The Nexus of Biofuels, Climate Change, and Human Health: Workshop Summary

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The Nexus of Biofuels, Climate Change, and Human Health

WORKSHOP SUMMARY

Robert Pool, *Rapporteur*

Roundtable on Environmental Health Sciences, Research, and Medicine

Board on Population Health and Public Health Practice

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OF THE NATIONAL ACADEMIES

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The serpent has been a symbol of long life, healing, and knowledge among almost all cultures and religions since the beginning of recorded history. The serpent adopted as a logotype by the Institute of Medicine is a relief carving from ancient Greece, now held by the Staatliche Museen in Berlin.

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"Knowing is not enough; we must apply.
Willing is not enough; we must do."
—Goethe

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This workshop summary has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the process. We wish to thank the following individuals for their review of this workshop summary:

Al McGartland, U.S. Environmental Protection Agency
Martin A. Philbert, University of Michigan School of Public Health
Judith Qualters, Centers for Disease Control and Prevention

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the workshop summary before its release. The review of this summary was overseen by **Susan J. Curry,** The University of Iowa. Appointed by the Institute of Medicine, she was responsible for making certain that an independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the rapporteur and the institution.

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Preface

On January 24–25, 2013, the Roundtable on Environmental Health Sciences, Research, and Medicine of the Institute of Medicine (IOM) held a 2-day, interactive, public workshop on the intersection of biofuels, climate change, and human health.

Liquid fuels are a major part of modern life. They supply energy for ground, water, and air transportation as well as power for industrial and farming machinery. But fossil fuels—the dominant liquid fuel in use for well over a century—have many disadvantages. For one thing, the use of fossil fuels has obvious health downsides, such as emissions of pollutants that are directly harmful to health. The burning of fossil fuels produces greenhouse gases, which contribute to global warming, itself a long-term threat to human health. There have also been health concerns related to insecurity of liquid fuel supplies and the potential of international conflicts being caused by fuel scarcity. Furthermore, there are concerns that the world's large but still limited supply of fossil fuels could be strained by the increasing demand that results from societies around the world achieving greater prosperity. In the face of these concerns, new policies have been created that encourage the development of renewable sources of energy in general and biofuels in particular.

In November 2007 the roundtable held a workshop titled "Environmental Health, Energy, and Transportation: Bringing Health to the Fuel Mixture." Workshop attendees explored public health issues related to the composition of traditional and alternative fuels and fuel additives, and they discussed the known and potential health impacts associated with the use of these fuels and fuel additives. Since 2007, the development of renewable biofuel resources has increased dramatically, both in quantity and in the types of fuels being developed. Newer approaches to evaluation of health impacts—those that incorporate health impact assessment in a broader framework of decision making as well as those that address sustainability—have also developed. Two recent reports by the National Research Council, *Improving Health in the*

United States: The Role of Health Impact Assessment[1] and *Sustainability and the U.S. EPA*,[2] have helped to illuminate these issues. However, they have yet to be applied to biofuels.

Hence, the workshop that is summarized in these pages, titled "The Nexus of Biofuels Energy, Climate Change, and Health," focused on air, water, land use, food, and social impacts of biofuels as an energy resource. The workshop's invited speakers described the state of the science and the health policy implications of using different types (and generations) of biofuels as an energy source.

The workshop was part of a series of workshops focused on current and emerging environmental issues and their impacts on human health. These workshops are sponsored by the Roundtable on Environmental Health Sciences, Research, and Medicine. The roundtable was established to provide a mechanism for parties from the academic, industrial, and federal research perspectives to meet and discuss sensitive and difficult environmental health issues in a neutral scientific setting. The purpose is to foster dialogue, but not to provide recommendations. In this workshop summary, statements, recommendations, and opinions expressed are those of individual presenters and participants, and are not necessarily endorsed or verified by the IOM, and they should not be construed as reflecting any group consensus.

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[1] NRC (National Research Council). 2011. *Improving health in the United States: The role of health impact assessment*. Washington, DC: The National Academies Press.

[2] NRC (National Research Council). 2011. *Sustainability and the U.S. EPA*. Washington, DC: The National Academies Press.

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Overview[1]

The workshop's first session offered an overview of the major issues related to biofuels in order to provide a common starting point for the presentations that would take place during the remainder of the workshop's 2 days. The issues reviewed in this session included the impacts of biofuels use on greenhouse gas emissions, water quality, and land use; the connection between increasing biofuels production and food insecurity; and the economics of biofuels production.

BIOFUELS, GREENHOUSE GASES, AND LAND USE

The session's first presenter was Timothy D. Searchinger, a research scholar and a lecturer in public and international affairs at Princeton University's Woodrow Wilson School. He spoke about the implications of biofuels use for the level of greenhouse gases in the atmosphere and, thus, the potential implications of biofuels use for global warming. A secondary topic was the effect of biofuels use on the worldwide food supply and how an increased emphasis on biofuels could bear on world hunger.

Liquid biofuels used for transportation represent just one form of bioenergy, Searchinger noted, but at this point it is the major form. About 40 percent of the U.S. corn crop is used to make ethanol, for example, and there is almost a comparable amount of ethanol being made

[1] The planning committee's role was limited to planning the workshop, and the workshop summary has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshop. Statements, recommendations, and opinions expressed are those of individual presenters and participants, and are not necessarily endorsed or verified by the Institute of Medicine, and they should not be construed as reflecting any group consensus.

from sugarcane in Brazil. Europe produces somewhat less biofuels, although still a considerable amount, mainly in the form of vegetable oil for biofuel.

Many governments around the world have either goals or mandates for biofuels, Searchinger said, and if these goals and mandates are met, biofuels will account for about 10 percent of the world's transportation fuels by 2020. This represents about 2.5 percent of the world's total energy budget, but Searchinger said, when the energy that it takes to make biofuels is taken into account, biofuels would be providing about 1.7 percent of the world's delivered energy by 2020.

How much of the world's crops would that take? By 2020 biofuels would require that about 26 percent of all the energy contained in the present production of the world's crops. By 2050 that figure would rise to 36 percent, he added. "So, that gives you some idea of the challenge, which is that it takes a large amount of biomass to get a small amount of energy."

Of course, liquid biofuels are only one form of bioenergy that people are interested in, he noted. For example, there is also a big push in Europe as well as in some U.S. states to produce electricity from wood products.

Governments are encouraging the use of bioenergy in various ways. The European Commission has required, for instance, that 20 percent of all energy in Europe be renewable by 2020—not just the energy from utilities, but all energy. It is expected now that more than half of that will come from bioenergy, Searchinger said. A number of states have renewable energy targets, he said, although they are not quite as stringent and are just for electricity.

The Effect of Biofuels Usage on Carbon Dioxide Levels

One of the main reasons that people support the use of biofuels, Searchinger said, is the belief that "when you switch from burning a fossil fuel to burning a biofuel you get some kind of direct greenhouse gas benefit." But, he said, a close examination indicates that this is not the case and that the belief that there is a direct benefit stems from an "accounting error."

The belief that burning biofuels contributes less carbon dioxide to the atmosphere than burning fossil fuels stems from the fact that biofuels are derived from plants, which absorb carbon dioxide as they grow. "So, the theory is that, in effect, bioenergy is just recycling carbon, not emitting new carbon." That is wrong, however, for the simple reason that land typically supports plant growth, whether it is used for bioenergy or not. For bioenergy to reduce greenhouse gas emissions through plant growth, it must lead to additional plant growth.

Searchinger showed a comparison of the net greenhouse gas emissions for gasoline versus ethanol (see Figure 1-1). The first few steps of the production process for biofuels always produce more emissions than the production process for gasoline, he said, "because it takes more energy and emissions to produce the crop and to transform it into ethanol than it does to mine crude oil and refine it into gasoline." The greenhouse gases emitted from the tailpipe of a car are about the same for ethanol and gasoline, but there is a another source of greenhouse gas emissions for the ethanol, which is the fermentation process. For every 2 grams of carbon emitted from a tailpipe for ethanol, there is another gram produced in the fermentation process.

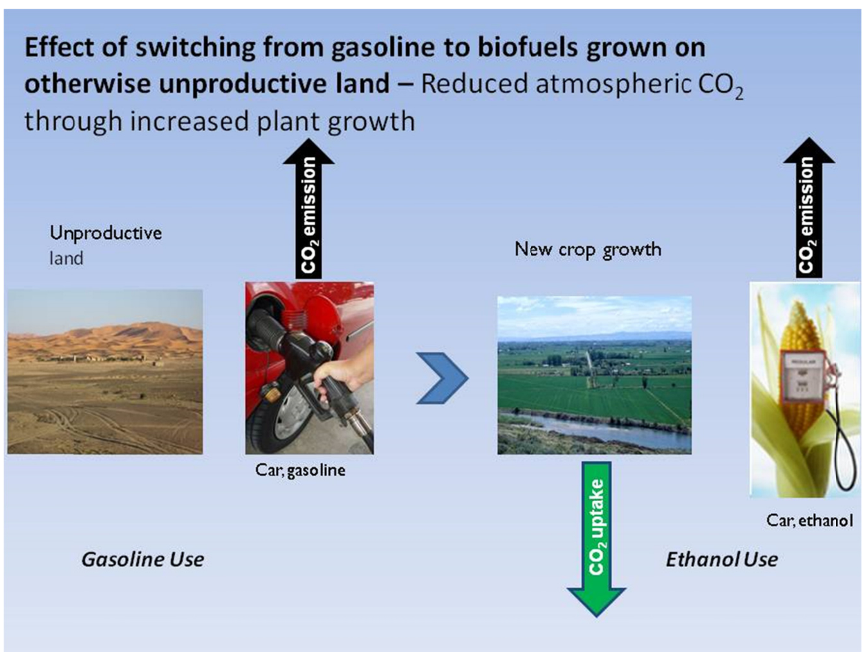

FIGURE 1-1 Net greenhouse gas emissions for ethanol versus gasoline.
NOTE: CO_2 = carbon dioxide.
SOURCE: Searchinger, 2013.

When all of the emissions have been taken into account, ethanol releases almost twice as much greenhouse gas into the atmosphere per unit of energy as gasoline. However, when the corn is grown to produce the ethanol, it absorbs carbon dioxide from the environment, so, in effect, the tailpipe emissions and the fermentation emissions can be ignored because that is carbon dioxide that had been pulled from the atmosphere by the growing plants. With this "plant credit" taken into account, the calculations show that the net greenhouse gas emission for the ethanol is 29 percent less than for the gasoline.

The key concept here, Searchinger said, is that the benefit from ethanol depends on the existence of an *offset* that makes up for the fact that producing and burning ethanol actually creates much more greenhouse gases than producing and burning gasoline. So, the question is: Is there really such an offset? It is true that growing corn leads to a certain amount of carbon dioxide being pulled from the atmosphere, but that is not all that goes into the determination of the offset. The critical requirement for an "offset" is that it be additional. No one can take credit for a carbon sink, such as a tree if that tree already exists anyway—in this case, regardless of whether the biofuels exist or not. One must take into account all of the circumstances surrounding the production of the ethanol and compare what happens when corn is being grown to produce ethanol to what happens when corn is not being grown to produce ethanol.

The first thing that must be considered is the land that is used to grow plants. "Land grows plants whether it's growing those plants for biofuels or not," Searchinger pointed out. "So, those plants are already up taking carbon if you're growing it for biofuels or not." Thus, the only way that there is a legitimate offset from growing corn for ethanol is if more plants are being grown on that same amount of land or, specifically, if more carbon dioxide is taken up by the corn crop than was taken up by whatever was growing on that land before the corn. "One way to think about it is that if you had a bare piece of land and you allowed it to grow as a forest, that forest would accumulate carbon, and it would reduce greenhouse gas emissions. On the other hand, if you simply had a forest that was growing anyway, you couldn't count that as an offset."

Ignoring this basic fact is a fundamental error that often appears in calculating the biofuels offset. "Biofuel analysis assumes typically that all plant growth offsets biofuels, rather than only additional plant growth," Searchinger said.

There are various ways that a real offset can be achieved, Searchinger noted. If, for example, a corn crop is planted on land that had few or no plants growing on it before, that is a legitimate greenhouse gas saving because there is a new crop absorbing additional carbon dioxide. Similarly, if there is a crop residue, such as rice straw, that would normally be burned but instead is used to make ethanol, that is a legitimate greenhouse gas saving because the usual carbon dioxide emissions from that rice field have been reduced. On the other hand, if one takes a corn crop that would have been grown anyway and simply diverts it for use in fuel, that does not represent a legitimate offset because there is no additional plant growth and no additional carbon dioxide removed from the atmosphere.

If biofuels use crops from existing cropland, there are indirect ways it could generate the offset and therefore greenhouse gas saving. If, for example, the corn crop used to produce ethanol is diverted from human and animal consumption—and assuming that the corn is not completely replaced by something else—then people and livestock eat less, and they consequently release less carbon in the form of greenhouse gases, mainly carbon dioxide and methane. "Most of us would not think that's a good thing," he noted drily, "but that does give you a greenhouse gas benefit."

Another type of indirect effect on greenhouse gases would arise if an increased demand for corn led farmers to increase their yield, growing more corn per acre, and thus absorbing more carbon dioxide per acre than before. That offset might be reduced somewhat, Searchinger noted, by higher greenhouse gas emissions from increased fertilizer use.

A third type of indirect effect of adopting ethanol would be the plowing up of new land in order to grow corn where no crops had been grown before. The corn crop will absorb carbon dioxide, but whatever plants had existed on the land before are no longer absorbing or continuing to store carbon dioxide, and one must compare the carbon absorbed by the corn with the carbon released (or not subsequently sequestered) by plowing up forests and grasslands.

Searchinger offered an analysis of the costs and benefits of creating new croplands from forests or grasslands. A hectare of corn that is grown for ethanol has a net benefit of about 3 tons of carbon dioxide per year. That counts the benefit of reduced emissions from gasoline, but includes the greenhouse gas costs of producing the corn and refining it into ethanol. But it also has another cost, which is the opportunity cost of the land, or the carbon benefits the land would produce if not used for ethanol. If that same hectare of land in Iowa were to be left fallow and allowed to reforest, it would absorb 7.5 to 12 tons of carbon dioxide per year, so using the land to grow corn has a net cost in terms of the amount of carbon dioxide being sequestered. The most effective approach would be producing cellulosic ethanol—ethanol produced from wood or grasses—on the land, but even in that case, Searchinger said, "you're simply matching the opportunity cost of using that land for another purpose." And if the cropland is created by clearing forest, there is a much greater cost in greenhouse gases because plowing up forests will release 12 to 35 tons of carbon dioxide per hectare each year for 30 years. Thus, the best-case biofuels scenario would be to take fallow land and use it for the production of cellulosic ethanol, he said, but even in that case it is only a break-even situation if the land would otherwise come from abandoned land, and it would increase emissions if the land used was previously forest. There is no offset.

In short, out of the three possible indirect effects of growing corn to produce ethanol, Searchinger said, two are bad. "Land-use change leads to greenhouse gas emissions and habitat loss, and reduced food consumption leads to hunger. The only real effect that would be beneficial is if the overwhelming response for biofuels was simply that farmers produce more food on the same land." The implication is that in deciding to create biofuels simply by going out and buying crops that were already growing, policy makers are, in effect, betting that the main effect of this policy will be a yield gain and that there will be relatively little decrease in food consumption and relatively little increase in the amount of land devoted to farming.

It is not at all clear that this is what has happened, Searchinger said, and he then took a closer look at the effects of biofuels production on food consumption.

Biofuels and Food Consumption

Interestingly, although reduced food consumption would not appear to be a desirable result, it is exactly what is assumed in the major models used to predict the greenhouse gas effects of biofuels, Searchinger said. "You have to find this deeply in the data," he said. "It's generally not reported. Take, for example, the Environmental Protection Agency [EPA] analysis of corn ethanol, which found relatively little land-use change compared to some other studies. One reason it didn't find as much land-use change as other studies is that it actually estimated that a quarter of all the calories that are diverted to ethanol aren't replaced."

Similarly, the model used by the California Air Resources Board assumed that more than half of the calories from the corn diverted from human and animal consumption to ethanol would not be replaced. A major model used by the European Union assumes that a quarter of the calories from either corn ethanol or wheat ethanol are not replaced.

Thus, the greenhouse gases benefit from using biofuels, as calculated by these models, depends on humans and animals eating less, expending less energy, and thus breathing out less carbon dioxide (and producing less methane). "If you were to eliminate these savings," he said, "you would not have greenhouse gas savings according to all these models."

Of course, he noted, the decreased consumption assumed by these models is not a desirable effect because there remains a great deal of hunger in the world—roughly 900 million people are hungry according to recent estimates. Thus, it is particularly worrisome that the frequency of food crises worldwide has essentially tripled since 2005, when the amount of biofuels use began to increase sharply. And according to a recent report by the High-Level Panel on Food Security, of which Searchinger is a member, that is not a coincidence (HLPE, 2013). "We basically conclude that biofuels are the dominant source of food price increases."

In particular, the increase in corn prices in the United States can be traced to the cost of oil combined with government tax credits for ethanol production. With crude oil at $80 per barrel and with the current U.S. tax credits for ethanol, it is economical to use corn to make ethanol and to replace gasoline until the price of corn reaches about $6.80 per bushel. "Roughly speaking," he said, "this is a 275 percent higher price than the long-term corn price in the first part of the 2000s." Thus, corn prices get bid up until they get close to that level—and as the price for corn intended for ethanol production increases, the price for corn intended for consumption increases along with it, for the crops are the same. Furthermore, as the price of corn increases, the price of wheat and soybeans—and, to a lesser extent, rice—track the price of corn very closely because the crops can, to a significant extent, be substituted for one another. "So, this force by itself is perfectly adequate to explain the vast majority of the price rise that we've had," Searchinger said.

Some people have suggested that the increase in prices have been due mainly to supply problems, but Searchinger said that grain yields have increased steadily, so "the problem was not that supply wasn't doing its best to keep up." Instead, the problem has been the rapidly growing demand for grains for use in biofuels. "Although farmers have been able to keep up with the growth of demand for food and feed, farmers haven't quite been able to keep up with that rate of growth and to supply biofuels at the same time."

Global Consequences of Increasing Biofuels Use

In the last portion of his talk, Searchinger took a broad look at the environmental costs of biofuels making up a large percentage of transportation fuels or, more broadly, bioenergy making up a large percentage of the global energy budget.

He began by asking whether the yield of key crops could be expected to increase enough over the next several decades to produce the necessary biofuels without adding additional cropland. An examination of the trends in crop yield from 1960 to 2006 shows that there was a steady, linear increase during that time that changed little from year to year. During that time, the crops were devoted mainly to food and feed, but the growing demand for biofuels in the future will require that yields be increased more quickly than in the past. To produce all the crops needed by 2020 for both food and biofuels without any change in land use will require a doubling of the historical yield growth rate, Searchinger said, "and that's not going to happen."

Compounding the problem is that in addition to the growing demand for biofuels, there is projected to be a huge growth in demand for food between now and 2050. "You need to produce 64 percent more crop calories by 2050 compared to 2006, and 70 percent more meat and milk," he said. "When you compare that to historical growth rates, that means calorie growth would have to grow as much as it did each year during the height of the green revolution, and meat production would have to grow 30 percent higher." Furthermore, even during the green revolution, when irrigation rates doubled and many parts of the world began using fertilizer that hadn't used it before, there was still an increase of more than 400 million hectares of land devoted to crops. "So, the point is that even without an increased demand for crops for biofuels, it will be a very tight challenge to produce all the food we want on the same land," Searchinger said.

Thus, there will certainly need to be land-use change if the demand for biofuels is to be met in the future, and a number of studies have examined the issue of how much bioenergy could be created by devoting land to crops for bioenergy. One study by the Intergovernmental Panel on Climate Change, for example, asked how much bioenergy could be produced by using all the world's potential cropland that is not being used for crops. The study found that there were about 1.3 billion hectares of potential cropland that could be used for bioenergy. "If we use all of that for biofuels and get really high yield," Searchinger said, "we could essentially produce all of our energy needs with bioenergy." But the analysis ignored the carbon costs of the change in land use.

Some of those 1.3 billion hectares are forests, which store and in many cases continue to accumulate carbon dioxide. Indeed, Searchinger noted, "the accumulation of carbon in forests is a huge factor holding down climate change. It's why when we burn carbon dioxide we assume that only half of it stays there [in the atmosphere], in part because a quarter of it goes into forests." So, cutting down forests to produce croplands to produce bioenergy would, in essence, add a great deal of carbon dioxide to the atmosphere.

Another type of land that could be used to produce bioenergy is abandoned cropland. But in many cases that abandoned cropland is slowly returning to forest, so, again, turning it to cropland would have the effect of adding carbon dioxide to the atmosphere.

Yet another type of land that is talked about as potential cropland are grazing lands and savannas, particularly in Africa. Searchinger and colleagues have prepared a paper analyzing whether there would be a greenhouse gas benefit by using the African savannas to make biofuels. Assuming "a pretty high yield," the group estimated that "only about 3 percent of that [savanna] would produce a greenhouse gas benefit over 20 years."

The real challenge with bioenergy, Searchinger said, is that photosynthesis is extremely inefficient. "If you're really lucky you get half a percent of the solar energy transformed into plant biomass—that's extraordinary achievement over the course of the year. And eventually maybe a tenth or two-tenths of the original solar energy will end up actually in delivered energy like electricity." By contrast, a solar cell turns 10 percent of solar energy into electricity. "So, compare one-tenth of 1 percent with 10 percent, and you'll get an idea of the inefficiency of using land. What that means is it takes a tremendous amount of land to make a small amount of bioenergy."

The bottom line is that to provide 10 percent of the world's transportation fuel by 2050 would require 36 percent of all of today's crop production, and it would amount to less than 2 percent of the world's delivered energy at that time.

There are some people who have a much more ambitious goal for bioenergy—they would like to produce 20 percent of the world's energy from bioenergy by 2050. That would require all of the plants harvested today around the world for any purpose—all crops, all grasses eaten by livestock, all wood, and all crop residues.

The bottom line, Searchinger said, is that trying to make energy from crops will drive up food prices and have a major health effect through hunger, while at the same time, because of the issues surrounding changing land use, increasing biofuels production would not actually reduce greenhouse gas emissions.

BIOFUELS IN THE CONTEXT OF THE LARGER ENERGY PICTURE

In the session's second presentation, Howard Gruenspecht, the deputy administrator of the U.S. Energy Information Administration (EIA), placed biofuels in the context of the larger energy picture. The EIA, he noted, is a statistical and analytical agency within the Department of Energy, and, as such, it aims to provide an objective view of biofuels and not to advocate for one position or another. He began by discussing the current role of biofuels in the overall energy picture and then spoke about the outlook for biofuels in the future.

The Current Role of Biofuels

Although the use of liquid biofuels has grown significantly during the past decade, Gruenspecht said, biofuels still represent a very small part of the nation's overall energy use. In particular, as can be seen in Figure 1-2, they currently provide about 1 percent of total U.S. energy. They represent a somewhat larger but still modest share—about 4 percent by energy content—of the supply of transportation fuels.

The role of biofuels can be considered from various perspectives in addition to their percentage of the total U.S. energy budget, Gruenspecht said. For example, one of the motivations in adopting policies to increase the use of biofuels has been concern over how much the country relies on imported oil. From that perspective, a key fact is that the country's reliance on oil imports has been declining sharply during the past 8 years. In 2005 net petroleum and biofuels imports peaked at about 60 percent of the total liquid fuels used in the United States; by 2012 that had

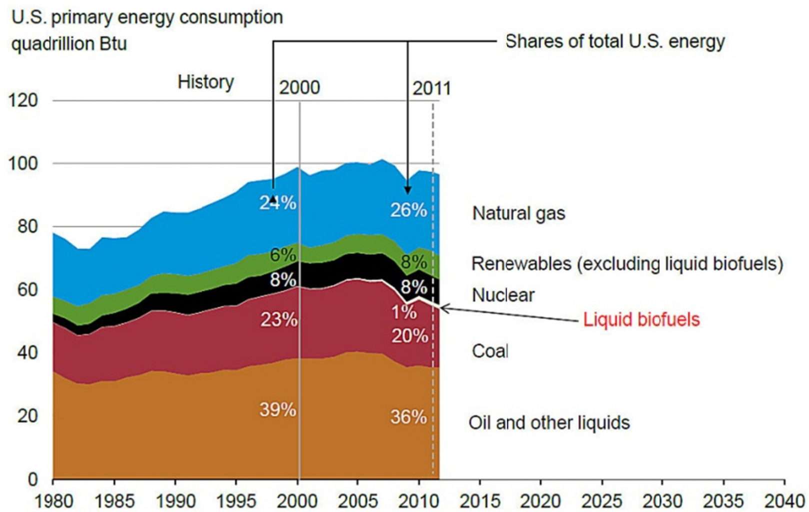

FIGURE 1-2 Sources of U.S. energy, 1980–2012.
SOURCE: EIA, 2013.

dropped to only about 40 percent, he said, and the EIA's latest short-term outlook indicates that this will have fallen even further, to slightly above 30 percent, by 2014. "Higher production and lower consumption are both contributing to recent trends in this area," he said.

The transportation sector alone accounts for 70 percent of total U.S. liquid fuel use. Gasoline now accounts for about 60 percent of all liquid fuels used by the U.S. transportation sector, Gruenspecht said, and that gasoline contains an average of about 10 percent ethanol by volume. In absolute terms, the use of motor gasoline was growing steadily until about 2005, at which point it leveled off for several years and then began falling. This decrease in gasoline consumption is part of an overall decline in energy consumption by the transportation sector, which is in part due to the effects of the recent economic downturn, which has led to a decrease in vehicle miles of travel. Another factor in the decline in energy consumption by the transportation sector has been the growing efficiency of the light-duty vehicle fleet, which has resulted both from market effects and regulations on fuel economy. "More stringent fuel economy regulations that have already been promulgated for light-duty vehicles through model year 2025 are expected to have a further impact in dampening the demand for gasoline," Gruenspecht added. This is vital context for biofuels, he noted, because at present about 98 percent of all ethanol being produced in used as a blend stock in gasoline.

Trends in Biofuels Use

Taking a closer look at the growth in biofuels, Gruenspecht showed how biofuels use has grown during the past decade. In 2000 ethanol made up well under 1 percent of the gasoline fuel sold in the United States. That number began climbing steadily around 2002 and started to accelerate around 2005 or 2006. By 2011 ethanol made up more than 9 percent of all gasoline sold by volume, although it represented only about 6 percent of gasoline fuel in terms of energy content. By contrast, biodiesel makes up a much smaller percentage of all diesel fuel sold in the United States—just fewer than 2 percent both in terms of volume and in terms of energy content.

Ethanol is not likely to move past 10 percent of total gasoline sales (by volume) any time soon, Gruenspecht said. “Although the EPA has recently approved the use of gasoline blends containing up to 15 percent ethanol in all model-year 2001 and newer light-duty vehicles,” he said, “10 percent remains the ethanol blending limit for gasoline used in older vehicles as well as in marine applications and for small gasoline engines used in power equipment like your lawn mower or chainsaw.” Furthermore, the EPA’s approval of 15 percent ethanol blends for use in newer vehicles has been controversial, he said, and there has been little movement toward widespread retail distribution of blends with more than 10 percent ethanol. Thus, 10 percent is often referred to as the “blend wall,” meaning that it is represents a level that will not be easy to break through.

Economic Considerations

In economic terms, ethanol has generally been somewhat less expensive than gasoline on a per-gallon basis during the past several years. However, global crude oil, gasoline, and diesel prices were all at record high annual average levels in 2012, and even given this favorable situation, ethanol producers were seeing relatively little profit, thanks in large part to the high prices for corn.

Furthermore, if prices are compared on the basis of energy content, ethanol has been consistently more expensive than gasoline because a gallon of ethanol has less energy than a gallon of petroleum-based gasoline. Thus, from this perspective, ethanol producers are making little money even though their biofuel is more expensive than gasoline in terms of energy supplied per gallon.

"The difference has some major implications for the economic prospects of expanding the use of ethanol in higher percentage blends where its lesser energy content per gallon would be more noticeable to consumers," Gruenspecht said. Years ago, when customers had a choice between 100 percent petroleum-based gasoline and gasoline containing 10 percent ethanol, their behavior indicated that they generally looked for the cheapest price per gallon without taking into account the lower energy content of gasoline with ethanol. And today it does not matter because nearly all gasoline available at retail outlets contains 10 percent ethanol by volume. But things could change with a move to make gasoline with higher ethanol content, he said. "Experience in Brazil, where high-percentage ethanol fuels are sold, suggests consumers definitely make purchase decisions based on energy content pricing rather than simply buying the cheapest gallons when considering such fuels. So, there are some interesting economics that come into play in this area."

In the case of diesel, biodiesel is significantly more expensive than 100 percent petroleum-based diesel fuel. The main reason it is used today is the existence of tax credits and some mandates requiring a specified percentage of biodiesel in the overall fuel pool, Gruenspecht said.

Biofuels Trade

For much of the past decade, the United States was a net importer of biofuels. This was particularly true from 2006 to 2008, Gruenspecht said, when "the phaseout of other octane enhancing additives used in petroleum gasoline created a sharp upsurge in ethanol consumption." During that time, much of the imported biofuels came from Brazil.

However, since 2010 the United States has been a net exporter of biofuels, and, interestingly enough, there has been a significant amount of two-way trade with Brazil. "The two-way trade generally involves U.S. imports of sugarcane ethanol and U.S. exports of corn-based ethanol," he said. In terms of the characteristics of the fuel, the two types of ethanol are indistinguishable, he said, so the United States is both sending ethanol to Brazil and buying ethanol from Brazil. The existence of this unusual two-way trade is "in large part attributable to specific features of federal and state level policies which provide several types of extra credit for using ethanol produced from sugarcane due to calculations related to life-cycle emissions."

Policy Considerations

Federal and state policies regarding biofuels are constantly evolving, Gruenspecht said. For example, there was a federal requirement in the early 1990s for the use of oxygenates in reformulated gasoline. It was intended to promote the use of ethanol, but in most markets the non-ethanol oxygenate MTBE (methyl tertiary-butyl ether) outcompeted ethanol. However, after 2000 a number of states became concerned about possible ground-water contamination by MTBE and banned it, which caused ethanol use to grow significantly. Then the Energy Policy Act of 2005 led refiners to decide that the liability risks of continuing to use MTBE were too large, and its use was phased out on a national basis beginning in 2006, which led to an upsurge in demand for ethanol.

Furthermore, since the 1980s there have been federal—and, in some cases, state—tax incentives for the use of ethanol and other biofuels. These tax incentives combined with the phaseout of MTBE drove much of the increase in biofuels use.

Three federal tax incentives—two for ethanol and one for biodiesel—expired at the end of 2011. One incentive, the tax credit for cellulosic ethanol, was scheduled to expire at the end of 2012, but it was renewed as part of the "fiscal cliff" legislation.

The renewable fuels standards, which were enacted in the Energy Policy Act of 2005 and expanded by the Energy Independence and Security Act of 2007, set a series of annual targets for various groups of biofuels. "The number that people remember," Gruenspecht said, "is the 2022 number for total biofuels, which is 36 billion gallons, of which 21 billion falls in the category of advanced biofuels, with 16 billion of that 21 billion falling in the advanced fuels subcategory of cellulosic biofuels."

To date, he added, there has been little success in producing cellulosic biofuels, and the EPA has ended up modifying the statutory goal in each of the years through 2012. "So, for instance, in 2012 instead of 500 million gallons, they set a goal of about 10 million gallons." The 2013 goal is likely to be modified as well, he said.[2] "It's supposed to be a billion gallons. . . . I don't know exactly what it's going to be. I know that my agency is required by statute to send a letter to the EPA each October to say what we think can be produced, and we thought in

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[2] Since the time of the workshop, the EPA has modified the statutory goal for cellulosic biofuel to 6 million gallons. Available at http://www.epa.gov/otaq/fuels/renewablefuels/documents/420f13042.pdf (accessed August 20, 2013).

October 2011 that up to 10 million gallons could be produced in 2012." (That estimate has since been revised downward to only 4 million gallons.) The yearly statutory goals are set to rise rapidly through 2022, he noted. By 2016, for instance, the country is supposed to be producing 4.25 billion gallons of cellulosic biofuels. It will be a "tough slog," Gruenspecht predicted.

The Outlook for Biofuels

With that background, Gruenspecht described the outlook for biofuels over the next decade. Before he began, however, he noted that there is a great deal of uncertainty in the forecast. "Energy projections can be wrong for any number of reasons, including assumptions about economic growth, energy market developments, energy technology improvements, changes in consumer preferences, and energy policy developments, only to name a few." So, the outlook should be heard with that in mind.

The outlook is based on the EIA's *Annual Energy Outlook 2013*. It generally assumes current laws and regulations, he said, and although it does assume technological improvements, they are only trend improvements. "We're not guessing when breakthroughs will occur," Gruenspecht said. The key results from the projection are

- Growth in energy production outstrips consumption growth.
- Crude oil production, particularly from tight oil[3] fields, rises sharply during the next decade.
- Natural gas production grows faster than in previous projections, serving the industrial and power sectors and an expanding export market.
- Motor gasoline consumption reflects the introduction of more stringent fuel economy standards, while diesel fuel consumption is moderated by increased natural gas use in heavy-duty vehicles.
- The United States becomes a larger exporter of natural gas and coal than was projected in earlier projections.
- All renewable fuels grow, but biomass and biofuels growth is slower than in previous projections.

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[3] "Tight oil" refers to the light crude oil trapped in shale, limestone, and sandstone formations characterized by very low porosity and permeability.

- U.S. energy-related carbon dioxide emissions remain more than 5 percent below their 2005 level through 2040, reflecting increased efficiency and the shift to a less carbon-intensive fuel mix (EIA, 2013).

Annual Energy Outlook 2013 projects where the United States will get its energy through 2040. As can be seen in Figure 1-3, the expectation is for overall energy use to rise very slowly. Thanks in large part to increasing energy efficiency, primary energy consumption is not projected to get back to the 2007 level until about 2022.

Renewables are predicted to meet a large share of the growth in energy use. Much of that growth is expected to come in renewables (excluding liquid biofuels), which are forecast to grow from 8 percent of total U.S. energy use in 2011 to 11 percent by 2040. The energy provided by liquid biofuels is also projected to increase—from 1 percent of total energy use in 2011 to 2 percent by 2040—but the growth is expected to be far below the targets in the federal legislation, Gruenspecht noted, in part because of the issues related to cellulosic ethanol.

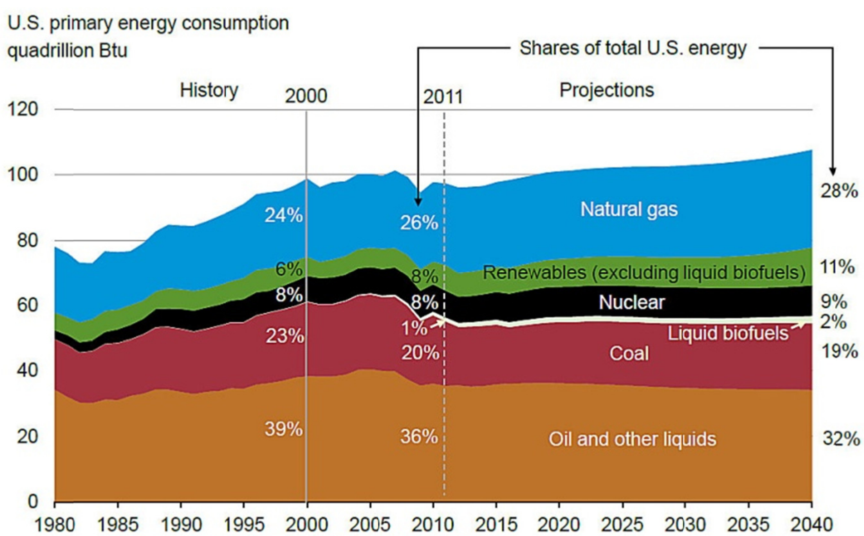

FIGURE 1-3 Sources of U.S. energy, projected to 2040.
NOTE: Because of rounding, percentages may not add to 100 percent.
SOURCE: EIA, 2013.

The percentage of total energy consumption provided by fossil fuels is projected to decline somewhat, but it will remain quite significant, which has implications for climate change, he noted. And the energy provided by oil and other liquids is projected to decline both in percentage and in absolute terms even though the growth in liquid biofuels is small. “I think that’s an interesting observation—there are other alternatives to oil beside biofuels.”

In the transportation sector, despite continued growth in travel, energy consumption by light-duty vehicles is projected to decline significantly. The consumption of motor gasoline is predicted to fall sharply during the period, dropping from 60 percent to only 47 percent of all transportation fuel. Meanwhile, diesel and liquid natural gas are expected to provide increasing percentages of transportation energy. This shift in the overall fuel mix arises from an effort to increase efficiency and thus decrease dependence on oil. Domestic oil production is projected to increase sharply in the next few years, reaching a peak around 2017 to 2020, after which it slowly decreases. The increase is due predominantly to the dramatically growing production of tight oil, or shale oil.

Because of the increase in domestic oil production, the import of liquid fuels—both petroleum and biofuels—is projected to continue dropping for the next several years and then remain relatively constant through 2040. “We don’t expect the reliance on net petroleum and biofuels imports to rise to where it was in 2005,” Gruenspecht said. “We see it remaining well below 40 percent [of total liquid fuels] throughout the entire forecast period.” There are also scenarios in which a more robust domestic production outlook combined with additional improvements in fuel efficiency, additional switching to alternate fuels, and various transportation applications led to a much smaller U.S. reliance on petroleum imports. “A situation in which the United States uses no net imported liquid fuels is a stretch,” he said, “but it’s certainly not beyond the realm of possibility.”

The projections for biofuels use show a relatively slow rise over the next decade. Total biofuels use in 2011 was just less than 15 billion ethanol-equivalent gallons; that is predicted to increase to about 19 billion gallons by 2022. This is far below the 36 billion gallons called for in federal legislation. Similarly, the cellulosic biofuels are projected to fall far short of the 16 billion gallons called for in the federal legislation; according to the projections far less than 1 billion gallons of cellulosic biofuels will be used in 2022. However, Gruenspecht said, “As the price of oil goes up . . . and as technology improves, we do expect more biofuels to come in." According to the projections, by 2040 more than 25 billion ethanol-equivalent gallons of biofuels will be used, including some 9 billion gallons of cellulosic biofuels.

In closing, Gruenspecht said that it is important to keep in mind that the market for motor fuels is very complex and that biofuels can play several different roles in that market. In particular, ethanol has played three distinct roles. It has been used as a source of octane, notably as a replacement for MTBE in reformulated gasoline following the phaseout of that additive. After MTBE was phased out, gasoline producers would pay almost anything for ethanol, he said. "You couldn't sell fuel unless you had enough octane in the fuel, so it almost didn't matter what it cost—it [the ethanol] was a small percentage of the fuel you had to buy." A second role has been as a "volume enhancer," Gruenspecht said. "It's like a meat filler in the sense that you put in this stuff that has lower energy content per unit of volume, but people don't notice." Finally, ethanol also competes as an energy content provider. This is a more difficult market for ethanol, he noted, because ethanol costs more than gasoline per unit of energy.

