Creating Markets for Green Biofuels:
Measuring and improving environmental performance

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Abbreviations Used

CHP	Combined heat and power
CRP	Conservation Reserve Program
CSP	Conservation Security Program
DG	Distillers grains
DDGS	Dried distillers grains with solubles
EBAMM	ERG Biomass Analysis Meta Model
FSC	Forest Stewardship Council
GGE	Gasoline gallon equivalent
GHG	Greenhouse gas
GMO	Genetically modified organism
GREET	Greenhouse Gas, Regulated Emissions and Energy Use in Transportation (well-to-wheels LCA model)
GWI	Global warming intensity
GWP	Global warming potential
IATP	Institute of Agriculture and Trade Policy
LCA	Lifecycle assessment
LEED	Leadership in Energy and Environmental Design
MJ	Megajoule
MSW	Municipal solid waste
NIST	National Institute of Standards and Technology
NOP	National Organic Program
RIN	Renewable Identification Number
RFS	Renewable Fuel Standard
SRWC	Short-rotation woody crops
USDA	U.S. Department of Agriculture
VOC	Volatile organic compound
WDG	Wet distillers grains

Executive Summary

While "green" and "environmentally friendly" may seem synonymous with "biofuels," this is not necessarily true in practice; all biofuels entail tradeoffs among positive and negative environmental effects. Because the environmental performance of biofuels is not measured today, consumers have no information about how to buy greener biofuels and producers have no incentive to manufacture and market them. The right set of market signals and regulatory requirements can change this situation, so that American consumers could buy biofuels certified as environmentally friendly, and so that the American agriculture and energy industries would have incentives to improve. Markets for green biofuels would stimulate a new wave of innovation, creating high-value and truly green biofuels, and enhancing energy security by diversifying our energy sources. However, without appropriate information, incentives, and rules, the biofuels industry is likely to expand production in environmentally harmful ways.

This study describes how some biofuels are produced, emphasizing agricultural production systems, and considers what is needed in order to measure and communicate environmental performance, and gives examples of how this might be done. We describe a set of seven uses of a Green Biofuels Index, from a wholly market-driven implementation through a set of increasingly intrusive regulatory approaches. We then present several case studies of specific biofuel production pathways using a lifecycle analysis of the inputs to feedstock production and processing, but excluding market-mediated effects.

We recommend four steps to create markets for green biofuels:
1. Measure the global warming intensity of biofuels.
2. Measure the overall environmental performance of biomass feedstock production.
3. Develop and implement a combined Green Biofuels Index.
4. Research better practices, assessment tools, and assurance methods.

A Green Biofuels Index should be developed through a cooperative effort by environmental and energy regulators, agricultural agencies, and stakeholders from these communities, at either the state or national levels. Such an approach could be extended to other fuels as well.

Research is needed to develop better methods for producing biofuels as well as better ways of assessing and verifying the environmental performance of biofuels. Further work is crucially needed to address uncertainties and missing elements in current approaches, especially in agricultural greenhouse gas emissions, the effects of land-use change, greenhouse gas emission and ecosystems impacts associated with biomass thinning in forests, and indirect effects created by changes in markets for biomass feedstocks or food. The National Academies could, along with appropriate scientific bodies and stakeholders, help identify a research agenda to enable and expand markets for green biofuels. Regulators, the National Science Foundation, and other appropriate agencies (federal, state, and private) should support such a research agenda.

"Mom, why are we getting gas from this green pump?"

"Because this is where we get ethanol instead of gasoline."

"Why don't we use gasoline?"

"Gasoline comes from oil in the ground and puts carbon dioxide in the air, which causes global warming. Remember last year, when it hardly snowed all winter and you couldn't use your new sled?"

"What's ethanol?"

"Ethanol is a fuel made from plants like corn that take carbon dioxide out of the air, so when we use ethanol instead of gas we don't hurt the earth's climate."

Mrs. Greensleeves proceeded to fill her flex-fuel car with ethanol distilled from corn in a distant, coal-fired plant, and shipped a long way. The corn came from farms that had recently intensified their production in response to the growing demand for biofuels, switching from alternating corn with soybeans to every-year corn and applying more fertilizer to increase yields. Mrs. Greensleeves would be surprised to learn that the ethanol she pumped that day had essentially the same global warming impact as the gasoline she had so thoughtfully avoided. Her good intentions were thwarted by a broad policy failure that this study addresses.

Because biofuels can be evaluated for their real contribution to environmental goals, government could help Mrs. Greensleeves by requiring environmental performance labels, or even by providing tax credits for environmentally preferable ethanol production. Then Mrs. Greensleeves might see lower prices at the gas stations that used (for example) ethanol made in biomass-powered factories. Even her indifferent neighbor, Mr. Brown, would then have an incentive to fuel his car in an environmentally responsible way. And other states could set their own standards according to local interests, so that (for example) Mrs. Greensleeves' brother-in-law in the next state over would be assured that all of the ethanol available where he lived was good for the environment, because fuel with poor environmental performance had been banned entirely.

Which policy approach is best depends on many political and contextual factors, but both depend on being able to distinguish environmentally friendly biofuels from environmentally inferior types. In this study we show that it is possible to make such distinctions and offer some practical suggestions about how to do so, and thus create markets for green biofuels.

1 Introduction

Markets for biofuels—liquid transportation fuels from biomass that replace petroleum-based fuels—are growing rapidly around the globe, driven by government regulation and subsidies as well as high petroleum prices. Support for these government policies has three sources: a desire to support agriculture, to reduce the use of imported petroleum, and to improve environmental quality (especially global warming due to carbon dioxide, CO_2, emissions from fossil fuels). However, the environmental impacts of biofuel production and use are not measured.

This study focuses on the third rationale for biofuels, environmental improvement. It is motivated by our recognition that treating all biofuels as generally "green," whether on the part of consumers or policymakers, is wrong because of large differences in the environmental benefits not only of different biofuels, but of the same fuel made in different ways. At present, neither government nor consumers have any way of knowing whether using any particular biofuel is good, indifferent, or bad for the environment. When biofuel markets were relatively small this was deemed acceptable, in part to allow the industry to develop. However, as the industry has entered an explosive growth phase, it is well past time to address the environmental performance of biofuels.

To support markets for green biofuels, a *Green Biofuels Index* is needed to provide a framework for measuring and communicating the environmental performance of biofuels. This performance can be communicated in many ways, from consumer information to producer incentives to regulation. We discuss the key concepts involved in creating such an index, show three ways an index could be constructed, examine seven possible implementations, and provide examples of how biofuels might perform on these indices.

Ignoring the differential environmental effects of particular biofuels made in particular ways is unwise, for several reasons. First, the biofuel industry is supplying nearly 5 percent of the total U.S. gasoline market, growing rapidly, and very profitable. Government policies to further subsidize, mandate, and otherwise promote biofuels are being implemented, and more are proposed. Given the large investments in research and capital that continue to flow into the biofuels sector, it is time to provide incentives and requirements for high environmental performance so that the economy is not saddled with the legacy costs of shortsighted investments. Second, biofuels are now being proposed as solutions to environmental problems, especially climate change, and good management of any issue requires high-quality information about achieving appropriate goals. Third, new feedstocks and new processing technologies are now emerging, with many more in the wings, so providing appropriate incentives for the commercialization of the cleaner of these approaches is critical.

Current government policies tend to ignore both the environmental costs and the environmental benefits of biofuels. The present market will not achieve a socially optimal outcome because these effects are neither captured in biofuel prices nor visible to decision makers. This study outlines the major positive and negative environmental consequences of different biofuels' production and explains how we can maximize the benefits of biofuels through the measurement and management of their environmental consequences. We propose a green biofuels index in order to provide a systematic way to communicate the environmental merits of any given biofuel, to (a) enable a market for clean "green biofuels," (b) promote innovation in the biofuels sector, (c) provide consumers with information about the environmental attributes of different fuels, and (d) establish a basis for regulatory action. The index includes quantitative measures of greenhouse gas emissions and petroleum consumption for each fuel pathway, and qualitative measures of the environmental effects of feedstock production.

Maximizing the overall social benefits of biofuels therefore requires a reliable index of environmental performance, or a green biofuels index. Creating such an index would enable a wide array of possible implementations, seven of which are discussed in Section 5.

As an example, we illustrate how a green ethanol index could be constructed for domestically produced ethanol. Other biofuels (such as biodiesel) are important, but we have chosen to focus on ethanol because it is currently, and will be for the near future, the largest existing biofuel in production and use in the United States, the beneficiary of large subsidies and regulatory support (such as fuel content mandates), and the subject of active debate as to its environmental benefits. The themes and methods discussed here for certifying the "greenness" of U.S. ethanol production are largely applicable to other fuels (like biodiesel) and production contexts (such as tropical palm oil production), with some significant additional variables introduced by alternative technologies, unique concerns of other locales, and the exigencies of international trade. An important gap that must be filled by future research is how a green biofuels metric could work in an international context, for both energy and agricultural markets are global. In addition, this study is limited to environmental performance and does not consider important social and economic issues, which should be addressed in future efforts to develop sustainable energy systems.

U.S. agriculture is clearly capable of producing biofuels with high environmental performance, and many existing producers could achieve very high scores under the indices we propose, if they are given incentive to do so. Using a green biofuels index in one of the implementations identified above would allow producers to differentiate their products and command higher prices by using environmentally superior practices. Consumers would know when their consumption of biofuels was improving environmental quality, and government could have a basis for supporting biofuels that improve public value. Thus, a market for green biofuels might begin to develop, one that could eventually replace some of the current agricultural subsidy system and lead to a stronger agricultural economy in the United States.

The environmental benefits of biofuels must be evaluated based on the "lifecycle" of production, use, and disposal.[1] For instance, corn, the primary ethanol *feedstock* in the United States, is often responsible for significant environmental harm, including damage to water quality, soil, and biodiversity. And converting the corn feedstock to liquid fuels can, depending on the technology and energy sources used, consume large amounts of water and result in significant greenhouse gas and other air emissions. Looking at tailpipe emissions alone is not enough.

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[1] The concept of "lifecycle" can also include supply infrastructure and end-use equipment. In this study, we assume that biofuels are liquids that can be blended into, or substitute for, liquid hydrocarbon fuels relatively easily. In this case, the changes to supply infrastructure and end-use technologies necessary for the use of green biofuels will be small (especially relative to biofuels with poor environmental performance); therefore, we ignore them.

For instance, increasing corn production could increase soil erosion and nutrient runoff and even push agriculture into natural habitat land. And when ethanol plants burn coal for power, the resulting biofuel can be essentially equivalent to gasoline in terms of lifecycle greenhouse gas emissions. On the other hand, biofuels production can also have positive impacts on the environment. Converting row crops to perennial crops such as switchgrass, for example, reduces erosion, water consumption and chemical use while significantly increasing soil carbon.

The wide variety of biofuel feedstocks, processing technologies, coproducts, and fuel formulations makes biofuel policy complex. For example, biodiesel can be made from a range of feedstocks, including soybeans, canola oil, palm oil, and restaurant waste oil. Ethanol can be made from food crops such as corn and sugarcane; from numerous "cellulosic" feedstocks including purpose-grown poplar, willow, and switchgrass; or from agricultural residues, timber industry waste, and municipal solid waste—all with different environmental impacts. In addition, biofuel production facilities can use a range of energy sources for heat and power (e.g., natural gas, coal, wood chips, corn stover, and manure), resulting in drastically different greenhouse gas emission profiles.

This study does not focus on net energy or on reductions in petroleum consumption, because neither helps decision makers. Net energy is not a useful metric because it combines different types of energy that have very different uses and values and should therefore not simply be added together (Farrell, Plevin, et al. 2006). Petroleum scarcity is not as much an environmental issue as are the consequences of petroleum use and production, especially the use of low-quality petroleum resources. (Farrell and Brandt 2006). Moreover, while the "energy security" benefits are a driving political force behind biofuel policies, lifecycle assessments (LCAs) consistently show that ethanol and biodiesel production uses very little petroleum, regardless of the production pathway (Sheehan, Camobreco, et al. 1998; Wang 2001; Farrell, Plevin, et al. 2006).[2] Substituting *any* biofuels for liquid fossil fuels reduces petroleum consumption, so there is little value in discriminating among them on this basis.

Of course, ordinary fossil-based fuels are not green either, and biofuels should be compared on an equal basis to the entire range of available transportation fuels to allow for a fair comparison and choice among all fuels. A green biofuels standard could burden biofuels with stricter standards than we apply to conventional fuels, which would be inappropriate. The preferred approach would be to develop a green fuel standard applicable to all fuels, perhaps following the model in California, where a fuel-neutral Low Carbon Fuel Standard is being developed (Schwarzenegger 2007). However, this task is beyond the scope of the current study and must be left for future research.

With these limitations, the recommendations in this study can still be applied to a wide array of biofuels in different places around the world. The most general description of the approach we recommend is to measure important performance characteristics with rigorous methods so that a variety of policy measures can give fuel producers and consumers incentives to improve the performance of these fuels.

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[2] Note that some researchers obscure this fact by using petroleum-based energy units to measure the fossil fuel inputs to biofuel production, even though the vast majority of fossil fuel inputs to biofuel production today are coal and natural gas, not petroleum.

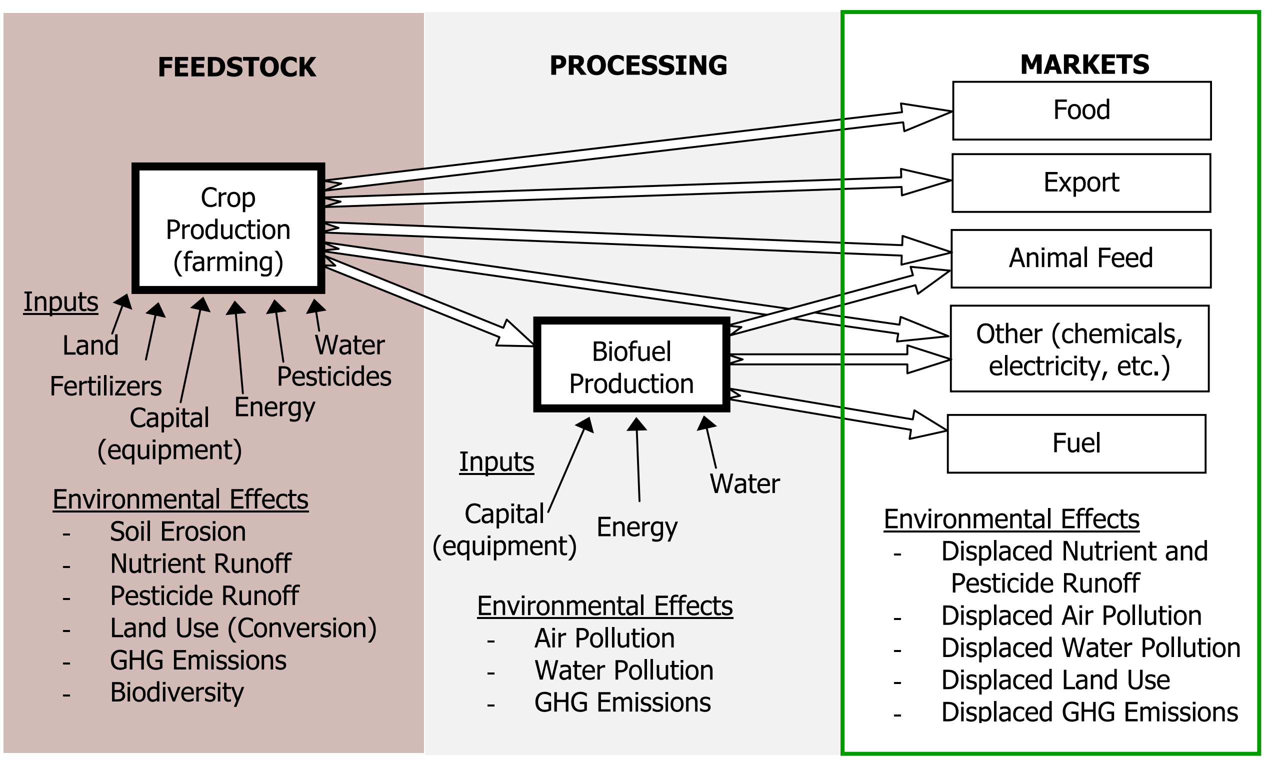
2 How Biofuels Are Produced

Biofuels are produced in two distinct stages, feedstock production (or collection) and processing (sometimes called conversion or biorefining). Figure 1 shows the place of biofuel production in the larger agricultural production system, and shows the major inputs and environmental concerns with each stage. On the left is the feedstock phase, which is illustrated as crop production. In the center is processing, represented as a biorefinery. This study considers these two phases.

On the right are some of the important markets into which biofuels are sold. Note that biofuel production generally yields one or more coproducts, or may be a coproduct of some other, higher-valued product. (A type of animal feed is often the coproduct of corn ethanol, while biodiesel is often thought of as a coproduct of soymeal.) Many of these markets are global.

Figure 1 illustrates the crucial idea that biofuel production affects many different markets, including markets for inputs (e.g., land and water) as well as markets for agricultural products and biofuel coproducts (e.g., food and animal feed). For this reason, many factors can affect the costs of producing biofuels and the prices at which they can be sold. Similarly, many factors can affect the environmental effects of biofuel production.

Figure 1: General Biofuel Pathway with Inputs and Environmental Impacts (simplified)



Note that in addition to causing environmental effects, such as soil erosion and GHG emissions, biofuel production and use also *displaces* some environmental effects because they substitute in fuel and other markets for products that have their own environmental effects. At small quantities, displacement may be a reasonable way to think about these effects, but as biofuels grow in magnitude, it will become more important to identify and quantify how biofuels affect markets by effectively increasing supply and therefore the amount demanded.

These interactions vary greatly by fuel and pathway (as illustrated in Figure 2), so any attempt to illustrate a comprehensive set of biofuel pathways and related markets would quickly become overwhelming. This is especially true because different production pathways will often involve competition and substitution among inputs and coproducts. In most biofuel production today, the animal feed market is among the most important because it is large and because most agricultural biofuel production yields a fraction of low-quality product that is salable only as animal feed.

Just two biofuels are currently in commercial production: ethanol and biodiesel. In the future, additional options may become available, including bio-butanol and biomass-based Fischer-Tropsch diesel. Only current biofuel feedstocks and conversion pathways are discussed in this section.

2.1 Feedstock production

Most biofuel feedstocks are presently produced through conventional agricultural activity. Major commodity crops are raised in large-scale, highly industrialized agricultural operations. The vast majority of biofuel consumed in the United States today is domestically produced corn ethanol.[3] As of 2005, domestic ethanol production was about 40 times larger than domestic biodiesel production, on an energy basis.[4] The primary biodiesel feedstock used in the United States is soybeans, the second-largest crop grown in the United States after corn.[5] (See the Corn Production box, below.)

In the medium-term future, ethanol feedstocks will include lignocellulosic materials such as agricultural and forestry residues, timber industry and municipal waste, manure, and energy crops such trees and grasses. Unlike the production of energy crops, the utilization of residues and wastes requires no additional land use, and thus biofuels produced from these feedstocks do not compete with food or fodder. It is important to recognize, however, that agricultural and some forest residues (for example, slash)—often miscategorized as *waste*—serve agronomic and environmental purposes such as reducing soil erosion, providing wildlife habitat, and improving soil quality. Thus, the quantity safely, or wisely, available is limited.

