethanol from starch crops, with studies on sugarcane bagasse, corn stover, and wheat straw exhibiting figures ranging from 25-90 GJ/ha.a when substituting fossil fuels.

Sugar-based ethanol production systems achieve much higher GHG emissions reduction effects per hectare of cropped land than starch-based systems, with tropical sugarcane again by far the most efficient crop. Seven of the studies evaluated additional environmental impact categories beyond energy and GHGs, and the results were mixed. Overall, acidification, human toxicity, and ecological toxicity impacts, mainly occurring during the harvesting and processing of the biomass, were more often unfavourable than favourable for bio-ethanol. Further assessment is needed in this area.

Factors important to the energy performance of bio-ethanol systems are: crop/climate productivity and the nature of the feedstock. Despite differing assumptions and system boundaries, the following general lessons emerge from the assessed studies: (1) make ethanol from sugar crops, in tropical countries, but approach expansion of agricultural land usage with extreme caution; (2) consider hydrolysing and fermenting lignocellulosic residues to ethanol; and (3) the life-cycle assessment results on grasses as feedstock are insufficient to draw conclusions.

The authors suggest that future bio-ethanol sustainability assessments not repeat detailed energy and GHG assessments, but focus instead on filling critical gaps and carrying out full life cycle assessments on ethanol from tropical sugar crops and on 2nd generation bio-ethanol from cellulosic cropped feedstocks. These assessments should be cradle-to-grave and should pay attention to evaluating the disputed environmental categories of acidification, eutrophication, photochemical smog, human and ecotoxicity, as well as land use and its effects on biodiversity. Overall, the safeguard subjects of human and ecological health need to feature more prominently next to those of climate change and resource depletion concerns.

Web-link available at:
http://www.cmu.edu/index.shtml,
(Under search terms "LCA of Bio-Ethanol Systems")

Ethanol Can Contribute to Energy and Environmental Goals, by Farrell et al, Science, volume 311, 2006, pages 506-508

This paper presents a comparison of six studies illustrating the range of assumptions and data found for corn-based ethanol and calculates metrics for ethanol's net energy, greenhouse gas (GHG) emissions, and primary energy inputs.

The authors argue that two of the studies, which state that ethanol has negative net energy values and relatively high GHG emissions and petroleum inputs, are incorrect, because they use obsolete data and incorrectly ignore ethanol's co-products (such as dried distiller grains with solubles, corn gluten feed, and corn oil), which can partially offset the energy required for ethanol production. They subsequently develop a model that allows for direct and meaningful comparison of the data and assumptions across the studies and use it to (1) add co-product credit where needed, (2) apply a consistent system boundary by adding missing parameters (i.e. effluent processing energy) and dropping unnecessary ones (i.e. labourer food energy), (3) account for different energy types, and (4) calculate policy-relevant metrics.

The authors use the best data from the six studies to create the following three cases: (1) *Ethanol Today*, which includes typical values for the current U.S. corn ethanol industry and requires the fewest assumptions; (2) *CO_2 Intensive*, based on current plans to ship Nebraska corn to a lignite-powered ethanol plant in North Dakota; and (3) *Cellulosic*, which assumes that production of cellulosic ethanol from switchgrass becomes economic as represented in one of the studies.

For all three cases, producing one MJ of ethanol requires far less petroleum than is required to produce one MJ of gasoline, while GHG emissions vary greatly depending on the production process. However, such single-factor metrics may be poor guides for policy, as the petroleum intensity metric shows that *Ethanol Today* is slightly preferred over the *Cellulosic* case, while the GHG metric demonstrates the *Ethanol Today* case as far worse than *Cellulosic*. Additional environmental metrics are now being developed for biofuels, with some having been applied to ethanol production, but several key issues remain unquantified, including soil erosion and the conversion of forest to agriculture.

The paper concludes that evaluations of biofuel policy should use realistic assumptions (i.e. the inclusion of co-product credits), accurate data, clearly defined future scenarios, and performance metrics relevant to policy goals such as reducing GHG emissions, petroleum inputs, and soil erosion. Progress toward attaining these goals will require new technologies and practices, such as sustainable agriculture and cellulosic ethanol production. Such an approach could lead to a biofuels industry much larger than today's that, in conjunction with greater vehicle efficiency, could play a key role in meeting the energy and environmental goals of the US.

Web-link available at:
http://www-personal.umich.edu/~twod/oil-ns/articles/science_ethanol_farrell_feb06.pdf

Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels, by Hill et al, Proceedings of the National Academy of Sciences, volume 103, number 30, 2006, pages 11206-11210

This paper examines the net societal benefits of corn grain ethanol and soybean biodiesel relative to gasoline and diesel. It utilizes life cycle accounting and data on farm yields, commodity and fuel prices, farm energy and agrichemical inputs, production plant efficiencies, co-product production, greenhouse gas (GHG) emissions, and other environmental effects, in order to determine whether the biofuels (1) provide a net energy gain, (2) have environmental benefits, (3) are economically competitive, and (4) are producible in large quantities without reducing food supplies. The authors find that soybean biodiesel has major advantages over corn grain ethanol.

The authors utilized expansive system boundaries for energy inputs and both biofuels produced positive net energy balances (NEBs), due in most part to recent advances in crop yields and biofuel production efficiencies. However, biodiesel is found to have an NEB of 93% while corn ethanol's is only 25% (primarily attributable to ethanol's co-product, animal feed, and not to energy embodied in ethanol itself).

The paper calculates that biodiesel reduces GHG emissions by 41% compared with diesel, reduces several major air pollutants, and has a minimal impact on human and environmental health through N, P, and pesticide release. Corn grain ethanol provides a 12% reduction in GHGs and has greater environmental and human health impacts because of increased release of five air pollutants and nitrate, nitrite, and pesticides.

Biofuels tend not to be cost competitive with petroleum-based fuels at present, given current high production costs. However, a biofuel can provide net benefits to society if it is not economically competitive but provides environmental benefits vis-à-vis its fossil fuel alternatives and can thereby merit subsidies when otherwise economically uncompetitive. The authors believe that biodiesel provides sufficient environmental advantages to warrant subsidy.

The authors determine that neither of the two biofuels can significantly replace petroleum production without impacting food supplies. Even if all 2005 U.S. corn and soybean production had been devoted to ethanol and biodiesel, U.S. gasoline and diesel demand would have been offset 12% and 6%, respectively. This would provide a net energy gain equivalent to just 2.4% and 2.9% of U.S. gasoline and diesel consumption.

The report states that, in general, biofuels would provide greater benefits if their biomass feedstocks (1) were producible with less fertilizer, pesticide, and energy inputs; (2) were grown on land with low agricultural value; and (3) required low-input energy to be converted to biofuel. Neither corn grain ethanol nor soybean biodiesel do particularly well on the first two criteria. Soybean biodiesel, however, requires far less energy to convert biomass to biofuel than corn grain ethanol. Nonfood feedstocks such as switchgrass and woody plants offer advantages for these three energetic, environmental, and economic criteria. Therefore, transportation biofuels such as synfuel hydrocarbons or cellulosic ethanol, if produced from low-input biomass grown on agriculturally marginal land or from waste biomass, could provide much greater supplies and environmental benefits than food-based biofuels.

Web link available at:
http://www.pnas.org/content/103/30/11206.full.pdf+html

Energy Balances of Biodiesel Production from Soybean and Canola in Canada, by Smith et al, Canadian Journal of Plant Science, volume 87, number 4, 2007, pages 793-801

This paper estimates the life cycle energy balances for biodiesel produced from soybean and canola oil in Canada. The three broad areas of energy inputs are found to be crop production, oil extraction, and transesterfication of the vegetable oil into biodiesel. Energy required for production of biodiesel's co-products, which in Canada include protein meal (a by-product of oil extraction) and glycerine (a by-product of transesterfication), is also incorporated. This co-product allocation is important because it affects biodiesel's calculated energy balance; for example, if energy were not allocated to protein meal, the energy output to input ratio would decline from 1.70 to 1.52 for soybean and from 2.16 to 1.91 for canola.