At the moment, he said, ethanol is facing some significant challenges in moving beyond its current roles as a source of octane and as a volume enhancer. One challenge, Gruenspecht said is the "blend wall"—the difficulty in moving beyond 10 percent of overall gasoline sales. A second is the poor availability of E85 (gasoline fuel made with 85 percent ethanol) and other gasoline blends with a high percentage of ethanol. A third challenge is the difficulty of pricing E85 and other high-percentage blends to be competitive on an energy content basis.

Finally, Gruenspecht noted that the use of biofuels intersects with a number of public policy issues. First, the use of biofuels affects dependence on petroleum imports. It also can play a role in efforts to mitigate greenhouse gases. And it can have implications for rural economic development as well as food, water, environmental, and health policies. All of these should be considered in setting biofuels policies.

INDUSTRY PERSPECTIVE

The session's last speaker was Roger Prince, a senior research associate with ExxonMobil Biomedical Sciences in New Jersey. He offered the industry perspective on the production and use of biofuels.

Trends in World Energy Use

Prince began with a broad look at expected energy demand over the next several decades (ExxonMobil Corporation, 2013). The population of the countries of the Organisation for Economic Co-operation and Development is expected to stay more or less constant, while its gross domestic product (GDP) is expected to continue increasing steadily. However, although an increasing GDP has historically coincided with increasing energy use, energy efficiencies are expected to result in energy demand staying relatively flat in the next 30 years or more. By contrast, the rest of the world is expected to grow substantially in population, global energy demand, and energy consumption. Still, Prince said, there will be huge amounts of energy saved over what would normally have been expected because of the efficiencies that are coming into the market.

To meet that energy demand, the world will use a diverse mix of fuels that will change over time. Prince showed a figure illustrating the projected sources of the world's energy from 2010 to 2040 (see Figure 1-4).

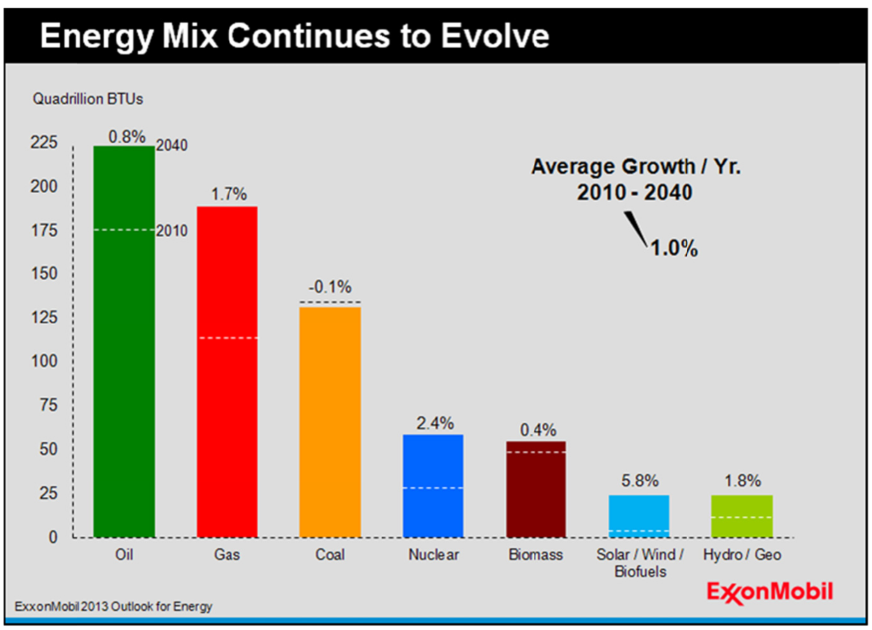

FIGURE 1-4 Worldwide fuel mix, 2010–2040.
SOURCE: Modified from ExxonMobil Corporation, 2013. Reprinted with permission from the ExxonMobil Corporation.

According to the projections, the world's rising demand for energy will be met by increases in every category of fuel except for coal, which is forecast to decrease in total energy supplied toward the end of the period. The greatest increases will likely come from natural gas and renewables.

By far the largest amount of renewable energy now comes from biomass, Prince said. "But this is far from benign; this is the biomass that people use for cooking in the form of, say, animal dung or very green vegetation." Because of the negative effects of burning this sort of biomass, governments and nongovernmental organizations are working to persuade people to stop using it, which should lead over time to a gradual slowdown in the increasing use of this material and, eventually, a decline, but that decline is not predicted to begin before 2030.

Renewables make up a relatively small part of the overall energy mix, and the category of "wind, solar, and biofuels" makes up a very small part of the renewable energy mix. Thus, despite recent efforts to increase the amount of renewable energy produced, Prince said, renewables still make up only a tiny sliver of the world's overall energy budget. That percentage will grow in the next several decades but will still remain a relatively small part of the entire fuel mix.

One thing that is not widely appreciated, Prince said, is just how much energy people use on an individual basis—and how that individual use varies from region to region around the world. A human consumes about 2,000 kilocalories per day in food, he said, which is about 8,000 BTU. "If you think back to 1800, that was what the average person had to work with. If they went to chop wood, they were using that 8,000 BTU as an investment to chop wood to get wood."

Today, by contrast, people in North America use an average of 740,000 BTU per person each day. This staggering increase in energy consumption is what allows our modern lifestyle. About 60 percent of that daily energy usage is indirect—used to make the various items that people use in their lives, from smart phones and food to roads and buildings—and about half of individuals' direct energy usages is for personal vehicles. Energy usage per capita in North America is far higher than it is in any other region of the world—the closest regions are the Russian/Caspian region and Europe, both of which have average individual energy use of around 400,000 BTU—and the percentage of energy use devoted to personal vehicles is several times higher in North America than in any other region. Average energy use per person is less than 150,000 BTU in Latin America and less than 100,000 BTU in Africa.

Thus, it is no surprise that energy use worldwide is expected to grow. "Approximately a quarter of the world's population doesn't yet have electricity," Price said, "and something like a third of them don't have modern cooking and heating. And those people are all going to want to have increased energy use."

One problem with this increasing demand for energy is that it will come into conflict with the desire to keep greenhouse gases in check. A study carried out at the Massachusetts Institute of Technology examined what it would take to keep the level of carbon dioxide in the atmosphere from going above 550 parts per million, which is already significantly higher than the current level of 400 parts per million. Because the world's population and the individual energy use per capita are both increasing steadily, various changes will be required to bring fossil fuel use down to a level that will prevent atmospheric greenhouse gases from continuing to climb. The study assumed that sharp increases in energy efficiency and decreases in demand per capita can be achieved in the next 70 years, but that still left a rapidly growing need for energy produced with little or no greenhouse gas emissions, such as nuclear power, fossil fuel plants with carbon capture technology, and renewables.

There is tremendous public support for bioenergy to be a large part of that renewable energy segment, Prince said. However, he cautioned, "I'm afraid it's rather more optimistic than our view."

Biofuels Efficiency

To understand the earth's overall capacity to produce bioenergy, it is useful to think in terms of its net primary productivity (NPP), which is "the amount of photosynthetic biomass available for exploitation by the biosphere." It can also be thought of as the total amount of carbon dioxide taken in by plants during photosynthesis minus the total amount of carbon dioxide released by plants through respiration. The earth's NPP is staggeringly large, Prince said—about 56 gigatonnes of carbon dioxide per year.

It turns out, he said, that humans already use about 30 percent of that NPP for food, fabrics, construction, and other uses. Any increase in the use of biofuels will require an increase in the amount of the earth's NPP being appropriated for human use. And of course, Prince noted, essentially 100 percent of this NPP is already being used—if not by humans, then by various animals, fungi, bacteria, and other forms of life—so any increase in the human use of the NPP will take away from other ecosystem processes. One possibility would be to increase the earth's total NPP—to grow crops, such as algae, where there is currently little growing. "But we already do an amazingly good job at harvesting the natural world," he said, "and it will be very hard for us to harvest a lot more without displacing every orangutan and every zebra."

Given these constraints, it is clear that a crucial factor in the success of biofuels will be how efficiently they can be produced. And unfortunately, the first-generation biofuels that are in use today—ethanol from corn, sugarcane, wheat, sugar beets, and other plants, and biodiesel from vegetable oils from such plants as soybeans and rapeseed are simply not very efficient in harvesting energy from the sun. Calculating efficiency in terms of how much energy is available from the biofuel versus how much energy was in the sunlight hitting the plants used to produce the biofuel, the efficiency of ethanol made from corn is only about 0.03 percent. Ethanol made from sugarcane is much more efficient but still only about 0.14 percent (Kheshgi et al., 2000). So, there are serious questions, Prince said, as to whether biofuels can be efficient enough to contribute significantly to the world energy budget.

"It is generally agreed that in the United States we make about a 30 percent energy profit when we make ethanol," Prince said, "so that means that you need to produce four liters of ethanol to export one from the farm-distillery complex to have a self-contained energy system." This implies, among other things, that it would be essentially impossible to use ethanol to completely replace gasoline, he said. "If you wanted to be entirely petroleum free, you'd have to produce 4 gallons of ethanol for every gallon you exported to the consumer. And that makes it an impossibility at current scales."

There are other factors that must be taken into account as well in discussing ethanol's ultimate potential. One important factor is that corn production causes substantial soil loss. "The Midwest loses about 4 kilograms of soil for every liter of ethanol that's made in the Midwest," Prince said. "It all goes out down the Mississippi. It's an interesting question as to how long one can continue doing that." There are efforts under way to use no-till farming to reduce the soil loss, but their widespread adoption is still uncertain.

A positive factor is that the major byproducts of converting corn into ethanol are used as animal feed. "You get a roughly equal weight of ethanol and animal feed when you convert corn into ethanol," Prince said. "That's very important for the economics. It's also important in that dried distillers grains can't be stored very long, so they have to be put through the animals quite quickly, and that keeps the price of meat gratifyingly low."

Producing ethanol from sugarcane yields no byproduct that can be used as animal feed, Prince noted. "The rest of the plant is burned. There are no real co-products other than electricity."

Another byproduct of ethanol production is carbon dioxide. Today, Prince said, the carbon dioxide is generally captured and sold for use in carbonating beverages, but it could also be used in carbon sequestration. Because the gases from a fermenter are pure carbon dioxide, it is straightforward to compress them and bury them underground, and, indeed, there is a pilot plant at the Arthur Daniels Midland distillery in North Dakota that is doing just that. In Brazil, the carbon dioxide production from distilling ethanol from sugarcane is so efficient that if the carbon dioxide byproduct were to be captured and put underground, the net result of producing and burning the ethanol would be to remove carbon dioxide from the atmosphere (Kheshgi and Prince, 2005). A pilot project has proven the technical feasibility of the process, but it remains to be seen whether it can be scaled up economically to a degree that will make a significant contribution to greenhouse gas reduction.

The efficiencies for biodiesel are different and even less promising than for ethanol. The biodiesel yield is generally about 50 to 60 gallons per acre of planted crop, as opposed to 250 gallons per acre for ethanol. As with ethanol production from corn, a byproduct of biodiesel production from soybeans can be used as animal feed, and it plays an important role in the economics of biodiesel production. And as with ethanol production, there are serious problems of soil erosion that accompany the production of biodiesel.

Other Bioenergy Pathways

There are many biofuels other than ethanol that can be made from plants, Prince noted. The sugars from corn or sugarcane can be transformed through fermentation to not only ethanol but also acetone, butanol, and isobutanol, among others. The fermentations are done anaerobically using either bacteria or yeast. There are several companies trying to commercialize sugar-derived butanol right now, he said.

There are also aerobic systems where algae and yeasts convert sugars into oils. "These are important, for example, in baby formula," Prince said. It is also possible that engineered yeasts can be used to make such molecules as farnesene and farnesane, which are branched small alkanes.

The challenge with these approaches is that they all require sugar that is low-cost and of reasonable purity. Corn syrup works well, but it is expensive, and the yields are small enough that it is not yet commercially viable. Several companies are moving to Brazil to use sugarcane as the raw material for such processes.

Eventually, developing commercially viable biofuels will require much cheaper and more abundant sources of glucose than corn or sugarcane, Prince said. Thus, it would be valuable to find an efficient way to convert cellulose into sugars that can then be turned into these products. The cellulose could come from crop residues or specially grown crops. But finding an economical way to use cellulose has proved challenging.

One problem is simply crop supply: The trees and grasses that are the most efficient producers of cellulose are not yet farmed, and the crop densities preclude long-distance shipping. Another problem, Prince said, is that although it is reasonably easy to grow cellulose, separating the cellulose from the lignin that comes with it in the plant is a challenge, and it seems to be a different challenge for every different plant. Furthermore, separation processes tend to generate microbial inhibitors.

One of the biggest challenges is the economics of the system, Prince said. “Many predictions imagine that farmers will be willing to sell cellulosic biomass for the order of $40 or $50 a ton. Today, they can get $200 a ton for hay.” Given the difference, it is unlikely that many farmers will switch over from hay to cellulosic biomass.

Looking ahead, Prince said that there are a number of bioenergy pathways emerging—ways in which bioenergy could contribute to the overall energy supply. A simple one that is already being used in Scandinavia is burning biomass to make electricity and distributed home heating. Anaerobic conversions can be used in various ways, such as to first gasify the biomass and then convert the resulting gases—e.g., methane and carbon monoxide—by a microbial process into liquid fuels. “People have started working on that,” he said, “but right now the price of natural gas is so low that they’re moving from using biogas to moving back to natural gas.”

Gas from the gasification of biomass could be turned into methanol which could then be converted into gasoline. This can be done on an economic scale, Prince said, but it is not practiced today.

As previously described, cellulosic biomass can be treated to separate out the lignin from the cellulose, which can then be fermented to produce ethanol and perhaps other biofuels such as butanol and other alcohols.

Further out on the horizon is the growing of algae for use in producing biofuels. "The nice thing about algae," Prince said, "is that they grow all year round, and you can imagine that you could adjust their concentration so they're very efficient users of sunlight." On the other hand, one of the challenges will be "to persuade the algae to make oil rather than to make more algae."

In conclusion, he said, the main question about biofuels is whether they can be produced on a large enough scale to be of any real importance to the world. The world already uses an enormous amount of energy—the equivalent of more than 250 million barrels of oil per day—and that number will certainly increase. "These numbers are just so staggering that it's a real challenge to imagine biofuels having a significant impact," Prince said. "And as you do produce them, can you do it with an acceptable environmental impact? As I've said, naysayers could compare current biofuels with mining—we lose more soil than we gain in fuel from current farming practices. So, in the long run, whether we can do this is a real challenge, and I don't think the answers are at all clear yet."

DISCUSSION

To start off the discussion following the presentations, session moderator Lynn Goldman asked Gruenspecht if all of the increased use of ethanol in fuel has been motivated by mandates, or if some of it has been market-driven. The sales of ethanol as an octane enhancer were certainly market-driven, he said. "I guess the question is what drove MTBE out and how legitimate those concerns were," but once MTBE was no longer available, there was a real need for octane enhancement, and ethanol filled that need. The use of ethanol as a volume enhancer in fuel has not been driven by the mandates, either, he said, but it has been driven by the existence of the tax credits for producing ethanol from corn. "People were looking for the cheapest volumes, and with the tax credits on a volume basis the ethanol was cheaper, so retailers and distributors were happy to put as much of ethanol into the fuel as they could, which was that 10 percent blend wall," Gruenspecht said.

Carlos Santos-Burgoa from the Pan American Health Organization asked whether there is any information on the actual impact of ethanol production on the cost of corn for consumers, especially in countries where corn is a major source of food. Gruenspecht answered that studies in the literature come up with a wide range of numbers, so that there is no well-supported answer to the question. However, he said, he suspects that "this is an area where the community has possibly been affected by the fact that there are interests at stake." Such a situation should not influence the science, he said, "but I think it does."

Santos-Burgoa also asked about the issue of soil erosion and other potential impacts in countries where forests are being clear cut to provide land for growing crops to produce biofuels. Gruenspecht answered that converting any biome to a farming biome has "a huge energy cost, a huge cost in soil carbon, a huge cost in erosion, all those things." The same thing is true for cutting down rainforest to grow sugarcane as for cutting down deciduous forest to put in a shopping mall. "There's a huge cost environmentally, and it needs to be taken into account. Usually, we don't bother to worry about it. We should," Gruenspecht said.

Catherine Kling from Iowa State University commented that it is not clear that all of the food prices seen around the world can be attributed to the biofuels mandates. The literature clearly indicates that biofuels production has had some effect, "but there also have been some important droughts, and there have been some very bad policies that foreign governments have undertaken in response to price increases, such closing markets, which actually aggravated it."

More broadly, she said, it is important to look carefully at the connection between ethanol production and food prices and also the connection between food prices and health. First, she noted, "Corn went from $4 in 2007 to about $7 now. That cannot translate into a tripling of food prices. So I'm not quite sure where that number comes from, but I'd just be a little careful about some of those world prices."

Second, it is not clear that higher prices for corn are always a bad thing. In the United States, for instance, higher corn prices lead to higher prices for meat and corn sweetener, and if consumption of those two items drops it is probably good for health. "It's a very different question if you're looking at food prices internationally," Kling continued. "There people don't have heavy meat diets. There are places in the world where people are definitely starving and these food prices changes can be very significant." Even so, she said, it is important to ask whether the right way to address that particular issue is to tinker with biofuels or whether it would make more sense to provide more food aid, technology, lump-sum payments, or other ways to improve food security.

Panel member Al McGartland asked about the issue of transporting biofuels. "As I read some of the literature," he said, "ethanol is largely transported by truck and not by pipeline. And I'm wondering if we're going to expand biofuels, would that be an obstacle?" Gruenspecht explained that most ethanol is transported by rail or by truck. It is difficult to move through pipelines because of the presence of water in the pipelines. One option would be to use the second-generation biofuel biobutanol in place of ethanol, as it does not have the same problem with exposure to water. Biobutanol has a higher energy density than ethanol, but does not provide the same octane enhancement, Gruenspecht said. Other biofuels are also under consideration, but they have other issues. In short, there is no silver bullet that will solve the transport issue for biofuels. "There's only silver buckshot, so we should be doing everything." However, if there are a number of different types of biofuels, each with its own transportation infrastructures, that would become a constraint in and of itself, he said. "So, I think there are some real challenges related to those issues. But it's just kind of hard to get into."

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2

Case Study: The Palm Oil Example

Palm oil accounts for 33 percent of all of the world's production of vegetable oils, with soybean oil—at 27 percent—its nearest competitor. One of its uses is as a raw material in the production of palm oil–based biodiesel fuel. In the workshop's second session, Jamal Hisham Hashim, a research fellow at the United Nations University International Institute for Global Health and a professor of environmental health at the National University of Malaysia, described Malaysia's efforts at using palm oil to produce biodiesel fuel. The example highlighted some of the major benefits and challenges of developing biofuels.

THE MALAYSIAN PALM OIL INDUSTRY

Malaysia is located in Southeast Asia and is split into two land areas; one is on a peninsula south of Thailand and the other is on the island of Borneo, which borders with Indonesia and Brunei. Malaysia and Indonesia together produce 85 percent of the world's palm oil. The climate of these two countries is particularly well suited for the growing of palm oil, Hisham Hashim said. There have been attempts to grow palm oil in countries farther north, such as Cambodia, but it is possible only in the southern part of the country because it is too dry farther north.

Although the palm oil is not native to Malaysia—it was brought over from Africa—it is now well established, and it serves as both a food crop and a cash crop. The Malaysian palm oil industry has been around for more than 100 years, and there are now 5 million hectares of palm oil plantations—almost 14 percent of the country's total land area (May, 2012). Until recently, Malaysia was the world's largest producer of palm oil. It is now second to Indonesia, which has much more area available to grow the palms. Because Indonesia consumes a portion of its palm oil domestically, Malaysia remains the world's largest exporter of palm oil and palm products. In 2011, it exported 24.3 million metric tons of the oil (Chin, 2011).

The Malaysian government has identified the palm oil industry as 1 of the 12 national key economic areas to spearhead its economic transformation program, whose goal is to transform Malaysia into a developed nation by 2020. The growth strategy for the palm oil industry is not to increase the acreage being planted with palm oil, but rather to increase production to 6 metric tons per hectare per year. "It is already a very productive crop," Hisham Hashim said, "but we intend to increase productivity further through genetic methods and so on." Another focus is on value-added downstream activities, such as processed foods, oleo derivatives, phytonutrients, and palm biodiesel.

Most of Malaysia's palm oil–derived exports—almost 75 percent—are in the form of the crude palm oil itself, with products such as oleochemicals, palm kernel cake, palm kernel oil, and biodiesel making up far smaller percentages (May, 2012). The government would like to increase the amounts of these value-added products. "We are investing a lot in research and conservation to improve the products, especially the oleo chemicals and also the potential of turning it into biodiesel," Hisham Hashim said.

The palm oil industry is a valuable segment of Malaysia's economy; accounting for 8 percent of the country's gross national income per capita, and is the fourth-largest contributor to Malaysia's economy (RSPO, 2011). World palm oil production more than tripled between 1995 and 2011, so the global demand the palm oil products is very strong. In 2011, heavy rainfall, which disrupted harvesting, combined with increasing demand, caused the price of crude palm oil to jump to US$1,065 per metric ton. The main importers of Malaysia's palm oil are China, the European Union, India, Pakistan, and the United States. Malaysia's major competitor for these imports is Indonesia.

PALM OIL AS A BIOFUEL

Palm oil has a variety of uses, Hisham Hashim said. Its traditional use has been as cooking oil, but it is now used as a food additive and an industrial lubricant as well as in the production of various cosmetic ingredients. "We have a very active palm oil research area in Malaysia that helped to generate these other important products," he said. One particularly promising use is in the production of phytonutrients—plant-derived chemicals that are added to food which contribute to health. Recently, palm oil has been used as a feedstock in the production of biodiesel.

The Malaysian government's plan is to combine 5 percent palm biodiesel with 95 percent petroleum diesel, in a way similar to the addition of 10 percent ethanol into gasoline in the United States. In response to a question about why the percentage should be just 5 percent, Hisham Hashim explained that it is simply an economic issue. At present, the cost of palm oil is more than US$1,000 per metric ton, and any price over about US$600 per ton makes palm biodiesel noncompetitive in Malaysia when compared to petroleum-derived diesel. However, Hisham Hashim said, much of the situation is driven by the government's subsidy framework. "Diesel is highly subsidized in Malaysia, and at the moment the government is not yet extending this subsidy to palm oil biodiesel. So, that makes it very uncompetitive with other uses of palm oil," he said. Hence, it is better for palm oil producers to sell the product for uses other than biodiesel.

Nonetheless, palm oil has several advantages as a potential biofuel source, Hisham Hashim said. It has a larger yield than any other source of vegetable oil, for example at 3.93 tonnes per hectare per year, it has nearly three times the yield of rapeseed, its closest competitor. "It is cheaper than any other vegetable oil used in biodiesel production," he said. "And it is a perennial crop with a life-cycle of 25 years, so it can be very productive over a significant duration of time." Indeed, one issue in Malaysia is that the overall yield per hectare is declining because so many of the palms are getting close to the end of their productive period and their yield is decreasing, but the plantation owners are putting off replanting because the cash flow is still substantial.

When compared to petroleum-based diesel, biodiesel from palm oil has certain advantages in its physical and chemical characteristics, Hisham Hashim said. For example, its sulfur content is much lower; this is an advantage because the sulfur dioxide release from the use of petroleum-based diesel is a serious atmospheric pollutant which can lead to acid rain and is hazardous to human health. A recently developed variety of palm biodiesel has a very low pour point so that it pours more easily at cold temperatures, making it a possible product for use in colder climates. Palm biodiesel also has an advantage in its cetane number—which is analogous to the octane number for gasoline—when compared with petroleum-based diesel. It also produces far less carbon residues, which means that it will leave less carbon build-up in a diesel engine than petroleum diesel.

Palm biodiesel also has some physical and chemical disadvantages, such as a higher viscosity, a higher flashpoint, and a lower gross heat of combustion. But all in all, Hisham Hashim said, the potential is there for palm biodiesel to be a valuable and promising product. One of the most intriguing products is the low-pour-point palm biodiesel, which is not yet being made on a production scale, but is showing a lot of promise.

To date, however, movement toward the production of palm oil biodiesel in Malaysia has been very slow. Fifty-six licenses for biodiesel plants were issued under the Malaysia Biofuel Industry Act of 2007 (Chin, 2011), but so far only 25 biodiesel plants have been built. The major reason for this, Hisham Hashim said, is that petroleum diesel is receiving a significant subsidy from the government, and palm biodiesel cannot compete.

Furthermore, diesel vehicle use in Malaysia is very small, accounting for only 5 percent of the total number of private vehicles. The initial government plan for encouraging palm biodiesel was to require government diesel vehicles to use a fuel blend with 5 percent palm diesel, referred to as B5. However, the total amount of palm oil diesel used by government vehicles running on B5 in 2009 was only 40 tonnes per month—an amount far too small to make it profitable for petroleum companies to set up B5 blending facilities. Even a nationwide B5 mandate in Malaysia would translate into a biodiesel consumption of only 500,000 tonnes. “So the potential for local consumption of biodiesel is not significant,” Hisham Hashim said. “The only way that we can do this is if we can export biodiesel to other countries, such as the European Union.”

ENVIRONMENTAL IMPACTS OF PALM OIL

Hisham Hashim next discussed the environmental impacts of palm oil. Deforestation is a major issue because 15 percent of the country’s total land area has been transformed into palm oil plantations. That will not be as much a problem in the future, however, because the country now has strict regulations that require environment impact assessments to be carried out before opening more large tracts of land for palm oil plantations.

Loss of tropical biodiversity is also an issue, he said, but Malaysia is now emphasizing sustainable palm oil production, with 48 percent of the Roundtable on Sustainable Palm Oil[1]–certified palm oil coming from Malaysia.

The mass clearing of forest areas to create palm oil plantations has resulted in significant soil erosion, and palm oil mills have produced liquid effluents that end up in the water. In the past, Hisham Hashim said, the government would issue contravening licenses to palm oil mills even when they did not meet regulatory standards for liquid effluents, but that no longer happens. Palm oil mills also produce a certain amount of air pollution. Indeed, most of the air and water pollution due to palm oil now comes from the refining of the oil, although occasionally there was air pollution caused by the burning of trees in order to clear land for plantations, or the burning of old palm oil trees for replanting. One of the worst instances came in 1997, an El Niño year, when the fires used to clear land spread into the surrounding forest and caused extensive forest fires and a heavy load of air pollution. "Some of this is still happening," Hisham Hashim said, "but the government is clamping down on the palm oil plantation owners."

OCCUPATIONAL HEALTH HAZARDS IN THE PALM OIL INDUSTRY

One of the main occupational health hazards in the palm oil industry is the risk of back problems caused by the harvesting. "We're manually harvesting the fruit," Hisham Hashim explained, "so we're causing ergonomic problems like lower back pain and injury." Eye injuries are another risk of fruit harvesting, because workers use sickles to harvest the fruit, which can lead to debris flying into workers' eyes if they do not have eye protection. And the palm fronds have thorns that can scratch or puncture skin.

Palms attract rats, which feed on the fruits, and the rats in turn attract snakes, so historically snake bites have been occupational hazards for workers on palm oil plantations. Today, some of the plantations use barn

[1] The Roundtable on Sustainable Palm Oil was established in 2004 to promote the production and use of sustainable palm oil. Available at http://www.rspo.org/en/who_is_rspo (accessed July 29, 2013).

owls as a way of controlling the rat population and, consequently, the number of snakes.

As with many forms of agriculture, the use of pesticides poses a hazard for workers on palm oil plantations. Before its ban, many plantations used paraquat for weed control because the ground has to be free of weeds in order for the palm oil to be productive. Paraquat is highly effective in controlling weeds, but it is also toxic to humans and animals. Thus, many palm oil plantations have begun grazing cattle on the land among the palms. The cattle eat the weeds, which minimizes the need for pesticides.

In summary, Hisham Hashim said that because of the high demand for palm oil, the palm oil industry will likely remain an important economic driver for the Malaysian and Indonesian economies. Furthermore, palm oil has great potential as a source of biofuel. However, he said, at the current prices for crude palm oil, palm biofuel is not viable. Thus, the palm oil that is produced today is sold for uses other than biofuel.

Introducing palm oil trees with a higher yield and developing value-added downstream products will help cushion the environmental damage from palm oil production. That is, instead of increasing the acreage devoted to palm oils, Malaysia is concentrating on improving yields and diversifying the products that can be generated from palm oil.

Furthermore, the Malaysian government is focusing on responsible plantation management as a way of minimizing environmental damage and occupational health hazards associated with palm oil production. "Many of these plantations are huge companies, so they should be responsible for putting together better and a more sustainable management of palm oil plantations. But it is not easy to control them because some are located in remote areas accessible only by helicopters and four-wheel-drive vehicles, so they are out of sight of the regulator," Hisham Hashim explained. Still, he said, it can be done. "It is a matter of commitment from the plantation managers and owners."

DISCUSSION

Jack Spengler, roundtable member, opened the discussion session with a comment. Ramon Sanchez, one of his graduate students, looked at the use of biodiesel in Mexico City and found that it resulted in a reduction of particulates, which led to health benefits in the population.

This has important implications for the health equation regarding biofuels, he said.

Then Spengler asked a question: "If palm oil has been used for so many years, why does it have to be done on big plantations? Can it actually be distributed to smaller-scale operations, a village for instance?" Hisham Hashim responded that the palm oil industry started out as a poverty-eradication project. "We cut down the trees and opened up land for resettlement of the poor rural families into this cooperative plantation operated by Felda," he said. "And the economic benefit was quite significant in trying to bridge the gap between the poor and the more affluent segment of the society. So that was quite successful." But with the rising price of palm oil, the Malaysian government saw an opportunity to make the palm oil industry a significant contributor to the Malaysian economy, and "that's when they started big concessions to companies to open up huge tracts of land." The yield on a large palm oil plantation is about double the yield achieved by the small holders. Thus, it seemed that moving to large plantations would be the best way to manage the industry, he said, but there does seem to be a need "to balance between large plantations and small holders."

Hisham Hashim added some details about the prospects of exporting biodiesel, given that local consumption is limited. One approach would be to export biodiesel to the European Union, but the European Union has strict regulations on the types of biodiesel that can be used. For example, any biofuel used in diesel mixtures in Europe must offer a 35 percent carbon reduction according to life-cycle analysis, and palm biodiesel offers only 19 percent. "Because of that, we cannot penetrate the European market at the moment," he said. Another problem is that the European Union requires that the palms not be planted in highly biodiversed land or land with high carbon content, and "some of the palm oil plantations have been planted over peat soil, which has a lot of carbon storage." The problem, he explained, is that planting the palms requires that the land be drained, and the dried-out peat soil sometimes catches fire, releasing carbon.

However, he said, not all palm oil plantations are on peat land. So Malaysia is now negotiating with the European Union as well as other markets in hopes of getting palm biodiesel accepted as a fuel for use in these countries.

Another workshop participant asked Hisham Hashim about the water pollution resulting from the smaller-scale palm oil operations. "I'm wondering if that happens because of a lack of available technology. Is it that those villagers chose to not use technology which would have prevented the contamination of that valued waterway, or is it that the type of technology for wastewater treatment isn't available remotely?"

Hisham Hashim answered that it is not a problem with the technology because the waste is mainly organic components and the water can be easily treated in a not particularly sophisticated water treatment plant. And, indeed, the small holders tend to be more environmentally conscious than the bigger plantation management, he said. These huge plantations are generally located in remote areas, far away from the regulatory agencies, which gives them the opportunity to violate the laws.

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3

Occupational Health and Biofuels Production

In the workshop's third session, Stephen Reynolds, director of the High Plains Intermountain Center for Agricultural Health and Safety and a professor of industrial hygiene at Colorado State University, provided an overview of the occupational health issues that are related to the use of biofuels. As session moderator Henry Anderson of the Wisconsin Health Department noted in his opening remarks, these issues do not typically get included in the economic analyses done concerning biofuels, so one goal of the session was to provide some additional factors that economists might take into account in their models of biofuels production.

Reynolds began by noting that his presentation built on a white paper that came out of a 2011 conference on energy (Mulloy et al., 2013). "What we've done is try to do an updated review of what is available in the peer-reviewed literature in terms of programs that we can find in the United States that specifically address occupational health and safety related to biofuels," he said. Thus, the goal of the presentation would be to discuss what is known on the topic, to identify some of the gaps in knowledge, and to offer some recommendations for needs going forward.

RISKS ASSOCIATED WITH BIOFUELS

During the past decade, Reynolds said, there has been a substantial increase in biofuels production in the United States as well as an increase in the workforce that is employed in this industry. It is estimated that the biofuels industry could employ up to 94,000 people by 2016 (Bio Economic Research Associates, 2009).

The limited data that are currently available suggest that workers in the renewable energy industry may experience reduced rates of occupational injury, illness, and fatality than do traditional fossil fuel energy extraction industries (Sumner and Layde, 2009). However, Reynolds said, although there has been a great deal of research carried out on life-cycle and economic assessments for biofuels production, there is very little published information concerning research or programs that address occupational health and safety in biofuels in the United States. As an example, he showed a slide listing the components and agencies participating in the U.S. National Biomass Program. Workforce creation was listed as a component of both the economic and social aspects of the program, but there was nothing listed that explicitly dealt with the health and sustainability of that workforce. In particular, the two major agencies responsible for occupational health in the United States—the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA)—do not appear to be considered part of the program.

Although no systematic surveillance or evaluation of fatalities, injuries, and illnesses associated with biofuels production has been conducted, a number of serious accidents and fatalities have been associated with biofuels production, both in the United States and abroad. In the United States, for example, two employees were burned by ethanol vapors escaping an adsorption column, and one employee was killed while welding in a storage tank when residual glycerin and ethanol vapors were ignited. In Europe, at least nine people have been killed by carbon monoxide poisoning after they entered wood pellet storage areas.

The production of biofuels has matured to include a variety of different production systems using various feedstocks, including corn, municipal wastes, cellulosic biomass, and algae and other microcrops. Much is already known about the hazards associated with the production of various agriculture inputs as well as with the distribution and end use of biofuels products, Reynolds noted, and this knowledge can be applied proactively to manage risk in this industry. However, the risks of familiar hazards in new production situations and of novel hazards, such as genetically modified organisms or the use of nanotechnology, have not been addressed well in this industry.

A wide variety of potential hazards have been identified in the biofuels industry, including biological, chemical, and physical hazards. The potential exposures to these hazards are quite variable and depend on the specific technology, the stage of development, and the size of the operation.

Reynolds mentioned in particular the use of engineered nanomaterials in biofuels production. Research in this area has developed rapidly during the past decade, and the potential occupational health risks involved in manufacturing and using these materials have not been characterized. Researchers have explored nanomaterials and nanosize catalysts, especially in trans-esterification reactions for both biodiesel and bioethanol, but there are little data on the possible adverse health effects from the use of these engineered nanomaterials. Thus, before these materials are used in biofuels production (or in any other industry), their risks to health should be carefully assessed.

A number of types of occupational diseases are known to be associated with exposure to the organic materials that are used as biofuels feedstocks. The most fully explored links are between organic dust and respiratory disorders, but there are also studies that have linked contact dermatitis, infectious diseases, and other problems to such exposures. In the 1990s, for example, research found that gastrointestinal diseases were more common among workers in refuse-derived fuel plants (Mahar et al., 1999).

Knowledge of such exposure–disease relationships and experience with developing effective controls can be used to develop best practices and to reduce the risk of disease in evolving biofuels industries, Reynolds said. To that end, he offered three specific examples of recent research in the area.

Case Study 1: Wood Pellet Plant

Sweden is the world's second-largest producer of compressed wood pellets, which are being used as a renewable replacement for fossil fuels. Hagstrom and colleagues (2008) found that workers at pellet production plants were exposed to excessive concentrations of wood dust and resin acids, indicating potential for a significant respiratory health risk. Although they did not collect health data, this is an example where occupational exposure guidelines have been established that can be used to develop control systems in the biofuels industry.

Case Study 2: Biodiesel Refinery

As part of a NIOSH initiative focusing on biofuels, a 2011 study of a biodiesel refinery by Law and colleagues (2011) focused on the alcohol that is most commonly used in the trans-esterification step to produce biofuels from agricultural feedstocks (e.g., methanol). The hazards of this process included the methanol itself as well as caustic chemicals used for catalysts and a number of physical hazards.

In this particular case, NIOSH followed up on the study with recommendations focused on some very basic health and safety issues, including recommendations for properly storing and labeling bulk chemicals. One of the problems in this facility is that incompatible acids, bases, and flammables were being stored together with no containment. One of the major recommendations that came out of this study was simply to implement and adhere to the process safety management or chemical safety management standards that already exist and that are effective in other industries.

Case Study 3: Biofuels Energy Plants

A 2011 study in Denmark evaluated exposure and health outcomes among workers at a woodchip biofuel plant and a straw biofuel plant versus workers at conventional heating and power plants. It found that exposure to dusts, endotoxins, and fungi was higher at the biofuels plants. It also found that higher endotoxin exposure was associated with an increase in respiratory symptoms—a finding that is consistent with the literature on organic dust exposures in agriculture and other industries (Schlünssen et al., 2011). Again, lessons learned from other industries can be applied to anticipate and reduce exposure in the biofuels industry.

ENSURING HEALTH AND SAFETY IN BIOFUELS PRODUCTION

Although there is relatively little research on health risks in biofuels production specifically, there are already a number of government activities and programs in the United States and abroad aimed at improving occupational health and safety in this industry.

National Institute for Occupational Safety and Health

NIOSH has an initiative addressing exposures, primarily chemical and physical exposures, as part of the National Occupational Research Agenda (NORA) within the manufacturing sector. Much of the current research in this area focuses on the end use of biodiesel, Reynolds said, and, in particular, there is a great deal of work studying the effects of biodiesel in underground mining.

NIOSH was also an important partner and sponsor for the 2011 Energy Summit Workshop held in Denver, Colorado, which addressed a broad range of renewable energy strategies. Furthermore, there has been discussion in NIOSH about including biofuels as a more prominent part of the NORA activities, especially as related to the agriculture, forestry, and fishing sector. It is not clear, however, how big a role NIOSH has played in the larger U.S. renewable energy initiatives operated by the U.S. Department of Energy and the U.S. Department of Agriculture (USDA).

Occupational Safety and Health Administration

By contrast, OSHA has been active in the biofuels industry, both from a regulatory standpoint and from a consultation standpoint. The primary focus has been on high-profile and fatal incidents typical of chemical processing and grain handling and storage. Typical regulatory violations include failure to use proper electrical equipment, deficiencies in hazard analysis and operating procedures, catastrophic chemical releases, training of workers, and respiratory protection programs. Some of these issues can be catastrophic and immediately fatal, Reynolds said.

A large proportion of biofuels businesses are small and therefore are eligible for consultation services from OSHA. One example is the Colorado OSHA consultation program, which Reynolds works with. "We're doing some work with a small company that is developing and implementing mobile biofuel energy systems that are being deployed around the globe," he said. "It is a company that is on the cutting edge in terms of development, and that is an issue that a lot of these operations are dealing with—that they are pushing the boundaries."

