Plants at the Pump

Biofuels, Climate Change, and Sustainability

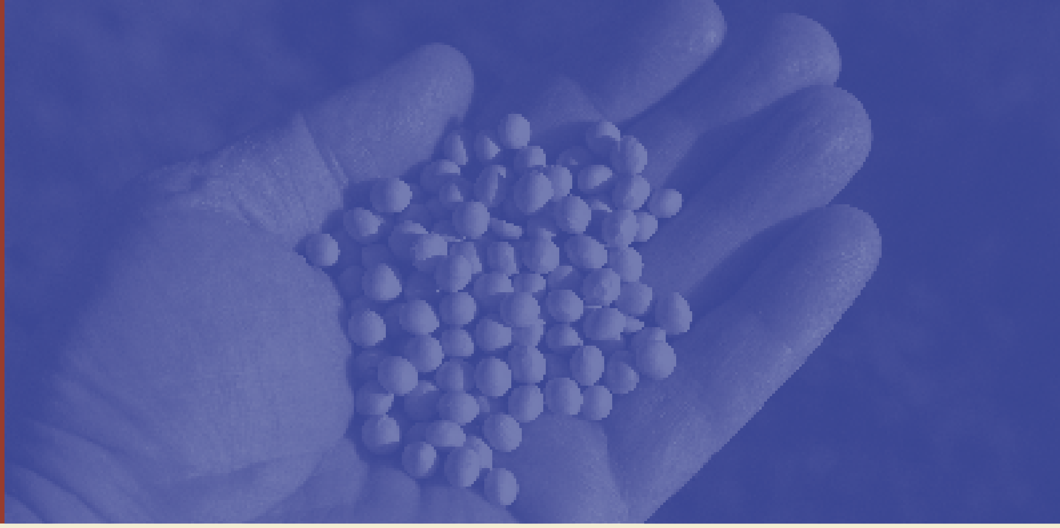
Britt Childs

Rob Bradley

WORLD RESOURCES INSTITUTE

In conjunction with...

Goldman Sachs Center for Environmental Markets



Deploying Climate-Friendly Technologies: A Wedges Approach to Clean Investment

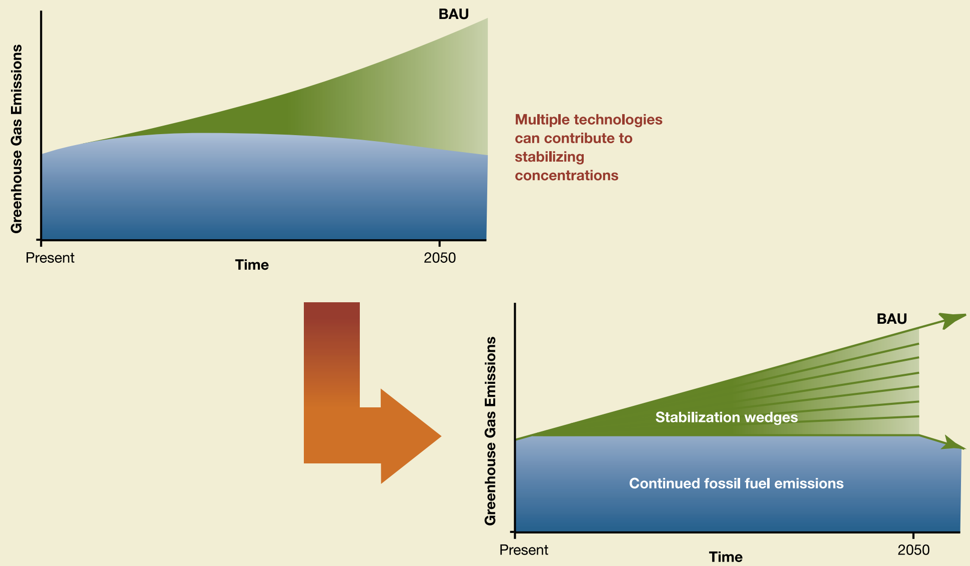
There is no shortage of options and suggestions for how to address climate change. The more difficult task is determining which solutions, or mix of solutions, will reduce greenhouse gas emissions on the scale of what is needed to avoid disastrous climate change impacts.

In the face of rapidly developing economies, population growth, and rising energy demand, it is clear that technology absolutely must be part of the solution. We will need significantly cleaner energy sources than the ones used today. And we need much faster market penetration than has been the historic norm.

In a 2004 *Science* magazine article, Princeton professors Rob Socolow and Stephen Pacala introduced the wedge approach to frame this debate. The idea is elegant and simple. To stabilize emissions in the next 50 years, the world must reduce emissions by about 7 gigatons of carbon (not carbon dioxide) compared to “business as usual” scenarios. So Socolow and Pacala identify 15 stabilization wedges that, if deployed at a significant global scale, could conceivably reduce emissions by 1 gigaton each. At 1 gigaton apiece, each technology wedge still represents a huge investment, but they are nonetheless conceivable.

Seven gigatons of reductions are needed to achieve stabilization, so 7 of 15 wedges would, in theory, reach that goal. If deeper reductions become necessary, additional wedges could be added to the mix.

The Wedges Concept



Source: Pacala and Socolow, Science, 2004. Note: Each “wedge” in this figure represents 1 gigaton of carbon per year; seven wedges are needed if emissions are to be brought back to current levels by 2050 globally – and because of the likely increase in demand, additional efforts would be needed post-2050 to stabilize concentrations. Pacala and Socolow identify options for 15 wedges in their analysis.

The challenge for policymakers is to decide which wedges are preferable, and how to redirect capital toward the deployment of preferred technologies. WRI’s climate policy and capital markets projects have teamed up to analyze the best ways to accelerate the global adoption of technologies in the wedge model through government policies, corporate action, and financial investment. In other words, turn the wedge approach into action as quickly as possible.

Plants at the Pump

Biofuels, Climate Change, and Sustainability

Contents

Executive Summary	**2**
Introduction	**7**
A biofuels climate wedge	8
Evaluating biofuels	9
This report	9
Technology	**10**
Energy balance	11
Carbon balance	12
Logistics	13
Economics	14
The fuels in detail	14
Ethanol	14
Biodiesel	18
Next-generation fuels	19
The challenge of getting to scale	23
Policy	**25**
What is the purpose of biofuels policy?	25
Improving energy security by reducing oil dependence	25
Improving balance of trade	25
Raising rural incomes	26
Reducing greenhouse gas emissions	26
Biofuels policy today	27
Brazil	27
European Union	28
United States	29
A backlash against biofuels?	32
Food, fuel, and international trade	32
Land-use pressures	33
Water	34
Genetically modified fuels?	35
Improving biofuels policy	35
Fix transport policy first	35
Applying carbon standards to fuels	36
Certification and international trade	36
Investment	**39**
The playing field	39
Growing	39
Producing	40
Distributing	41
Issues of concern	43
Building a bridge to nowhere?	44
Environmental and social impacts: fearing the backlash	44
Paving the way for tomorrow's biofuels	45
Scaling up may be slower than we think	50
Conclusions	**51**

Executive Summary

In a world of rapidly rising carbon emissions and growing unease about imported oil, the appeal of renewable fuels is growing apace. Biofuels — liquids produced from plant matter that can substitute for gasoline or diesel — are attracting significant public support and, in hot pursuit, private investment. The biofuels dream envisages a seamless transition from the age of oil, with its overly powerful suppliers, erratic prices, and high levels of pollution, to a world of clean fuels produced from lush fields by prosperous farmers. Sugarcane, corn, soy, and canola will supply our fuels today; wood, grasses, and even algae will meet our fuel needs in just a few years.

For those concerned about climate change, biofuels look timely. Transport fuels account for about 20 percent of CO_2 emissions today, but the proportion is much higher in some wealthy countries, and the share is rising globally. Many alternative fuels for transportation are even more highly polluting than oil,[1] *and so far electric vehicles and hydrogen have failed to meet motorists' demands at acceptable prices. Meanwhile, auto companies, eager to protect their more profitable niches (particularly bigger, heavier vehicles), have embraced biofuels, as enthusiasm for "green" fuels has reduced political pressure to improve corporate average fuel economies.*

Put a panacea in your tank?

Transport fuels present a special challenge. Not only are they a fast-growing source of greenhouse gas (GHG) emissions, but their use is also closely linked with such issues as mobility, lifestyle choices, land-use patterns, and international trade. As populations and incomes grow, all of these issues represent pressure toward greater fuel use. Considering only fuels in designing sustainable transport solutions is therefore inadequate.

Even when focusing only on oil, the problem is still quite complex. In oil-importing countries, a range of alternative fuels are being explored in response to growing concerns about dependence on sometimes unreliable suppliers, as well as the high and rising price of crude. Of the options facing such countries, biofuels appear to be the only near-term alternative that can offer both stable fuel supplies and potentially significant reductions in carbon emissions.

There is no question that in certain cases biofuels can be deployed in highly beneficial ways. There are, however, significant parts of today's biofuels mix that do not contribute substantially to either climate protection or reduced oil demand. The problem is a complex one of scale and timing: some biofuels

[1]For a discussion of these fuels see *Trouble in your Tank*. Washington, DC: World Resources Institute (forthcoming).

replace oil and reduce CO_2 emissions, but as production reaches scale the associated social, environmental, and financial costs can far outweigh any potential benefits.

This report first examines the **technology** of biofuels, exploring both the challenges raised by today's production and distribution technologies and the prospects for a new generation of fuels and feedstocks to make a major contribution to fuels markets in the medium term. It then turns to the **policy structures** that drive biofuels technologies today, examining some of the fuels' impacts as well as approaches that might mitigate the worst of these impacts. The next section analyzes some of the resulting drivers for **investment** and argues that some incentives for technology companies will make rapid scale-up of next-generation biofuels particularly challenging. WRI concludes that a shift to more environmentally and economically attractive biofuels is possible, but that it will likely be harder and slower than is often assumed. The push to boost near-term biofuels production will likely succeed only if standards and incentives are put in place that reward improved carbon and energy performance and promote sustainability.

Technology

Biofuels consumption today is dominated by ethanol from sugarcane in Brazil, ethanol from grains in the U.S., and biodiesel from oil seeds in the European Union (E.U.). The technologies for producing these fuels have been in use for many decades, with mixed results in terms of fuel savings and GHG reductions. However, new technologies are being developed, including fuels such as biobutanol and feedstocks such as cellulose and lignocellulose (the fibrous and woody parts of plants).

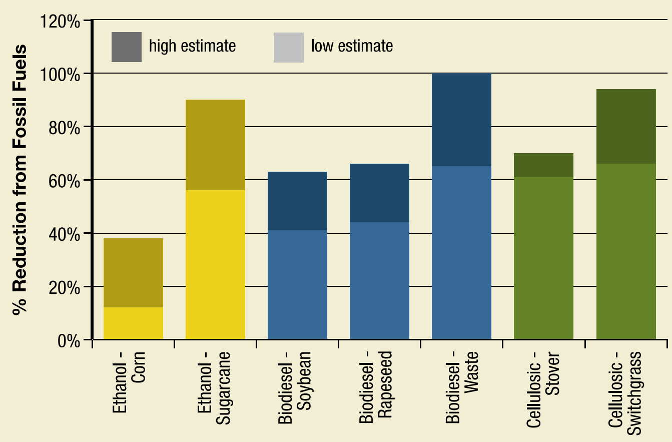
The energy benefits of biofuels depend largely on the production method and how it is fueled. Brazilian sugarcane is relatively easy to turn into ethanol, and the energy required can largely be derived from other parts of the plant itself. Conversely, producing ethanol from grain is an energy-intensive business, typically yielding a fuel containing only 1.3 to 1.5 energy units for every unit of energy it took to make. In addition, in the U.S. this energy input is generally derived from coal or natural gas, making matters worse from a GHG perspective. Meanwhile, biodiesel's energy and carbon performance varies widely depending on the feedstocks used, with the best fuels performing even better than Brazilian sugarcane.