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[3] Ninety-five percent of U.S. ethanol is made from corn, 70 percent of which is produced in the top four corn-producing states of Iowa, Minnesota, Nebraska, and Illinois. Ethanol is also produced from wheat, sorghum, and brewery or dairy waste, but these sources constitute a small percentage of the market. Similarly, biodiesel is produced largely from soybeans, but it is also being domestically produced in relatively small quantities from canola and sunflower oils and restaurant waste oils and grease. Given their overwhelming dominance as feedstocks, we focus our discussion on corn and soybeans.

[4] 2005 ethanol production was approximately 4 billion gallons, whereas biodiesel production was 75 million gallons. See http://www.biodiesel.org/pdf_files/fuelfactsheets/production_graph_slide.pdf, www.ethanolrfa.org.

[5] Throughout the 1990s, 95 percent of soybean acreage was in rotation with other crops, predominantly corn. See Padgitt, et al., "Production Practices for Major Crops in U.S. Agriculture 1990-1997."

Box: Corn production

Corn is the largest crop in the United States by acreage (U.S. Dept. of Agriculture 2005) and receives the most fertilizer and pesticide per unit area of any major crop (Padgitt, Newton, et al. 2000). These nutrients and chemicals have had detrimental effects on groundwater and surface waters, especially in the Corn Belt and downstream through the Mississippi River to the Gulf of Mexico (Battaglin, Furlong, et al. 2001; Capel, Hamilton, et al. 2004). Most farms in corn production use some form of *conservation* or *reduced* tillage; only about a third use conventional tillage, which has higher erosion rates. Many farmers practice rotation of crops, often growing corn in annual or 2/1 rotation with soybeans. This practice reduces the external nitrogen fertilizer needs of the corn crop and disrupts pest lifecycles, reducing pesticide needs (though the practical difference for farmers' practices may be smaller than advocates had expected).

One reliable study of potential domestic bioenergy production from agriculture and forestry and some of the cellulosic content of municipal solid waste (MSW) found that as much as 1.3 billion tons of cellulosic feedstocks may be technically available annually (Perlack, Wright, et al. 2005). This feedstock could theoretically produce enough biofuel to replace one-third of current gas consumption. While no commercial-scale cellulosic ethanol facilities are currently operating, several demonstration plants are in operation in the United States, Canada, and Europe, and several commercial-scale facilities are now planned.

2.2 Fuel processing

Biofuels production facilities increasingly deserve to be called *biorefineries*. Rather than producing only biofuels, a biorefinery can convert one or more feedstocks into a range of products, including biofuels, electricity, animal feed, and, eventually, other value-added chemicals. Conversion processes differ by feedstock and the slate of coproducts desired. We first discuss ethanol production, and then biodiesel production.

Ethanol

Fuel ethanol is produced much as alcoholic beverages have been for millennia: Yeasts are used to ferment sugars into alcohol, which is separated from water by distillation. Differences in fuel ethanol production processes are largely based on what is required to make sugars available to the yeast.

For "sugar crops" like sugarcane, sweet sorghum, or sugar beets with high native levels of sucrose, all that is needed is to press or soak out the sugar syrup. Crops like corn, wheat, or grain sorghum are made up mainly of starch, which is a chain of many sugars connected together. Producing ethanol from these crops first requires converting the starch to sugars (sucrose and glucose) in a process called *saccharification*. In practice, saccharification is accomplished by grinding the starch-containing grains, adding water to create a slurry, and then adding enzymes that break down the starch to sugars. Finally, in the case of cellulosic ethanol, woody or herbaceous biomass first must be subjected to relatively intense treatment with heat, acid, or additional enzymes to make the complex carbohydrates in cellulose available for saccharification. This step has been the main obstacle to economic cellulosic ethanol. Importantly, the final product of all these pathways is exactly the same: Ethanol is a simple molecule, and there is no way to distinguish finished cellulosic ethanol from corn ethanol.

The result of any of these initial processes is sugar syrup. Yeast is added to ferment the sugar to alcohol, which is distilled several times to increase the alcohol strength to 95.6 percent and finally forced through a molecular sieve to achieve 99.5 percent ethanol. The last step in producing fuel-grade ethanol is the addition of a small amount of a “denaturant” to render the alcohol undrinkable and thus exempt from beverage alcohol regulation. Most fuel ethanol in the United States contains 5 percent gasoline as the denaturant.

Today’s ethanol plants include older and newer facilities, almost all of which use corn kernels as their feedstock. Early ethanol plants were food-processing facilities in which ethanol production was merely one of many processes, rather than the primary focus of plant design and operation. Thus, these older plants use “wet milling,” a process that allows the simultaneous production of several commodities from whole corn, including corn oil, corn gluten, and germ meal. From the corn starch, either high-fructose corn syrup or ethanol can be made.

In contrast, almost all new corn ethanol plants, and now the majority of plants in production, use the “dry grind” process, a simpler and more efficient way to produce ethanol but not the other commercial products of corn. Dry-grind plants ferment the whole crushed corn kernel and separate out its one coproduct, *distillers grains*,[6] from the solids left after fermentation. Most distillers grains (DG) are used as animal feed for dairy cows, beef cattle, swine, and poultry.

Most ethanol facilities process corn grown within 30 to 40 miles. This minimizes transportation costs and is also a reflection of the local, cooperative ownership of many facilities. Approximately one-third of domestic ethanol production capacity is cooperatively owned.

Biodiesel

Biodiesel is typically produced in a two-step process in which oils are first extracted from lipid-bearing biomass feedstocks (in the United States, most often soybeans) and then converted to fuel. Extraction involves crushing the oilseed and using a chemical solvent (often hexane) to extract the oil. The resulting oils are reacted with an alcohol (typically methanol) in the presence of a catalyst to produce methyl esters (biodiesel) and glycerol as a coproduct. Crushing soybeans also yields soymeal, which is a valuable animal feed.

The market for biodiesel in the United States today is quite different from the U.S. ethanol market. Although biodiesel is typically compatible with existing diesel engines without modification, oilseed crops, in the United States at least, have comparatively low yields of fuel per acre (50–100 gallons per acre for soy biodiesel vs. 300–500 gallons per acre for corn ethanol). Further, biodiesel is essentially a coproduct to soymeal. Until and unless these basic facts change, domestic biodiesel is likely to remain expensive and its market small.

Figure 2 illustrates the place of corn ethanol and soy biodiesel among the many markets in which they participate, and shows just how complex the interactions of these two can be. The largest market for both corn and soybeans is domestic animal feed, which accounts for more than half of all U.S. corn and soybean consumption. Exports (for both food and animal feed) are the second-

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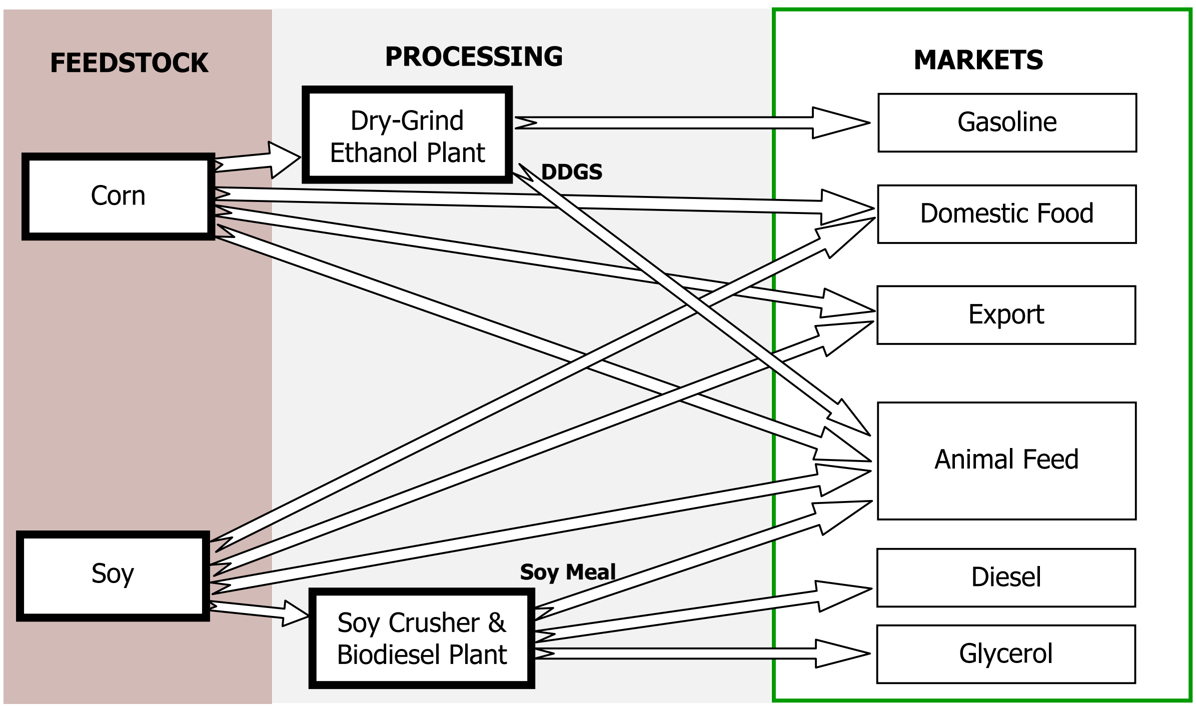
[6] Distillers grains may be mixed with the condensed solutes from fermentation and may be sold wet or dry. The most common formulation is dried distillers grains with solubles, hence the common abbreviation DDGS. Here we use the more generally applicable DG.

biggest market at about 18 percent of consumption. Ethanol consumed about 13 percent of U.S. corn in 2004 and has begun to take market share away from exports. Food and other uses account for about 13 percent of U.S. corn production. Soy biodiesel, as a coproduct of animal feed, is not counted as a separate component of soybean production.

Dry-grind ethanol plants sell into two markets, gasoline and animal feed, while biodiesel production has three product markets, diesel, glycerol, and animal feed. One important feature not show in this figure is how corn and soy compete for land. Most corn is grown in *rotation* with soy, with one soy crop between one to three corn crops, largely because soy is a legume whose roots host bacterial colonies that add nitrogen to the soil beyond what the plant requires. Therefore, while corn production can be increased by going to all-corn rotations, this lowers per-crop yield, requires more chemical fertilizer, and causes additional soil erosion than corn-soy rotations.

Figure 2: Key U.S. Energy Crop Production Pathways (simplified)



2.3 Environmental consequences

The two stages of biofuel production, feedstock and processing, pose fundamentally different challenges in measuring environmental performance. Feedstock production is highly diverse, is linked to many other processes, and has some effects that are not only highly variable because of weather and local conditions, but also very difficult to measure. Therefore, a green biofuels metric will have to rely on a combination of measured, modeling-based, and practice-based methods for evaluating environmental performance for feedstock production. In contrast, processing has much more limited and measurable environmental effects. Each is discussed in turn.

2.3.1 Feedstock

A key analytic requirement for an environmental index is that any environmental harm caused by raising a feedstock crop be attributed to the fuel and its coproducts. Thus, addressing the environmental effects of agricultural production is a necessary component of an environmental index for biofuels. Feedstock production entails the same variety of environmental risks or damage—which depend as much on farming practice as on the crop in question—as those that result from any type of agriculture.

Most of the environmental impacts from feedstock production occur on the farm, in growing and harvesting crops or in removing crop residues. Greenhouse gases are released by burning fossil fuels in most farm operations, and microbial activity in the soil releases significant quantities of nitrous oxide (N_2O), a powerful greenhouse gas, primarily as a result of fertilizer application. Soil quality suffers as tillage and cultivation expose soil to wind and water erosion, hastening soil loss from land and siltation in rivers. The use of heavy machinery compacts the soil, reducing water and oxygen availability, resulting in declining soil quality. Water used in irrigation may be an environmental concern if it is pumped from overdrawn aquifers or transported from distant basins. The infiltration or runoff of excess nutrients results in groundwater contamination as well as algal blooms and oxygen-starved water in aquatic ecosystems downstream. The use of pesticides causes pollution of surface water and groundwater and unintended harm to humans and wildlife. Removing crop residues increases soil erosion, reduces soil organic content, removes nutrients, lowers yield, and consumes fossil fuels (Wilhelm, Johnson, et al. 2004). For more detail, see Appendix A: Measuring Multiple Dimensions of Environmental Performance.

The use of crops for biomass feedstock can affect markets for global commodities like corn, because the crops use land that would otherwise have other uses; the production of biofuel feedstocks displaces these other uses. This displacement induces economic effects, which in turn can induce changes in land use elsewhere. These effects are not well characterized today and are excluded from current analytical methods, suggesting an important area for further research (Delucchi 2004).

For instance, increased demand for corn by ethanol plants in the United States appears to have reduced U.S. corn exports and raised the price of corn on global markets. Such a price increase will both reduce demand (with possible consumer welfare impacts) and create incentives for more land in the exporting nation (the United States) and importing nations to be put into corn production (extensification). Thus, the use of U.S.-grown corn for ethanol production can induce the conversion of previously uncultivated lands elsewhere, a phenomenon called “leakage.” (The effects of an action, growing corn for ethanol production, has leaked, in this case from where it might be controlled by a green biofuels program to where it will not be.) A green biofuels system must recognize this potential for leakage of environmental impacts to systems outside the strict biofuel system boundary, however how to do so is not clear and should be the subject of further research.

2.3.2 Processing

The environmental consequences of biorefining are few, and they are easily quantified and managed. They include energy use, which results in emissions of volatile organics, toxics, and greenhouse gases; and water use in processing and in boiler system cooling. The specific impacts vary with feedstock and energy source.

Biofuel production typically requires both thermal and electrical energy. Ethanol producers today use a variety of fuel sources (e.g., coal, natural gas, biomass) and energy conversion technologies (combustion, gasification, cogeneration) resulting in a range of environmental outcomes.

Typical dry-grind corn ethanol facilities burn natural gas for heat and buy electricity from the grid. However, in response to higher natural gas prices, several U.S. dry-grind plants are exploring or deploying innovative alternatives to natural gas. Some plants are being developed or redesigned to use coal, and others are gasifying or combusting wood waste, distillers grains, and corn stover or using advanced cogeneration units (Nilles 2006). Others are locating near cattle feedlots to sell wet distillers grains, halving a typical plant's natural gas consumption by not drying the coproduced distillers grains. The challenge for policy makers is to ensure that incentive structures encourage the more socially beneficial configurations and energy sources, and that they discourage much less beneficial options such as switching to coal. The GHG profiles of several biorefineries are detailed in Section 6.

The environmental impacts of the dominant corn ethanol dry-grind process include water consumption, air emissions from fuel consumption and drying distillers grains, and carbon dioxide from both fermentation and fuel consumption.

Water consumption is a particular concern in the Midwest where competition for water supplies is increasing (Keeney and Muller 2006). According to a report by the Institute of Agriculture and Trade Policy (IATP), only one state, Minnesota, tracks water consumption by ethanol plants. The average water consumption rate in Minnesota declined from 5.8 gallons of water per gallon of ethanol in 1998 to 4.2 gallons in 2005, with most plants using 3.5 to 6.0 gallons (Keeney and Muller 2006). New plants reportedly use 3 gallons of water per gallon of ethanol. IATP estimates the average in 2006 was 4.0 gallons.

Because the production of biodiesel is much simpler than the production of ethanol, the environmental implications are fewer. They include water consumption and greenhouse gas emissions from fossil fuel combustion, and hexane volatilization.

3 Measuring and Communicating Environmental Performance

To improve the environmental performance of biofuels, so that they really can be called "green," requires appropriately measuring environmental performance and communicating the results with information and incentives. However, the best way to do so varies with the type of environmental impact under consideration and the purpose of the communication. Describing the environmental consequences of the two biofuel production stages—feedstock production and processing—may require different tactics. The distinct nature of each phase, the goals of the regulatory program, and the state of the art for various tools will determine the best approach.

For reasons outlined below, directly measuring the environmental performance of agriculture will likely remain infeasible. Agro-environmental models may eventually allow accurate estimation of the environmental performance of individual producers, but in the short term, feedstocks can be characterized only by using approximate or categorical performance measures, even for environmental effects that are in principle quantitative (e.g., GHG emissions). In contrast, the specific environmental consequences of processing can typically be measured quantitatively at a reasonable cost.

A number of existing certification systems may be relevant, including the USDA Organic, Forest Stewardship Council, U.S. Green Building Council's LEED® sustainability standard, Green Gold, and the United Kingdom Renewable Transportation Fuel Obligation. These programs are discussed in Appendix B.

There are three general approaches to measuring environmental performance: direct observation, which is quantitative; modeling, which is also quantitative; and indirect, qualitative categorization. The following section describes the use of these in relation to the stages and impacts of feedstock production.

It is important first to identify the distinction between average and marginal cases. Unlike aggregate lifecycle analysis, which is used to assess the lifecycle impacts of an *average* unit of a good, a green biofuels index would be used to measure and communicate the specific, *individual* impact of each unit of biofuel (or at least the average impacts of an individual batch of fuel). The discussion that follows should be understood as a brief examination of an environmental index that could be constructed for a unit of a particular fuel (for example, "ethanol produced between June 1 and June 7 in the Smith Refinery").

3.1 Feedstock

Agriculture is a complex, semi-natural system, but prevailing approaches to agriculture are widely criticized on environmental grounds. Changes to prevailing practices can have an extensive mix of intended and unintended effects, both directly on the farm and on upstream and downstream processes (Kulshreshtha, Junkins, et al. 2000). For example, reducing nitrogen application may reduce both the nutrient runoff and N_2O emissions from soil, but it also decreases yield, which can cause more land to be converted from a natural state into production elsewhere. One way to reduce nitrogen runoff is to use "precision" fertilization methods, but these can entail more frequent passes through the field with tractors and equipment, and so greater diesel fuel consumption on the farm. Similarly, reducing the use of herbicides often requires increased mechanical or flame-based weed control, which can increase soil disturbance and erosion, fossil fuel use, and GHG emissions.

Measuring, or even estimating, the exact environmental impacts from specific agricultural production systems is particularly vexing. Agriculture is a classic "nonpoint source" of emissions that occur over an entire landscape, without a convenient smokestack or drainpipe at which to measure them. While researchers have created experimental systems to measure emissions on small plots, there is no practical way to directly measure soil erosion, nutrient runoff, or pesticide drift on actual fields, especially the millions of acres of U.S. agriculture.

Not only are impacts difficult to measure directly, but their complexity and site-specificity means that estimating or modeling emissions is difficult. For instance, agricultural soils emit N_2O, a powerful greenhouse gas, roughly in proportion to the rate of nitrogen fertilizer application or atmospheric nitrogen fixation. Actual emissions, however, depend on several site-specific factors including agronomic practices, temperature, and moisture. Moreover, the emissions are highly variable, both spatially and temporally. Thus, N_2O emissions can vary widely across a single field, even over distances as short as several inches, and emission rates can vary by orders of magnitude over the course of a year (Skiba and Smith 2000; Gibbons, Ramsden, et al. 2006). Finally, nitrogen leached from an agricultural field may later result in N_2O emissions from the aquatic systems to which it flows.