It would be useful, Reynolds suggested, if OSHA would develop a more systematic approach to the biofuels industry.

Other U.S. Initiatives

Beyond NIOSH and OSHA, there appears to be very little activity specifically aimed at occupational health and safety in the biofuels industry, Reynolds said, but the number of efforts is beginning to pick up.

For example, the USDA's Cooperative Extension and the National Renewable Energy Laboratory have developed a number of practice guidelines that have been disseminated to the industry. A big step forward occurred in 2010 when the USDA issued a call for proposals for the development of biofuels that was related to the department's agriculture and food research initiative; for that program, the USDA required that proposals include a component dealing with occupational health and safety from the originating concept all the way up to the pilot scale implementation of the programs.

The Virginia Cooperative Extension included hazard information on methane and confined spaces in its guidelines on biomethane technologies on U.S. livestock farms, and it also provides education on OSHA compliance. The Colorado State University extension service published safety guidelines for small-scale biodiesel production. A book published by Biodiesel Basics, *Building a Successful Biodiesel Business*, includes a chapter with a short overview of laboratory safety, workplace safety, and OSHA.

In short, Reynolds said, there are a number of initiatives, but relative to the amount of research and growth of the industry, it is still a fairly small effort.

International Initiatives

There are a number of significant initiatives outside the United States that can help share lessons learned and offer opportunities for collaboration, Reynolds said. For example, the UK Health and Safety Executive has developed a fairly robust program that includes research and outreach to industry. The World Health Organization and the European Union's European Agency for Safety and Health at Work have both tackled policy and equity associated with green jobs. And the Stockholm Environment Institute in Sweden has evaluated potential sustainable developments of a wide array of bioenergy projects, specifically asking whether the project contributes to improving the health and safety of workers.

Summing up, Reynolds said that biofuels operations are diverse and range from large, industrial bioethanol plants to small fermentation devices on family farms. They include a number of technologies that are at different stages of development and implementation. Unlike solar and wind power, the use of biomass requires production of "fuel," generally through production agriculture or forestry, which present significant occupational health challenges. To date, the U.S. health and safety initiatives in this area can be considered ad hoc, and the potential resources, including NIOSH and OSHA, have not been systematically engaged. Still, there are lessons learned, particularly from agriculture and chemical process safety, that can be applied at this time, especially to the major U.S. producers.

In light of the situation, Reynolds offered a number of specific recommendations:

- The occupational health and safety community, specifically including NIOSH and OSHA, should be engaged in U.S. programs such as the U.S. Biomass Program. From a risk management standpoint, a systematic national industry approach needs to address worker health and safety as an integral component of production, quality, environment, and security.
- The NIOSH agriculture, forestry, and fishing health and safety centers and the NIOSH education research centers are an important national resource that can be tapped for their technical experience and practical connections to industries throughout the United States.
- There are a number of significant initiatives outside the United States that can share lessons learned and offer opportunities for collaboration.
- Basic research is needed on emerging biomass hazards, including bioaerosols, nanotechnology, genetically modified micro-organisms, and other agents used in the rapidly evolving biomass technologies.
- The basic research should be complemented by prospective cohort studies of workers in the field, including monitoring of exposure levels and long-term follow-up of workers.
- Systematic surveillance or evaluation of fatalities, injuries, and illnesses is essential to setting priorities and evaluating the success of prevention and intervention efforts.
- Industry participation is essential in identifying occupational health and safety risk priorities and in developing relevant cost-effective solutions and best practices is essential.

There are lessons and solutions from agriculture and chemical process safety that can be directly applied to prevent injuries and fatalities. Because so little is known about novel hazards such as bioaerosols and nanotechnology, prudent strategies for exposure control are needed.

In conclusion, Reynolds said, "There are indeed significant occupational hazards associated with the biofuels industry, including recognized hazards in new environments and new hazards with novel agents. To make informed decisions concerning energy policy as a society, we need to understand the true costs of energy production, including the cost of occupational risks. And, again, a successful management strategy needs to systematically address worker health and safety as a component of production, quality, environment, and security."

DISCUSSION

The first question in the discussion came from an audience member who asked how occupational health standards in the biomass production industry compare with those of other industries.

Reynolds answered that his perception is that the petrochemical processing industry is very advanced in terms of its risk hazard assessment and risk management, while the biofuels processing industry in not nearly so far along. "There are a number of fairly small operations out there that have not—at least the ones that I've been involved with—had the same ability to think about the risks and the hazards . . . nor have they had the resources or the expertise to address that." It is an evolving, growing area, and many of the companies involved in it are small, entrepreneurial operations. Similarly, the storage and transportation of biofuels are areas in which risk assessment and management need further attention. And, agriculture, although it is not a new industry, "in general is one of the more hazardous occupations in this country," he said. In general, he said, although there have been some significant developments and advancement in the past couple of decades, the area of handling risk remains a very significant problem in the entire biofuels industry.

An audience member offered a follow-up comment, noting that although occupational safety standards may be high in petrochemical production, the job of getting oil from the ground remains one of the more dangerous occupations. Those risks should be included in any discussion of the risks associated with producing gasoline or petrochemicals.

Reynolds agreed. "We do need to be careful about including all of the costs and thinking about those upstream costs as well to be comprehensive," he said.

An audience member observed that ethanol production facilities tend to be in rural areas that have little medical infrastructure. So, is anything being done, he asked, to increase medical capacity in these areas?

"It remains a significant problem," Reynolds replied, but there are things being done to address it. "There are 10 agriculture centers around the country right now and 20 education and research centers. Some of the initiatives that we have been taking as a group have been focused on the training of physicians, nurses, and physician assistants specifically on rural hazards." So, one strategy is to provide the health care community with the skills needed to understand and deal with—and ultimately prevent—the health problems that may arise in relation to biofuels production. "We have begun working with a number of state organizations in our region to try to bring together resources to make them more readily available to the communities that are out there," he said, and one initiative has been working with biofuels producers to help them develop their own capacity to deal internally with some of those issues. "We've got a long way to go," he concluded.

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4

Biofuels Impact on Air, Atmosphere, and Health

One of the major reasons for encouraging the use of biofuels has been the positive effects their use is expected to play in reducing greenhouse gases and also air pollutants, with concomitant improvements in health. The speakers in the workshop's fourth session offered details on how the production and use of biofuels should affect greenhouse gas levels, air quality, and health.

BIODISTALLATE FUELS AND EMISSIONS

In the first presentation, S. Kent Hoekman, research professor in the Division of Atmospheric Sciences at the Desert Research Institute, discussed biodistillate fuels and emissions. The term *biodistillate* is a more general term than *biodiesel*, he explained, and it includes not only biodiesel but also related biofuels.

Background

Hoekman began by offering some basic background on biodiesel and other biodistillate fuels, beginning with the drivers. "Why are we interested in biodiesel? I think today the simplest and most direct answer is because it's the law." In particular, the U.S. Environmental Protection Agency (EPA), in implementing several congressional mandates, has requirements for the use of renewable fuels divided into conventional biofuels, cellulosic biofuels, biomass-based diesel, and other advanced biofuels.

The ultimate drivers for the use of biofuels—that is, the reasons behind the political decision to impose requirements for the use of biofuels—include concerns about greenhouse gas emissions, the desire to develop renewable or sustainable energy sources, the desire to develop secure domestic fuel supplies, and an interest in rural development. Interestingly, Hoekman said, neither air quality concerns nor health concerns have been major factors in the push to increase the use of biofuels. "They are somewhat important, but they have not been the main drivers."

Terminology

Next, Hoekman went over some basic terminology related to biofuels in order to clarify exactly what is meant by various terms. According to ASTM International, *biodiesel fuel* refers to "mono-alkyl esters of long-chain fatty acids derived from vegetable oils and animal fats." The term can also refer to trans-esterified triglycerides or to fatty acid methyl esters (FAMEs), which are both closely related to ASTM's definition. Biodiesel fuel is sometimes referred to as B100.

Renewable diesel is produced from the same feedstocks as biodiesel, Hoekman said, but it is produced through hydroprocessing technologies so that the product is a hydrocarbon (HC), not an ester. It is also referred to as "green diesel."

Co-processed renewable diesel is a form of renewable diesel that is produced by adding vegetable oils or animal fats to feedstocks that are being hydrotreated to produce diesel fuel, creating a single product that is a mixture of bio and fossil HCs.

Cellulosic biodiesel fuel, or synthetic biodiesel, is produced by pyrolysis or gasification of lignocellulosic feedstocks, such as grasses and woods. The resulting liquid generally requires rather considerable additional processing or upgrading before it can be blended into petroleum fuel stock.

Biodistillate Production Technologies

A variety of different production methods are used to produce the different types of biodistillates. Hoekman illustrated them with a single figure that showed the feedstocks, processing methods, and resulting fuels (see Figure 4-1).

Hoekman pointed out that, as the figure indicates, there are many different types of fats and oils that can be used to produce biodistillates. "And this is an abbreviated list shown here," he said. The line at the top of the figure represents the traditional biodiesel production pathway that uses methanol in a trans-esterification pathway to produce biodiesel and glycerin. "We haven't heard a lot about that," he said, "but glycerin is the main byproduct of biodiesel production. About one-tenth as much glycerin is produced as biodiesel." None of the rest of the production pathways produces glycerin, he noted. Furthermore, he noted that other than the biodiesel produced in that first production pathway, the rest of the fuels produced are HCs. It is only biodiesel that is oxygenated.

At present, he said, biodiesel remains by far the most commonly produced biodistillate. In the United States, soy oil is the main feedstock used to produce biodistillates, with some waste cooking oil, sunflower oil, and other oils used as well. In Europe, the main feedstock is rapeseed, while in much of the rest of the world palm oil is the dominant feedstock.

In the United States production of biodiesel is at an all-time high, with more than 1 billion gallons produced in 2011 and 2012, up from next to nothing a decade earlier. To put that in context, Hoekman said, the total U.S. petroleum diesel fuel production is about 60 billion gallons per year, and gasoline is about double that amount.

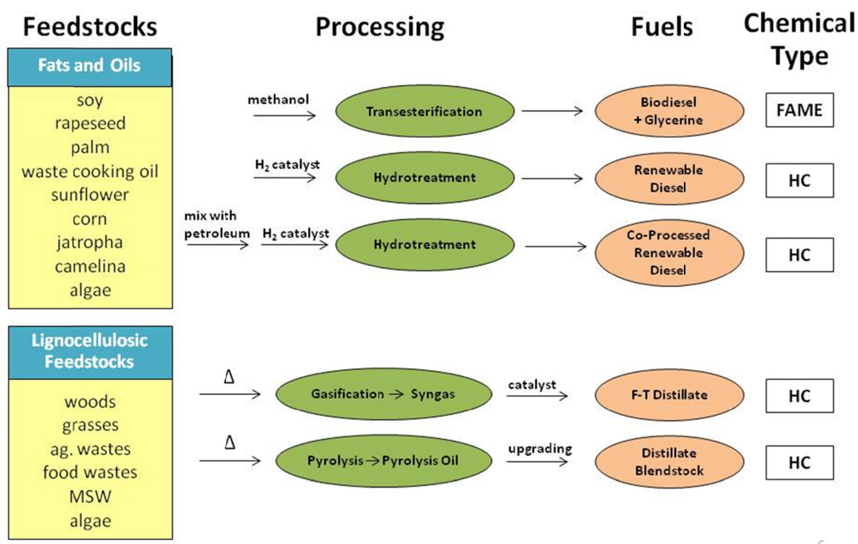

FIGURE 4-1 Biodistillate production technologies beginning with feedstock used, processing technology used, fuel produced, and chemical type.
NOTE: ag = agricultural, FAME = fatty acid methyl ester, F-T = Fischer-Tropsch, HC = hydrocarbon, H_2 = molecular hydrogen, MSW = municipal solid waste.
SOURCE: Hoekman, 2013.

Biodistillate Properties and Composition

Biodiesel and renewable biodiesel differ from petroleum-based diesel in a number of ways. One of the most important is the presence of oxygen. Neither petroleum diesel nor renewable biodiesel contains oxygen, while biodiesel is roughly 11 percent oxygen by weight. Another important difference can be found in the energy content of the different fuels. Petroleum diesel has a high energy content of 130,000 BTU per gallon. Biodiesel is 6 to 7 percent less—121,000 BTU per gallon for biodiesel and 122,000 BTU per gallon for renewable biodiesel.

With respect to the chemical composition of the various types of diesel fuel, two critical factors influence the physical properties and performance attributes of the fuels, including their emissions. The first is the length of carbon chains in the molecules of the fuels. In conventional diesel the chains are typically 12 to 24 carbons long, although some molecules are somewhat shorter or somewhat longer. Biodiesel, being made from fatty acids, tends to have molecules with carbon chains that are 16 or 18 carbons in length. The second important factor is the degree of unsaturation, which is, roughly speaking, a measure of how many fewer hydrogen atoms a molecule with a certain number of carbon atoms has than it could have if the carbon atoms were arranged to maximize the number of hydrogen atoms in the molecule. The degree of unsaturation is important, Hoekman explained. Having too much unsaturation makes for an oxidatively unstable product, while having too little unsaturation results in a product with poor low-temperature performance—that is, it tends to "wax up" when the temperature drops. Compared to biodiesel, conventional diesel has lower unsaturation overall, and it has more branching of the HCs, he said. "Those are important for physical and chemical properties."

Different oil feedstocks lead to biodiesels with different chemical compositions. For example, soybean oil is dominated by linoleic acid entities, consisting of an 18-carbon chain with two double bonds. "That's rather highly unsaturated in terms of fuel stability," Hoekman said. By contrast, rapeseed is mainly oleic acid, a molecule with an 18-carbon chain but only one double bond, so it is not so highly unsaturated.

Emissions Standards and Controls

Diesel engine and vehicle emissions are regulated by the EPA as well as by some states, most notably California, Hoekman said. Different sets of standards are defined for different applications and purposes. For example, there are different emissions standards for different engine sizes—light-duty, medium-duty, and heavy-duty application—and, in fact, each of these categories has subsets with their own sets of standards. There are also different standards for on- and off-road applications. Off-road applications make up a significant part of diesel fuel usage, he said, and they include railroads, mining, and farming.

Historically, four different types of emissions have been regulated for diesel uses: HC, carbon monoxide (CO), nitrogen oxide (NOx), and particulate matter (PM). Of those four, Hoekman said, the latter two have been of the greatest concern and have been under regulatory scrutiny for the longest time, principally for reasons related to air quality.

The emissions standards are not static sets of numbers, he said. They have been steadily evolving. In particular, emissions standards have become much more stringent during the past 25 years, and the maximum allowable emissions of NOx and PM have been reduced by almost two orders of magnitude during that time. For example, in the late 1980s, NOx was regulated at 10.5 grams per brake horsepower-hour; today, the standard is 0.2 grams per brake horsepower-hour. Similarly, the standard for PM went from 0.6 to 0.01 grams per brake horsepower-hour.

Those emission standards apply only to new engines and vehicles, he noted. They are not automatically applied to fleet vehicles already in use, and fleet turnover is very slow, particularly for heavy-duty diesel vehicles.

The large reductions in emissions required by the standards have been achieved by a combination of engine improvements and improvements in emission control systems. Engine improvements have included the adoption of high-pressure, common-rail fuel injection; variable injection timing; and electronic monitoring and control systems. A recently developed emission control system used to reduce particulate emissions is the particulate trap. Particulate traps require regeneration, Hoekman noted, and there have been some issues regarding the regeneration of those traps. To control NOx, engines are now being built with selective catalytic reduction systems. These use urea injection to reduce NOx to molecular nitrogen. Those are significant changes that have taken place in just the past couple of years, he said.

Another change that has made it possible to dramatically reduce emissions has been the introduction of ultra-low-sulfur diesel (ULSD). "The primary reason for having that is to enable satisfactory long-term operation of those sophisticated emission control systems," Hoekman said. "It's analogous to getting the lead out of gasoline so that catalytic control systems can function properly."

Effect of Biodiesel on Engine Emissions

The traditional understanding of how using biodiesel in an engine affects tailpipe emissions comes from a 2002 EPA draft report (2002) that was "rather famous but never officially published in a final version," Hoekman said. That report showed that as the blending level of biodiesel is increased from B0 (0 percent) all the way to B100 (100 percent), there are significant reductions in HC, CO, and PM emissions, while there is a slight increase in NOx emissions. "That increase in NOx has been a source of tremendous controversy in a lot of studies over the years," Hoekman said. In most real-world applications, he noted, biodiesel is used at low concentrations, usually B5 to B20. So, it is in that range that it is most important to understand what happens to emissions.

Recently, the Desert Research Institute, working on behalf of the Coordinating Research Council, conducted an updated literature review in order to examine more recent and comprehensive information concerning the effects of using biodiesel on engine emissions. The review, which Hoekman was a part of, examined more than 1,000 literature sources and analyzed the data with various sorting and statistical analysis methods.

Focusing just on the data for NOx emissions, Hoekman noted that there was "tremendous scatter" in the data. That is, there was no smooth curve that could describe what happened to the emissions as the percentage of biodiesel increased from 0 to 100 percent; instead, the data points were scattered all over the graph. This was not particularly surprising, he observed, because the data were from a wide range of literature sources. The various studies were done under a very wide range of conditions, with many different forms of biodiesel blended into different base fuels, and many other differences as well. And the data scatter was just as large for HC, CO, and PM emissions, he noted.

Still, it was possible to discern a trend in the NOx emissions. The data showed an upward trend in NOx as the percentage of biodiesel increased in the category of heavy- and medium-duty engine dynamometer emissions. However, the trend was the opposite for the category of heavy- and medium-duty chassis dynamometer emissions. The main difference between the tests lies in where the dynamometer is mounted during the test—coupled directly to an engine that is independent of a vehicle, versus coupled to the power train of a vehicle through the drive wheel or wheels without removing the engine from the frame of the vehicle. This difference in observed NOx effects, depending on the testing methodology used, is one illustration of why it is so difficult to determine the "true impacts" of fuel changes on engine emissions when applied across the entire vehicle fleet, Hoekman said.

The study found significant decreases in HC, CO, and PM emissions with increasing percentage of biodiesel, which were in "reasonably good agreement" with the earlier EPA findings. "So, I think this is probably the best idea you can get as to the impact of biodiesel use on emissions across the whole fleet," Hoekman said.

Emissions from B20 Fuel

Hoekman then focused specifically on the issue of emissions from B20 fuel because "that's the upper end of the most common range of biodiesel usage levels."

He discussed a study by Robbins and colleagues (2011), in which the results were broken down by engine class: medium- and heavy-duty engine, medium- and heavy-duty engine on a chassis, and light-duty engine. Overall, there were large reductions in HC, CO, and PM emissions, with a slight increase in NOx emissions, although there was a large scatter in the results. The results in the study by Robbins and colleagues (2011) (HC, –17.4; CO, –14.1; PM, –17.2; NOx, +1.8) generally agreed quite well with the results from the earlier EPA study (EPA, 2002) (HC, –21.1; CO, –11.0; PM, –10.1; NOx, +2.0).

Given that the review involved more than 1,000 individual studies, Hoekman said, it was possible to sort the studies according to various criteria, including the feedstock used for the biodiesel (soy oil, rapeseed oil, yellow grease, palm oil), the base fuel into which the biodiesel was mixed (No. 2 diesel, ULSD, California Air Resources Board [CARB] certified diesel), the engine year (as a proxy for the certification levels for the emissions and, particularly, the NOx certification level), and the test cycle load (light, medium, heavy).

When Hoekman and his colleagues examined how these different criteria affected the emissions levels from the various biofuels, they found that there was so much data scatter in the results that it was difficult to detect significant effects across the whole fleet. To illustrate, he showed graphs of how B20's effects on emissions varied by the type of feedstock used, the type of base fuel, the engine year, and the test cycle load. In each case, the error bars were larger than the effect sizes, so it was impossible to conclude that any of these factors had an influence on how B20 affected emissions.

Moving on, Hoekman spoke briefly about mobile source air toxic (MSAT) emissions from biodiesel. There are dozens of MSATs, but those of greatest interest with respect to biodiesel are polycyclic aromatic HCs, aldehydes (formaldehyde, acetaldehyde, proprionaldehyde, and acrolein), and the total PM discussed previously. Oxygenated organics, such as biodiesel, might be expected to produce higher levels of oxygenated MSATs, Hoekman said, but there is very little relevant experimental data that address this issue. The existing data suggest that the use of biodiesel does not consistently increase emissions of these MSATs, he said.

Hoekman concluded his presentation with a number of general observations about biofuels emissions. First, he said, although biodiesel—the FAME version—is currently the dominant form of biodistillate being produced, he believes that in the future the nonoxygenated biodistillates are likely to grow in use and perhaps even become the dominant form of biodistillate.

Recent reviews of the biodiesel literature have confirmed what the EPA and others have been saying for many years—that the use of biodiesel reduces emissions of HC, CO, and PM while increasing NOx emissions by a small amount. Although data on the emissions of renewable biodiesel—that is, the non-oxygenated, HC biodistillates—are sparse, it does appear that renewable diesel provides emission reduction benefits that are just as big as, if not bigger than, those from biodiesel.

Exhaust emission standards for diesel engines and vehicles have become much more stringent during the past 25 years, which has resulted in the development of advanced emission control systems that reduce emissions dramatically, much more so than a change in the fuel composition to include biodistillate fuels.

Determining the effects of fuel-type fleet-wide emissions is difficult because of the variability of engine and vehicle types, test cycles, emissions control systems, and other factors. The variability in the data prevents drawing firm conclusions about the effects of biodiesel feedstock, base fuel type, the engine model year, or the test cycle on diesel emissions when using B20. In the case of aldehyde emissions, although the data are sparse, the use of biodiesel does not appear to affect the emissions in a consistent or significant way. The effects of biodiesel on polycyclic aromatic HC emissions are hard to ascertain, but the few data that exist suggest little effect, if any.

Finally, Hoekman offered a recommendation. The various advanced diesel emission control systems, such as the selective catalytic reduction device and the particulate trap, have been in use for only a couple of years, he reiterated. “I believe that additional research and study monitoring is needed to assess the long-term effects of biodiesel and its impurities on the performance of those systems. If those systems fail over a shortened lifetime, that would have significant effect.”

Discussion

Following Hoekman’s presentation, there was a discussion period devoted to just his talk. The first question, which came from an audience member, was whether any work had been done to study the effect that contaminants in biofuels might have on health. In particular, the question concerned biofuels produced from things such as frying oils used for french fries and other foods, which could have a variety of contaminants.

Hoekman replied that he was not sure if any data exist concerning the health effects of such contaminants. However, he noted that there is a rather long and stringent list of specifications for biodiesel fuel—as there is for petroleum-based diesel—because the diesel engines are expected to run for half a million miles or even longer on these fuels without breaking down. “The feeling is if there are excessive levels of salts or metals, they may impede the performance of emission control systems,” he said. “They may use some of the capacity of the trap, thereby reducing its overall efficiency.”

In a follow-up question, Hoekman was asked about the difference between more versus less unsaturated feedstocks for biofuels. Plant-derived biofuels can vary in how unsaturated they are, depending on which plants they are derived from. So the question was whether that difference could lead to a difference in emissions from the biofuels.

Hoekman answered that there has been quite a lot of work looking at how the extent of unsaturation affects total emissions and, especially, NOx emissions. The results have been somewhat equivocal, he said, but there is some evidence that the higher the unsaturation, the more NOx emissions there may be. However, he added, “what’s much more important with respect to unsaturation is the physical property—the oxidative stability of the fuel. Can you keep it out in the marketplace? Is it an acceptable fuel regardless of what happens when you burn it?”

In response to a question about whether automotive manufacturers are willing to warranty engines used with a biodiesel mix, Hoekman said that his understanding is that most manufacturers of heavy-duty engines now accept up to B20. In fact, he said, the international standards organization ASTM has developed standards for biodiesel in the range of B6 to B20. "So, in that range, I believe biodiesel is accepted by all the U.S. heavy-duty engine manufacturers," he said. However, he did not know whether manufacturers of light-duty vehicles have yet reached the same point.

REGIONAL IMPACTS OF BIOFUELS ON HEALTH AND CLIMATE CHANGE IN BRAZIL

In the next presentation, Elliott Campbell, an assistant professor at the School of Engineering at the University of California Merced Energy Research Institute, moved from the micro-level issue of tailpipe emissions to the macro-level question of how the use of biofuels might affect health and climate change on a regional scale.

To begin, Campbell noted that much of the current discussion related to the effects of biofuels on climate change concerns those changes on the global scale. It concerns issues such as carbon cycle in the use of biomass feedstock and land-use change. But there is also emerging interest in examining the effects of biofuels use at a regional scale—for example, in studying how the broad use of E85 (a fuel with 85 percent ethanol and 15 percent gasoline) might affect air quality in a region such as Los Angeles and surrounding areas (Jacobson, 2007) or looking at the regional climate impacts from the widespread use of second-generation cellulosic biofuels products (Georgescu et al., 2011). Noting that there has been quite a bit of this sort of work done on the regional scale in the United States, he said that his talk would be focused instead on some emerging analysis of the regional climate and health impacts of biofuels production in Brazil.

Background

He began by providing some basic background on biofuels in Brazil. As can be seen in the top section of Figure 4-2, the consumption of liquid fuels has steadily increased during the past decade, as has the production, and in recent years production and consumption have been approximately equal. As can be seen in the bottom section of the figure, hydroelectricity produces a large majority of the country's electricity, with fossil fuels a distant second. Nuclear power accounts for a very small percentage of the total electric power and is a smaller proportion than renewable energy sources other than hydroelectricity and nuclear. Two energy-related concerns in Brazil are the export of biofuels and diversifying local electric power production.

Brazil produces large amounts of sugarcane whose sugar is used in the production of ethanol, and one issue of importance to Brazilian policy makers is what to do with the parts of the sugarcane plant that are not converted into ethanol. At present, Campbell said, about half of the sugarcane crop is subjected to pre-harvest burning, which makes the harvesting process much easier and less expensive and also returns nutrients to the soil. However, it produces massive amounts of air pollution during the time of the pre-harvest burning, and it is also wasting a large amount of energy that could be captured and used elsewhere.

Reducing the amount of pre-harvest burning would lead to much larger quantities of available sugarcane residue, which could be turned into energy in two ways: it could be burned in electricity-generating plants, or it could be turned into cellulosic ethanol. Converting the residue into electricity has greater greenhouse gas benefits than using the residue to produce ethanol, he said, and, furthermore, converting the residue into electricity could have a massive impact on Brazilian energy security.

The Level of Direct Emissions

After providing that brief overview, Campbell took a more careful look at the emissions caused by the field burning of sugarcane (Tsao et al., 2012). One way to understand these direct emissions, he said, is to use a bottom-up approach that combines emissions factors from the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model from Argonne National Laboratory, maps of sugarcane production, and basic conversion factors generated from other agronomic and life-cycle assessment data. When the calculations are done, they show that field burning does indeed release massive amounts of various gases: CO, volatile organic compounds, NOx, PM, and carbon dioxide. So, field burning is a very important component of the direct emissions associated with the production of biofuels, he concluded.

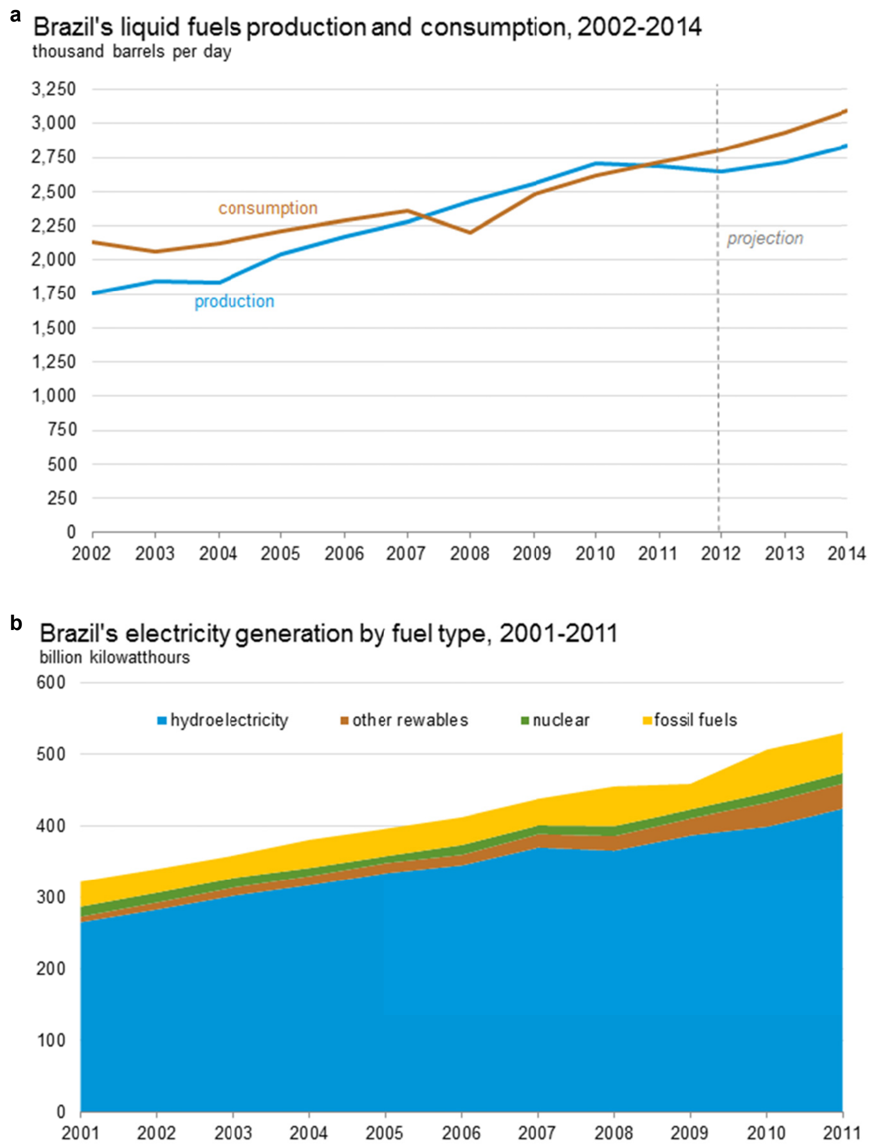

FIGURE 4-2 Energy in Brazil: (a) liquid fuels production and consumption (2002–2014); (b) electricity generation, by fuel type (2001–2011).
SOURCE: EIA, 2012.

During the past decade, he said, the emissions of various gases have grown despite the move to mechanization, and he illustrated this with a figure that showed emissions over time in the Brazilian state in which most of the sugarcane production takes place (see Figure 4-3). This increase in emissions is due to the expansion of the areas in which sugarcane is grown, so that even with growing mechanization, the amount of field burning has been increasing.

Researchers have used various methods to estimate the direct emissions from field burning, Campbell said. One such method has been remote sensing from satellites. This is a convenient method because it makes it possible to get estimates from many different sugarcane-growing regions with relatively little additional effort over what it takes to get estimates from just one area. However, the top-down data from such satellites have proven to significantly underestimate the emissions versus the bottom-up estimates.

"One important question is 'Why the difference?,' because we would love to be able to use the remote sensing data," Campbell said. There are a number of factors at play. One is that the remote sensing comes up with significantly different estimates for the size of the burned areas than the bottom-up approach. There are also major differences in the estimates of

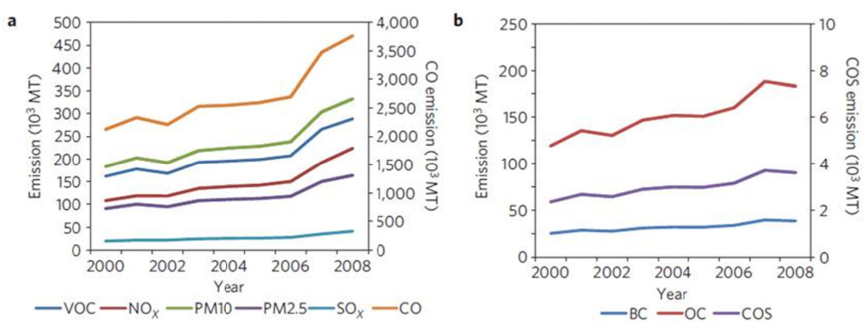

FIGURE 4-3 Estimated life-cycle emissions of ethanol in Brazil from crop year 2000 to 2008 (crop year is from April to January the following year).
NOTE: (a) Emissions of volatile organic compound (VOC), nitrogen oxide (NOx), particulate matter less than 10 microns in diameter (PM10), particulate matter less than 2.5 microns in diameter (PM2.5), sulfur oxide (SOx), and carbon monoxide (CO). (b) Emissions of black carbon (BC), organic carbon (OC), and carbonyl sulphide (COS), which are estimated only for the field-burning phase. MT = metric tons.
SOURCE: Tsao et al., 2012. Reprinted with permission. Copyright 2012 American Chemical Society.

the fuel load (the amount of biomass per unit area) and the emission factors (total emissions per kilogram of biomass).

Regional Health and Climate Impacts

With a growing understanding of the emissions from pre-harvest burning, the next question is, What might the health and climate impacts of these emissions be? To answer that question, Campbell said, one begins by trying to understand what the change in air quality is—not just how the emissions change, but how atmospheric species change in concentration and how those concentrations vary in space and time. The next steps in quantifying the human health effects are to determine the exposed populations, estimate the health effects, and determine a health baseline incidence. “You can try to gather these data at a variety of spatial scales in Brazil,” he said, including city-level, province-level, or country-level data.

There are a number of studies that estimate the health effects of various levels of atmospheric pollution, Campbell noted, “and the change in the atmospheric concentration comes from these regional atmospheric models that I talked about previously.” To illustrate, he showed a map of PM levels in Brazil in January, during the sugarcane growing season, and in May, when the pre-harvest burning takes place.

Combining models of this sort with estimates of the health effects for various levels of PM in the atmosphere, it is possible to derive estimates of the health effects of the pre-harvest burning of sugarcane based on the following approach: health effect = (air quality change) × (exposed population) × (health effect estimate) × (health baseline incidence). In looking at annual mortality changes, “you get somewhere between 20 and 4,000 deaths per billion gallons of ethanol,” Campbell reported. To put these numbers into perspective, it is helpful to review a study that compared deaths associated with operating gasoline-fueled vehicles versus those fueled with a blend of 85 percent ethanol (E85) based on modeling for 2020. Jacobson (2007) found that E85-fueled vehicles increase ozone-related mortalities by about 185 deaths per year, which corresponds to a 4 percent increase over the U.S. projected death rate of operating gasoline vehicles. Campbell noted that there is obviously much uncertainty in the exact number of deaths from the air quality effects of the pre-harvest burning, but from this preliminary analysis there appears to be significant potential for the health impacts to be quite large.

Estimating climate effects caused by the emissions from pre-harvest burning is even more difficult. "It requires advanced climate modeling," Campbell said, "but if you use climate forcing factors based on emissions for black carbon from the fields and from the boilers at the ethanol refineries, the climate forcing per unit energy of ethanol for sugarcane can increase from what we think it is now to something that may exceed regulatory thresholds."

Indirect Emissions

In addition to the direct emissions from pre-harvest burning, there are also indirect emissions caused by *indirect land-use change*, meaning, in essence, a change in the use of land from forest or some other non-cultivated land to cultivated cropland. Such land-use change generally involves the clearing of forest or other land, which in turn involves cutting down and burning trees or other vegetation, which releases carbon and other elements into the atmosphere.

Calculations show that rangeland converted to biofuels production in Brazil led to a significant amount of PM released into the atmosphere, Campbell said, but that the conversion of forest to rangeland accounted for far more emissions.

When the indirect emissions from indirect land-use change are included in the calculations for total emissions in the life-cycle of sugarcane ethanol, a very different picture emerges. For PM (in particular, $PM_{2.5}$, which refers to particles less than 2.5 micrometers in diameter), including indirect land-use change in the calculations may nearly double the estimated emissions due to the production of biofuels. To put this in perspective, Campbell compared the indirect emissions of PM from biofuels production to the emissions of PM caused by Amazonian deforestation. "Adding a billion gallons of ethanol is potentially on the order of all the emissions from deforestation in roughly the last decade," he said.

In summing up his presentation, Campbell offered the following takeaway messages:

- The emerging trade regime for biofuels, with Brazilian biofuels being exported to developed nations, presents important "leakage" challenges with respect to regional health and climate impacts.
- Previous burning estimates may underestimate the burned area by a factor of four.

- Sugarcane regional health impacts are potentially much larger than those of other biofuels, although a great deal of work remains to produce better estimates.
- The regional climate impacts from biofuels production may mean that sugarcane ethanol, instead of providing a significant reduction in climate impacts relative to the fossil fuels that it replaces, is actually causing climate warming, at least at a regional scale.

Finally, Campbell offered several research recommendations:

- Regional climate and health impacts research should focus on Brazil, given the potential for relatively high impacts there.
- The critical research gaps that should be addressed include top-down studies of burned area (in order to resolve the difference from bottom-up estimates), observation-based emissions factors (because they vary widely), and three-dimensional atmospheric modeling.
- Integrate research and policy to address leakage issues for regional impacts (e.g., air quality, aerosol forcing) in addition to the current focus on global impacts (e.g., carbon dioxide).

Discussion

Campbell's presentation was followed by a discussion period. Christopher Portier, director of the National Center for Environmental Health, Centers for Disease Control and Prevention, began by asking whether Campbell's climate forcing model with which he examined the effects of field burning included carbon black. It only included carbon, Campbell replied, which is one of the weaknesses of that analysis. There have been some very simple ballpark estimates of the climate forcing of carbon black that have been public, he said, and applying those estimates implies that field burning "can potentially exceed some thresholds for life-cycle greenhouse gas emissions." However, Campbell said, what is really needed is to run a regional climate model "because the climate forcing from these species varies so much depending on the domain, the time of year, the timing of the emissions, all of these kinds of factors." Thus, the jury is definitely still out on the effects of these carbon black emissions.

Carlos Santos-Burgoa from the Pan American Health Organization asked whether there were any changes that could be made to the sugarcane ethanol production process that would improve the emissions.

One approach would be to continue reducing the amount of pre-harvest burning, Campbell said. There has been a pretty dramatic shift over the past decade away from pre-harvest burning and toward mechanization. “Brazil has a voluntary program that’s trying to move toward those better cultivation approaches,” he said, “but it’s unclear what the future trends would be if sugarcane cultivation expanded rapidly to try and meet demand for export of biofuels.”

Roundtable member Bernard Goldstein referred to Campbell’s statement that the residue-based ethanol made in Brazil and shipped to the United States has little impact on the energy security of the United States but would have massive impact on Brazil’s energy security if it were not exported. Goldstein then suggested that economists would likely respond to this situation by saying that energy security is not being priced appropriately.

Al McGartland responded that the EPA does include an analysis of energy security in the ethanol regulations when it sets a mandate. There are a variety of security benefits to ethanol production, he said, including making the economy less vulnerable to the price of oil and potentially decreasing military expenditures in the Middle East if imported petroleum is less vital to the national interest. The value of these security benefits “is not a trivial number” for the United States, he said, although he was not familiar with the case of Brazil.