Many biofuels can be mixed freely with conventional fuels with minimal complications. The primary exception is ethanol, which is both hydrophilic and corrosive. While it can be blended in low concentrations in gasoline without ill effects, in high concentrations it requires separate handling as well as vehicle engine modifications. As such, a push to high-level blends such as E85 (85 percent ethanol, 15 percent gasoline) means building a parallel infrastructure including tanks, pumps, and nozzles that will not corrode when used with ethanol, and transforming the existing vehicle fleet.

Climate impacts

A full explanation of the climate impacts of biofuels production is extremely complex. While tropical production — as with Brazilian sugarcane or Southeast Asian palm oil — is energy efficient, there are significant carbon impacts from the land-use changes that biofuels production demands. In the case of palm oil, both deforestation and the drying of peatlands (which release vast quantities of carbon when they burn) must be taken into account, and can overwhelm any emission reductions from reduced fossil fuel use. In the case of sugarcane, this effect is less direct, as the sugarcane itself is not generally grown on newly deforested land. However, expanding sugarcane production creates competition with other land uses and puts further pressure on land availability, which in turn almost certainly results in carbon release from cleared land. Figure A summarizes the carbon balance of the various fuels.

Figure A: **Percent Reduction in Life-cycle GHG Emissions from Selected Biofuels**



Notes: Figures for ethanol estimate the level of emissions reduced compared to gasoline. Biodiesel reductions are compared to diesel.

Source: World Resources Institute, based on multiple sources.

Other impacts

As with other large-scale agricultural production, deployment of biofuels can have a range of other impacts, both positive and negative. Some of these include:

- **Food and feed supply.** Biofuels crops often compete with food and feed crops for land use, water, and other inputs, or are themselves food crops diverted from the table or stable to the fuel tank. Biofuels demand has contributed to dramatic price increases in some staple crops in recent years, which have precipitated protests by the urban poor in some countries (e.g., Mexico and Myanmar).
- **Conservation.** Biofuels feedstocks are sometimes planted in high conservation value areas, damaging local ecosystems and displacing species.
- **Rural incomes and distribution.** A significant part of the allure of biofuels in most countries is that it adds a new income stream for rural communities. This has certainly been the case, although in many instances concerns have been raised over distribution and land rights.

The next generation

The range of impacts associated with biofuels in their present form has led many to argue that biofuels will only make a major contribution to energy security and environmental goals once a new generation of fuels and technologies emerges. In the near term this may include new feedstocks for ethanol production, particularly cellulose, as well as new fuels. In the longer term, specially cultivated algae and the promise of various advances in biotechnology have excited the interest of researchers and investors.

Even the "near term," however, may be further away than it seems. The proprietary nature of many technologies makes progress in this area hard to gauge. Deploying next-generation technologies at scale will take time once they become commercially available. Even under fairly optimistic projections, "first generation" feedstocks and fuels will dominate for years to come. A key issue for policy, then, is how national and international as well as private interests can promote and manage a transition to next-generation biofuels.

Policy

A wide range of support exists for biofuels deployment. In today's three main markets —Brazil, the E.U., and the U.S. — mandates and obligations predominate. These dictate a given volume of biofuels consumption across the economy. Certain technologies are sometimes favored (for instance, the U.S. Renewable Fuel Standard includes a separate mandate for cellulosic ethanol), but these mandates generally target increased biofuels consumption rather than particular policy goals, such as energy balance or GHG performance. Moreover, they do not effectively mitigate the potentially negative consequences of expanded biofuels production.

This has led to some perverse results. In the United States, for instance, the amount of fuel displaced by ethanol is more than offset by increased gasoline consumption due to the less stringent vehicle efficiency standards permitted by legislation. A biofuels program costing some $7 billion per year therefore goes toward keeping oil consumption roughly the same as it would be if the U.S. had no biofuels policy at all. In greenhouse gas terms, performance is not much better. Meanwhile, E.U. biofuels policy has contributed to conservation policy decisions that may result in considerable loss of habitat and carbon stocks. Conversely, ethanol promotion has yielded some impressive results in Brazil, where external debt is an estimated $100 billion lower today than it would otherwise have been.

Outside of specific mandates, biofuels policy is a mixture of lavish support for today's fuels combined with a set of measures aimed at coaxing newer technologies into the market. These measures include funding for research, development, and demonstration as well as specific promotion in emerging mandates. In addition, the U.S. has a raft of measures currently under debate to support development of an infrastructure — based on trucks, pumps, and flex-fuel vehicles — to handle E85.

Presently the three big biofuels markets are largely geared to support domestic production. This means that impacts on water, soil, and air quality are governed by domestic regulation within those markets. This shapes market development. For instance, Brazil's widespread use of high-level (~25 percent) ethanol blends in today's conventional vehicles would not be compatible with U.S. air quality standards. However, as demand grows beyond what domestic agriculture can provide, some countries have begun importing fuels and feedstocks, particularly from more productive regions (e.g., the tropics). As a result, they have "exported" some significant environmental and social impacts to these areas.

As international trade in biofuels grows, there is growing interest in regulating impacts outside the major markets. The idea of biofuels certification has gained many adherents (one model is being piloted in the U.K.). There is also the potential for a backlash against public support for biofuels. Rising food prices, or a clear adverse impact on tropical forests, for instance, may weaken the public's appetite for subsidies. On the other hand, even badly structured agricultural subsidies tend to have great staying power.

Investment

The promise of biofuels —as well as strong policy support — has generated something of a gold rush among investors. In part this has occurred among major established players, but newcomers have rushed in as well. In 2006, biofuels worldwide attracted $2.3 billion in venture capital and private equity dollars, with about 80 percent of this funding going toward expansion projects for mature technologies, and the remainder going toward development of next-generation technologies. Venture capital funding increased sevenfold from the previous year to $740 million in 2006, mainly in the United States. Initial Public Offerings (IPOs) in the biofuels sector totaled $3.2 billion in 2006, fifteen times more than in 2005. Land prices have also risen dramatically, with the price of Iowa farmland increasing faster than the prices for Manhattan or London real estate.

Further growth will require plenty of capital. The average ethanol plant in the U.S. has a capacity of approximately 50 million gallons per year (190 million liters per year), which would require $75 million to $100 million in capital costs. For biodiesel facilities, the minimum efficient scale is smaller than that for ethanol plants, which means that their capital requirements are commensurably smaller. Due to the greater complexity, capital costs for next-generation biofuels will likely be higher than for current technology. As the technology is still being developed, it is not reasonable at this stage to estimate the incremental capital requirement needed to bring these fuels to scale.

Build it, but they may not come

A major risk in the ethanol market is for those investing in E85 infrastructure. E85 filling pumps can cost up to $200,000 each, and pipelines $1 million per mile. Such investment makes sense only if and where E85 becomes an important fuel. In the U.S., this is not a realistic scenario at the national level. E85 can and will be deployed on a regional basis, yet pumps are being deployed where there is neither E85 to sell nor vehicles to use it. Currently, this extravagance is underwritten by policy, but should the focus of policy change, investors may be left stranded with a redundant infrastructure. Betting on national deployment of a lower-level ethanol blend, such as E10, seems safer in the near term because it requires no major infrastructure spending. As they emerge, next-generation fuels may provide much larger volumes of ethanol, but the chances are also good that they will include fuels, such as biobutanol, that can be safely used in conventional infrastructure and vehicles.

When will the next generation arrive?

Anticipating the next generation of biofuels is central to both investment and policy success. Venture capital interest has helped push forward the range of technologies being explored, and major investors are starting to take equity stakes in developers of new enzymes and processes. As noted, policy makers are explicitly creating a space for newer feedstocks and fuels.

However, this part of the biofuels world has under-delivered to date. The industry assures investors and policy makers that commercialization is just a few years away. But they have said this for a few years already. The lack of incentives for developers and owners of promising new technologies lead us to doubt whether the next 10-15 years will see these emerge into serious volume production. This is not to say that the technology companies themselves represent poor investments, but that policy makers should have a realistic view of when more sustainable biofuels will emerge at a scale that impacts major policy goals such as reducing GHG emissions and displacing oil.

Conclusions

Although biofuels will likely play a major role in energy and agricultural policy in the years to come, today's policy structures do not maximize the potential advantages — such as reduced GHG emissions and enhanced energy security — that biofuels offer. However, realizing these advantages is far from simple. Unwise policy design choices can not only negate the potential energy and emission benefits of biofuels, but can also impact human welfare through higher food prices, and damage the environment through deforestation and more intensive farming. These impacts may produce a backlash sufficient to undermine public support for biofuels in important markets. Where agriculture is concerned, unwise policy decisions are more the rule than the exception.

This report attempts to place both the advantages and drawbacks of biofuels in context, and to draw lessons for policy makers and investors from humanity's experience to date. Our starting point is the search to implement key climate technology "wedges" that can contribute in a major way to mitigating greenhouse gas emissions. Our conclusions are:

1. Biofuels are not a complete, nor even the primary, solution to our transport fuel needs. Biofuels have the potential to play some role in fulfilling figure transport demand, but carbon displacement on the gigaton scale seems unlikely to be feasible.

In order to displace one gigaton of carbon emissions, the wedges vision assumed both a large improvement in production efficiency and the use of one sixth of global agricultural land for biofuels. It is unlikely that this would be feasible without significant destruction of the world's forests, which would undermine the benefits of biofuels, or impacts on food prices, which would impose politically and morally untenable hardship on the poor. Biofuels will not save policy makers from the uncomfortable but necessary task of using fuel prices, taxation, and mandated efficiencies to restrain transport fuel demand and decarbonize mobility.

2. Today's biofuels policies illustrate the potential for both positive and negative impacts.

Biofuels policy in Brazil has put pressure on forests and agricultural markets, but has also undoubtedly played a major role in enhancing the country's energy security, raising rural incomes, reducing foreign debt and reducing GHG emissions. European Union biodiesel policy and U.S. ethanol policy have effectively been simple financial transfers to the farm sector, contributing to neither energy nor environmental goals. Biofuels policy should not take a one-size fits all approach, as the term "biofuels" disguises a range of products with varying abilities to achieve policy aims.

3. Biofuels should be rewarded, within a broader policy framework, with support that is in proportion to the specific benefits that they bring.

Short of a world in which externalities such as carbon emissions and energy security are adequately reflected in price signals through taxes or caps, incentives supporting biofuels and other alternatives should be proportional to the actual benefits they offer, such as life-cycle reductions in carbon emissions. At the very least, applying a technology neutral "low-carbon fuel standard" rather than a renewable fuels standard would yield more economically efficient outcomes, and could help spur a number of technology solutions, including, in particular, next-generation fuels.

