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Biofuel Supply Chains: Impacts, Indicators and Sustainability Metrics

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Biofuel supply chains in the United States are expected to expand considerably, in part due to the Energy Independence and Security Act (EISA) of 2007. This law mandates through the EPA's Renewable Fuel Standard an expansion to 36 billion gallons of renewable fuels per year by 2022. This paper considers these expanding biofuel supply chains and example impacts, indicators and sustainability metrics for evaluating them. In particular, the impact category considered is reduction of greenhouse gases, the indicator studied is the amount of yield for biofuel crops, and the sustainability metric reviewed is the energy ratio. Ranges of values are found for each of these, and variability and tradeoffs are the expected results in the study of biofuel supply chains.

1. Introduction

In the United States, a large number of corporations, academics and Federal Agencies are interested in the expanding supply chains for biofuels. See Figure 1 for expected quantities of biofuels in the U.S. The U.S. Environmental Protection Agency (EPA) has documented a Final Rule for Changes to the Renewable Fuel Standard (Federal Register, 2010) and a corresponding Regulatory Impact Analysis (U.S. EPA 2010). Other Agencies including the U.S. Department of Agriculture and U.S. Department of Energy are leading research and development efforts through the Biomass Research & Development Initiative (supported by a board of 11 Agencies). EPA is responsible for a triennial Biofuels Report to Congress, with the first Report complete in 2010.

A number of organizations are working on biofuel criteria, indicators and standards. Included in these organizations are the American National Standards Institute, the International Organization for Standardization, the Global Bioenergy Partnership, the Council on Sustainable Biomass Production, the Roundtable on Sustainable Biofuels, and the Interagency Working Group, among others. Indicators are one way of evaluating biofuel supply chains.

Another method for assessing the environmental aspects of biofuel supply chains is through impact assessments as found in life cycle assessments. Example impact methods are available in tools such as the Waste Reduction Algorithm (WAR) - Young and Cabezas, 1999 - the Tool for the Replacement and Assessment of Chemical and

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other environmental Impacts (TRACI) - Bare et al., 2003 - and the Dutch consensus method ReCiPe - Goedkoop et al., 2009.
In this paper, a third method for assessing biofuel supply chains is through sustainability metrics. These metrics are comprised of aspects of the overall system, whereas the indicators and impacts described above can be specific to only a particular part of the system. For instance, toxicity might be equated with only part of the system (e.g., burning fuels in vehicles). This differs from the sustainability metrics developed and used by Hopton et al. (2010) for a region of the U.S., such as system emergy, ecological footprint, green net regional product, and Fisher information.
This paper will briefly discuss example impacts, indicators and sustainability metrics for biofuels, with the understanding that many other examples could be used.

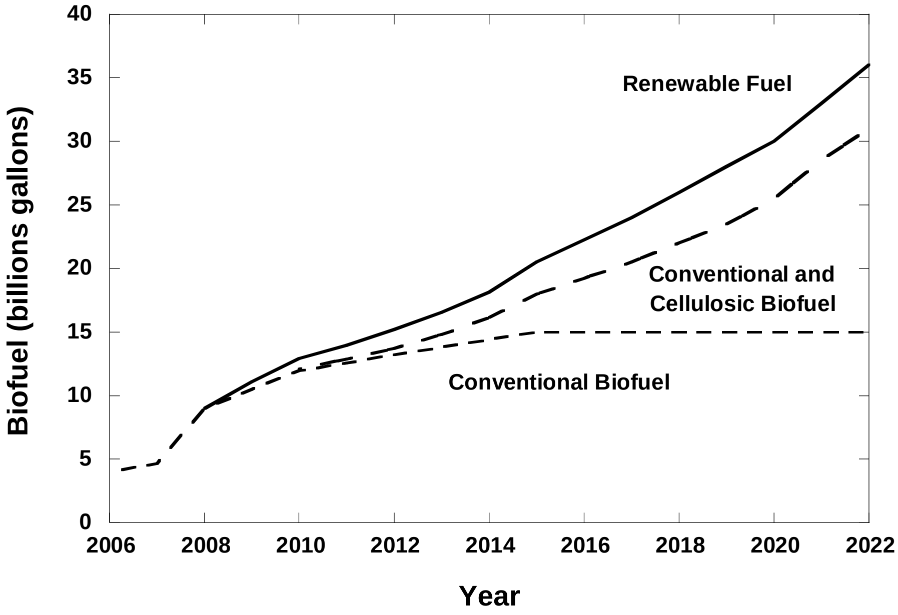

Figure 1: U.S. projected biofuel production amounts.

2. Impacts, Indicators and Sustainability Metrics

The following subsections describe examples in the areas of impacts, indicators and sustainability metrics.

