BIOFUELS

An Important Part of a Low-Carbon Diet

UNION OF CONCERNED SCIENTISTS
CLEAN VEHICLES PROGRAM

November 2007

The Union of Concerned Scientists is the leading science-based nonprofit working for a healthy environment and a safer world.

The UCS Clean Vehicles Program develops and promotes strategies to reduce the adverse environmental impact of the U.S. transportation system.

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Executive Summary

To reduce transportation-related emissions—responsible for nearly 40 percent of the United States' total global warming pollution—we need more efficient vehicles, fewer miles driven, and lower-carbon fuels (i.e., fuels that generate significantly less heat-trapping gases per unit of energy delivered than today's petroleum-based gasoline and diesel). Hydrogen, electricity, and biofuels (fuels produced from plants) all have the potential—if produced in a sustainable manner—to not only reduce transportation-related emissions but also promote economic and energy security by curbing our country's growing oil dependence.

Biofuels can quickly become a staple of a low-carbon fuel diet because they integrate well with our existing fuel distribution infrastructure and offer potentially abundant domestic supplies with significant opportunities for growth. But not all biofuels are the same. There is a wide range in the estimated heat-trapping emissions and other environmental impacts from each biofuel over its life cycle (i.e., from farm to finished fuel to use in the vehicle), depending on the feedstock, production process, and model inputs and assumptions. There are also concerns about emissions and impacts from land conversion and land use associated with biofuel production.

New rules are being developed that will require fuel providers to account for and reduce the heat-trapping emissions associated with the production and use of transportation fuels. For example, both the U.S. Congress and Environmental Protection Agency (EPA) are considering strategies to promote low-carbon and renewable transportation fuels (including biofuels). California, the nation's largest market for transportation fuel, is developing a Low Carbon Fuel Standard that will require fuel providers to demonstrate reductions in global warming pollution per unit of energy delivered, regardless of fuel source. More state, regional, and federal rules will undoubtedly follow.

The purposes of this report are two-fold:

1. To ensure that we "count carbs" accurately, by explaining why we need a comprehensive accounting system for carbon emissions—one that measures global warming emissions over a transportation fuel's entire life cycle. An effective accounting system will not only need to be robust enough to encompass the fuel life cycle, but also address uncertainties and allow for changes over time as better assessment tools and methods become available.

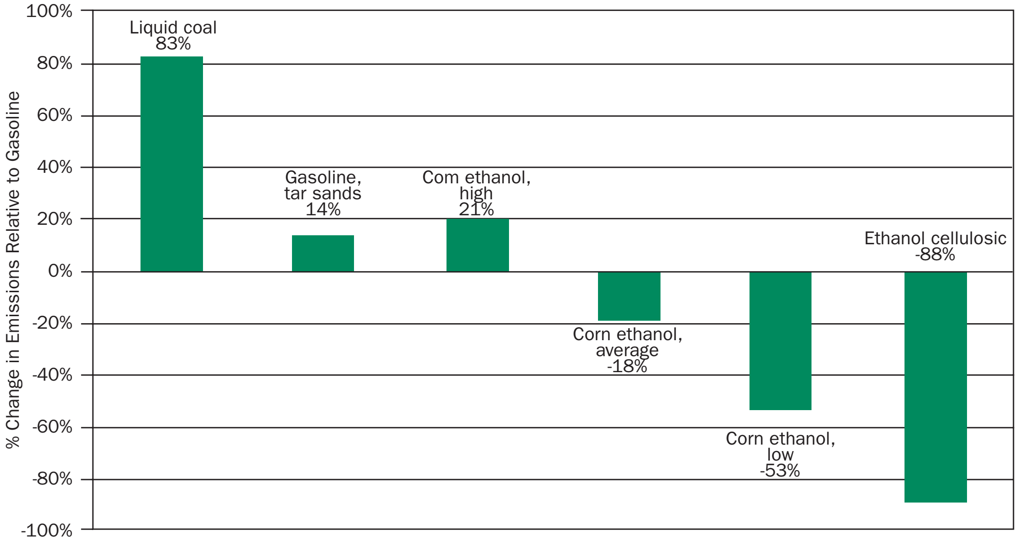
2. To "make carbs count" by describing performance-based policies that will reward low-carbon transportation fuels for their performance and help them compete against highly polluting fuels such as liquid coal (gasoline or diesel made from coal). For example, low-carbon fuel standards require a reduction in the average amount of global warming pollution per gallon of fuel.

A market for low-carbon fuels can produce a rare convergence of business, agricultural, and environmental interests that, if pursued wisely, could represent a "win-win-win" opportunity. But the promise of a lower-carbon transportation future can only be realized through federal and state policies that "count carbs and make carbs count."

COUNTING CARBS

To fully assess the global warming impact of transportation fuels, we must measure their full life cycle emissions per unit of energy delivered. This poses an analytical challenge for a number of reasons. For

FIGURE ES-1 **Life Cycle Global Warming Pollution Relative to Gasoline**



NOTE: These values do not include all potential sources of global warming pollution, particularly the effect of direct or indirect land use changes. Actual global warming emissions may be higher than these estimates.

SOURCES: Gasoline estimate is from Wang (2006). Liquid coal estimate is from Williams (2005). Gasoline from tar sands estimate is from Moorhouse (2006). High corn ethanol estimate is based on ethanol used in California but produced in a Midwest coal-fired dry mill (Unnasch et al. 2007). Current industry average for corn ethanol is from Farrell et al. (2006a). Low corn ethanol estimate is based on ethanol produced in a biomass-fired wet mill (Turner et al. 2007). Cellulosic ethanol estimate is based on switchgrass (Farrell et al. 2006a).

example, plants capture carbon dioxide (CO_2, a potent heat-trapping gas) from the atmosphere during photosynthesis, but the impact of this carbon capture on biofuel emissions varies by feedstock. The global warming pollution produced by farming varies depending on the farming equipment, fertilizers, tillage practices, and perhaps most important, whether forests and grassland are converted into cropland. Even the refining process used to convert biomass into biofuels produces varying amounts of heat-trapping emissions.

Figure ES-1 illustrates how emissions may vary depending on the feedstock and refining process. Liquid coal, for example, can increase emissions more than 80 percent compared with gasoline. Gasoline produced from tar sands can increase emissions about 14 percent. Corn ethanol, depending on how it is processed, can produce higher emissions than gasoline or cut emissions more than 50 percent. Cellulosic ethanol, which is made from woody plants, may be able to reduce emissions more than 85 percent.

Life cycle analysis tools such as the U.S. Department of Energy's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (Wang 2006) have been critical in building understanding of the full impact of transportation fuels. But there is currently no scientific consensus on a single analytical approach, particularly for biofuels. Key areas of debate include the impact of land use changes, fertilizer use and emissions, coproducts, process emissions, and uncertainties or poor data (Farrell and Sperling 2007a).

While life cycle models typically estimate that today's average corn ethanol cuts global warming pollution about 20 percent compared with gasoline, some researchers estimate that it may actually ***increase*** global warming pollution (Patzek 2007). Similarly, biodiesel is generally credited with a 50 percent reduction in global warming pollution (Hill et al. 2006), but there is also research indicating that it may increase emissions as well (Delucchi, unpublished, in Farrell and Sperling 2007a). In addition, biofuel production could exacerbate deforestation, generating more global warming pollution and a host of concerns about the industry's sustainability.

The key to improving our understanding and quantification of life cycle emissions is to hold transportation fuel providers responsible for their global warming pollution. Our current system provides no incentive for fuel providers to accurately measure or minimize their carbon emissions. In contrast, a system that requires providers to account for their emissions would spur increased research into life cycle analysis and provide a public process for evaluating the benefits and limitations of different analytical methods. By developing emissions standards that are periodically updated using the best data available, the market can steer fuel production toward lower-carbon pathways.

MAKING CARBS COUNT

Without a framework in place to lower the carbon intensity of our transportation fuels, we risk losing a precious opportunity to cut our global warming pollution substantially. We therefore need smart fuel policies such as California's Low Carbon Fuel Standard, which is slated to take effect as early as 2010. This standard does not "pick winners" by focusing on specific fuels, but instead relies on performance criteria that require each gallon of fuel (on an energy-equivalent basis) to meet a standard for global warming pollution that becomes more strict over time. The standard encompasses the fuel's entire life cycle, promoting carbon reduction along every link in the fuel supply chain.

Low-carbon fuel standards would also create market certainty for cleaner fuels and complement existing vehicle standards by ensuring the fuel industry does its part—along with automakers and consumers—to reduce transportation-related emissions. Other states considering such regulations include Arizona, Minnesota, New Mexico, Oregon, and Washington.

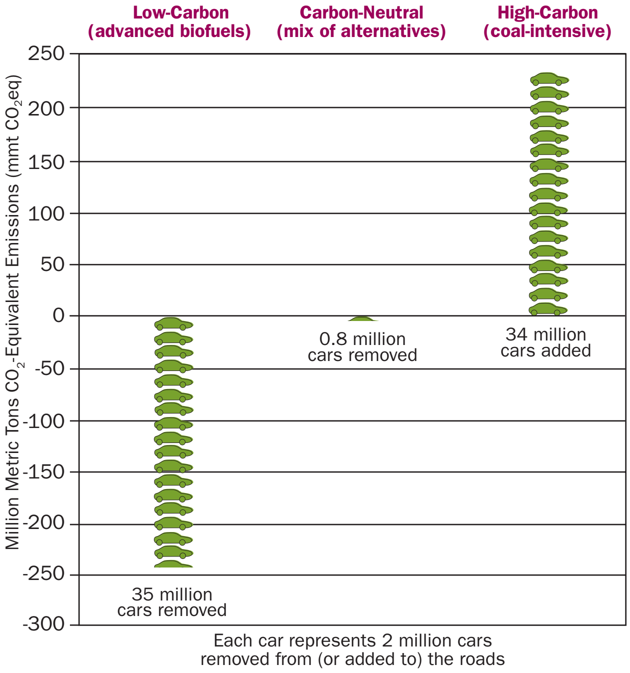
At the national level, efforts are under way to incorporate heat-trapping emissions requirements into the current Renewable Fuel Standard, and several bills have been introduced in Congress that would establish a separate low-carbon fuel standard. The Bush administration is also preparing rules for reducing gasoline use that would include a low-carbon fuel component.