4. Successful biofuels deployment will depend critically on the emergence of more advanced fuels, feedstocks, and conversion processes. Although these fuels have promise, it is not clear how quickly they can be deployed at meaningful scale.

New processes capable of converting feedstocks such as lignocellulose are vital, as is the use of feedstocks that can be grown on land unsuitable for agriculture. Until these are commercially available, governments should refrain from stimulating demand for biofuels. Rather, efforts should be focused on bringing these next-generation fuels to market at scale. This would include enhanced RD&D support for new biofuels technologies and low-carbon fuel standards, rather than large-scale renewable fuels standards.

5. Measures to ensure high environmental and social standards at the point of production, including certification, are essential.

As biofuels become a larger part of the social, economic, and environmental strategies of countries around the world, standards and regulations are needed to ensure that support for biofuels do, in fact, achieve the intended policy goals. Developing standards in an open and participatory manner, devising a transparent system to effectively monitor compliance and ensuring that the standards are not discriminatory or in violation of WTO principles will be challenging.

6. Until next-generation fuels are ready for commercial deployment, policy makers and investors should avoid creating new, parallel infrastructures for ethanol.

Biodiesel, biobutanol, and octanol can all be delivered through standard fuel distribution channels, as can ethanol in low-level blends. The present U.S. policy focus on deploying a national infrastructure for E85, including flex-fuel vehicles and distribution channels, is misguided. If E85 infrastructure is to be deployed at all, it should be on a regional basis in response to market forces. Promoting flex-fuel vehicles by undermining fuel efficiency standards aggravates the very problems of oil dependence and GHG emissions that policy seeks to address.

Introduction

In a world of rapidly rising carbon emissions and growing unease about imported oil, the appeal of renewable fuels is growing apace. Biofuels — namely, liquids produced from plant matter that can be used as an alternative to gasoline or diesel — have become a hot topic from Capitol Hill to Silicon Valley and from the halls of the European Parliament to the forests of Southeast Asia. They are attracting significant public support and private investment. Increasingly however, governments and investors are under pressure to ensure that their support for biofuels does not generate negative consequences.

Biofuels are promoted as a transport fuel substitute for several primary reasons: 1) their potential to improve national energy security by displacing imported petroleum with a renewable, domestically produced alternative; 2) the possible environmental benefits associated with that displacement, particularly a reduction in life-cycle greenhouse gas (GHG) emissions; and 3) the potential to support domestic agricultural markets in a way that complements traditional agricultural subsidies. In heavily agricultural economies, biofuels are also seen as a market opportunity that will give agriculture sector actors a high-value market outlet for their products and therefore help pull large portions of the population out of poverty.

Biofuels have the potential to achieve these objectives. Under this idealized scenario, the world would move from the age of oil — with its powerful suppliers, erratic prices, and high pollution — to a world of clean fuels produced by prosperous farmers. Sugarcane, corn, palm oil, soy, and canola can provide our fuels today; jatropha, wood, switchgrass, and even algae may become economic fuel sources over the next several years.

For those concerned about climate change, the rise of biofuels appears timely. Transport accounts for approximately 20 percent of global CO_2 emissions today, but the proportion is much higher in wealthy countries and the share is rising globally.[2] Many alternative fuels for transportation are even more highly polluting than oil — in terms of CO_2 emissions as well as other environmentally harmful substances,[3] — and so far electric vehicles and hydrogen have failed to meet motorists' demands at acceptable prices. Meanwhile, auto companies, wanting to protect well-established markets in heavier, more lucrative vehicles, have embraced biofuels as an alternative to increased vehicle efficiency.

Biofuels have even emerged as an instrument of foreign relations. On U.S. President George Bush's tour of Latin America in March 2007, ethanol production was a focus for upbeat announcements amid otherwise tense discussions. The U.S. was looking for ways to address rising fuel prices; countries such as Brazil were eager to embrace roles as exporters of clean technology and encourage importers to reduce or eliminate their import duties. As Bush and Brazilian President Lula DaSilva promoted ethanol, while Fidel Castro and Hugo Chavez denounced it, biofuels looked to have a distinct public relations edge.

[2]Climate Analysis Indicators Tool (CAIT) version 4.0. 2007. Washington, DC: World Resources Institute. Available online at: http://cait.wri.org. CO_2 emissions from transport are as high as 30% in the U.S., for instance.

[3]For a discussion of these fuels see *Trouble in your Tank*. Washington, DC: World Resources Institute (forthcoming).

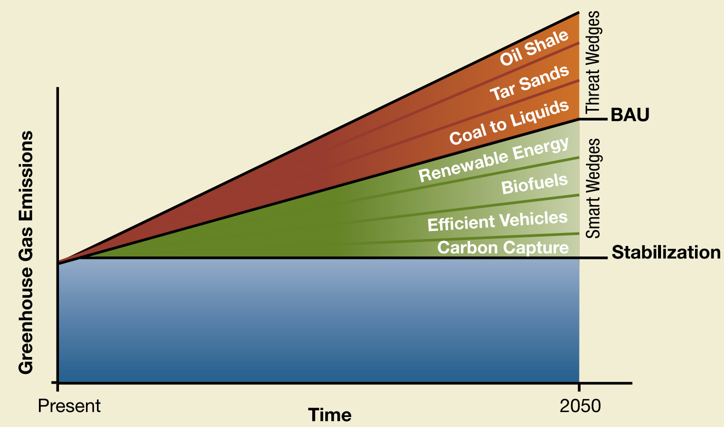
With such promise, expectations are high. But facing the huge scale of today's oil markets and the emission reductions needed to prevent the worst of climate change, can biofuels deliver? Many people hope so.

A biofuels climate wedge

Since 2004, the "wedges" model for climate protection proposed by two Princeton University researchers, Stephen Pacala and Robert Socolow, has been widely used to illustrate the scale of application needed to limit climate change using today's technologies.[4] This model divides the emission reductions needed by 2050 into discrete technological measures, each of which reduces emissions relative to a business as usual (BAU) projection by one gigaton of carbon (GtC or one billion metric tons).[5] While each of these represents a daunting task, they rely on existing technologies, or some incremental improvement of them. Implementation of at least seven such wedges will be required to limit climate change to less than catastrophic levels. One suggested wedge is the large-scale deployment of biofuels for transportation, displacing oil.

Transport fuels present a special challenge. Not only are they a fast-growing source of GHG emissions, but — as with most of the wedges — the policy challenges associated with them extend well beyond climate change. In particular, energy security concerns are another important policy driver behind the rush to biofuels. In response to growing concerns in oil importing countries about their dependence on sometimes unreliable suppliers, as well as the high and rising price of crude, a range of other fuels are being explored. Some of these significantly challenge the response to climate change as outlined in the wedges vision. In particular, fuels such as coal-to-liquids, oil shale, and tar sands threaten to increase CO_2 emissions dramatically compared with BAU projections, rendering the challenge of fighting climate change far more difficult. This has led WRI to expand the wedges model, introducing the concept of "threat wedges" to contrast with the "smart wedges" of the original (see Figure 1).

Figure 1: **Indicative Illustration of Smart Wedges and Threat Wedges**



Source: World Resources Institute. Note that the wedges are schematic, indicative, and not drawn to a specific scale.

Of the fuel options facing countries concerned about oil imports, biofuels appear to be the only alternative fuel that belongs among the smart wedges, allowing countries to tackle concerns about energy security and climate change. It is no small wonder, then, that biofuels have attracted so many adherents.

In certain cases, biofuels can indeed be deployed in ways that are highly beneficial to society and the environment. However, significant parts of today's biofuels mix do not appreciably contribute to either climate protection or reduced oil demand. Where today's biofuels may not help achieve these goals, many supporters of biofuels see current policies as creating the necessary infrastructure, incentives, and market demand to allow more efficient and environmentally benign technologies to emerge. The fundamental question is whether investments in current technologies help or hurt the emergence of next-generation technologies. Optimists argue that biofuels markets today facilitate the path to next-generation fuels by creating the requisite infrastructure and market demand. However, by strengthening political constituencies that benefit from today's production technologies, these markets may equally create barriers to newer fuels by raising the economic and political hurdles that next-generation technologies must surmount.

[4]Pacala, Stephen and Robert Socolow. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science* 305. 2004: 968-972.

[5]Note: Gigatons of carbon (GtC) can be converted into gigatons of carbon dioxide ($GtCO_2$) by multiplying the result by the ratio of the atomic weight of carbon (12) to the molecular weight of carbon dioxide (44), or by multiplying the result by a factor of 0.273.

Evaluating biofuels

As stated, proponents of biofuels seek to displace oil consumption with homegrown alternative fuels, and in the process achieve several aims including mitigating climate change, improving energy security, and supporting rural incomes. Certainly biofuels technologies should be evaluated on their ability to deliver on these goals. However, their ultimate success will be judged on a range of issues, including land-use impacts, distributional equity, water use, destruction of wildlife habitats, and other environmental concerns.

As both agricultural and energy markets are international, the potential advantages and problems associated with biofuels expansion extend well beyond national borders. Given the scale of global demand, dependence on natural resource-based commodities always entails significant impacts. Just as demand for oil has contributed to pollution, human rights abuses, corruption, and dictatorship in the developing world,[6] the broader impacts of biofuels on rural incomes, land rights, deforestation, and other issues are equally pressing and must be addressed.

Awareness is increasing that biofuels are not intrinsically "green", nor are they necessarily energy-saving, pro-poor, or development oriented. There are many ways to grow feedstocks, process them into biofuels, structure ownership of refining capacity, and distribute benefits among stakeholders; these aspects of production, and not the product's chemical composition, will determine whether biofuels will be broadly beneficial or not. The degree of benefit — or harm — may depend critically on the local scale of production. At some point production reaches a level where it puts maximum pressure on the surrounding environment. Large-scale global biofuels deployment would be very costly. Policy makers and investors must carefully evaluate the benefits and impacts, both direct and indirect, of biofuels technologies to determine if these investments are indeed worth making.

This report

Extensive analysis has been done in recent years on the technological, economic, and political aspects of biofuels production and use. This report aims to provide a succinct overview of these analyses, and to draw out relevant lessons for policy makers and investors. WRI examines the impacts and trade-offs related to large-scale biofuels deployment, placing its analysis within the framework outlined in *Scaling Up: Global Technology Deployment to Stabilize Emissions*, the introductory piece for this research.

This report first examines the **technology** of biofuels, exploring both the challenges raised by today's production and distribution technologies and the prospects for a new generation of fuels and feedstocks to make a major contribution to fuels markets in the medium term. It then turns to the **policy structures** that drive biofuels technologies today, examining some of the fuels' impacts, as well as approaches that might mitigate the worst of these impacts. The next section analyzes some of the resulting drivers for **investment** and argues that some incentives for technology companies will make the rapid scale-up of next-generation biofuels particularly challenging. Examples of noteworthy companies and collaboratives seeking to address barriers to biofuels deployment are highlighted throughout; these are largely U.S. focused. WRI concludes that a shift to more environmentally and economically attractive biofuels is possible, but that it will likely be harder and slower than is often assumed. The push to boost near-term biofuels production will likely succeed only if standards and incentives are put in place that reward improved carbon and energy performance and promote sustainability.