For these reasons, determining the environmental impacts of a unit of fuel from its agriculture phase requires either accurate modeling or practice-based indices.

Biofuel policy would be tremendously strengthened by the use of accurate, robust, and manageable agro-environmental models for estimating the actual environmental performance of biofuel feedstock production for use in regulation. Agro-ecosystem models offer an alternative to measurement in quantifying the environmental performance of agriculture. These models use site-specific data on soil, climate, and practices to predict associated impacts, including erosion, soil organic content, nutrient and chemical runoff, and greenhouse gas emissions. Ideally, agro-ecological models would require a relatively manageable set of input data yet allow for the characterization of environmental impacts from a specific set of fields, crops, and practices. In short, modeling would allow the quantitative measurement of agro-environmental performance.

An ideal agro-environmental model for biofuels assessment would allow farm managers to customize the baseline conditions of their farm, using historical climatic frequency distributions and soil type distribution and average slopes for a finite number of field units. On this foundation would be modeled the specific crop in each year, with the field operations performed and inputs added. Finally, a small set of tests–such as crop tissue nutrient tests–might be performed to gather additional data. The resulting calculations would yield quantification of nutrient runoff and leaching, pesticide runoff, soil erosion, and GHG emissions. Because this model could be installed on the farmer's home computer, she could use it to estimate the effect of changes in practices on performance indicators of interest, and so calculate the tradeoffs of changes in practices versus changes in performance—and then compare the respective costs and benefits of each.

In this way, accurate models that allow for the quantification of agricultural performance would not only create more powerful and useful regulation, but would strengthen the feedback and learning process for farmers. Models that allow farmers to predict the relationship between practice and performance would lead to better choices among current practices, and would support cost-efficient innovation as farmers devise new solutions and methods. Also, as modeling can be used in performance standards, it allows a greater diversity of performance regulations to be used. Performance-based standards are likely to result in more cost-effective improvements in environmental outcomes than are practice-based standards.

However, the state of the art in agro-environmental modeling is inadequate for the purposes discussed here. For one thing, some researchers have questioned the accuracy of existing models in predicting specific emissions from specific fields (Cassman 2006; Baker, Ochsner, et al. 2007). Moreover, models of multiple environmental impacts are not well integrated. Finally, the administrative burden to farmers or regulators of implementing many current modeling approaches could be high. Improving, integrating, and streamlining these modeling approaches should be a particular priority of future biofuel research.

For the reasons outlined above, it does not appear possible at this stage to measure the environmental outcomes of specific agricultural practices by specific producers. Therefore, less specific methods must be used.

Instead of specific emissions or accurate emissions models, what can be observed are the relative performances of different categories of crop, farm conditions, and farmer practices. To the extent that certain sets of crops, conditions, and practices consistently result in superior results, they can be identified as “best practices.” These best practices, tailored for each farm, can be reliably predicted to reduce negative environmental impacts. For instance, between annual and perennial crops, all else being equal, the perennial crop will exhibit lower erosion, nutrient runoff, and greenhouse gas emissions. Between corn grown in non-irrigated Minnesota and irrigated Nebraska, Nebraska corn will have higher water use and greenhouse gas emissions. And between corn grown with conventional tillage and corn grown with conservation tillage, all else being equal, conservation tillage will result in lower emissions. Some of these characteristics, specifically crop and region, are distinct and robust enough to be used directly in a qualitative assessment. The majority of best practices, however, must be determined as a set, in the context of the whole farm.

The use of this comprehensive best-practices approach consists of three steps:

- a resource assessment, detailing the unique characteristics of the farm and surrounding environment including soil type, climate, water availability and quality, terrestrial and aquatic habitat, and vulnerability to the impacts of farming, including soil erosion, chemical runoff and drift, and greenhouse gas emissions;
- resource management plans that propose mitigation measures to reduce each potential negative impact below a specified threshold. Indicators may be used to identify this threshold; and
- assurance, review, and adaptation programs ensuring that the management plans are carried out, that their effectiveness is periodically assessed, and that adaptive management occurs to revise and refine plans where necessary.

The primary goals for best practices should be to reduce water depletion (i.e., usage in excess of recharge rates), soil erosion, agrichemical runoff and drift, and GHG emissions. In addition, feedstock producers should avoid environmentally harmful land-use change involving habitat destruction, deforestation, or the conversion of grasslands to row crops. They should also eliminate the use of the most toxic pesticides.

A good model of such a resource management best-practices program is found in the USDA's Conservation Security Program (CSP), enacted as part of the 2002 Farm Bill. Under this voluntary program, farmers develop and implement resource management plans specific to their farmland in return for five to ten years of clearly defined per-acre annual payments (McKnight Foundation 2005). Of course, other examples exist as well.

Adaptive management of best-practices approaches to feedstock production must take a whole-system view. That is, practices at the farm level should be reviewed and modified to support the best outcomes possible in light of the farm's unique circumstances, but also the palette of practices and evaluation methods should be continually monitored, reviewed, and updated to reflect evolution of the applicable science, advances in technology, changing environmental priorities, and shifts in the relative costs of inputs. All this must be accomplished in an environment of rapid growth and technological innovation in biofuels, where new feedstocks may lead to new types of impacts before producers, regulators, or researchers have even learned to recognize them.

Biomass from forestry systems have important similarities to and differences from agricultural energy crops and biomass residues. Accordingly, some existing systems are able to encompass the environmental performance of forestry biomass, while other forestry biomass sources do not have well-developed criteria (Rotherham 1999).

"Short-rotation woody crops" (SRWC), meaning plantings of willow, poplar, or other crops that are grown in a coppice system for five to ten years with annual harvests of wood chips, are appropriately captured in the same agriculture-oriented best-practices systems described above. Biomass systems involving longer-life and larger timber species, such as eucalyptus plantations, can be addressed under standards for plantation forests, such as the Forest Stewardship Council plantation certification (Forest Stewardship Council 2006). And forestry residues from FSC-certified forests can carry the certification level of the forest, as biomass residue harvest would necessarily be regulated under the forest certification.

However, the environmentally responsible use of biomass residues from conventional forests is not well defined at present (Richardson 2005). Forest thinning operations for forest health or fire fuel reduction, commercial thinning operations, commercial logging operations, and the processing of forest products all generate residues—but none of these sources have satisfactory environmental performance or certification systems. This is an outstanding research need.

3.2 Processing

Biorefining, in contrast to agriculture, is a relatively simple, linear process in a controlled environment, with easily measured environmental outcomes and established process alternatives.

The primary environmental impacts, as discussed above, are air emissions of greenhouse gases, volatile organic compounds (VOCs), and toxins due to fuel combustion and drying of distillers grains; water consumption; and emissions to surface waters.

These environmental impacts can be usefully observed and linked to market units of fuel by direct observation or calculation, rather than by scoring or ranking practices as we think necessary for agriculture. Emissions of criteria pollutants are already managed or measured with standard control technologies. Greenhouse gas emissions are easily determined by the use of fuels, e.g., coal, natural gas, biomass, or biogas. Water use and emissions can be measured by plants.

3.3 Performance- vs. practice-based standards

The distinction between a *performance-based* index and a *practice-based* index is critical, in part because this determines how goals are measured, how many goals can be encompassed, and the breadth of the index's possible applications. Briefly, a performance-based index is built on information about the actual consequences of manufacture and use of a product, while a practice-based index assures that certain methods were employed in production.

A performance-based index is preferable in tax/subsidy and regulatory applications because no one technology is necessarily privileged. Instead, the desired end results are specified, and producers retain maximum flexibility in the means by which they meet performance goals. This is always important for maximizing cost-effectiveness, but in the rapidly developing biofuels industry, it is especially desirable not to place any unnecessary restrictions on technological development. Finally, performance indices are also likely to be necessary for complying with the non-discriminatory standards of international trade agreements.

However, performance-based indices can be created only for quantifiable policy goals, such as greenhouse gas emissions or water consumption. "Performance" assumes that the characteristic of each fuel production pathway with regard to a policy goal is both observable and quantifiable. The measurability requirement limits the strength of performance indices in regulating impacts with high uncertainty, though uncertainty can be accommodated as long as the size of potential error is small relative to the magnitude of the effect.

Practice-based standards can address a broad range of policy goals, including environmental impacts that are unobservable, unquantifiable, or highly uncertain. Practice-based standards offer a way to improve environmental performance, even if the exact performance isn't known. In other words, the performance of practices can be ordered, even if the magnitude of the differences cannot.

Performance standards are preferable, when conditions permit, for two reasons. First, performance is what we care about, while practices are not as closely linked to actual outcomes. Furthermore, public policy (e.g., a regulation, label, or graduated subsidy) based on a performance index invites innovation in the ways in which performance goals are reached. The performance standard for a fire extinguisher, for example, specifies that to receive a 1A rating, it must extinguish a flaming, fully involved "log cabin" of wood pieces of specified dimensions and moisture content in a certain time.[7] In contrast, a practice standard would refer to production or manufacturing processes for the fire extinguisher: It might specify how much of what chemical, under what charge pressure, the device must contain. However, practice standards suppress technical innovation; if a better fire extinguisher chemical were discovered, it could not be rated under a practice standard until the rating body established and promulgated an entirely new standard.

Accordingly, we recommend performance standards where we can, in biorefinery application, and practice-based standards for evaluating agricultural production of biofuels.

3.4 Quantitative GHG measurement

As discussed in Section 3.1, calculating the specific, quantitative environmental impacts from specific agricultural fields is not currently feasible in most cases. This is particularly true of greenhouse gas emissions from agriculture. In fact, to date, few best practices have been identified which reliably reduce greenhouse gases across different farming practices. In particular, the uncertainty range for N_2O emissions from soil and from N emitted into waterways is likely larger than the emissions differences between agricultural practices (Farrell, Brandt, et al. 2005), and the change in soil organic carbon under various tillage regimes is a matter of active debate (Cassman 2006).

In the face of such uncertainty, the characterization of greenhouse gases must retreat to the level where categorization is robust. Therefore, to calculate the GHG emissions from biofuels production, we recommend estimating the *average* emissions per feedstock type (e.g., corn, switchgrass, corn stover) with adjustments for large-scale regional differences that affect energy use, such as whether the crops in the region are predominantly rain-fed or irrigated. These regional feedstock emissions would be added to the specific biorefinery emissions to calculate the GHG emissions for the resulting fuel.

In contrast, the measurement of GHG emissions from biorefineries is relatively straightforward: Biorefining is a linear engineered process with clearly defined relationships between inputs and emissions. Reliable estimates of the GHG emissions from this process can be made from a few easily measured parameters (generally measured per gallon of fuel produced): thermal energy, thermal energy source (i.e. coal, natural gas, corn stover, etc.), electricity, biofuel yield, and coproduct yield.

3.5 Leakage

A comprehensive biofuels rating system should have some mechanism for accounting for the possible environmental effects that arise indirectly from feedstock production. As discussed in Section 2.3.1, the displacement of current land uses by biofuel feedstock production can lead to more, or more intense, land use elsewhere, potentially driving a leakage of environmental impacts from the green biofuels production chain to other, unregulated, systems.

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[7] ANSI 711.

These leakage effects of biofuels production are difficult to capture, even in the aggregate, as they require economic-agricultural-land use modeling that can isolate the effects of biofuels production from other economic variables. It is then even more difficult to allocate these aggregate effects to individual biofuel producers, as would be required under a green biofuels standard. Because the effect is aggregate, there is no direct linkage from individual producers. Thus, the fairest option would appear to be the assignment of “average” leakage effects from each feedstock type. For instance, if the specific effect of increased corn ethanol production on corn prices, and the effect of increased corn prices on land conversion, could be determined, than an average effect of each corn ethanol producer on land conversion could, theoretically, be assigned to each producer. Such factors are not currently available but should be a focus of research and development in a green biofuels system.

3.6 Practical implementation

The measurement and communication of the environmental quality of different biofuels should be practical to implement. The strength of incentives transmitted to producers and consumers is dependent on the structure of measurement, verification, and enforcement processes. Thus, the burden placed on feedstock producers and processors and biofuel producers and distributors, relative to the potential gain, is a critical consideration.

The cost of measuring and verifying environmental performance will increase the cost of production, and uncertainties about the potential for higher prices for green biofuels can create fundamental impediments to participation by farmers, processors, and biofuel producers that would undermine the entire market, leading to potentially unacceptable market volatility and extreme peak prices. Thus, it is crucial to any measurement and verification process not only that cost and regulatory burden be reasonable, but also that the process be, and be seen as, feasible.

The burden of demonstrating environmental performance falls on different actors at different points in the supply chain. Biofuel producers must source feedstock and must plan, attain, and demonstrate the environmental performance of their facilities; suppliers, brokers, aggregators, and distributors must track and document appropriate data along the entire supply chain.

For farmers, the link between their actions and the price premiums they stand to gain should be clear and direct. Producers should be able to estimate in advance the likely effect of practice changes on environmental performance, and the relation between a change in performance to change in value of the final product. In this regard, as from a regulatory perspective, accurate predictive agro-environmental modeling represents the gold standard: If farmers can reliably predict how their choices will affect productivity and environmental performance at the start of each season, they can understand how to maximize their incomes. Thus, the creativity of producers is engaged to find the best approach for their individual farm, potentially surpassing the consensus best practices determined by scientists and extension agents. Creating such modeling systems should be a priority of biofuel researchers.

However, as in the regulatory setting, such accurate, integrated modeling remains out of reach for the near future. In its absence, practice-based policies assure the farmer of receiving clearly defined benefits for specific actions. If the adoption of a specific suite of practices is explicitly tied to specific product quality levels, and if these levels correspond to clear market prices, the producer can directly compare benefits to costs. For example, if a farmer can be reasonably assured that the adoption of practice suite A (with an added production cost of X) will lead to a “four-star” rating (discussed later) for her crop, and if she can observe that “four-star” crops fetch a price premium of Y relative to her current crops, then she can compare X and Y and readily see whether the premium (Y) is likely to be greater than the additional cost (X). Without this certainty, the producer faces risk that reduces the value of any premium, decreasing supply and increasing the cost of sustainable feedstock.

Practice-based standards require a process called “assurance,” which includes *enrollment*, *verification*, and *enforcement*. It entails the development of a management plan, and regular verification of plan compliance (with enforcement of established sanctions for noncompliance) by a trustworthy third party. The process should also entail a research and adaptive management component to improve performance over time and improve the correspondence between practice and performance.

Enrollment, verification, and enforcement are established principles under many existing certification frameworks. For instance, the National Organic Program (NOP) requires consistent methodology among the 92 independent bodies accredited to certify organic producers. Steps to ensure this include the creation of an Organic Systems Plan, ongoing documentation of certified practices, and annual site inspections to verify compliance. However, the NOP does not include either a pre- or post-planning performance evaluation of the effect of practices on the environment or health. In contrast, the Conservation Security Program (CSP) does endeavor to determine and refine the effect of practices on the environment through site-specific evaluations and conservation stewardship planning, but it does not include provisions for independent verification of practices (unless a specific complaint is filed against a producer).

The NOP is more transparent and accessible to producers—mandatory or prohibited practices are clear and invariant, but verification is more intrusive. The CSP is less predictable—it is not necessarily clear which practices will qualify for eligibility, and they may evolve over time—but verification that these practices occur is minimally intrusive.

Documenting the environmental performance of biofuel processing facilities would necessitate auditing and documentation of plant operations. Because the number of inputs and processes is small, the burden of recording these, especially over annual operations, is likely also to be small. Issues of industrial disclosure can be assuaged through the development of a licensed third-party certification industry. Such an industry also serves important technical support and educational functions, helping regulated entities to develop the capacity to cheaply meet certification requirements.

The cost and feasibility of tracking and chain-of-custody documentation is also an important consideration to farmers, consolidators (grain elevators, brokers, etc.), and biofuel producers. These issues are discussed in Section 3.9, below.

The liquidity of markets; the availability of loans, contracts, futures, and options; and the sophistication of aggregators, processors, and distributors are also key to reducing the burden of measurement and tracking placed on producers. These institutions reduce risk across many dimensions and are especially critical in the early stages of a program. A certification program must be designed with consideration given to the ability of new and existing institutions to adapt to the needs of the system.

The complexity of the foregoing is important, but a variety of existing schemes for certification of many things, from the safety of foods and medicines to the accuracy of measuring devices (including the pump that dispenses ethanol to drivers) to the authenticity of organic food, shows that obstacles can be overcome at reasonable cost.

3.7 Dimensionality

Choices by decision makers—whether by a consumer buying fuel, a distributor supplying retailers, or a policy maker designing regulations—to purchase or support one product over another is intrinsically a one-dimensional process. While the decision maker may consider a variety of relevant qualities, including the product's price, its quality, its ability to meet his needs, its popularity, and perhaps even its social value such as environmental performance, the final decision is made because one product is "better" than another. The abstract quality of "betterness" is necessarily a reduction of all the relevant qualities into one dimension when the choice is made.

In effect the decision maker, at any moment, must consider a set of performance measures that represent the contribution of each relevant dimension of choice to the scalar ordering. Moreover, each consumer generally has her own personal tradeoff function among different product qualities.

A subset of these relative *prices* pertains to collapsing various environmental performance dimensions into the one-dimensional measure of environmental quality she may wish to use in the larger aggregation of qualities in her overall product preference. For example, she may think four pounds of greenhouse gas emissions are as bad as one pound of pesticide runoff into the Mississippi River. If all consumers had the same set of performance measures, and if these were known, products could be scored on environmental performance accurately and unambiguously into a single number appropriate for all users. However, neither of these conditions is true; consumer preferences vary and are known only approximately.

There is an inherent tradeoff between reporting a multidimensional list of individual environmental performance measures versus aggregating them into a one-dimensional score. The former may incur high costs for consumers to assess the multiple dimensions and calculate their own tradeoffs, and it risks high costs to society if consumers are discouraged from making any rational calculation by the cost of processing an overabundance of information. However, relying on a predetermined aggregation system in order to report a single summary statistic loses the efficiency and democracy of letting consumers exercise their sovereignty. A measure of limited dimensions ensures that almost everyone will make more or less incorrect *personal* choices, but it saves us all time for other things we value. Providing more information doesn't in any case guarantee more correct choices.

3.8 Compensatory vs. mandatory minimums

Aggregating multiple dimensions involves tradeoffs among impacts: Better performance in one dimension can compensate for worse performance in another. This could occur in performance-based standards or where multiple practices are structured as "tiers" of performance. An alternative to this is an aggregated metric with a minimum performance requirement in each dimension.

As an example, the LEED® sustainability standard designates multiple compliant practice options in each of several sustainability dimensions. These practices are designated with increasing levels of "points" according to their relative sustainability. These points are then aggregated to calculate the overall sustainability level of the project (Silver, Gold, or Platinum), so more points in one dimension may, to an extent, compensate for fewer points in another. This effect is limited, however, by mandatory minimum performance in each dimension for each level.