Goldstein then asked if it is correct that a drop in the price of oil would mean there would be less of a push for biofuels. McGartland replied that this is the case. Right now, biodiesel would not be made without a mandate because it costs more than petroleum-based diesel, but if the price of regular diesel fuel went up enough, biodiesel would be made without a mandate.

Goldstein next asked how to get air pollution and other health issues considered more in the discussion concerning biofuels. Stephen Reynolds suggested that life-cycle assessments (LCAs) might offer a way in. “The whole concept of life-cycle assessments has become pretty popular these days,” he noted. “In fact, it’s mandated by certain regulatory agencies that some form of LCA must be done to evaluate the broader impacts of fuels or other technology introductions.” These LCAs have tended to focus more on greenhouse gases and energy balances and not so much on “mobile-source air toxics,” Reynolds said. So, one place to start getting more attention to health issues in the discussion on biofuels would be to work to get more consideration of toxic emissions in LCAs.

An audience member elaborated on the importance of persuading decision makers—and especially the economists who advise them—that air quality needs to be taken into account as a serious policy concern. "I think that air quality is one of a class of health-related issues that traditionally have been marginalized," he said, "in part because although economists will pay lip service to issues of health and productivity, I'm not sure that the current economic theory really believes it." The result is that economic models often minimize or leave out health considerations. If people are removed from a labor market that is already glutted with free labor, for example, that does not have much overall economic impact. Thus, more work needs to be done to health and productivity and economic development. "Some progress is being made in health and productivity studies of the type that are being done in industry to relate health promotion to productivity," he said, "but that so far has been very narrow and very rich-country-oriented. I think we need a far more robust economic approach."

Another audience member immediately challenged those comments. "With all due respect to the last speaker, most of what he said is really quite wrong from an economics perspective. The environmental economics community . . . would never think about valuing health in the way that was described. We know that it is absolutely wrong to think about the benefits from loss of life or illness as something as simple as lost life years or lost productivity. It's wrong from an economic analysis perspective. It feels in-the-gut wrong, and it is wrong. So, I don't want to give you a big long lecture, but that notion is really not an accurate depiction of the state of the field."

In reality, the commenter said, the benefits of improved human health are very well understood as belonging in cost-benefit analysis, and there are many studies doing this.

Goldstein offered a relevant anecdote. Forty years ago, as a young investigator at the U.S. Office of Management and Budget (OMB), he gave a talk about the effects of sulfur dioxide and mentioned the infants who had died in the London great smog event of 1952. "I was asked by the OMB economists whether they were male infants or female infants, and when I looked horrified, and . . . asked why would that be a question, it was pointed out that females did not contribute to gross domestic product, but males did. So, OMB has come a long way."

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5

Water Use, Water Pollution, and Biofuels

The production of biofuels requires water both in the development of the feedstock—corn, soy, switchgrass, and so on—and in the processing of the feedstock into biofuels. The workshop's fifth session dealt with the effects that biofuels production has on the water supply, both its quality and its quantity.

WATER IMPLICATIONS OF BIOFUELS PRODUCTION IN THE UNITED STATES

The session's first speaker was Jerald L. Schnoor, professor of civil and environmental engineering at the University of Iowa and co-director of the Center for Global and Regional Environmental Research. Schnoor focused on water quantity issues related to biofuels. There are two main areas in the production of biofuels that involve water, Schnoor said—the agricultural side of biofuels and the production side—and each has implications for water quantity. The main questions, then, are: "How much water does it take to grow the feedstocks for biofuels? And how much water does it take to produce the biofuels for industry?"

The Energy Independence and Security Act of 2007, Schnoor noted, requires that 36 billion gallons of biofuels of various sorts be used in the United States by 2022. According to Schnoor, to many it seems that there is a greater chance of a camel passing through the eye of a needle than of that mandate for cellulosic biofuels being met by 2022.

The U.S. Environmental Protection Agency (EPA) has the power to modify the numbers in the mandate, and it has already done this for cellulosic biofuels, he noted. The number was to be 400 million gallons per year in 2010. "We weren't able to make that," Schnoor said. "In fact, we're at about 25,000 gallons currently, so we're well below that. And that calls into question the future, especially for the bottom line." In response to this situation, some people have talked about trading with Brazil as a means to provide some of the "advanced biofuels" as they are presently defined.

It is the cellulosic biofuels component of the mix—with a mandate for 16 billion gallons by 2022—that seems most in jeopardy of not being achieved, he said. It is both an economic and a technological issue—economic in that the cellulosic biofuels cost too much, and technological because there has not been the breakthrough in technology necessary to produce those cellulosic biofuels efficiently. "It's really two sides of the same coin," Schnoor said.

One problem lies in the fermentation process of cellulosic enzyme. "The enzymes alone are costing on the order of a dollar per gallon," he said, "and we're trying to produce the fuel for roughly a dollar and a half per gallon, so we're quite far away from a commercial cellulosic biofuel." Furthermore, Schnoor noted, if the mandated production for cellulosic biofuels was to be met by 2015 and 2020 and 2022, the plants would have to be built now—and they are not. "So, it's virtually assured that there's no way we're going to make that portion—the 16 billion gallons for cellulosic biofuels of the 36 billion gallon total."

Background on Corn

Corn has a variety of uses, Schnoor said. A bushel of corn—about 54 pounds—can be used to produce 31.5 pounds of starch or food, 33 pounds of sweetener, or 2.8 gallons of ethanol plus 13.5 pounds of gluten feed plus 2.6 pounds of gluten meal plus 1.5 pounds of corn oil. He pointed out that when making ethanol from corn, the byproducts are important for animal feed and that up to one-third of the original feed value of the corn is still available in the byproducts (dry distillers grains) after the ethanol has been produced.

Ethanol production is also a job creator, Schnoor said. A smaller plant that makes 50 million gallons per year of ethanol has about 40 full-time employees. "When you multiply that by hundreds of plants, it starts to make a significant number of jobs."

Concerning the economics of ethanol production, he noted that the tax credit for blenders of corn ethanol expired in 2012, but biodiesel and cellulosic ethanol still enjoy a substantial tax credit of $1.01 per gallon.

In 2012 growers planted a record 94 million acres of corn in the United States, and 40 percent of that was used in ethanol production—

more than the 37 percent used for animal feed. In Iowa, he said, the percentage is much more than that—maybe two-thirds or even three-quarters of the total corn planted is converted to ethanol. Indeed, some have suggested that if the production of ethanol continues to expand, Iowa might have to become a corn-importing state in order to feed its animals.

Many people in the ethanol industry say that the food-versus-fuel issue of corn devoted to ethanol is not something to worry about, Schnoor said. They argue that large increases in yield will make it possible to keep up with the growing demand of corn for biofuels. "But I'm sorry to say that I don't think the figures, at least so far, bear that out," he said. The trend over the past several decades has certainly been toward growing more and more bushels of corn per acre, as can be seen in Figure 5-1, which shows an average increase of two bushels per acre each year. But history also shows, he said, that the yield is vulnerable to various outside forces. Widespread droughts or floods can reduce the yield dramatically, for example. "And you can't always depend on your feedstock supply," he said. "That's what happened in 2012, when we dropped down to about 123 bushels per acre."

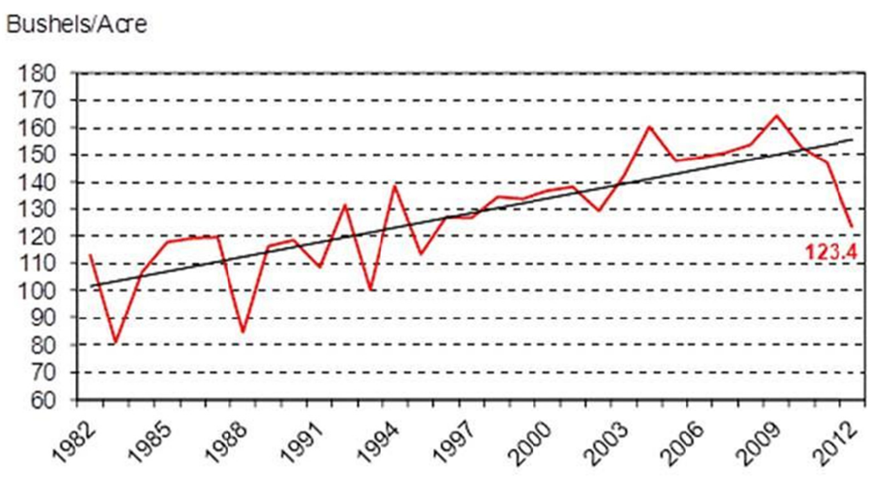

FIGURE 5-1 U.S. corn yield, 1982–2012.
SOURCE: USDA-NASS, 2013.

Water Requirements for Corn Biofuels

To provide water to grow corn for biofuels, Schnoor said, farmers can use the "green water" provided by natural precipitation or the "blue water" taken from surface water or groundwater and fed through irrigation systems. "The crop might use roughly the same amount of water either way," he said, "but if it comes from . . . a groundwater supply that might be being depleted, there are real sustainability issues involved with the irrigation of that crop."

There is relatively little irrigation needed in Iowa, where there is generally plenty of rain during the growing season, Schnoor said, but farmers growing corn in other parts of the country—particularly the western half—do irrigate. "In California in the Central Valley you might need 4,000 gallons of water per bushel of feedstock, in this case corn," he said, "and in the High Plains or in the Ogallala Aquifer of Nebraska you might need 2,000 gallons of water per bushel of corn." The result of such irrigation is a drawing down of the aquifers.

Water is required not only for the feedstock, but also for the production facilities, Schnoor said. The facilities that produce ethanol require high-purity water, which is largely taken from confined aquifers, even in the rain-fed Midwest. He displayed a figure that showed the ethanol facilities and the major aquifers in the United States (see Figure 5-2). In the figure, the larger the dot representing an ethanol facility, the greater the production capacity of that facility.

Given the use of the water from the aquifers, there is clearly a certain amount of unsustainable pumping taking place, he said. This is not unique to the ethanol industry, he said. "Any industry that has a large water requirement would be permitted to do the same thing." But what is happening here is that there is a large concentration of these ethanol facilities in limited geographical locales, which is a recipe for having a major impact on the aquifers in question. In Iowa, for example, there are a large number of ethanol production plants, and the Cambrian-Ordovician aquifer, known as the Jordan aquifer, has been pumped down by 150 or 200 feet, so eventually future generations will not be able to use that aquifer. "It does recharge," Schnoor noted, "but it recharges over a much longer time scale than would be of interest."

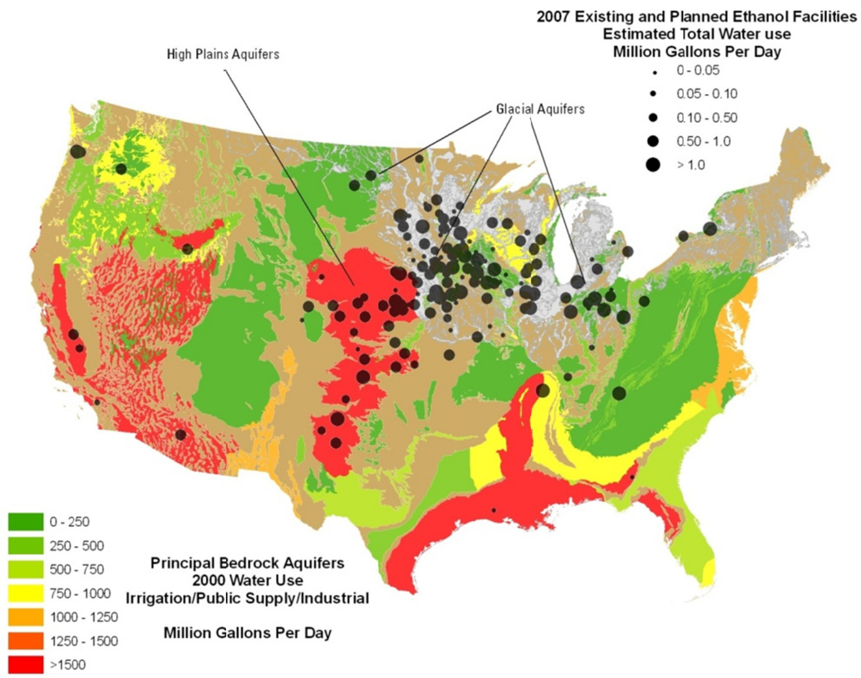

FIGURE 5-2 Existing and planned ethanol facilities (2007) and their estimated total water use mapped with the principal bedrock aquifers of the United States and total water use in year 2000.
SOURCE: Janice Ward, U.S. Geological Survey, personal communication, July 12, 2007 (NRC, 2008).

Effects of Biofuels on Water Quality

Growing either corn or soybeans to produce conventional biofuels—ethanol from corn and biodiesel from soybeans—demands large amounts of both fertilizer and pesticides, Schnoor said. Thus, as the amount of cropland devoted to growing corn has increased, there has been greater and greater negative impact on water quality even though the total acreage of land in the United States committed to agriculture has not increased in recent decades. And it is not only the states where corn is being grown for ethanol whose water quality is being affected, he said, because the runoff from the croplands ends up traveling down the Mississippi River all the way to the Gulf of Mexico.

To illustrate the problem, Schnoor described the Lincolnway Energy Plant in Iowa. It is a typical plant for producing conventional biofuels. It produces 50 million gallons of ethanol per year. To do that, it uses about 18 million bushels of corn and about 150–200 million gallons of water each year. "The older facilities, like this one, are averaging about 4 gallons of water per gallon of ethanol produced," he said. "The newer facilities can get down to maybe 2.5 or even 3 gallons. They are becoming more and more efficient." The water for such plants is generally pumped from the ground in order to provide the high-purity water that is necessary for the production processes.

To put the water use in perspective, Schnoor noted that a facility that produces 100 million gallons of ethanol per year will use about 300 million or 400 million gallons of water a year, which is roughly equivalent to what a town of 5,000 people uses. "For every black dot on the previous maps [see Figure 5-2], you can think of a new town springing up with water needs for roughly 5,000 people. So, it is a pretty intensive industry in terms of water."

Given the effects of conventional biofuels production on water quality and quantity, the hope is that cellulosic biofuels would require less water, Schnoor said. Because there are not yet any commercial facilities in operation for producing cellulosic biofuels, it is impossible to be sure what the effects will be, but the expectation is that there will be some real benefits in terms of water quality and, to some extent, water quantity.

The Potential for Cellulosic Biofuels

Cellulosic ethanol could be derived from corn stover—the leaves and stalks of the corn plants left in the field after the harvest—or from wood residues or dedicated bioenergy crops. There are issues facing the development of each.

How, for example, can the corn stover—a "diffuse, light, fluffy material," as Schnoor described it—be collected efficiently in the field and transported to the production facility? One advantage of using the corn stover is that it is located in the same place as the corn used for ethanol. An ethanol facility that turns out 50 million gallons per year will generally be sited in the middle of 100,000 acres of corn, which it uses for its feedstock. Putting a cellulosic biofuels facility in the same location would allow it to draw from the same 100,000 acres of corn stover. "But you've got to get it there, you've got to harvest it, and you've got to preserve it [because] you need it all year long, and you're only going to get it one time per year," Schnoor said. A plant that produces 40 million gallons per year of cellulosic biofuels will require hundreds of truckloads of corn stover arriving each day.

One basic question concerning the corn stover is how much of it can be efficiently collected. "Most studies indicate that you could take at least 50 percent of it as long as the land isn't too sloped," Schnoor said, and that should increase with the new genetically modified crops because they are planted much closer together. "They are producing so much stover, so much residue, that you would almost have to remove some," he said. Of course, removing the stover means that its nutrients are not returned to the soil, so the fields will need more fertilizer to replace the nutrients from the stover.

One possible alternative to processing corn stover would be to use thermochemical processes with switchgrass and mixed prairie grasses. It has been suggested that this could produce cellulosic biofuels at higher yields with lower water inputs, less fertilizer use, and lower energy inputs than producing ethanol from corn—and with lower greenhouse gas emissions as well—but there is as yet little experience with this process (Tilman et al., 2006). "I have some feeling that we will tend to fertilize much more, maybe irrigate more than one might think which affects the life-cycle assessment," Schnoor said. "So, the truth is . . . we need to gain experience if this is going to be an important contribution to the portfolio for biofuels."

Other dedicated energy crops will likely be important, too, he said. The ones most frequently mentioned are poplar, willow, and southern pine. It is possible that they could use less water, fertilizers, and pesticides, but again, not enough is known.

Can the Cellulosic Biofuels Goal Be Met?

"In our committee, we like to joke that cellulosic ethanol is just 5 years away, and it always has been and it always will be 5 years away. That's where we stand today as well," Schnoor said. So, how practical is the goal of producing 16 billion gallons of cellulosic biofuels per year by 2022?

Two studies conducted by the U.S. Department of Energy (DOE) have asked a simpler question: Can we grow enough biomass with existing land for all these needs, both waste energy and for biofuels? "The answer is probably yes," Schnoor said. According to DOE estimates, there are 500 or 600 million tons of biomass per year available from corn stover and forest residue. "Certainly the southeastern United States with its wood products would be a source of both wood waste residues and a lot of byproducts for making cellulosic ethanol."

Unfortunately, although the raw materials may exist, there is an economic problem facing cellulosic ethanol: There is a huge gap between what the producers of the biomass feedstock—such as farmers with corn stover—are willing to accept for the product and what the production facilities are willing to pay. According to one survey, the willingness to accept is in the order of $75 to $100, while the willingness to pay is only about $25 (NRC, 2011). "So, we're really quite far off from having a meeting of the minds in a commercial venture here," Schnoor observed.

The EPA's renewable fuel standards call for 15 billion gallons of conventional biofuels per year being produced by 2022. "We're almost at the 15 billion gallons now," Schnoor noted. "Iowa alone is making about 3.7 billion gallons per year." However, considerable water is required for this fuel, both in the growing of the corn and the processing of the corn into ethanol, and there are already local water problems—drawdown of the aquifers—associated with ethanol production facilities. There are also water quality issues, including the 8 grams of nutrients for every gallon of ethanol that ends up in the Gulf of Mexico and the 20 to 40 pounds of soil that are eroded for every gallon of ethanol produced.

On the other hand, cellulosic biofuels are highly unlikely to meet the EPA's goal of 16 billion gallons per year by 2022, Schnoor said. The reasons are not simply economic and technological; one major stumbling block is that meeting that goal would require that the plants be built now, "and few are on the horizon."

Finally, Schnoor offered three recommendations. First, he would not expand conventional biofuels production in the future because of its negative environmental consequences. The EPA's goal for conventional biofuels has almost been met, and the goal should not be increased.

"Number two, I think we will need to delay and revise our cellulosic biofuels mandate," he said. "I don't know if EPA will do that year by year or how it will manifest itself, but definitely that needs to change," Schnoor said.

And finally, he said, as the cellulosic biofuels industry is developed, it will be important to make sure that its production is as efficient and as environmentally sensitive as possible.

Discussion

In the discussion session following Schnoor's presentation, Richard Jackson, University of California, Los Angeles, asked what happens with the water used for ethanol production after it is used. "Is it going to municipal treatment sites, is it going back into the aquifer? Where is it being put?" Schnoor answered that there is generally an onsite treatment facility which discharges the water into streams "in hopefully acceptable quality."

Responding to a follow-up comment about the amount of effluents that end up in the Gulf of Mexico, Schnoor said that part of the problem is that the corn plants are amazingly good at absorbing nitrogen from the soil and storing it in the grain itself. Thus, it takes a lot of fertilizer to replace that nitrogen. "Theoretically, the crop should take it all up," he said, "but if it rains after you apply, down the Mississippi it goes."

Dennis Devlin of ExxonMobil then asked Schnoor whether, given the significant water use and the drawdown of the aquifers, local water districts are getting involved in the permitting process, and whether there have been any cases where water permit applications have been denied.

"I'm told that there have been some denied in Kansas," Schnoor answered. "But in Iowa I don't believe any have been denied. It's a statewide permitting authority, not county."

An audience member asked Schnoor if corn ethanol plants could be converted to produce cellulosic biofuels, assuming the production of cellulosic biofuels becomes economically feasible. Schnoor responded that cellulosic production would probably be co-located with corn ethanol production at the same sites. Following up, the audience member explained that the original implication of the question was that once cellulosic biofuels became cost-effective to produce, it would drive the corn ethanol producers out of business. In that case, Schnoor replied, it would be very possible to convert the corn ethanol plants into cellulosic biofuel plants. "They share a lot of processes in common."

WATER QUALITY: CORN VERSUS SWITCHGRASS

The session's second speaker was Catherine Kling, the head of the Resource and Environmental Policy Division of the Center for Agricultural and Rural Development at Iowa State University, whose focus was on the effects of biofuels production on water quality as well as some related economics issues.

Overview of Water Quality Problems Associated with Agriculture

To begin, Kling offered a broad overview of the water quality problems that are associated with large-scale agricultural land use, and she explained that she was not talking about large farms. "I mean land that has been intensively used by agriculture," she said, which describes much of the Midwest as well as many other parts of the country.

One of the major problems with water quality in different areas across the country is the presence of cyanobacteria blooms, which are caused by toxic algae. "This is a problem in the Midwest, in the East Coast in the Chesapeake Bay, and in the western part of the United States," Kling said, "and it's largely driven by humans generating too much nutrients." In particular, the main harmful nutrients are nitrogen and phosphorous. In the Chesapeake Bay many of these nutrients are from urban sources, such as the fertilizers that homeowners put on their lawns, but in the Midwest it comes mainly from the fertilizers used in agriculture and the manure produced by farm animals.

"It drains off into local waters and streams where it does what fertilizer does—it makes stuff grow." And although that may be desirable in farm fields, she said, in lakes, streams, and rivers it causes algae and other kinds of plants to "grow excessively and create all sorts of havoc," Kling said.

According to an EPA survey of 43 percent of the lakes, reservoirs, and ponds in the United States, 67 percent of the surveyed bodies of water had impaired water quality to support their designated uses, and more than 12 million acres were impaired. Agriculture was found to be the third-highest cause of the impairment. The same survey looked at 28 percent of the rivers and streams in the United States, and found that 52 percent of them had impaired water quality to support their designated uses, and almost half a million stream miles were impaired. In this case, agriculture was found to be the leading cause of the impairment (EPA, 2013a). Although there are a number of problems with the data, Kling said, the overall picture concerning U.S. bodies of water is clear: "There are far too many nutrients in them. They are growing algae, and that's creating problems for habitat, and it makes the water smell. There can be fish kills. There can be any number of problems."

On the other hand, the human health effects of these water quality problems are not particularly large, Kling said. "We don't drink this water; if the water is bad, it goes through purification plants. All of our water from cities is tested." There may be some risk to people who get into the water. "Largely, though, most people consider this an ecosystem health problem." And it is not getting better. That is the main take-home message.

A related problem is the presence of hypoxia or "dead zones" in bodies of water—and, in particular, in the Gulf of Mexico. These occur because of the presence of large amounts of nutrients, particularly nitrogen and phosphorous, in the water. These nutrients tend to sit near the surface and feed the algae to create algae blooms. When the algae die, they sink and decompose, using up all of the oxygen in the water column below the bloom. The result is that the oxygen concentration drops to 2 parts per million or so in large parts of the zone, and this is too little oxygen to support life. "Anything that can move, like the big fish, swim away if they can. Small things die," Kling said.

The die-off may have major long-term effects on the ecosystem, Kling said, but these are not yet well documented or well understood. "What is pretty well understood is the size of the zone from year to year and the major sources of the problem." As shown in Figure 5-3, the hypoxic zone is that part of the Gulf of Mexico that has less than 2 parts per million of oxygen. The shaded area represents the Mississippi River Basin, and any water in that area ultimately flows to the Gulf of Mexico. Two parts of the basin that make up only about one-third of its area—the Upper Mississippi Basin and the Ohio–Tennessee Basin—are responsible for about 80 percent of the nitrogen and 70 percent of the phosphorus that end up in the Gulf of Mexico. "So, if you want to target your efforts to solve problems related to the Gulf, you want to be focused on those areas," Kling said.

It is important to note that the size of the dead zone varies by year. It can be huge. It can also be small. "It's very much affected by weather in addition to the amount of nutrients that come in," Kling said. "But it is clearly much larger than it would've been without human-induced nutrients flowing into it, and the only way to address it and make it much smaller is to significantly cut back on the amount of nutrients."

Contribution of Corn Production to Water Quality Problems

Corn is an annual crop, Kling pointed out. "You plant new seed each year, it grows, and it produces this highly valuable product." To keep the yield high, however, requires adding a great deal of nutrients to the soil, generally in the form of manure and fertilizer high in nitrogen. And even with the best management practices, much of that nitrogen will be carried out of the fields by water and eventually into streams and rivers. A large part of the problem is that the land is bare half of each year. Thus, corn is known as a "leaky" crop—some of the nutrients applied to it inevitably leak out of the fields where it is planted.

In addition to the nitrogen, phosphorous is carried out of the fields in the sediment that is inevitably eroded into surrounding streams and rivers. The nitrogen moves with the water, Kling explained, while the phosphorus moves with the sediment.

The fact that the Corn Belt states of the Midwest get a great deal of rain means that there are fewer problems with water quantity than in other parts of the country because there is less need for irrigation and thus less stress on the aquifers. However, Kling pointed out, this comes at a cost for the Gulf of Mexico, as all that rain washes nutrients from the cornfields downstream.

FIGURE 5-3 The sources of the Gulf of Mexico dead zone.
SOURCE: EPA, 2013b.

In economics terms, Kling said, these consequences are an unpriced externality. The costs of these consequences are not borne by the farmers who grow the corn.

There are various ways that these externalities could be addressed. Farmers could do a better job with fertilizer timing and the amounts they use. They could plant cover crops so that the land is not bare for 6 months. They could change how they till. Or wetlands could be created carefully and strategically in a watershed so that they would capture the nutrients coming off the fields and process them before they move down to rivers and streams. "There are bioreactors. There are tile drains. There are a number of different things that can be done."

But none of these things is done, she noted. She suggested that nothing is done because it is costly and there is no reason for an individual producer to do it. The externality is not priced. There are few regulations or requirements, and hence there is the predictable situation where too many nutrients are coming off this land.

Experts believe that a 40 to 50 percent reduction in nutrients will be needed to achieve reductions in the hypoxic zone, and this would require not just one or two changes being made, Kling said, but rather widespread adoption of multiple practices. "We'd need a major change in what that landscape looks like."

Switchgrass as a Potential Solution

This is where switchgrass comes in, Kling said. It is a very tall grass plant, and for environmental purposes what is most important about it is that it is a perennial, not an annual. It has very deep roots that stay in place year after year. Once it has been planted, the top of the plant can be harvested, and the roots and lower part of the plant remain. This is part of the reason that people are excited about its potential for producing biofuels. It has far fewer problems with erosion than corn, and it also appears as though it will need less nitrogen and other nutrients than corn.

Researchers have examined the issue of how the use of switchgrass for biofuels might affect water quality, assuming that switchgrass could be made into an economically viable feedstock, Kling said. In particular, she described a study done in 2008 concerning various land uses in the Raccoon River Watershed in Iowa (Schilling et al., 2008). The baseline was the existing usage of the land in 2004: About 76 percent of it was cropland in a corn/soybean rotation, with corn planted one year and soybeans the next; 2 percent was retired cropland that was in a conservation program; 17 percent was grassland; 4 percent was forest; and 1 percent was for people and animals.

The researchers calculated how modifying the land use would affect the amounts of nitrogen, phosphorus, and sediment ending up in the watershed. In three scenarios, they expanded the amount of corn being planted—by planting the retired cropland with corn, by transforming all the grassland into cornfields, and by converting all the grassland into cornfields and growing corn all the time instead of alternating with soybeans. In three other scenarios, they planted switchgrass—on 25 percent of the most erodible cropland in the watershed, on 50 percent of the cropland, and on 100 percent of the cropland. The results are shown in Table 5-1.

Expanding the amount of corn production increased the amounts of nitrogen, phosphorus, and sediment going into the watershed from a little to a lot, depending on how much additional corn was planted. Conversely, switching to switchgrass led to a decrease in all three. The decrease in the sediments and phosphorus was particularly dramatic—almost 100 percent reduction when all the cropland was converted to switchgrass. The decrease in nitrogen was much more modest—only 11 percent with total conversion to switchgrass.

TABLE 5-1 Water Quality Effects of Switchgrass Versus Corn

Scenario		Nitrogen Change	Phosphorus Change	Sediment Change
Baseline	76% corn/soybean, 17% grassland, 4% forest, 2% retired cropland, 1% urban	—	—	—
Corn Expansion	1. Convert retired cropland to corn (2% increase)	4%	5%	7%
	2. Convert all current grassland to corn (18% increase)	33%	33%	44%
	3. Convert all grassland and soybean (96%) to corn	55%	28%	38%
Switchgrass (fertilized)	1. 25% of most erodible land converted	–3%	–51%	–63%
	2. 50% converted	–5%	–71%	–79%
	3. 100% converted	–11%	–97%	–98%

NOTE: Data from Schilling et al., 2008.
SOURCE: Kling, 2013.

"The model predicts a relatively small reduction in nitrogen relative to some of the other studies that have been done," Kling said, "and I think the main difference is the amount of fertilization you assume would be done if switchgrass is being grown for commercial purposes. If you put prairie grasses out there and don't treat them as a commercial product, of course you wouldn't fertilize. But if you fertilize them to the amount that is going to be the most efficient for commercial profit making, then you're still going to put nitrogen fertilizer on, and you're still going to get some runoff. So, that's the source of the difference."

In another study, Kling and her colleagues examined the possibilities of using switchgrass as a way to reduce flood risk. Because it is a perennial, switchgrass is very good at holding water on the land, she said, and the analysis found that planting switchgrass in place of corn over 50 percent or 100 percent of the cropland would reduce the risk of flooding significantly, with a much larger reduction in the 100 percent conversion scenario (Kling et al., 2011).

Kling began her summary by asking, Is switchgrass the answer? That depends, she said, on the question. "If the question is how we best use our land to produce the most valuable mix of food and fuel and environmental services, then we want to think broadly about water quality, greenhouse gases, the value of food, the value of energy, and everything else . . . and not get focused just on greenhouse gases or just on hypoxia or any particular thing. And in that case the answer is: maybe."

The bottom line, Kling said, is that in deciding what to grow, where to grow it, and what to use it for, there will always be trade-offs. "We have only a fixed amount of land, and we have to decide what's the most productive and valuable way of using that land, and we need to account for all of the externalities that are out there. Switchgrass has some good features. Corn has some good features. We're probably going to end up wanting a mixture of the two if we can ever get second-generation biofuels to be productive."

Finally, she offered a number of take-home points:

- Water quality is a big problem, and row-crop agriculture (corn and soybeans) is a major cause of water degradation.
- Failure to price or regulate the externality has had the expected results, that is, there is more of the product than there would be if the externality was appropriately priced.

- Second-generation biofuels have great potential, but much is still unknown: Fertilization? Field performance?
- Trade-offs between alternative products coming from fixed land are inevitable.
- Well-functioning markets do a great job of allocating resources to their highest value, but not when unpriced externalities exist, such as greenhouse gases and water pollution.
- Externalities need to be priced (or, equivalently, capped or regulated) to correct the problem.
- It is best not to identify the best specific approach, but instead to create clear market incentives to achieve outcomes.

Discussion

In the discussion session following Kling's presentation, an audience member began by asking Kling how she would go about putting a price on the various externalities in order to make sure that the market prices of the various biofuels options reflected their true costs.

Kling responded that she would use economic tools for nonmarket valuation. As an example, she briefly described work she has done in Iowa on the value of reducing the amounts of nutrients in lakes. "The way we've done that is to take information from people on how often they visit lakes of low water quality and high water quality," she said. "They drive further and spend more time and money to go to lakes of high water quality." From that information, using statistical analyses, she deduced the monetized value of having lakes with better water quality.

James Bartram of the University of North Carolina at Chapel Hill, next asked Kling whether there were generally setbacks between the cornfields and adjacent bodies of water, as the use of setbacks has been one approach to reducing runoff from the fields into the streams and rivers. No, Kling said, there are no setbacks. "Since the price of corn has gone up, you can drive through Iowa and see where people used to keep some distance between rivers and now they plant right on down. There are no requirements of setbacks."

Bartram followed up by suggesting that it might make sense to reintroduce setbacks but to use them to plant switchgrass so that the land used for switchgrass would still be used for producing feedstock for biofuels. It would be a way of "having the cake and eating it too."

Kling said such things have been talked about. Once cost-effective ways are found to make biofuels from switchgrass, the question is where to plant the switchgrass, given that the land there is very productive for growing corn. One approach would be to take land that is marginal for growing corn along with land that should be taken out of production for environmental purposes, such as the setback land, and put switchgrass there. However, she said, "The economics of it are really, really, really hard because not only do you have to figure out how to make the switchgrass work, but then you have to make it work in the hardest circumstance possible—when the feedstock is all spread out." So, yes, she said, that is the hope, but she thinks that it is not just 5 years away. "I'm afraid that one is 25 years away."

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6

Implications of Biofuels for Land Use and Health

In the workshop's sixth session—and the last one on the first day—two speakers spoke about air and land issues related to the increasing use of biofuels. The focus of the first presentation was on determining in detail the way that biofuels-related emissions are distributed in space and time as a way of understanding which groups of people are likely to be most affected by increasing use of biofuels. The second presentation examined how the U.S. forestry industry might be affected by the push to use more biofuels and bio-based products in general.

LIFE-CYCLE ASSESSMENTS OF BIOFUELS USE ON LAND AND AIR QUALITY

In the session's first presentation, Jason Hill, assistant professor in bioproducts and biosystems engineering at the University of Minnesota, discussed the life-cycle impacts of transportation biofuels on land and air quality.

Hill began by noting the wide variation that appears in reports that carry out life-cycle assessments (LCAs) of the various impacts of biofuels production. For example, he displayed the results of seven studies that looked at the life-cycle greenhouse gas emissions of ethanol produced from corn (NRC, 2011). The studies, all published between 2006 and 2011, produced estimates of the amount of carbon dioxide equivalent released per megajoule of energy in the production of corn-based ethanol. The figures ranged from a low of 52 grams of carbon dioxide per megajoule to a high of 177 grams per megajoule. He mentioned that gasoline is approximately 95 grams of carbon dioxide per megajoule, meaning that some investigators have concluded that corn ethanol is a higher emitter of greenhouse gases and others have found it to be lower. Much of the variation is caused by the studies' underlying assumptions, he said.

At first glance, this variation seems somewhat surprising, he said, because LCA is standardized by the International Organization for Standardization (ISO). He noted, however, that the ISO standard itself is more concerned with standardizing terminology and reporting than it is in the particular steps one takes when conducting an LCA. To offer a specific, detailed example of how and why LCAs vary, he described how studies of the same phenomenon—ethanol production—might be carried out from three very different perspectives.

Three Approaches to Life-Cycle Assessments

Hill noted that the three approaches he would describe are summarized from a lengthier discussion in a National Research Council report, *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy* (NRC, 2011). The approaches examine how three different people might use an LCA, approaching the subject from the point of view of an ethanol plant owner, an ethanol industry analyst, and a government regulator.

To begin with, these individuals might be interested in very different physical volumes of ethanol, Hill said. "An ethanol plant owner may be wondering about the greenhouse gas profile of the fuel being produced in his or her facility. The ethanol industry analyst may be wondering about the average corn ethanol produced in the United States in a given year. And the regulator may be interested in the marginal increase in ethanol production that occurs as a result of a policy, say RFS2 [Renewable Fuel Standard, version 2.0]," he said.

Furthermore, each of the individuals would likely choose different data as model inputs. Consider yield (mass of crop per acres harvested), for example. The ethanol plant owner might choose the yield of the corn that feeds into his or her facility. The ethanol industry analyst might choose the average yield for all U.S. corn production. The government regulator might focus on the future yield that is expected as a result of a certain policy. "All of those methods are correct, but they need to be used only for their intended purposes," Hill said. "Otherwise, you run into trouble."

The three different individuals might also differ in which "flavor" of LCA they chose. *Attributional* LCA looks at the overall impact of a production process—the total emissions, for example—and divides that impact among the different inputs and processes that went into the production. It requires, for example, a careful examination of the supply chain for a process.

By contrast, *consequential* LCA seeks to estimate the change in environmental impact resulting from running a given process. It asks, What is the change in total emissions as a result of a marginal change in the production or consumption of a product? This approach includes things such as market-mediated effects that may occur as a result of changes in supply and demand of different products. The two different approaches to LCAs can lead to very different results, Hill said.

Challenges with Life-Cycle Assessments

Although the intentions behind LCAs are good, challenges arise in how they are constructed, applied, and interpreted, Hill said. As an example, he discussed how the U.S. Environmental Protection Agency (EPA) concluded that corn ethanol reduces greenhouse gas emissions 21 percent relative to gasoline. Corn ethanol needed to reduce greenhouse gas emissions by at least 20 percent in order to meet the EPA standard, he noted, although he added, "Most of it was grandfathered in, so it is basically an academic question." Still, it is valuable to examine how the EPA reached its determination.

Table 6-1 shows the EPA's estimates of the relative greenhouse gas emissions of corn ethanol compared to gasoline. The EPA estimated that by 2022 corn ethanol produced with energy supplied by natural gas would emit either 17 or 27 percent fewer greenhouse gases than gasoline, depending on whether the process had wet or dry co-products. The EPA performed a weighted average of the 2022 estimates, based on how it believed the industry would be operated over time, and came up with a 21 percent decrease in emissions.

What does not appear explicitly in the numbers, Hill said, is how the estimates for the greenhouse gas emissions associated with corn ethanol production went from 21 to 33 percent greater than gasoline in 2012 to 17 to 27 percent less than gasoline in 2022. What happened, he explained, is both the result of an anticipated increase in industry efficiency and the result of the particular method of accounting for land-use change that the EPA used in their analysis. Specifically, a large contributor to the greenhouse gas emissions of corn ethanol is the change in land use, with forests or grasslands being converted to agriculture either directly or indirectly, with an associated increase in greenhouse gas emissions. In the EPA's analysis, most of these emissions are allocated

TABLE 6-1 Greenhouse Gas Emissions from Corn-Grain Ethanol Relative to Gasoline as Determined by the EPA

Biorefinery Heat Source	Dried Distillers Grain with Solubles	2012	2017	2022
Natural Gas	Dry	33%	10%	–17%
	Wet	21%	–2%	–27%*
Coal	Dry	66%	41%	12%
	Wet	41%	17%	–10%
Biomass	Dry	6%	–15%	–40%*
	Wet	–3%	–16%	–41%*

NOTE: * = meets 20 percent reduction in greenhouse gas emissions for corn ethanol; + = higher greenhouse gas emissions than gasoline; – = lower greenhouse gas emissions than gasoline. Dried distillers grains with solubles is a feed co-product produced in wet and dry forms as a result of ethanol production.
SOURCE: EPA, 2010.

to the 2012 and 2017 estimates of life-cycle greenhouse gas emissions, which makes the apparent cost of land use appear artificially low in the 2022 estimates. As a second example of the sorts of challenges that can arise in LCAs of biofuels, Hill discussed the uncertainty in future biomass availability. He described projections from three federal agencies of how the 2022 EPA targets for cellulosic biofuels and other advanced biofuels could be met. As had been noted several times earlier in the workshop, the mandate calls for 21 billion gallons of advanced biofuels to be produced by 2022, of which at least 16 billion gallons must be advanced cellulosic biofuels, in addition to 15 billion gallons of ethanol produced from corn.