The assumed yields of the crops were 2.48 tonnes per hectare (t/ha) for soybean in Eastern Canada and 1.39 t/ha for canola in Western Canada. The actual energy input required to produce a tonne of each crop was 1.55-2.08 gigajoules per tonne (GJ t^{-1}) for soybean and 4.42-5.50 GJ t^{-1} for canola. The authors thereby find that, for zero tillage canola, a total of 8.31 GJ t^{-1} canola was expended to grow and process the seed, of which 9.0% was allocated to meal, 10.4% to glycerine, and 80.6% to the biodiesel. For zero tillage soybean, of a total energy input of 5.06 GJ t^{-1} soybean, 28.5% was allocated to meal, 8.1% to glycerine, and 63.4% to biodiesel. The ratio of biodiesel energy produced per energy input ranged from 2.08 to 2.41. Overall, the energy output to input ratio was very similar for both canola and soybean. Soybean required fewer energy inputs, but also produced less oil than canola for a given weight of seed. Tillage impacted significantly on the energy output to input ratio, which was about 14% higher for zero-tillage than for conventional tillage. In addition, nitrogen is the main energy input for canola and any change in energy required to produce nitrogen or in nitrogen use efficiency would impact greatly upon the canola biodiesel energy balance.

These figures are counter to reports that indicate that biodiesel has an energy ratio of less than 1.0. The authors' estimated life-cycle energy inputs for canola and for soybean are lower than those in other reports (i.e. Hill et al., 2006) because of the absence of liming, the use of lower tillage intensity, and the fact that the energy used by personnel on the farm and in the processing industry is not included in this study.

The authors conclude that the economics of biodiesel production are generally poor, as the price of the vegetable oil feedstock must be below \$508 t^{-1} for biodiesel to be profitable at a fuel price of \$0.503 L^{-1}. Incentives, such as subsidies or mandatory blends, would be required to encourage expanded biodiesel production. At the same time, large-scale production of biodiesel will affect the liquid fuel sector and other economic sectors such as livestock feeding, crops, and glycerine, and the net economy-wide impacts of such changes thereby merit further attention.

Web-link available at:
http://article.pubs.nrc-cnrc.gc.ca/ppv/RPViewDoc?_handler_=HandleInitialGet&journal=cjps&volume=87&articleFile=CJPS06067.pdf

Greenhouse Gas Emissions of Bioenergy from Agriculture Compared to Fossil Energy for Heat and Electricity Supply, by Jungmeier & Spitzer, Nutrient Cycling in Agroecosystems, volume 60, numbers 1-3, 2001, pages 267-273

In this study, selected bioenergy systems from agriculture for heat supply and combined electricity and heat supply are compared with the fossil energy systems of oil, natural gas, and coal. These bioenergy systems cover different conversion technologies and different fuels from agriculture, including wood chips from poplar and willow, miscanthus, rapeseed and sunflower methylester, and biogas from manure, among others. The systems are considered for the Austrian case in the year 2000 and comparisons are made with respect to greenhouse gas (GHG) emissions over the entire life cycle.

Systems boundaries cover all processes from biomass production to processing and conversion to final disposal, and consider aspects such as the use of by-products and the avoided reference use of the biomass or the land area. Reference use refers here to what happens with the biomass if it is not used for energy or what happens on an arable area if no biogenic resources are produced. For example, in the case of biogas production, the avoided reference use of biomass is the storage of the manure and in the case of short rotation forestry, the avoided reference use of the area is set aside land.

Results are presented as emissions of CO_2-equivalents per kWh in comparison to fossil fuel systems and as a percentage of CO_2-equivalent reduction. The authors find that, in general, the GHG emissions of bioenergy systems are lower than those associated with fossil systems. In addition, some bioenergy systems from agriculture have no net GHG emissions or are even associated with 'negative' emissions, such as biogas and methylester. This is because of avoided emissions of the reference biomass use and/or because of certain substitution effects of by-products. For example, in the case of biogas, emissions from the reference biomass use (or storing the manure, associated with uncontrolled CH_4 emissions) are avoided and fertilizer efficiency is increased through the use of digested manure instead of undigested manure, avoiding N_2O emissions from mineral fertilizers. In the case of methylester, negative emissions are due to substitution effects of by-products, for example with glycerine substituting conventionally-produced glycerine for chemical use and rape cake substituting soybean feed. The authors conclude that the comparisons outlined in this study should help policy makers, utilities providers, and industry to identify effective agricultural biomass options in order to reach emission reduction targets.

Analysing Ontario Biofuel Options: Greenhouse Gas Mitigation Efficiency and Costs, by Samson et al, for the BIOCAP Canada Foundation, Kingston, 2008, 33 pages

This study compares the cost effectiveness of various alternative energy policy incentives in mitigating greenhouse gas (GHG) emissions in the province of Ontario. It calculates two values for Ontario-subsidized liquid transportation fuels, or canola-based biodiesel and corn ethanol, and for green electrical power generation alternatives, or wind, small biomass, and solar photovoltaic (PV) power. These values are (1) the dollar cost in subsidies for each unit of energy produced ($/GJ), and (2) the net GHG savings that would be realized when the alternative energy source replaced a traditional fossil fuel source per unit of energy produced (kgCO_2e/GJ). By combining the two values, the study determines the costs in government subsidies of abating a tonne of CO_2e ($/t CO_2e) for each of the alternative sources.

The authors find that GHG emissions abatement cost $379/t CO_2e in government subsidies when using corn ethanol and $98/t CO_2e when using canola-based biodiesel to offset gasoline and diesel, respectively. Canola-based biodiesel is noted to have a greater GHG offset per delivered energy (57 kg CO_2e/GJ versus corn ethanol's 21 kg CO_2e/GJ) and a lower incentive cost ($5.61/GJ versus corn ethanol's $8/GJ), providing a more cost-effective mitigation strategy. In contrast with liquid fuels, incentives for alternative sources of small-scale electric power tended to be more cost-effective, largely because they replace coal, the dirtiest of fossil fuels. Wind power incentives are found to be the most cost-effective, at $52/t CO_2e when replacing coal-fired power, while small-scale biogas electrical power is slightly more expensive at $57/t CO_2e. Solar PV power, however, while quite efficient at avoiding CO_2 emissions, is calculated to be very expensive ($374/t CO_2e), due to the large subsidy ($101/GJ) it receives from the province of Ontario.

The report's major conclusion is that government incentives applied to large-scale solid biofuels (which do not currently receive direct provincial or federal incentives) would surpass even the most effective existing subsidies — those for wind power — at reducing GHG emissions. If green heat (residential/industrial heating) programs and large-scale power incentives were provided at a rate of $4/GJ for biomass pellets, CO_2e offsets would be created at a cost of less than $50/t CO_2e when displacing coal. Solid biofuels also have the advantage over wind power in that they can be stored and used for base or peak load in power applications and in that production and transportation of solid biofuels at the necessary scale could act to stimulate the rural economy. The authors conclude that a solid biofuel incentive would cost 1/2 as much per tonne of CO_2e avoided as comparable biodiesel programs, and 1/8 as much as current ethanol programs.

Web-link available at:
http://www.reap-canada.com/online_library/grass_pellets/BIOCAP_REAP_bioenergy_policy_incentives08Jan18-Final.pdf

Life Cycle Assessment of Biogas from Maize Silage and from Manure, by Thyo and Wenzel, Institute for Product Development, Aalborg, 2007, 47 pages

This report presents an environmental life cycle assessment (LCA) of biogas produced from both maize (corn) silage and animal manure. The LCA comprises both environmental impacts and effects on resource consumption, and covers utilization of the produced biogas for either heat and power generation or transport in an upgraded (cleaned) and compressed form. The study is comparative and shows the consequences of making biogas in light of lost alternatives. For example, biogas from manure is compared to manure's storage and use as an agricultural fertilizer and biogas from maize silage is compared to using the same agricultural land for other bioenergy purposes, such as growth of maize for bioethanol, rapeseed for biodiesel, or willow for heat and power.