A sharp distinction separates a so-called *lexicographic* ordering from a weighted one. In a lexicographic ordering, such as is used in a dictionary, *axe* appears before *bad* even though on average the position of the letters in the second word is earlier in the alphabet than that of the former; nothing can compensate for the fact that *a* precedes *b.* There is no "averaging" of the position of the other letters.

An example for biofuels could start by assuming that the highest ranking requires that crops be grown under a Tier III CSP contract, that fuel processing have very low impacts, *and* that GHG emissions be very low. In a non-compensatory index, no biofuels made with crops grown under a Tier II CSP contract could ever qualify for this highest rating, even if processing had no environmental impact at all and net GHGs were negative. This example illustrates that non-compensatory indices avoid the task of comparing incommensurate criteria, but they are rigid and may lead to unnecessarily strict or even deceptive results.

3.9 Tracking, trading, and banking

Tracking—by which we mean maintaining an association between feedstocks and fuels and their environmental scores across the stages of production—has two distinct purposes. The first is to assure the correctness of any aggregate claim made about a batch of fuel mixed together from different sources. The second is to assure the communication of incentives from downstream consumers (or regulated retailers) to upstream producers. The feasibility, reliability, and expense of tracking this behavior in the variety of situations in which it may be required are important policy considerations.

The burden of tracking is largely related to the degree of physical control necessary and the strength of incentives to cheat. For instance, Identity Preserved (IP) systems developed for non-GMO crops have proven the feasibility of systems that control specific physical quanta of agricultural products from producers to consumers. While some researchers have asserted that the small premium earned by non-GMO crops demonstrates that IP systems impose small costs (Bullock and Desquilbet 2002), others use a bottom-up approach to assert that the expense of separate storage and processing facilities, in addition to recordkeeping protocol, imposes high direct costs and, moreover, significant indirect market barriers (Kalaitzandonakes, Maltsbarger, et al. 2001).

A more flexible system averages the performance across a producer's products in a given period. For instance, the Forest Stewardship Council's *chain-of-custody* system includes a "Mixed" designation, under which producers of wood products may certify their product as partially certified according to the proportion of certified wood input that is used (Forest Stewardship Council 2006). Under this system, physical tracking is transformed to a statistical statement of each producer's average performance.

Finally, tracking of feedstocks' and fuels' environmental performance may be wholly abstracted from physical quanta using a credit system. For instance, feedstock producers could generate, along with each batch of feedstock, environmental credits that could be sold and traded separately from the feedstock. Biofuel producers similarly would purchase these credits to create a certain rated biofuel, and the biofuel rating credits would be generated along with batches of biofuel. These biofuel rating credits would be purchased by fuel blenders and retailers along with batches of biofuels to support the quantity of each level of biofuel sold.

Trading, a potentially important element of a green biofuels policy, introduces important flexibility into the market. Trading improves economic efficiency by allowing firms with poor-performing assets (such as older, inefficient processing facilities) to compete in the biofuel market by purchasing credits from very green facilities, rather than face closure or very high retrofitting costs. The green facilities, of course, would see an additional revenue stream and might have sufficient incentive to improve their performance even more. Over time, this arrangement, especially in the face of tightening GHG emissions restrictions, would tend to encourage innovation and investment in green technologies and practices without inefficiently wasting existing investments. Private firms could also enter into long-term contracts for especially green biofuels into the future. Such contracts could be used by the buyer to hedge risks and by the seller to obtain construction financing, creating additional green biofuel production. In this way, trading also encourages economically efficient investments over time (called *dynamic efficiency*).

Banking is the practice of holding biofuel credits, whether traded or restricted to a single firm, from one compliance period to the next. Banking smooths the demand for green biofuels and capital investments (like the combination of trading and long-term contracts described above). In addition, banking serves as a hedge against changes in market or weather conditions, and it creates an incentive for voluntary reductions ahead of the compliance schedule. That is, banking allows firms to overcomply, especially in the early years, and then to hold allowances as a hedge against greater fuel demand or poor weather in the future. This encourages innovation and investment in the near term.

A combination of trading and banking, plus the potential for long-term contracts, provides a flexible yet robust compliance strategy without the need to "borrow" allowances from the future. Existing emission control programs that have used trading and banking have been very successful, achieving extremely high compliance rates and low costs without the need for borrowing (Farrell and Lave 2004).[8]

The tracking system proposed under the federal Renewable Fuel Standard (RFS) presents a prototype foundation for a biofuels environmental credit system (U.S. Environmental Protection Agency 2006). Under the RFS proposal, each batch of biofuels would be assigned a series of unique Renewable Identification Numbers (RIN) corresponding to each gallon of fuel. These RINs would be separable from the fuel itself and would be bought, sold, traded, saved, and borrowed by and among fuel producers, brokers, and blenders. The purpose of the RIN is to allow regulated entities—fuel wholesalers—to demonstrate compliance by surrendering to the government the number of RINs corresponding to their assigned renewable-fuel production obligation. The RFS system even foreshadows environmental tracking in its provision for the differential generation of additional RIN for cellulosic ethanol.

This system allows for demonstration of aggregate compliance without the need for detailed tracking of the fate of every fuel. Instead, environmental performance is monitored only at the point of production, and compliance is enforced in the wholesale market. An environmental performance tracking system could be similarly structured, with credits generated for feedstock production that are purchased by fuel producers, and credits in turn generated in fuel production that are purchased and surrendered by fuel wholesalers.

3.10 Compatibility with other regulatory structures

Many implementations of a green biofuels index are likely to interact with other policies and so should be designed to at least minimize conflicts, and ideally maximize compatibility, with other regulations. One of the important considerations in examining compatibility is the breadth of coverage of the regulated sector. For instance, standards for biofuel producers will capture almost all such plants, but standards for many types of biomass producers (e.g., corn farmers) will capture only a portion of such producers.

3.11 International trade

International suppliers of biofuels or raw biomass are likely to be major participants in an expanded biofuels industry in the United States. International trade raises three important issues that complicate measuring the environmental performance of biofuels: difficulty in determining impacts; restrictions on regulatory standards posed by international trading agreements; and conflict between the long-term incentives for a foreign government overseeing compliance to establish a solid reputation for reliability and trustworthiness, and the short-term incentive to advantage its domestic producers.

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[8] The successful outcome of existing market-based environmental (mainly air pollution) regulations discussed in Farrell and Lave (2004) resulted from political and regulatory processes that created unequivocal, detailed rules that have to be defined carefully to ensure both that the resulting market is viable and that the desired environmental outcomes are obtained. Poor market-based regulation is possible, and in one case (part of California's RECLAIM program) has been adopted, but the regulatory and legal system in the United States has prevented such ill-designed policies from being adopted or (in the solitary case of RECLAIM) overturned the problematic provisions.

The feasibility, expense, and reliability of measuring and tracking biomass and fuel production data from developing countries may be a significant obstacle, because of poorly developed institutions and infrastructure. Other differences such as in income levels and agricultural practices, compared with the U.S. context considered here, probably require a different green biofuels index. Such difficulties could inhibit the application of any green biofuels index or act as a barrier to some producers, possibly contravening the trade principles described below. Conversely, they could provide a powerful incentive to these producing countries to develop data collection systems that would add value to their products. For instance, hoof-and-mouth disease was stamped out in South America mainly so its beef could be sold fresh in the United States, but this benefited South American consumers as well.

According to expert interpretation of the text of trade agreements and the case precedent of adjudicatory decisions, several principles should be considered in designing a green biofuels index (Lancaster 2006; Rogers 2006). Measures need to be consistent with World Trade Organization rules, be based on legitimate domestic or global objectives of the importing country, and take into account the capabilities of developing countries. Standards should be based on scientifically sound principles with a clear nexus to health, safety, or conservation of exhaustible resources.

Certification standards should not explicitly or implicitly discriminate between domestic and imported products, or among the products of different foreign countries. Methodologies for green biofuels measurement and regulation should be developed and implemented with consultation and cooperation of international stakeholders, including all prospective export countries, and should incorporate as much as possible existing methods developed under international protocols.

While this study addresses the narrow issue of U.S.-produced biofuels, any environmental index should be designed to be as compatible as possible with potential future application to internationally produced biofuels. Future research in this area is needed.

3.12 Legibility, convention, and implicit ceilings

Any index of performance is interpreted by users against a background of social and other conventions that we infer from related contexts. For example, hygiene ratings of food service establishments use A as the highest category and not D, or Q, or 13, because we are conditioned from school, and from other systems that conform to the familiar pattern, to regard A as a top grade. In the present context, we think it important that a green fuels index not imply a ceiling on performance. If fuels are rated on a scale from 0 to 100, a user can reasonably infer that 100 is the most green a fuel can be, and with technical and managerial progress, this is certainly not the case for any existing fuel. Accordingly, a criterion for any rating system is not only that it not have a top score, but that it not appear to have one. The two examples that follow include one that observes this discipline and another that does not, for illustrative purposes.

4 Examples of green biofuels indices

Among the many ways to create a environmental performance index, we present two different methods for calculating such an index, and several different methods for aggregating these indices. These indices are proposed as initial efforts that could be implemented very quickly, but would need to be updated on a regular basis as biofuel production processes, the ability to measure environmental performance, and environmental goals all advance.

We propose just two measures of environmental performance, GHG emissions and a simple feedstock rating.

4.1 A quantitative compensatory index

The first example is a simple compensatory index that uses two measures of environmental performance, GHG emissions and feedstock production practices, and for which better performance is indicated by higher values. GHG emissions are quantitative and can be determined by modeling (for feedstock production) and observation (for fuel processing). Evaluation of feedstock production is based on the following categories:

- conventional row crops, residues, and wastes
- low-environmental-impact row crops
- perennial crops
- low-environmental-impact residues and wastes

Of course, these categories would have to be defined in more detail, and the protocol used to measure GHG emissions would also have to be defined.

Such a simple index is readily understandable and allows for improvements that innovation might bring because fuels produced with new technologies could always be assigned higher ratings. One complication is that “better performance” often means less of something, like lower GHG emissions or less soil erosion. To account for this, such measurements should be included as a negative value, but for understandability the reported value should be positive. Below, we show one approach to doing so.

The quantitative index could be turned into a simpler rating system, again to improve the understanding of the differences among different biofuels. One approach would be to use something like the metals associated with Olympic prizes (bronze, silver, gold). However, this approach might limit the number of categories to three and doesn’t easily accommodate ever-improving performance. A better approach might be to use something like a “star” rating, where more stars means better performance. We show examples of both.

A simplified compensatory approach would be quite practical in that much of the information needed to rate all biofuels is already available. In addition, this approach addresses many of the environmental impacts that are not already managed through regulation. For instance, water consumption and emissions by biofuel processing plants, as well as emissions of criteria air pollutants and toxins, are regulated by local, state, and national laws and permitting systems.

GHG emissions, however, are not, nor are many of the environmental impacts of agricultural production.

In a compensatory index, of course, it is possible to trade off performance on one measure (GHGs) for performance on another (feedstock production practices). The overall index can be readily imagined as a weighted average. However, we need to account for the fact that lower GHG emissions are better, but that we want to have positive values for the rating. One way to do this would be to define *GWI* as global warming intensity, *M* as the maximum GWI we would ever expect, a *Feedstock Rating* value, and weights α_1 and α_1 for global warming and feedstock production, respectively. Then we could calculate the green biofuels index like this:

$$Green\ Biofuels\ Index = \alpha_1 (M - GWI) + \alpha_2\ Feedstock\ Rating$$

In this index, two measures, one for global warming intensity (GWI) and another for feedstock environmental impacts, are traded for each other depending on the weights α_1 and α_2 that are assigned.

To illustrate how this index might work, we will use the cases described in Section 6, for which GWI values are calculated, and to which Feedstock Ratings can be applied. In order to have an index that has higher values for better performance, we use the following ratings:

Category	**Rating**
Conventional row crops, residues, and wastes	1
Low-environmental-impact row crops	2
Perennial crops	3
Low-environmental-impact residues and wastes	4

If we assume that approximately equal weights for the two components are appropriate, then the values for *M,* α_1 and α_2 should be chosen so that biofuel production that spans the full range from worst to best performance under current conditions will affect the green biofuels index about the same. If we measure the global warming intensity in units of grams of CO_2-equivalent per MJ of fuel, then most biofuels would measure at about 95 or less. For convenience, *M* could be set to 100, and then appropriate values would be α_1=1 and α_2=25. Thus, our cases would be rated as in Table 1.

The table also illustrates a categorical rating system awarding a star for each 40 “points” in the combined index. The numerical index has a risk of suggesting that 100 is a perfect score, but the star rating makes it less likely, as (for example) generals in the army top out at five stars, but Michelin restaurant ratings stop at three and hotels at four.

Table 1: A Quantitative Compensatory Green Biofuels Index (illustrative values)

Case	Fuel / Technology	GWI	Feedstock Rating	Green Biofuels Index	Value	Star Rating*
1	Conventional agriculture, coal-fired dry mill with CHP	93	1	(100-93) +25 =	32	
2	Conventional agriculture, natural gas	65	1	(100-65) + 25 =	60	☆
2a	Improved corn agriculture, natural gas	65	2	(100-65) + 50 =	85	☆☆
3	Conventional agriculture, natural gas, no drying	56	1	(100-56) + 25 =	69	☆
4	Conventional agriculture, biomass gasification	42	1	(100-42) + 25 =	83	☆☆
4a	Improved corn agriculture, biomass gasification	42	2	(100-42) + 50 =	108	☆☆☆
5	Switchgrass	16	3	(100-16) + 75 =	159	☆☆☆
6	Low-environmental-impact residues and wastes	25	4	(100-25) + 100 =	175	☆☆☆☆

* One star is awarded for each 40 value units.

Global Warming Intensity

A GWI measure should be associated with each batch of biofuel, based on the combined GWI of the feedstock and biorefining phases. Initially, this measure would combine an average global warming intensity per distinct feedstock, as estimated by a transparent, publicly available model (e.g. GREET) based on average feedstock production methods, with the calculated results for a specific biorefinery.

The standard would initially address only the three main greenhouse gases, carbon dioxide (CO_2), methane, (CH_4), and nitrous oxide (N_2O), weighted by their 100-year global warming potentials as per the latest available IPCC assessment, currently 1, 23, and 296, respectively. While we recognize that other factors (e.g., aerosols, particulates, albedo) affect the climate impacts of producing and using biofuels, these factors are less well understood and are included in only one model, which is not publicly available (Delucchi 2003). The purpose of measuring GWI is not to determine a “true” value; this is not possible given the many uncertainties involved. Rather, the goal is to create a transparent estimation of the impacts that is accurate enough to create incentives for lower-GWI production methods. Accounting for the three primary GHGs achieves this goal.

Note that GWI should be reported as an absolute measure for each biofuel pathway. It is tempting to report the GWI of biofuels relative to gasoline (i.e., as a percentage of gasoline’s GWI), but to do so creates confusion, because there are many possible formulations of gasoline (conventional, California reformulated, gasoline “blendstocks”), numerous feedstocks (e.g., petroleum, tar sands, extra heavy oil, coal), and many processes (e.g., conventional on-shore production, off-shore production, enhanced recovery, coal liquefaction) with differing GWIs. Moreover, the average GWI of gasoline is increasing as lower-quality resources are exploited. Instead, the GWI of biofuels should be understood as an absolute measure that can be compared to the measure of gasoline, and of diesel, and electricity, and all other transportation fuels.

While it is important that a green biofuels standard be used to encourage better environmental outcomes among biofuels, it is equally important that biofuels not be disadvantaged vis-à-vis other fuels *because* of a green standard. Instead, every effort should be made to ensure that standards equally applicable to various fuels be equally applied, to encourage better environmental outcomes for fuels. The global warming intensity of transportation fuels is applicable to all fuels, and it should be so applied. This is the only meaningful use of this measure.

Feedstock Rating System
At this time, it is impractical to measure and track site-specific agricultural impacts such as soil erosion or nutrient and pesticide runoff. As discussed earlier, we believe that practice-based standards are more appropriate for agriculture until agro-environmental modeling is able to provide accurate, robust quantification of actual performance. However, because practices are not generally amenable to quantification, qualitative ratings should be used. Initially, average per-feedstock values can be used, allowing feedstock producers to opt in if robust and practical feedstock-specific measures become available. More refined estimates for specific regions, soil types, and agronomic practices could be generated, but this lack of data is not an impediment to creating a useful biofuels standard.

To manage the environmental effects of feedstock production, we propose using a framework like that created by USDA Organic, the Conservation Security Program, or the Forest Stewardship Council (Forest Stewardship Council 2006). These programs design ecological management plans appropriate to each farm, and use a conservation systems approach rather than addressing single practices.

4.2 A qualitative compensatory index

Another compensatory approach is illustrated in Figure 3. Here, we simply plot the cases according to category of feedstock production practices (horizontal) and total GWI (vertical) and designate five regions of performance: unrated and then “one-star” through “four-star.” Note that in this rough, categorical index, many different types of fuel have the same rating and thus may be indistinguishable. Thus, cases 1 and 3 are both unrated even though they are actually rather different, and similarly 4 and 2a are both two-star.

Another approach would be to label cases with *both* the GWI and the overall rating, so Case 2 would be ✰–65, while Case 4 would be ✰✰–42. However, this gives further weight to the GWI. It might be simpler just to have a dual rating: a star rating referring to the feedstock production practice rating and the number referring to the GWI.

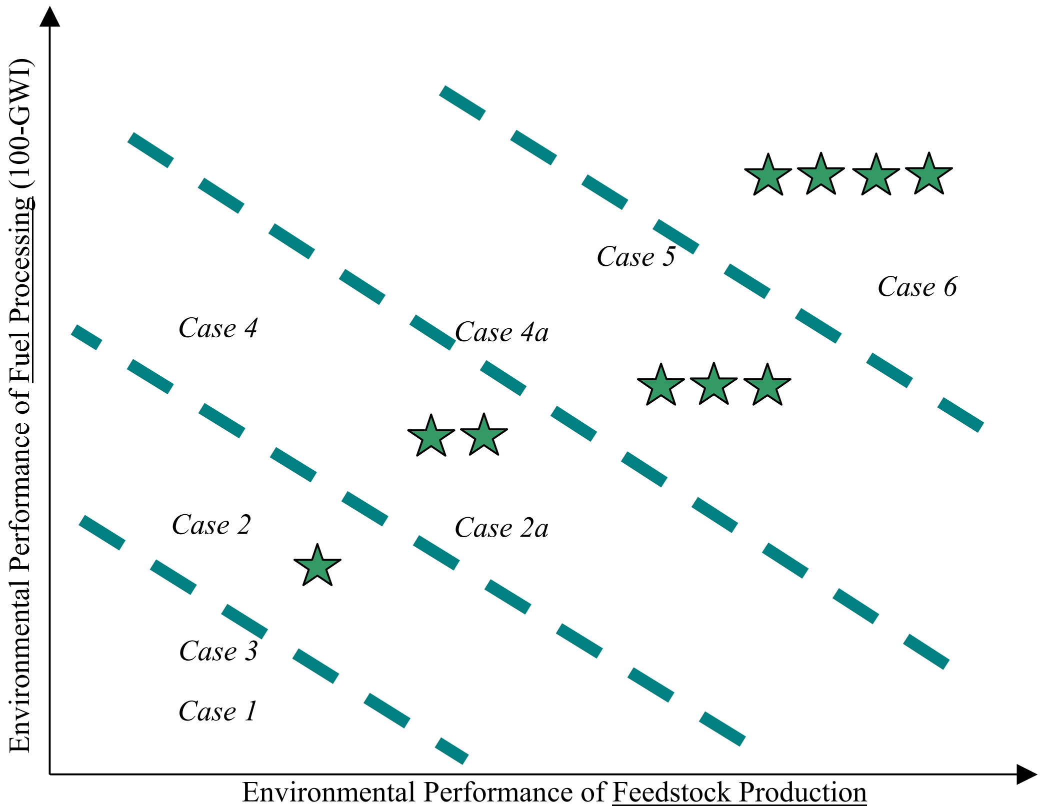

Figure 3: A Qualitative Compensatory Green Biofuels Index (illustrative)

4.3 A lexicographic non-compensatory index

It is possible to aggregate the quantitative and qualitative measures to produce a single overall qualitative rating. However, creating qualitative labels requires defining arbitrary boundaries between values that naturally occur on a continuum, creating biases toward one pathway or another. This reduces incentives for producers to continually improve their ratings since no additional benefits accrue until and unless their product crosses into the next rating category.