Figure 6-1 shows how models from the EPA, the U.S. Department of Energy (DOE), and the U.S. Department of Agriculture (USDA) each project that the 2022 mandate will be met. Although all agree that 15 billion gallons of corn-based ethanol will be produced by 2022, they agree on little else. The EPA model, for example, expects that ethanol made from perennial grasses will make up a major portion of the advanced biofuels mandate—nearly 8 billion gallons—while DOE's model sees perennial grasses contributing barely more than 3 billion gallons. The USDA model expects more than 7 billion gallons of ethanol per year to be produced from sweet sorghum and other annual energy crops, while DOE's and the EPA's models predict very little, if any, ethanol to come from this source. The EPA's model expects almost 5 billion gallons of biofuels from municipal solid wastes and imported sources, while those sources are almost nonexistent in the USDA's and

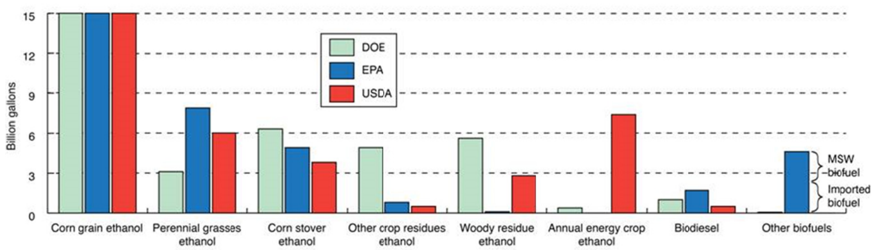

FIGURE 6-1 The types of biomass expected to be produced by 2022.
NOTE: DOE = U.S. Department of Energy, EPA = U.S. Environmental Protection Agency, MSW = municipal solid waste, USDA = U.S. Department of Agriculture.
SOURCE: Keeler et al., 2013. Reprinted with permission. Copyright 2013 American Chemical Society.

DOE's model projections. In short, Hill said, there are very large differences in how the industry is projected to develop, even among federal agencies.

Similarly, the three agencies differ greatly in their projections of where biomass will be grown for use in fuels. In the USDA's estimates for corn stover, for instance, Minnesota will be a large producer, while in the EPA's estimates it will produce none. In the case of perennial grasses, the USDA's scenario assumes that Conservation Reserve Program land will be open to production, which leads it to predict many acres of perennial grasses being grown in Iowa, Minnesota, and North and South Dakota, while the EPA's and DOE's projections include no such use in those states at all. While DOE's estimate relies almost exclusively on Kansas, Oklahoma, and Texas for the production of switchgrass in 2022, the USDA's estimate has the production shifted further north. And that, Hill noted, means that the agencies predict very different futures for things such as the change in ecosystem services and the change in water quality. "So, if you're looking to invest any sort of resources into the development of the industry, you have very different potential outcomes depending on which of these projections you are listening to," Hill said.

These differing expectations matter, he said, because the estimates are used to determine the different agencies' plans. The expectations will influence where DOE funds pilot and commercialization facilities, for example, and where the USDA invests its dollars in research programs and how the EPA will institute its final rule for different biofuels.

Another Approach

In assessing the environmental impacts of biofuels, Hill said, researchers have typically relied on two types of studies. The first is the LCA. It uses broad characterization factors and typically provides little detail about where resources are used and where emissions occur, let alone where the impacts occur.

Landscape-level studies, in contrast, typically provide a substantial amount of detail, but often miss the impacts that occur beyond a particular landscape. In particular, they miss impacts that may occur in the supply chain or as a result of market-mediated effects.

Hill then described an approach that he and colleagues have developed that is intended to combine the advantages of the two types of studies and to produce spatially and temporally explicit life-cycle inventories and impact analyses. In his description of the new approach, he focused on air quality, but it can be used to analyze any sort of impact.

In a typical LCA, one sums up the resources used and emissions released in the stages of ethanol production and compares them to the resources used and emissions released using gasoline. With this bottom line in hand, one can then use this information to decide which direction to take.

"There are all sorts of problems with simply using that approach," Hill said, "but what I want to focus on is how we can improve that." To illustrate, he showed a graph of the different emissions from gasoline and various biofuels (see Figure 6-2). The numbers come from the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model from Argonne National Laboratory.

One thing to notice from the graph, he said, is that for all the different types of gases, the tailpipe emissions—labeled as "Use" in the graph—are pretty much the same no matter whether the fuel is gasoline, corn ethanol, cellulosic ethanol from stover, or cellulosic ethanol from switchgrass. For volatile organic compounds (VOCs), a large percentage of the total emissions are tailpipe emissions, so the best approach to decreasing those emissions would be to capture the emissions from the vehicles.

However, in the case of the sulfur oxides, the nitrogen oxides, and ammonia, the vast majority of the emissions come from the production end (except for ammonia, which is a minor production byproduct when making gasoline). "So, if you're just looking at tailpipe emissions," Hill said, "you're missing most of the story of the impact of those different

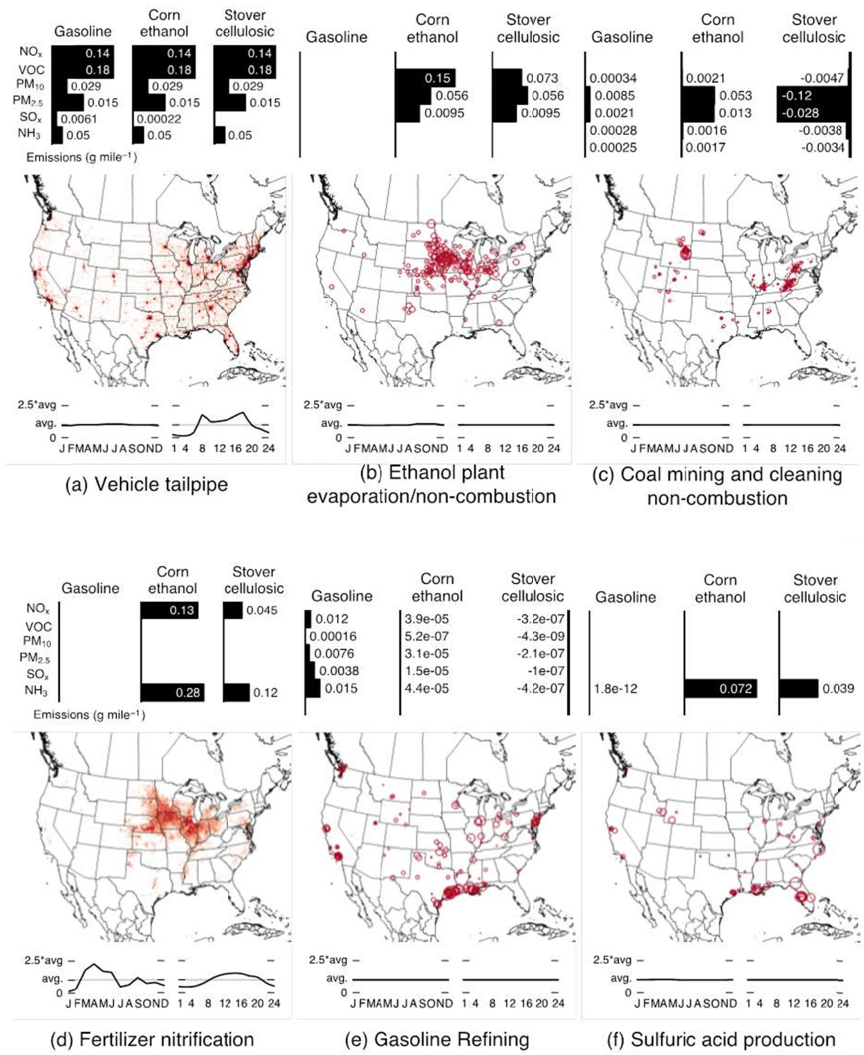

FIGURE 6-2 Spatial and temporal distributions of emissions from gasoline and various biofuels for six of the highest emitting processes in the life-cycles.
NOTE: NH_3 = ammonia, NOx = nitrogen oxide, $PM_{2.5}$ = particulate matter less than 2.5 microns in diameter, PM_{10} = particulate matter less than 10 microns in diameter, SOx = sulfur oxide*,* VOC = volatile organic compound.
SOURCE: Tessum et al., 2012. Reprinted with permission. Copyright 2012 American Chemical Society.

fuels." The lesson is that it is very important to look at the entire life-cycle when developing impact assessments. "Certainly it's important to understand the tailpipe emissions, but you need to know a lot more."

Understanding exactly where those emissions come from can be extremely complicated, Hill said. "There are actually hundreds of different emission sources in the supply chain of the production and use of these different fuels."

What Hill and his colleagues did was to examine each of the different sources and track the levels of emissions geographically and through time. It involved tracking a number of different pollutants; for example, VOCs consist of many different compounds, each of which may vary from the others in its spatial and temporal profiles. The result was a dataset showing where and when various emissions of various compounds took place in the life-cycle of various fuels. Figure 6-2 shows the sort of results that were produced.

The six sections of the figure show the geographic distribution of six different processes: vehicle tailpipe emissions, ethanol plant evaporation and non-combustion, coal mining with non-combustion included, fertilizer nitrification, gasoline refining, and sulfuric acid production. The spatial emission profiles vary according to which fuel is under consideration: gasoline, corn ethanol, or cellulosic biofuel from corn stover. And there are actually more than six processes, Hill noted, with many hundreds in the production of these fuels alone.

Furthermore, the emission profiles vary in time, both month to month and hour to hour within a day. For example, the profile for vehicle tailpipe emissions in section (a) has two peaks, corresponding to the morning and evening rush hours.

Hill described the process he uses to get complete profiles for emissions from gasoline and biofuels: "You take all those individual profiles and you layer them, one on top of the other. Hundreds of those layer on top of the other for each species for each fuel. What you get is a spatially explicit, temporally explicit inventory of fuels. These are done at hourly time steps over the whole year as well."

The result is a set of figures like Figure 6-3, which shows the distribution of ammonia emissions around the country for gasoline versus corn ethanol and stover cellulosic ethanol. As can be seen, the emissions are by far the highest in the Midwest because that is where ethanol production is centered. The emissions due to gasoline are far smaller and are concentrated in the large metropolitan areas.

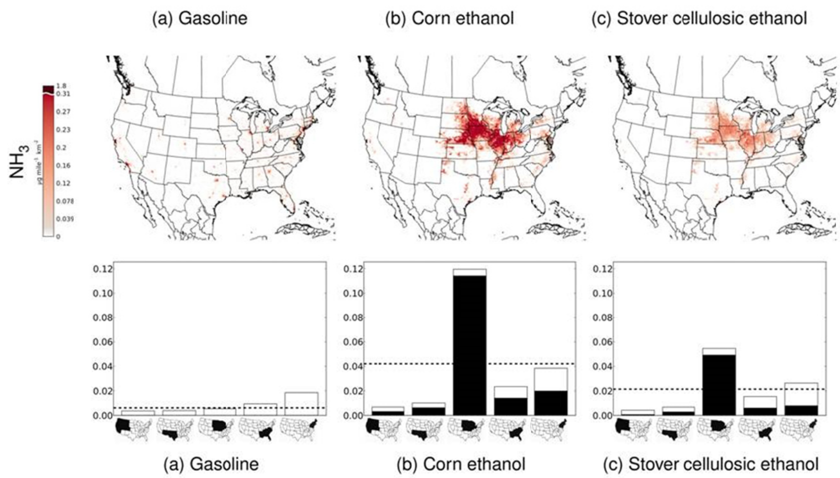

FIGURE 6-3 Cumulative spatial distributions of ammonia emissions from gasoline, corn ethanol, and stover cellulosic ethanol.
NOTE: NH_3 = ammonia.
SOURCE: Tessum et al., 2012. Reprinted with permission. Copyright 2012 American Chemical Society.

Hill and his colleagues have also produced cumulative temporal emission profiles that are done hour to hour throughout the day, day to day throughout the week, and month to month throughout the year. The emission of volatile organic compounds and particulate matter dips on the weekend, for example, while ammonia emissions jump during the spring when plants are being fertilized most heavily.

It is not enough to simply look at when and where these emissions occur, Hill said. It is important to understand the ultimate implications for health. "So, we're looking at advanced dispersion modeling, air quality impacts, and then finally environmental justice."

He then showed some preliminary results from those sorts of analyses. In particular, he and his colleagues examined the health costs of meeting the mandates set in RFS2, the Renewable Fuel Standard, version 2.0, above and beyond meeting the mandates set in RFS1. To get from RSF1 to RFS2 requires producing an additional 7.5 billion gallons per year of corn ethanol. They also assumed that the mandate will lead to an increase of 5 billion gallons per year of stover cellulosic ethanol. This is not enough to meet the current mandate, but most people do not think that mandate is realistic, so Hill and his colleagues took 5 billion gallons as a more realistic result, and they choose stover cellulosic ethanol because stover was likely to be the lowest-cost feedstock. “So, in our scenarios, we ran 5 billion gallons a year of stover cellulosic ethanol and 7.5 billion gallons a year of corn ethanol and summed those two and compared them to the energy-equivalent volumes of gasoline that could have been used in their stead,” Hill said.

They produced spatial distribution maps of the various emissions due to the increase in the use of biofuels resulting from RFS2. Not surprisingly, the emissions were concentrated in the Midwest, where the vast majority of biomass production and biofuels plants are located. From there it was possible to estimate the health effects by looking at the geographic distribution of the emissions, combining that with the geographic distribution of the population, and using what is known about how increases in various atmospheric pollutants affect health.

Hill and his colleagues used the data to estimate the number of deaths caused by emissions from the biofuels versus gasoline. Replacing approximately 8 billion gallons of gasoline per year with 7.5 billion gallons of corn ethanol and 5 billion gallons of stover cellulosic ethanol could be expected to lead to an additional 260 deaths per year in the United States, they found. (Ethanol has approximately two-thirds the energy density of gasoline such that the miles that can be driven on 12.5 billion gallons of ethanol is approximately equal to those that can be driven on approximately 8 billion gallons of gasoline.)

One of the more interesting aspects of the study, Hill said, is that it makes it possible to look at the demographic distribution of the health effects—to see, for example, how rural populations are affected by the changes versus urban populations, or low-income populations versus high-income. Preliminary results indicated that in the case of income groups, low-income individuals are slightly more affected by gasoline emissions than high-income individuals, and there is very little difference between the groups for biofuels. In terms of race, nonwhite groups are much more affected by gasoline emissions than white groups, while the difference for biofuels is much smaller, although it is still apparent. Not surprisingly, people in urban areas are approximately twice as likely to die as those from rural areas from the health effects of emissions from the use of gasoline—cities have a far greater concentration of cars. Switching to biofuels evens that out somewhat, as those in rural areas—where biomass production and ethanol production plants are most likely to be situated—are much more affected by the biofuels-related emissions than are those in cities.

So, in terms of environmental justice, switching from gasoline to biofuels may likely lead to increased mortality, but may somewhat blunt the disparate health impacts of the emissions related to transportation fuels, reducing the current disadvantage experienced by low-income individuals, nonwhite individuals, and people living in urban areas by, in essence, switching to a type of fuel whose related emissions are more likely to affect those who are high-income, white, or living in rural areas.

FOREST MANAGEMENT AND FOREST-BASED BIOENERGY INITIATIVES

The session's second presenter was Daniel Cassidy, a senior adviser for renewable energy and natural resources at the USDA, who spoke on forest management and forest-based bioenergy initiatives.

He began by showing a map illustrating which parts of the United States have forests. The majority of forestland, he noted, is in the Southeast, the Northeast, and the Pacific Northwest. There are about 750 million acres of forest land in the country—roughly the same amount as a century ago—and about 80 percent of it is government-owned. The 20 percent that is privately owned supplies 60 percent of the wood fiber to the forest products industry. About 328 million dry tons of forest products are harvested each year.

The woody biomass that could be used for biofuels consists of the parts of the tree left over after harvesting—stumps, limbs, and branches. Cassidy noted that it had been referred to as *wood waste* earlier, but he suggested avoiding that term "because if it's a waste, then it means it's worth nothing to us." And some of the woody biomass used for biofuels is wood grown specifically for that purpose, he noted.

If the wood residuals are to be used for biofuels, it will be important to have safe and efficient ways to collect and transport them. The smaller branches and debris—the "slash"—can be put into piles that are then formed into log-shaped assemblies using a material similar to chicken wire; these assemblies are called slash logs. But the larger pieces, Cassidy said, will require the development of equipment to collect and package them for transport, and safety will be an important consideration in the design of that equipment since the larger pieces are heavy enough to cause serious injury.

In the Southeast, pine trees are planted and grown on pine plantations, with the trees evenly spaced in long rows. "It's our version of row cropping," Cassidy commented. The trees take several decades to reach the size at which they are harvested, and while they are growing, he suggested, it would be possible to plant switchgrass between the trees "so you can have an annual harvest of switchgrass and then you can harvest the trees when they reach the size that you need for your commercial operations."

Why Wood-Based Biofuels Production Could Help the Forestry Industry

The forestry industry supports 1.6 million workers with $50 billion of annual income, he said, but in recent years a number of the pulp mills and paper mills have closed. "So, this is an industry that needs some type of support, and we think that bio-based products and biofuels—or, as I like to call it, the bio-economy—can really fit this need," Cassidy said.

A lot of the country's forest stands now are overstocked because they are not getting harvested, he said. "There are just no markets." And that creates another set of problems in addition to the economic needs of the workers. One threat comes from forest fires. "There have been over 200,000 acres burned just this month alone in the United States—just from January 1 to today [January 24]," Cassidy said. The smoke from the fires creates both air pollution and greenhouse gases. It would be good for the overstocked forests if some of their trees could be harvested and used in the bio-economy.

Furthermore, large sections of forest are filled with trees that have been killed by insects. "In British Columbia, they've lost 43 million acres to a bug about the size of a grain of rice," he said, noting that 43 million acres is about the size of Uruguay. This leaves a tremendous amount of standing dead wood that can't be used for lumber. "We can't use it for anything except for the bio-economy, which would be perfect for it," Cassidy said.

Finally, Cassidy noted that forest areas are regularly being cleared to build new homes and subdivisions. "They clear out forestland because developers can pay a landowner more for it than the landowner can maintain it for." This offers another potential source of wood for the bio-economy.

The Bio-Economy

The bio-economy, Cassidy said, refers to the production of products based on biological products. Many chemicals are bio-based, he said.

"The global chemical industry is expected to grow by 6 percent annually between now and 2025, and over 20 percent of that growth can come from biomass and bio-based products." The USDA has a program, the Biopreferred Program, that calls for purchasing, whenever possible, products that are safe and green and come from biomass.

A specific example of a product in the bio-economy is the wood pellets that are now being used in many places to provide heat. There is increasing demand for the pellets, Cassidy said, and much of that growth is being driven by the demand from the European Union, which is moving away from coal and toward using wood products. The pellets are being used to heat an elementary school in Darby, Montana, as part of a Fuels for Schools Program sponsored by the U.S. Forest Service. "We were able to put in a system that would use wood pellets to heat the entire school," he said. "It's saving them $62,000 on annual heating costs. In a school system as small as Darby, Montana, that's a significant amount of money." He added that the USDA is also working to create bio-based aviation fuels.

The USDA is only interested in bio-based products that can be sustainable, Cassidy said, and they should be sustainable in several ways. They should be economically sustainable, and "the bottom line will guide the path forward." They should also be environmentally sustainable, which involves a variety of factors: water, air, soil, biodiversity, and carbon sequestration, among others. And they should be socially sustainable. "Is this something that we want in our backyards? Do our communities feel that this is safe and healthy? Do we have the infrastructure to manage these types of facilities?"

Opportunities

There are a variety of opportunities for people interested in developing uses for woody biomass, Cassidy said. The Forest Service has woody biomass research grants, for example. "They are looking at the logistics and engineering plans and safety plans of all the equipment and how we can go out and harvest these wood residues."

Cassidy explained that he is working on detail as a senior adviser but is also a National Program Leader with the National Institute of Food and Agriculture, "so I'd like to talk a little bit about the opportunities there." The goal at the institute is to develop regionally appropriate biofuels and bio-based product programs, he said, and one way it is approaching this is with the use of CAPs, or coordinated agriculture programs. The CAPs bring together academic researchers with people from industry and landowners. "We're building a large alliance to help support the regional sustainable biofuels systems," Cassidy said.

The USDA's efforts to develop bio-based products and biofuels cover a spectrum of approaches, from working to develop superior genotypes of energy crops to improving feedstock production practices, developing conversion technologies that can accept a broad range of feedstocks, and working on regional sustainability analyses and decision-making tools.

The National Institute of Food and Agriculture is currently working with the Agricultural Research Service's National Agricultural Library to develop an open-source, LCA database for the United States so that "all this great information that universities are producing" will be made available to industry so that companies can do a better job of analyzing their options, Cassidy said.

Other USDA programs are the Agriculture and Food Research Initiative and the Biomass Research and Development Initiative. The latter is working with the Global Bioenergy Partnership, which has come up with a set of criteria for developing bioenergy, including criteria concerning the health of the worker involved.

DISCUSSION

A brief discussion period followed Cassidy's presentation. The first question concerned the role that recycling has played in the recent economic woes of the forestry industry. "I think that recycling plays a major role in the paper industry," Cassidy said, "but I don't believe it's what killed the paper industry. I believe what killed it was finding ways to do business cheaper overseas."

Stephen Reynolds from Colorado State University noted that forestry remains one of the most dangerous occupations in the United States, and the costs to the industry of the occupational hazards are not insignificant. "There hasn't been a lot of work on this, but Paul Lee at University of California, Davis, estimated that the cost of occupational injuries and fatalities in the United States is around of $250 billion per year. A good proportion of that derives from agriculture and forestry in particular." This issue of workforce risks and the associated costs should be taken into account in any efforts to develop biofuels from wood products, he suggested.

Bernard Goldstein of the University of Pittsburgh asked whether the database being developed by the National Agricultural Library will have quality standards. In particular, he mentioned Hill's comment that LCAs are sometimes in need of improvement. Cassidy responded that he believed there would be standards and that they would probably be applied in a way that encouraged careful LCAs. The USDA will probably also use its power as a funding agency to shape the reporting of findings, he suggested. "One of the great things about being a granting agency is . . . we can basically tell you, 'If you want this money, this is the standard of reporting you're going to have to meet.'" Hill reinforced that comment, saying, "From the point of view of somebody who is going to be submitting to that database, they have made very good efforts to engage us in the process—everything from how the databases would be set up to how our reporting could be done so as to be consistent with other institutions."

Responding to a question from Jack Spengler of Harvard University on the subject of environmental justice and how big a role it is likely to play in decisions concerning biofuels, Hill commented that one of the advantages of LCA is that it makes it possible to quantify some of the impacts of decisions on the different groups or populations that are affected. "If we're shifting different parts of the burden of these different energy sources or agricultural products . . . from one part of the supply chain to another, there are going to be different impacts. And if we're producing large amounts of these biofuels in the upper Midwest and displacing fuels that would otherwise be produced in Texas and North Dakota and California, there are going to be differences there as well. What this lets us do is understand the magnitude of those differences and whether they matter. . . . It then allows us to target our mitigation efforts more effectively."

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7

Ethical and Social Issues

Biofuels production affects people in many different ways, from its social and economic effects to its environmental and health effects. Thus, the development of any policy on biofuels should take into account the various ethical and social issues that arise when individuals and communities feel the effects of that policy. This session was devoted to a discussion of such issues.

ETHICAL ISSUES RELATING TO BIOFUELS

The session's first speaker was Alena Buyx, a senior research associate at the School of Public Policy at University College London and head of the Emmy Noether Group in Bioethics at the University of Muenster. Buyx, who presented via video from Germany, spoke on ethical issues relating to biofuels.

Buyx, who is the former assistant director of the Nuffield Council on Bioethics, began with a brief description of that body. Established in 1991 and jointly funded by the Medical Research Council, the Nuffield Foundation, and the Wellcome Trust, it "looks at ethical questions that are raised by advances in the biomedical sciences." The council strives to stimulate debate, she said, but is has also been reasonably successful in contributing to policy making in the past few years.

In 2011 the council published a report on the ethical issues related to biofuels production, *Biofuels: Ethical Issues* (Nuffield Council on Bioethics, 2011). Much of Buyx's presentation, she said, was based on issues and policy recommendations from that report. "What I hope to bring to the table today is a very comprehensive way to bind many things together and to have a look at some of the pressing ethical issues that we encounter in this field, which is very complex and, by its very nature, very interdisciplinary."

The Current Situation

To set the stage, Buyx offered a brief description of the current situation surrounding biofuels. There is very little debate, she said, on the climate-related problems caused by fossil fuels or on the need to reduce fossil fuel consumption. “But there will be a short- and mid-term need for liquid transport fuels,” she added. “Anybody who says any different is a dreamer, at this stage.”

Although there are various alternatives for transport fuel on the horizon, such as hydrogen, none is yet mature enough to be put into production now. “Biofuels are one of the few alternatives we actually have now for energy for transport,” Buyx said, “so that is our background. We are talking about a real existing technology, as opposed to many others that are quite far away.”

Transport accounts for about 30 percent of the world’s energy use, and biofuels are currently a small proportion of that. Some studies predict that biofuels could make up around 9 to 10 percent of world transport use by 2020.

Biofuels are attractive for a number of reasons, she said. Many countries are interested in them because they could provide a path to energy security and energy independence from the countries that today produce much of the world’s energy. Biofuels also have the potential to promote further economic development, both in developed countries and in the developing world. In Europe, the main reason for turning to biofuels, she said, is their potential to help in the mitigation of climate change by reducing greenhouse gas emissions.

A number of policies and targets have been implemented over the past decade to encourage the use of biofuels, such as the Renewable Fuel Standard in the United States and, in Europe, the European Renewable Energy Directive and the Fuel Quality Directive, which mandate that by 2020, 10 percent of all transport energy needs to be from renewable sources and all transport emissions need to be reduced by 6 percent. It is fair to say that in the early 2000s, biofuels were seen as something of a silver bullet for energy problems, Buyx said.

The two main types of biofuels currently in production, as noted earlier in the workshop, are bioethanol and biodiesel. There are a number of new approaches that may provide large amounts of bioenergy in the future but that are still being developed. These include the use of waste products as fuel, including straw, cooking oil, and municipal wastes; lignocellulosic biofuels derived from such things as willow trees, miscanthus, and switchgrass; and algal biofuels, which are still mostly at the experimental stage.

The report by the Nuffield Council on Bioethics "found a number of quite serious ethical concerns, mainly focusing on deforestation and biodiversity loss, risks to food security, some human rights breaches, and concerns of inequity," Buyx said. Although it was not the council's intent to focus on ethical concerns related mainly to bioethanol and biodiesel, this is what they ended up focusing on because these two fuels are so dominant today and so much further along in development relative to the other types of biofuels.

Case Studies

Buyx described three cases studies from the ethics council's report. All three were concerned with issues with current biofuels production, not potential future problems. "Let me say that biofuels production is very heterogeneous from an ethics point of view, not just from a technical one," she said. "One of the take-home messages is that we need to look at it on a case-by-case basis." In particular, the U.S. case study—which is the first case study she described—is not one homogenous case study; it has many parts.

One of the ethical issues stemming from corn ethanol production in the United States is the effect that such production has on food prices and food security. Certainly food prices went up significantly during the past decade as a significant portion of the U.S. corn crop was diverted into biofuels, which in turn led to some highly publicized riots in Mexico, among other places, that were in response to sharp rises in the price of staples. Although it has been shown that biofuels were by no means the only culprit, they did contribute to the increase in food prices, and the effect may increase as biofuels production goes up. This tension between biofuels production in the United States and affordable food worldwide raises a number of ethical issues.

A second set of issues concerns the question of indirect land-use change and its effect on greenhouse gas emissions. As discussed earlier in the workshop, life-cycle assessments call into question the claim that the use of biofuels can reduce greenhouse gas emissions because when the effects of land-use change are taken into account, the greenhouse gas benefits may disappear. Indeed, Buyx noted, some calculations show that biofuels production actually makes the greenhouse gas problem worse than simply using gasoline.

A second case study looked at Brazil. That country has a well-developed industry for producing ethanol from sugarcane. "The main issues that came up there," she said, "were centered on the environmental sustainability of this production." Deforestation is a major concern, as some rainforests have been cleared for sugarcane production.

A second great concern in Brazil centers on workers' rights. There have been reports of conditions on the sugarcane mills that amount to slave labor as well as reports of very unhealthy working conditions and of informal child labor in the mills.

Buyx noted that while she was focusing on particular countries because these were the places where the problems were most apparent or, at least, where they received the most attention, similar problems appear in many places around the world. "Actually, to some degree, these are globalized problems."

Malaysia provided the third case study, which focuses mainly on palm oil diesel production. "Again, environmental sustainability was a great issue there," Buyx said. "Deforestation occurred with forest land being cleared for palm oil plantations, which led to significant biodiversity losses." There were also a number of land grabs, both by governmental organizations and by entities in the private sector, and these land grabs led to the disruption of subsistence economies in the areas in which they occurred. There are also food security concerns caused by rising prices for palm oil and for foods that use palm oil.

Moving Toward More Ethical Production of Biofuels

In short, Buyx said, the case studies indicate that much of the current production of biofuels is "quite unsustainable." Thus, one of the main messages in the report is that, from an ethical point of view, there is a need to improve current production methods. "We need to continue to develop alternatives for the future, alternatives that are better at doing what biofuels set out to do." The report offers an ethical framework for policy makers intended to help them move toward more ethical production of biofuels.

According to that framework, policy decisions concerning biofuels should take into account certain moral values. These include human rights and global justice, solidarity and the common good, stewardship, sustainability, and intergenerational equity. "These are the big philosophical concepts that are touched upon when we discuss production of biofuels."

These philosophical concepts are quite theoretical, Buyx noted, so in order to help policy makers reflect these values in practical policy making, the report reframed them into a set of more practical principles. These five ethical principles and one ethical duty formed the core of the report's ethical framework, she said. They are

- Biofuels development should not be at the expense of people's essential human rights, including food, health, and water.
- Biofuels should be environmentally sustainable.
- Biofuels should contribute to a net reduction of total greenhouse gas emissions.
- Biofuels should adhere to fair trade principles.
- The costs and benefits of biofuels should be distributed in an equitable way. It should not happen, for example, that the benefits occur in the developed world and the costs occur disproportionately in poor countries.
- If these five principles are respected, depending on certain key considerations, such as absolute cost or whether there are even better alternatives, there is a duty to develop such biofuels.

Although this list may sound very demanding, Buyx said, there are many examples of biofuels development where these principles are respected. In such cases, there is a duty to go ahead with this kind of production and support it as well as possible.

The report recommended that these principles be applied not just to biofuels, but to comparable technologies and products as well, in order not to unduly penalize biofuels. An industry that adheres to ethical practices should not have to compete with other areas of technology in which unethical practices are common. "We believe this should be a benchmark for the whole energy sector," Buyx said.

The recommendations offered in the report were targeted at UK and European institutions, Buyx said, but they apply equally well to other countries around the world.

In the area of human rights, one concern is that the rapid increase in production of biofuels may lead to some human rights abuses. Thus, it will be important to have effective monitoring systems in place, which do not currently exist. There are currently some excellent voluntary standards in place such as the Roundtable on Sustainable Biofuels, Buyx said. "We believe that such very good standards, which have been broken down into a lot of applicable codes and tools already, should be made compulsory through certification."

In the area of environmental sustainability, she said, it will be important to develop an international environmental sustainability standard for biofuels production, which will make it possible to determine when a violation of environmental sustainability occurs. The United Nations Environment Programme has been working on such a standard in the past; hopefully, she said, this project would be completed soon.

A related issue is the contribution of biofuels production to global warming. It will be important to develop an international regulatory standard for assessing life-cycle greenhouse gas emissions from biofuels, she said. "The Global Partnership for Bioenergy has been working on this for quite a while, and we applaud those efforts and believe that is a very important tool that we will hopefully gain." With regard to indirect land-use change, the best option will be to address land-use change directly with a global coordinated response. "Land-use change should be monitored directly at the source," Buyx said, "and we should protect our land by a good, global, and, coordinated land-use policy. We are fully aware of the high demand and complexity this places upon international policy making. Currently, most countries do not even have a national land-use policy."

Under the heading of "just reward," Buyx said that biofuels production targets should promote fair pay and fair trade principles, so as not to encourage low wages and unhealthy working conditions, and that licensing schemes should address all intellectual property issues transparently, with a way to sanction violations.

On the topic of equitable distribution, she said that policies should ensure that benefits are shared equitably—for example, through public–private partnerships—and that the costs should be shared equitably as well. "We have seen that this can work through public–private partnerships, for example, in drug development in the developing world," Buyx said. "We see some early encouraging efforts in the energy sector as well."

At the same time, however, biofuels policies should not discourage local, small-scale biofuels production. "There needs to be a certain degree of flexibility, because some areas are very fuel-poor and might depend on this kind of energy. It is very important to look on a case-by-case basis and to have a certain sophistication in how these certification standards can allow for exceptions," Buyx said.

To apply these ethical principles, policy makers will need to look at broad energy portfolios, rather than individual technology options, because they will inevitably have to make comparisons between different technologies. The ethical principles should be used as an "ethical checklist" in evaluating different energy options and policies. In particular, policy makers should incentivize research and development of new biofuels and technologies that need less land and other resources, avoid social and environmental harms, and reduce greenhouse gas emissions.

In sum, Buyx said, a more sophisticated target-based strategy is needed. "We don't say to abandon all targets because there needs to be some continuity for the public and the private sector to be able to invest in this area. It just needs to be more sophisticated and more reflective of issues and problems that might come up." That strategy should be based on a comprehensive ethical standard, which is properly enforced through a certification scheme. The standard should include all of the principles described above. In addition, there should be a strong focus on investment in the new biofuels technologies to help make sure that the targets can be met.

Currently, Buyx said, there is an imbalance between existing biofuels and new, unproven ones. There are strong financial and regulatory incentives to stay with the established biofuels. "We need to rebalance this by focusing far more on the new biofuels and by bringing in a lot of incentives," she said, and added that she and her colleagues have lobbied the UK government to take this into account when adopting the European targets for UK policy.

Buyx closed with what she described as "one quite encouraging policy development that we have seen since we have published this report." In October 2012 proposals for revised targets for the European Commission's Renewable Energy Directive were announced. It now seems likely that the overall target will stay the same—10 percent of transportation fuels to come from renewable sources by 2020—but that there will be a limit on how much of that can come from cereal and other food crops. That will provide an incentive to increase the development of biofuels that do not compete with food—and which, therefore, avoid violating the first principle from the council's report.

SOCIOECONOMIC EFFECTS OF BIOFUELS DEVELOPMENT

The session's second speaker was Theresa Selfa, an associate professor in the department of environmental studies at the State University of New York's College of Environmental Science and Forestry. She spoke on the socioeconomic impacts of biofuels in rural communities, with a primary focus on Iowa and Kansas, as well as about a pilot study in Colombia that is looking at sugarcane ethanol production with particular attention paid to the issues of land and water grabs.

Selfa began by noting that in addition to energy independence and climate benefits, biofuels were promoted in many countries as an opportunity for rural economic development. Many rural municipal governments, particularly in the Midwest, gave tax breaks, created tax increment financing districts, and upgraded roads, water and sewer plants, and other infrastructure to attract ethanol plants.

A Study on Biofuels Impacts on Rural Communities in the U.S. Midwest

Noting the efforts to attract ethanol production, Selfa began a project to examine the socioeconomic impacts of ethanol production in six rural communities in Iowa and Kansas. It was focused particularly on community perceptions of the economic and environmental costs and benefits of ethanol production.

The study involved six case studies chosen according to a variety of criteria, she said. She and her colleagues were looking for variation in the dates that the ethanol plants were established, in their size (some small and some large), in their ownership structure (some locally owned and some not), the presence of community opposition or support, and the availability or scarcity of water. "Iowa is actually a pretty water-rich state," Selfa noted. "Kansas, especially as you move farther west, is quite arid. So there was a gradient of water availability."

The case studies used several different methods. For example, the researchers analyzed contacts at newspapers to see how people in the six communities had talked about the plants, both before and after their establishment. "Was the community in support of it? Was there much discussion?" The researchers also developed profiles of the demographic changes that had taken place in the different communities from 1980 to 2007. "A lot of communities had lost population," Selfa explained. "It was thought that these plants were going to help revitalize and maintain populations."

The group carried out community surveys concerning the perceived benefits and costs of ethanol as well as the residents' environmental attitudes and behaviors. More than 1,000 people in the 6 communities filled out the survey, Selfa said. "Finally, we did focus groups and in-depth interviews with a variety of stakeholders in all of the communities, including farmers, plant workers, plant owners, local government officials, environmental organizations, school administrators, community members, and business owners."

As a side note, Selfa said that of the six plants featured in the case studies, one was idled at the time of the workshop because the price of corn had gotten so high the previous year that it was not feasible for it to run, and one had already gone bankrupt and restructured. "One of our conclusions is that it is not an obvious win-win for rural communities."

The communities in the study were all small communities—the largest had just more than 20,000 people, and the smallest had fewer than 2,600—and most had lost population. Three of them had lost 10 percent of more of their population between 2000 and 2010, while only two had grown during that time, and both had seen population increases of less than 2 percent. As measured by the percent of the population below the poverty line, four of them had significant poverty. The demographics of the community as well as some information about the plants are shown in Table 7-1.

The community survey's findings offer an insight into how the communities felt in general about the ethanol plants. For example, one question asked respondents to rate the overall impact of the plant on the local quality of life. The responses were relatively balanced between seeing the plant as an overall positive versus seeing it as an overall negative—40 percent said the benefits outweighed the costs, 36 percent said the benefits and costs were about equal, and 24 percent said the costs outweighed the benefits. "Nothing too striking here, in terms of the benefits as outstanding or the costs as onerous," Selfa said.

In addition to having community members fill out the questionnaire, the researchers also did a number of interviews in an attempt to get a better understanding of the plants' economic benefits and the community members' perceptions of those benefits. One finding that emerged from the interviews was that the perception that the ethanol plant provided economic benefits increased with residents' income and education levels.

The researchers also discovered that there was "this sort of intangible community pride" concerning the presence of the ethanol plants, Selfa said, almost as if the plants were providing a "psychological boost." People would also talk about how the plant was a good fit for the community because it was a farming town.

TABLE 7-1 Community Case Study Demographics

Community	Population 2010	Percent Population Change 2000–2010	Median Household Income 2009	Percent Below Poverty Line 2009	Plant Start Date	Ownership	Plant Capacity	Feedstock	No. Employees
Greene County, IA	10,366	–9.9	$41,244	11.3	2009	Absentee	100 mgy	Corn	60
Russell, KS	4,506	–10.9	$31,425	19.4	2001	Absentee	48 mgy	Milo/wheat starch	35
Garnett, KS	3,415	–6.1	$36,847	9.2	2005	Local	35 mgy	Corn	30
Liberal/Hayne, KS	20,525	+1.9	$39,392 (Liberal)	23.9	2007	Local	110 mgy	Milo/corn	50
Nevada, IA	6,658	+0.7	$50,621	3.9	2006	Local	55 mgy	Corn	35
Phillipsburg, KS	2,581	–12.0	$44,070	6.2	2006	Local	40 mgy	Milo/corn	31

NOTE: mgy = millions of gallons per year.
SOURCE: Selfa, 2013.