The authors derive the following conclusions about biogas from manure and maize. First, manure-based biogas has very high GHG emissions reductions and very high fossil fuel savings compared to the conventional storage and soil application of the manure. Manure should have the highest priority of all the compared bioenergy types and be utilized for biogas production prior to soil application, due to its high fossil fuel replacement, avoided CH_4 emissions from manure storage, reduced N_2O emissions from soil application of the manure, and improved plant availability of the nitrogen in the manure. Second, maize-based biogas demonstrates, along with heat and power from willow, the highest reductions in GHG emissions and highest savings of fossil fuel among the compared types of bioenergy, due to high yields per hectare of land, large fossil fuel substitution efficiency, and the energy infrastructure aspects of the bioenergy technology. Land area dedicated to energy crops should be prioritized for crops specifically designated for either heat and power or for biogas.

Overall, the study concludes that environmentally and in terms of fossil fuel savings, energy crops should be prioritized for heat and power purposes either (1) through a preceding biogas generation or (2) by direct incineration or gasification. These two processes lead to almost equal CO_2 reductions and fossil fuel savings. Energy crops converted directly into a transport fuel imply significantly lower CO_2 reductions and fossil fuel savings. For example, rape seed biodiesel has a very low energy yield per hectare and the 1st and 2nd generation bioethanol conversion process is associated with large energy requirements.

Web-link available at:
http://www.biogas-e.be/Pdf/LCA%20of%20biogas%20from%20maize%20and%20manure.pdf

2.3 Land Base Issues

Bio-Ethanol Production in Brazil, by Boddey et al, from "Biofuels, Solar and Wind as Renewable Energy Systems-Benefits and Risks," edited by D. Pimentel, Springer Science, 2008, pages 321-356

This book chapter presents a comprehensive look at the Brazilian program for bioethanol production from sugarcane, covering aspects of the program's history and current situation with regards to scale and agronomic and industrial practices. It evaluates primarily the environmental impacts of the program, both in terms of global scale such as energy balance and GHG emissions and local and regional impacts such as soil erosion and atmospheric and water pollution.

In terms of global impacts, the energy balance (total energy yield [TEY] divided by fossil energy invested [FEI]) of Brazilian sugarcane ethanol production is found to equal 8.8. This calculation incorporates widespread energy inputs, including fuel for agricultural operations; agricultural inputs such as manual labour, fertilizers, pesticides, planting material, and irrigation; agricultural machinery; transportation, at all stages of the life cycle; and factory inputs, primarily those involved in construction, water pumping, and ethanol production. Sugarcane has a yield of 76.6 Mg ha^{-1}, which can produce 6280 L of ethanol per ha. The authors then calculate the total associated GHG emissions at approximately 2.36 Mg CO_2e ha^{-1} yr^{-1}. This indicates that using bioethanol produced from sugarcane under present practices will result in a 79% abatement of GHG emissions compared to "pure" gasoline, or a 73% abatement compared to Brazilian "gasohol" (gasoline with a 22–24% ethanol addition).

In terms of local and regional impacts, the authors find that while Brazilian ethanol production has several negative environmental impacts, including air pollution from pre-harvest burning of cane and water pollution from distillery waste (vinasse), conditions are improving. There is a gradual phasing out of cane burning and the return of vinasse and other effluents to the fields. The authors highlight that historically severe soil erosion has been an issue, but with the introduction of no-till techniques and green cane harvesting, erosion is being reduced. Similarly, impacts on the Amazon rainforest and other reserves of biodiversity are minute and the rural poor will not face food shortages, as Brazil does not lack arable land. Increased mechanization of sugarcane production will have negative effects on rural employment (though positive effects on salaries and working conditions), but should act to increase sugarcane ethanol's energy balance, and reduce its GHG life cycle emissions and other environmental impacts, through the further abandonment of pre-harvest burning and introduction of no-till planting. The authors believe that, with proper environmental and employment policies, the Brazilian bioethanol program could be of great environmental and economic benefit to the country and could play a small but significant global role in mitigating GHG emissions from motor vehicles and reducing the consumption of petroleum.

III. Socio-Economic Assessment of the Sustainability of Bio-Energy Production

SUMMARY

Biofuels development not only impacts upon the environment as outlined in Section I and Section II, but is also associated with varying socioeconomic effects. Section III thereby addresses the widespread social and economic sustainability considerations related to bioenergy production.

This section analyses how growing different feedstocks and processing them into biofuels impacts upon rural economic development and employment levels. Results vary widely depending on type of feedstock, scale of technology, degree of farmer ownership, and especially, local and regional economic contexts. In addition, this section looks at the impacts on food prices and global food security of shifting cropland use away from food production towards increased production of biofuel feedstocks. This occurs when farmers are driven towards producing biomass as a means of making a better living than they can by growing food crops.

The above issues deal with a series of complex tradeoffs. For example, heightened demand for biofuels, and subsequent increased crop prices, has the potential to enhance agricultural production and farm incomes (and likely reduce GHG emissions) in both developing and industrialized nations. At the same time, however, if scaled up too quickly or at too large a scale, biofuels development could lead to food inflation and to strong negative impacts on the urban poor in developing countries and on global food security. Of particular concern is the possibility that the growth in demand for food crops for non-food uses (i.e. biofuels) could outstrip the annual growth in production of these commodities, thereby creating a decrease in global carryover stocks. How all of these factors interact is not certain, making the food vs. fuel debate extremely complicated. Further research on this topic, and on the potential for 2nd generation energy feedstocks, would be helpful in this regard. Also important to future research is how an increase in crop prices, as well as heightened production of co-products such as distiller's grain, would impact upon the cost of animal feed, and subsequently on livestock farmers and meat consumers. More information on how small-scale (i.e. biogas or pellets) and large-scale (i.e. ethanol) biofuel conversion technologies affect local sustainability and farmers' ownership of the technology is also required.

Overall, life-cycle analyses generally lack comprehensive social and economic assessment, and it would be helpful to address issues surrounding job creation (quality and permanence); social responsibility; and social equity, for example regarding wealth distribution and the food vs. fuel debate.

Sustainable Bioenergy: A Framework for Decision Makers, by UN-Energy, 2007, 64 pages

This paper addresses nine key social, economic, and ecological sustainability issues that stem from small- and large-scale applications of bioenergy, focusing primarily on modern bioenergy such as liquid biofuels, biogas, and solid biomass for heat and power. These issues include modern bioenergy's ability to provide energy services for the poor, and its implications for agro-industrial development and job creation; health and gender; the structure of agriculture; food security; government budget; trade, foreign exchange balances, and energy security; biodiversity and natural resource management; and climate change.

One of the key sustainability issues relates to bioenergy's implications for agro-industrial development and job creation. The authors note that while bioenergy offers employment in areas such as farming, transportation, and processing, the development of large-scale, mechanized farming for economies of scale can displace workers and be associated with poor working conditions. Job creation may subsequently be enhanced by encouraging labour-intensive bioenergy feedstocks, biodiesel versus ethanol production, and/or community-focused bioenergy applications. In addition, cooperative structures may be established in which several independent small and medium-sized enterprise (SME) biomass producers work together to supply larger facilities or markets. However, while the economic development benefits of bioenergy are enhanced dramatically when more people own more of the value-added chain, small-scale and labour-intensive production may diminish production efficiency and economic competitiveness.

Another issue stems from the impacts of bioenergy on the structure of agriculture, with increasingly high concentrations of ownership particularly harmful to farmers who do not own their own land and heightened demand for land resulting in food price increases and difficulties for the rural and urban poor who are net buyers of food.