A proliferation of numerical ratings, however, would be undesirable. In practice we believe only one numeric measure must be reported: *global warming impact.* No biofuel pathways—present and currently envisioned—use much petroleum (Farrell et al. 2006; Wang, Wu, et al. 2006; Wang 2006). Petroleum use should be measured to prevent backsliding, but it need not be reported to the consumer, nor are incentives or regulations required to improve this outcome.

For reporting overall biofuel environmental performance, we propose a four-tier lexicographic (non-compensatory) index: Gold, Silver, Bronze, and Brown. The technical definition of these categories should be adjusted on a regular (e.g., five-year) basis to incorporate new scientific understanding, technical capabilities, policy goals, and market conditions.

Though it is beyond the scope of this study to define the specifics of this standard, we offer a (somewhat incomplete) sketch of how this might work. This is shown in Table 2. Each fuel is assigned the rating for which it meets *all* of the applicable standards in Feedstock, Processing, and GHGs, as shown below. Note that the use of CSP contracts is only one possible approach.

Table 2: A Lexicographic (Non-Compensatory) Green Biofuels Index (illustrative)

Rating	**Performance Requirements**		
	Feedstock	Processing	GHGs*
GOLD	- Post-recycling biogenic waste, or - Agricultural residues removed from crops under a Tier III CSP contract	- Zero process water effluent, and - Maximum of 3.0 gallons of water consumed per gge fuel (for ethanol)	<40
SILVER	- Crops under a Tier II or III CSP contract, or - Post-recycling biogenic waste, or - Agricultural residues removed from crops under a Tier II or III CSP contract	- Zero process water effluent, and - Maximum of 3.5 gallons of water consumed per gge fuel (for ethanol)	<60
BRONZE	- Crops under a Tier I, II, or III CSP contract, or - Post-recycling biogenic waste, or - Agricultural residues removed from crops under a Tier II or III CSP contract	- Low process water effluent, and - Maximum of 4.5 gallons of water consumed per gge fuel (for ethanol)	<80
BROWN	- Crops or residues from farms without CSP contracts	- Higher-than-benchmark process water effluent or overall water consumption	<100
EXCLUDED	- Feedstocks from converted high-habitat-value land - Municipal solid waste before removal of recyclable material - Tires, plastics, or fossil-based wastes		>100

* GHGs are measured in g-CO_2 eq/MJ

Under this system, "good" environmental performance is variously defined by the "Bronze," "Silver," and "Gold" designations, while the "Brown" designation is intended to capture fuels for which no preference over baseline fuels (e.g., gasoline) is provided. Finally, the system should establish a minimum level of performance below which fuels would be excluded from any rating. Such fuels could be prohibited from consumption because of unacceptable environmental performance.

4.4 Blending fuels and feedstocks

Only the quantitative portion of any index can meaningfully be blended into an average score; a series of lexicographic ratings cannot be "averaged" without explicit tradeoffs of non-commensurate value that the categorical system was originally intended to avoid. Nevertheless, as would probably be necessary under any regulatory approach that placed requirements on a blender's entire product line, arbitrary blending rules can be created to establish that, for instance, one part gold and one part bronze make a silver. Unrated biofuels, because their performance has no known minimum value, should not be thus "redeemed," however.

5 Implementations of a Green Biofuels Index

A wide range of environmental indices for biofuels is possible, varying across several dimensions, including number of components (e.g., agricultural practices, GHG emissions, etc.), accuracy, implementation cost, auditability, and theoretical grounding. Which of the many possible indices is best depends on the goals the index is intended to support. Government policies to increase the use of green fuels can be chosen from a surprisingly wide variety of generic options. Different indices for a particular fuel can vary in many ways. They might include more or fewer components, and might be determined in practice by methods that are more or less precise and/or accurate, more or less expensive to implement, and more or less auditable or defensible on both theoretical and policy grounds.

We now turn to a set of brief characterizations of some distinctive ways in which a green biofuels index could be used. Options are discussed in approximately their order of increasing intrusiveness. For each implementation, we mention how effective it might be in creating markets for green biofuels.

5.1 Allow the market to find its way to efficient labeling and claims

The least intrusive approach, much like the regime currently in place, allows sellers to determine whether and how to communicate the environmental performance of their fuel. Completely private mechanisms of this kind are not unknown; for example, *Good Housekeeping* magazine contracts with advertisers to allow the use of a trademarked seal indicating veracity of advertising claims. It is possible that participants in the energy market would come to a collective agreement, effective even without legal force, defining a green biofuels index that they would all use. However, the dimensionality of the measure and the uncertainty over what to include and how to aggregate individual measurements almost certainly make it difficult for a robust, effective metric to arise.

Accordingly, such regimes are often fragile, as evidenced by the continuing confusion over food health claims. This approach also has a fundamental theoretical defect: It does not account for benefits to society as a whole that private consumers do not wish to pay for. Reducing global warming by private action is probably the most complete case of common-property resource market failure: Anyone's contribution is diluted by being spread across the entire population of the planet, so anyone who makes a sacrifice for the common good experiences exactly the same future as someone who doesn't, whether or not others do likewise. It might be argued that current interest in government policy in this area is justified largely on this basis alone.

The market has not produced markets for green biofuels so far, and it is implausible that an unregulated market would do so in the future.

5.2 Define allowable claims and protocols to support them

A step beyond an unregulated market of claims and measures is government prohibition of all but a single index in marketing claims. The simplest and most familiar example of this approach is the system of legal weights and measures: The foot, yard, pound, quart, meter, and other important units are defined in terms of standards maintained by the National Institute of Standards and Technology (NIST), and no others are permitted to be used in trade. Another example is USDA's establishment of an operational definition of *organic*, and regulatory restriction of the word to denote only what is covered by the definition. This public action, a response to criticism of the growing number of standards and certification programs, strengthened producers' certainty and simplified consumers' purchasing analysis, but it also led to ongoing controversy as to whether USDA had chosen the right definition.

Any version of indexing discussed above is suitable for a regime of this kind, requiring only a government agency, such as NIST, or a nonprofit organization or research institution to establish it and legislation to enact it. A federal requirement would avoid a patchwork system of inconsistent requirements from state to state. Enforcement of unauthorized labeling or mislabeling might be through state weights and measures agencies, or by private fraud actions against market participants.

If index credits are detached from physical product, however, it is not clear that labeling for consumer choice will be acceptable in view of the long-standing expectation that a label describe the specific item to which it is applied. This expectation is rooted in our traditional association between labels and the private consequences of buying and using a good. For instance, the gas mileage on an EPA sticker may motivate a car buyer to choose a small, efficient car for the good of the planet, but he reasonably expects it to describe his personal experience, not an efficiency realized by an unknown mix of other cars while he personally pays for more gas than predicted.

Defining allowable claims about the environmental performance seems like a necessary condition for healthy markets for green biofuels, but it hardly seems sufficient. Green products typically capture only a very small share of any market, unless they have no additional cost at all.

5.3 Require environmental labeling

A step beyond defining protocols would have the government require labeling much as the FDA requires processed food to bear ingredient and nutrition labels. These labels, incidentally, offer a model of what a multidimensional green biofuels index might look like; the tradeoff between simplicity of use and precision of match to consumer concerns is obvious.

As with Section 5.2, any of the index forms discussed above could apply. However, mandatory labeling entails the further establishment of size, location, typography, and more. Presumably fuels would be labeled at the pump, but it could be necessary (given that people have little experience with real differences among motor fuels and frequently misunderstand and misuse the one measure—octane—commonly displayed) to require advertising to carry labels as well, a daunting expansion of government intrusiveness and oversight.

These two regimes, focused on consumer decision, impose some important constraints on the form of the index presentation. The most important is simplicity and transparency; buying the right motor fuel will never justify even the kind of attention people pay to their food, and an index with a simple scale and/or few categories will be essential. Also important is consideration of the implicit as well as the explicit technical information provided. Most rating systems incorporate social conventions such as an A or a score of 100 indicating a top or best grade, or the gold/silver/bronze ordering of athletic medals. Establishing a scale that doesn't cap future performance by running out of headroom (such as awarding an A rating to today's highest-performing fuels) and that meets social conventions for legibility is not a simple matter, though our example of stars that can be awarded without limit may be one.

Requiring environmental labels is a further step toward the development of markets for green biofuels, but it also seems insufficient. As noted, higher-priced green products typically capture only a very small share of any market. And millions of Americans consume unhealthy and even unsafe products despite warnings and public service advertising.

5.4 Require government (and contractors) to purchase green biofuels

Government often uses its purchasing power to demonstrate leadership and help develop markets for products with socially desirable properties. For example, many governments require that all paper purchased have a minimum recycled content. Similarly, governments could require that their agencies (and possibly their contractors) purchase only biofuels with a minimum green index rating. As purchase is a binary action (buy or don't buy), any index used for this option must be one-dimensional in the end.

Government procurement has a mixed record in supporting the development of new markets for environmentally preferable products. Successful government markets can support specialized producers or specialized divisions within larger firms, and these producers' operations may yield innovation that can spread, lowering costs and improving performance throughout the industry. Less successful interventions create high costs for taxpayers and entrenched niche producers with little public benefits. The size and the direction of this effect are critically influenced by the size of government procurement relative to the total market, the size of government procurement within each firm's sales, and the market structure of the industry (multiple highly competitive firms are likely to show larger effects than fewer oligopolistic firms). Green procurement by government shows the highest benefits when it is directed at innovation rather than the support of ongoing operations. Based on these criteria, government procurement standards for green performance in the nascent biofuels industry could exert some influence on innovators, but it is unlikely to shift the industry significantly.

5.5 Subsidize or tax based on environmental performance

Expanding the scope of market intervention beyond government purchases, government could pay direct subsidies at varying levels according to an environmental index, or tax fuels according (most simply) to their net GHG emission. This policy is analogous to the current ethanol subsidy but could be much better targeted and more efficient in diverting the market to better fuels. In theory it is possible to determine optimal tax rates by measuring the costs and benefits of fuel production accurately and unambiguously. However, for the environmental performance of biofuels, this is likely to be impractical because of problems associated with measuring the physical changes from agricultural production. Moreover, the subjective judgments required to monetize these changes ensure that taxes or subsidies will be far from perfect. Consider the fierce debate about just one issue, climate change damages, as illustrated with the recent Stern report (Stern, Peters, et al. 2006). The decision to tax environmental externalities is not avoidable: A tax of zero is a tax like any other, and obviously it misrepresents the social cost of individual behavior.

Payments (either taxes or subsidies) provide for flexibility. Producers can choose the level of environmental performance that is efficient for their businesses. Furthermore, taxes create a pervasive incentive for all producers to find ways to do less of the taxed behavior at all times, whereas a regulation provides no such incentive once compliance is achieved, and low-cost emission reducers become an important political constituency for the policy. Also, payments can be adjusted to follow changes in biofuel production and environmental goals. Finally, a tax mechanism is much more flexible and adaptable to a multidimensional measure of environmental benefit; each dimension can be assigned its own tax rate. Regulation, on the other hand, typically demands high aggregation or else risks completely ignoring important dimensions. Accordingly, a tax or subsidy scheme allows the most complete and accurate incorporation of the index information available of any of these options.

This option, along with the two that follow, impose the least burden of analysis on consumers, and best protect individuals from the perverse incentives of the common property resource problem.

Because market participants are focused on costs and prices, the use of subsidies or taxes could strongly support the development of markets for green biofuels.

5.6 Require an aggregate green biofuels performance

Mandating the environmental performance of an overall industry is likely to ensure a specific environmental outcome while preserving some flexibility for producers to meet the overall standard. The Corporate Average Fuel Economy (CAFE) requirements for automobiles is a policy in which sellers of a product are obliged to maintain some average performance level in their total sales.

As discussed in Section 5.5, above, even the most complex indexing information can be incorporated into a requirement of this kind. The main disadvantage of this approach, and the one that follows, is its implicit acceptance of an infinite step in the marginal benefit schedule: A prohibition, in practice, means that something below it is so bad on the dimensions constrained that it can’t matter what other benefits might flow from a small shortfall. A related disadvantage is the inability of a prohibitory regime to display or encourage improved performance above the minimum demanded.

Fuel producers are already regulated in many ways, and these regulations have changed fuel markets substantially. Regulatory requirements for environmental performance are likely to have a similarly strong effect. One example of such an approach is the Low Carbon Fuel Standard being developed in California (Schwarzenegger 2007), which would encourage a market for fuels with lower GWI. This is both broader than the markets for green biofuels envisioned here (because other fuels, like electricity, could compete) and narrower as well (only GWI is considered.

5.7 Forbid sale of fuel below some level

The most coercive policy alternative is to simply forbid the production of fuel whose environmental index is below a prescribed level. For the near future, the available quantities of biofuels and other non-fossil fuels, even with extremely optimistic assumptions, suggest that a policy of this kind is impractical before a long period of adaptation and capital investment. Such an approach would create markets for fuels with some minimum level of environmental performance, but not necessarily for greener biofuels. Where the risks of certain practices are extremely high, for instance in the loss of both tropical rainforest and peat soil carbon in the conversion of palm oil plantations in Indonesia, outright bans may be appropriate.

6 Case Studies

The following case studies demonstrate the practice measures that would be applied to feedstock production and the quantitative measures applicable to biorefining. We then illustrate how these feedstock and biorefinery ratings could be combined into a single rating. We present six cases that demonstrate how practice measures could be applied to feedstock production and the quantitative measures applicable to biorefining. Five are for various types of corn ethanol, and the last is for ethanol based on switchgrass or corn stover.

6.1 Feedstock production

As described above, a biofuels index will need to use practice-based measures to identify and encourage ecologically preferred feedstock production systems. To demonstrate the range of outcomes, we examine three ethanol feedstock production systems: best-practices corn production, switchgrass, and conventional corn production with stover collection.

6.1.1 Best-practices corn

The Willow Creek Farm produces corn and soybeans on 3,800 acres in southwest Minnesota. The farm is operated under a Conservation Stewardship Plan, qualifying it for a CSP Tier III contract, developed with a USDA technical service provider. The plan identifies the unique resources and constraints of the farm and identifies the specific practices to be followed to minimize impacts. The crops are grown in rotation to reduce fertilizer and pesticide needs. A "ridge till" tillage system and filter strips on downslope field edges reduce erosion and runoff. Soil and crop tests are used to determine fertilizer needs before and during the season, and tractors are outfitted with a Global Positioning System (GPS) allowing precise placement of seed, fertilizer, and pesticide.

Corn and soybeans produced by Willow Creek receive a Silver rating, or three stars, the top ratings available to annual row crops. To understand why this corn does not earn a Gold rating, it's helpful to compare corn to switchgrass. The corn receives about 170 pounds of nitrogen per acre, while switchgrass is expected to require between 50 and 150 pounds per acre. Corn is also an annual crop, requiring replanting every spring. Switchgrass is a perennial that is replanted approximately once a decade. So, while Willow Creek produces corn about as well as it can be produced, corn is still responsible for more environmental harm than switchgrass.

6.1.2 Switchgrass

Switchgrass is a perennial species that, once established, can be harvested annually for a decade. It produces high yields while requiring less fertilizer and much less pesticide than corn. It is also water efficient, because of its deep root system, which also builds soil carbon. Switchgrass is native to the eastern two-thirds of the United States and can provide a valuable habitat to native wildlife. A switchgrass plantation tolerates substantial intergrowth of other native species that would be noxious weeds in a row crop context.

The hypothetical Husker Farms, a 7,300-acre dryland farm in northwestern Nebraska, was until recently cropped with dryland wheat and groundwater-irrigated corn. The farm created a

Conservation Stewardship Plan, identifying the lands best suited for row crop and biomass production and the appropriate practices for both to maximize ecological benefits. Starting with land classified as “highly erodible” under the Conservation Reserve Program contract, increasing acreages have been put into switchgrass production. Switchgrass is planted in the spring with an initial suite of fertilizers and soil amendments, and managed for the first year with moderate cultivation and herbicides to establish a dense stand. Each year, the stand receives a maintenance application of fertilizers. The switchgrass crop is cut and baled once annually in the late fall, after nutrients have translocated from the “shoots to the roots”; this minimizes the subsequent need for fertilization and lowers the disruption to nesting species (Greene 2004). Switchgrass grown under these conditions warrants a Gold or 4-star rating.

6.1.3 Agricultural residues

The hypothetical Goldfinch Hollow, a 4,200-acre corn-and-soybean operation in central Iowa, developed a Conservation Stewardship Plan to identify sustainable practices for the farm, including the sustainable collection of corn stover and soybean residues. Based on the cropping plan, no-till practices, topography, soil type, and climate, a plan for 30 percent residue collection has been established. A soil carbon test and siltation trap will be used in the five-year plan review to modify this collection rate. Some nutrients are removed with the residues, so this system uses slightly more fertilizer and pesticide than does a crop-only program. Residues are collected by a modified combine during grain harvest. Because this feedstock is also annual and does not provide soil carbon or habitat benefits, it is eligible for only a Silver or 3-star rating.

Agricultural residues also may be used for process energy in a corn ethanol plant. For instance, Chippewa Valley Ethanol Company in Benson, Minnesota, is implementing a biomass gasifier to convert corn stover into process heat and electricity (Lee 2006). Because these agricultural residues are as much of a feedstock as the corn, they must also be rated and their environmental performance reported and averaged with the primary feedstock.

6.1.4 Other feedstocks

Several feedstocks are undesirable enough that they should be excluded from the rating system. These include conventionally tilled corn grown without ecological improvements to limit agrichemical runoff and soil erosion, any energy crops grown on newly deforested land, or any row crops grown on converted CRP land (due to biodiversity loss and release of soil carbon).

Ratings for agricultural residues depend on whether sufficient ground coverage remains after collection. However, “sufficiency” is poorly understood and site-specific (Wilhelm, Johnson, et al. 2004). Removal of more than 50 percent of corn stover, for example, is almost certainly undesirable; the actual limit in some cases will be even lower.