THE BENEFITS OF A LOW-CARBON DIET

The stakes are extremely high when it comes to determining the mix of transportation fuels we will use to reduce our heat-trapping emissions. This becomes clear when comparing three scenarios designed by the Union of Concerned Scientists to displace 37 billion gallons of gasoline (Figure ES-2).

We evaluated each fuel's life cycle emissions and included all heat-trapping gases on a CO_2-equivalent (CO_2eq) basis (i.e., the amount of CO_2 that would have the same global warming potential as another gas). For the purposes of this analysis, we made the following assumptions: compared with today's gasoline, conventional biofuels would reduce global

FIGURE ES-2 **Global Warming Pollution from Three Alternative Fuel Scenarios**



NOTES: Each scenario assumes that 37 billion gallons of gasoline are displaced by alternative fuels and that conventional biofuels meet 25 percent of the demand for alternative fuels. In the low-carbon scenario, advanced biofuels meet the remaining 75 percent of demand. In the carbon-neutral scenario, the remaining demand is split equally between low- and high-carbon fuels. In the high-carbon scenario, liquid coal meets the remaining 75 percent. We assumed conventional biofuels reduce global warming pollution by 20% relative to gasoline, advanced biofuels reduce global warming pollution by 70%, and high-carbon liquid coal increases global warming pollution by 80%.

warming pollution by 20 percent; advanced low-carbon biofuels would reduce emissions by 70 percent; and high-carbon liquid coal would increase emissions by 80 percent.

Our scenarios also assume that one-quarter of the total demand for alternative fuels will be met with conventional biofuels, while the share provided by liquid coal and advanced biofuels varies. This produced the following key findings (Figure ES-2):

- In the high-carbon scenario (in which liquid coal meets 75 percent of the demand for alternative fuels), global warming pollution would *increase* by 233 million metric tons (mmt) CO_2eq—the same impact as adding approximately 34 million cars to the road (about two year's worth of new vehicle sales at today's rate).

- In the carbon-neutral scenario (in which liquid coal and advanced biofuels each meet 37.5 percent of the demand for alternative fuels), emissions are reduced by just 5 mmt CO_2eq—the same impact as removing 0.8 million cars from the road.

- The low-carbon scenario (in which liquid coal does not gain a foothold and advanced biofuels meet three-quarters of the demand for alternative fuels) will only be possible if policies that require a reduction in global warming pollution from transportation fuels are put in place. In this scenario, global warming pollution would be reduced by more than 244 mmt CO_2eq—the same impact as removing approximately 35 million cars from the road.

Focusing on low-carbon fuels may be good not only for public health and the environment, but also for business. Demand for lower-carbon fuels can create new opportunities for the agriculture and forestry sectors (which can provide a diverse array of energy crops) and for renewable fuel producers (who can lead the transition to cleaner resources and away from high-carbon alternatives such as liquid fuels from tar sands, oil shale, and coal). The domestic economy should also benefit from expanded consumer choice and new job opportunities for scientists, engineers, construction workers, and the many others who would help develop and deploy low-carbon fuel technologies throughout the United States.

THE OTHER KEYS TO A LOW-CARBON DIET

A system that only accounts for carbon emissions is not enough to ensure sustainable fuel production due to the fact that petroleum and alternative fuels can both do serious harm to the environment. Locating and extracting oil, for example, can disrupt and contaminate underground aquifers and cause land subsidence and damage to wildlife and ecosystems. As oil becomes more expensive, the pressure to drill in sensitive areas such as Alaska's Arctic National Wildlife Refuge intensifies. Liquid coal production would expand the especially destructive practice of mountaintop removal mining. And if done wrong, biomass production could destroy habitats, worsen water or air quality, raise food prices, and even jeopardize the long-term viability of the biomass resource itself.

A low-carbon fuel standard that accounts for all of the global warming pollution produced over a fuel's entire life cycle would help prevent some—but not all—of these harmful impacts. For example, a full accounting of the global warming pollution generated when virgin lands are converted into coal mines or agricultural lands would help advance broader objectives such as biodiversity and the preservation of open space. Accounting for heat-trapping nitrous oxide emissions from the fertilizers used to grow biofuel feedstocks would encourage reduced fertilizer use, which in turn would help protect water and air quality. Nevertheless, standards designed to reduce a fuel's global warming pollution will not address all of the fuel's potentially harmful impacts—especially social issues such as food access and pricing.

The most comprehensive low-carbon fuel policies will therefore provide adequate safeguards for ensuring that fuels are produced in a sustainable manner. While there is no international consensus on a single accounting system that would certify biofuel production as "sustainable," efforts are under way (both in Europe and the United States) to develop consistent metrics. Marrying a low-carbon fuel standard with environmental protections will give us a head start on the road to cleaner and more sustainable transportation fuels.

CHAPTER 1

Introduction

Global warming is one of the most serious challenges humankind has ever faced. The U.S. National Academy of Sciences, the U.N. Intergovernmental Panel on Climate Change (Parry et al. 2007), and scientific academies of 10 nations have all stated that human activity is changing our climate at an unprecedented rate. Every time we drive a car, use electricity from coal-fired power plants, or heat our homes with oil or natural gas, we release carbon dioxide (CO_2) and other heat-trapping gases into the air. We therefore have a fundamental responsibility to future generations to address this profound threat to the natural world before the most dangerous consequences become irreversible.

To avoid such dangerous climate change, the United States and other developed countries must reduce their global warming emissions at least 80 percent below 2000 levels by mid-century (Luers et al. 2007, Meinshausen 2006). This goal is attainable, but only if we act immediately and address both our energy supply and energy demand—by using energy more efficiently and shifting to renewable energy resources such as wind, solar, and bioenergy/biofuels.

Biofuels—transportation fuels produced from organic matter (or "biomass")—may have the potential to increase our energy security, promote economic development, and, most important, decrease global warming pollution. But expanding biofuel production does not automatically guarantee decreases in global warming pollution. For example, clearing forestland to grow biofuel crops could result in an *increase* in heat-trapping emissions. Unchecked, large-scale expansion of biofuel production and use could have other unintended economic, environmental, and social consequences such as higher food prices, loss of biodiversity, and contaminated water supplies.

Definitions: Bioenergy and Biofuel

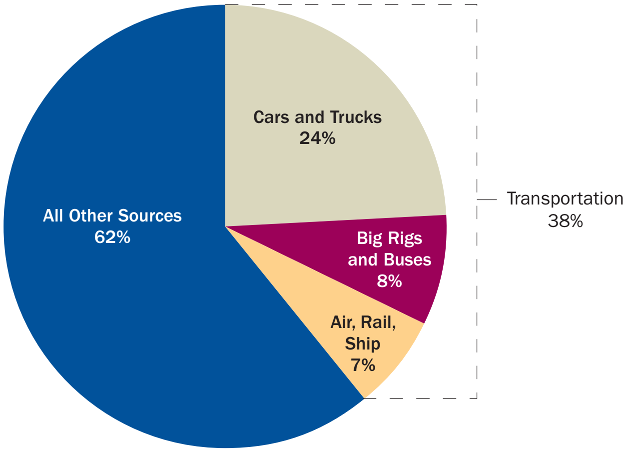
Bioenergy refers to electricity and solid, liquid, or gaseous fuels derived from **biomass**: plant- or animal-based materials such as crops, crop residues, trees, animal fats, by-products, and wastes. These materials are often obtained from agriculture and forests, but can also be derived from industrial and municipal waste streams including landfills and food processing facilities.

Biofuels are a subset of bioenergy, and include solid, liquid, or gaseous fuels derived from biomass. For the purposes of this report, biofuel refers specifically to liquid or gas transportation fuels such as ethanol and biodiesel.

We must therefore develop this resource in a way that meets our current energy needs without compromising the health or security of this generation or those to come. In addition, biofuels should be pursued as part of a larger solution set that also includes aggressive increases in energy efficiency, reductions in energy demand through conservation, and reforms in land use policies.

Bioenergy research and policy work at the Union of Concerned Scientists (UCS) is guided by a set of core principles (UCS 2007) designed to ensure that this resource leads to a cleaner, more secure energy future. In short, bioenergy development must:

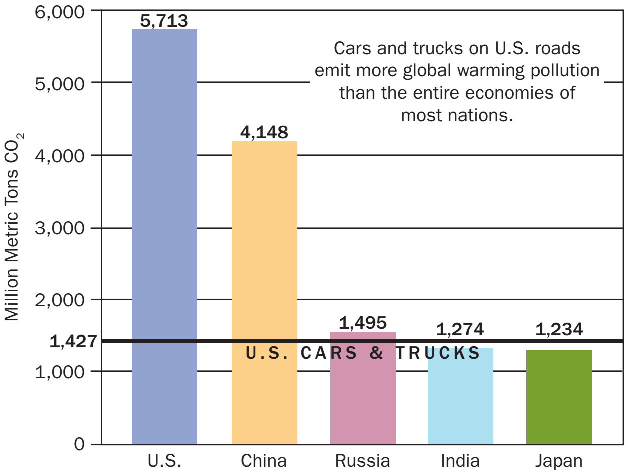
FIGURE 1 **Transportation's Share of U.S. Heat-trapping Emissions (2005)**



NOTE: Totals for sectoral emissions have been rounded.

SOURCE: Tailpipe emissions data from the U.S. Environmental Protection Agency (EPA 2007a). To estimate full fuel cycle emissions, we applied the emissions factor for gasoline (50% reformulated gasoline and 50% conventional) from Wang (2006). For sectoral emissions, this factor is a gross approximation, since each transportation fuel (e.g., diesel, jet fuel, locomotive fuel, marine fuel) will have a unique upstream carbon footprint.

FIGURE 2 **Top Five Global Warming Polluters from Fossil Fuel Combustion (2004)**



NOTE: To estimate full fuel cycle emissions, we applied the emissions factor for gasoline (50% reformulated gasoline and 50% conventional) from Wang (2006).