[6] Yergin, Daniel. *The Prize: The Epic Quest for Oil, Money & Power*. New York: Free Press. 1991.

Biofuels are considered to be carbon neutral because as the feedstock grows, it absorbs carbon from the atmosphere, and when burned, the amount of carbon released is equal to the carbon absorbed (in contrast to fossil fuels which, when burned, release carbon that has been stored underground for millennia). However, this carbon replacement value does not necessarily make biofuels intrinsically better or more eco-friendly than fossil fuels. Many factors impact the sustainability of biofuels (see Box 1). Potential environmental impacts from increased biofuels consumption arise throughout the fuel's life cycle, from production and transportation of feedstocks, to processing those feedstocks into fuel, to combustion of that fuel for transportation energy. These negative environmental impacts must be minimized to ensure that biofuels are indeed produced sustainably. Moreover, biofuels compete with other potential uses of biomass for energy, such as for heat and power generation. Accordingly, the most efficient allocation of biomass between fuel and power uses — or between energy and other uses — is not clear.[8]

Box 1: Sustainability

Sustainability is a concept with many definitions. Broadly, "sustainable" describes a condition or state that can be maintained indefinitely. One of the most widely cited definitions of sustainability, though, comes from the Brundtland Report of 1987. This report described sustainable development as development that "seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future."[9] This definition need not apply only to economic development, however.

For biofuels production, sustainability means that maintaining today's production and consumption will not adversely impact the ability to do the same in the future. The fuel's carbon neutrality is only one component to consider in determining its sustainability. Biofuels can have socio-economic and environmental impacts throughout the product's life cycle. For instance, the negative impacts that feedstock production can have on the surrounding ecosystem may decrease the land's ability to yield viable crops for conversion in the future or provide other valuable ecosystem services.

Technology

The term "biofuels" covers a wide range of alternative transport fuels made from organic matter such as crops and agricultural residue; some of these fuels include biobutanol, biodiesel, ethanol, and methanol. Use of biofuels and the environmental impacts associated with their production vary widely around the globe. Feedstocks for ethanol production tend to be starch- or sugar-rich crops such as sugarcane, sugar beets, corn, wheat, or cassava, while appropriate feedstocks for biodiesel production include oil-rich crops such as soybean, jatropha, palm oil, rapeseed (canola), sunflower seeds, or cotton seeds. Ethanol production and use is higher in the U.S. and Brazil than in any other country. These countries use roughly the same amount of fuel, but in Brazil this volume accounts for approximately thirteen percent of the road-fuel consumption, while in the U.S. it accounts for less than three percent.[7]

The primary biofuels in the global fuel mix today are ethanol and biodiesel. These fuels can be used as motor fuel in either pure form or as a blending component. Currently biofuels consumption is still quite low — in 2006 biofuels met only one percent of global road-transport fuel needs[10] — but consumption levels, particularly of ethanol and biodiesel, are growing rapidly worldwide (see Box 2). Biofuels proponents believe that

[7]Organization for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA). *World Energy Outlook*. 2006. Paris: IEA/OECD.

[8]Doornbosch, Richard and Ronald Steenblik. "Biofuels: Is the Cure Worse Than the Disease?" Organization for Economic Cooperation and Development (OECD). Report SG/SD/RT(2007)3. Prepared for Round Table on Sustainable Development, Paris, September 11-12, 2007.

[9]World Commission on Environment and Development. "Our Common Future." (The Brundtland Report). Oxford and New York: Oxford University Press. 1987.

[10]OECD/IEA. *World Energy Outlook*. 2006.

these fuels offer the potential to displace a significant amount of petroleum and to bring widespread environmental and energy security benefits.[11] However, not everyone is so optimistic, and increasingly, people are becoming aware of biofuels' potential downsides.

Box 2: Market Growth

Global markets for biofuels, namely ethanol and biodiesel, have seen enormous growth in the past decade. Global ethanol production doubled between 2000 and 2005,[12] and this strong growth trend continued in 2006 with an 11 percent increase in global production. Brazil and the United States manufacture the majority of the world's ethanol: in 2006, the U.S. produced 4.9 billion gallons of ethanol (19 billion liters), while Brazil produced 4.5 billion gallons (17 billion liters), accounting for 36 and 33 percent of global ethanol production, respectively.[13] Brazil is also emerging as a major producer of biodiesel.

Biodiesel is in an earlier stage of development, but has exhibited an even higher growth rate than the ethanol market. Global biodiesel production quadrupled from 2000 to 2005, exceeding 6 billion liters (1.6 billion gallons) in 2006. The European Union is currently the largest producer of biodiesel, accounting for 90 percent of global production.[14]

While biofuels potentially offer environmental and energy security benefits, one cannot take for granted that they will. While most biofuels generally have low toxicity, meaning spills are not as problematic as conventional fuel spills, the different feedstocks and processes involved in producing these fuels determine their life-cycle environmental impacts — and these are not necessarily any less than those of petroleum-based fuels. Some negative impacts of biofuels production are already visible in many regions, indicating that today's technologies do not guarantee all of the potential benefits of biofuels will be achieved.

Some biofuels are more ecologically and socio-economically sustainable than others. The merits of the biofuels technologies available and under development today ought to be judged based on the whole range of their direct and indirect life-cycle impacts. However, as reduced fossil fuel consumption, and the improved energy security and reduced GHG emissions that would theoretically result, are the leading drivers of interest in biofuels today, it is important to evaluate biofuels technologies based on their ability to reduce fossil fuel demand. What has proved challenging is placing the quantifiable energy and GHG impacts in a larger framework — one that would give a sense of the economic valuation of the oil and emissions savings weighed against externalities such as impacts on land, water, food price, and biodiversity.

Energy balance

The net energy balance per gallon of biofuels varies significantly depending on the feedstock and the process used to produce the fuel. The methods for calculating and accounting for these figures also vary. Life-cycle calculations take into account all of the energy inputs associated with growing, harvesting, and transporting the feedstock, as well as with producing, transporting, distributing, and combusting the fuel. Assumptions about inputs can vary widely, and the value that different researchers assign to inputs, as well as to co-products that get credited, will affect the outcome.

There is still significant debate around most of these figures, but Figure 2 displays estimates for the energy balance of a range of popular feedstocks. The benefit from today's corn-based ethanol is moderate, meaning that the energy in ethanol is only slightly greater than the energy input required to produce the fuel. Most estimates suggest that for every unit of energy input into ethanol production, approximately 1.3 – 1.5 units are returned.[15] The energy balance of sugarcane-based ethanol is more favorable, because the bagasse (the plant material that remains once the sugar has been extracted for fermentation) can be burned to provide process energy, thereby obviating the need for additional energy sources. As such, for every unit of energy put into producing sugarcane-based ethanol, 8.3 units of energy are returned. For biodiesel, the energy balance varies widely as well. Biodiesel generally fares better than corn-based ethanol: soy-based biodiesel has an energy return greater than three units,[16] while palm oil biodiesel returns roughly nine units.[17]

[11] Broad coalitions of industry, business, political, and interest groups have formed to champion specific goals for biofuels production. In the U.S., for instance, 25x'25 is a coalition of agricultural, business, conservation groups, etc. committed to replacing 25% of American oil consumption with renewable fuels. Also in the U.S., the Governors Ethanol Coalition has recommended that the U.S. adopt the goal of replacing 20%, or roughly 60 billion gallons, of its oil consumption with renewable fuels. In the E.U. the Biofuels Research Advisory Council is pushing for 25% of transport fuel to come from biofuels by 2030.

[12] OECD/IEA. *World Energy Outlook*. 2006.

[13] Renewable Fuels Association (RFA). "Industry Statistics." Available online at: http://ethanolrfa.org/industry/statistics/.

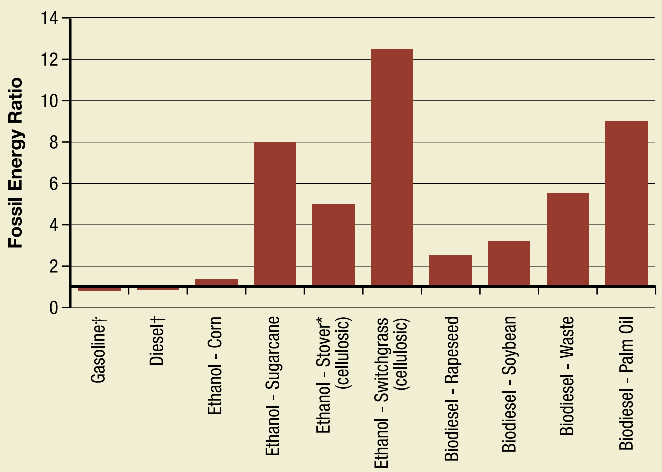
[14] OECD/IEA. *World Energy Outlook*. 2006.

[15] Worldwatch Institute. *Biofuels for Transport: Global Potential and Implications for Energy and Agriculture*. Prepared by Worldwatch Institute for the German Ministry of Food, Agriculture and Consumer Protection (BMELV) in coordination with the German Agency for Technical Cooperation (GTZ) and the German Agency of Renewable Resources (FNR). London: Earthscan. 2007.

[16] Sheehan, John, Vince Camobreco, James Duffield, Michael Graboski, and Housein Shapouri. "An Overview of Biodiesel and Petroleum Diesel Life Cycles." Golden, Colorado: National Renewable Energy Lab. May 1998. Available online at: http://devafdc.nrel.gov/pdfs/3812.pdf.

[17] Kaltner, Franz J. et al. "Liquid Biofuels for Transportation in Brazil: Potential and Implications for Sustainable Agriculture and Energy in the 21st Century." Study prepared by Fundação Brasileira para o Desenvolvimento Sustentável (FBDS) on behalf of the German Agency for Technical Cooperation (GTZ). November 2005.

Figure 2: **Energy Balance of Biofuels Feedstocks**



Notes: † The negatives for gasoline and diesel simply reflect the net losses of fossil fuels in the production, refining, and distribution stages of these fuels.

* 5:1 may prove a conservative expectation for stover yields, once further research is completed.

Sources: World Resources Institute, based on multiple sources[18]

Many ethanol critics argue that ethanol actually has a negative energy balance — that more fossil fuel is used to create it (e.g., natural gas for producing fertilizer and petroleum diesel for producing crops and transporting feedstocks) than is displaced by its use.[19] However, the studies that reach these conclusions have been widely criticized as relying on flawed and antiquated data, and the argument has lost traction in most scientific circles. More recent studies and reviews find a positive (though small) net energy balance per gallon using current corn-based technology and predict significantly more favorable energy returns from cellulosic technology, as shown above.[20] Today's technology clearly will not wean the world off of fossil fuels in any great hurry, but many are optimistic about the potential contributions of technologies under development, and see today's fuels as tiding us over until these newer fuels are more widely available.

Carbon balance

This wide range of energy balance ratios means that there is an equally wide range of carbon and greenhouse gas benefits that these various biofuels provide (see Figure 3). Whether biofuels are net carbon neutral, positive, or negative depends on the production process from feedstock production to fuel conversion.