6.2 Biorefining

In the 1990s, the form of new ethanol plants became fairly standardized. Typical facilities have a capacity of 40 million gallons per year and use dry-grind processes, natural gas for heat, and grid electricity for power. Newer plants tend to be larger, with annual capacities of 50 million to 100 million gallons (Collins 2006). (For comparison, total U.S. gasoline consumption is about 367 million gallons per *day*, or 134 *billion* gallons per year. Therefore, a 100 million gallon per year ethanol plant could meet about 0.05 percent of U.S. gasoline demand, taking into account differences in energy content. Typical oil refineries are two to ten times larger.)

While biofuel production has several important environmental effects, only GHG emissions can be quantified with any degree of certainty. Other considerations either are problematic only in certain locations (e.g., water consumption) or are already subject to various local, state, and federal controls (e.g., toxic emissions).

Therefore to illustrate the range of environmental effects possible from producing biofuels, we examine the lifecycle GHG emissions for ethanol produced under different configurations of the standard dry-grind process and possible future advanced-technology scenarios. Focusing on a single fuel pathway helps to highlight the significant differences in GHG emissions associated with the choice of energy source in the ethanol facility. For comparison, we include values for gasoline and for one possible cellulosic ethanol production pathway.

Ethanol plants generally use steam for cooking the corn mash, for distillation, and for evaporation. Most plants use steam or natural gas to dry distillers grains. We examine a typical current configuration that uses natural gas, as well as three facilities that have chosen alternative energy sources. Due to high gas prices and a lack of incentives to account for GHG emissions, new facilities are considering a wide range of energy alternatives that save money for the producer but have widely varying GHG emission implications.

We examined these four cases using GREET 1.7, a “well-to-wheels” fuel-cycle model developed by Michael Wang at Argonne National Laboratory. This model is widely recognized as the most comprehensive and accurate tool available. It has been used extensively by both industry and government and has been used in the peer-reviewed literature (Wang 2002; Brinkman, Wang, et al. 2005; Wu, Wu, et al. 2006).

To highlight the differences among biorefining processes, we assume average GHG emissions from corn production, as defined in GREET, in all cases.

6.3 Corn ethanol 1: Coal-fired ethanol production with cogenerated electricity

The first coal-fired dry-grind ethanol facilities started production in 2006 (Energy and Environmental Analysis Inc. 2006). At least eight facilities now in operation or under construction are planning to use coal, including at least one that uses combined heat and power (CHP, also called cogeneration).[9]

Cogeneration technologies increase energy efficiency by generating electricity near a facility that can use the waste heat. A typical ethanol facility burns fuel to produce process heat and purchases electricity from the local utility. In contrast, a CHP plant boils water to drive a steam turbine generator and then uses the energy remaining in the steam exiting the turbine for process

[9] Dry-grind facilities using or planning to use coal include: Agassiz Energy LLC, Erskine, MN; Big Horn Basin Ethanol LLC, Greybull, WY; Central Illinois Energy Co-op, Canton, IL; Green Renewable Energy, Ethanol & Nutrition-Holding LLC, Tremont, PA; Heron Lake BioEnergy, LLC, Heron Lake, MN; Midwest Ethanol Producers Inc., O’Neill, NE; Red Trail Energy, LLC, Richardton, ND; and Sunnyside Ethanol LLC, Curwensville, PA.

heat. The main energy efficiency gain is that the exhaust heat after electricity generation (typically two-thirds of the primary energy in the fuel) is put to use and not wasted. There are also smaller efficiency gains from avoiding transmission and distribution losses associated with grid electricity. On the other hand, smaller thermal electricity generation systems like those likely to be installed at ethanol facilities are somewhat less efficient than large central stations. These factors combine to reduce total fuel used directly and indirectly by the cogeneration-equipped ethanol plant by about 10 percent (Energy and Environmental Analysis Inc. 2006).

Greenhouse gases are emitted on the farm during corn feedstock production. Conventional Illinois farmers use slightly more nitrogen fertilizer than the national average, resulting in a higher yield, but they use much less energy on the farm in the form of petroleum fuels, natural gas, and electricity. Overall, the high GHG emissions associated with nitrogen fertilizer use largely offset lower energy use on the farm, so the lifecycle GHG emissions from producing Illinois corn is only 5 percent lower than the average of the nine largest corn-producing states.

A coal-powered dry-grind facility using conventional Illinois corn and CHP as discussed here produces lifecycle GHG emissions of 93 g CO_2-equivalent per MJ of ethanol. Without CHP, the emissions are 96 g CO_2eq/MJ. With or without CHP, the emissions are essentially indistinguishable from those of conventional gasoline circa 2000 (94 g CO_2eq/MJ). Coal-fired wet-mill plants have even higher GHG emission rates.

6.4 Corn ethanol 2: Natural gas–fired ethanol production

The second case is based on a new, dry-grind facility with a capacity of 50 million gallons per year. This hypothetical plant uses 0.75 kWh of electricity and 32,330 Btu of natural gas per gallon of ethanol produced, with an ethanol yield of 2.8 gallons per bushel of corn (Energy and Environmental Analysis Inc. 2006). The plant coproduces dried distillers grains and solubles (DDGS), so the total above includes natural gas used for drying and for running the thermal oxidation unit that destroys volatile organic compounds released during drying.

Modeling this facility in GREET 1.7 shows a lifecycle GHG balance for the ethanol produced of 65 g CO_2eq/MJ. This is 31 percent lower than the value for gasoline, which is 94 g/MJ.

6.5 Corn ethanol 3: Integrated ethanol production / animal feedlot

E3 Biofuels-Mead in Nebraska (an actual facility) began producing ethanol in December 2006. The facility integrates an ethanol plant with a cattle feedlot, allowing the production of corn ethanol with greatly reduced lifecycle greenhouse gas emissions. The facility avoids drying distillers grains since the wet distillers grains (wet cake) can be fed directly to the cattle, reducing plant energy requirements by about half; it also avoids the costs and emissions normally associated with drying and distributing distillers grains. The cattle must be local because wet cake spoils quickly and the transport of the heavier material is generally not economical. E3's wet cake provides 40 percent of the cattle's rations.[10]

The cattle's manure and the *thin stillage*—the liquid remaining after centrifuging the corn mash to produce wet cake—are combined in two four-million-gallon anaerobic digestion tanks to

[10] http://www.e3biofuels.com.

produce methane-rich biogas that is used to meet the rest of the plant's thermal requirements. E3 purchases electricity from the local grid.

According to the USDA, Nebraska farmers used an average of 69,700 Btu per bushel of corn produced in 2001, making the state the least energy-efficient (and most GHG-intensive) of the top nine corn-producing states (Shapouri, Duffield, et al. 2004). This is due to a slightly lower than average corn yield combined with very high use of natural gas and electricity (especially for powering irrigation) on the farm.

In our GHG emissions modeling, we ignored the avoided GHG emissions from reducing cattle manure methane release since any concentrated animal feeding operation can use an anaerobic digestion system with or without a neighboring biorefinery. We also did not count any additional electricity required to mix the anaerobic digester tanks or pump the manure, since these too can be attributed to animal waste management.

Because of the biorefinery's efficiencies and low-GHG energy source, despite the relatively high energy intensity of Nebraska corn, E3 Biofuels produces ethanol from corn with extremely low lifecycle GHG emissions: 56 g CO_2-equivalent per MJ, far below the emissions level for average ethanol and nearly 40 percent lower than gasoline.

6.6 Corn ethanol 4: Biomass-powered ethanol production

Minnesota is one of the most energy-efficient and GHG-efficient corn producing states. According to the USDA, Minnesota farmers used an average of 40,500 Btu per bushel of corn produced in 2001, versus an average of 50,000 for the top nine corn-producing states (Shapouri, Duffield, et al. 2004). Minnesota farmers enjoyed 3 percent greater yield while using 15 percent less nitrogen fertilizer—as well as less potash, phosphate, and lime. This resulted in about 30 percent lower lifecycle GHG emissions from corn production than the 2001 Corn Belt average.

The Chippewa Valley Ethanol Company (CVEC) has been producing ethanol in Benson, Minnesota, since 1996. The CVEC plant was built to use natural gas for thermal energy, but the cooperative is finishing construction of a biomass gasification system designed to utilize a range of feedstocks, including agricultural residues, grasses, clean wood from forestry or processing operations, and various coproducts from the corn ethanol process such as distillers grains, distillers solubles, and crude corn oil.

Ample supplies of corn stover are immediately available in the vicinity of the plant, and only about 30 percent of the stover from any cornfield is required to fuel the production of ethanol from the field's grain (Morey, Tiffany, et al. 2006). It is widely agreed that at some level, stover removal will negatively reduce soil quality and increase erosion. However, the portion that should be left on the field to prevent these effects depends on specific field and agronomic factors (Mann, Tolbert, et al. 2002; Wilhelm and Wortmann 2004). Although prototype single-pass harvesting systems that simultaneously collect grain and stover have been explored by researchers (e.g., Hoskinson, Karlen, et al. In Press), we modeled here a more conservative process in which stover is collected separately (Sheehan, Aden, et al. 2003). We have assumed that the stover will be taken from the same fields as the grain. Collecting corn stover is likely to increase the fertilizer and pesticide demands of the overall crop, and thus the emissions associated with these fertilizers, and those from the collection process, constitute the GHG emissions from stover production.

According to our modeling, corn ethanol produced at CVEC using gasified stover for process heat results in ethanol with lifecycle GHG emissions of 44 g CO_2-equivalent per MJ, about 47 percent of the lifecycle emissions for gasoline.

6.7 Cellulosic ethanol production

Cellulosic ethanol refineries are in active development in many parts of the world. Several different processes, including acid hydrolysis, enzymatic hydrolysis, and gasification/fermentation, are in simultaneous development, and it is unclear which will succeed technologically and economically. However, all processes have in common the use of part of the feedstock (usually the lignin, the portion most resistant to conversion to sugars) to power the process. This use of biomass for power results in no additional greenhouse gas emissions. In fact, some plants may be able to export excess electricity, potentially displacing GHG emissions elsewhere. Thus, the GHG rating is based on that of the feedstock production, plus transportation.

In this scenario, both switchgrass and stover production result in similar levels of farm GHG emissions, with no biorefinery emissions, and so achieve a lifecycle rating of 14 g CO2e/MJ, about 15 percent that of gasoline.

6.8 Case studies summary

Due largely to uncertainties in calculating the lifecycle GHG emissions from the agricultural phase, it is impossible to know whether a coal-fired dry-grind corn ethanol plant produces a fuel with higher or lower lifecycle greenhouse gas emissions than gasoline—even assuming cogeneration for greater energy efficiency. However, GHG-reducing options are available to ethanol producers that are much more likely to result in lower GHG emissions. Other options exist as well, including “no-cook” fermentation processes in use at more than a dozen corn ethanol plants, which lower energy requirements, and new techniques to extract and convert a greater percentage of the starch from each grain of corn.

There are few potentially low-GHG alternatives to petroleum fuels. If we fail to pay attention to the GHG emissions from the production of biofuels, we may not gain any climate benefits from their use. Options exist to ensure solid GHG reductions from corn ethanol, but while the benefits are public, the costs are private, and in the absence of a carbon tax or regulation, seizing these opportunities will not be to the advantage of producers. Figure 4 illustrates the GHG impacts of the cases, with a few other examples for comparison.

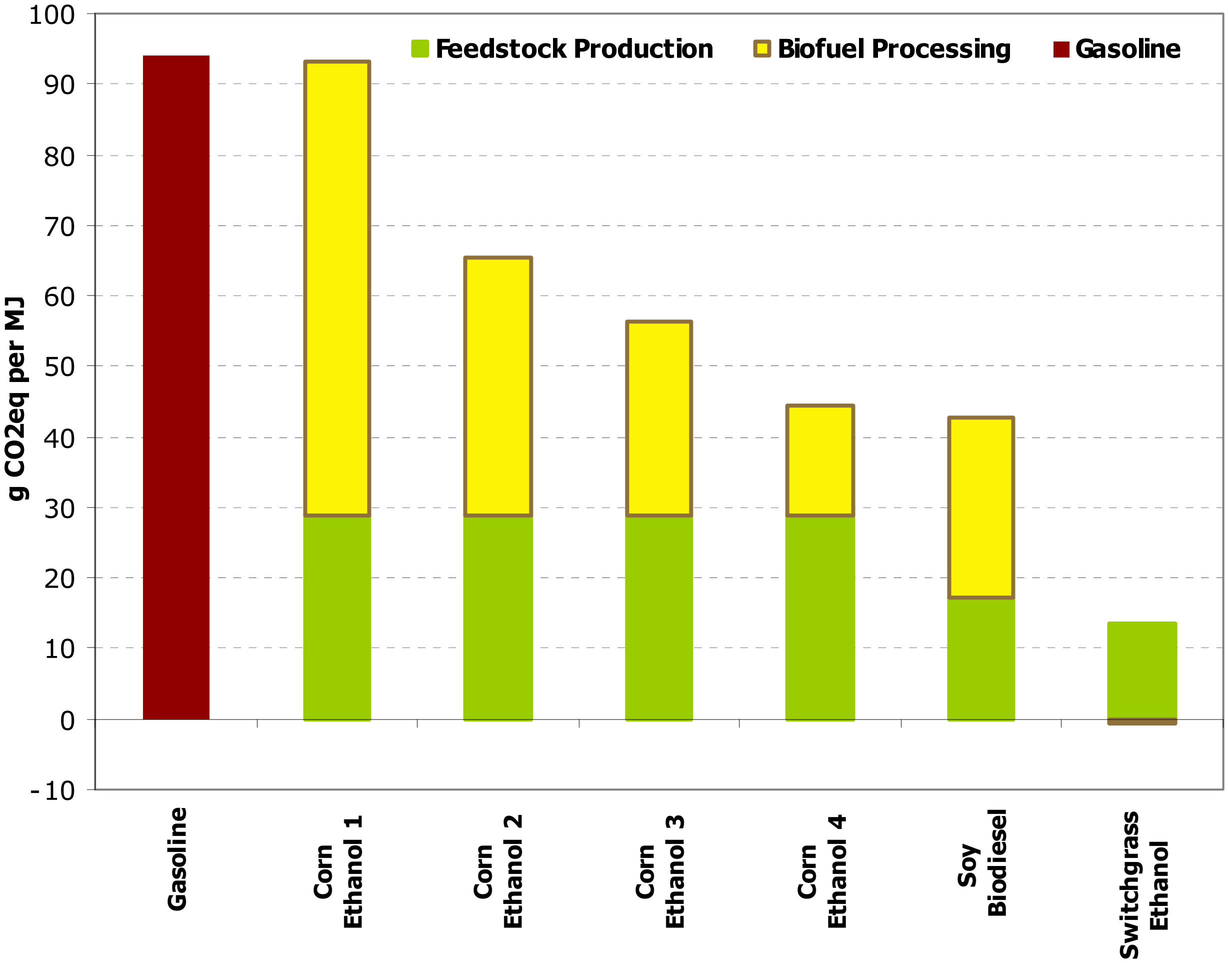

Figure 4. Well-to-Tank GHG Emissions From Various Fuel Pathways (Illustrative)

GHG emissions from gasoline production and combustion are 94 g CO_2eq / MJ. Corn Ethanol 1, a new dry-mill burning coal to cogenerate heat and electricity, produces ethanol with no GHG benefits. (Without the cogeneration, emissions are 96 g CO_2eq / MJ—slightly *greater* than for gasoline.) Corn Ethanol 2 shows a standard natural gas–fired dry-mill, producing ethanol with emissions of 65 g CO_2eq / MJ. Corn Ethanol 3 shows ethanol produced in a natural gas dry-mill that delivers its coproduct distillers grains wet, avoiding the energy costs and emissions of drying distillers grains. Emissions for this pathway are 56 g CO_2eq / MJ. Corn Ethanol 4 shows a biomass-fired dry-mill, with emissions of 44 g CO_2eq / MJ—less than half the emissions of gasoline. The emissions from corn production are assumed to be the average (as represented in GREET 1.7) for all four dry-mill cases. The emissions from switchgrass ethanol, assuming an acid hydrolysis / fermentation process, are estimated to be 14 g CO_2eq / MJ. These values do not include indirect effects and a number of potentially important factors, so actual GWI values may be greater than those shown (Delucchi 2004). *Source: GREET 1.7 beta, modified.*

7 Recommendations

Because the environmental performance of biofuels is not measured today, consumers have no information about how to buy green biofuels and producers have no incentive to produce and market them. Therefore, while biofuels, including corn ethanol, can contribute to the nation's energy and environmental goals, they do not do so today, with minor exceptions. To solve this problem, we recommend four steps to help create markets for green biofuels. These steps should be taken through a transparent, data-driven, and accessible process so that producers and stakeholders can understand the relationship between practices and ratings and act accordingly.

1. **Measure the global warming impact of biofuels.**

The first step toward markets for green biofuels is to develop methods for measuring the global warming impact of fuel production and use. Several official processes for evaluating individual biofuels in a regulatory framework are currently under development, including the Renewable Transport Fuels Obligation in the United Kingdom and the Low Carbon Transport Fuels Standard in California. Methods for measuring the GWI of biofuels can be adopted by environmental or energy regulators in coordination with agricultural agencies and could be feasible at either the state or national level.

2. **Measure the overall environmental performance of biomass feedstock production.**

A second and necessary step toward markets for green biofuels is to develop methods for measuring the environmental implications of biomass production (e.g., farming or residue collection). The Conservation Security Program provides a ready model for agriculture based on site-specific conservation planning. Markets for green biofuels would need a more refined approach that ensured minimum performance across the range of possible biofuel feedstocks and had stronger compliance verification. A system to measure the environmental performance of biomass production should be developed through a cooperative process among environmental regulators, agricultural agencies, and stakeholders. It should be updated as better methods and data become available, possibly adopting the principles of adaptive management.

3. **Develop and implement a combined Green Biofuels Index.**

A Green Biofuels Index that producers, consumers, and regulators can rely on is the critical missing element that is needed to create markets for green biofuels. Combining a GWI measure and a feedstock production rating would create such an index. It could be used in many different ways: solely as a consumer information tool, by government agencies and contractors and private firms to establish procurement requirements, as the basis for awarding a sliding scale of biofuel subsidies, or to set minimum performance requirements for all products in the marketplace. By no means are these strategies mutually exclusive; indeed, several implementations could exist in various parts of the market at the same time, or simultaneously within a single market.

4. **Develop better assessment tools, practices, and assurance methods.**

Understanding the relationship between agricultural practices and environmental performance is the inescapable foundation of a healthy market for green biofuels. Much more research is needed to develop and refine the assessment methods by which these relationships are established and communicated. The goal should be a robust, transparent, and accessible modeling framework that will allow regulators to understand the continuous differentiation of performance and will allow producers to accurately predict, and innovate upon, the effect of practices on value production. Further, several outstanding issues remain largely unexplored, creating significant uncertainties in current assessment systems. These include biomass residues from conventional forest systems, and indirect effects caused through market interactions in food, fuel, and other commodities. These indirect effects may have significant implications for land use, so this is a particularly important area for research.