SOURCES: Data for China, Russia, India, and Japan from Marland et al. (2007). Data for U.S. economy-wide emissions and car and truck tailpipe emissions from the EPA (2007a).

1. Minimize global warming pollution
2. Be combined with efficiency, conservation, and smart growth
3. Protect public health
4. Promote ecologically sound systems
5. Expand economic opportunity

TRANSPORTATION EMISSIONS AS AN OPPORTUNITY

The transportation sector is the United States' largest source of global warming pollution, accounting for 38 percent of total heat-trapping emissions (including "upstream" emissions—those released during the extraction, production, and distribution of transportation fuels) (Figure 1). The vehicles we drive have a huge impact: cars and light trucks account for about 60 percent of the U.S. transportation sector's emissions and roughly one-quarter of all U.S. global warming emissions.

In 2005, transportation emitted more global warming pollution than any other U.S. sector.* Moreover, heat-trapping emissions from U.S. cars and trucks accounted for more global warming pollution than the entire economies of most countries—all but China and Russia (Figure 2).

The amount of global warming pollution each of us generates as a result of our transportation needs is determined by three factors: vehicle miles traveled, vehicle fuel economy, and the heat-trapping emissions associated with the vehicle fuel over its entire life cycle. Since all of these factors contribute to global warming, we must take a three-pronged approach to address this issue.

Low-carbon fuels (such as certain biofuels) alone cannot achieve the dramatic reductions in transportation-related global warming pollution that are needed

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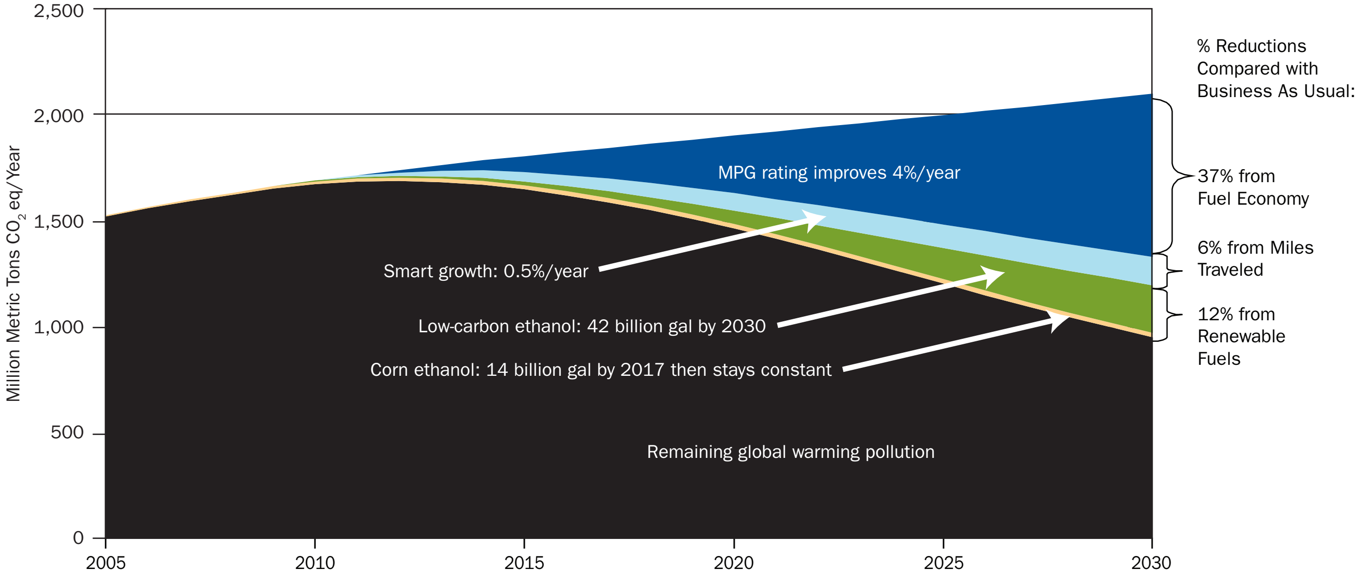
* The transportation sector emissions include the full fuel life cycle. The original data from the EPA (2007b) estimated tailpipe emissions only. We modified the data, applying the emissions factor for gasoline from Wang (2006).

FIGURE 3 **Potential Reductions in Global Warming Pollution from U.S. Cars and Trucks**



NOTES: To evaluate emissions savings, we used a calibrated stock model covering the period 2010–2030. This model uses the annual sales and fuel economy of new vehicles, along with other key input data, to predict annual fleet fuel usage. We assumed a light-duty vehicle Corporate Average Fuel Economy requirement would increase at 4% per year until 2030. For fuels savings, we assumed life cycle emissions reductions would be 20% and 70% (compared with gasoline) for corn and cellulosic ethanol respectively. For miles traveled, we assumed annual miles traveled would decrease 0.5% per year due to improvements in public transportation and other smart-growth initiatives.

to reduce the risks of dangerous climate change. To illustrate this point, Figure 3 projects the cumulative effects of a 4 percent per year increase in fuel economy, a 0.5 percent per year reduction in vehicle miles traveled, and the use of 56 billion gallons of renewable fuels (14 billion from corn ethanol and the remainder from low-carbon cellulosic ethanol—that is, ethanol derived from the cellulose in stalks and stems rather than from sugars and starches). As this scenario demonstrates, low-carbon fuels can account for a portion of the "solutions wedge," but modest fuel economy improvements have a much greater impact.

DETERMINING A PROPER ROLE FOR BIOFUELS

If effective low-carbon policies are put in place to help fuel producers, consumers, and automakers all play a part in reducing transportation-related emissions, the sector's contribution to global warming can be slashed over the next two decades. Forecasting the exact volumes and types of biofuels that will emerge in our energy future has already been done and is outside the scope of this report. Instead, we attempt to answer the following questions: How do we evaluate the impact of biofuels on global warming? What will it take to help ensure that biofuels live up to their promise in a new energy future?

CHAPTER 2

Counting Carbs

Currently, many stakeholders at the state, federal, and international levels are working to develop improved systems for estimating emissions of CO_2 and other heat-trapping gases from transportation fuels including biofuels. California's regulatory agencies, for example, are working with stakeholders to develop such a system for the state's Low Carbon Fuel Standard, and a similar effort led by the U.S. Environmental Protection Agency (EPA) is beginning to take shape at the federal level. European countries such as the Netherlands and United Kingdom are developing tools to assess individual biofuel supply chains more consistently. These governmental agencies are all struggling to develop a robust, simple-to-use, and low-cost accounting system that encourages and facilitates accurate reporting for every link in the fuel supply chain, including changes in land use related to bioenergy crop production. Due to insufficient data, uncertainties, and debates regarding system boundaries, this is not a simple or straightforward task.

In this chapter, we describe how the emissions of a fuel over its full life cycle are currently evaluated and discuss why all fuels are not created equal. We then describe the uncertainties and challenges we face in implementing an accounting system for biofuels.

FIGURE 4 **Life Cycle Emissions of Transportation Fuels**

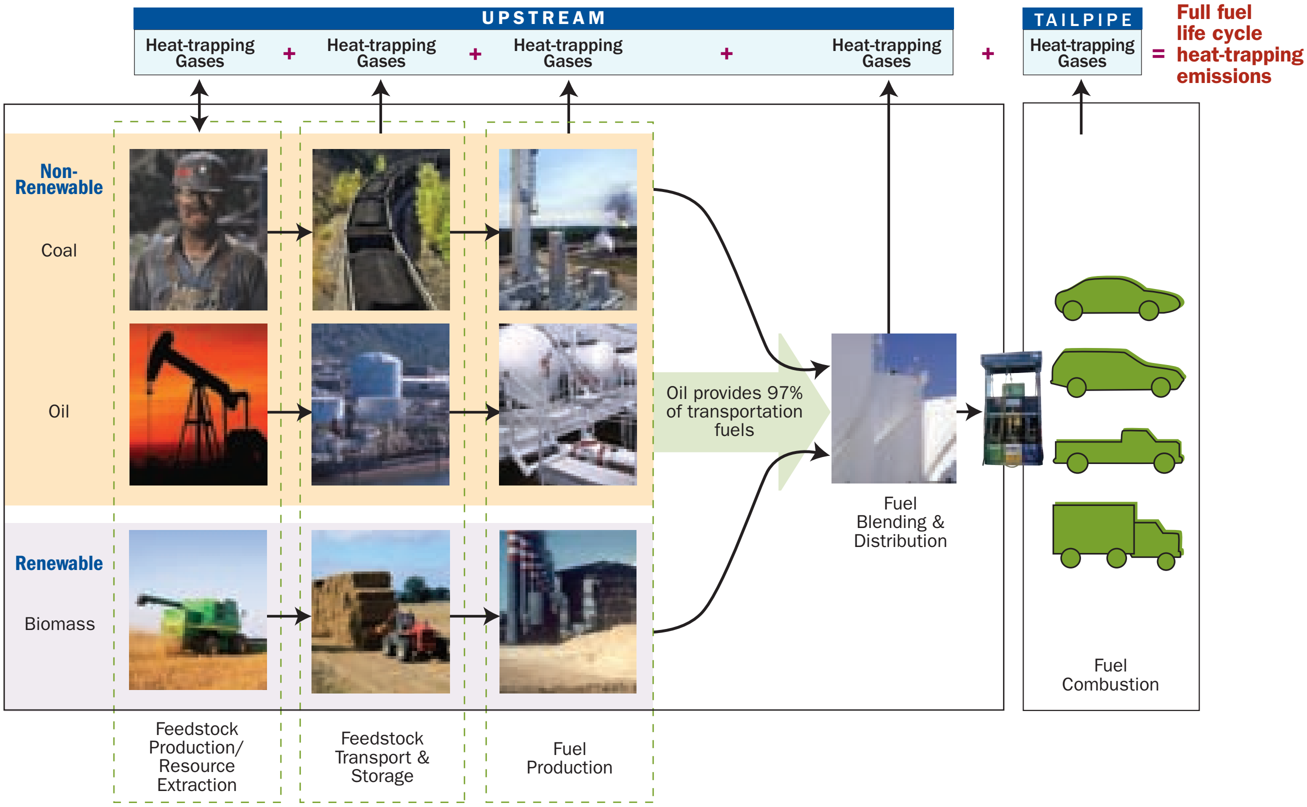
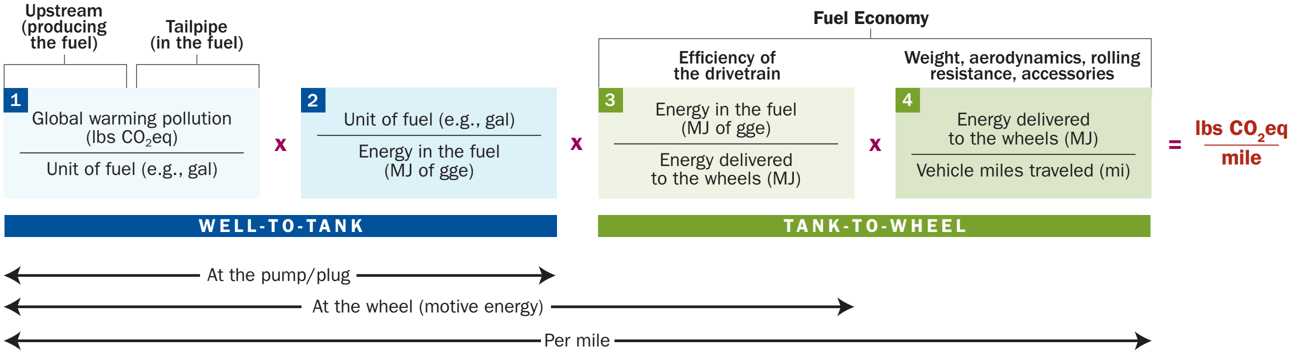