A school superintendent from one of the Kansas communities put it this way:

> "I think most people are . . . proud that [we have] an ethanol plant, I think, again, that that it's a sign of being a community that's a little bit more progressive than the community next door that we may be rivals [with]. . . . I think the ethanol plant is looked at as a feather in our cap."

Even if people did not personally benefit from the ethanol plant, Selfa said, they were often glad it was there. "I think a lot of these communities initially felt that it gave them sort of a boost because they had had decades of out-migration and not a lot of economic growth. They felt like, 'We are on the right track, we are starting to grow again.'"

The survey also had open-ended questions such as "What are your impressions of the plant?," and the answers to these offer a different sort of insight. Some of the positive comments were

> "It smells and smokes, but any job in this town is better than none at all," "Glad to have it, especially with several communities losing jobs in western Kansas," "We support it, we love it, we want it to stay here," and "I think most people like having it here. It brings more awareness of the availability of E85 as an alternative to gasoline."

There were fewer negative comments than positive comments. The negative comments included

> "It may soon close, and we will be burdened with a tax load, as we already are, and we had no say about it; no election! We done this, now you taxpayers eat it."

> "Very frustrated with increase in traffic to and from the plant, and a disappointment in the addition of jobs that are not available to local residents."

> "Most people don't have any idea about who runs the plant and who benefits from it locally."

> "The only problem I have with the ethanol plant is why should our county go into debt to build a paved road to the plant to make the investors money?"

> "The downside that scares me to death is, we have built a lot of things around this plant and other towns have built around plants like it, and the stroke of the market could shut them all down. The upheaval caused would be tremendous. A lot of money being lost in investment."

Concerns similar to the final one were expressed by people in several communities, Selfa said. "There was definitely a lot of concern around what is the future, is this really sustainable, is it economically feasible."

The survey also focused on the specific impacts that community members observed that they attributed to the plants. The impact noted by the greatest number of people—42.1 percent of respondents—was a change in the crops planted by farmers. Beyond that, the surveys reported increased traffic congestion (34.5 percent of respondents), local roads showing heavy wear (31.2 percent), and increased local food prices (17.6 percent). The survey was carried out between 2008 and 2009, Selfa noted, which was a time when there was a great deal of concern in general about ethanol production driving up food prices, but this concern does not seem to have trickled down to the local communities, at least not to the degree that a large percentage of people in the communities noted food price increases.

Other impacts noted by the surveys were that the plants had generated noticeable odors (40.6 percent), that water resources had been diverted from other important needs of the community (25.2 percent), and air pollution had increased (23.2 percent). Only 9 percent of respondents claimed to have noticed a decrease in the overall quality of the environment, and only 4.9 percent reported increased water pollution.

"What intrigued us," Selfa said, "was why residents would identify particular problems, such as water resources having been diverted or odors, but then they didn't translate that into an overall decrease in the quality of the environment." The comment from a city official in Kansas was representative of the local focus:

> "I would say water. . . . There is always a concern, especially in western Kansas where we have a lot of drought, that we are using a resource that might not

> come back to us without rain. I would say that water usage and consumption is always a big concern."

Selfa commented, "It was somewhat paradoxical, we thought, that although the residents mentioned specific environmental concerns—the odors, water scarcity, air pollution—they did not seem to be overly concerned about a decline in their local environmental quality." When she and her colleagues followed up on the issue in their interviews, what they found was that relative to the other industries in these communities—which in Iowa and Kansas are generally such things as feedlots, oil refineries, and meatpacking plants—the ethanol industry seemed pretty benign to these residents. Furthermore, she added, many rural communities are desperate for any kind of economic growth. "That plays into them competing against each other to draw plants to their towns, despite relatively few direct jobs and what later became a lot of instability in the industry, due to farm prices."

Selfa offered several conclusions that were drawn from the project: State and local governments have incentivized ethanol production in rural communities. The new market for corn has benefitted some farmers, but it has also led to an intensification of production, with some negative environmental impacts. The plants provide relatively few jobs directly, and recently some of the ethanol plants have closed or idled, due to market instabilities. Investors and local governments are being left with the debt.

Sugarcane Ethanol Production in Colombia

Selfa next described a research project just getting started in Colombia for which a pilot project was performed in the summer of 2012. The subject is sugarcane ethanol production in Colombia and the potential for Bonsucro certification—a certification for sugarcane—to address water and land grabs. Land grabs in particular have been a major concern in Colombia.

As in the United States, there has been dramatic growth in biofuels production in Latin America during the past 5 to 10 years, she said. The governments there have played a major role in this growth by setting production mandates. Furthermore, because the European Union 2009 Renewable Energy Directive targets sugarcane as an advanced biofuel, there has been increased interest in Latin American countries in producing sugarcane for ethanol production. That certainly triggered further interest in production for export. The growth in biofuels production has also driven the development of various standards and certification systems, including the Bonsucro certification.

In Latin America, the national state has generally played a central role in promoting biofuels, Selfa said. The domestic elites have also played a critical role, while foreign investors have been a less important part of the developments.

There has been growing awareness of how the interest in biofuels has been driving land grabs, not just in Latin America but also around the world, Selfa said. "When we talk about land grabs, the traditional meaning of it is that it is a foreign investor coming in and buying up large tracts of land," she noted. However, in Latin America the land grabs do not always result in the expulsion of people, as is the case in many of the high-profile land grabs that get attention.

Colombia is one of the larger producers of sugarcane ethanol in Latin America, after Brazil. The country is just starting to move into palm oil production. The biofuels mandates are seen as a major strategy for rural development in Colombia, which has a great deal of armed conflict in rural areas. The idea is to create a new activity in these rural areas to bring jobs and economic development. Also, Colombia has the goal of becoming a major exporter of biofuels. However, Selfa noted, the country has not yet met its domestic use mandates.

Selfa's pilot study was carried out in the Valle del Cauca in southwest Colombia. "My graduate student did exploratory interviews with stakeholders in the sugarcane and ethanol industries, farmers, activists, government officials, industry associations, refineries, and agronomists," she said.

The Valle del Cauca has been a sugarcane production region for 140 years, and historically it has had highly unequal land distribution, with 5 percent of the population owning 61 percent of the land. The area requires irrigation, unlike Brazil, which does not, so it relies on cheap irrigation provided by the government. There has been a dramatic growth in sugarcane production there—a 20 percent increase from 2001 to 2011—and the sugarcane has pushed out most of the remaining food and other cash crops.

A major question Selfa has examined is who is benefiting from Colombia's biofuels policies. "Certainly the rhetoric has been that it is a rural development strategy," she said. However, her research has indicated that it is mainly benefiting the large producers and that it is reinforcing land inequities through the use of tax exemptions; access to land, loans, and exports; and access to cheap and plentiful irrigation water. That access to irrigation water provided to the large producers has been to the detriment of community users, she said, and it has also been increasing water pollution because of the intensified sugarcane production. And the policies have been deepening the existing pattern of land ownership and concentration.

What role is the Bonsucro certification playing? "As we heard yesterday," Selfa said, "there are different certification initiatives that are merging to certify for sustainable biofuels. Colombia has become interested in joining Bonsucro in particular so that it can access the European Union markets." Another reason for seeking Bonsucro certification, she said, is to demonstrate social responsibility at the national level, with the goal of avoiding more conflict with local communities, especially around water issues and health issues related to sugarcane burning. Colombia's goal is to have 40 percent of its sugarcane Bonsucro certified by 2013.

In the area of land grabs, Bonsucro has several principles designed to discourage outside investors from taking land from local owners. However, Selfa said, Bonsucro is designed to address the "classical" land grab scenario, which is not what is going on in Latin America. For example, one Bonsucro principle is that the local land-use laws must be obeyed. But that is of little use in preventing what is happening in Colombia because most land transactions are occurring legally. The Bonsucro principles do not address the central role that the government has played in perpetuating the inequitable land distribution, she said, nor do they address land reform or land restitution issues or the issue of violence, all of which play prominent roles in what is happening in Colombia.

Water grabs are another concern in the Colombian sugarcane ethanol-producing regions. In the Valle del Cacua, 64 percent of the surface water and 88 percent of the aquifer's water is going toward sugarcane. Household users account for 26 percent of the surface water usage, and there is very little water left for other agriculture, industry, and other users. An agricultural researcher summed up the situation this way:

> "The municipalities which depend on underground water suffer in the dry seasons of shortages in the water supply because the water is being robbed by the sugar industry, and with license of CVC [the Cauca Valley Corporation, an agency similar to the Tennessee Valley Authority,

> which is responsible for development of the region's water]. Candelaria, Pradera, many towns are affected by the lack of water during El Niño. . . . There are [restrictions on water use] but . . . all the water management in Valle del Cauca is corrupt, CVC is co-opted by the sugar mills, nobody knows what is happening. . . . I have the impression that ethanol was necessary to justify the pumping because it is very expensive."

In essence, Selfa said, the researcher was suggesting that now that the sugar is going toward the ethanol market, this provides even greater justification for why the sugar industry should be using all of that water.

In summary, Selfa said that biofuels are not an overwhelming win-win for rural communities, although they may represent a win for some, especially large, producers. National, state, and local governments have promoted the expansion of biofuels industries, but there has been less attention to the social, environmental, and economic costs to communities. Governments have exercised limited oversight in terms of environmental and socioeconomic externalities.

Finally, she said, corn and sugarcane ethanol production is reinforcing and extending land-use patterns and agricultural practices, which results in negative environmental impacts and social inequalities.

DISCUSSION

In the ensuing discussion, Jamal Hisham Hashim, National University of Malaysia, noted that in Malaysia the government has the legal right to acquire land in situations that involve the national interest, as for building a dam or a large petrochemical complex, and he asked Buyx if there are any ethical guidelines on the best way to undertake this sort of relocation, not only for palm oil plantations but for other projects, such as dam construction.

Buyx answered that there have been some early efforts at establishing national land-use policies which include codes of conduct for such things as how to deal with the customary rights of indigenous people who live in particular areas and make use of the land for food, shelter, medicine, and other reasons. However, she said, she could not point to any such efforts that she would single out as being sufficient. "What we have suggested," she said, "is to mainly focus on avoiding the most egregious breaches, because some of these land grabs are clearly highly problematic. We focus on tightening existing policy or enforcing existing policy that tries to protect indigent population from being displaced." She also suggested that developed countries should support developing countries "in enforcing this kind of policy, both financially and in terms of actual help on the ground." This should help make it more likely that the policies already in place are actually enforced.

Next, Bernard Goldstein of the University of Pittsburgh asked Buyx how one goes about defining solidarity and the common good. In many societies, he said, the terms seemed to be defined by advertising managers and politicians rather than by some general consensus. "How do you make sure that what you are looking at is something that has been agreed to as a common good . . . rather than just simply something that has been manipulated?"

Buyx said that she has no definition of the common good, but that the Nuffield Council on Bioethics did "propose a definition of what we understand solidarity in this context to be." She began by noting that "solidarity" has been used in many areas and to mean many different things. One way that it often appears in the United Kingdom, she said, is when cuts in government funding are proposed. Then people speak of solidarity in the sense of "We owe each other assistance and we all have to tighten our belts. We are in this together."

And, indeed, the notion of being in it together, of sharing a common fate, is one of the elements of how the council defined solidarity behavior between states. "It is very rare to define solidarity between states, and not very many have attempted it," she said. In the council's efforts, the definition was very much oriented toward practice. For example, in the case of climate change, many countries will be affected and are already being affected. "This notion of sharing one problem is part of the definition," she said. "The other part of the definition is that, because we share this problem, there is an obligation to help each other dealing with it."

One implication of this is that there needs to be special focus on protecting the most vulnerable members of the world society from this common problem. This understanding of solidarity, she noted, includes an appeal to the common good, but the council did not define that term "because that was just too big for us." Instead, the council made the specific practical recommendation that the first focus of any action should be to protect the weakest members. That implies, for example, that efforts should be made to protect the weakest populations in developing countries from such things as fluctuations in food prices or land grabs.

Next, Luz Claudio, Mount Sinai School of Medicine, asked Selfa whether comments from the community were solicited at some point during the siting processes for the six plants that she studied or if public meetings to discuss the plants were held.

"There were six communities, so they were all a little bit different," she said. "Sometimes, the people who organized them said, yes, we had them [community meetings], but no one came." Generally speaking, the members of the communities did not seem to feel very well informed about the plants, she said, and she provided some evidence that this was indeed the case. She carried out a study of plants in both Iowa and Kansas—not just the six in her major study, but many more—to see how many times they had received citations for environmental violations. About half the plants in both states had received citations for water and air pollution violations. But the community perception was that the plants were very clean plants—that there were no environmental externalities and no environmental impacts. "It made me wonder," she said. "I guess it just doesn't get into the public discourse or the media that a plant was cited for improper permitting or excess affluence."

In one Kansas community in particular, a long drought combined with the water use by the plant led to water restrictions for households on outside watering. At that point, Selfa said, some of the community members were saying, "If we had any idea that the plant was going to use this much water, of course we would have not wanted it in our community."

In response to a comment about whether empowerment should be an ethical consideration is developing biofuels, Buyx responded that "an ethical appraisal of biofuels would indeed be incomplete without taking that onboard." She explained that the council's report goes into some detail on how to work with local communities in a way that includes them as part of the whole process and that there are some good examples of applying that principle in the report. In addition to this being the ethical approach, it is also often the practical approach, she said. "There are a thousand different types and kinds of biofuels production. They are not the same. They have to be looked at case by case." In many cases, she said, well-thought-out policies already exist for dealing with the particular problems that arise. The difficulties actually lie with implementtation, and that is where the local population can help. "It works best if all partners, including industry on the one side and also the local populations, are a part of the process. There needs to be consultations, processes, and real participation."

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8

Biofuels and Food Security Issues

The session moderator, Frank Loy, noted in his introductory remarks that the workshop's discussions to this point had shown that the competition between food and fuel is central to the main question being addressed by the workshop—that is, whether any kind of products that come from biomass can provide a significant substitute for fossil fuels, in particular for use in the transportation sector. The two speakers in this session delved further into the relationship between biofuels and food security issues.

BIOFUELS AND THE WORLD FOOD ECONOMY

The session's first speaker was Lester Brown, founder and president of the Earth Policy Institute and one of the world's best-known environmental analysts. He spoke on the importance of biofuels in the world food economy.

Food Demand Issues

Last year, Brown began, 129 million tons of grain were converted into ethanol in the United States, and because there are about 400 million tons of grain produced in the country each year, that means that the share going to biofuels is roughly 30 percent. Indeed, the amount of grain going to biofuels production exceeded the amount of grain being used to feed livestock and poultry, he said. "We are now diverting more grain to fuel than to feed."

To put the 129 million tons into perspective, Brown pointed out that this is more grain than Russia produces in total. "So, we have taken out of the food/feed economy a chunk of grain," he said. "It is as though

Russia had disappeared from the face of the earth, in terms of production." The point is that the amount of grain being converted into fuel for cars is far from inconsequential. "That 129 million tons is certainly enough to raise food prices worldwide."

The effects of this are not really felt in the United States, Brown said. "The price of grain doubles, and the value of wheat in a loaf of bread, which was 10 cents before the price of grain doubled, is now 20 cents." If that leads to a 10-cent increase in the cost of a $3 loaf of bread, few Americans will notice. However, he said, a person who lives in New Delhi and buys wheat from the market to make chapatis is much more sensitive to price increases. "Basically, you are bringing home the wheat and grinding it, and making the chapatis. If the world price of wheat doubles, the price of your chapatis doubles. Low-income people around the world are much more affected by this massive chunk of grain that we are now using to produce fuel."

Thus, the use of grains to make biofuels is beginning to have consequences that have not been seen before, Brown said, at least not on this scale. "In the past, when food supplies tightened, the low-income segments of world society reduced the number of meals per day to one. They would have just one meal per day. Now, we see a new sort of phenomenon, which is foodless days." Brown mentioned a survey conducted in the past couple of years that showed how prevalent this phenomenon is. In Nigeria, he said, 27 percent of all families now routinely plan foodless days. In India, 24 percent of families can no longer afford to eat every day. In Peru, it is 14 percent.

"The point is," Brown said, "that we are moving into a new situation now, in terms of the adequacy of the food supply." At current prices, there is simply not enough grain to go around, so the prices go up.

The diversion of 129 million tons of grain to the production of biofuels in the United States is obviously a major factor, but there are at least two other factors involved. One is world population growth. Each year there are 80 million more mouths to feed than a year earlier. "There will be 219,000 people at the dinner table tonight who were not there last night. This is relentless, it just keeps going on and on," Brown said.

The second factor is the increasing amount of grain used for animal feed. Most of the difference between India's consumption of almost 400 pounds of grain per person per year and grain consumption in the United States, which is roughly 1,400 pounds per year, is due to the production of meat, milk, and eggs. Thus, rising affluence is now a major source of growth in the demand for grain, Brown said. The effect has been most dramatic in China, which has gone from consuming very little meat to now consuming twice as much meat as the United States.

"When people ask me how many people can the world feed, I always ask, 'At what level of consumption?' If it is at the U.S. level of consumption, it is about 2.5 billion. If it is at the India level of consumption, it is about 10 billion," Brown said.

One of the consequences of this growing demand for animal products has been that the demand for corn, which is the basic animal feed grain, has expanded much more than the demand for wheat or rice, which are food grains. In round numbers, world production of corn is about 900 million tons per year, while world production of wheat is about 690 million tons, and rice is about 460 million tons.

The result of this growing demand for animal products combined with the use of grain to power cars has been that the annual growth in the demand for grain has doubled during the past decade. Ten years ago, world grain consumption grew by about 21 million tons per year, while in the past few years, it has grown by 41 million tons per year. "In absolute terms," Brown said, "we are seeing much greater growth in demand."

Food Supply Issues

The other half of the food equation is the supply side. A variety of factors are making it difficult for farmers to keep up with the record growth in the demand for grain. The four most important are water shortages, climate change, soil erosion, and hitting the ceiling on grain yields, in particular.

"Water shortages aren't entirely new," Brown said, "but water shortages on the scale we are seeing today are unique." Half of the world's people live in countries where water tables are falling as a result of overpumping, including the three major grain producers: China, India, and the United States. "The World Bank estimates that in India, 175 million people are being fed with grain produced by overpumping," he said. "My estimate for China is 130 million."

In the United States, the irrigated areas in California and Texas, the country's two largest agricultural states, are steadily shrinking, Brown said. In Texas, that is mostly because the wells are going dry. Many of the wells there rely on the Ogallala Aquifer, which is a fossil aquifer. In California, the shrinkage is partly due to wells going dry, but part of the reason is that substantial irrigation water is being diverted to cities.

"Cities can pay much more for water than farmers can," Brown commented. "In that competition, agriculture always loses."

And for the first time there is a sub-region of the world with declining grain production as a result of water shortages, that is, the Arab Middle East, including Iraq, Jordan, Saudi Arabia, Syria, and Yemen. In those countries, grain production is not only falling, Brown said, but falling at a fairly substantial rate because the wells are going dry. In Saudi Arabia, much of the pumping has come from a fossil aquifer, and it is almost gone now. "As it goes, so will their wheat production go."

With the second major factor affecting food supply—climate change—there is still much that is not known, Brown commented. There is a rule of thumb that for every 1°Celsius rise in temperature, a 10 percent decline in grain yields can be expected. A recent empirically based study that drew on data from hundreds of counties in the United States indicates that a 17 percent decline in grain yields for each 1°Celsius rise in temperature may be more realistic.

The root of the issue lies in the relationship between temperature and photosynthesis. As temperature rises, Brown said, so does photosynthesis—but only up to 68°Fahrenheit (F). From 68°F degrees to 95°F, the photosynthesis remains constant, and above 95°F it begins to drop. Once the average temperature reaches 104°F, plants go into thermal shock and photosynthesis stops. Thus, he said, as the world's average temperature edges up, it will affect grain yields adversely, unless the problem can be somehow offset through plant breeding, which researchers are now trying to do.

Climate change will bring other changes as well, such as changes in rainfall patterns. "The main point," Brown said, "is that the agricultural system that we have now evolved over an 11,000-year period of rather remarkable climate stability. Now, suddenly, the climate system is changing." Farmers no longer know exactly what to expect and do not have enough information to do long-term planning.

A third factor affecting food supply is soil erosion. The world is seeing more soil erosion than at any time in history. The United States experienced a dust bowl in the 1930s. To get it under control, farmers turned some of the land back into grasslands and instituted a variety of farming practices designed to minimize soil erosion. When the Soviet Union experienced a similar problem in the late 1950s, they reacted in a similar way. "There are now two dust bowls forming in the world," Brown said, "both far larger than either the one in the United States in the 1930s or the one in Russia in the late 1950s." They are in northern

China and the African Sahel. Indeed, the entire northern part of China is becoming a huge dust bowl. Rather than overplowing, however, the main reason is overgrazing. "The vegetation is simply being destroyed," he said.

China has about the same grazing capacity as the United States, but it has far more animals. Although both countries have close to 100 million head of cattle, the United States has only 9 million sheep and goats, while China has 284 million. "They are literally just destroying the vegetation throughout northern China," Brown said. The government seems politically unable to deal with the problem, because of the potential unrest that would be caused by trying to reduce flocks to a sustainable level.

The fourth factor affecting food supply is that grain yields seem to have reached a point where it will be very difficult to increase them much more. In Japan and South Korea, rice yields were rising for decades. "Suddenly, about 15 years ago, they stopped rising and they have been flat as a pancake since then," Brown said. China is just now reaching the same yields that Japan has, and unless China can take its rice yields beyond those in Japan—which Brown doubts will happen—that country is also about to hit a ceiling on rice yields. In Europe, wheat yields in the three major producers—France, Germany, and the United Kingdom—have all been flat now for more than a decade. "In none of these countries that have hit the glass ceiling, has anyone been able to break out of it," Brown said, "because they are being boxed in by the limits of photosynthesis itself. Unless someone can figure out a process that is more efficient than photosynthesis or somehow modify photosynthesis, which is not an easy thing, we are going to have to face the reality of more and more agriculturally advanced countries hitting these glass ceilings."

Maintaining Stability in the World Food Economy

So, what can be done, Brown asked, to maintain stability in the world food economy? His first suggestion was to abandon the idea of producing biofuels.

In 1978, when the program started, it seemed like a good idea, he said. There was excess agricultural capacity, and the federal government was paying farmers not to plant on some of their land. But the push to produce biofuels did not really get going until after Hurricane Katrina struck in 2005. The disruption of oil refining in the Gulf area caused by

Katrina pushed the price of gasoline way up, and suddenly it was quite profitable to convert corn costing $2 per bushel into ethanol. "We had this orgy of investment in the 2005–2010 period," he said. "Most of the ethanol distilleries were built during that time." But to ensure food stability around the world, grain-based biofuels need to go.

Second, he said, a worldwide effort is needed to increase water productivity. The focus has been on land productivity for a long time. "We measure land productivity in bushels per acre or tons per hectare," Brown said, "but we don't have a measure of water productivity—how many tons of water per ton of grain, for example. It is not part of our mindset."

People need to start thinking about water productivity, he said, because it is water, not land, that is now the principal constraint on efforts to expand world food production. Raising water productivity will be key to increasing world food productivity, and the first step to raising water productivity will be to price water at its real value. "We have been treating water as a free good for so long that we tend to think it is still free," Brown said. "It is not. Water is now a very valuable resource."

A third step will be to stabilize population, which will go hand in hand with eradicating poverty. "There are millions of women in the world today who want to plan their families, but who do not have access to family planning services," Brown said. "Just getting them the services they want would take care of much of the population growth in the world today."

It will also be important to cut carbon emissions. "Climate is a major threat to future food security," Brown said. "I don't think we can even begin to imagine the consequences of continually rising temperature and the shifts in the earth's climate system." A modest rise in sea level would not have a major effect on U.S. agricultural production, but it could seriously affect rice production in Asia because so much rice is produced in river deltas.

Brown said that he believes the goal that many political leaders speak of today—of cutting carbon emissions 80 percent by 2050—will be too little, too late. "If we stay with that, the game will be over long before 2050," he said. "I think we have to cut carbon emissions 80 percent by 2020. . . . We need a wartime-like mobilization."

Brown mentioned the mobilization that took place in the United States during World War II. Within a few months of the Pearl Harbor attack on December 7, 1941, the U.S. industrial economy had been totally restructured, with, for example, the production of new cars shut down so that the automobile industry could produce tanks and planes. "We could do the same thing today if we understood the urgency of doing so," Brown said. "Instead of producing cars, we could be producing wind turbines on assembly lines, for example."

Indeed, Brown said, it would be possible to run the entire U.S. economy on wind energy. "Probably the wind energy in Texas alone would be enough," he said. China is building seven large wind power complexes, the largest of which is in Inner Mongolia. "It will have a generating capacity, when completed, of 38,000 megawatts. That is enough electricity to satisfy the needs of a country like Poland."

A major advantage of wind power, he said, is that wind scales up like no other energy source. It is not particularly useful on a small scale. For example, it is not feasible to put a wind turbine on the roof of a house, but it scales up nicely. "That is where I think we need to be headed. I think wind will be the centerpiece of the new energy economy," he said.

DOMESTIC FOOD AND BIOFUELS ISSUES

The session's second presenter was Erik D. Olson, the director of food programs at the Pew Charitable Trusts. He spoke on biofuels and domestic foods.

Olson first offered some information on the Pew Charitable Trusts, explaining that it advocates for science-based policies, with an emphasis on pragmatic, effective solutions that engage all stakeholders. He noted that he was speaking on his own behalf, and that his comments should not be interpreted as official Pew policies.

Background

Olson began by providing some background on biofuels. Reflecting on comments by several previous speakers, he listed the reasons for using biofuels as concerns about greenhouse gases and global warming, a desire to reduce the environmental and health impacts of petroleum-based fuels, and concerns about national security—particularly the fact that the United States imports almost half of its liquid fuel (mostly petroleum), with much of it coming from volatile regions. Almost 60 percent of the U.S. trade gap of approximately $1 billion per day is due to oil imports, he said.

Thus, there is a long history of congressional incentives for biofuels. These include the Renewable Fuel Standard (RFS), which has appeared in two rounds, RFS1 and RFS2. Historically, Olson noted, the vast majority of biofuels have been based on corn ethanol, with some soy biodiesel emerging recently. However, RFS2 is intended to encourage cellulosic biofuels. Tax incentives have also been used to encourage biofuels production, including several that have lapsed. There is still debate on the remaining tax incentives, and Olson said he thinks there will be additional pressure to get rid of those as well as pressure to end the trade restrictions and tariffs that have been intended to encourage domestic biofuels production.

Almost 40 U.S. states also have incentives for various biofuels, primarily ethanol. Internationally, the European Union, Brazil, and some other major global players are also encouraging biofuels production in various ways.

The Impact of Biofuels on Food Prices

The push for biofuels raised the question: What has been the impact of biofuels production on food prices? “I think there is a general consensus that it has had an impact,” Olson said, “and has caused increases.”

There is no doubt that corn prices have increased dramatically since 2006, as can be seen in Figure 8-1. Obviously, biofuels played a role in that, he said, but there were other factors as well: tight commodity markets, an increasing global population, increased meat consumption, the value of the U.S. dollar, and energy price increases.

The exact role that the RFS has played in the jump in corn and soybean prices has been fairly controversial, Olson said. Some estimates have suggested that 20 to 40 percent of the price increases in 2007–2008 were related to biofuels policies, specifically to the RFS. Adding to that was the worst drought to hit the United States in decades. In general, he said, extreme weather certainly has been having effects on yield, and thus on increasing prices. This is affecting not just the United States, but also countries around the world. In 2010, for example, Russia experienced a major wheat crop failure.

About 40 percent of the corn grown in the United States is used to produce ethanol, Olson said. However, a portion of the residual value goes to dry distiller grains with solubles, which are fed to livestock, so the total devoted to ethanol would be slightly lower. Globally, about 15 percent of corn crops are used for ethanol production.

FIGURE 8-1 Prices received for corn by month—United States, 2004–2013.
SOURCE: USDA-NASS, 2013.

Other crops are also being used for biofuels—sugarcane in Brazil, for instance, and soybeans in the United States. By some estimates, Olson said, about 14 percent of U.S. soy acres planted in 2012 went to biodiesel.

All of this suggests that biofuels production is starting to have some pretty significant impacts on food prices in some areas globally, but the impact is different in the United States than in many other parts of the world. Grain prices make up a relatively small percentage of the total cost of food in the United States, most of which is processed, Olson noted. "The amount of money in your box of corn flakes that goes to the actual corn is relatively small. The same with most processed foods, so the impact of price increases on U.S. food is somewhat muted by that fact." Still, he said, grocery manufacturers and others have been quite concerned about biofuels because of the implications for prices.

The biofuels industry has contested some of the studies that have claimed biofuels production has significantly raised food prices. However, Olson said, there seems to be fairly broad agreement that biofuels production has had some substantial impact on commodity prices and, therefore, that there has been some impact on retail prices. What the exact effect has been is still unclear.

Environmental and Health Issues

There are also a number of major environmental and health issues that need to be considered as the country moves toward additional use of biofuels, Olson said. In the case of corn and soybeans, one major issue is the runoff of pesticides and fertilizer into streams and rivers. Another environmental concern is that as the price of corn has risen, there has been increasing pressure to convert marginal farmlands and even forests into cropland. Life-cycle assessment raises the question of exactly how much greenhouse gas improvement is actually derived from using corn and soybeans to produce biofuels, and water use is yet another major environmental issue.

One major health issue that needs to be addressed, Olson said, is the health effects of a diet that includes a large percentage of processed foods, particularly diets that are heavily dependent on corn and soybean products. That is something that does not get much attention, he said, but an Institute of Medicine workshop (IOM, 2014) will soon be taking a look at this issue—the relationship between sustainable diets and the healthfulness of the diet.[1] Biofuels must obviously play a role in the discussion, he said.

Advanced Biofuels

The development of advanced biofuels will play a role in the impact that biofuels have on food issues, he said. There is a variety of ways to produce biofuels other than using corn or soybeans or sugarcane. The RFS is trying to move the system toward greater use of cellulosic biofuels, produced from sawgrass and switchgrass, short-rotation woody crops, and so on. Agricultural and industrial wastes and biogas all have some promise, he said, and algae is really starting to look interesting as a potential source of biofuels.

The most straightforward new technologies to deploy are the so-called "drop-in technologies," which refer to technologies that can work with the existing infrastructure. For example, Olson said, "You may be able to simply substitute some of these biofuels directly for gasoline or

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[1] The Institute of Medicine's Food Forum and Roundtable on Environmental Health Sciences, Research, and Medicine held a workshop on sustainable diets on May 7–8, 2013. Additional information is available at http://www.iom.edu/Activities/Nutrition/FoodForum/2013-MAY-07.aspx.

for petroleum-based fuels without major changes in infrastructure, which would obviously save quite a bit of technology, as well as resources."

There are a number of benefits that are expected from the use of the more advanced biofuels. One is a reduction in greenhouse gases. Another is that at least some of these biofuels would have very little impact on food crop prices and on food crops generally. They are expected to require less fertilizer and pesticide use, they generally use less water, particularly the perennials, and they have fewer land impacts.

Generally speaking, he said, moving toward the more advanced biofuels has promise. The advanced biofuels have the potential to reduce impacts on food prices, to reduce impacts on environment and health, to reduce greenhouse gas emissions far more significantly than traditional biofuels, and to offer some national security benefits by reducing the country's heavy reliance on petroleum-based fuels that come in from fairly volatile regions overseas.

Some pretty significant challenges remain in the development of these advanced biofuels. There are a number of technological challenges that have so far kept the cellulosic biofuels industry from taking off in the way that many people thought it would. There are also timing problems; shifting the U.S. fuel supply to advanced biofuels is going to take some time, he said, unless there is a complete, dramatic change in the way that we do business. Finally, the infrastructure challenges are very significant as well.

DISCUSSION

A lively discussion followed each of the two presentations. For simplicity, the two discussions are combined into one here.

Loy began by following up on Brown's observations concerning the effects that the growing demand for meat and other animal products has on demand for grain. In particular, he asked whether there are any developments that would permit an increase in meat production without the same increased demand for grain.

Brown answered that, in part, the market has actually been doing that. "When we look at the grain requirements to produce meat," he said, "the rule of thumb is that producing a pound of beef in the feedlot takes about 7 pounds of grain. Producing a pound of pork takes between 3 and 4 pounds of grain. Producing a pound of poultry is about 2 pounds of grain. If you get down to farmed catfish or carp, you can get down to an almost 1-to-1 conversion rate."

Thus, he continued, one way to lighten pressure on the system is for people to eat less red meat and more white meat—less beef, more chicken, and more fish. "That is what is happening," Brown said. "What we are seeing in the United States now is that red meat consumption is actually declining."

There are various reasons for the decline. One is price—a pound of beef costs a lot more than a pound of poultry. A second is concern about the health consequences of eating too much red meat. A third is a cultural shift that is under way. Young people are far less likely than people in previous generations to think of beef as more desirable than chicken—to celebrate special occasions with a steak, for instance.

Brown continued that there is also an ongoing shift in how cars are powered. "It looks as though we are moving toward electricity as the principal source of power for cars, whether it is all electric cars or plug-in hybrids," he said. That obviously has important implications for the demand for biofuels.

At the same time, he said, there is a trend away from using coal to produce electricity. Of 492 U.S. coal-fired generating plants, 121 have closed or are closing, he said. One reason is the availability of inexpensive natural gas, which is taking over a large percentage of generating capacity from coal. Furthermore, greater efficiencies in electrical devices have led to a decrease in electricity usage.

Yet another relevant trend is the growing success of bike-sharing programs in major U.S. cities. These are particularly popular among younger people. These, too, lead to a decrease in demand for transportation fuels.

"I think a lot of the changes are going to be generational," Brown said. "It will be easier as we make the generational shift."

Tee Guidotti, Consultant, Medical Advisory Services, asked Brown a question about how wind power could become a major part of the national energy supply when it is so variable. A common criticism of wind power is that it cannot serve as baseload generating capacity because it is not steadily available 24 hours per day, 7 days per week.

What happens, Brown said, is that "as wind farms grow larger, and as we move toward a national grid, then wind becomes baseload, because the wind is always blowing somewhere. We have onshore breezes, we have winds in the Great Plains, we have wind in the mountains, et cetera. There is always wind. It is not as much of a problem as you would think."

Three of the states in north Germany now get between 40 and 50 percent of their electricity from wind, he said, and they do not experience breakdowns or power outages because of that.

In the United States, the creation of a national grid is actually under way. At this point there are basically three grids in the country: the eastern grid, which goes from the East Coast to the Rocky Mountains; the West Coast grid, which comes down through California and into Arizona and New Mexico; and a Texas grid. "They are now being interconnected in Clovis, New Mexico," Brown said. "It is not massive lines that have been linked, but the linkage has been made." What remains to be done is to build sets of high-capacity direct-current transmission lines to move electricity long distances efficiently. "The stage is set in this country now for a national grid, given this connection. It is just a matter of building the links."

With such a national grid, wind-generated electricity can be moved from place to place as needed. There are investors building giant wind farms in Texas that will supply wind power to the Southeast. Investors in the western states are developing wind farms that will be selling electricity to California. "We are beginning to see a national approach to the management of wind resources falling into place," Brown said.

In response to a question by Guidotti about algae, Brown pointed out that since algae depend on photosynthesis, they have the same photosynthetic limits that plants have. Furthermore, growing algae requires water and a large area. "I am not sure we are going to see algae playing a major role as a source of fuel or food or feed in the future," he said. "I know ExxonMobil has been working on this for a decade now, and they still don't have anything that approaches a meaningful commercial use of the technology."

Jack Spengler, Harvard School of Public Health, mentioned Brown's call for an 80 percent reduction in greenhouse gas emissions by 2020 and asked Brown if he saw any reason to believe that such an aggressive plan could be accomplished.

Not yet, Brown said. "The question is how many summers like last summer will it take in the U.S. Midwest, the Corn Belt, and the Great Plains before we begin to take the climate thing seriously?" He mentioned those parts of the country because the weather there directly affects the food supply. Most people do not understand the difference between 350 parts per million of carbon dioxide in the atmosphere and 400 million parts per million, but they do understand food prices. "That, I think, is going to be the driver of changes in energy policy," he said. "It could come much faster than we think."

Loy noted that at the 2009 Copenhagen Conference, President Obama put a 17 percent reduction from 2005 to 2020 on the table. The conventional wisdom is that 17 percent reduction is doable, but only if the U.S. Environmental Protection Agency adopts regulations regarding emissions from existing coal-fired power plants. "I think that is plausible, but that gets you only to 17 percent." The difficulty of getting even a 17 percent reduction puts the goal of 80 percent into perspective, Loy said.

Lynn Goldman, George Washington University School of Public Health, asked Olson what role the health sector might play in the discussions about biofuels policy. Part of what this Roundtable is trying to do, she noted, is to shine a light on these kinds of problems from the standpoint of health. So, what could people in the health sector do to have more of an impact or have a more effective voice in policy discussions?

Olson answered that having the health implications well documented and out in the public domain is really important. "I think that the problem has been that the word hasn't really gotten out quite as much as it might about what the actual public health implications are of the current policies." People tend to get motivated when their own health may be affected. Also, he said, it is useful when people in the health community are willing not only to document the relevant health effects but also to speak publicly about them, whether in speaking with policy makers or the general public.

Brown added to Olson's comments by saying that analyses of the health costs of various fuels are usually very limited. "In this country, the epidemiological calculations show that we have 13,100 deaths each year as a result of burning coal," he said, but beyond that there are probably hundreds of thousands of people who suffer respiratory illnesses from being near a coal plant or from the pollutants released by burning coal, and the discussion of the health effects generally missed much of that. Furthermore, Brown said, the health effects of climate change could be severe, because climate change will affect food production and lead to more hunger and more malnutrition.

Christopher Portier, director of the National Center for Environmental Health, Centers for Disease Control and Prevention, noted that the Pew Charitable Trust does some very good health impact assessments (HIAs) and suggested that it would be useful if Pew would take on an HIA of biofuels. The situation "screams" for something like a total HIA of biofuels on a global basis, he said. Olson agreed that the health impact assessment process would be a promising way to frame the issue "because it is somewhat similar to environmental impact assessment, but it is focused on health." Olson continued, "If somebody were to propose a major review of the health impacts of biofuels policy . . . I would certainly be interested."

Jerald L. Schnoor, University of Iowa, noted the different opinions that Brown and Olson had on biofuels, with Brown suggesting they should be eliminated altogether and Olson saying that he saw promise in advanced biofuels. In light of that, Schnoor asked Olson whether it made sense to increase advanced biofuels production to the 16 billion gallons annually called for in RFS2. Given how much land that will require, he said, won't that also drive up food prices because of the competition for land?