Different feedstocks result in fuels with different emissions profiles. Indeed, fuels produced from the same kind of feedstock may have different profiles depending on how those feedstocks were grown. For instance, the GHG benefits of biodiesel from palm oil are controversial. If palm is grown on unproductive lands, the GHG benefits can be positive. However, considerable amounts of methane are released during storage of palm oil mill effluent, and sizeable quantities of CO_2 are emitted when natural forests are converted to plantations. For instance, by draining wetlands to make way for oil-palm plantations (and thus hastening the decomposition of peat soils), Indonesia generates an average of 33 tons of CO_2 per ton of palm oil produced. Burning a ton of palm oil instead of fossil fuel, however, saves only three tons of emissions.[21] This massive initial release of emissions will be paid back only after the plantation has been in operation for decades. However, palm-oil plantations that do not convert land in this manner may have lower lifecycle emissions profiles.

The impacts are not so clear in other parts of the world. In Brazil, for instance, sugarcane does not grow well in the climate prevalent in forested regions, and forests are therefore not cleared for sugarcane plantations directly, as is more frequently seen in Southeast Asia. However, this does not mean that expanding sugarcane production has no impact on Brazil's forest; it is simply that the impacts are less direct. In Brazil, most sugarcane is grown in the São Paolo region. If sugarcane is planted on land that was previously being used for other productive purposes, such as growing other crops or grazing livestock, these activities may be displaced. This land-use pressure could ultimately lead to deforestation elsewhere, and therefore carbon emissions indirectly attributable to ethanol production (see Box 10).

[18]Farrell, Alex. "Energy Overview: Synthetic Biology." University of California Berkeley. Energy and Resources Group. 2006. Powerpoint presentation available online at: http://openwetware.org/images/2/20/Farrell_-_Synthetic_Biology_022206.pdf; U.S. Department of Energy (DOE). Energy Efficiency and Renewable Energy. Biomass Program. http://www1.eere.energy.gov/biomass/net_energy_balance.html; Worldwatch Institute. 2007.

[19]See articles by David Pimentel and Tad Patzek, such as:
Pimentel, David. "The limitations of biomass energy." *Encyclopedia on Physical Science and Technology*. San Diego: Academic Press. 2001. 159-171.
Pimentel, David and Tad Patzek. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resources Research*. Netherlands: Springer Netherlands. March 2005.

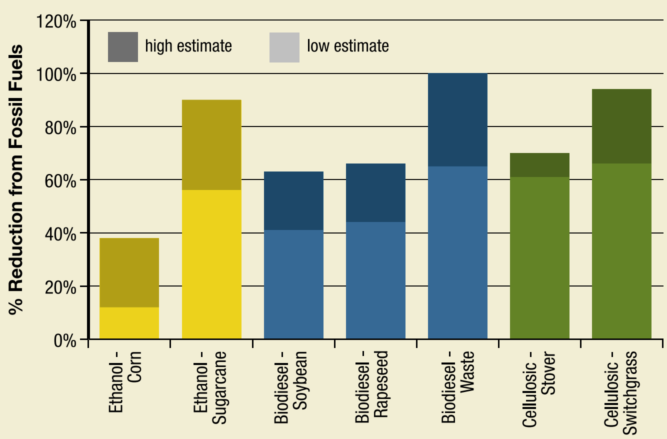
[20]Shapouri, Hosein, James A. Duffield and Michael Wang. *The Energy Balance of Corn Ethanol: An Update*. U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses. Agricultural Economic Report No. 813. July 2002.
Farrell, Alexander E., Richard J. Plevin, Brian T. Turner, Andrew D. Jones, Michael O'Hare, and Daniel M. Kammen. "Ethanol Can Contribute to Energy and Environmental Goals." *Science*. 311. January 27, 2006: 506-508.
Wang, Michael, C Saricks, and D. Santini. *Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions*. U.S. Department of Energy, Argonne National Laboratory, Center for Transportation Research, Argonne, IL, 1999.

[21]Hooijer, A., Silvius, M., Wösten, H. and Page, S. *PEAT-CO_2, Assessment of CO_2 Emissions from Drained Peatlands in SE Asia*. Delft Hydraulics. Report Q3943. 2006.

The fuel conversion process also impacts the emissions profile of the resulting biofuels. Each of the energy inputs described above has a carbon footprint. If GHG reduction is one of the primary drivers behind the enthusiasm for biofuels, it is important to clarify that not all biofuels are equal in this regard. Indeed, the range of GHG impacts is even larger than that of energy balances because the different sources of heat and power in biofuels production facilities have a range of carbon intensities. For instance, ethanol produced with electricity from renewable resources or natural gas will have a far lower emissions profile than ethanol produced with coal-fired electricity. Yet the energy input for biofuels production comes largely from fossil fuels, meaning that the more energy intensive the biofuels are to produce, the less end benefit they will provide in terms of reduced emissions.

As this discussion indicates, the effective carbon intensity of a fuel is extremely difficult to derive. In particular, indirect carbon impacts due to land-use changes are a major factor in determining the overall climate impact of biofuels. Policies based on carbon intensity of fuels face significant technical hurdles, and a lot of further research is needed to establish whether carbon impacts can be reliably determined.

Figure 3: **Percent Reduction in Life-cycle GHG Emissions from Selected Biofuels**



Notes: Figures for ethanol estimate the level of emissions reduced compared with gasoline. Biodiesel reductions are compared with diesel. Emissions from palm oil based biodiesel are excluded here, as the wide range of estimates makes them less useful and somewhat controversial.

Sources: World Resources Institute, based on multiple sources[22]

Logistics

Fuels from different feedstocks also have different infrastructure requirements. In particular, there are a host of logistical difficulties associated with the high-volume, low-density biofeedstocks. The bulky organic material must be transported from the point of production to biorefineries. In addition, once produced, the fuel must be incorporated into the fuel mix for distribution. This poses an additional challenge, more so for some fuels than for others. For instance, in some biofuels-producing regions — particularly Brazil — feedstock and fuel transport is not as significant of a concern, but this is changing as production continues to grow (see Box 3). Significant new investment in infrastructure is starting to take place there as well. Transport constraints are particularly severe in the case of ethanol, which features bulky and low-density feedstocks as well as fuel characteristics that prohibit smooth incorporation into the existing fuel infrastructure.

Box 3: Ethanol Infrastructure in Brazil

To catalyze development of the ethanol industry, the Brazilian government in the mid-1970s offered low-interest loans and credit guarantees to sugar growers to construct distilleries on their plantations. These distilleries continue to convert sugarcane into ethanol in situ where the feedstock is grown, reducing the need for additional transport infrastructure for the raw feedstock. The ethanol is shipped from agricultural regions to Petrobras' refining complex. Tanker trucks then transport the ethanol to major ports for export, or to domestic commercial centers.

However, as Brazil plans to quadruple exports to one billion gallons per year by 2011 (3.8 billion liters per year), the existing ethanol infrastructure will not be sufficient. To achieve this scale, Brazil is investing in a dedicated ethanol pipeline from the Petrobras refining facility to Santos, the largest port in Latin America. Brazil is also investing in terminals along major rivers, which pass through the sugar plantations of the Center-South. These terminals will minimize the distance that the ethanol needs to be shipped by trucks, allowing it instead to be transferred to barges and shipped via these river systems to the Petrobras refinery.

[22]Fulton, L. et al. *Biofuels for Transport: An International Perspective*. Paris, France: International Energy Agency; 2004. Groode, Tiffany A. and John B. Heywood. *Ethanol: A Look Ahead*. Laboratory for Energy and Environment, Massachusetts Institute of Technology. Publication No. LFEE 2007-002 RP.; 2007. Hill, Jason et al. 2006. "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels." Proceedings of the National Academy of Sciences (PNAS), Jul 2006. 103: 11206 – 11210; U.S. Environmental Protection Agency (EPA). 2007. Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use. EPA420-F-07-035. Washington, DC: EPA Office of Transportation and Air Quality; Worldwatch Institute. 2007.

Economics

The biofuels industry has made dramatic improvements toward reducing the cost of biofuels production. However, to compete with petroleum-based fuels, biofuels producers still rely on subsidies, particularly for the agricultural inputs, in most markets — Brazil being the primary exception. Currently, only Brazilian ethanol producers can compete subsidy-free with conventional gasoline (see Figure 4).[23]

Feedstock costs, which account for more than half of biofuels production costs, fluctuate widely, and it is difficult for producers to pass on any increases in these costs as biofuels prices tend to follow closely the price of petroleum-based fuels. It is unlikely that these costs will decline, given rising competition for land (see page 33).[24] Another important component of biofuels production costs is the price of energy, which is also a variable cost. Energy cost is less of an issue for Brazilian ethanol as bagasse, the plant residue, is burned for power generation. This is also true of next-generation fuels, if lignin co-generation is used to power the plant (see page 22).

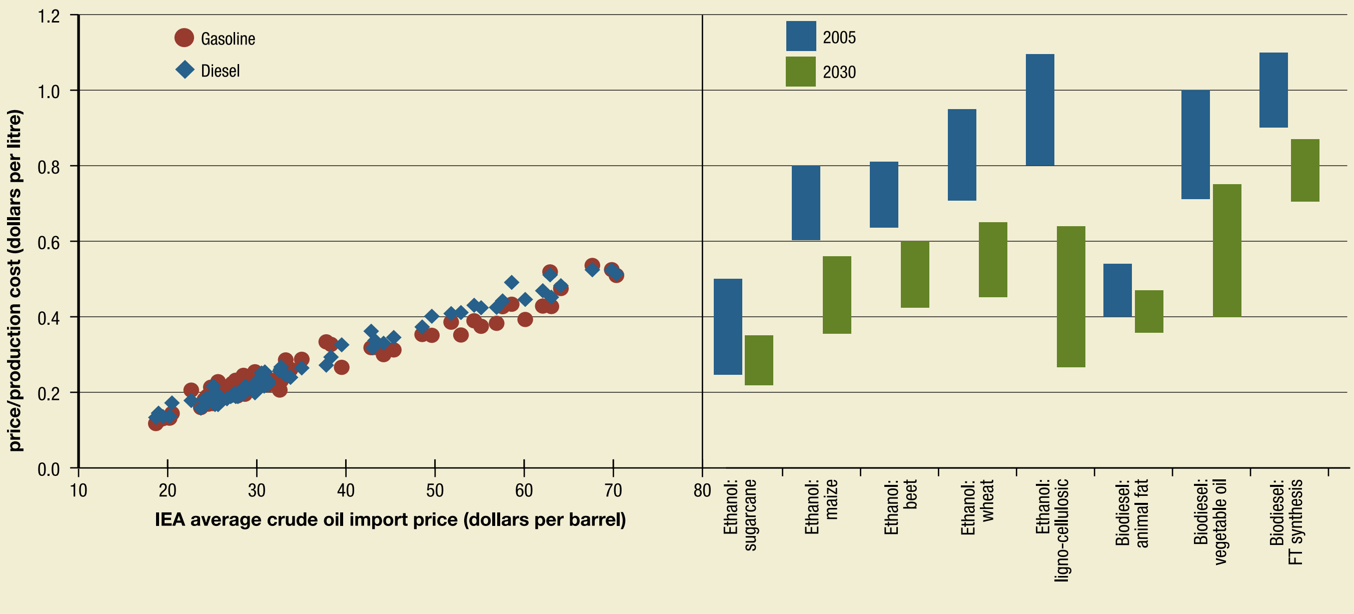
Biofuels production also yields co-products, which, once their value is factored into the overall economics, make the production costs for biofuels more attractive. These co-products include glycerine (an input for cosmetics and soap) and animal feed. For ethanol, the most important co-product is dried distiller grains (DDG, an animal feed), which can account for up to 20 percent of a mill's income.[25] However, the market for these co-products is not as insatiable as the fuels market, so as biofuels production expands, the value of the co-products will likely decrease. Next-generation fuels do not have high-value co-products, because the plant matter is all converted into fuel.