FIGURE 5 **Fuel Life Cycle Terminology**



gge=gallon gasoline equivalent **MJ**=megajoules

Finally, we review the various efforts that have been undertaken to measure, track, and reduce transportation-related emissions.

THE FUEL LIFE CYCLE

To properly assess the emissions created by the production and use of transportation fuels, our analysis must encompass a fuel's entire life cycle. That is, we must account for all emissions from the initial extraction of the resource (at the wellhead, mine mouth, or cornfield) to the ultimate release of exhaust from a vehicle's tailpipe (Figure 4).

Fuel life cycle analyses use different units and terminology to describe the emissions generated at different stages of the cycle. As depicted in Figure 5, these include:

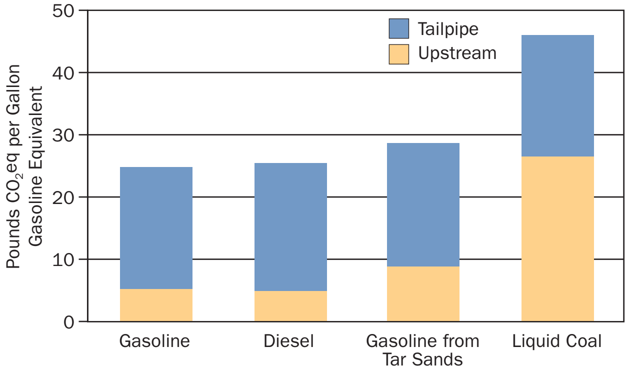
1. The amount of upstream and tailpipe global warming pollution contained in a gallon of fuel.
2. Since different fuels contain different amounts of energy per gallon, emissions are adjusted on a per-unit-of-energy (megajoules, MJ) or gallon-gas-equivalent (gge) basis.
3. And, because different engine/drivetrain combinations have different efficiencies when converting the energy stored in the fuel into motive energy at the wheel, an adjustment factor must be used.
4. Finally, when emissions are expressed on a per-mile basis, vehicle efficiency is included. Since this can vary widely depending on vehicle weight, aerodynamics, and accessories, researchers have recommended that emissions standards use the "motive energy at the wheel" numbers (Farrell and Sperling 2007a, 2007b).

FOSSIL FUEL-RELATED EMISSIONS

Nearly all the transportation fuels we currently use are hydrocarbons—organic compounds containing various combinations of hydrogen and carbon atoms derived from the fossilized remains of ancient plants and animals. When a hydrocarbon fuel such as gasoline is burned, the carbon in the fuel bonds with oxygen in the air to form carbon dioxide (CO_2). Every gallon of gasoline burned emits about 20 pounds of CO_2, but to account for *all* of the global warming emissions related to gasoline (or any fuel), we must account for the upstream emissions related to its extraction, production, and distribution.

For example, gasoline's total life cycle emissions amount to approximately 25 pounds of CO_2-equivalent (i.e., all heat-trapping gases expressed in terms of the amount of CO_2 that would have the same global warming potential) per gallon (Wang 2006)—comparable to diesel emissions on an energy-equivalent basis (Figure 6). Gasoline derived from tar sands could increase global warming pollution 14 percent relative to gasoline derived from conventional petroleum (Moorhouse 2006), and fuels derived from coal ("liquid coal") could increase global warming pollution 80 percent relative to conventional gasoline (Williams 2005).

FIGURE 6 **Upstream and Tailpipe Emissions of Fossil Fuels**



NOTE: For feedstock extraction, fuel processing, and refining, we assume no sequestration of global warming pollution.

SOURCES: Gasoline and diesel data from Wang (2006), tar sands data from Moorhouse (2006), liquid coal data from Williams (2005).

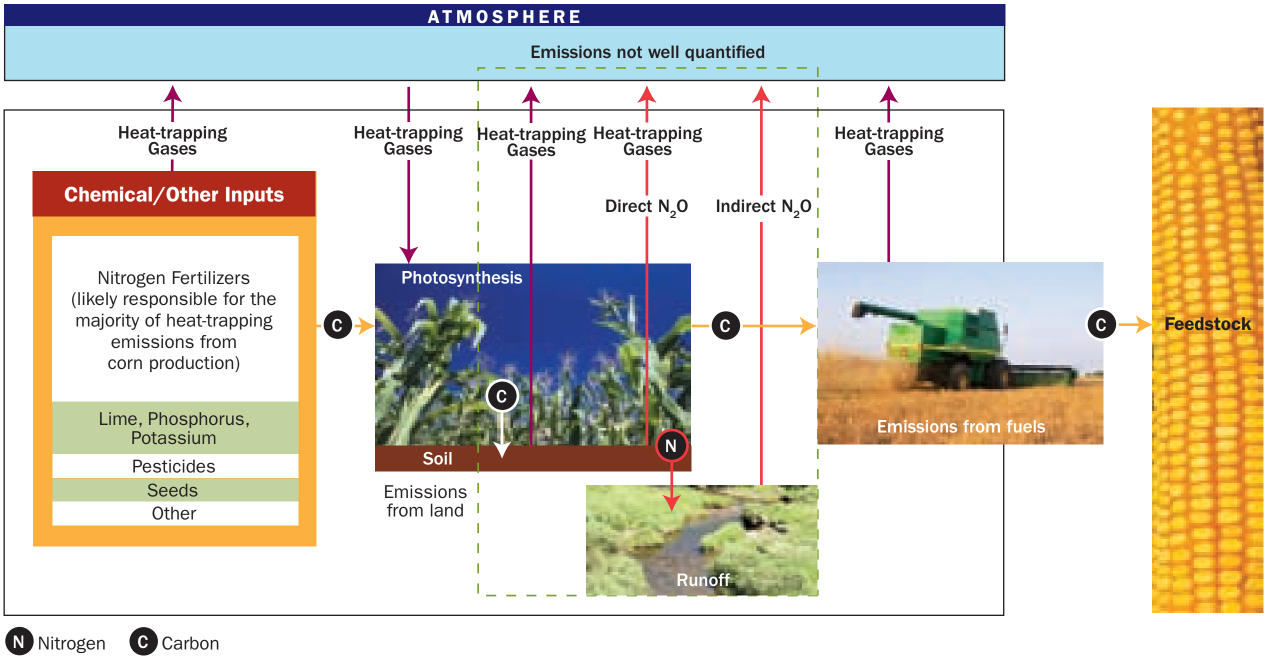
BIOFUEL-RELATED EMISSIONS

Plants capture carbon from the atmosphere through the process of photosynthesis. The burning of biomass returns this recently captured carbon to the atmosphere, a cycle that—unlike the combustion of fossil fuels—produces no net increase in atmospheric carbon. Unfortunately, biofuel production is typically powered by fossil fuels, so the global warming pollution from that process must be added to the equation.

In addition, heat-trapping emissions generated by biomass production practices not related to combustion must be taken into account. This includes significant amounts of CO_2 and methane (CH_4) from petroleum recovery and natural gas processing, and nitrous oxide (N_2O) from fertilizers added to the soil (Alder et al. 2007). Direct and indirect changes in land use can also have an impact on emissions.

The net impact of bioenergy on global warming depends on the type of biomass being used; how the feedstock is grown; the fuel production, refining, and delivery methods; the energy resource being displaced; and how the land would have been used if it had not been converted for bioenergy use.

FIGURE 7 **Emissions from Biomass Feedstock Production**



Feedstock Production

As illustrated in Figure 7, heat-trapping emissions are generated in many ways during the growth, harvesting, and transport of biomass resources. The amount of emissions varies by crop and can also vary by region (due to differences in soil, precipitation, and climate) and by agricultural practice (e.g., tillage, crop rotation, fertilizer application). The most obvious—and easiest to measure—emissions from biomass production are those related to fossil fuel use. Gasoline and diesel power the tractors, trucks, combines, and various other machines needed to till, plant, harvest, fertilize, and spread nutrients, pesticides, and herbicides.

Life cycle analysis also includes the emissions created in the production of chemical nutrients, pesticides, and herbicides used to grow the crops. For example, production of the nitrogen fertilizers used to raise corn as a feedstock typically accounts for more than half of the total CO_2 emissions associated with this feedstock (Farrell et al. 2006b).