Olson answered that this was a very fair point. He said he believes that the shift to biofuels will have its major impact when the economics change to the point that the RFS is not even necessary. "I think until the economics change, you are not really going to see that major shift toward lower impact on land use and on food prices," he said.

Catherine Kling, Iowa State University, reiterated a point made earlier in the workshop—that the increase in corn prices does not have much of an effect on food security in the United States. The Consumer Price Index for food has increased only about 3 percent per year since 2004, she said, so "the price of food in the United States is really just a non-issue." However, in developing countries the price of food is a huge issue, and grain prices can drive major changes in food affordability. So, although this is not a health concern in the United States, it is a huge health concern worldwide.

There is also likely to be a huge disparity in the impact of climate change on the United States versus the rest of the world, Kling said. "We really need to understand that when we are thinking about policy."

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9

Environmental Health Policies and Opportunities

An afternoon session on the workshop's second day offered a panel discussion on environmental health policies and opportunities. The panel's three speakers focused on assessments of health and sustainability as ways to inform policy making concerning biofuels. The panel moderator, John Balbus, National Institute of Environmental Health Sciences, noted that such assessments are crucial tools in determining how to weigh the different issues involved in the production and use of biofuels, which can run the gamut from environmental issues, such as fertilizer runoff and soil erosion, to social issues, such as the health of communities, to economic issues, such as the costs of food and fuel.

A FRAMEWORK FOR ASSESSING HEALTH IMPACTS OF BIOFUELS

The first speaker was Lynn Goldman, dean of the School of Public Health at George Washington University. She discussed some factors that should be taken into account when assessing the health impacts of biofuels.

There have been a number of health policy drivers for biofuels production, she said. These include reducing air pollution, including greenhouse gas emissions from biomass fuels and coal; increasing fuel security; benefiting rural economies; and increasing energy availability, both for today's growing populations and for future generations. She addressed each of these in turn.

Reducing Air Pollution

Goldman noted that there are a variety of considerations to take into account when reducing air pollution, specifically, levels of ozone, particulate matter, volatile organic compounds, nitrous and sulfur oxides, and metals like mercury. For example, policy makers should consider how fuels burn, and whether one fuel is cleaner than another. "We add fuel oxygenates to motor vehicle fuels to increase octane and make them burn more cleanly, and ethanol has substituted for MTBE (methyl tertiary-butyl ether) and some of the other oxygenates," she said.

Second, she noted that diesel fuel combustion creates a great deal of air pollution. The U.S. Environmental Protection Agency (EPA) and other regulatory authorities have sought to develop cleaner diesel fuel, and biodiesel has been thought to be a pathway to development of cleaner alternatives.

Third, she identified the problem of indoor air pollution from burning biomass fuels for household heating and cooking. Such fuels are very dangerous in terms of the pollution they produce indoors. Alternative fuels that burn more cleanly could replace the biomass fuels or could be used to generate electricity for households thus reducing exposures within the home environment.

At the same time, Goldman said, it is important to take into account the life-cycle effects of the various potential energy sources. Thus, when considering air pollution levels, it is important to take into account not only the air pollution that is generated by fuel combustion, but also the air emissions that occur across the entire life-cycle of growing the plants, producing the fuels, and transporting the fuels. Unfortunately, she said, "that is not generally how we perform risk assessment."

Reducing Greenhouse Gases

A second major policy goal is reducing air pollutants that act as greenhouse gases. "We know that global climate change already is having a profound impact on the public's health," Goldman said. However, as Timothy D. Searchinger, Princeton University, pointed out in his talk, it now seems that some of the early assessments of the potential of biofuels to reduce greenhouse gasses were overly optimistic, largely they did not take into account land-use changes.

She asserted that although it was once thought that biofuels would play a significant role in efforts to reduce greenhouse gases, no clear benefits have been demonstrated by current alternatives. This clearly underscores that it is crucial to do a careful life-cycle assessment when considering the benefits of using biofuels.

Increasing Fuel Security

According to Goldman, fuel security is an important public health issue. For example, she said, "Increasing fuel security could potentially increase national security and thereby prevent adverse health impacts that are related to regional and global conflicts." Such impacts occur as the direct result of conflicts, she said, but they can also occur indirectly because of the displacement of civilian populations during conflicts and morbidity and mortality impacts on such populations.

However, Goldman said, U.S. energy use per capita is so massive and the potential production of biofuels so small by comparison that, to date, conventional biofuels have had very little impact on fuel security in the United States, nor is there evidence that biofuels have had a major impact on fuel security in most other countries in the world. Of course, she added, there is always the hope that newer technologies will produce biofuels more efficiently and thus change the fuel security equation.

Benefiting Rural Economies

Another way that biofuels could affect health is through the benefits they provide to rural economies. This is not something that would normally appear in a risk assessment framework, Goldman said, but it is certainly reasonable to believe that biofuels production could support efforts to rebuild the economies in some rural communities, which would lead to improvements in health not only by rebuilding health care systems but also by supporting other basic infrastructure needs like transportation and education systems.

However, she added, the outmigration of young people is thought to be responsible for many of the negative impacts on rural communities. Economic development that enables young people to live and work in rural communities is an important policy objective but, as other speakers had pointed out, evidence to date indicates that biofuels production is resulting in dramatic increases in jobs that would serve as a strong incentive for retaining young people in these communities.

Yet another factor—which is almost never considered in a risk assessment context—is the potential effects that boom-and-bust cycles can have on health. Such a situation can arise when an industry expands rapidly and creates jobs creating a boom, and then contracts quickly because of changes in incentives, subsidies, or mandates or resource constraints, resulting in a bust. She said that this can ultimately have a negative effect on the health of the community's members.

One other factor that Goldman considered is the potential depletion of soil and water resources caused by biofuels production. Soil resources can be damaged by overfarming in marginal areas. Depletion of water resources has been of greatest concern in areas dependent on groundwater sources like the Ogalalla aquifer, which is very slowly renewable. Depletion of soil and water resources could damage rural economies and the health of people who live in those parts of the country, now and in the future.

Increasing Energy Availability

Another factor to consider concerning biofuels is the effects on health of increasing energy availability, both now and for future generations. This is another factor that is not usually considered in risk assessments, Goldman said, but for people who live with little available energy, major health benefits are associated with increasing energy supplies. There is evidence that increased availability of energy improves health only up to a point, however (Wilkinson et al., 2007). "There is very little evidence that the level of energy consumption that we have in the United States, for example, is actually beneficial to our health," she said. "It is possible that we have some health impacts from overconsumption."

At the lower range of energy availability, however, the health benefits of increasing energy availability appear in several ways. Having light available in households helps to promote reading and literacy. Sources of energy that do not require a great deal of manual labor by children and women—e.g., gathering firewood and fuel—makes it possible to spend more time and effort on education and economic activity. Availability of electric-powered refrigeration both improves food safety and makes it possible to deliver immunizations to more people.

Many parts of the world need more clean energy, Goldman said, and biofuels have the potential to provide local sources of such energy in those countries. However, legal mandates in places like the United States and the European Union may be making biofuels less affordable in developing countries by artificially increasing demand for biofuels in industrialized countries. Furthermore, if biofuels production leads to increased food prices, that could offset any benefits to health.

The availability of energy for future generations—the "well-being of our children and our grandchildren"—is of particular concern to Goldman. An important question to ask in this regard is whether biofuels are actually renewables. "Many people seem to assume that they are," she said, but the presentations and discussions in the workshop had indicated that may not actually be the case in the long run. A number of factors bring into question just how renewable biofuels are: requirements for chemical fertilizers and pesticides, soil losses over time, and the increased use of water for growing the crops and producing the biofuels. Sustainability of water use is particularly doubtful when the water is coming from fossil water supplies, like the Ogallala aquifer, bringing biofuels production into competition for the water with other human and environmental purposes, and with preserving the water for future generations.

Given the need to expand future production, there may be serious limitations on how much biofuels production can be expanded, she said. "That is the reality with growing populations as well as increasing development worldwide—we will need to produce more food as well as more energy."

Again, she noted, the development of new technologies might lead to a situation in which biofuels production is more sustainable.

In conclusion, she said, the governments of the Brazil, the European Union, and United States, and other countries have moved forward rapidly with mandates and subsidies to promote the development of biofuels with very little consideration of the potential health impacts, either today or in the future. A more important challenge, she said, will be reengineering the policy process so that it supports the conduct of health assessments before policy decisions are made, rather than after the fact. "I think that is an enormous challenge that lies before us, not only as a country, but for the world. I don't have the answer, but I think it is fundamental to the problem that we are looking at today," Goldman said.

A SUSTAINABILITY ASSESSMENT METHODOLOGY

The next speaker, Bernard Goldstein, emeritus dean and emeritus professor at the University of Pittsburgh Graduate School of Public

Health, discussed a sustainability assessment methodology proposed by a National Academy of Sciences committee in response to a request from Lisa Jackson, the head of the EPA, who had asked the committee to come up with an effective way to assemble the various issues affecting sustainability into a formal framework.

The resulting publication, *Sustainability and the U.S. EPA* (NRC, 2011a), is often referred to as the Green Book, as compared to the Red Book, a 1983 National Research Council publication that laid out a framework for risk assessment (NRC, 1983). The Red Book gave a major push to the field of risk assessment, but even so, Goldstein said, it took a while for risk assessment methods to be broadly adopted. He expects something similar from the Green Book and its influence on the frameworks that people use to assess sustainability.

As the committee that would produce the Green Book was forming in November 2010, the EPA received a report that it was late in responding to a congressional mandate for a risk assessment of biofuels. The committee members took that as an example for the development of the framework, Goldstein said, because "we had in mind that in the future Congress would ask the EPA and other agencies for a sustainability assessment of biofuels, not for a risk assessment." Such a sustainability assessment extends well beyond the issue of risk and examines many different types of trade-offs. "That is what I will be talking about," he said.

The Evolution of the EPA

To set the stage, Goldstein offered a brief history of the EPA's approach to environmental protection policies. When the agency began in the 1970s, it used a command-and-control approach to environmental protection—"basically looking at the very dirty air and dirty water and how to deal with that," he said.

The agency's move to a risk assessment approach was, in a sense, "a response to the recognition that even though we couldn't see it and touch it, there were risks out there that we had to measure to be responsive to [demands for] effective environmental policy and to what society was demanding of us," Goldstein said.

In time, Goldstein said, the agency will move into a sustainability period. "Perhaps we are in it now." There is already great work being done in this area, he said, such as life-cycle assessment. That is clearly one of the tools that will be needed for sustainability assessments.

This evolution was driven in large part by the sorts of problems the EPA was facing, he said. The agency is no longer looking just at regulating such simple issues as the effluents from a single pipe or a single smokestack. Instead, it is facing multidimensional problems, and it needs tools that allow it to look across those dimensions instead of focusing on just one.

The Green Book

The committee that produced the Green Book was asked to answer four specific questions. They were

1. What should be the operational framework for sustainability for the EPA?
2. What scientific and analytical tools are needed to support the framework?
3. How can the EPA decision making process rooted in the risk assessment/risk management (RA/RM) paradigm be integrated into this new sustainability framework?
4. What expertise is needed to support the framework?

The committee did not spend significant time in defining "sustainability," Goldstein said. Instead, it "finessed" the definition issue. "As I think we all well know," he said, "developing approaches to sustainability is sometimes inhibited by people spending a lot of time arguing over what we mean." Some of the definitions suggested for "sustainability" refer to goals, while others refer to process. The committee, which Goldstein chaired, decided to approach it in terms of process.

"What we simply said is that if you go back to the nation's first major environmental act, the National Environmental Policy Act [NEPA] of 1969, signed by President Nixon, all of the aspects of sustainability are in that act, even though the word *sustainability* is not mentioned. We did this in part because we wanted to anchor this beyond any particular political party." But the key was that the 1969 act already explicitly mentioned all of the same issues that the committee was dealing with. Thus, Goldstein said, he "ruled out of order any discussion that had to do with how to define 'sustainability.'" Instead, the committee simply worked from the 1969 act to define a word that did not actually appear in the act. NEPA[1] states that its goal is "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations."

The Sustainability Framework

The sustainability framework that the committee developed for the EPA has two levels, Goldstein explained. As can be seen in Figure 9-1, everything starts with the "sustainability paradigm," which, in essence, sets forth the principles from which everything else follows. The paradigm consists of three separate pieces. The first contains three individual sets of principles—economics, environmental, and social, with "social" including health issues. The second piece consists of EPA sustainability principles and the third of various legal mandates relating to sustainability.

"We suggested that the EPA needs a sustainability vision," Goldstein said, and that vision should be informed by the sustainability paradigm. That vision should in turn be converted into specific goals and objectives, and metrics, using indicators as needed. Industry has done a very good job of developing and responding to sustainability goals and objectives, he said.

The other components in Level 1 are organizational and cultural issues, sustainability assessment and management, and periodic evaluation and public reporting. The last piece is very important, Goldstein said. "We need to know if we are meeting these goals. If we are not measuring, we can't really find out whether this is more than just hand waving."

Level 2 of the framework expands the sustainability and management component in Level 1. It begins with a screening process that examines a particular decision under consideration to determine if it has significant sustainability implications. "We can't expect every single action of the EPA to be governed by a relatively complex approach," Goldstein said. "Most actions will probably not need any major sustainability assessment." Assuming that further analysis is needed, the next step involves scoping and options identification, stakeholder identification, indicator and metrics selection, and assessing collaboration opportunities. Next comes

[1] Available at http://www.epa.gov/compliance/nepa (accessed August 20, 2013).

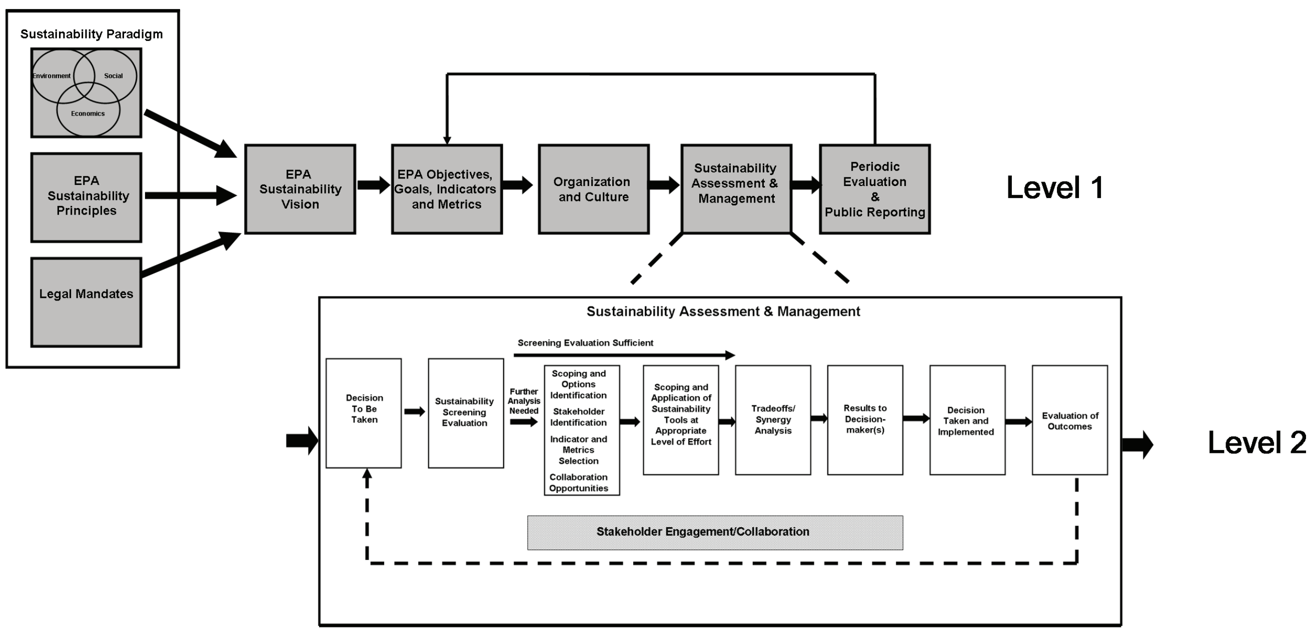

FIGURE 9-1 Sustainability framework for the U.S. Environmental Protection Agency (EPA).
SOURCE: NRC, 2011a.

the scoping and application of sustainability tools at the appropriate level of effort, followed by an analysis of the trade-offs and synergy involved, providing the results to the decision maker, making and implementing the decision, and evaluating the outcomes in order to inform future decisions.

Sustainability Assessment Tools

The sustainability assessment process only works effectively with the appropriate tools, Goldstein said. Risk assessment is an important tool, as is health impact assessment (HIA). Life-cycle assessment and cost-benefit analysis are two other well-known tools that are important to sustainability assessment, and a variety of other tools also play a role: ecosystem services valuation, integrated assessment models, sustainability impact assessment, and environmental justice tools. Many more tools need to be developed, he said.

It may take a while for some of these tools to be fully developed, Goldstein said. He noted that the 1983 risk assessment framework emphasized exposure assessment as an important tool, but it was not until around 1986 that the first society for exposure analysis was formed, and it was not until the 1990s that the EPA had a formal exposure analysis program.

In that case the EPA's risk assessment forum played a vital role in developing the area of exposure analysis. "It basically sat down with all of the players across the EPA and hammered out an agreement about whether you extrapolate from animals to humans by body area or weight . . . or whatever it was that needed to be considered." Afterward, exposure assessment was performed uniformly. Other workshop speakers had already mentioned the importance of developing such a uniform approach to life-cycle assessment, Goldstein noted, "and certainly we are going to need that for environmental justice tools and for a lot of the other tools that are needed for the assessment."

In closing, Goldstein said, "I really think we are on the cusp of developing these new tools. We need to, if we are going to face the kind of challenges we have heard about in this meeting." When the EPA approaches an environmental issue, it should not think about the issue just in terms of minimizing risk. Instead, it needs to think in terms of how to maximize a whole collection of benefits while still minimizing risk. It is a very broad approach to thinking about environmental issues, he said, but "that type of breadth of approach is what we need for these kinds of challenges, such as biofuels."

A CALL FOR HEALTH IMPACT ASSESSMENTS

The panel's final presenter was Richard Jackson, professor and chair of environmental health sciences at the Fielding School of Public Health at the University of California, Los Angeles, and former director of the Centers for Disease Control and Prevention's (CDC's) National Center for Environmental Health.

Jackson began by pointing out that many agencies of the federal government, not just the Department of Health and Human Services but also the Departments of Agriculture, Education, and Transportation and many others, are involved with health in one way or another. This is also true for the various agencies involved with energy. "If we have learned anything from the past 2 days," he said, "it is that these energy decisions, biofuels, solar, fossil fuels, and the rest have health implications." Unfortunately, however, there has been relatively little attention paid to the various ways in which energy decisions affect health.

"What I was struck by in the past 2 days is that I don't think we have ever done an adequate environmental impact assessment on biofuels," Jackson said. "I have probably read 100 environmental impact assessments [EIAs]. What I have found is you review thousands of pages, and the last three pages claim to be about health. For example, the EIA will assert: 'No air pollution standards, no water pollution standards will be violated, no noise will disturb the neighbors.' I assert, and the Academy's committee on Health Impact Assessment asserts: we don't adequately capture health in the environmental impact assessment process, even though it is required under the National Environmental Policy Act."

Jackson described his experience serving on the joint National Research Council and Institute of Medicine Committee on Health Impact Assessment with Dinah Bear, who was with the Council of Environmental Quality in the White House. She was a very experienced lawyer with 25 years of experience, working on NEPA. When the other members of the committee would say that they wanted HIA required under NEPA, she would counter, "No, we already require health impact assessment in NEPA. We just have not done it."

It is reasonable to expect that virtually all forms of biofuels will have not just environmental impacts, but impact on health, Jackson said. For example, growing corn for biofuels means that various nitrogen compounds end up in the soil and the water because of fertilizer use. Jackson, continued,

> When the United States produced large quantities of ethanol from immense quantities of corn, we clearly need to examine the impacts on the environment, but just as important are the impacts on health. Did the impact assessment include the health impacts on contamination of surface and ground water with nitrates from fertilizer, a known cause of infant methemoglobinemia? Do we examine the health effects of water contamination of corn herbicides like atrazine and allocholor? How about the loss of 7,000 square miles of prime seafood producing areas of the Gulf of Mexico from eutrophication? Or the air pollution produced by energy neutral burning of fossil fuels to grow the corn? Do we capture the negative impacts of inadequate production of "specialty crops" like fruits and the production of foods we in public health recommend over production of sugars and oils?

Jackson also showed some images from the book *Portraits in Biodiversity* by David Liitschwager. One image shows all the various organisms found in a cubic foot of a meadow in Cape Town, South Africa, while another shows the organisms from a cubic foot in a U.S. cornfield. The difference in biodiversity is striking—there are 10 or more times as many organisms in the image from South Africa than in the image from the U.S. cornfield. "When you think about it," Jackson said, "maybe that has long-term effects—not just environmental impacts, but health and social impacts."

In 2011 *Improving Health in the United States: The Role of Health Impact Assessment* was published (NRC, 2011b). Jackson chaired the committee that produced the report. "We had a mix of public health people, also economists, international folks with a lot of experience, toxicologists, and others," he commented.

The committee concluded that health is affected by a broad array of factors, including those that shape the conditions in which people are born, grow, live, work, and age. Public health has been linked, for example, to housing policies, transportation policies, urban planning policies, agricultural policies, and economic-development policies. Thus, Jackson said, it is important to make systematic assessments of the health consequences of various policies, programs, plans, and projects in order to protect and promote health.

"We asserted the need for 'health impact assessment,'" Jackson said. The committee defined it as follows:

> HIA is a systematic process that uses an array of data sources and analytic methods and considers input from stakeholders to determine the potential effects of a proposed policy, plan, program, or project on the health of a population and the distribution of those effects within the population. HIA provides recommendations on monitoring and managing those effects. (NRC, 2011b)

Jackson said he believes that this definition makes HIA quite different from risk assessment. "It not only captures the adverse effects, but it captures the beneficial effects," he said. "There are beneficial effects to having 40 people have a job year round in an ethanol production plant. There are beneficial effects to many of the changes that occur in these communities." On the other hand, there are also negative effects, such as the boom/bust cycles that can occur.

HIAs also consider various types of evidence—not just toxicological evidence, as in risk assessment, but many other types of evidence as well. It also engages communities and stakeholders early and throughout the deliberative process, not just at the end.

In practice, HIAs should not be restricted by a narrow definition of health or restricted to any particular policy sector, level of government, type of proposal, or specific health outcome or issue. Instead, they should be focused on applications that present the greatest opportunity to protect or promote health and to raise awareness of the health consequences of decision making. In short, Jackson said, "It ought to focus on things that are important. Don't spend a lot of time doing risk assessment or health impact assessment on things that don't really matter. Worry about the big issues that affect people's health."

The committee recommended a six-step framework for carrying out HIAs. The steps were screening, scoping, assessment, recommendations, reporting, and monitoring and evaluation. In the case of the use of biofuels, the first five steps were not carried out before decisions were made, but it is not too late to monitor what happens. "Maybe we should be tracking from a health standpoint as well as an environmental life-cycle standpoint," Jackson said. Once there are data concerning what is going on, the data should be evaluated, and at that time some evidence-based recommendations could be made.

One of the committee's conclusions was that it is important to be careful about quantitative estimates. "Numbers are helpful," Jackson said, "but just because you measure it doesn't mean it is important, and just because you can't measure it doesn't mean it is unimportant."

One practical challenge in carrying out HIAs is synthesizing and presenting results on dissimilar health effects in a manner that is intelligible and useful to decision makers and stakeholders. Although summary measures—such as quality-adjusted life years—can be used, the committee recommended that effects be described and characterized separately in a way that allows users to judge their cumulative nature.

In closing, Jackson said, "I do think that we in the health world need to be touching on these energy decisions much more profoundly. . . . I think we desperately need more research in the energy world, and we need more research that touches on both health and energy."

DISCUSSION

In opening the discussion session that followed the panel's presentations, John Balbus, National Institute of Environmental Health Sciences, noted that each of the speakers had spoken of the time that it takes to implement changes, but it is clear that there is a certain urgency in the need for these sorts of assessments. So, he asked, "How do we keep a real sustainability and health assessment from becoming the cellulosic ethanol of environmental health, which is just 5 years away and always has been and always will be? Who has the responsibility and how do we get this process started?"

Goldstein commented that there is already work being done with various sorts of health assessments, and there is a great deal of support among EPA staff for HIAs. "They just don't have a framework, a setting, which allows them to move forward as readily as they could, if some sort of framework was in front of them."

Goldman added, "I would say that what needs to happen is that people need to start performing health impact assessments, and not waiting for mandates or waiting for administrative requirements." An approach that might be taken is to leverage private-sector efforts or interest by industry in this area.

Visible movement forward on using these assessments, Goldman said, may inspire the administrative changes that need to happen. "I think that you are going to have to . . . lead by example."

An audience member commented that most of the workshop presentations had focused on sustainability, which involves protecting resources for future generations. "I worry sometimes that by focusing on a distant concept of future generations, we can overlook children today." So, she asked, are any of the tools that had been mentioned in the presentations being used to protect children? Goldman agreed that the health of children today is an important issue. She noted that many of the topics discussed, including nutrition and adequate energy supplies, apply to today's children. Goldman said that freeing children from using all their energy for work is important to protect their ability to learn and grow. Jackson explained that because every action has an impact, the focus of sustainability should be to achieve the maximum positive impact and the least negative impact of each action. He stated that children today deserve a world that is diverse and healthful, and while some things will produce negative impacts, it is important to maximize the positives for them.

Luz Claudio asked a question about making HIAs understandable to policy makers and the general public, not just specialists. Jackson commented that an HIA for a new subway was just being finished up in Los Angeles. "It is about 100 pages," he said. "It is written in absolutely the most understandable language, and it captures multiple domains of both risk and services." It explains that it is not possible to put a subway in without having negative impacts of various kinds in various areas, but that there will also be positive impacts, and it is important to think about how they balance out over time. "A well-educated lay person can read this quite comfortably," Jackson said. "It will really, I hope, help inform a big important decision."

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10

Government Perspectives on Biofuels and Human Health

The workshop's final session was devoted to government agency perspectives on biofuels and human health. The four panel members represented four different U.S. government agencies: the National Institute of Environmental Health Sciences (NIEHS), the Centers for Disease Control and Prevention (CDC), the U.S. Department of Agriculture (USDA), and the U.S. Environmental Protection Agency (EPA). The panel presentations were followed by an open discussion.

NATIONAL INSTITUTE OF ENVIRONMENTAL HEALTH SCIENCES

The first speaker was John Balbus, physician and a senior advisor to the director of the NIEHS on public health issues. He also is the leader for the NIEHS efforts on climate change and human health.

NIEHS is 1 of the 27 institutes and centers that make up the National Institutes of Health (NIH). "We are unique in many ways within the NIH," Balbus said, "not just because we are in North Carolina and everybody else is in Maryland, but also because we don't focus on one organ system or one set of diseases or one population. Environmental health is very broad, and our portfolio reflects the breadth of it, ranging from toxicological investigations at the molecular level to community epidemiology and over a large number of different kinds of health impacts."

Thus, the main contribution that the NIEHS can make to the biofuels discussion, Balbus said, is to provide basic scientific results that can be used to inform health impact assessments (HIAs) and sustainability assessments. "Our core mission is research."

The NIEHS budget is approximately $800 million, of which about 40 percent goes to funding investigator-initiated research and centers research in institutions outside of the NIEHS. Another third of the budget goes to funding the NIEHS's intramural labs, which focus on a variety of molecular toxicological questions as well as some substantial epidemiology studies.

Within those areas of research, Balbus said, the institute has a long history of air pollution research. "We have funded many of the fundamental air pollution studies that inform current risk assessment models," he said. "We continue to look at an ever-widening range of health impacts, so that is a core area which has been our strength and will, I think, continue to be an area where we will contribute."

By contrast, the NIEHS is relatively new to research on climate change impacts. During the past 3 years, it has been leading the development of a pilot funding program at NIH that aims to build a community of health researchers focused on the impacts of climate change. "One of the things that is important about our climate change impact research program," Balbus said, "is that not only does it focus on what happens from changes in weather, precipitation, and climate, but it also explicitly includes the health implications of measures taken to either mitigate climate change by reducing greenhouse gases or to adapt to climate change impacts." For example, the program examines how measures such as changes in types of fuel or changes in housing impact health.

Out of the 14 or so grants that are now being funded in the NIEHS climate change program, two are looking at the implications of climate change policies. One is examining the health implications of air conditioning use and, in particular, of increasing air conditioning use in the Midwest, while the other is looking at changes in housing insulation and housing stock and what those changes imply for the rates of heat stress and heat mortality.

Another NIEHS program that may be of interest to those assessing biofuels-related impacts is the National Toxicology Program (NTP). That program's mission, Balbus said, is to support the EPA, U.S. Food and Drug Administration, and other agencies by carrying out gold-standard toxicological investigations, developing of new methods, and other projects. A new research project there is focused on polycyclic aromatic hydrocarbons. It is important to know the properties of these cancer-causing chemicals for use in analyses of various petrochemical issues, but knowledge about them could also inform analyses of biofuels-related issues. The NTP accepts nominations for toxicologic analysis of substances from the general public as well as from federal colleagues. “This is the kind of thing that the National Toxicology Program could be taking on—looking at specific components of any aspect of biofuels, whether it is additives to enhance their performance in engines, or emissions themselves,” he said.

Finally, Balbus noted that although much of the NIEHS budget is devoted to supporting fundamental research, it also has a research translation mission. “The support of this roundtable is one of the manifestations of this,” he said. “We believe that the best science and the best decisions are made when we bring our science to forums like this to inform those who are making those decisions.”

The NIEHS also considers its research translation mission to have a global component. As part of its global environmental health program, it is supporting an “innovation collaborative” focused on sustainable development. The goal is to study the decisions that are made around the world concerning energy policy, agricultural policy, and economic development and examine how environmental health plays a role in those decisions—or sometimes does not play the role that it should. The ultimate goal is to learn how to “create the frameworks, the basic science, the indicators and metrics, and the surveillance and evaluation programs that can allow sustainable development decisions to be properly informed by environmental health science.”

CENTERS FOR DISEASE CONTROL AND PREVENTION

The next panelist was Christopher J. Portier, director of the National Center for Environmental Health (NCEH), which is part of the CDC, and the Agency for Toxic Substances and Disease Registry (ATSDR). He began by talking about the things he had learned from the workshop. Replacing petroleum-based fuels with biofuels is likely to produce a spectrum of pollutants that is less damaging, although it is not completely clear yet. Biofuels production can provide economic support to rural communities. “It potentially contributes to national security, although I have my doubts after some of our discussions yesterday.”

A variety of biofuels-related issues are likely to have implications for health, both good and bad, he continued. Biofuels effects on food and water security and on the depletion of agricultural resources all have the potential to affect health.

"I found some things confusing," Portier said. "Is it or is it not efficient to create ethanol from corn? That is a fundamental question for us. If it takes 1 unit of energy to produce 1.01 units of energy, then why are we doing this? Yet, that fundamental question has not really been brought to the forefront, and a complete answer given." This is not just a question about economics, he said; it is also a question that concerns health. If producing biofuels is not energy-efficient, "then the energy that is spent to make the biofuel itself is a pollution source that will be contributing to health concerns."

With that introduction, he described NCEH and ATSDR. It is a classic CDC center, he said, or, literally, linked center and agency. Its combined mission is to protect people and save lives by preventing harmful exposures to things in the environment. The center/agency has a number of programs that touch on the biofuels issue, he said, but biofuels are not a major focus of their programs. The center/agency does have a climate and health program, and the staff there is aware of what is going on in biofuels, but, again, biofuels is not a large focus of their efforts.

One of the efforts that has examined biofuels is the asthma control program. It has studied whether the exhaust from biofuel-powered vehicles triggers asthma to the same extent as exhaust from gasoline- and diesel-powered vehicles. "They are still looking at that issue," Portier said.

There is also an environmental public health laboratory at NCEH. One of its missions is to perform bio-monitoring on the U.S. population, looking for chemicals in blood, urine, and other bodily fluids of individuals, and trying to determine if there are any national trends in the distribution of those compounds. Some of the studies carried out by that laboratory are relevant to biofuels, Portier said. For example, the lab keeps track of aldehydes and "a dozen other things" that are relevant to biofuels. He said he did not know if there is anything in place that is looking at whether exposures to biofuels in the United States are increasing. "It is something we will look into and think about," he said.

Describing himself as a "systems person," Portier said, "When I think of environmental exposures, I think in terms of systems interacting with systems. For example, human beings don't just exist by themselves. They exist within an international network of our environment."

Human bodies also contain networks, he noted. "These networks interact within our bodies, our bodies interact with the outside world. When you tweak that complex outside environment in which we live, the consequences for health are extraordinarily complicated." Thus, Portier said, "when you think about energy policy in the United States, and its implications for health, it gets very complicated."

To illustrate that complexity, he showed a diagram of the various ways in which energy usage may affect human health (see Figure 10-1). "When I start thinking about biofuels and what the net impact might be, this picture is pretty good for playing that question," he said.

For example, the diagram indicates that a move to biofuels will lead to changes in air pollution. "We are not actually certain what they are," Portier noted. "Changes in air pollution can be detrimental or beneficial to health, depending on which way they go. I think that is an area we have to carefully examine."

Climate change is something else that could be affected by biofuels use. The effects are not just environmental, he noted. Climate change has many different types of implications for human health.

Using biofuels can also alter ecological systems, as when grasslands are turned into croplands and used for growing corn. The ecosystem effects in turn affect human health in various ways. "We have to be able to understand that, as well," Portier said.

One issue that is not often mentioned in discussions about the impacts of biofuels is an evaluation of what social systems are affected. "You go into a small community, you put a large factory into it, and you bring in a lot of outside workers, and a number of things happen to health," Portier said. "Sexually transmitted disease levels go up, the cost of housing goes up, and mental health issues go up in those communities. We have seen it over and over again. Those types of boom-and-bust situations have major impacts on human health."

Thus, when one carries out an HIA looking at, say, using biofuels at the current level versus not using them, these are the sorts of issues that must be taken into account in order to get a complete and accurate picture on how biofuels affect health.

U.S. DEPARTMENT OF AGRICULTURE

The next panelist was Daniel Cassidy from the USDA's Office of the Chief Scientist and the senior advisor for renewable energy and natural resources. He offered the USDA's perspective on biofuels.

He began by explaining the USDA's focus concerning biofuels, which is the development of regional sustainable biofuels systems. "We look at everything from developing the plant, all the way through to the

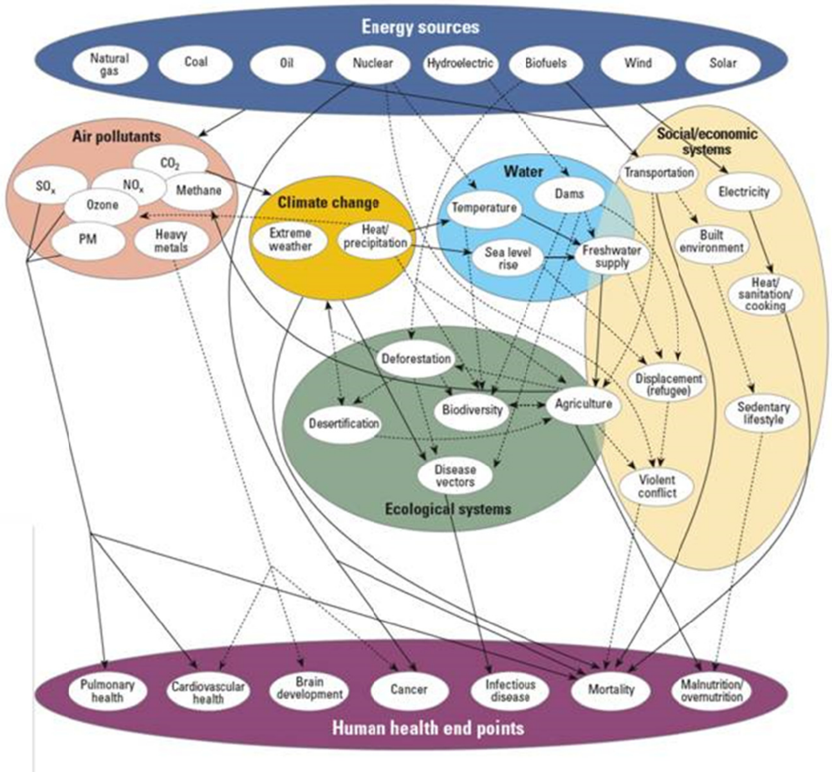

FIGURE 10-1 Direct and indirect routes by which energy sources may affect human health.
NOTE: CO_2 = carbon dioxide, NO_x = nitrogen oxide, PM = particulate matter, SO_x = sulfur oxide.
SOURCE: Gohlke et al., 2008.

distribution . . . the logistics, the storage, and the conversion technologies." The USDA's Office of the Chief Scientist also interacts with partners at the U.S. Department of Energy (DOE), Cassidy said. "We want to make sure that the feedstocks we are developing are matching the conversion technologies that they are developing." He also spends a great deal of time working on reviews for the EPA—reviews on fuel pathway and feedstock decisions, for example.

Given that focus, he said, he was not really sure why he had been invited to take part in the workshop. He had wondered, "What does that have to do with health?" But after hearing the first day's presentations, Cassidy said, he had revisited the vision statement for the Office of the

Chief Scientist. It is built on six pillars: energy and natural resources; food safety, nutrition, and food security; plant health; animal health; agricultural systems and technology; and agricultural economics in rural communities.

"Now, all of the presentations that I have seen over the past 2 days touch on every single one of those six pillars," Cassidy said. "I now understand the [way in which] USDA needs to be more active with this group."

His office's major focus is on research and development, both basic and applied, he said. And there are a number of those program that would be applicable to the issue of biofuels and health.

For example, the office conducts genetics and genomics research concerning the production of plants in which the goal is to lower the amounts of fertilizer—particularly the nitrogen and phosphorus—that make their way into waterways. There is also research aimed at developing plants that use less water so that there is less need for irrigation and more clean water left for other uses. A related program is studying water reuse as a way of using existing water supplies more efficiently. The office has joint programs with the U.S. Forest Service looking for ways to make the harvesting of wood—a potential feedstock for biofuels—safer. And the coordinated agricultural projects funded by his office have a health and safety aspect to them, mainly involving equipment safety. "After what I have heard this week," Cassidy said, "I think we need to expand that health area."

His office also has a program involved with assessment. The Natural Resources Conservation Service runs a program called the Conservation Effects Assessment Program, a multidisciplinary, multi-institution effort to examine the environmental effects over time of putting best management practices in place. For example, in trying to help farmers and ranchers do their work in a more sustainable way, are they really having an impact on the land?

Cassidy said he is seeing a large increase in multidisciplinary collaborations and consortia. "I thought at first that agriculture and engineering would never meet because we were always in separate buildings." But now, he said, it seems as though every grant application his office gets includes both an agricultural and an engineering component to it. "We need to expand that," he continued. "We need to include more social scientists, and we need to include more scientists [looking at] the medical aspects of our biofuels programs. I highly encourage that. I think those applications would rise to the top."