The fuels in detail

Ethanol

Ethanol is an alcohol that is used as a gasoline alternative. It has been used as a fuel since the invention of the automobile. In fact, Henry Ford designed his Model T to run on ethanol, and Brazilian policy makers sought to use ethanol from sugarcane as a motor fuel as early as 1900.

Figure 4: **Production Costs of Biofuels**



Source: OECD/IEA[26]

[23]OECD/IEA. *World Energy Outlook*. 2006.

[24]Doornbosch, Richard and Ronald Steenblik. "Biofuels: Is the Cure Worse Than the Disease?" Organization for Economic Cooperation and Development (OECD). Report SG/SD/RT(2007)3. Prepared for Round Table on Sustainable Development, Paris, September 11-12, 2007.

[25]Worldwatch, 2007.

[26]OECD/IEA. *World Energy Outlook*. 2006.

Fuel properties

Several characteristics of ethanol make it an attractive fuel and blending agent. Ethanol is an oxygenate (meaning it contains oxygen), which improves combustion and reduces pollutants such as carbon monoxide and particulate matter. Ethanol is low in sulfur relative to gasoline, meaning it contributes less to acid rain and harmful health impacts. In addition, ethanol's high octane reduces engine "knock" (which happens when a vehicle is working hard and the fuel combusts too early in the cylinder), which allows vehicles to operate more efficiently.

However, ethanol has roughly two thirds of the energy content of gasoline by volume, which means that a driver operating a vehicle on ethanol should expect a reduction in fuel economy of 25-30 percent depending on vehicle characteristics and driving conditions, as compared with driving on gasoline. It therefore requires more ethanol than gasoline to drive a given distance, meaning more frequent trips to the pump than when operating on pure gasoline or diesel. Also, ethanol can increase a vehicle's NOx emissions, which are known to contribute to smog formation.

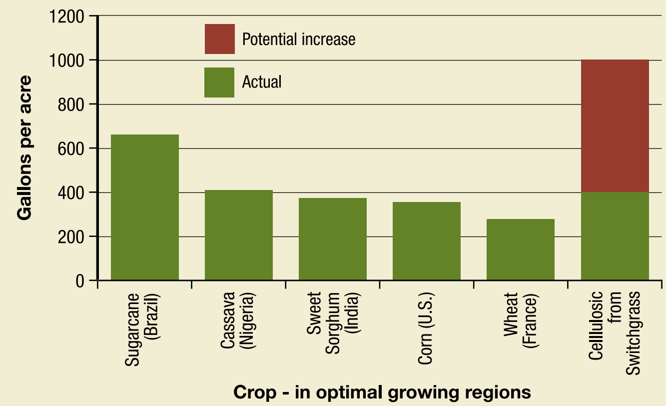
Feedstocks

Ethanol can be derived from a variety of feedstocks by fermenting grains, cereals, sugar crops, and other starches. Fermentation — a modification of the method used to make moonshine during the U.S. Prohibition Era — is a well-known and established process. Sugar is removed from the plant matter by crushing and soaking, and then is fermented to alcohol using yeasts. The technology for producing ethanol from grain feedstocks is more complex and less efficient than that for producing ethanol from sugar.

Sugarcane is the feedstock of choice in Brazil, where ethanol now accounts for a significant portion of the country's fuel mix. Sugarcane is an efficient feedstock, yielding an estimated 650-700 gallons of ethanol per acre (6,000 – 6,500 liters per hectare). Corn is used to produce more than 95 percent of the ethanol in the U.S. and provides an average ethanol yield of roughly 400 gallons per acre, or about 3,700 liters per hectare (see Figure 5). This is relatively low, because for grain-based ethanol production, only the starchy part of the plant (the kernel) is converted to fuel.

The cellulose — the leaves and stalks — can also be converted to ethanol, although this process is even more complex. Cellulosic ethanol, also called second- or next-generation ethanol, is discussed in greater detail beginning on page 19.

Figure 5: **Ethanol Fuel Yields**



Source: Earth Policy Institute[27]

Research to improve yields is ongoing; industry has already invested billions of dollars in efforts to increase the amount of fuel that can ultimately be squeezed from a seed. Advances in agricultural systems, plant breeding, and biotechnology have led to improvements in both plant yield per acre and gallons of fuel per ton of plant matter. In the U.S., research has particularly targeted improving the yield of ethanol from an acre of corn. In 2000, corn yield averaged less than 140 bushels per acre (8,600 kilograms per hectare).[28] The U.S. Department of Agriculture (USDA) is predicting a yield of 153 bushels per acre for 2007 (9,600 kilograms per hectare). Yields have historically increased at roughly two percent per year, and this trend is expected to continue or even accelerate. At this rate, yields could reach 180 bushels per acre (11,300 kilograms per hectare) by 2015.[29] Similar advances in crop yields have been achieved in Europe, as well as in Brazil, but the real scope for dramatic future improvements is in the developing world.[30]

Fuel yields per unit of plant matter have also improved. In the U.S., ethanol yields from a bushel of corn have increased as the biofuels market has matured. In 2000, ethanol facilities averaged roughly 2.5 gallons of ethanol per bushel (0.37 liters of ethanol per kilogram of corn). Today, state-of-the-art facilities can yield 2.8 gallons per bushel (0.42 liters per kilogram), while the industry averages closer to 2.65 gallons per bushel (0.40

[27]Brown, Lester R. *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble.* 2006 NY: W.W. Norton & Co. Available online at: http://www.earth-policy.org/Books/PB2/PB2ch2_ss5.htm

[28]A bushel is a measurement of dry volume commonly used in agriculture. For corn a bushel is 56 lbs of shelled corn or 70 lbs of ears of corn.

[29]U.S. Department of Agriculture, National Agricultural Statistics Service. Available online at: http://www.nass.usda.gov/Newsroom/2007/08_10_2007.asp.

[30]Worldwatch Institute. 2007.

liters per kilogram).[31] Ethanol yields will continue to increase as more state-of-the-art facilities come on-line. Given the publicly and privately funded research aimed at increasing the "miles per acre" (or effective fuel economy) of biofuels, continued improvements seem certain (see Box 4). Another method being pursued to increase ethanol yield from corn is to convert corn stover — stalk, husks, and cobs — as well as the kernel into ethanol (see page 20). As land-use concerns are among the most severe of biofuels' negative impacts, improving fuel yield is an important step for increasing the sustainability of biofuels, so long as these improvements do not involve vast quantities of fertilizers and chemicals. These efforts do, however, raise the controversial issue of genetic modification, which will be discussed in greater detail below.

Logistical Challenges to Scaling Up Ethanol Deployment

Large-scale deployment of a technology involves a more complex set of issues than merely seeking commercialization at the margins of the market. In the case of ethanol, scale-up issues are found primarily around distribution infrastructure.

Distribution

Ethanol is hydrophilic and therefore easily picks up water from pipelines and storage tanks, which contaminates the fuel. Ethanol is also extremely corrosive, which can compromise the integrity of existing pipeline fittings and aluminum storage tanks. Finally, ethanol is an effective solvent that picks up residues of other materials that have passed through the pipelines, resulting in cleaner pipes but dirtier fuel, which damages vehicle engines.

Box 4: Research to Improve Yields

With additional demand for corn already affecting commodity prices throughout the U.S. economy, a concerted effort is underway to improve corn ethanol yields there. Many companies and research labs are working to improve yields of both bushels of corn per acre planted and gallons of ethanol obtained per bushel of corn.

DuPont subsidiary Pioneer Hi-Bred International Inc. has developed more than 135 seed hybrids, which it is marketing through its IndustrySelect® program. Through this program, Pioneer uses conventional breeding to develop hybrid seeds designed with specialized traits that will produce higher crop yields for farmers and improve the efficiency of ethanol production. For instance, Pioneer® brand soybean varieties improved yields three times faster than the industry average.[32]

Monsanto invests roughly $1.5 million per day in RD&D of new products.[33] In biofuels-related research, Monsanto uses a variety of methods including conventional breeding, molecular breeding, crop analytics, and biotechnology to develop improved corn, cotton, and oilseeds (soy and canola or rapeseed) as well as fruits and vegetables. Some of their strains are specially developed for production of ethanol and biodiesel.[34]

Syngenta is a leading global agribusiness company, specializing in plant protection. Their large germplasm collection provides the basis for breeding new crop varieties to improve plant traits, including disease and drought resistance. Syngenta hopes by 2008 to begin selling genetically engineered corn seeds that already contain one of the enzymes necessary to convert corn to ethanol. In other words, this corn will be genetically engineered to help convert itself into ethanol. With help from ***Diversa***, a California-based chemical company, they have developed corn with kernels containing an enzyme used in the conversion process that would otherwise be added at the biorefinery. In 2006 Syngenta invested around $800 million in R&D, representing 10 percent of sales.[35]

Massachusetts Institute of Technology scientists have engineered yeast that can improve the speed and efficiency of ethanol conversion from corn and other grains. High ethanol levels are toxic to the yeast that ferments the plant material into ethanol, but by manipulating the yeast genome, the researchers developed a new yeast strain that can tolerate higher ethanol levels and produce ethanol faster than traditional yeast. The engineered yeast produced 50 percent more ethanol during a 21-hour test period than normal yeast.[36]

Carnegie Mellon University engineers have devised a new process to improve ethanol production efficiency. Using advanced process-design methods involving redesign of the distillation process and adding an energy recovery system, researchers have reduced the operating costs of corn-based bio-ethanol plants by more than 60 percent.[37]

[31]Grabowski, Dr. Michael S. "Comparison of USDA and Pimentel Net Energy Balances." National Corn Growers Association. August 2001. Available online at: http://www.ncga.com/public_policy/issues/2001/ethanol/08_22_01b.htm.

[32]DuPont press release. Available online at: http://vocuspr.vocus.com/VocusPR30/Newsroom/Query.aspx?SiteName=DupontNew&Entity=PRAsset&SF_PRAsset_PRAssetID_EQ=103880&XSL=PressRelease&Cache=False.

[33]Monsanto Company. "Corporate Profile". Available online at: http://www.monsanto.com/investors/corporate_profile.asp.

[34]Monsanto Company. *2006 Pledge Report*. Available online at: http://www.monsanto.com/pdf/pubs/2006/pledge_report.pdf.

[35]Sygenta. *Annual Review 2006*. Available online at: http://www.syngenta.com/en/downloads/Syngenta_AR2006_e.pdf.

[36]Trafton, Anne. "Engineered Yeast Improves Ethanol Production." Massachusetts Institute of Technology News Office. December 7, 2006. Available online at http://web.mit.edu/newsoffice/2006/biofuels.html.

[37]"Carnegie Mellon Engineers Devise New Process To Improve Energy Efficiency of Ethanol Production." Carnegie Mellon University Press Release. January 26, 2007. Available online at http://www.cmu.edu/news/archive/2007/January/jan26_ethanol.shtml.