Less obvious—and not easily quantified—are the land use and management practices that can affect heat-trapping emissions. For example, some sustainable farming practices can increase the amount of carbon-storing organic matter in soil and reduce or eliminate the need for fertilizers, pesticides, and herbicides. Many of the cause-and-effect relationships between the key variables in this equation are not fully understood or verifiable; the resulting emissions are highlighted with a dashed line in Figure 7.

The bulk of emissions from agricultural lands are caused by the overuse of synthetic nitrogen fertilizers. The production of these fertilizers is extremely energy-intensive and, when applied in the field, they release high quantities of N_2O as they degrade. Even organic fertilizers containing nitrogen, such as manure and compost, can increase N_2O emissions if used inefficiently. N_2O emissions are dependent on soil type, crop cultivated, climate, tillage practices, and amount of fertilizer used. Since it is difficult to measure such emissions, estimates can be derived from computer modeling or correlated with the rate of nitrogen fertilizer use (Parry et al. 2007). In Europe, the latter approach has been recommended (Bauen et al. 2007).

CASE STUDY

Biomass Lowers Minnesota Fuel Producer's Emissions, Energy Bills

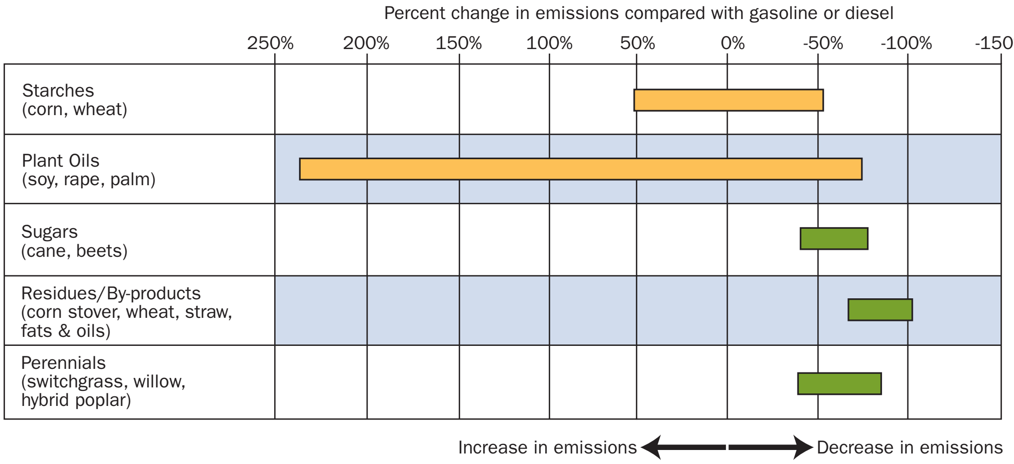
In the fall of 2007, the Central Minnesota Ethanol Co-op switched from natural gas to biomass—locally procured wood waste and by-products—to provide heat and approximately one-third of the plant's electricity. The original goal of this project was to comply with state and federal emissions standards in a way that would protect shareholders' interests by reducing operating costs. But the added benefit will be a more marketable lower-carbon fuel.

How does it work? Along with a syrupy by-product of ethanol production, wood waste (e.g., sawdust, carpentry tailings, debris from the cutting of timber) and yard waste will be fed into a fluidized-bed gasifier, where it will be converted into a gas and mixed with oxygen in a high-pressure, high-temperature environment. This "synthesis gas" will be used to produce steam for process heating and electricity when combusted in a turbine.

By using these materials as fuel, the Little Falls, MN, renewable fuel producer is reducing its landfill waste and global warming pollution, and supporting the region's economy by spending its energy dollars locally (instead of sending it to other countries to buy natural gas) (Bilek 2007).

Advanced biofuels offer significant opportunities to reduce fertilizer demand compared with corn ethanol. Biofuels can be derived from abundant and diverse materials including dedicated energy crops, ecologically safe amounts of forestry and agriculture residues, and other waste materials. For example, perennial

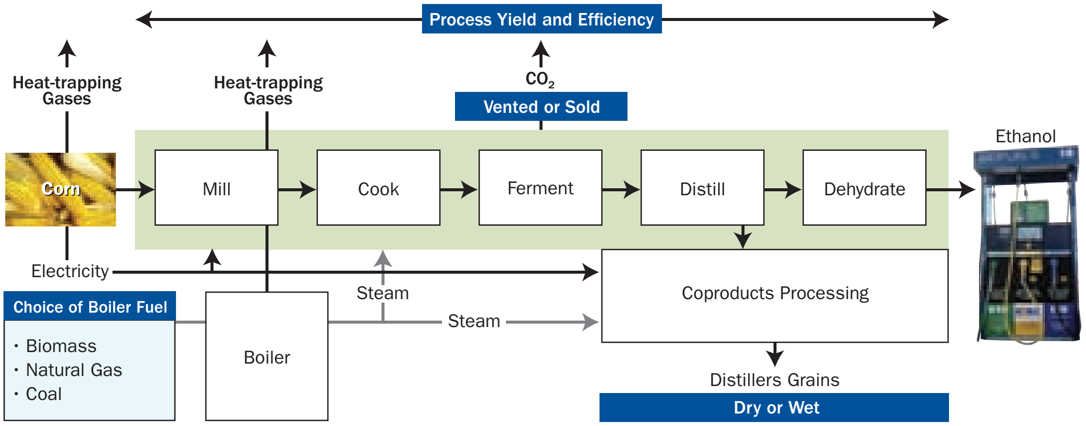
FIGURE 8 **Impact on Heat-trapping Emissions by Biofuel Feedstock**



NOTE: The data do not necessarily include impacts from land use changes (which are particularly important when land is converted from a natural system to agricultural land).

SOURCES: Data compiled from various fuel life cycle analyses. For starches, the minimum value is from Patzek (2007) and the maximum value is from Wang (2006), as modified by University of California–Berkeley researchers and reported in Turner et al. 2007. For plant oils, the minimum value is from Delucchi (unpublished) in Farrell and Sperling 2007a, and the maximum value is from Bauen et al. (2007). For sugars, data are from Bauen et al. (2007). For residues/ by-products, data are from the International Energy Agency as reported in Worldwatch Institute 2007. For perennials, the minimum value is from Delucchi (2005) and the maximum value is from Wang (2006).

FIGURE 9 **Heat-trapping Emissions Generated During Ethanol Production**



grasses (e.g., switchgrass, mixed native grasses, miscanthus) and fast-growing trees (e.g., willow, hybrid poplar) require substantially less fossil fuel-derived fertilizer and fewer man-hours per ton of biomass produced than corn, resulting in a smaller carbon footprint and better profitability for farmers. Most estimates have shown that biofuels produced from these cellulosic feedstocks will lower global warming pollution up to 90 percent per unit of energy delivered (Farrell and Brandt 2006). As illustrated in Figure 8, studies show wide variation in emissions reductions, particularly among conventional biofuel feedstocks such as corn and soy, but consistently substantial reductions for residues and cellulosic feedstocks.

In addition to emissions from the cultivation and harvesting of feedstocks, the energy required for transport, storage, and pre-processing could be considerable depending on the location of a fuel processing plant relative to its feedstock sources. For example, biodiesel plants in Virginia typically receive soybean oil shipped by rail from out-of-state soy-crushing facilities. Most biofuel processors in the Midwest, however, can procure local feedstocks within a reasonable distance. As refineries get larger, their need for larger quantities of feedstock expands the radius within which transport-related emissions would be generated. Also, the energy required and the emissions generated from transport, storage, and pre-processing may become more of an issue as new infrastructure capable of supporting large-scale cellulosic ethanol refineries is established. While many producers are attempting to solve these transportation issues, the more efficient solution could be smaller, more distributed fuel production facilities.

Fuel Production

It takes energy to convert a resource or feedstock (whether biomass, coal, or crude oil) into a usable liquid fuel, and this process inevitably emits CO_2. The typical ethanol production plant depicted in Figure 9 requires heat and electricity for various production processes such as cooking, distilling, and drying grain; heating accounts for a majority of the energy used at biofuel processing facilities (Graboski 2002).

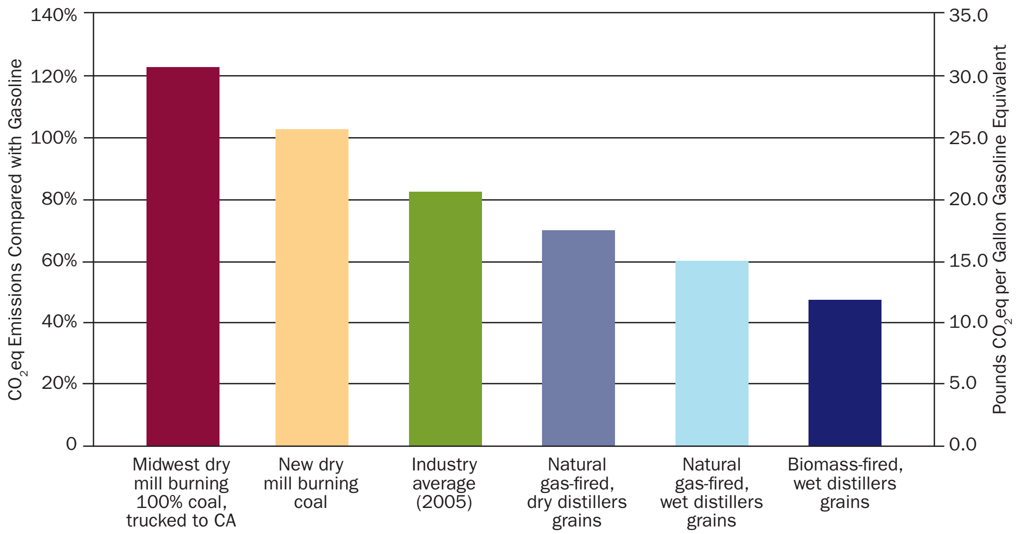
The CO_2 emissions per unit of energy in a given biofuel are dependent on the feedstock (i.e., coal, natural gas, or biomass), process efficiency (the amount of energy required for production), and process yield (e.g., gallons of ethanol per bushel of corn). Another factor is whether the ethanol production process generates other products such as cattle feed ("distillers grains").