In addition, the institutional capacity of green biofuels certification should be actively developed. The processes of assurance, tracking, trading, banking, and technical assistance should be encouraged and supported. Finally, adaptive management should be integrated into every stage of the regulatory process, just as it is on the farm. The performance of the Green Biofuels Index itself must be periodically evaluated, its strengths strengthened, and revised where it is not adequate.

A variety of institutions have roles to play here. The National Academies could, along with appropriately focused scientific bodies (e.g., American Society of Agricultural and Biological Engineers, United States Association for Energy Economics, Ecological Society of America), help identify a research agenda to enable and expand markets for green biofuels. The National Science Foundation, Department of Agriculture, Department of Energy, Environmental Protection Agency, and similar state bodies could support such a research agenda.

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Appendix A: Measuring Multiple Dimensions of Environmental Performance

In evaluating the environmental performance of biofuels, the range of concerns is potentially large. This Appendix is meant to be illustrative only, so a subset of issues that demonstrate the complexity of a more compete effort were chosen. They include:

- Greenhouse gases (GHG)
- Fossil fuel depletion
- Soil erosion
- Eutrophication
- Pesticides
- Water depletion
- Land-use change

Lifecycle analysis may take either an aggregate perspective (for instance, "What are the environmental implications of increasing ethanol consumption in the United States to 7.5 billion gallons?") or an individual perspective ("What is the environmental impact of the ethanol produced in May 2007 at the Smith biorefinery?"). The following discussion is an extended examination of a Green Biofuels Index attached to a unit of a particular fuel (for example, ethanol produced in May 2007 at the Smith refinery).

A.1 Greenhouse gases

One of the primary goals of encouraging the production of biofuels is a reduction in greenhouse gas emissions from the use of petroleum-based fuels in transportation. Because the carbon emitted from burning biofuels is absorbed by the biomass feedstock, these fuels are often considered carbon-neutral. However, greenhouse gas emissions occur in feedstock production and conversion through the use of fossil fuels and the emission of nitrous oxides in agriculture. Some of the greenhouse gas–producing processes are poorly understood, and some agricultural emissions are not controllable. But most greenhouse gas emissions can be calculated and controlled and so can be effectively addressed by a green biofuels index.

Greenhouse gas emissions in other sectors are also affected by the production and use of biofuels because biofuel coproducts may be sold into other markets. These changes are relevant in accounting for coproducts of biofuel production and in accounting for the final use.

Much of the GHG emissions in biofuel production occur in the combustion of fossil fuels in tractors, transportation, feedstock or coproduct drying, process heat, and power. Calculating these emissions is a straightforward task given the quantities and types of fuels used. In addition to being amenable to actual "tailpipe" emissions measurement, the emissions can be very accurately estimated from the chemical composition of the fuel.

Other significant GHG emissions in biofuel production are much more difficult to measure or even to estimate. Emissions of GHG from nitrogen fertilizer transformation to N_2O in agricultural fields, for instance, is both little understood and highly dependent on multiple interactive variables such as soil type, chemistry, and moisture as well as weather and fertilizer application. Similarly, little is known about the fate of the carbon in agricultural lime that is occasionally applied to acidic soils. Another unknown involves changes in soil organic carbon.

In addition to the actual processes of soil carbon changes, accounting for sequestration is problematic given the potential for leakage.

On the macro scale, while some GHG-emitting processes may be linked to biofuel production in the aggregate, they cannot necessarily be linked to specific biofuel production. For instance, increased demand for biofuels may increase pressure for the extension of agriculture into tropical forest areas, accelerating deforestation and exposing carbonaceous soils like peat. These effects could result in large greenhouse gas emissions but would be difficult to directly trace to specific biofuel feedstock production.

Another significant difficulty in accounting for GHG emissions from biofuels production is in allocating GHG emissions among coproducts. Multiple methods have been proposed by various researchers for determining coproduct "credits"; these include assigning a portion of total emissions to coproducts based on mass or economic value, or crediting coproducts with the emissions avoided by not producing the next-closest substitute product. The latter method, favored by most researchers in aggregate biofuel analysis, requires another set of GHG measurements for evaluating the alternative products.

Despite these complexities and uncertainties, accurate assessment of greenhouse gas emissions is possible with the use of models. Because agricultural emissions are difficult and expensive to monitor directly, making it impractical for field-level measurement, experimental measurement is used to develop models for estimating emissions that are then used with real-world field-level parameters. At the least, this process can yield accurate relative rankings of practices. Revised according to the best available science, interpreted by consensus scientific agreement, this approach is the best response to significant uncertainty, much of which may remain fundamentally intractable. Also, this approach provides the most robust quantitative capability, providing a defensible basis on which to structure performance-oriented policy.

A. 2 Fossil fuel depletion

Although not directly an environmental concern, fossil fuel depletion is clearly important. It is extremely salient politically as regards domestic and foreign oil consumption, and it is closely related to several possible environmental impacts.

Fossil fuel depletion can be measured as the consumption of fossil fuels in the biofuels production process. In addition to direct fossil fuel use in operating tractors or raising steam in an ethanol plant, each input to production, such as agricultural fertilizers, is associated with fossil fuel use in production. Fossil fuel depletion also includes the "upstream" fossil fuels used in producing that fuel.

Generally, an average breakdown of the fossil fuel types employed in that process will be sufficient for measuring fossil fuel depletion (and related impacts that are dependent on the type of fuel). For instance, the electricity use of ethanol plants in the Midwest can be evaluated for fossil fuel use by applying the average fossil fuel use of the electricity produced in the Midwest Reliability Organization's power pool. Only where a producer can show a significantly different power mix than the average, for instance electricity purchased through green certificates or vehicles operated on biofuels, will individual fossil fuel consumption need to be calculated.

The fossil fuel of most concern is petroleum. Biofuels could carry a "displacement ratio" measure, indicating the amount of petroleum used in their manufacture. This metric would be useful in policies directed at petroleum use reduction, such as the renewable fuels standard of the 2005 Energy Policy Act. The Renewable Identification Number and Equivalence Value structures identified in the proposed regulation provide a possible framework for this.

A.3 Soil erosion

Soil erosion is another example of a potential negative result of biomass production that is difficult to measure directly. It is extremely hard to measure in real time, and it is not linearly or perfectly correlated with a specific input but is instead dependent on a number of interrelated factors, including soil type, tillage practice, and weather. As with greenhouse gas emissions, sophisticated models exist to estimate the erosion rate from agricultural production given certain parameters including soil type, slope, and tillage practice.

Alternatively, soil erosion can be addressed through best practices. This has been the primary policy response since ancient times, as reflected in the earliest soil-related texts. Best practices became institutionalized in the United States with the creation of the Soil Conservation Service during the Dust Bowl years of the 1930s. Erosion control solutions must be tailored to particular land, climate, and crops. For this reason, the most universal best practice is the crafting of and adherence to an erosion control plan that examines the unique characteristics of the land and crop and identifies tailored solutions.

A.4 Eutrophication

Some amount of chemical nutrients (fertilizers) applied in agricultural production drains to aquatic systems, where it causes excess oxygen demand and damages aquatic ecologies. A major concern in the popular skepticism toward biofuels is the potential for increased biofuel production—especially from such fertilizer-intensive crops as corn—to increase the amount of nutrients currently causing widespread eutrophication in U.S. rivers and coastal waters.

The relationship between eutrophication and fertilization is a complex one. The degree to which biofuel production will cause eutrophication is a function of the amount and type of fertilizers applied, the method of application, the utilization of nutrients by the crop (in turn a function of timing, soil, weather, and crop genetics), and the condition and dynamics of the aquatic ecology of receiving waters. Eutrophication is sink-dependent, as some systems are nitrogen-limited while others are phosphorus-limited. Determining an a priori eutrophication potential based on quantities of nutrients in runoff, without reference to the receiving waters, would miss this sensitivity entirely.

Furthermore, determining the quantity of applied nutrients that run off is difficult without field-level measurement. One method would be to calculate the nutrient utilization of the crop (by testing the nutrient content of crop tissue) to determine the quantity of fertilizer assumed to run off. This nutrient-use efficiency of the crop may be the most desirable metric, but the expense of these detailed, laboratory-based calculations may be greater than the benefits gained in data. A more robust measure may be a simple nutrient efficiency metric calculated as kg fertilizer/kg crop.

This relatively direct and robust measure of the eutrophication potential of biofuels would be calculated by dividing the total quantity of fertilizers applied by the quantity of biofuels ultimately produced. By denominating in terms of yield, the measure incorporates a gross approximation of the nutrient efficiency of the crop application. This is important in creating incentives to optimize nutrient application in terms of crop yield, because yield captures crop utilization, the main determinant of whether there exist excess nutrients that could lead to eutrophication. This preserves incentives that could encourage the adoption of practices, such as precision application and crop testing for optimum timing, that are proven to reduce eutrophication. It should be noted that increasing research and development of agro-ecological models can lead to more accurate prediction of nutrient runoff and leaching, in turn supporting better management decisions. Any biofuel accounting system must include adaptation provisions to allow the best science to inform its methods.

It is also possible to address eutrophication while avoiding quantifying eutrophication potential entirely by specifying best practices known through experimentation to reduce eutrophication. Ideally, this system could be specifically tailored to watersheds, setting fertilizer use maxima for crops in specific systems. Other best practices could include testing for crop nutrient needs prior to application, precision application and timing, and planting of buffer strips for post-application nutrient scavenging from runoff.

A.5 Pesticides

Pesticides are widely used in conventional crop production. Pesticides can have a negative effect on ecosystems and human health. The potential harm from pesticides is a function of the toxicity of the pesticide itself and the manner of application (as well as certain environmental factors such as soil type and weather). The first parameter, the toxicity of the pesticide, is notoriously undermeasured—the process of researching human and ecological toxicity is laborious, lengthy, and necessarily incomplete (it is not possible to test all possible ecological receptors in all risk categories, and it is unethical to directly test humans). For instance, as of fiscal year 2005, 18 percent of pesticides introduced prior to passage of the Federal Insecticide, Fungicide, and Rodenticide Act had not completed basic risk assessment. Furthermore, the types of risk—for instance, cancer and non-cancer risk—cannot easily be aggregated. Broad categories of risk have been identified by various groups based on more robust risk factors such as carcinogenicity. For instance, Pesticide Action Network identifies "bad actors" that are of special concern.[11] Nevertheless, a comprehensive system linking pesticide application to predicted health outcomes will remain unachievable for the foreseeable future.

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[11] "Bad actor" pesticides include: (1) known or probable carcinogens, as designated by the International Agency for Research on Cancer (IARC), U.S. EPA, U.S. National Toxicology Program, and the State of California's Proposition 65 list; (2) reproductive or developmental toxicants, as designated by the State of California's Proposition 65 list; (3) neurotoxic cholinesterase inhibitors, as designated by the California Department of Pesticide Regulation, the Materials Safety Data Sheet for the particular chemical, or PAN staff evaluation of chemical structure (for organophosphorus compounds); (4) known groundwater contaminants, as designated by the State of California (for actively registered pesticides) or from historic groundwater monitoring records (for banned pesticides); and (5) pesticides with high acute toxicity, as designated by the World Health Organization (WHO), the U.S. EPA, or the U.S. National Toxicology Program. See www.panna.org.

Even the actual rate of pesticide drift and runoff is, like erosion and fertilizer runoff, difficult to measure directly. It can be modeled given sufficient parameter data, or best practices (such as precision application) can be identified. At the grossest level, a pesticide efficiency metric can be calculated as the quantity of pesticides of concern per mass of crop yielded.

A.6 Water depletion

Unlike fossil fuels that are conclusively used up when burned, water in farming and fuel production may be *consumed* (evaporated into the atmosphere or incorporated in products and removed from a limited stock like a fossil aquifer), *diverted* from an alternative use (drawn from an annual flow and evaporated or exported, leaving less for other users), or *cycled* from a source through a production process and returned to it. For example, municipal water supplies are partly consumed (evaporated from gardens and lawns) and partly cycled from (say) a river and back to it through a sewage treatment plant. Any of these may be considered *uses*, but they have very different environmental implications.

Water is used in biomass feedstock production and in biorefining. Many areas of biomass feedstock production may be irrigated (although most currently are not). For instance, corn grain grown in Nebraska uses an average of 7 inches (186,000 gallons) of irrigation water per acre of crop, while corn grown in Minnesota uses virtually none. Biorefineries also use large amounts of water, often as much as 4 or 5 gallons per gallon of fuel produced, or about 200 million gallons per year for an average-size ethanol plant. In the case of irrigation, much of the applied water is released to surface water sources and/or may percolate to aquifers, and so is not a consumptive use, except insofar as the runoff water is burdened with nutrient or pesticide loads. In contrast, most ethanol plant water is consumed in evaporation from cooling processes or exits the plant in the fuel product.

Water consumption is also source-dependent; it is sustainable or not only in reference to supply. Although rain-fed agriculture may be said to use water sustainably, irrigated agriculture is not necessarily unsustainable, depending on the resource available. For this reason, most water-use regulation in the United States is local; state and federal requirements require at most that local agencies address water-use regulation.

Net water consumption in biomass production is not known per se, as it is a function of both water applied and water-use efficiency by crops. The water use for specific crops can be estimated as the average predicted evapotranspiration for specific species under given climatic conditions, and water applied can be calculated as the sum of rainfall and irrigation applied.

Alternatively, best-practice standards for biomass production could ensure the most efficient use of water through the use of precision irrigation targeting and timing. Groundwater irrigation in regions with significant overdraft may be prohibited outright by such best-practice standards.

Measuring water use in biorefining can be done much more directly, and the metric of water per fuel volume produced is easily calculated. However, this still may miss the context-dependent nature of water scarcity, and so biorefineries may also be best addressed through best practices and prohibitions on excessive overdraft.

A.7 Land-use change

Land-use change is an environmental concern insofar as it entails the loss of ecological function, genetic resources, indigenous cultural practices, threatened species' habitats, or even the views and aesthetics of stakeholders. It is a critical issue in the intensification of agriculture that may occur with an expansion of biofuels production.

Land-use change can take a number of forms. Agricultural land in one crop may shift to another crop. Fallow land may shift into cultivation.[12] Natural lands may be cleared and used for cultivation. Even where biofuel crops are grown on existing cropland, the displaced crops may shift to previously marginal land, resulting in clearing of natural lands.

Natural land clearing or fallow land shifting into cultivation can result in the loss of habitat for threatened and endangered species. Refuge habitat for beneficial insects and gene reservoirs may be depleted. Such shifts may result in increased loss of soil and soil productivity as more erodible lands are brought into production. Hydrological function, including runoff and percolation, may change. Changes in climate-influencing conditions of land use, including albedo, evapotranspiration, and loss of soil carbon may influence regional and global climate.

It may be difficult to design a system for measuring land-use change that is comprehensive and inclusive. Connecting specific land-use changes to specific biofuel production can be difficult because of poor data availability and the high potential for temporal or spatial leakage. Spatial leakage occurs where the proximate cause of land-use change is not the biofuel crop but another crop that was in turn displaced from its existing cropland by the biofuel crop. Temporal leakage occurs when land cleared for another crop is used for biofuel crop production in successive years.

Because of the potential for leakage, best-practice prohibitions on feedstocks from recently cleared or converted sensitive land uses are at best a crude tool for addressing this concern, the effectiveness of which is unproven.[13] More comprehensive accounting of land-use change may be measurable only at the aggregate level. That is, we can know whether we have lost significant habitat, or other land use of concern, through time-series inventories after the fact. This may prove a basis for estimation of biofuels' complicity in this change if this total change in acreage is attributed to each biofuel producer in the region.

It is important to note the strong linkage between land-use change and GHG emissions, especially in the case of forested land clearance and peat swamp drainage for biofuel feedstock production. Both concerns provide ample motivation to perform the difficult calculations necessary to quantify land-use change, though care should be taken that the deep interaction of these effects not lead to "double counting" distortions.

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[12] For instance, in the United States it is predicted that increased demand for corn for ethanol production will result in less soybean acreage as well as the "reversion" of lands enrolled in the Conservation Reserve Program.

[13] Where such prohibitions have been strictly implemented, such as the Swampbuster provisions of U.S. farm bills, the effect has been modest. Where these prohibitions have been implemented through voluntary eco-certification systems, the effect has been negligible.

Appendix B: Other Certification Systems

There are numerous examples of environmental standards in use, including organic agriculture certification, forest stewardship, and marine stewardship. The USDA Organic standard is particularly instructive in that the federal law and oversight role were established to prevent confusion among customers and dilution of producers' premiums by multiple standards, some of which were considered overly lax. This is an example of the sort of implementation described in Section 5.1 of the main text being replaced by the sort described in Section 5.2. However, by establishing a nationwide single standard, the regulatory agency faces capture, an inability to adapt to new technologies, and the standards create a barrier of entry to smaller producers.

B.1 USDA Organic

USDA's National Organic Program (NOP) is the product of the Organic Foods Production Act of 1990 (OFPA), the goal of which was a standardization of the definitions and presentation of the "organic" label on consumer goods. The USDA program is thus designed to bring consistency to what was a sometimes competing and confusing patchwork of standards and certifiers for organic production that emerged from multiple state and private actors.

"Organic" is primarily a practice-based standard applied to agricultural production, mostly of foodstuffs, that focuses on the inputs used in production and the methods and management of production. It is both a negative standard that seeks to assure consumers that production did not include certain practices and ingredients considered potentially harmful to consumers or the environment, and a positive standard that requires producers to engage in practices intended to conserve and improve local ecological function. Prohibitions include synthetic fertilizers, pesticides, and additives, and affirmative mandates include crop rotation and reduced tillage. The standard's livestock production guidelines include requirements for animal living conditions such as sufficient physical space, access to open air and sunlight, and provision for "comfort behaviors."

Organic certification is based on the creation of a compliant organic production plan followed by the annual auditing of the producer's operations by authorized certifying agents to assure compliance with the certified plan.

An organic system plan contains six components. First, the plan must describe the practices and procedures used, including the frequency with which they are used, in the certified operation. Second, it must list and characterize each substance used as a production or handling input, including the documentation of commercial availability, as applicable. Third, it must identify the monitoring techniques used to verify that the organic plan is being implemented in a manner that complies with all applicable requirements. Fourth, it must explain the recordkeeping system used to preserve the identity of organic products from the point of certification through delivery to the customer who assumes legal title to the goods. Fifth, the organic system plan must describe the management practices and physical barriers established to prevent commingling of organic and nonorganic products on a split operation and to prevent contact of organic production and handling operations and products with prohibited substances. Finally, the organic system plan must contain any additional information deemed necessary by the certifying agent to evaluate site-specific conditions relevant to compliance with these or applicable state program regulations. Producers or handlers may submit a plan developed to comply with other federal, state, or local regulatory programs if it fulfills the requirements of an organic system plan.

Foreign production of organic products is accommodated in two ways: Foreign organic certification programs are accepted by USDA as substantially equivalent to the U.S. program, or foreign certifying agents are accredited by USDA to apply the NOP standards and directly certify producers abroad.

B.2 LEED®

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System was developed and is managed by a nongovernmental organization, the U.S. Green Building Council. Thus, it is the type of standard described in Section 5.1. LEED is a system for rating the materials and practices used in planning and constructing buildings to communicate the sustainability of the building in five dimensions. These are: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality.