Finally, Cassidy mentioned the education efforts that his office funds. A memorandum of understanding was recently signed between the USDA, DOE, and the State Extension Partnership. The goal of the memorandum was to increase energy efficiency but also to increase energy literacy.

He mentioned that his 5-year-old daughter has little understanding of where food comes from. She always just thought of milk as coming from the grocery store. But he recently took her to the Smithsonian Folklife Festival, where Mississippi State University had set up a robotic cow and held demonstrations on how to milk a cow. Now his daughter understands where milk comes from.

The story offers a lesson for the importance of energy literacy as well, he said. "I think it would go a long ways if we could explain to our leaders, our community leaders, and our families where energy actually comes from and how it impacts us."

U.S. ENVIRONMENTAL PROTECTION AGENCY

The panel's final speaker was Karl Simon, director of the Transportation and Climate Division of the Office of Transportation and Air Quality at the EPA. He offered an overview of the Renewable Fuel Standard (RFS) program and related issues at the EPA.

As had been noted by other speakers, RFS was established in the Energy Policy Act of 2005 and is implemented by the EPA. The Energy Independence and Security Act of 2007 required changes to the program, producing what is known as RFS2. One of the important features of the 2007 act, Simon said, is that it required the EPA to do life-cycle assessment. According to the act, the life-cycle assessment for each renewable fuel category must look at "direct emissions and significant indirect emissions, such as significant emissions from land-use changes." That is a fairly broad statement, Simon noted, and it "has been the subject of an awful lot of thinking by the agency and . . . also a number of people that have been helping us interpret and implement that provision."

The RFS2 consists of four separate standards: biomass-based diesel (1 billion gallons by 2012 and beyond), cellulosic biofuel (16 billion gallons by 2022), advanced biofuel (total of 21 billion gallons by 2022, including cellulosic biofuel), and total renewable biofuel (36 billion gallons by 2022). It is worth noting that the numbers for cellulosic biofuel can be adjusted every year, and it has been done the past couple of years. "If we actually adjust those volumes," Simon said, "we have the opportunity—but we don't have to—to adjust both total and advanced biofuel numbers, as well."

Another point is that there is a grandfathering provision: Biofuels facilities in existence or that have commenced construction prior to December 19, 2007 (domestic and foreign), are not required to meet the greenhouse gases threshold for the general renewable fuel category. This applies primarily to corn-based ethanol, and in practice it means that there are somewhere between 14 and 17 billion gallons of corn ethanol production, depending on who is counting, that do not need to meet any of the life-cycle requirements from the act.

In putting together the final rule, the EPA carried out an impact analysis of the program, assuming the standards would be met by 2022. According to that analysis, RFS2 is projected to result in about 7 percent of the expected annual gasoline and diesel consumption in 2022 being replaced by biofuels, with a resulting decrease of $41.5 billion in oil imports. A much smaller amount of other fuels are also projected to be replaced by biofuels, including jet fuel, home heating oil, and locomotive fuel.

According to the EPA's life-cycle estimates, once the program is fully implemented in 2022, the use of renewable fuels is expected to reduce greenhouse gas emissions by 138 million metric tons—equivalent to the annual emissions of 27 million passenger vehicles. Net farm income is expected to increase by $13 billion by 2022. The effects of the use of biofuels on emissions and air quality will vary both by region and type of pollutant, with some emissions expected to increase and some expected to decrease.

Simon then described the life-cycle modeling approach that the EPA used to produce its estimates. It modeled the U.S. agricultural sector, the international agricultural sector, biofuels processing in both the domestic and international agricultural sectors, and land-use change. The processing model, for instance, examines such things as how fuel gets processed and the impacts associated with processing it. Because different sources can be used to provide energy to make the biofuels, that must be taken into account—electricity from the grid has different impacts than electricity generated from, say, captured biogas.

The life-cycle assessments were conducted in close coordination with the USDA and DOE. The EPA worked with stakeholders and experts to determine the most up-to-date data for use in the modeling, Simon said, and it conducts regular technical exchange with organizations pursuing similar analyses.

The proposed rule was subjected to public review, with a 120-day public comment period and a 2-day workshop for stakeholders to detail the methodology of the proposed life-cycle assessments.

In addition, the proposed rule went through an independent peer review which focused on four areas of the life-cycle assessment that covered new ground: land-use modeling, methods to account for the variable timing of greenhouse gas emissions, greenhouse gas emissions from foreign crop production, and how the models the EPA relied on were used together to provide overall life-cycle estimates.

Based on the life-cycle assessment, the EPA developed a list of qualifying biofuels pathways—that is, ways to produce biofuels that meet the standards. For example, ethanol produced from corn starch at a new facility powered by natural gas, biomass, or biogas and using advanced efficient technologies meets the 20 percent threshold; coal-fired facilities are not eligible. Biodiesel produced from soy, canola, wastes, or algae meets the 50 percent threshold.

The EPA is carrying out ongoing life-cycle assessments. "One of the many things we have learned as we have gone through this program," Simon said, "is never underestimate the ingenuity of the American or international business community in terms of trying to find ways to make fuels out of anything. It has been nothing short of amazing, and sometimes, you have to scratch your head at the questions that we get from people that are bringing various feedstocks in, and saying can they make a renewable fuel out of it." So, the RFS program provides a petition process through which parties can request that the EPA analyze new fuel pathways and provide a compliance determination.

Simon then briefly discussed the air quality assessment that the EPA carried out that looked at the impact of using 36 billion gallons of biofuels in 2022, relative to the RFS1 requirements, which called for 7.5 billion gallons of ethanol. In the assessment, the EPA assumed that 34 billion of the 36 billion gallons would be ethanol and also assumed that 20 billion gallons would be used in the form of E85 (85 percent ethanol, 15 percent gasoline), with the remaining 14 billion gallons used in the form of E10.

The analysis accounted for the rule's impacts on emissions from vehicles and engines, production of feedstock, and fuel production and distribution. It modeled the 48 contiguous states using the Community Multiscale Air Quality 4.7 photochemical model that the agency uses for many of its air quality assessments; the model translates the various calculated emissions into a map of ozone concentrations and other air pollution impacts. According to the model, the air pollutants that are expected to increase include hydrocarbons, nitrogen oxides, acetaldehyde, and ethanol, while decreases are predicted for carbon monoxide, benzene, and 1,3-butadiene. The air quality impacts are expected to vary widely across regions, Simon said, but in total the modeling predicts that increases in annual average ambient levels of particulate matter and ozone concentrations could cause up to 245 cases of adult premature mortality.

"That was based on the emissions impacts from the vehicles that we understood at the time as well as the assessment on both the health impacts and also where we thought the fuel mix would be," Simon said.

There is a great deal of additional work under way that may sharpen or modify some of these conclusions, Simon said. Much of it centers on emissions modeling that reflects the effects of fuel properties. One piece of it is an extensive vehicle emission test program being supported by the EPA, DOE, and the Coordinating Research Council. There has been a "really-well-done study" that has provided a significant amount of high-quality fuel-effects data for statistical modeling of gaseous and particulate matter emissions. These data will be very helpful in updating the understanding of the potential impacts of ethanol and different blends on motor vehicle emissions, he said, and the results are being analyzed and incorporated into the EPA's motor vehicle emissions model.

The EPA is also carrying out what Simon referred to as an "anti-backsliding study." The purpose is to examine the impact on air quality of the biofuels required by the RFS and to make sure that the biofuels do not make air quality worse. The agency is in the process of carrying out that anti-backsliding study, and it is also updating earlier analyses with the use of new tools. He said he did not yet know when the updated analyses would be released, but he said he believes it will help "expand the state of understanding . . . of the impacts on renewable fuels in this country."

DISCUSSION

A brief discussion followed the panelists' presentations. Jamal Hisham Hashim, United Nations University International Institute for Global Health, asked Simon about life-cycle assessments for palm oil. "Has that been done, or is it still in the process? If Malaysia as a producer of biodiesel would like to have that assessment done, how would we go about achieving that?"

Simon responded that the EPA has been working on a palm oil analysis and that, indeed, it had issued a Notice of Data Assessment in 2012 concerning its preliminary life-cycle assessment for palm oil. The analysis included numbers for both regular biodiesel and renewable diesel, and both fell below the 20 percent threshold, he said.

Since the analysis was put out for public comment, the EPA has received "60,000 comments and counting," Simon said. "We have been working closely with the Indonesian and Malaysian governments as well as stakeholders there to both understand the data and also to see what else is out there. We want to make sure we have the best information before us." Thus, nothing needs to be done to get such an assessment carried out, he said.

There are three particular issues concerning palm oil that the EPA is trying to sort through, Simon said. "One is what is the appropriate number to use for the impact of palm oil production on peat oil and peat emissions? Two would be methane capture—what is the appropriate number on that? Three, there is a significant amount of uncertainty on what the land-use implications would be for providing that pathway for palm oil."

As a follow-up question, Hisham Hashim asked if the life-cycle assessment was based on data from Malaysia and Indonesia. Simon answered that because 90 percent of the world's production of palm oil comes from those two areas, the appropriate way to model palm oil was to use data from those areas. Similarly, the life-cycle assessment for corn-based ethanol used the United States as the primary market, and for the life-cycle assessment for sugarcane-based ethanol, it was Brazil.

Al McGartland, National Center for Environmental Economics at the EPA, asked Cassidy whether any work had been done on the effects of replacing some of the coal in coal-fired boilers with woody biomass and what might be the life-cycle implications of such a switch. Cassidy replied that the USDA does quite a bit of research on using wood in coal-fired boilers, mainly through the U.S. Forest Service. The EPA has also collaborated on the research. Much of the work is focused on such questions as, How big should the wood chips be and how should the coal be pulverized so that one gets the best mix? What are the resulting emissions? What type of scrubber technology can be used to lower those emissions? There is a large body of research going on there, Cassidy said.

McGartland also asked whether the USDA funds research on converting stover—the leftover corn stalks and leaves—into cellulosic ethanol or other uses. Cassidy replied that yes, corn stover is an acceptable feedstock that the USDA is studying. The department's researchers are very interested in cellulosic biofuels in general, and they are looking not only at corn stover, but also at oilseeds, wood, perennial grasses, and even algae, although most of the research on algae is being carried out by DOE.

Luz Claudio, Mount Sinai School of Medicine, asked if the emphasis on biofuels as an alternative source of energy might be taking attention away from other alternative sources, such as solar energy or wind power. Cassidy responded that he wouldn't comment on the policy itself, but he said that the USDA rural development mission area still does support a lot of wind, solar, and biomass research. These other alternative energy sources are "not out of our portfolio," he said.

Simon said he agreed with Cassidy that the EPA's interest in biofuels was not taking away any of its focus on other alternative energy sources.

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Closing Session

Frank Loy, roundtable chair, closed the workshop with some personal observations and set forth what he saw as the key points from the 2 days of the workshop. The first point to note is the huge impact that increased use of biofuels will have on food production. This will likely be the major focus of our society, Loy said.

Second, at the moment it takes a lot of biofuel to make a relatively little amount of energy. Both fossil fuels and biofuels emit greenhouse gas (although not equally), and the potential greenhouse gas savings from biofuels arises largely from the fact that the growing plants absorb carbon dioxide.

It seems set in stone that biofuels will make up an increasing percentage of transportation fuels. By 2050, it is expected that 20 percent of all transport fuels will be biofuels. Today, 40 percent of the corn production in the United States is used for biofuels, which obviously has a major impact both on corn producers and on consumers.

Given that the reduction in greenhouse gas emissions from using biofuels is not great, it might seem that there would be a reversal of the trend toward more biofuels for transportation fuel, but Loy said he did not think that was going to happen.

There are two main drivers behind the push for biofuels. One is the urgency of climate change. The second one is political. "Once you have an established industry, there is great pressure not to meddle with it and not to reduce it, and not to put any handicaps in its way," Loy said. "I think there is going to be biofuels production used for transport fuels for a long time to come."

Main concerns raised during the workshop were the health issues related to biofuels. The use of biofuels raises some health issues, but they do not appear to be major. The more important health issues, Loy said, arise from their production, specifically, the increased use of pesticides and herbicides and fertilizers in an effort to boost production. Those chemicals make their way into the country's streams and rivers, with potentially serious consequences for water quality. "These are health issues of a rather large magnitude," he said.

Increased use of biofuels also has some adverse health implications for the quantity of water, although this is not as immediate a health issue as the effect on quality of the water. Biofuels use also has consequences for food prices, although these are probably more serious in developing countries than in the United States. As food gets more expensive, the tendency to choose foods that are cheap, rather than healthy, becomes very real, Loy said. And if nations are unable to deliver food at reasonable prices the stability of those nations is threatened. Ultimately, we face a very real possibility of a more destabilized world.

"The net result of all of this," Loy said, "is that the essentials of life—food and water—are going to be under increased pressure from the equally intense pressure to address climate change. As health professionals, this group here has a substantial ability and responsibility to contribute thoughtfully to that discussion."

Finally, Loy spoke of the urgency of health professionals addressing climate change. Referring to Lester Brown's call for an 80 percent reduction in greenhouse gas emissions by 2020, Loy said that clearly is not going to happen. Indeed, we will be lucky to meet the current, much more modest, 2020 goals by 2020.

There is not much pressure on our political leaders to address climate change aggressively, Loy said. "What we need to do in the United States, I think, is to broaden the number of Americans who care about that, who are somewhat knowledgeable about that, and who are not either agnostic or hostile to dealing with it." A key element in our society that can help achieve such a change is the health community. And one way to do that, he said, is to get more health professionals involved.

"The reason the health community should get actively involved is not only because it is the right thing to do, but because Americans trust health professionals," Loy said. They may not necessarily trust professors of public health, he noted, but they trust doctors and nurses and other health professionals with whom they come in contact.

"Our medical schools and our public health schools, it seems to me, are important places where the urgency of dealing with climate change, both in a personal and a political fashion, ought to be addressed," Loy said.

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AGENDA

January 24–25, 2013
Auditorium
National Academy of Sciences Building
2100 Constitution Avenue, NW
Washington, DC

January 24, 2013

8:30 a.m. **Welcome**

Frank Loy, LL.B.
Roundtable Chair

Session 1: Overview of Biofuels

Moderator: Lynn Goldman, M.D., M.P.H., Roundtable Vice-Chair, Dean, George Washington University School of Public Health

8:45 a.m. **Historical Overview and Policy Drivers of Biofuels as a Source of Energy**

Timothy D. Searchinger, J.D. (via video link)
Associate Research Scholar and Lecturer in Public and International Affairs
Woodrow Wilson School
Princeton University

9:15 a.m. **Biofuels: Context and Outlook**

Howard Gruenspecht, Ph.D.
Deputy Administrator, U.S. Energy Information Administration

9:40 a.m. **Biofuels: Past, Present, and Future?**

Roger Prince, Ph.D.
Senior Research Associate, ExxonMobil

10:00 a.m. **Discussion**

10:30 a.m. **Break**

Session 2: Emerging Issues and Biofuels

Moderator: Dennis J. Devlin, Ph.D., Senior Environmental Health Advisor, ExxonMobil Corporation

10:50 a.m. **The Palm Oil Example**

Jamal Hisham Hashim, Ph.D., MCIEH
Professor of Environmental Health and Research Fellow
United Nations University-International Institute for Global Health

11:15 a.m. **Discussion**

11:35 a.m. **Lunch**

Session 3: Occupational Health and Biofuels Production

Moderator: Henry Anderson, M.D., State Health Officer, Wisconsin Division of Public Health

12:35 p.m. **Occupational Risks**

Stephen Reynolds, Ph.D.
Director of the High Plains Intermountain Center for Agricultural Health and Safety
Colorado State University

1:00 p.m. **Discussion**

Session 4: Biofuels Impacts on Air, Atmosphere, and Health

Moderator: Bernard D. Goldstein, M.D., Professor Emeritus, Department of Environmental and Occupational Health, Graduate School of Public Health, University of Pittsburgh

1:25 p.m. **Regional Impacts of Biofuels on Health and Climate Change**

Elliott Campbell (via videolink)
University of California, Merced

1:45 p.m. **Biodistillate Fuels and Emissions in the United States**

S. Kent Hoekman, Ph.D.
Desert Research Institute

2:10 p.m. **Discussion**

2:40 p.m.	**Break**

Session 5: Water Use, Water Pollution, and Biofuels

Moderator: James Bartram, Ph.D., Don and Jennifer Holzworth Distinguished Professor, Director of the Water Institute, University of North Carolina at Chapel Hill

3:00 p.m.	**Water Implications of Biofuels Production in the United States** Jerald L. Schnoor, Ph.D. Allen S. Henry Chair in Engineering and Professor of Civil and Environmental Engineering University of Iowa
3:20 p.m.	**Water Quality: Corn vs. Switchgrass** Catherine Kling, Ph.D. Professor of Economics Iowa State University
3:40 p.m.	**Discussion**

Session 6: Implications of Biofuels for Land Use and Health

Moderator: Jay Lemery, M.D., Assistant Professor of Emergency Medicine, University of Colorado

4:00 p.m.	**Life-Cycle Impacts on Land and Air** Jason Hill, Ph.D. Assistant Professor in Bioproducts and Biosystems Engineering University of Minnesota
4:20 p.m.	**Forest Management and Forest-Based Bioenergy Initiatives** Daniel Cassidy, Ph.D. Senior Advisor, Office of Chief Scientist U.S. Department of Agriculture
4:40 p.m.	**Discussion**
5:10 p.m.	**Adjourn for the Day**

January 25, 2013

8:30 a.m. **Welcome Back**

Lynn Goldman, Roundtable Vice-Chair

Session 7: Societal Impacts and Ethics of Biofuels

Moderator: Anne Sweeney, Ph.D., Professor, Department of Epidemiology and Biostatistics, School of Rural Public Health, Texas A&M University

8:40 a.m. **Ethics of Biofuels**

Alena Buyx, Dr.Med. (via video link)
Head of Emmy Noether Group in Bioethics, University of Muenster
Senior Research Associate, University College London

9:05 a.m. **Socioeconomic Impacts of Biofuels in Rural Communities**

Theresa Selfa, Ph.D.
Associate Professor, Environmental Studies
SUNY College of Environmental Science and Forestry

9:25 a.m. **Discussion**

9:50 a.m. **Break**

Session 8: Impacts of Biofuels Policies on Food Security Issues

Moderator: Frank Loy, Roundtable Chair

10:15 a.m. **Food Adequacy and Access**

Frank Loy, LL.B.

10:25 a.m. **Food Insecurity in a Biofuels World**

Lester Brown, M.P.H.
President
Earth Policy Institute

10:50 a.m. **Discussion**

11:10 a.m. **Pressure Points of Domestic Food and Biofuels Policies**

Erik D. Olson, J.D.
Director of Food Programs
Pew Health Group, Pew Charitable Trusts

11:25 a.m.	**Discussion**
11:40 a.m.	**Lunch**

Session 9: Environmental Health Policies and Opportunities

Moderator: John M. Balbus, M.D., M.P.H., Senior Advisor for Public Health, National Institute of Environmental Health Sciences

12:50 p.m.	**Evaluating Health Impacts of Biofuels Feedstocks with Current Risk Assessments**
	Lynn Goldman, Roundtable Vice-Chair
	Sustainability Assessment
	Bernard D. Goldstein, Roundtable Member
	Health Impact Assessment
	Richard J. Jackson, Roundtable Member
1:35 p.m.	**Discussion**
2:00 p.m.	**Break**

Session 10: Government Perspectives on Biofuels and Human Health

Moderator: Lynn Goldman, Roundtable Vice-Chair

2:20 p.m.	**U.S. Department of Agriculture**
	Daniel Cassidy, Ph.D.
	U.S. Environmental Protection Agency
	Karl Simon, J.D.
	National Institute of Environmental Health Sciences
	John M. Balbus, M.D., M.P.H.
	Centers for Disease Control and Prevention
	Christopher J. Portier, Ph.D.
3:20 p.m.	**Discussion**
3:50 p.m.	**Summation**
	Frank Loy, Roundtable Chair
4:00 p.m.	**ADJOURN**

B

Speaker Biosketches

Lester Brown, M.P.H. The *Washington Post* called Mr. Brown "one of the world's most influential thinkers." The *Telegraph of Calcutta* refers to him as "the guru of the environmental movement." In 1986, the Library of Congress requested his personal papers, noting that his writings "have already strongly affected thinking about problems of world population and resources."

Mr. Brown started his career as a farmer, growing tomatoes in southern New Jersey with his younger brother during high school and college. Shortly after earning a degree in agricultural science from Rutgers University in 1955, he spent 6 months living in rural India, where he became intimately familiar with the food/population issue. In 1959 Mr. Brown joined the U.S. Department of Agriculture's Foreign Agricultural Service as an international analyst.

Mr. Brown earned a master's degree in agricultural economics from the University of Maryland and a master's degree in public administration from Harvard University. In 1964, he became an adviser to Secretary of Agriculture Orville Freeman on foreign agricultural policy. In 1966, the secretary appointed him administrator of the department's International Agricultural Development Service. In early 1969, he left government to help establish the Overseas Development Council.

In 1974, with support of the Rockefeller Brothers Fund, Mr. Brown founded the Worldwatch Institute, the first research institute devoted to the analysis of global environmental issues. While there, he launched the *Worldwatch Papers*, the annual *State of the World* reports, *World Watch* magazine, a second annual report titled *Vital Signs: The Trends That Are Shaping Our Future*, and the Environmental Alert book series.

Mr. Brown has authored or co-authored 50 books. One of the world's most widely published authors, his books have appeared in some 40 languages. Among his earlier books are *Man, Land and Food*, *World Without Borders*, and *Building a Sustainable Society*. His 1995 book

Who Will Feed China? challenged the official view of China's food prospect, spawning hundreds of conferences and seminars.

In May 2001, he founded the Earth Policy Institute to provide a vision and a roadmap for achieving an environmentally sustainable economy. In November 2001, he published *Eco-Economy: Building an Economy for the Earth*, which was hailed by E. O. Wilson as "an instant classic." His most recent book is *World on the Edge*, which the *Financial Times* called "a provocative primer on some of the key global issues that businesses will face in the coming decades."

Mr. Brown is the recipient of many prizes and awards, including 25 honorary degrees, a MacArthur Fellowship, the 1987 United Nations Environment Prize, the 1989 World Wide Fund for Nature Gold Medal, and the 1994 Blue Planet Prize for his "exceptional contributions to solving global environmental problems." In 2012, he was inducted into the Earth Hall of Fame.

Alena Buyx, Dr.Med., is a bioethicist with a background in medicine, philosophy, and sociology. After her studies in Münster, London, and York, she was assistant professor of medical ethics at the Institute of Ethics, History and Philosophy of Medicine, Münster. Following that, she spent a year as visiting scholar in the Harvard Program in Ethics and Health, where she mainly worked on issues of justice in health care and public health. From 2009 until early 2012, she was assistant director of the Nuffield Council on Bioethics, London, furthering her research in bioethics and adding a new focus on developing well-argued recommendations for policy makers. She remains an advisor to the Nuffield Council and is also a senior research associate at the School of Public Policy, University College, London.

Dr. Buyx has worked across the whole field of bioethics, with particular focus on justice questions in applied contexts such as resource allocation, transplantation, personalized and commercialized medicine, and public health. Other main areas of work include neuroethics, ethics of renewable energies and climate change, philosophy of medicine and theory of medical professionalism, and medical ethics teaching. During her tenure at the Nuffield Council, she was lead or co-author of reports on the ethics of biofuels, solidarity in bioethics, ethics of novel neurotechnologies, mitochondrial donation, emerging biotechnologies, donation in medicine and research, personalized medicine, and dementia. She has been published widely in high-ranking journals, including *Science*, *BMJ*, *Bioethics*, the *Journal of Medical Ethics*, and many others, and lectures nationally and internationally in her areas of expertise. She continues to work with the Nuffield Council on a number of topics, including the solidarity in bioethics project.

Elliott Campbell, Ph.D., is an assistant professor at the School of Engineering and Energy Research Institute at the University of California, Merced. He received his master's degree in environmental engineering from Stanford University and his Ph.D. from the University of Iowa. His primary research efforts focus on sustainable bioenergy assessment, chemical transport modeling, and carbonyl sulfide/carbon cycle interactions.

Dr. Campbell is a consultant for the United Nations Environmental Programme, the U.S. Environmental Protection Agency, the U.S. Government Accountability Office, the California Council on Science and Technology, and the Chilean Environmental Protection Agency. He holds a grant from the National Science Foundation.

Daniel Cassidy, Ph.D., is senior advisor for renewable energy and natural resources at the U.S. Department of Agriculture's (USDA's) Office of the Chief Scientist. As senior advisor, he facilitates the coordination of the department's research, education, and extension programs that promote sustainable bioenergy, biofuels, and biobased product systems. Prior to this role, he spent 6 years with the National Institute of Food and Agriculture, most recently as the national program leader for forest-based bioenergy, providing leadership for the Agriculture and Food Research Initiative's Sustainable Bioenergy Challenge, the Investing in America's Scientific Corps Education program, and the Biomass Research and Development Initiative. Dr. Cassidy has also served as the chair for the Federal Woody Biomass Utilization Working Group and as the deputy team leader for the U.S. Forest Service's Woody Biomass Utilization Team.

Dr. Cassidy is a silviculturalist and dendrochronologist by training who received his Ph.D. in natural resources from the University of Tennessee, where he studied the historical development and distribution of shortleaf pine in the southeastern United States. Prior to joining the USDA, Dr. Cassidy was the director of the Southern Forest Research Partnership's Wood-to-Energy Initiative, where he worked to coordinate regional research and education projects that promoted a bio-based economy. He has held a postdoctorate faculty position at the University of Georgia and worked for International Paper as a private forest landowner advisor.

Dr. Cassidy received a B.S. in forest management from Mississippi State University with a focus on economics and an M.S. in forest policy from the University of Tennessee.

Howard Gruenspecht, Ph.D., was named deputy administrator of the U.S. Energy Information Administration (EIA) in March 2003. As the EIA deputy administrator, Dr. Gruenspecht assists the administrator in collecting, analyzing, and disseminating independent and impartial energy information to promote sound policy making, efficient markets, and public understanding of energy and its interaction with the economy and the environment. EIA provides a wide range of information and data products covering energy production, stocks, demand, imports, exports, and prices. EIA also prepares analyses and special reports on topics of current interest. Dr. Gruenspecht works closely with the administrator to provide overall leadership, planning, and policy direction for the agency, and, when necessary, he serves as acting administrator.

During the past 30 years, Dr. Gruenspecht has worked extensively on electricity policy issues, including restructuring and reliability, regulations affecting motor fuels and vehicles, energy-related environmental issues, and economy-wide energy modeling. Before joining EIA, he was a resident scholar at Resources for the Future. From 1993 to 2000, Dr. Gruenspecht served as director of Economic, Electricity and Natural Gas Analysis in the Department of Energy's (DOE's) Office of Policy, having originally come to DOE in 1991 as deputy assistant secretary for economic and environmental policy. His accomplishments as a career senior executive at DOE have been recognized with three Presidential Rank Awards.

Prior to his service at DOE, Dr. Gruenspecht was senior staff economist at the Council of Economic Advisers (1989–1991), with primary responsibilities in the areas of environment, energy, regulation, and international trade. His other professional experience includes service as a faculty member at the Graduate School of Industrial Administration, Carnegie Mellon University (1981–1988), economic adviser to the chairman of the U.S. International Trade Commission (1988–1989), and assistant director, economics and business, on the White House Domestic Policy Staff (1978–1979).

Dr. Gruenspecht received his B.A. from McGill University in 1975 and his Ph.D. in economics from Yale University in 1982.

Jamal Hisham Hashim, Ph.D., is currently a research fellow at the United Nations University (UNU) International Institute for Global Health. He is also a professor of environmental health at the National University of Malaysia (UKM). He has a Ph.D. in environmental health sciences from the School of Public Health, University of Michigan.

He has been teaching and conducting research and consultancy in environmental and occupational health at UKM and UNU for the past 29 years. His research interests are mainly on the health effects of heavy metals, pesticides, solvents, air pollution, and, recently, climate change. He has been the principal investigator of nine research projects and co-investigator of another six projects, and has more than 220 publications and presentations to date.

He has been engaged as an environmental health consultant in more than 50 local and overseas projects, primarily in the area of environmental health impact and risk assessment. He has also been consulted by the World Health Organization, the Risk Science Institute in the United States, and the governments of Malaysia, Cambodia, Indonesia, and Saudi Arabia on various environmental health issues. He is a registered environmental impact assessment consultant with the Department of Environment, Malaysia, and a member of the Chartered Institute of Environmental Health in the United Kingdom.

Jason Hill, Ph.D., is an assistant professor in bioproducts and biosystems engineering. His research interests include the technological, environmental, economic, and social aspects of sustainable bioenergy production from current and next-generation feedstocks. Dr. Hill's work on the life-cycle impacts of transportation biofuels has been published in the journals *Science* and the *Proceedings of the National Academy of Sciences of the United States of America.*

Dr. Hill has testified before U.S. Senate committees on the use of diverse prairie biomass in biofuels production, as well as the impacts of land-use change on net greenhouse gas emissions from ethanol and biodiesel. His current research focuses on the effects the global biofuels industry will have on climate change, land use, biodiversity, and human health.

Dr. Hill received his bachelor's degree in biology from Harvard College and his doctorate in plant biological sciences from the University of Minnesota.

S. Kent Hoekman, Ph.D., is a research professor within the Division of Atmospheric Sciences at the Desert Research Institute (DRI). DRI is a statewide division of the Nevada System of Higher Education that pursues basic and applied environmental research on local, national, and international scales. His professional interests include environmental impacts of energy production, distribution, and use; development of renewable and sustainable energy systems; conversion of biomass to biofuels; air quality impacts of vehicle emissions; and impacts of advanced-technology fuels and vehicles on emissions and energy use. He is also interested in the interface between politics and environmental science, particularly in the areas of energy policy, renewable fuels, greenhouse gases, and climate change.

In addition to his personal professional activities, Dr. Hoekman has provided leadership for DRI in the identification, protection, and licensing of intellectual property developed at the institute. Dr. Hoekman was instrumental in establishing a joint Technology Transfer Office (TTO) between DRI and the University of Nevada, Reno. He currently serves as DRI's liaison to the TTO, and oversees the activities of this office on behalf of DRI.

Dr. Hoekman has also served DRI by coordinating and promoting the institute's research and development portfolio in the field of renewable energy. He has led the effort to establish a Renewable Energy Center (REC) at DRI, and continues to provide leadership in this area. For further information about the DRI-REC, please refer to its website: http://www.dri.edu/rec.

Catherine Kling, Ph.D., professor of economics at Iowa State University, serves as the division head of the Center for Agricultrual and Rural Development's (CARD's) Resource and Environmental Policy Division. She received a bachelor's degree in business and economics from the University of Iowa and a doctorate in economics from the University of Maryland. In her work at CARD, Dr. Kling is undertaking research to examine how agricultural practices affect water quality, wildlife, soil carbon content, and greenhouse gases.

Erik D. Olson, J.D., is the director of food programs at the Pew Charitable Trusts. He was deputy staff director and general counsel of the Senate Committee on Environment and Public Works until November 2008 and has 25 years of experience in environmental policy and consumer advocacy. Mr. Olson is responsible for consumer product safety, including efforts to improve food safety, overhaul toxic chemical regulatory programs to better protect children and other vulnerable people, and establish safeguards for emerging risks in consumer products.

During his Senate tenure, Mr. Olson worked on environmental issues and health threats from toxic chemicals, playing a key role in major environmental legislation and hearings on global warming, toxic chemicals, children's environmental health, clean air, drinking water, clean water, and environmental justice, among other issues. He also helped to negotiate the lead and phthalates provisions enacted in the Consumer Product Safety Improvement Act of 2008 and the green buildings and green schools provisions of the Energy Independent Security Act of 2007.

Prior to his Senate work, Mr. Olson worked for 15 years at the Natural Resources Defense Council (NRDC), where he held various positions, including advocacy center director, public health program director, and senior attorney. At NRDC, he worked extensively on toxic chemicals, pesticides, drinking water, hazardous waste, and many other environmental and health issues. He previously served as counsel for the National Wildlife Federation's environmental quality program for 5 years and as an attorney for the U.S. Environmental Protection Agency's Office of General Counsel, working on hazardous waste and water issues.

Mr. Olson graduated from the University of Virginia School of Law, where he was inducted into the Order of the Coif legal honor society and served as an editor of the environmental law journal, and is a graduate of Columbia College of Columbia University, where he created an independent major in environmental biology and policy.

Roger Prince, Ph.D., is a senior research associate with ExxonMobil Biomedical Sciences, Inc., in Annandale, New Jersey. He has worked on various aspects of environmental and bioprocessing microbiology during his career with ExxonMobil, and is currently assessing various biofuel options for transportation fuels, especially algal biofuels in ExxonMobil's alliance with Synthetic Genomics, Inc. He was Exxon's lead scientist in the monitoring of the successful bioremediation of the Exxon Valdez spill, and has also done field work on experimental spills in the Arctic. He has served on a number of government and international workshops and panels, including the National Research Council's Panel on Marine Biotechnology.

Prior to joining ExxonMobil, Dr. Prince was a visiting faculty member at the University of California, Berkeley, and on the faculty of the University of Pennsylvania. He serves on the editorial board of the *Bioremediation Journal* and the editorial advisory board of *Environmental Science and Technology*. He has published more than 300 papers and chapters in the refereed literature. Dr. Prince was awarded Stanford's Farrel W. Lytle Prize for Contributions to Synchrotron Spectroscopy in 2000 and the American Chemical Society North Jersey Section Lifetime Achievement Award in 2007.

Stephen Reynolds, Ph.D., focuses on development of exposure assessment methods for organic and biological aerosols and the application of these methods for epidemiological investigations of respiratory disease. In particular, his current research focuses on comparative assay and chemical approaches to evaluating gram-negative bacterial endotoxins and their role, along with genetic risk factors, in lung disease among agricultural workers. Related research into environmental causes of asthma and other respiratory disease problems among children and adults in nonindustrial environments also focuses on effectiveness of interventions to prevent disease. Dr. Reynolds' other initiatives include research concerning exposure assessment methods for pesticides and development of international education programs for the occupational hygiene profession, primarily in the former Soviet Union countries.

Dr. Reynolds is director of the High Plains Intermountain Center for Agriculture Health and Safety under the Centers for Disease Control and Prevention's National Institute for Occupational Safety and Health. In that role, he is involved in rural and agricultural health research, education, outreach, and policy on a regional and national level.

Jerald L. Schnoor, Ph.D., professor at the University of Iowa, co-founded the Center for Global and Regional Environmental Research (CGRER) in 1990. As the organization's co-director, Dr. Schnoor allocates seed grants, organizes symposiums, and conducts lectures nationwide about environmental change. Along with co-director Greg Carmichael, he makes yearly budgeting, managerial, and promotional decisions for the center.

Dr. Schnoor is a professor in the departments of civil and environmental engineering and occupational and environmental health. He joined the university's College of Engineering in 1977, and now holds the esteemed Allen S. Henry Chair in Engineering. His research interests include carbon sequestration, water quality modeling, phyto-remediation, and the causes of global warming.

In 2007, Iowa Governor Chet Culver hired Dr. Schnoor to head the Iowa Climate Change Advisory Council (ICCAC). A 27-member panel of academics and professionals, the council guides Governor Culver's effort to reduce Iowa's greenhouse gas emissions. In 2008, the ICCAC issued its final report, a 470-page document to direct the governor's environmental agenda.

Also in 2007, Schnoor became editor-in-chief of *Environmental Science & Technology* (ES&T). Launched in 1967 by the American Chemical Society, ES&T is a bimonthly magazine that publishes both peer-reviewed scholarly research and journalistic feature articles. The publication ranks among the leading international environmental journals, according to recent impact factor and citation figures.

Among his prior achievements, Dr. Schnoor testified before the U.S. Congress to support the Clean Air Act Amendment of 1990 at the request of the U.S. Environmental Protection Agency's (EPA's) head administrator. He has also served on several commissions for the EPA, including the Board of Scientific Counselors and the Scientific Advisory Board.

Dr. Schnoor earned a Ph.D. in civil engineering in 1975 and an M.S. in environmental health engineering in 1974 from the University of Texas. In 1972 he received a B.S. in chemical engineering from Iowa State University.

He represents the University of Iowa and CGRER at numerous speaking engagements every month. Schnoor has addressed politicians and elementary school students alike about green energy, climate change, and reducing atmospheric carbon emissions. Along with his scholarly pursuits, Dr. Schnoor and his CGRER graduate assistants have planted more than 250,000 trees to help sequester carbon from the environment.

Timothy D. Searchinger, J.D., is a research scholar and lecturer in public and international affairs at Princeton University's Woodrow Wilson School. He is also a Transatlantic Fellow of the German Marshall Fund of the United States. Trained as a lawyer, Dr. Searchinger now works primarily on interdisciplinary environmental issues related to agriculture.

For 17 years, Searchinger worked at the Environmental Defense Fund, where he co-founded the Center for Conservation Incentives, and supervised work on agricultural incentive and wetland protection programs. He has also been a deputy general counsel to Governor Robert

P. Casey of Pennsylvania and a law clerk to Judge Edward R. Becker of the United States Court of Appeals for the Third Circuit. He is a graduate, summa cum laude, of Amherst College and holds a J.D. from Yale Law School, where he was senior editor of the *Yale Law Journal*. Dr. Searchinger first proposed the Conservation Reserve Enhancement Program to the U.S. Department of Agriculture and worked closely with state officials to develop programs that have now restored 1 million acres of riparian buffers and wetlands to protect priority rivers and estuaries in Illinois, Maryland, and Minnesota, among other states. Searchinger received a National Wetlands Protection Award from the U.S. Environmental Protection Agency in 1992 for a technical book about the functions of seasonal wetlands of which he was principal author. His most recent writings focus on the greenhouse gas emissions from biofuels and agricultural conservation strategies to clean up nutrient runoff.

Theresa Selfa, Ph.D., is an associate professor in the Department of Environmental Studies at the State University of New York College of Environmental Science and Forestry. Her research interests include the social ecological impacts of bioenergy development in the United States and Latin America, sustainable agriculture and food systems, environmental politics, and interdisciplinary water management. She is an active member of the Rural Sociological Society. Dr. Selfa received a Ph.D. in development sociology from Cornell University.

Karl Simon, J.D., is the recently named director of the Transportation and Climate Division of the Office of Transportation and Air Quality at the U.S. Environmental Protection Agency (EPA). His portfolio includes work with renewable fuels, voluntary programs like Smartway, and modeling and forecasting of mobile source emissions trends. He previously served as director of the Compliance and Innovative Strategies Division, where he was responsible for managing the certification, registration, and compliance activities associated with all engines and fuels sold in the United States. Some of the major activities he has been extensively involved in are the 2004 Clean Nonroad Engine and Fuel Program, the National Low Emission Vehicle program, and the Renewable Fuels Programs. He also works on international mobile source harmonization issues. Previously, he was the assistant director for the office, worked in the mobile source recall branch at the EPA, and worked in the submarine construction and design division at Newport News Ship Building and Dry Dock Company.

Dr. Simon holds a B.S. degree in aerospace engineering from the University of Notre Dame, a J.D. from the George Mason University School of Law, and a master's in environmental law from George Washington University.