Figure 10 compares the impact of different corn ethanol production processes on heat-trapping emissions. As the figure makes clear, not all corn ethanol is the same, and a biofuel's carbon footprint is not only dependent on what the fuel is made from but also on how it is made. Because most biofuel production facilities already measure these variables accurately and monitor them closely for cost-accounting purposes, expanding production-related emissions data into a fuel life cycle reporting system should not prove burdensome to the producer. For U.S. producers, the Renewable Identification Number (RIN) tracking system developed for the current federal Renewable Fuel Standard (RFS) can be used to easily transfer emissions data to the next entity in the supply chain.

Fuel Blending and Distribution

Once a biofuel is produced it is typically shipped via rail, truck, barge, or pipeline to a terminal where it is blended and then distributed to commercial and retail gas stations. This process also requires energy that generates heat-trapping emissions. If the point of production is close to the point of consumption, less energy is required and less emissions are generated.

FIGURE 10 **Emissions Reductions from Various Methods of Ethanol Production**



NOTES: Baseline is 2005 CO_2 emissions from gasoline. The first bar represents emissions from ethanol used in California and produced in the Midwest by a 100% coal-fired dry-mill plant. The second bar represents the estimated average for a new coal-fired dry-mill plant. The third bar represents the 2005 estimated industry average for corn ethanol, which consists of 35% wet-mill and 65% dry-mill plants with varying heat sources (coal and natural gas). The fourth bar represents the estimated average for a new dry-mill plant with natural gas-fired heat. When distillers grains are not dried, ethanol producers save energy (and reduce emissions), as reflected by the fifth bar. The final bar represents a producer that combines various energy-saving production methods and burns or gasifies biomass to provide heat.

SOURCE: Data for Midwest dry mill are from Unnasch et al. (2007). All other data are from Turner et al. (2007).

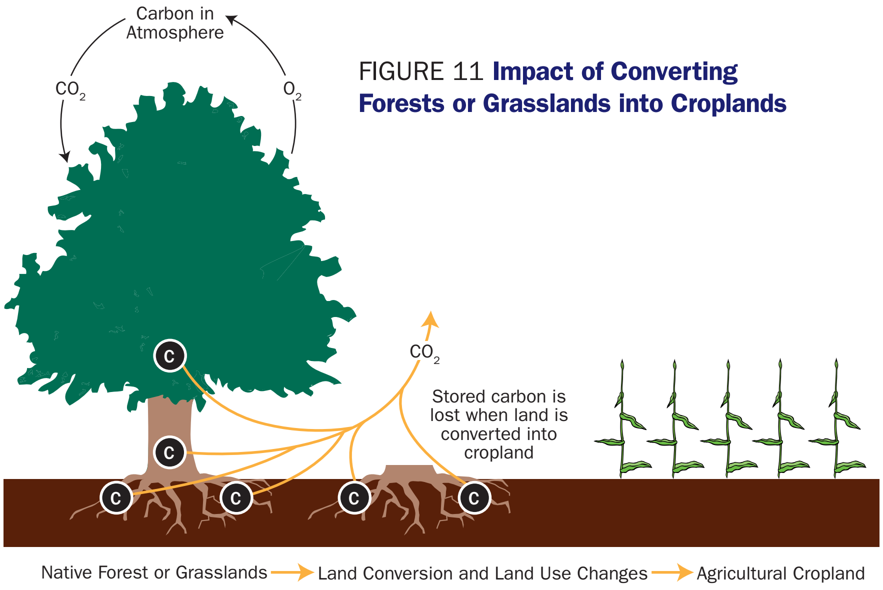


FIGURE 11 **Impact of Converting Forests or Grasslands into Croplands**

However, the majority of biofuels are currently produced in the Midwest and shipped all over the country. Emissions generated from fuel distribution should therefore be included in overall life cycle emissions.

Land Use and Land Cover Changes

Forests and grasslands play a critical role in Earth's carbon cycle, through the storage (or sequestration) of carbon in trees, roots, and soil. When these lands are cleared for agricultural use, much of the stored carbon is released into the atmosphere in the form of CO_2 (Figure 11). Therefore, changes in land use or land cover due to the conversion of forests and grasslands into agricultural lands can generate large amounts of heat-trapping emissions and drastically reduce the amount of carbon currently sequestered.

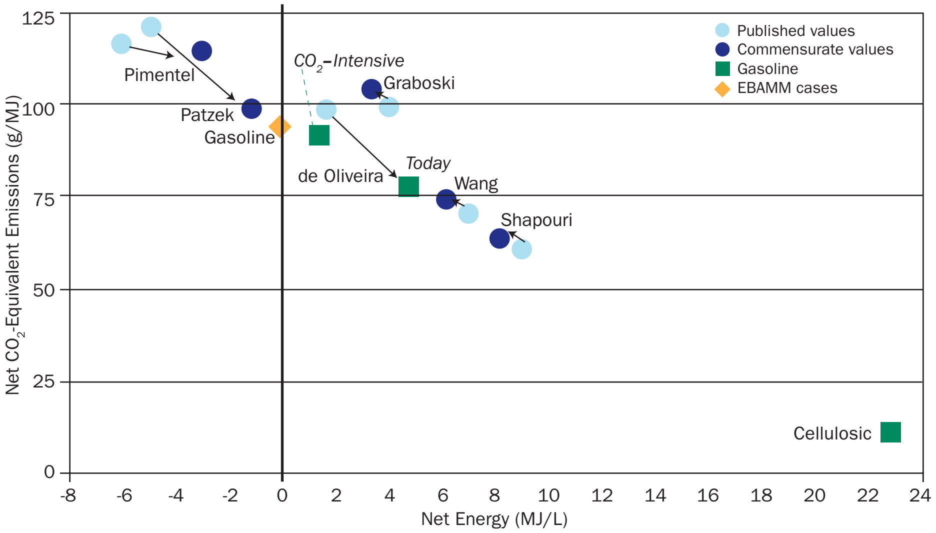
Most fuel life cycle analyses do not include land use changes associated with biofuel production, which is likely to have a significant impact on a fuel's estimated emissions. One model that does attempt to account for these emissions is the Lifecycle Emissions Model (LEM) developed by Delucchi (2003). Because increased demand for biomass feedstocks in the United States and abroad will likely cause large-scale changes in land use, the impact must be integrated into assessment models.

One estimate of the impact of land use changes is that tropical forest converted into sugarcane fields results in a 50 percent increase in global warming pollution compared with gasoline use (Tilman and Hill 2007). Furthermore, some researchers argue that indirect changes should also be included in a fuel's overall emissions impact (Delucchi 2003). In other words, expanding acreage for biomass production could crowd out crops needed for other purposes, which could lead to the displacement of forests or grasslands in other places and higher costs for food and other products.

LACK OF CONSENSUS ON ACCOUNTING METHODS

Due to the potential rapid expansion of biofuel production in response to urgent climate and energy concerns, the long-standing debate about biofuels' life cycle emissions has ratcheted up a notch. In January 2006, a University of California–Berkeley (UCB) research team studied the methodologies and assumptions of six published life cycle (or "well-to-wheel") analyses of corn-based ethanol conducted by scientists with a range of opinions on ethanol. Figure 12 displays the widely varying results of these analyses in terms of the net energy used to produce the fuel (megajoule per liter) versus the net heat-trapping emissions generated (grams of CO_2-equivalent per megajoule).

FIGURE 12 **Comparison of Fuel Life Cycle Analyses of Corn Ethanol**



SOURCE: Farrell et al. 2006b.

The UCB study concluded that the bulk of differences between results was due to varying methodologies for allocating energy and emissions credits to coproducts generated during biofuel production. Ethanol coproducts include distillers grains used for animal feed and corn oil, while biodiesel coproducts include glycerin, which is often used in beauty products. Many argue that a portion of the emissions generated during fuel production should be credited to the coproduct; this would have the effect of lowering the fuel's heat-trapping emissions and energy-per-gallon value.

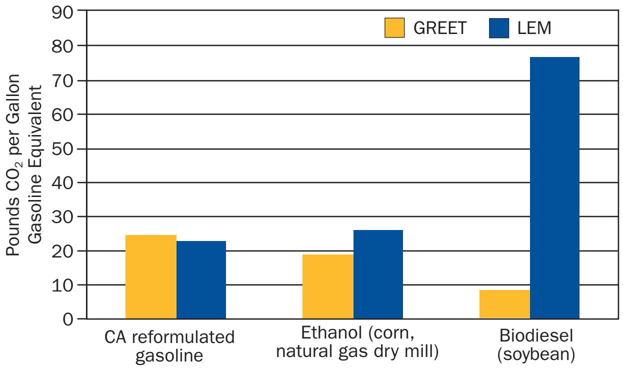
In addition, the six analyses made differing assumptions about system boundaries. Some expanded the boundaries to include the energy required to produce the farming machinery and ethanol processing equipment, as well as the food energy consumed by farm workers. The UCB study found that any remaining differences between analyses were due to differing input parameters and sources.

The UCB researchers then constructed their own life cycle energy and emissions models for corn ethanol and switchgrass (cellulosic) ethanol based on the data from the six analyses. The result was named the Energy and Resource Group Biofuels Analysis Meta-Model, or EBAMM (Farrell et al. 2006a).

This study did not, however, evaluate more complex models such as the LEM, which attempts to evaluate the complex changes in carbon and nitrogen cycles associated with both direct and indirect land use changes (Farrell and Sperling 2007a). The differences in estimated emissions between LEM and the well-known Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by the U.S. Department of Energy (DOE; Wang 2006) are compared in Figure 13 on page 18.

The two models provide very different estimates of ethanol and biodiesel emissions. For soy biodiesel emissions, the estimates differ by an order of magnitude. For corn ethanol, GREET estimates that fuel produced at a natural gas-fired dry-mill plant would reduce emissions 28 percent compared with California-reformulated gasoline. LEM, on the other hand, estimates an 18 percent increase. The models provide markedly different results due to differing assumptions regarding system boundaries and emissions from land use and other variables.

FIGURE 13 **Global Warming Pollution Estimated by Two Life Cycle Models**



SOURCES: Delucchi (unpublished) in Farrell and Sperling 2007a, and Wang (2006) in Unnasch et al. 2007.