The LEED program uses a system of prerequisites and credits. Each dimension requires certain prerequisite (minimum acceptable) practices, and additional credits are awarded for better performance based on practices and product choices. The overall LEED rating (Certified, Silver, Gold, or Platinum) is thus a combination of achieving prerequisites and earning credits. The use of credit aggregates means that, beyond the minimum prerequisite thresholds, there is an unweighted tradeoff of performance among dimensions.

B.3 Forest Stewardship Council

The Forest Stewardship Council (FSC) is a nongovernmental group organized to develop and apply standards for the sustainable production of timber, pulp, and other forest products. The council's certification is voluntary, serving both as an information tool for producers desiring guidance in sustainable production and as a consumer information device on the basis of which producers can ask a price premium. Thus, it too is the type of standard described in Section 5.1.

The FSC's standards are based on 10 principles of sustainable forest management (see box, below). Three to 10 criteria are also identified for each principle (not shown). These principles and criteria are further defined by region-specific standards. The processes of developing and revising criteria and standards are expected to be as inclusive and transparent as possible. FSC criteria are relatively comprehensive, including substantial concentration on social and economic sustainability.

BOX: Forestry Stewardship Council Principles of Sustainable Forest Management

Principle #1: Compliance With Law and FSC Principles
Forest management shall respect all applicable laws of the country in which they occur, and international treaties and agreements to which the country is a signatory, and comply with all FSC Principles and Criteria.

Principle #2: Tenure and Use Rights and Responsibilities
Long-term tenure and use rights to the land and forest resources shall be clearly defined, documented and legally established.

Principle #3: Indigenous People's Rights
The legal and customary rights of indigenous peoples to own, use, and manage their lands, territories, and resources shall be recognized and respected.

Principle #4: Community Relations and Workers' Rights
Forest management operations shall maintain or enhance the long-term social and economic well-being of forest workers and local communities.

Principle #5: Benefits from the Forest
Forest management operations shall encourage the efficient use of the forest's multiple products and services to ensure economic viability and a wide range of environmental and social benefits.

Principle #6: Environmental Impact
Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest.

Principle #7: Management Plan
A management plan—appropriate to the scale and intensity of the operations—shall be written, implemented, and kept up to date. The long-term objectives of management, and the means of achieving them, shall be clearly stated.

Principle #8: Monitoring and Assessment
Monitoring shall be conducted—appropriate to the scale and intensity of forest management—to assess the condition of the forest, yields of forest products, chain of custody, management activities, and their social and environmental impacts.

Principle #9: Maintenance of High Conservation Value Forests
Management activities in high conservation value forests shall maintain or enhance the attributes that define such forests. Decisions regarding high conservation value forests shall always be considered in the context of a precautionary approach.

Principle #10: Plantations
While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests.

B.4 U.K. Renewable Transport Fuel Obligation

In 2005, the United Kingdom enacted a Renewable Transport Fuel Obligation (RTFO) with goals similar to those of the present proposal, although its scope is limited to reducing GHG emissions from transportation. In support of this program, Bauen, Howes, et al. (2005) propose a GHG emission certification program for renewable transport fuels. The proposal includes several important insights and grapples with many of the logistical challenges of tracking and certifying biofuels along the supply chain. The report explores three main options:

1. No certification
2. Certification based on default values for feedstocks and processes (either with single default values per fuel, or with values differentiated by production pathway)
3. Certification based on verified process data, with a fallback to default values

The authors conclude that option 1 provides no guarantees of GHG reductions; that option 2 is somewhat better but offers little incentive for producers to reduce the global warming impact of fuels; and that option 3 is not only the most beneficial approach in providing incentives to reduce GHG emissions, but also the most likely to survive challenges in the World Trade Organization.

The authors propose a three-tier approach to data collection that uses the best available data while allowing for differences in willingness or ability to provide detailed data. Tier A evidence is based on actual process data, used whenever available. Tier B evidence uses verifiable information about the types of farming systems and processes employed. Tier C relies on default factors based on the scientific literature and is designed to be conservative so as to provide incentives for producers to provide Tier A or B evidence to earn additional credit.

The report also considers the costs of verification and tracking along the supply chain and judges the net impact on fuel prices to be minimal. The authors estimate annual costs in the United Kingdom of about £225 ($425 U.S.) for farms of 250 hectares or larger, £700 ($1,350) per logistic (transport) company, and £2,000 ($3,800) for fuel processing plants.

While this proposal provides an excellent framework for developing a green biofuels index, the proposal fails to address several of the vexing issues raised in the present paper. One of these gaps derives from the study's exclusive consideration of biofuel pathways based on energy crops. Were the authors to broaden their analysis to include waste-to-biofuels pathways, they would encounter conflicts with their "consistency of assessment" principle, which requires consistent system boundaries and coproduct allocation methods across pathways. In addition, the report does not consider the role of markets in determining lifecycle GHGs, although it does characterize several shortcomings of the usual array of coproduct allocation methods.

This proposal also suggests omitting soil emissions, at least initially. However, this omission introduces a bias in favor of corn ethanol relative to cellulosic feedstocks and sugarcane, as N_2O emissions are greater per unit of ethanol produced from corn than from these other feedstocks.

Reference

Bauen, A., J. Howes, et al. (2005). *Feasibility study on certification for a Renewable Transport Fuel Obligation*, E4tech, Edinburgh Centre for Carbon Management Ltd. and Imperial College, London.

Appendix C: Lifecycle Assessment of Biofuels

Lifecycle assessment is the practice of analyzing costs or impacts created by all processes associated with the manufacture, use, and disposal of a product. Lifecycle GHG assessment of fuels computes the GHG emissions in feedstock production (e.g., fossil fuel extraction or biomass agriculture), refining, distribution, consumption in the vehicle, and "disposal" in the atmosphere. The emissions from each of these stages can differ according to feedstock, production processes used, types of materials and energy used, and vehicle technology.

The *combustion* of biofuels is considered to produce no net carbon dioxide emissions since the carbon released as CO_2 during combustion is absorbed from atmospheric CO_2 during feedstock growth. However, the *production* of biofuels does result in greenhouse gas emissions from energy consumption and from chemical and microbial processes. Figure 1 shows the major stages of the corn ethanol production cycle. All stages emit greenhouse gases, although the carbon dioxide from combusting the fuel is not a greenhouse gas because it is made from carbon dioxide recently captured by the plant that creates the biomass feedstock.

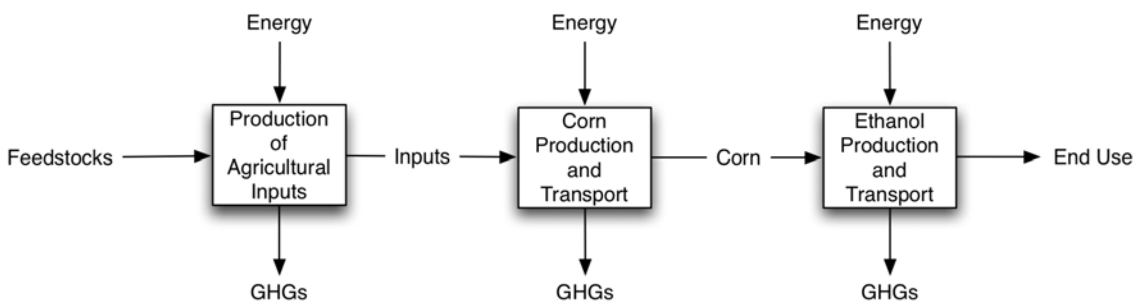

Figure C-1. Corn Ethanol Production Lifecycle

A complete understanding of the environmental impacts linked to the use of biofuels requires an inventory and assessment of all material and energy inputs and effluents resulting from the production of biofuels and biofuel feedstocks.

The formal methodology for performing such accounting is called *Lifecycle Assessment* (LCA). The standard procedure for performing an LCA is defined by ISO 14040 (ISO 2006).

A full LCA includes four stages:

1. Goal and scope definition, including definition of system boundaries and level of detail.
2. Lifecycle inventory (LCI) analysis. In this stage, data are collected on all inputs to and outputs of production.
3. Lifecycle impact assessment (LCIA). In this stage, additional information is collected to help understand the results of the inventory analysis and the product's environmental performance.
4. Interpretation. Summarizes and discusses the results of the LCI and LCIA stages, with recommendations in accordance with the goals of the LCA.

Many biofuels analyses are partial LCAs focused on particular inputs such as energy (e.g., Morris and Ahmed 1992; Graboski 2002; Shapouri, Duffield, et al. 2004) and outputs such as greenhouse gases (e.g., Dias De Oliveira, Vaughan, et al. 2005). Argonne National Laboratory's GREET model is a partial LCA with a fairly broad scope, tracking energy inputs and numerous effluents including greenhouse gases, criteria pollutants, and particulate matter, but it doesn't track other inputs such as water and other materials, nor effluents such as nutrient runoff and soil erosion (Wang 1999).

The cases examined in this study were evaluated in GREET 1.7, which computes the fuel cycle energy use and emissions for a wide range of fuels and automotive technologies. In the case of biofuels, GREET is designed to estimate the emissions from the average feedstocks used in the industry's average conversion facilities. To permit the analysis of specific pathways, we used a version of the spreadsheet modified by GREET author Michael Wang to model the fuel cycle energy use and emissions for several different ethanol production process configurations. We further modified the model to incorporate different corn production data from Shapouri et al. (2004) for the states of Illinois, Minnesota, and Nebraska.

C.1 Difference between aggregate lifecycle analysis and individual impact analysis

Most lifecycle analysis of biofuels considers the environmental impacts associated with producing a marginal quantity (e.g., a gallon or megajoule) of biofuel. A regulatory system, however, is intended to consider the individual impact of each unit of biofuel. In many dimensions, these differences in perspective of analysis do not matter, but in some very important dimensions the differences are significant. These dimensions are:

- Coproduct allocation
- Baseline
- Land-use change (including habitat alteration)
- Food prices

C.2 Coproduct allocation

Lifecycle assessment of biofuels to date has largely been concerned with examining the total impacts of embracing a particular biofuel production pathway, usually in comparison with another fuel production technology. Though these impacts may be expressed on a small-unit basis (such as liters or gallons of fuel), they are derived from an examination of an aggregate system (such as the 4 billion to 5 billion gallons of ethanol produced in the United States in 2006). Starting from an aggregate analysis provides certain advantages. Often the average inputs into production are used; thus the tradeoffs between fertilizer and yield that vary dramatically with geography are covered over in the average input budgets and yield reports of the USDA statistics. And coproduct "credits" are often awarded based on the displacement of products in substitute markets—a displacement that can be discerned only in an aggregate analysis.

The most sophisticated lifecycle assessment seeks to answer this question: *What is the net impact of a given policy choice (e.g., promoting a major expansion in biofuels production) versus some baseline?* This analysis would need to encompass changes in production and impacts across multiple markets. Lifecycle analyses of biofuels for certification purposes would need to determine the impact of producing a marginal unit of ethanol, which, by definition, doesn't affect the market.[14] This regulatory-level lifecycle analysis asks this question: *What is the actual, gross impact of producing this one unit of biofuel?* (Delucchi 2005)

The difference between these analyses is especially apparent in the allocation of production impacts to the coproducts of biofuels. State-of-the-art aggregate lifecycle analysis credits coproducts with the impacts that would have occurred from producing a substitute product, based on substitution effects that can be discerned only in aggregate market effects.

Five methods of coproduct allocation have been used in lifecycle analysis:

- Process model: Allocate impacts based on engineering model of production process
- Mass balance: Allocate impacts by relative weight of products
- Energy balance: Allocate impacts based on relative energy content of products
- Market value: Allocate impacts based on relative market value of products
- Displacement: Calculate impact of substitute product and assign this value to coproduct

The process model approach is most useful where it is easiest: where the aspects of production necessary for coproducts are clearly conceptually separable from the main product. The mass balance approach has almost no theoretical justification, except for impacts directly related to mass (such as transportation costs). Energy balance may be an appropriate method where coproducts are energy products; otherwise it too is limited. Market value is potentially very useful in that it encompasses many of the tradeoffs and substitutability that the displacement method also tries to incorporate in an intrinsically responsive, marginal indicator of price. But market price volatility can make this an unreliable indicator, and economic externalities, especially in the impacts these methods are used to evaluate, ensure that market prices will not accurately allocate nonmarket impacts.

The displacement method, especially the “system expansion” approach, is theoretically robust and powerful at capturing the effects of a contemplated or past policy change at the aggregate level. Even in this use, however, displacement has functional faults. Displacement awards credits against actual impacts for impacts theoretically avoided—an issue that implicates questions of “baseline” and “additionality” familiar to critics of offsets in other contexts. It also leads to circular arguments, where a coproduct credit (of, for instance, corn ethanol) is based on the primary product in another system (i.e., soy), which is in turn evaluated based partially on the fact that it displaces the first product (i.e., corn).

Most important, displacement based on aggregate economic equilibrium analyses is not appropriate for evaluating the coproducts of specific products from specific producers. These producers use unique processes to produce coproducts with unique characteristics that are sold into specific markets. There may be substantial discretion for choices by biofuel producers that affect the real-life impacts of producing and consuming those coproducts.

[14] Typical biofuel LCAs don’t really model marginal production, either. Instead, they rely on various averages (e.g. wet and dry mills over decades of technological change and corn production across various states and years) while attempting to identify the marginal MJ of ethanol for this statistically defined process. When using averages, it is more appropriate and meaningful to examine the impact of the total ethanol produced by the plants included in the average—compared to having produced no ethanol at all.

For these reasons, coproduct credits will need to be a primary and continual research topic for any green biofuels standard. Some credit must be awarded for any coproducts that have positive value. This credit should be an actual quantity of impacts (as opposed to a percentage) deducted from the primary product's inventory. The credit could be informed by displacement, market value, process modeling, and even mass and energy where appropriate, but ultimately the choice of coproduct credits will be somewhat arbitrary. Therefore it should be determined by a panel of experts in an open, transparent process and should be updated regularly.

C.3 Baseline, or the "zero option"

One requirement of a GHG accounting system for biofuels is that the analytic framework be consistent across pathways. To have it otherwise would create a bias toward some fuel pathways. Expanding the biofuels lifecycle analysis to include some processes, notably waste-based pathways, highlights additional problems with the analytic approach typically used for crop-based pathways.

Most crop-based LCAs treat all emissions from the studied process as additional to a hypothetical status quo. These studies do not consider the GHGs from the alternative fate of corn or of cornfields, implicitly assuming the corn wouldn't be grown if not for ethanol, and that idle land has a global warming potential of zero—both false. In fact, a substantial fraction of the corn used for ethanol would likely be grown in any case to meet the demand for feed, which is partially met by distillers grains coproduced with corn ethanol. A recent analysis concluded that 34 percent of the feed value of corn is available in distillers grains coproduced with ethanol (Jones and Thompson 2006).[15]

In contrast, waste management LCAs do account for the alternative fate of the waste when considering various management options (Finnveden, Johansson, et al. 2000; Eriksson, Carlsson, Reich, et al. 2005; Lombardi, Carnevale, et al. 2006). Typically, waste-to-energy alternatives receive a credit for methane emissions avoided by not landfilling. Because this is not equivalent to the "zero option" of crop production, avoided emissions should not be counted as "coproduct" of waste-to-biofuel processes.

C.4 Leakage, or can the tail wag the dog?

Biomass production for biofuels is only a small portion of agriculture. When a regulatory system is imposed on only a part of an industry, several processes can serve to dilute the change for which the regulation was designed. In these cases, it may be difficult for regulations on biofuels to affect the actual practice and results of agriculture; it may not be possible for the tail to wag the dog.

C.5 Imports and leakage

Leakage occurs when emissions increase in unregulated areas that counteract reductions in a regulated area. For example, under a regime that prohibits biofuels production on deforested land, producers could convert cropland to palm plantations while clearing rainforest to provide

[15] Graboski (2002) computed a value of 72%, but at that time the ethanol industry comprised 54% wet-mills; the current fraction is 20%. Wet-mills generate coproducts with higher feed value than do dry-mills. Graboski also assumes the use of soy hulls (an otherwise unused residue of soybean production) to increase caloric content.

more cropland. Bauen, Howes, et al. (2005) recommend disallowing biofuels produced on recently cleared land from a regulated trading regime. However, this is not guaranteed to prevent leakage, as land is fairly fungible: Lands cleared more recently than, say, 10 years ago might be used for export markets where no restrictions apply, while land cleared more than 10 years ago would be used for regulated markets. Note that this can be a problem for domestically produced as well as imported biofuels, most notably if Conservation Reserve Program (CRP) or other grasslands are converted to row crops such as corn and soybeans.[16]

C.6 Spatial leakage

Biomass produced in one location creates pressure on agriculture in other locations. Crops that are displaced by biofuels face extensive and intensive pressure elsewhere. These pressures may take the form of increased emissions from fertilizers and pesticides, or they may lead to habitat loss as production expands.

C.7 Temporal leakage

It is difficult to capture all impacts caused by current biomass development because some impacts may be lost in temporal leakage. For example, biofuel producers wishing to avoid being charged the impacts of land clearing need only wait—by growing alternative crops—for a period of time before the biofuel crop is planted.

C.8 Sorting

In the heterogeneous world of agriculture, some farmers will naturally have lower environmental impacts than other farmers producing the same crop. Under a system of regulation or certification that creates a requirement for low-impact crops in a much larger overall market, low-impact crops may be directed to the regulated use while higher-impact producers sell into the general market. The net result may be no net change in practice, although a higher price may be paid to low-impact producers. This is not a necessary result, but it is a possible one.

C.9 Comparing Biofuels LCAs

When comparing the results of LCAs, it is essential to understand the specific system boundaries and the sources and vintage of all data used in the analysis. Published biofuels energy analyses generally differ somewhat in these regards, leading to incommensurate results (Farrell, Plevin, et al. 2006). For example, some authors of biofuels energy analyses include the energy required to build farm machinery or to feed workers; others do not. Most, but not all, authors allocate some input energy to the salable products such as the distillers grains coproduced with the biofuel. Allocating all input energy to one of the products unduly inflates the energy estimate for that product and contradicts standard LCA methodology (Farrell, Plevin, et al. 2006; ISO 2006). Most biofuels analyses that consider greenhouse gases track only carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), yet climate change is impacted by other biofuel-related emissions such as aerosols, particulates, and “indirect” greenhouse gases such as carbon monoxide and non-methane organic compounds (NMOCs), which participate in the formation of ozone, which is a direct GHG (Delucchi 2004).

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[16] See Bauen et al. (2005) for discussion of how biofuel certification relates to international trade rules.

Due to the limited availability of current data, the values used in the LCI and LCIA stages are often contentious and, in many cases, unrepresentative of current practices (Farrell, Plevin, et al. 2006). Decades-old process energy data, for example, are particularly problematic given the rapid evolution of the biofuels industry, which nearly tripled in production capacity in the United States between 2001 and the end of 2006 (Ethanol Renewable Fuel Association 2006). During this period, conversion yields have increased and process energy requirements have decreased, and the percentage of industry capacity relying on the more efficient dry-grind process has increased (Energy and Environmental Analysis Inc. 2006; Plevin 2006).

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