Given these characteristics, ethanol is generally transported by truck, train, or barge. This distribution system, however, is not a scalable solution. Consider a 200,000 barrel-per-day, 1,000-mile (1,600-km) pipeline: trucking the amount of fuel that this pipeline would transport would require an additional 2,000 large tanker truck trips per day to transport 200,000 barrels per day (only two percent of the nine million barrels per day of motor gasoline consumed in the U.S. in 2005) on an already strained highway network.[38]

Scaling up ethanol consumption in the U.S. would likely require dedicated pipelines to transport significant fuel quantities, as well as storage tanks and distribution infrastructure at gas stations, including either new or extensively cleaned tanks, valves, filters, hoses, and nozzles.[39] The pipeline model works well for gasoline because production takes place in concentrated geographical areas from which the product can be distributed to supply dispersed demand. With ethanol, it would be more complex as production is dispersed as well, thus requiring a network of gathering pipelines in addition to long-haul pipelines to demand markets. Barriers to deployment of this supporting infrastructure are discussed further beginning on page 41.

As discussed, ethanol's lower energy content relative to gasoline further exacerbates infrastructure issues. If today's vehicle technology remains constant, more ethanol in the fuel mix will require that *more* fuel be produced, transported, and dispensed than today to meet consumer mobility demands (vehicle miles traveled at constant fuel efficiency) — adding additional pressure on the fuel distribution infrastructure.

Vehicles

Ethanol can be blended with gasoline at low levels without requiring engine modifications. Low-level blends are widely used to stretch oil supplies. In the U.S., gasoline is blended with up to 10 percent ethanol (E10). Using E10 does not require any additional retail infrastructure (though it still requires substantial investment in the transport and distribution system), and can be used in the existing vehicle fleet (except for vehicles produced before the early 1980s) without voiding manufacturer warranties.[40] In addition, it is theoretically possible to increase the blend level beyond E10 without requiring substantial vehicle modification.[41] In Brazil, for instance, all gasoline is blended with 20-25 percent ethanol, as mandated by the government. However, at this level, ethanol can have negative air quality impacts, particularly in regions with smog problems.

Ethanol can also be used in higher concentrations, such as E85 (85 percent ethanol, 15 percent gasoline) or pure ethanol, but this requires changes to the vehicle engine. Flex-fuel vehicles (FFVs), which can run on ethanol, gasoline, or any blend of the two, are increasing their market penetration in the U.S. and Brazil. Several automakers have been producing and selling FFVs in the U.S. and Brazil since the late 1990s, and there are now more than 6 million on the road today.[42] Automakers have stated that the incremental cost of making a flex-fuel vehicle is only $100-$150 per vehicle, including ethanol-compatible parts (no rubber or aluminum) in the fuel system and an engine control computer that can recognize the kind of fuel being used.[43] In 2006, thirty-three FFV models were offered in the U.S., and Ford, GM, and DaimlerChrysler each pledged to produce at least 500,000 ethanol-compatible vehicles within five years.

In Brazil, consumers historically had a choice between gasoline-only and ethanol only vehicles, but when the price of ethanol rose above the price of gasoline in the 1980s, consumer confidence in ethanol and ethanol-vehicles plummeted and the Brazilian public became wary of exclusive dependence on biofuels.[44] However, consumers have been returning to ethanol since the introduction of FFVs. In fact, in 2005 FFVs took more than half of the market for new vehicle purchases in Brazil, outselling conventional petrol-fueled vehicles for the first time since the 1980s.[45] FFVs enable the consumer to choose the fuel based on price, performance, branding, or personal preference, which helps ease the transition to a new fuel and has therefore increased consumer uptake of ethanol.

[38]U.S. Energy Information Agency (EIA). "Petroleum Products Consumption." Last Updated October 2006. Available online at: http://www.eia.doe.gov/neic/infosheets/petroleumproductsconsumption.html

[39]U.S. Government Accountability Office (GAO). *Biofuels: DOE Lacks a Strategic Approach to Coordinate Increasing Production with Infrastructure Development and Vehicle Needs*. Report to Congressional Requesters. June 2007.
Handbook for Storing, Handling, and Dispensing E85. Publication jointly prepared by the National Renewable Energy Laboratory (NREL) and the National Ethanol Vehicle Coalition. DOE/GO-1002001-956. April 2002.

[40]Currently warranties from most vehicle manufacturers become void if the owner runs a non-FFV vehicle on an ethanol blend higher than E10.

[41]Schnepf, Randy and Brent D. Yacobucci. *Ethanol and Biofuels: Agriculture, Infrastructure and Market Constraints Related to Expanded Production*. CRS Report for Congress (RL33928). March 16, 2007.

[42]OECD/IEA. "Biofuel Production." *IEA Technology Essentials*. January 2007. Available online at: http://www.iea.org/Textbase/techno/essentials2.pdf.

[43]E2. Environmental Entrepreneurs Newsletter. January 2007. Available online at http://www.e2.org/ext/jsp/controller?docId=9684&section=stateofunion.

[44]Moreira, José Roberto, Luiz Horta Noguiera, and Virginia Parente. "Biofuels for Transport, Development, and Climate Change." In *Growing in the Greenhouse: Protecting the Climate by Putting Development First*. Rob Bradley and Kevin A. Baumert (eds). 2005. Washington, D.C.: World Resources Institute.

[45]BBC News. "More Brazil Cars Run on Ethanol." January 11, 2006. Available online at: http://news.bbc.co.uk/2/hi/business/4602972.stm.

The primary disadvantage of FFVs is that they are currently less fuel-efficient than gasoline vehicles. This is partly a function of automakers' strategies to take advantage of opportunities created by CAFE policies (see Box 9): many automakers offer E85 versions of only their largest models. However, the lower efficiency is primarily a result of today's vehicles not being optimized for ethanol. The fuel economy of ethanol-powered vehicles could be improved — and even surpass that of today's standard gas engines — if manufacturers optimized their products, using a combination of existing and developing technologies, to take advantage of ethanol's fuel combustion properties. It is unclear, however, if this could be achieved in a FFV, and it is more likely that current research will enable E85-only vehicles to achieve this greater efficiency. These vehicles will not have broad market penetration until E85 fuels become widely available and are competitively priced with ethanol, which is not likely in the near-term.

Many companies have taken an interest in this opportunity nonetheless (see Box 5), and the private sector is receiving a great deal of public support for this undertaking. In August 2007, the U.S. Department of Energy awarded more than $15 million in funding for research aimed at optimizing FFV engines by taking advantage of ethanol's high octane.

Biodiesel

Biodiesel, the other widely used biofuel, can be made from many feedstocks including canola (or rapeseed), soybean, palm, sunflower, and other oil-seed crops, as well as organic waste materials such as waste cooking oil or animal fats. Today, soybean is the primary feedstock for biodiesel in the U.S., Brazil, and Argentina. In the E.U., three quarters of domestic biodiesel production uses rapeseed as a feedstock. Palm oil is the feedstock of choice in Southeast Asia and is considered a possibility in parts of South America and Africa, and jatropha is grown for biodiesel in drier climates such as India and parts of Africa. Soybeans are not a very land-efficient crop for converting to fuel (see Figure 6). Palm oil has a much greater yield per acre, but as discussed below, these acres sometimes come at the expense of rainforests and other high conservation value lands.

The feedstock transport logistics associated with biodiesel production are less of a problem than with starch-based ethanol production, because the oil-based feedstocks are denser than starch or cellulose, making transport more cost-effective. Further, production of biodiesel is based on simpler technology, which is economically viable even at relatively small scales. This not only reduces some logistical challenges related to infrastructure, but

Box 5: Private Interest and Public Support for Research to Optimize Ethanol Vehicle Engines

While FFVs are currently not designed to take advantage of ethanol's high octane levels, the private sector is actively investing in new technologies to capitalize on these fuel properties and increase engine efficiency. These companies have received strong financial backing from the U.S. government.[46]

Delphi Automotive Systems LLC is currently developing a vehicle with an E85-optimized engine that achieves 30 percent greater fuel efficiency than current flex-fuel vehicles. Delphi has received $2.2 million from the U.S. Department of Energy (DOE) to help fund the project.

General Motors Corporation is developing a cooled exhaust gas recirculation combustion prototype, which will allow for a smaller engine without sacrificing any power. GM is already a world leader in the production of FFVs. In 2007, the company offered 16 E85-compatible models and planned to produce 400,000 FFVs.[47] GM will receive up to $1.9 million toward their advanced FFV research from DOE.

Siemens Governmental Services, Inc. is investing in a turbo-charged, direct-injection engine that runs on E85, seeking to improve efficiency and combustion while reducing emissions. DOE has agreed to provide up to $3 million in funding for Siemens' endeavor.

Ford Motor Company is examining the potential for using a smaller, more fuel-efficient engine when ethanol is used as a fuel. Ethanol in place of gasoline reduces the damaging spontaneous combustion of fuel in the engine ("knock"), which allows for the use of technologies such as turbocharging and higher compression ratios that can more than double an engine's power. Using ethanol as the primary fuel, these technologies would allow engines of half today's size to generate the same amount of power. DOE has agreed to provide up to $3.2 million for the project.

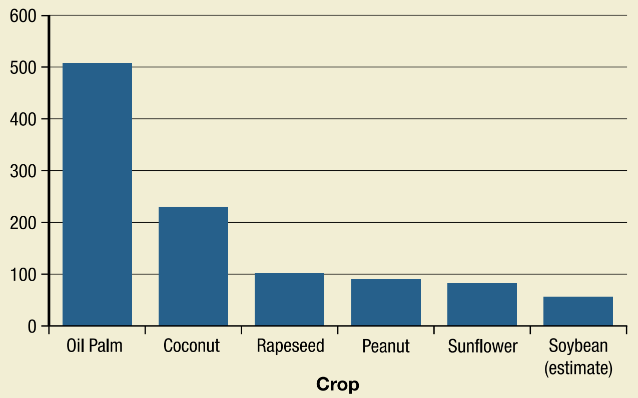
Robert Bosch LLC, in partnership with U.K.-based Ricardo company and the University of Michigan, is developing hardware modifications with novel sensing and control strategies which, when applied to a flex-fuel vehicle, will achieve fuel efficiency equivalent to vehicles fueled by conventional gasoline.

Visteon Corp. is teaming with DOE's Argonne National Laboratory, U.K.-based Mahle Powertrain, and Michigan State University to develop a flex-fuel engine system that achieves the same efficiency as conventional engines by reducing thermal, dynamic, and volumetric efficiency losses. DOE is providing up to $2.3 million to support the project.

[46] U.S. DOE Press Release. "DOE Provides up to $21.5 million for Research to Improve Vehicle Efficiency." August 7, 2007. Available online at: http://www.energy.gov/news/5298.htm.

[47] General Motors. "GM Leads Industry with More Vehicles that Achieve 30 Miles Per Gallon." Available online at: http://www.gm.com/corporate/responsibility/environment/news/2006/epa_fuel_economy_101806.jsp.

Figure 6: **Biodiesel Fuel Yields**



Source: Earth Policy Institute[48]

also increases the opportunity for smaller-scale producers to enter the market, increasing local economic and development benefits. However, it is not clear that small producers can refine and purify the product enough to meet modern fuels standards.