Overall, bioenergy development leads to unclear costs and benefits for society. For example, while smaller-scale bioenergy industries offer higher social returns on public investments, they may also be associated with lower production efficiency (likely necessitating higher government subsidies). Additionally, some feedstocks are better suited for large-scale production, while others are well suited to small-scale applications. It is therefore important to weigh the costs and benefits of small-scale versus large-scale bioenergy production and distribution in different local and regional contexts.

Regardless of the scale of production, however, one thing is clear: the more involved farmers are in the production, processing, and use of biofuels, the more likely they are to share in the benefits. For example, where biomass producers have a stake in a value-added segment such as processing, they are buffered from the risk of falling agricultural commodity prices, a high-quality supply of feedstock is better ensured for the processing facility, and the economic multiplier effect in rural communities is dramatically enhanced. Bioenergy from forest products and perennials in particular can offer such opportunities to SMEs and will play an important role in the future of bioenergy.

Web-link available at:
ftp://ftp.fao.org/docrep/fao/010/a1094e/a1094e00.pdf

Ethanol and the Local Economy: Industry Trends, Location Factors, Economic Impacts, and Risks, by Isserman and Low, Economic Development Quarterly (forthcoming), February 2009, 42 pages

This paper addresses three questions: (1) where in the United States have ethanol plants been locating, (2) what factors make a location attractive for an ethanol plant, and (3) what are the local economic impacts of a typical ethanol plant?

Most ethanol plants are in rural America, with two-thirds located in the Midwest. Plants tend to be situated in close proximity to: input supplies such as energy, corn or other feedstocks, and water; transportation and marketing infrastructure; and by-product users, such as cattle feeding facilities that can use distiller's grains, corn ethanol's main by-product.

There are two steps to measuring the local economic effects of an ethanol plant. These are known as scenario building and economic modeling and the paper applies these approaches to the hypothetical ethanol plants of four selected counties that have different urbanization levels, resources, and economies.

Each of the four scenarios presents four ways that a new ethanol plant will undoubtedly benefit a local economy: (1) by producing ethanol, which entails purchasing labor and other inputs locally, (2) by paying a premium for corn, which provides added income for farmland owners, (3) by drawing additional land into corn production, and (4) by making cheaper, wet grain feed available, which might increase cattle production. However, the extent of these economic impacts will ultimately depend on the size of the plant, the complexity of the local economy, what goods and services are available locally, how much income is generated locally by the corn price premium, and other specific factors. Under the most favorable conditions (a complex economy with high farmland values), the ethanol plant can lead to 250 direct and indirect jobs. Ethanol plants can therefore offer a community the employment benefits of a typical manufacturing plant plus greater job security, because of ties to the local economy's corn, railroad, water, energy, and market resources.

At the same time, however, ethanol plant job security is threatened by the industry's dependence upon: changing relative prices of corn, oil, and ethanol; federal and state policy incentives; and large amounts of water and energy. Plants also face rapidly changing industrial organization, new technologies, and potential competition from imported ethanol as threats to their competitive edge and profitability.

In all, then, an ethanol plant is a contributor, not an economic panacea, for a county. Its economic contributions are small enough to merit a careful look at the demands a plant would place on local services, infrastructure, and resources, and to recognize the uncertainties that surround the ethanol industry and the viability of a particular plant.

Web link (to older version) available at:
http://www.farmdoc.uiuc.edu/policy/research_reports/ethanol_report/Ethanol%20Report.pdf#page=65

A Review of the Economic Rewards and Risks of Ethanol Production, by Swenson, from "Biofuels, Solar and Wind as Renewable Energy Systems-Benefits and Risks," edited by D. Pimentel, Springer Science, 2008, 57-78

David Swenson writes on the social and economic sustainability of the ethanol industry in the United States. In this book chapter, he assesses the potential economic benefits and rural resurgence associated with the industry by investigating the consequences of ethanol plant development in the Midwest and in the US as a whole.

The author's analysis includes a review of a report prepared for the Iowa Renewable Fuels Association (IRFA) in 2007, which concluded that Iowa's ethanol industry had created 46,938 jobs and contributed $7.315 billion in state domestic product. While ethanol development has brought some job creation in the state, particularly in the ethanol plants themselves and in the maintenance, financial, and chemical sectors, the author argues that the employment figures cited in the IRFA study are overstated. He states that many of the "new" jobs associated with capital development and construction, corn production, and transportation already existed or were spatially temporary. For example, as ethanol production does not increase corn production but rather shifts corn deliveries away from export towards local processing, there is no increase in corn farmers alongside an expansion in Iowa ethanol facilities. Thus, when all necessary subtractions are made, it becomes more likely that in Iowa approximately 5,431 total direct and indirect jobs, or 200 jobs per plant, are attributable to ethanol production in 28 plants.

The article subsequently offers a set of probable consequences associated with ethanol development. To begin, ethanol plants may be bought by outside investors and/or may diminish in profitability, meaning that local plant development does not inevitably breed positive localized economic side-effects. In addition, increased corn prices are often associated with heightened input costs and land rents, making economic improvements of corn farmers alongside commodity price increases neither uniform nor guaranteed. But the impacts of ethanol development extend beyond corn farmers and their communities. For example, heightened corn prices hike up the feed and input costs of meat and poultry farmers, impacting upon consumer prices. Also, expanded corn production creates new transport and storage needs (which could translate into excess capacity should cellulosic ethanol be developed); takes land from other crops and thus increases imports; heightens demand for energy inputs, increasing prices for other users; and leads to varied environmental impacts.

Overall, Swenson identifies the biofuels industry to be capital intensive and therefore prone to obtaining economies of scale, making for larger, more efficient plants that demand fewer and fewer employees and other local inputs. Expanded ethanol production may therefore have the potential to continue, if not accelerate, the fundamental factors already undermining US rural areas. Thus, while future progress in cellulosic ethanol production may bring a different set of impacts for rural areas, current assumptions about ethanol development bringing rural rejuvenation through employment appear uncertain.

Web link available at:
http://www.springerlink.com/content/g3226700t15610u4/

<u>*The Ripple Effect: Biofuels, Food Security, and the Environment*, by Naylor et al, Environment, volume 49, issue 9, 2007, pages 32-43</u>

This paper aims to conceptualize the transmission of agricultural prices from major biofuels-producing and consuming nations to the international market, and subsequently to local markets in food-deficit countries

It first describes the potential effects on both commodity markets and the environment of major players in the biofuels market and their roles in the global production, export, and/or import of key bioenergy feedstocks. The following four case studies are thereby derived: (1) US corn production for domestic bio-ethanol, (2) Chinese cassava imports for domestic bio-ethanol, (3) expansion of Brazilian sugarcane and soy, and (4) Indonesian oil palms for global biodiesel. Overall, these case studies demonstrate that biofuels can cause an abrupt increase in demand for certain agricultural commodities, which can subsequently alter the acreage planted to field crops, for example leading to shifts from soybean plantings to corn for ethanol production. This is placing upward pressure on crop prices and a consequential increase in food prices and livestock production costs.

The authors also summarize the price forecasts from seven key studies that project future agricultural prices related to biofuels development. Although these studies are not directly comparable to one another, as they use different biofuel development scenarios, they generally anticipate the following bioenergy-related outcomes: large increases in cassava prices; moderate-to-large increases in wheat prices; slightly smaller increases in wheat prices; small-to-large increases in sugar prices; moderate increases in vegetable and palm oil prices; and ambiguous effects on soybean prices, as meal and oil prices move in opposite directions. The impact of these rising international market prices on agricultural development potential remains uncertain.