FEDERAL STANDARDS ARE NEEDED

Developing an accurate, relatively simple, and flexible emissions reporting system will be a challenging task, but is absolutely necessary as we move into a carbon-constrained future. California is establishing a groundbreaking low-carbon fuel standard, and federal government agencies (such as the EPA, DOE, and U.S. Department of Agriculture) can and should work with California to build upon this initial work. Furthermore, the impact of specific alternative fuels over their entire life cycle should be accurately tracked and accounted for within any type of federal fuel mandate, and the government must also work with stakeholders to design a system with flexible measurements and modeling tools. Such a system would adjust over time as farming practices and fuel processing technologies evolve, and as our understanding of global warming pollution from agricultural processes and land use changes grows.

A national low-carbon fuel standard that is implemented sooner rather than later would benefit consumers and enable U.S. biofuel producers to be more competitive in a global biofuels marketplace. Unfortunately, the federal government has argued in its Renewable Fuel Standard Notice of Proposed Rulemaking (Section III.B.4.c) that the lack of consensus on specific values and ongoing changes in supply chain processes would lead to uncertainty in using life cycle analyses in its calculations (EPA 2007b). The EPA also states in this section that “there currently exists no single body, governmental or otherwise, that has organized a comprehensive dialogue among stakeholders about the appropriate tools and assumptions behind any lifecycle analyses with the goal of coming to agreement.”

However, the regulatory authority and production tracking mechanisms proposed in the RFS rulemaking, and the additional activity the EPA has undertaken to implement President Bush’s “20 in 10” plan to reduce gasoline use 20 percent in 10 years, give the agency the perfect opportunity and tools to organize such a “comprehensive dialogue.” While a system to evaluate and track fuel life cycle impacts will not be put in place overnight, the EPA (in cooperation with other appropriate federal and state agencies) should put a flexible process in place as soon as practicable to establish reporting standards and develop a scientific consensus on life cycle values and methodology.

CHAPTER 3

Making Carbs Count

Biofuels may have the potential to displace up to one-quarter of the United States' transportation fuels over the next two decades, depending on advances in vehicle and fuel technologies and policies (English et al. 2006, Perlack et al. 2005). But without requirements to minimize global warming pollution and ensure sustainable fuel production, a significant expansion of biofuels could lead to increased global warming pollution, loss of open space and biodiversity, and other harmful impacts.

As discussed in the previous chapter, a better route must start with an understanding of the carbon footprint of all fuels. Using this information, we can craft effective performance-based policies to guide our transition away from high-carbon fuels and toward low-carbon alternatives. This road is not without risks and we must ensure that our natural resources—air, water, food supply, and soil—are protected. Finally, this vision must be backed by incentives for "greener" biofuels as soon as possible.

Government leadership can provide every participant in the biofuels supply chain with direction for its technology development efforts as well as certainty about future regulations. To be truly successful, any policies designed to increase the use of renewable fuels must "*count carbon and make carbon count.*"

POLICIES FOR PROMOTING LOW-CARBON BIOFUELS

Without the necessary financial, regulatory, and policy support, future adoption of low-carbon fuels is unlikely. We must therefore ask what is the best way to drive low-carbon fuels to market: pushing for technical solutions through investments in research and development (R&D)? Or pulling solutions to market by establishing a regulatory framework that uses market incentives to promote private-sector investment? State and federal governments are taking both approaches.

Policy makers must balance irrational exuberance about biofuels with reality, first by focusing on the need for adequate life cycle performance metrics. Without such metrics, policies that support a massive expansion of biofuel production may have unintended consequences such as an increase in heat-trapping emissions, loss of virgin forests to cropland, or other harmful environmental impacts. A truly comprehensive biofuel policy would not only include such metrics but also incentives, regulation, and taxation.

Incentives for low-carbon fuel production could take the form of direct payments to producers or consumers, tax breaks, or R&D funding to push new technologies into the marketplace. One interesting idea is a modification to existing biofuel tax credits: instead of the current fixed subsidy for every gallon of renewable fuel, the tax credits could be recalculated on a sliding scale tied to emissions reductions. Better-performing fuels would get a larger credit and poorly performing fuels would get little or no credit.

Regulations could take the form of low-carbon fuel standards or renewable and alternative fuel mandates with emissions requirements. By setting a limit (in CO_2-equivalent terms) on the amount of global warming pollution created by various fuels, a low-carbon fuel standard would create market certainty for cleaner fuels and complement existing vehicle standards, ensuring that the fuel industry does its part to address climate change. As discussed previously, this standard should account for the full life cycle of the fuel—a critical prerequisite to achieving real and measurable reductions in global warming pollution.

Taxation could take the form of a sales tax on transportation fuels based on their life cycle emissions. This fuel carbon tax could be imposed on either fuel producers or consumers with the goal of increasing consumer demand for low-carbon fuels. But, given the widespread desire for lower fuel prices, political fear of any tax increase, and potential disparity in economic impact, a fuel carbon tax seems unlikely in the near future.

Ideally a comprehensive biofuels program should provide regulatory certainty (to the extent feasible given the limits of our current understanding), accountability for product tracking, meaningful enforcement and compliance, and low transaction costs. Finally, it should also be periodically revised to reflect the best data available and account for uncertainties.

An effective low-carbon fuel standard would be compatible with existing emissions control programs to avoid double-counting, and would promote sound biofuels policies that have environmental benefits. The result would be reductions in both our heat-trapping emissions and dependence on fossil fuels.

Additionally, a low-carbon fuel standard should permit the trading of carbon credits to encourage cost reductions through market forces. Trading should be limited, however, to companies in the fuels industry, since the buying or selling of credits from or to companies not regulated by the standard (e.g., electricity providers participating in similar carbon markets) could limit the growth of biofuels. Why? Given the relative costs, the fuels industry would be more likely to purchase carbon credits from other industries than to invest in low-carbon fuels. *Too much* market flexibility, therefore, could ironically dampen investment in low-carbon fuels, dangerously delaying the needed reductions in economy-wide emissions.

Turning a Vision into Reality

California Governor Arnold Schwarzenegger issued an executive order in January 2007 establishing a statewide goal of reducing transportation-related global warming pollution at least 10 percent by 2020. This low-carbon fuel standard will require California's fuel providers to demonstrate continual cuts in emissions per unit of energy delivered to the vehicle. The California Air Resources Board will be developing regulations for the standard that are likely to focus first on car, truck, and bus fuels, for which lower-carbon substitutes are already available.

Many states and countries may follow California's lead by enacting similar standards. A truly comprehensive climate and energy security strategy must include the adoption of such a standard at the federal level.

THE OTHER KEYS TO A LOW-CARBON DIET

The environmental impact of petroleum use is well established. Oil consumption results in periodic oil spills, the disruption and contamination of underground aquifers, land subsidence, and harm to both land-based and marine life. But now, as we expand into non-conventional oil sources such as oil shale and alternative fuels such as liquid coal and biofuels, we are just beginning to understand the risks that come with these resources.

Potentially Harmful Impacts of Biofuels

The environmental impact of biofuels is comparable to certain agricultural crops. For example, the growing of corn has similar consequences whether the corn is grown for food, animal feed, or as a biofuel feedstock. The environmental impact is particularly high when virgin forestland is cleared for monocrop farming of a current-generation feedstock such as corn.

Next-generation (cellulosic) feedstocks, on the other hand, offer a lower-impact alternative, especially if grown with farming practices including no- or low-till, plant diversification, and lower pesticide and fertilizer use.

The expansion of biofuel crops into lands that were previously wild represents a major threat to biodiversity and deforestation efforts (Worldwatch Institute 2007). Rain forests in Brazil, Indonesia, and Malaysia, for example, are being cleared to make way for palm oil plantations. While cattle ranching, food production, and illegal timber cutting are also responsible for deforestation, expanding biofuel production increases the threat to virgin lands. Already, one-fifth of the Amazon Basin, which 30 percent of the world's plant and animal species call home, has been burned or destroyed by agriculture (Pia Palermo 2005).

Increased feedstock cultivation also increases the risk of water contamination from pesticide and fertilizer use, and puts added pressure on limited fresh water supplies (for those feedstocks that require irrigation). Agriculture already accounts for an estimated 70 percent of the fresh water used in the world (Postel 2006), and biofuel production will increase this share. Furthermore, the processing of ethanol requires large amounts of water as well.

Some, but by no means all, of the harmful consequences of biofuel expansion can be avoided through a low-carbon fuel standard that accurately accounts for global warming pollution. For example, a strong standard could help prevent the clearing of virgin lands by assessing a hefty carbon penalty when land is converted to grow biofuels. An accurate life cycle accounting would also help advance broader objectives such as biodiversity and the preservation of open space, provide an incentive to reduce the use of fertilizers and pesticides, and help preserve water and air quality. Nevertheless, it should be noted that policies aimed at reducing heat-trapping emissions will not necessarily be able to address all of the potential environmental impacts of biofuels, and certainly not their social impacts (on food prices, food access, income distribution, etc.).

Certification and Standards

Along with a low-carbon fuel standard, expanding biofuel production requires safeguards that ensure the feedstocks are grown and the fuels processed in a sustainable manner. European countries have been wrestling with this issue and attempting to develop systems for monitoring and certifying fuels as "sustainable." California's Biomass Collaborative, comprising representatives of the science, government, industry, and environmental communities, is also exploring sustainability criteria. Other prominent efforts by the Netherlands, the Roundtable on Sustainable Palm Oil, the United Kingdom, and the Forest Stewardship Council have yet to produce a consistent metric, but they all represent a step in the right direction.

A program for promoting the sustainable production of low-carbon fuels will succeed if it meets three key criteria. First, fuel providers report on the impact of fuel production and make that information available to policy makers. Second, policy makers review the data to evaluate the full upstream impact of transportation fuels. Third and most importantly, policy makers establish standards that will minimize or avoid any harmful consequences, and fuel providers certify that they meet these standards.

CHAPTER 4

The Benefits of a Low-Carbon Diet

Low-carbon biofuels have the potential to help our nation increase its energy security, promote economic development, and decrease global warming pollution. Biofuels have a significant advantage over higher-carbon alternatives, but only when viewed in terms of life cycle emissions.