2.1 Impacts
There are many environmental impacts listed in tools such as TRACI, WAR, ReCiPe, etc. Examples of these include global warming potential, ozone depletion potential, smog formation, eutrophication, various toxicity potentials, among others. In any analysis of biofuels, one should not be surprised to find tradeoffs among the various impact categories. This paper will consider only global warming potential as represented by greenhouse gas (GHG) reductions.

In the U.S. only certain processes have been found to meet the requirements for reductions in GHGs (Federal Register, 2010, Tables V.C-6 and V.C-7), with older processes grandfathered in as compliant. Corn-to-ethanol processes are required to reduce greenhouse gases by an average of 20 % or more. Compliant processes include dry mills using natural gas (or biomass or biogas) for process energy and drying 50 % or less of their distillers' grains with solubles (DGS). Other similar compliant processes include those that use one advanced technology (listed below) that dry 65 % or less of their DGS. Processes that dry all of their DGS need to use two advanced technologies.
Advanced technologies for corn-to-ethanol production include corn fractionation, corn oil extraction, raw starch hydrolysis, membrane separation, and combined heat and power (CHP). Fractionation is a physical process that separates kernels into germ, bran and endosperm so they can be processed separately into co-products. (Distressed) corn oil (i.e., oil suitable in feed or for fuel applications) extraction is produced by centrifuging of thin stillage and/or DGS. The raw starch hydrolysis process is a cold starch fermentation that has been described as reducing energy needs, increasing production rates, and decreasing process emissions. Membranes may be able to replace some distillation and molecular sieve processes. Combined heat and power uses one fuel to produce electricity and steam from waste heat (U.S. EPA, 2010, pp. 95-99).

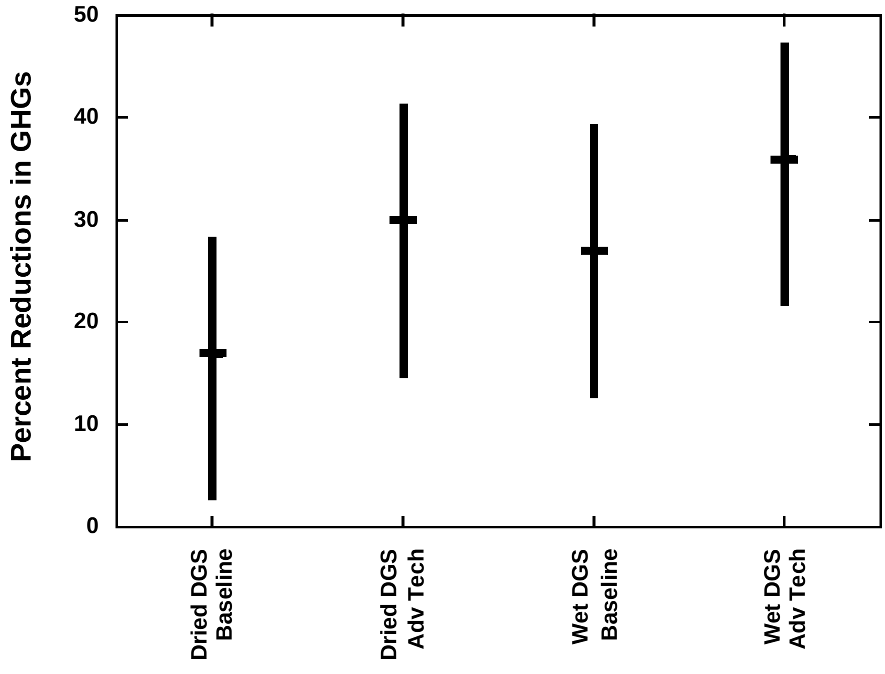

Figure 2: Reductions in greenhouse gases relative to gasoline for dry mills producing dried and wet distillers grains with solubles, using natural gas and either baseline or four advanced technologies. Maximum and minimum values show 95% confidence ranges (U.S. EPA, 2010, Table 2.6-1).

Reductions in greenhouse gases for dry mill corn-to-ethanol processes are presented in Figure 2. The processes shown describe the range of reductions available from using various technologies, from a baseline that does not use advanced technologies to processes that use four: fractionation, raw starch hydrolysis, membranes and CHP (the "Adv Tech" columns). Note that some compliant processes dry a fraction of their DGS. Wet DGS spoils easily and thus must be used quickly (i.e., close to the mill). Thus, one strategy for improving GHG performance of biofuel supply chains is to colocate mills and livestock areas, which would also reduce transportation energy use and emissions.

2.2 Indicators

Indicators can be defined as ratios that describe part of a process or product without describing the whole system (as sustainability metrics do). Example metrics for biofuels can include ethanol yield per amount of starch fed to a process, vehicle miles traveled per volume of fuel, etc. In this paper, the amount of crops produced per hectare will be described.