Four main conclusions stem from the above case studies and price forecasts. First, rapid growth in bioethanol and biodiesel markets is increasing demand for key agricultural commodities, resulting in heightened agricultural commodity prices for the main feedstocks in international markets. This is inducing substitutions in production and consumption and leading to price increases in a wider array of agricultural markets. Second, expansion of biofuels production will likely continue, despite fluctuations in petroleum prices, due to political support. Third, the leading agricultural commodities used as feedstocks also comprise a relatively large share of the diets of food-insecure people worldwide. Last, biofuels growth will continue to rely primarily on these food and feed commodities (as opposed to cellulosic feedstocks) over the coming decade and will be constrained largely by food crop production capacity and rising prices of these feedstocks.

The authors conclude that a better understanding of the ripple effects of crop-based biofuels on food security and the environment is urgently needed and that these effects must be considered carefully in the design of development policies and investments, especially for the sake of the world's poorest populations. They suggest that sustainability audits for the biofuels industry be designed and implemented and that such efforts remain true to sustainability objectives, rather than being used as trade barriers to protect domestic agricultural markets.

Web-link available at:
http://iis-db.stanford.edu/pubs/22064/Naylor_et_al_Env.pdf

Food Outlook: Global Market Analysis, by the Food and Agriculture Organization (FAO), Rome, November 2008, 98 pages

This semi-annual report provides market assessments of various agricultural commodities of critical importance to global food and feed markets, putting into perspective market developments in past months and aiming to provide insight into commodities outlooks for future months. Of particular relevance to biofuels, it includes inventories of world grain and oilseed stocks, summarizing changes in production and consumption levels and highlighting growth in non-food (including biofuels) use from year to year. The report exhibits that consumption of cereals, and coarse grains in particular, has increased rapidly in recent years.

The authors explain that soaring food prices have led to serious difficulties, especially for vulnerable population groups that spend a substantial part of their income on food, and that prices are unlikely to return to the low levels of previous years due to escalated costs of inputs and various demand factors, including expected increases in utilization. Thus, food prices will remain high despite a favorable global production outlook.

The most influential development in pushing up international prices of basic foods has been low levels of exportable supplies, resulting from utilization outstripping production for several crops in a number of major exporting countries. For some commodities, much of this increased utilization comes from "other uses" besides food and feed. For example, from 2006/07 to 2008/09, there is forecast to be a 10.3% increase in world cereal production, with a 2.9% increase in utilization for food and a 3.6% increase in utilization for feed, but a 24.0% increase in utilization of cereals for other uses. However, ending stocks look set to improve, with a projected growth of 9.4% from 2007/08 to 2008/09, compared to 1.6% the previous year. The outlook for coarse grains is less favorable: from 2006/07 to 2008/09, there is projected to be a 13.1% increase in world coarse grain (maize, barley, sorghum, millet, rye, oats, etc.) production, with a 5.0% increase in utilization for food and a 3.0% increase in utilization for feed (and a -0.7% change from 2007/08 to 2008/09, possibly linked to stagnation in global meat output in 2008), but a 29.9% increase in utilization of coarse grains for other uses. These heightened utilization levels stem mainly from higher biofuel usage, with the maize situation of particular concern, as this year's output is unlikely to exceed last year's record and demand for the production of ethanol does not show any signs of abating. As a result, stocks next season are likely to fall and this prospect is supportive to prices, which are already at very high levels. Ending stocks of coarse grains grew 4.3% from 2006/07 to 2007/08, but are projected to grow 1.9% from 2007/08 to 2008/09.

Overall, this FAO report is perhaps the best reference document for obtaining factual information about world grain production trends, changes in utilization, and subsequent impacts on carry-over stocks of cereal commodities.

Web-link available at:
ftp://ftp.fao.org/docrep/fao/010/ai466e/ai466e00.pdf

IV. Sustainable Biofuels Trade and Standards

SUMMARY

With biofuels development, and its subsequent environmental and socioeconomic impacts, comes increased trade in biomass between producers and consumers and an enhanced incentive to verify the sustainability characteristics of a biofuel's origin. Section IV thus explains the current characteristics of international biomass trade and recent developments in biofuels sustainability certification.

This section presents the main drivers of and limitations to international biofuels trade. It also highlights the specifics of Canada's bioenergy imports (mostly ethanol), exports (primarily wood pellets), and future biofuels trade potential. It should be noted that data on biomass trade is limited, which makes the calculation of accurate trade statistics on biofuels difficult at present.

Standards for the sustainable production of biomass will increasingly influence international bioenergy trade, and this section reviews existing and proposed biofuels certification systems. For example, the recent multi-stakeholder Roundtable on Sustainable Biofuels provides a twelve-criterion draft standard for sustainable biofuels production. The Inter-American Development Bank's Biofuels Sustainability Scorecard presents project developers with important sustainability measures that can be applied to the creation and monitoring of biofuels projects. An overview of other biofuels sustainability standards is available at: http://bioenergytrade.org/downloads/ieatask40certificationpaperannexesdraftforcomm.pdf.

Overall, these standards highlight what is needed to build a sustainable biofuels industry, and are therefore useful to both farmers and project developers, just as they are to policy makers. Further research would be helpful, however, on how best to apply these sustainability standards and criteria to actual government policies and to useful international certification initiatives.

<u>*Developments in International Bioenergy Trade*, by Junginger et al, Biomass and Bioenergy, volume 32, issue 8, 2008, pages 717-729</u>

This paper summarizes the main developments and drivers of international bioenergy trade, with a particular focus on wood pellets and bio-ethanol. The use of biomass for energy varies between a few percent of the national energy supply up to significant shares (ie/ 15-25% in Finland, Sweden, and Brazil). In many European countries such as Belgium, Finland, the Netherlands, Sweden, and the UK, imported biomass already forms a significant part of total biomass use (between 21% and 43%). These numbers look set to increase in coming years. While domestic biomass utilization still outweighs use of imported biomass, this may change, especially with certain biomass fuels.

Wood pellets are one of the most successful bioenergy-based commodities traded internationally. Their demand has soared due to a low moisture content and relatively high heating value, which allow long-distance shipping without affecting the energy balance. Wood pellets are currently exported by Canada, Finland, and (to a small extent) Brazil and Norway, and imported by Sweden, Belgium, the Netherlands, and the UK. In the Netherlands and Belgium, pellet imports contribute to a large share of total renewable electricity production.

Trade in bio-ethanol is another example of a rapidly growing international market. Of the current Task 40 members, Brazil (via sugar-cane) is the most important producer and user of bio-ethanol as a transportation fuel. Canada is also a bio-ethanol producer, though on a much smaller scale. With the EU setting targets for biofuel usage in transportation, bio-ethanol exports from Brazil and elsewhere to Europe are likely to increase.

Major drivers for international bioenergy trade in general are the large resource potentials and relatively low production costs in producing countries such as Canada and Brazil, and high fossil fuel prices and various policy incentives to stimulate biomass use in importing countries. However, certain issues impede upon further market development. First, logistical infrastructure in both exporting and importing countries must be improved in order to gain access to larger physical biomass volumes and to more end-users. Second, low data availability and methodological issues regarding direct and indirect trade (particularly in countries with large pulp and paper sectors) hinder the calculation of accurate biomass trade statistics and should be addressed. Third, favourable policies for renewable energy production and use are a main driver for the import of biomass (particularly in Europe) and sudden changes in these policies can impact greatly upon trade patterns. Last, as international trade in bioenergy increases rapidly, safeguards are required to ensure that biomass is produced in a sustainable manner. There is debate over whether the supporting systems should be national or international, mandatory or voluntary, and drawbacks exist with each proposed method (see paper by van Dam et al). The sustainable production of biomass is an issue that will likely increasingly influence international bioenergy trade in the future.

This paper focuses on the ten countries, including Canada, that are party to Task 40 (entitled "Sustainable International Bioenergy Trade-Securing Supply and Demand") of the International Energy Agency's (IEA) Bioenergy Division and utilizes information provided by these member countries as a key source of data. Please see http://bioenergytrade.org/ for more information on the IEA Task 40 and its activities.