In the agriculture sector, increased demand for lower-carbon biofuels will create new markets for biomass crops and new demand for old by-products. The U.S. economy as a whole will benefit from the development and deployment of new technologies, which provide new job opportunities for scientists, engineers, construction workers, and many others. And most important, low-carbon biofuels combined with sound economic incentives will help reduce heat-trapping emissions and the greatest risks of climate change.

A NEW AGRICULTURAL OPPORTUNITY

Though private and public investment in conventional biofuel expansion has created and will continue to create opportunities for economic development, the growth of new lower-carbon biofuels will open the door to significantly larger markets. Farmers and renewable fuel providers stand to reap the benefits once the United States develops a national climate change strategy and lower-carbon products are appropriately valued.

Policies that promote low-carbon biofuels should therefore provide incentives and regulatory certainty for the developing biofuels industry, which in turn will give investors confidence that a market for advanced biofuels will exist. In addition, policies should focus on the desired performance of a fuel (i.e., its reductions in carbon intensity) rather than "picking winners" by predetermining which alternative fuels or feedstocks will prevail in the marketplace. By allowing companies to compete with one another to produce the lowest-carbon fuels, both the public and the environment benefit because price and performance determine the eventual winners.

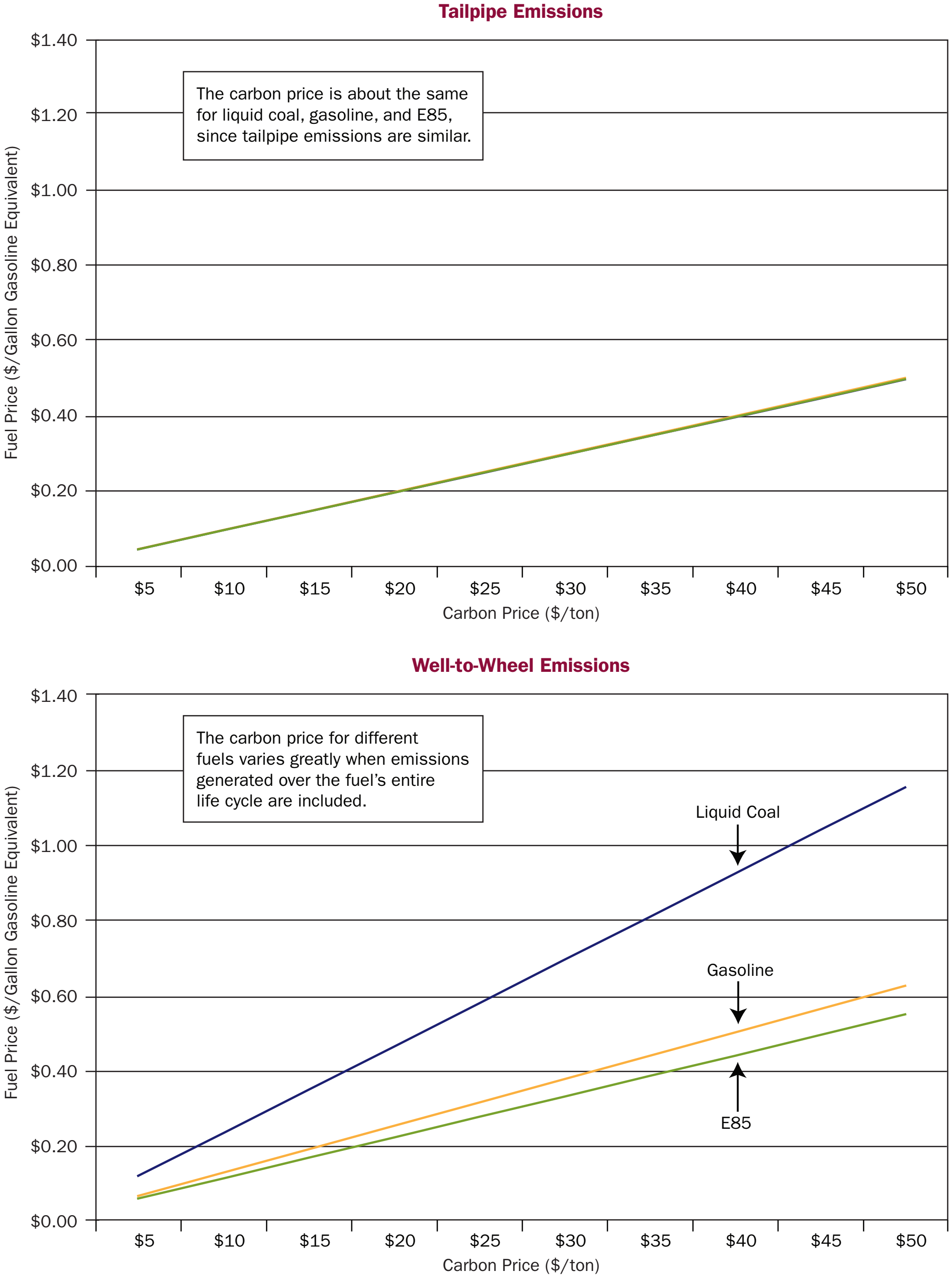
How to Ensure Renewable Fuels Can Compete

For biofuel producers, any expenses associated with new record-keeping requirements should be offset in the long run by financial incentives for lower-carbon fuels. In addition, policies that support low-carbon biofuels can simultaneously discourage production of higher-carbon substitutes for conventional petroleum (e.g., gasoline from tar sands, liquid coal).

Figure 14 shows the potential price differential between liquid coal, gasoline, and corn ethanol (E85) under two scenarios: when only tailpipe emissions are measured, and when emissions are measured over the fuel's entire life cycle. Viewed in terms of life cycle emissions, biofuels have a significant advantage over higher-carbon alternatives. If the carbon price moves to $40 a ton, for example, corn ethanol could have a $0.48 per gallon advantage over liquid coal, and advanced biofuels would have an even bigger advantage.

Until recently, the price of oil has not remained consistently high enough for petroleum alternatives to be economically competitive. However, the U.S. Energy Information Administration (EIA) projects that by 2030, liquid coal (also referred to as coal-to-liquids or CTL) will account for 93 percent of non-petroleum diesel alternatives (EIA 2007). But—in addition to

FIGURE 14 **Impact of Accounting Method on Fuels' Carbon Prices**



NOTE: Estimate for corn ethanol (E85) does not account for emissions from land use changes.

SOURCE: UCS calculation based on Wang (2006).

coal mining's damaging effects on the safety, health, and environment of neighboring communities—liquid coal produces almost twice as much global warming pollution per unit of energy delivered as today's petroleum fuels. Even if most of the CO_2 from the refining process is captured, liquid coal could still generate 4 to 8 percent more heat-trapping emissions over its total life cycle (EPA 2007b).

Recent energy concerns in this country have created a groundswell of support for any substitute for conventional petroleum, no matter what the carbon intensity. In his 2007 State of the Union address, President Bush proposed increasing the U.S. supply of renewable and alternative fuels to 35 billion gallons by 2017—nearly five times more than the current 2012 target. But, if just one-fifth of this goal (7 billion gallons) is met with liquid coal instead of renewables, we would lose the opportunity to reduce heat-trapping emissions by an additional 160 million metric tons per year.

Current federal legislative proposals that support higher-carbon alternatives such as liquid coal include loan guarantees for CTL plants (up to 10 plants at a cost of approximately $3 billion each), a tax credit of $0.51 for every gallon of liquid coal sold through 2020, and permission for the U.S. Air Force to purchase almost a billion gallons of coal-derived jet fuel every year (Andrews 2007).

Furthermore, the cost to build CTL production facilities is prohibitive. According to studies by the Massachusetts Institute of Technology (Katzer 2007) and the National Coal Council, it would cost between $70 billion and $211 billion to build enough CTL plants to displace just 10 percent of U.S. gasoline consumption (not including the costs of CO_2 disposal).

DIVERSIFIED SUPPLIES, GREATER CONSUMER CHOICE

The transportation sector relies on a single fossil fuel—oil—that has a finite supply and a carbon-intense life cycle, and is distributed through a highly centralized infrastructure. These traits put our society at risk for fuel shortages, supply disruptions, and the consequences of global warming. Any new fuel system should be designed to avoid these risks.

Biofuels offer us an opportunity to develop and deploy smaller production facilities wherever regional supplies of biomass are readily available and can be efficiently and cost-effectively processed into liquid fuels for local distribution and consumption. Given the challenges associated with moving large quantities of biomass over long distances, both the biofuels industry and consumers would be better served by networks of smaller plants in various regions, each specializing in feedstocks located within a reasonable distance.

LESS GLOBAL WARMING POLLUTION

Finally and most important, large-scale use of lower-carbon transportation fuels (along with increases in fuel economy and conservation) will be necessary to set our nation on a path with the goal of reducing our heat-trapping emissions at least 80 percent below 2000 levels by the middle of this century. Although future low-carbon transportation alternatives may include hydrogen and electricity, renewable biofuels developed in a sustainable manner represent our best short-term option for lowering the carbon intensity of transportation fuels.

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BIOFUELS

An Important Part of a Low-Carbon Diet

Biofuels—transportation fuels produced from plants and agricultural wastes—may have the potential to cut global warming pollution, enhance our energy security, and strengthen local economies. But expanding biofuel production does not automatically guarantee we will realize these benefits.

Biofuels must be held to performance standards that will reduce heat-trapping carbon emissions while protecting the environment. These standards must accurately assess the full global warming impact of transportation fuels, from oil well to wheels for gasoline and from seeds to wheels for biofuels. Compared with today's gasoline, for example, liquid coal may *increase* emissions by 80 percent over its life cycle, while advanced biofuels such as cellulosic ethanol may *cut* emissions by more than 80 percent.

California's Low Carbon Fuel Standard demonstrates how other states (and the federal government) can help cleaner fuels compete against highly polluting fuels like liquid coal. Combined with appropriate environmental safeguards, similar policies will steer transportation fuels toward a more sustainable and lower-carbon future.

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