Figure 3 shows crop yields per hectare for various crops. The materials described in the figure are not all the same, i.e., sugar, starch, lignocellulose, so the amounts shown give values that newer crops can consider as targets. For example, most lignocellulosic values are in the range of 10-13 Mg / ha. However, lignocellulose is not a uniform category either, as hard woods, soft woods, switchgrass, etc. can differ widely. This indicator is just a piece of information that can help describe biofuel supply chains.

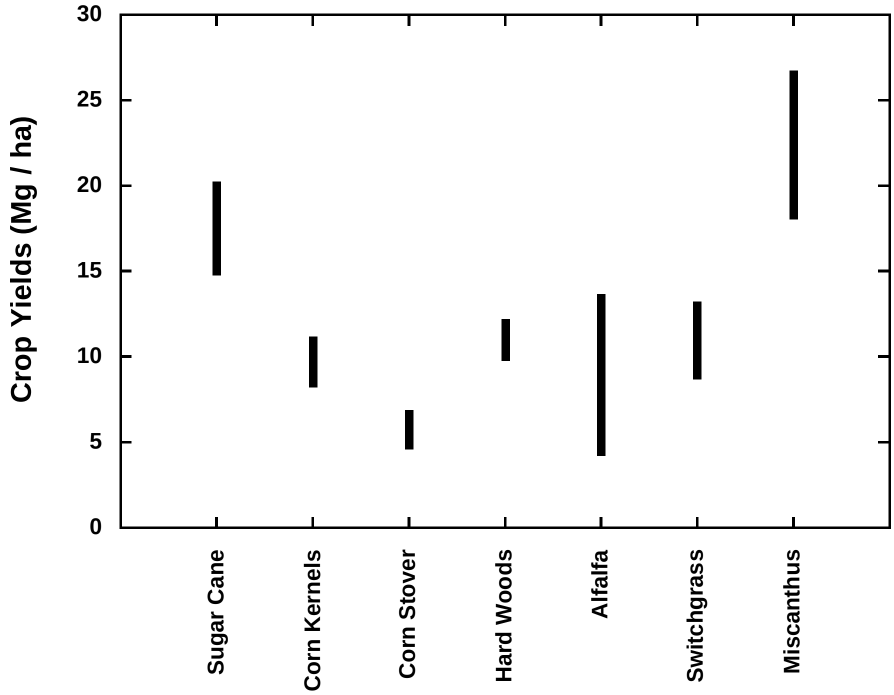

Figure 3: Crop yields for various crops, showing the range of values found in the literature. References for the values reported include Rogner et al. (2000), Heaton et al. (2004), Hoskinson et al. (2007), and Vadas et al. (2008).

2.3 Sustainability Metrics

Energy can be considered to be at the center of environmental, economic and social analyses; it affects all three pillars of sustainability (Sikdar, 2003). A review of energy indicators has been done by Gnansounou and Dauriat (2005), as well as by Farrell et al. (2006), and by Granda et al. (2007). Gnansounou and Dauriat's work reviewed energy ratios (from 25 publications), defined as the heat content in a fuel divided by the fossil energy consumed to produce a fuel, and found that five of the publications had energy ratios less than one. All of the ratios less than one were for the corn-to-ethanol supply chain (some were above one), whereas sugar beet, cereals and lignocellulosic energy ratios were all greater than one, and some of the ratios for lignocellulosic ethanol were twice or more than the averages for the other feedstock ratios. Farrell et al (2006) report net energy values, net greenhouse gas emission values, and petroleum input values based on several publications for corn-to-ethanol. The cellulosic ethanol ratios show much larger net energy values. The final review by Granda et al. (2007) also reports dramatically larger values of the energy ratio for non-corn ethanol. Repeatedly, studies show that ethanol made from sugarcane or lignocellulose give large positive net energy ratios. This sustainability metric shows that lignocellulosic ethanol has promise as a sustainable liquid biofuel.

3. Conclusions and Future Work

This paper has considered expanding biofuel supply chains and some example impacts, indicators and sustainability metrics for evaluating them. The impact category considered was the reduction of greenhouse gases, showing how certain processes and technologies meet U.S. limits, and how various technologies lead to increased reductions. The indicator studied in the paper was the yield of biofuel crops, showing the high yields of corn kernels and sugar and the prospect for miscanthus to produce large amounts of lignocellulose. Finally, one sustainability metric was reviewed, the energy ratio. Sugar- and lignocellulosic-based ethanol processes had much better energy ratios than corn-to-ethanol processes.

Future evaluations of biofuel supply chains will consider life cycle analyses with impact assessments, indicators and sustainability metrics used to assess the information derived from the studies. Supply chain modeling will examine ways that supply chain infrastructure can develop, and how changes in supply chains can lead to different effects in the evaluations.

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