Canada Report on Bioenergy 2008, by Climate Change Solutions, for Environment Canada (Member of IEA Bioenergy Task 40-Biotrade), Ottawa, 2008, 48 pages

This report provides an overview of Canada's bioenergy industry, trade, and potential as of 2008. It first outlines Canada's bioenergy policies, both federally and provincially; biomass resources, including woody biomass, agricultural residues, and municipal solid waste; different uses of biomass, such as heat and power, biofuels production, pyrolysis oil, and wood pellets; current biomass users; biomass production and consumption patterns; and biomass prices.

Next, the author outlines the nature of biomass imports and exports in Canada, focusing specifically on ethanol and biodiesel, pyrolysis oil, and wood pellets. First, while no official trade statistics exist for trade of either fuel ethanol or biodiesel, it can be said that Canada does not have excess capacity of ethanol for export. Current imports of fuel ethanol are hovering around 70-100 million litres annually, mainly from the U.S. Second, any potential future export of pyrolysis oil will be determined by price, renewable energy incentives in European and other markets, ocean freight costs, future domestic incentives for bio-products and carbon trading, and the suitability of pyrolysis oil as a feedstock for gasoline production in existing oil refineries. Third, in 2007, 32% of Canadian production of wood pellets was exported to the US while 54% went to Europe. US sales are expected to remain constant at 450,000 tonnes annually and European exports are projected to almost triple to 2 million tonnes. Pellets are currently exported primarily from British Columbia, Nova Scotia, and Quebec. It is likely that wood pellet exports represent the largest potential bioenergy export opportunity as 2.4 million tonnes of surplus residues existed in the 2005-2007 period.

The author concludes by presenting barriers and opportunities to Canadian trade in biomass. On the one hand, barriers include high ocean transport costs; the location of some of Canada' biomass far from ocean ports (i.e. in Ontario); Canada's limited numbers of year-round ports; undeveloped supply chains for forest harvest biomass; increasing domestic incentives and domestic pressure to keep biomass at home; European trade barriers; and a lack of testing thus far to prove the reliability and competitiveness of long distance pyrolysis oil supply chains. On the other hand, the greatest opportunities for biomass trade in Canada are to (1) establish pellet plants in Quebec for short-distance (5,000 km) supply chains to the European Union (EU); (2) create partnerships between prospective EU pyrolysis oil customers and domestic biomass owners to build pyrolysis plants dedicated to export; (3) succeed in research on super-densified pellets; (4) raise ocean shipping capacity to bring down costs; (5) establish a biomass industry in Newfoundland and Labrador; and (6) continue to turn Mountain Pine Beetle wood into transportable energy products.

Web-link available at:
http://www.bioenergytrade.org/downloads/canadacountryreportjun2008.pdf

Overview of Recent Developments in Sustainable Biomass Certification, by van Dam et al, Biomass and Bioenergy, volume 32, issue 8, 2008, pages 749-780

Mounting production and use of biomass for renewable energy has led to an international biomass market and increased trade in biomass resources. Sustainable production of feedstocks and biofuels is becoming a primary concern and may become a requirement for market access. Standards and certification mechanisms are seen as possible strategies for helping to ensure such sustainable production. The objective of this paper is to give a comprehensive review of initiatives on biomass certification from different viewpoints of stakeholders, including national governments, companies, NGOs, and international organizations.

Additionally, the paper presents limitations to the development of biomass certification, including difficulties in implementing truly broad-based multi-stakeholder decision-making; constraints imposed by international trade law; a lack of adequate criteria, indicators, monitoring, and control; barriers to small-scale stakeholders; varying levels of government legislative capacity; high certification costs; and issues related to inequalities in development and international trade. Certification systems can also take necessary focus away from government regulation by transferring responsibility towards other governance structures. Thus, while many national governments promote the use of biomass and the production of biofuels for renewable energy, few of them have taken initiative to develop principles and criteria for sustainable biomass trade.

The paper presents five different strategies for the implementation of a biomass certification system, which essentially vary from one another by their voluntary or mandatory character and their geographical coverage in terms of biomass end-use. The authors also provide several suggestions, as follows. First, enhanced stakeholder involvement, with particular attention to small stakeholders, should be attempted. Second, while a certification system should be thorough and reliable, it should not create a hurdle for emerging industries. Therefore, certification should be paired with assistance and incentives. Third, better international coordination between initiatives (possibly through the promotion of international agreements and standardization of criteria) is needed and should be combined with corresponding government policy instruments. Fourth, economic, social, and environmental criteria must be included in the eventual biomass certification system. There are presently two biomass certification systems in operation, both initiated by energy companies, and further concrete action should be taken to translate sustainability standards into operational criteria, indicators, monitoring, and verification. Experience and time are needed and a learning-based process would be helpful in this regard. Fifth, a process to assess the WTO-compatibility of a biomass certification scheme and to provide countries with the opportunities to exchange views on it is needed. Last, it is concluded that certification is not a goal on itself, but a means to an end, and that other policy tools should be used as well to ensure the sustainability of biomass use.

Web link (to older version) available at:
http://www.bioenergytrade.org/plaintext/downloads/ieatask40certificationpaperdraftforcomments22..pdf

Roundtable on Sustainable Biofuels (Version Zero), an initiative of L'École Polytechnique Fédérale de Lausanne (EPFL) Energy Center, Lausanne, 2008, 11 pages

In June 2007, the Roundtable on Sustainable Biofuels (RSB) Steering Board published draft principles for sustainable biofuels production as the basis for a global stakeholder discussion around requirements for sustainable biofuels. The result is 'Version Zero' (or a good first draft) of a globally applicable standard for sustainable biofuels. This draft standard states that biofuels production, processing, and projects shall:

1) Follow all applicable laws of the country in which they occur and endeavour to follow all international treaties relevant to biofuels' production to which the relevant country is a party;
2) Be designed and operated under appropriate, comprehensive, transparent, consultative, and participatory processes that involve all relevant stakeholders;
3) Contribute to climate change mitigation by significantly reducing GHG emissions as compared to fossil fuels;
4) Not violate human rights or labor rights and ensure decent work and the well-being of workers;
5) Contribute to the social and economic development of local, rural, and indigenous peoples and communities;
6) Not impair food security;
7) Avoid negative impacts on biodiversity, ecosystems, and areas of High Conservation Value;
8) Promote practices that seek to improve soil health and minimize degradation;
9) Optimize surface and groundwater resource use, including minimizing contamination or depletion of these resources, and not violate existing formal and customary water rights;
10) Minimize air pollution along the supply chain;
11) Be produced in the most cost-effective way in all stages of the biofuel value chain through the use of technologies that will improve production efficiency as well as social and environmental performance; and
12) Not violate land rights.

Alongside these twelve principles are provided criteria and suggestions for implementation, with the aims of addressing the direct activities that farmers and producers can undertake to prevent some of the unintended consequences of biofuels. In addition, the RSB recognizes that many efforts to minimize these risks must be addressed within government policy.

The RSB Steering Board was developed with the goal of representing in a balanced manner stakeholders from around the world and from different sectors of society and positions in the supply chain. RSB Board members serve in a personal capacity and represent neither their company nor their sector as a whole. Actors will be added to the Board as needed to achieve the above objectives.

The Board will collaborate with governments, international organizations, inter-governmental agencies, and concerned stakeholders during the coming year to achieve consensus on the best indicators and implementation mechanisms to use for measuring and mitigating the risks associated with biofuels. There will be a six-month round of global stakeholder feedback on Version Zero of the draft standard with the aims of ensuring that all stakeholders are given ample opportunity to input into the process. For more information, please see http://cgse.epfl.ch/page65660-en.html.

Biofuels Sustainability Scorecard, by the Inter-American Development Bank (IDB), Washington DC, 2008

The Inter-American Development Bank (IDB) has created a Biofuels Sustainability Scorecard based on the sustainability criteria of the Roundtable on Sustainable Biofuels. The primary objective of the Scorecard is to provide a tool for thinking through the complex issues associated with biofuels throughout their life-cycles, thereby encouraging higher levels of sustainability in biofuel development projects.

The Scorecard addresses environmental and social sustainability issues specific to biofuels projects through the use of both general and specific criteria during the cultivation, production, and distribution stages of biofuels production. The environmental sustainability criteria are as follows:

- General: yield, relative yield performance, biodiversity
- Cultivation: former land use, crop lifecycle, crop rotation / crop mix, harvesting method, water requirements for cultivation, fertilizer use, pesticide use
- Production: energy source for facility, water requirements for production, waste disposal, co-products use
- Transportation: relative energy efficiency of transport and distribution
- Transversal: energy balance, greenhouse gas emissions

The social sustainability criteria include human and labour rights, land ownership, use of best available technique, capacity building, poverty reduction, and consultation. The above sustainability criteria represent a mix of qualitative and quantitative indicators, as some criteria are difficult to quantify over a range of feedstocks and projects.

The Scorecard does not provide the user with a final score, but rather with a "color map" indicating performance across different areas. It may be used at multiple stages of a project's lifecycle and in turn can help users to identify areas for improvement and then to measure the impact of changes in these areas. While the Scorecard is geared primarily towards the private sector at the project level, it could be used more broadly as a means of identifying which criteria need to be assessed for sustainable biofuels development.

The scientific debate around these complex issues continues to evolve and the IDB therefore views the Scorecard as a work-in-process. It will continue to update and revise the Scorecard as needed and users may aid in this process by submitting their comments after filling out the Scorecard.

Web-link available at:
http://www.iadb.org/scorecard/scorecard.cfm

V. Summary of Issues and Policy Suggestions

SUMMARY

Section V overviews the environmental, social, and economic sustainability issues that stem from the development of different biofuel feedstocks, conversion processes, and end-use technologies. It addresses some of the overarching questions brought up in Sections I, II, III, and IV, including:

- Can biofuels help reduce GHGs?
- Can biofuels help achieve energy security?
- Do biofuels threaten land, water, biodiversity, or human health?
- What is the technical potential of biofuels?
- Which biofuels are the most cost-effective?
- Can biofuels help promote agricultural development?
- Do biofuels threaten global food security?
- What are the implications of current biofuels policies?
- What are the opportunities and barriers to international biomass trade?
- Can certification ensure that biofuels are produced sustainably?
- Overall, which forms of bioenergy provide more solutions than they do problems?

In addition, since biofuels production is not always economically viable, policy interventions, particularly in the form of subsidies and liquid biofuel mandates, tend to push the development of biofuels in many countries. This section therefore presents policy suggestions that could maximize the benefits and minimize the risks of biofuels. In general, it can be said that there seems to be a case for directing expenditures on biofuels towards further research and development, especially on 2nd generation technologies.

The State of Food and Agriculture: Biofuels: Prospects, Risks, and Opportunities, by the Food and Agriculture Organization (FAO), Rome, 2008, 128 pages

This Food and Agriculture Organization (FAO) report focuses particularly on liquid biofuels used for transportation and addresses several questions: (1) Do biofuels threaten food security?; (2) Can biofuels help promote agricultural development?; (3) Can biofuels help reduce greenhouse gas emissions?; (4) Do biofuels threaten land, water, and biodiversity?; and (5) Can biofuels help achieve energy security?. It provides a technical overview of biofuels; highlights key economic and policy drivers of liquid biofuels; explains biofuel markets and policy impacts; outlines social, economic, and environmental impacts of biofuels; and presents suggestions for policy improvement.

The report chronicles the historical links between agriculture and energy, highlighting recent increased demand for agricultural feedstocks to be converted into liquid biofuels. The authors note that a combination of factors, including weather-related production shortfalls, low global cereal stocks, and increasing fuel costs have all contributed to higher food prices, and that biofuels are not the sole driver. However, rapidly growing demand for biofuel feedstocks such as corn, sugar, oilseeds, and palm oil has contributed to higher prices for agricultural commodities in general, and for the resources used to produce them. This has immediately threatened the food security of poor net food buyers in both urban and rural areas globally. In the longer term and with appropriate policies and investments, expanded demand and increased prices for agricultural commodities via biofuel production could create opportunities for agricultural and rural development. The paper demonstrates that the impact of biofuels on greenhouse gas emissions and on the environment varies dramatically according to feedstock use, geographical location, agricultural practice, and conversion technology.

The production of liquid biofuels is not currently economically viable in many countries, due to existing agricultural production and biofuel processing technology capabilities, combined with increased prices of commodity feedstocks and crude oil. It is therefore policy interventions, especially in the form of subsidies and governmental liquid biofuel mandates requiring the blending of biofuels with fossil fuels, which are driving the rush to produce liquid biofuels. The authors find that these policies are often costly and with unintended consequences, especially to the extent that they promote rapid growth in biofuel production from an already stressed natural resource base. The paper presents the following five broad areas of policy action towards ensuring environmentally, economically, and socially sustainable biofuel production: (1) protecting the poor and food-insecure; (2) taking advantage of opportunities for agricultural and rural development; (3) ensuring environmental sustainability; (4) reviewing existing biofuel policies; and (5) enhancing international system support to sustainable biofuel development. The report concludes by reiterating that even minor contributions of biofuels to overall energy supply can have strong impacts on global agricultural markets, food security, and the environment; by stating that liquid biofuels will likely only replace a small share of global energy supplies and cannot alone eliminate dependence on fossil fuels; and by suggesting a move towards more research and development, especially on second-generation technologies.

Web link available at:
http://www.fao.org./sof/sofa/

Risk Governance Guidelines for Bioenergy Policies, by the International Risk Governance Council (IRGC), Geneva, 2008, 67 pages

This policy brief summarizes current bioenergy developments and policies, outlines associated risks and opportunities, and suggests areas for bioenergy policy improvement and benefit maximization in the long term.

While bioenergy development offers opportunities for energy security improvements, rural development, and GHG emissions reductions, it also poses several risks, including negative environmental impacts on biodiversity, water, soil, and air; social issues surrounding food security, land rights, and employment; and economic problems of rising prices, cost-effectiveness, and market and trade distortions. The IRGC believes that understanding and managing these risks requires a greater consideration of important trade-offs than has informed policy-making thus far. These trade-offs include energy vs. food; land used for energy vs. for food, forestry, ecosystem services, and other uses; energy security and supply vs. climate change mitigation; short-term vs. long-term; and competing interests at the local, national, and global levels.

The authors suggest risk governance strategies for the improved management of these trade-offs. During 'risk assessment', policy-makers should evaluate domestic energy needs and demands; assess domestic capacity for energy production; consult with stakeholders; implement case-specific life-cycle analyses of bioenergy production; and select situationally-appropriate technology, energy crops, scale, and agronomic processes. Next, during 'risk management', policy should establish proper land use policies, implement sustainability criteria and certification schemes, set up performance standards and mandates, choose appropriate economic instruments, and negotiate trade agreements. Overall, the authors suggest that bioenergy policies put greater emphasis on objectives and incentives that will encourage long-term opportunities and mitigate long-term risks; allow for market-oriented approaches that reduce distortions in liquid biofuel and agricultural markets; increase environmental sustainability; promote adaptive regulation, production, and behavior for more efficient production and conversion processes; pay attention to the food, employment, and energy concerns of developing countries; promote multi-stakeholder dialogue; focus on specific national and regional contexts, needs, and capacities; and encourage research and development. More specifically, industrialized countries and major developing country bioenergy exporters should develop bioenergy first and foremost for the reduction of GHG emissions over the entire life-cycle, and secondarily to contribute to energy security. Other developing countries and transition economies should develop bioenergy for the provision of more affordable, safe, and efficient heat, electricity, and transport fuel, and in such a way that it promotes wider sustainable development goals and does not jeopardize food security.

These policy strategies should dissuade risk governance deficits often associated with bioenergy production and policy, such as the failure to account for secondary and long-term impacts; overestimation of bioenergy's potential and underestimation of its risks; poor ecosystem and sustainability management; inefficient use of subsidies; construction of bioenergy policies as agricultural policies; and lack of emphasis on energy efficiency improvement and energy demand management.

Web link available at:
http://www.irgc.org/

Biofuels: Is the Cure Worse than the Disease?, by Doornbosch and Steenblik, for the Organisation for Economic Cooperation and Development (OECD), Paris, 2007, 57 pages

This Organisation for Economic Cooperation and Development (OECD) report addresses two fundamental questions: (1) Do the technical means exist to produce biofuels in ways that enable the world to meet demand for transportation energy in more secure and less harmful ways, on a meaningful scale, and without compromising the ability to feed a growing population?; and (2) Do current national and international policies that promote the production of biofuels represent the most cost-effective means of using biomass and the best way forward for the transport sector?

The authors conclude that biofuel production is generally not cost effective, with production costs relatively high per unit of fossil energy displaced or per unit of CO_2 emissions reduced. With the exception of Brazil, liquid biofuels are not competitive with oil prices around $70 per barrel without extensive government support. In most countries, supportive government policies are required to make biofuel production financially attractive. These policies (and the subsequent rush to produce energy crops) tend to be inefficient, cost-ineffective, and with several consequences, including threats to food supply and biodiversity; impacts on agricultural markets; environmental impacts (particularly by grain and oil-seed biofuels on up-stream environments) that can be worse than those caused by corresponding petroleum products; and variable impacts on energy security.

The creation of renewable-fuel targets and the inability of many countries to reach these targets through domestic production should have encouraged trade in biomass feedstock and biofuels. However, current trade barriers and subsidies mean that large-scale trade is hindered and modest when compared to total production levels. These obstacles decrease the potential of biofuels to achieve lower costs and to displace oil, in that liberalised international trade would enhance economic efficiency by directing production to the most efficient locations.

The report recommends five key policy changes. First, domestic policy efforts should be redirected from (subsidy) instruments aimed at the deployment of biofuels in general back to the research and development (R&D) and demonstration phase of advanced biofuel technologies. Government mandates for biofuels should be phased out and replaced by technology-neutral policies such as a carbon tax that will more effectively stimulate regulatory and market incentives for efficient technologies. Second, priority should be given to R&D on second-generation biofuels. This type of spending has the potential to be more cost-effective than supporting production from first-generation facilities. Third, governments should coordinate internationally to develop agreed standards for sustainable biofuels. Fourth, tariffs on imported biomass and biofuels should be removed, particularly for the improvement of economic efficiency and in order to allow countries (particularly developing) to maximise any comparative advantage in biomass production they may have. Fifth, governments should put proportionally more emphasis on the demand side of the transport fuel problem than on the supply side. Overall, given that a much larger supply of clean transportation energy will be needed than biofuels can supply, governments should apply regulatory interventions and fiscal resources in ways that will enable the widest array of technology options to compete.

Web-link available at:
http://www.oecd.org/dataoecd/48/54/39385749.pdf

Sustainable Biofuels Redux, by Robertson et al, Science, volume 322, 2008, pages 49-50

This paper discusses environmental sustainability issues, and subsequent policy implications, associated with both grain-based and cellulosic biofuels development. It notes that grain-based biofuel cropping systems as currently managed can cause environmental harm, including carbon debt associated with land use shifts and various negative impacts stemming from intensified agriculture, emphasizing that further development of these grain-based biofuels looks set to continue in the United States.

The paper highlights that recent government policies, such as the United States' 2008 Farm Bill that provides substantial subsidies for cellulosic ethanol production ($45 per ton of biomass for growers and $1.01 per gallon for refiners), will likely rapidly accelerate the production of cellulosic biofuels, which appear to be more environmentally friendly than grain-based biofuels, due to their high soil carbon sequestration, low nitrous oxide emissions, provision of biodiversity-based services to surrounding ecosystems, and high rates of energy return. However, such benefits will depend on which, where, and how cellulosic biofuels are produced. The authors note that trade-offs are unavoidable. For example, the use of marginal lands for cellulosic feedstock cropping takes pressure off of food supply and minimizes carbon debt, but at the same time potentially threatens biodiversity and requires large energy inputs. Trade-offs must also be made regarding crop choice, intensity of inputs, harvesting strategy, and other management options. Along these lines, the quick adoption of cellulosic biofuels may impede efforts to design and implement sustainable production practices and could bring about uncertain environmental consequences, meaning that cellulosic biofuels risk facing the same sustainability issues as grain-based biofuels.

The authors suggest a more comprehensive and collaborative research agenda than that which has been undertaken to date for the early identification of unintended environmental consequences associated with cellulosic biofuels, as follows. First, a systems approach assessing the energy yield, carbon implications, and full impact of production on downstream and downwind ecosystems should be implemented. Second, ecosystem services (including those that are biodiversity based) should be emphasized when determining appropriate land management practices. Third, policy and management implications should be considered at different spatial scales, from farm and forest to landscapes, watersheds, food-sheds and the globe. Overall, this should aid in creating knowledge- and science- based policies that will support long-term sustainability, avoid costly mistakes, and create a low-carbon economy that is substantially better than business as usual.

Web-link available at:
http://www.sciencemag.org/cgi/reprint/322/5898/49.pdf

Sustainable Biofuels: Prospects and Challenges, by The Royal Society, London, 2008, 82 pages

This paper provides a good overview of liquid biofuels and their individual merits, focusing specifically on biodiesel and bioethanol for use in the transport sector and their impacts and utility during cultivation, processing, distribution, and end-use. It recognizes that each biofuel is different and consequently will generate its own set of environmental, social, and economic impacts and overall aims to assess potential scientific developments that could contribute to greater and more efficient production of biofuels for transport.

First, the article presents the diverse feedstocks potentially available for transport-oriented biofuel development, from starch and sugar to lignocellulose to possible future sources produced via synthetic biology, and their specific land-use and ecosystem implications. Second, various biofuel conversion processes—biological, chemical, and thermal—are presented. It is noted that while commercial interests will ultimately decide which processing methods are used, it is also important to measure conversion processes against several sustainability metrics, such as net life-cycle GHG emissions, carbon efficiency, energy efficiency, and environmental impacts such as eutrophication and acidification, among others. The paper also analyses the defining characteristics of each biofuel at the distribution and end-use stages.

Life cycle assessment (LCA) is put forward as a method of evaluating the impacts of a biofuel throughout its lifetime. LCA can address issues regarding GHG emissions, land use, water consumption, pollution, and biodiversity, at all stages, from production to conversion to end use. There are some limitations to its current usage, however, including a lack of comprehensive social and economic assessment. It would be helpful to address within the larger bracket of social sustainability issues surrounding job creation (quality and permanence); social responsibility; and social equity, for example regarding wealth distribution and the food vs. fuel debate.

The article analyses current research and development (R&D), and incentive policies associated with biofuel development, stating that some of the biofuels being promoted today have environmental, food security, and land use implications that could lead to inefficient and harmful biofuels supply chains. The Royal Society notes that government policy requirements are often ahead of the scientific research needed to achieve the outcomes proposed. This can take necessary focus off of the development of alternative biofuels and new technologies (such as lignocellulosic biofuels) that have a higher potential to achieve policy requirements and to truly deliver GHG emissions reductions and establish sustainable transport systems. The Society subsequently recommends that policy frameworks address the social, economic, and environmental uncertainties associated with biofuel development by investing in further targeted R&D and by basing important policy decisions on solid rather than scant evidence.

Web-link available at:
http://royalsociety.org/document.asp?id=7366