The technology for converting oils to biodiesel is a relatively easy and well-established process. Most biodiesel plants use what is called *base transesterification*, which refers to the process of mixing an oil feedstock with an alcohol via a catalyst. The reaction takes place at a low temperature, meaning that biodiesel conversion has a relatively low energy input requirement compared to other alternative fuels.

Biodiesel has many other benefits over ethanol. Unlike ethanol, biodiesel can easily be incorporated into the fuel mix at any blend level without infrastructure or vehicle modifications, and can be used in pure form with only minor fuel system alterations.[49] Biodiesel also meets and often exceeds the quality of petroleum-based diesel for most fuel properties. For instance, biodiesel has very similar combustion properties to diesel but has a higher cetane number[50] and better lubricity than petroleum diesel, meaning that biodiesel provides superior performance. It also has a higher flash point than petroleum diesel, making it safer to handle.[51] On the downside, biodiesel does not quite measure up to diesel in cold weather performance, as it begins to congeal when temperatures dip to freezing, creating usability issues in many regions.

Biodiesel use is currently relatively low, with just over 1.6 billion gallons (6 billion liters) consumed worldwide in 2006, compared to 9.6 billion gallons (38 billion liters) of ethanol. However, biodiesel is gaining market share around the world. It already accounts for approximately 80 percent of the biofuels used in the E.U. and is the fastest growing fuel in the U.S.

However, the burgeoning market for biodiesel is stimulating demand for feedstocks internationally, especially for rapeseed oil from the U.S. and Canada, palm oil from Southeast Asia, and soybean oil from South America. Recent news reports attributing deforestation in Indonesia to energy-related demand for palm oil call into question the carbon benefits often attributed to biofuels combustion.[52]

Next-generation fuels

The vast majority of biofuels investment around the world continues to be in proven technologies. However, the much-discussed "cutting edge" in ethanol production generally refers to converting new *lignocellulosic* feedstocks to alcohol to produce what is known as cellulosic ethanol. Lignocellulose includes the cellulose, hemicellulose, and lignin. These compounds are the primary materials in green plants, making up the cell walls in stalks, leaves, grasses, and even trees. The fuel conversion technologies for these feedstocks are often called "second-" or "next-generation" as they are still in the R&D stages or are still proprietary and not yet available at commercial scale. However, it is widely expected that cellulose-based fuels will make an important contribution to the global fuel mix in the medium- to long-term.

Cellulosic ethanol may be the apparent leader among emerging next-generation technologies, but it is not the only option. Additional prospects for these advanced fuels include Fischer-Tropsch fuels, biobutanol and octanol, which are discussed below. Methanol is another alternative fuel option, but toxicity concerns have largely prevented broader acceptance of this fuel to date.

The potential benefits of cellulosic fuels over today's biofuels are numerous. Some of these fuels offer handling and performance advantages, and many offer energy and GHG balance benefits as well, although this is not necessarily the case for all next-generation fuels. The promise of next-generation biofuels will depend on a number of factors; as with grain-based ethanol, not all cellulosic fuels are created equal. The type and scale of potential benefits vary according to the feedstock and the process, of course, but

[48]Brown. 2006.

[49]Fulton, et. al. 2004.
Note: While biodiesel has been widely sold through existing retail equipment, the equipment has not been certified for biodiesel distribution. There has been little study of the long-term risks of using this equipment.

[50]A fuel's cetane number reflects its ability to autoignite: higher values indicate quicker fuel ignition. Petroleum diesel's cetane numbers range from 40-52 and biodiesel's range from 45.8-56.9 (Radich, Anthony. *Biodiesel Performance, Costs, and Use*. U.S. Energy Information Administration. June 8, 2004. http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/).

[51]U.S. Department of Energy. Energy Efficiency and Renewable Energy. Alternative Fuels and Advanced Vehicles Data Center. http://www.eere.energy.gov/afdc/fuels/biodiesel_benefits.html.

[52]Rosenthal, Elisabeth. "Once a Dream Fuel, Palm Oil May Be an Eco-Nightmare." *New York Times*. January 31, 2007.

they include a diverse array of perennial feedstocks requiring less intensive management than annual grains, a potential reduction in competition for food crops, and a significant reduction in demand for fossil fuels during processing. These benefits are widely anticipated, but cannot be taken for granted, as commercial-scale production has not yet been demonstrated.

New feedstocks and fuels

While today's fuels are produced from crops, next-generation technologies will be able to produce fuel from lower-maintenance feedstocks like agricultural residues, trees, native grasses (e.g., switchgrass and miscanthus), and algae.

Next-generation feedstocks generally have more biomass yield per acre than corn because the technology enables conversion of the cellulose rather than just the kernel, and there is significantly more cellulose than kernel per plant. The USDA estimates that with next-generation technologies, the U.S. could produce the equivalent of one third of its transport fuel requirements from biomass, using forest products and agricultural residues.[53] As discussed, an acre of corn currently yields between 350 and 400 gallons of ethanol (3,200-3,700 liters per hectare), but with next-generation technology using the corn stover as well as the kernel, one acre could yield close to 600 gallons (5,600 liters per hectare).[54] However, corn stover has historically been left in the field after the harvest to protect against soil erosion, enrich the soil, and conserve moisture. Several studies are underway to determine what effect removing the stover from harvested fields would have going forward. Initial results estimate that removing more than 25 percent of corn stover from the field would not be sustainable.[55]

For switchgrass, yields are currently lower than for corn stover. One Iowa-based project currently harvests 4 tons per acre (9 metric tons per hectare), but expects yields to increase to 6 tons per acre (13 metric tons per hectare) during commercial operation. However, as DOE noted, native grasses like switchgrass have not yet been intensively modified or engineered to improve their yields as crops. As a result, potential efficiency gains for these crops far exceed those of more traditional crops.[56] Switchgrass yields are roughly 400 gallons per acre (nearly 4,000 liters per hectare), which breaks down to 5 tons per acre (11 metric tons per hectare) and 80-90 gallons per ton (335-375 liters per metric ton).[57] This yield is expected to increase to 1,000 gallons per acre (nearly 10,000 liters per hectare) over the next decade, with a doubling of the feedstock production yield to 10 tons per acre (22 metric tons per hectare), and slight improvements in the fuel conversion yields to 100 gallons per ton (417 liters per metric ton).[58]

Some more obscure next-generation feedstock options under development include producing ethanol and biodiesel from algae or mold (see Box 6). According to some technology developers, algae are capable of producing ten to thirty times more oil per acre than the crops currently used for biofuels production. Additionally, algae can be grown in saltwater ponds on non-arable land, reducing and even eliminating the competition for fertile land.

Box 6: Algae Companies

Algae-based biofuels are a promising technology that has been less publicized than some other biofuels. Several universities and companies are currently engaged in research and demonstration, with the hope of eventually reaching commercialization.

GreenFuel Technologies has developed an algae bioreactor system that converts CO_2 in smokestack gases into biofuels through their patented "Emissions-to-Biofuels" process. The flue gas is introduced into the bioreactor where GreenFuel claims to produce algae growth rates exceeding any other process. Using standard technology, the algae is then extracted and converted to a range of biofuels, depending on the conversion process used (e.g., fermentation, transesterfication, or gasification). The company set up operation of its bioreactor on the RedHawk power plant in Arizona and announced in November 2006 that they had successfully recycled CO_2 from the plant to produce fuel. However, the process requires further refinement before GreenFuel will be able to commercialize its product. The Arizona project was suspended because it produced more algae than the company had capacity to convert to fuel. Using lessons from that experience, GreenFuel is now providing their technology to The Sunflower Integrated Bioenergy Center project in Holcomb, Kansas.[59]

GreenShift is a business development corporation whose mission is to develop and support companies and technologies that catalyze transformational environmental gains. They have invested in companies developing a number of technologies—among them, a process for converting algae and carbon dioxide into ethanol and biodiesel.

General Atomics is a California-based government contractor that specializes in defense and energy-related technologies. In 2007 the company opened an office in Carlsbad, New Mexico to develop biodiesel from saltwater microalgae.

[53]Perlack, R.D.; Wright, L.L.; Turhollow, A.F.; Graham, R.L.; Stokes, B.J.; and Erbach, D.C. *Biomass as Feedstocks for a Bioenergy and Bioproducts Industry: The Technical Feasibility of A Billion-Ton Annual Supply*. (Report No. ORNL/TM-2005/66). Oak Ridge National Laboratory. April 2005.

[54]Baker, Allen and Steven Zahniser. "Ethanol Reshapes the Corn Market." *Amber Waves*. April 2006. Available online at: http://www.ers.usda.gov/AmberWaves/April06/Features/Ethanol.htm.

[55]Blanco-Canqui, H.R., Lal, R., Post, W.M., Izaurralde, R.C., Owens, L.B. "Corn stover impacts on near-surface soil properties of no-till corn in Ohio." *Soil Science Society of America Journal*. 2006. 70:266-278.

[56]U.S. Department of Energy. *Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda*. DOE/SC-0095. June 2006.

[57]Crooks, Anthony. "From Grass to Gas." *Rural Cooperatives*. 73:5. September/October 2006. USDA. Available online at: http://www.rurdev.usda.gov/rbs/pub/sep06/grass.htm.

[58]Hladik, Maurice. "Cellulose Ethanol Is Ready to Go." Presentation to the Renewable Fuels Action Summit. June 12, 2006. Available online at: http://dorgan.senate.gov/documents/events/renewablesummit/hladik_iogen.ppt.

[59]GreenFuels. "Testing Of Coal-Based Algae-To-Biofuels System Begins At Sunflower Integrated Bioenergy Center." News Release from Prime Newswire. July 17, 2007. Available at: http://www.greenfuelonline.com/gf_files/KansasSunflower_PR.pdf.

Biobutanol is another oft-referenced alternative fuel. Today, butanol is primarily used as an industrial solvent, but like ethanol it can also be a gasoline replacement. The feedstocks for biobutanol are the same as for ethanol: it can be produced from corn or starchy feedstocks. Several organizations and companies are currently working on producing biobutanol from cellulosic feedstocks as well (see Box 7). Biobutanol is superior to ethanol in that it has a higher energy content, closer to that of gasoline, and can be used with existing distribution infrastructure. However, historically it has not been as attractive as ethanol because conversion yields have been far lower. Thus companies seeking to commercialize biobutanol must improve the conversion cost and the yield.

Box 7: Research on Biobutanol from Cellulose

Several companies and government agencies are investigating processes to produce butanol from cellulose feedstocks. Most of this research is taking place in the U.K. and in California.

Several well-known brands are getting in on this technology. **BP** and **DuPont**, for instance, have teamed up to commercialize biobutanol in the U.K. by the end of 2007. They have invested $400 million to construct an ethanol plant on BP's existing chemicals site at Saltend, Hull, U.K. This plant will also serve as a demonstration facility for biobutanol, once the technology becomes available.[60]

Using a similar model, in 2007 **BlueFire Ethanol** filed for a permit for a new cellulosic ethanol production plant that will serve as a future demonstration facility for BlueFire's bio-butanol production process.

Gevo Inc., a spinoff from **Caltech**, has received financing from **Khosla Ventures** and **Virgin Fuels** to produce biobutanol and other advanced biofuels from a variety of biomass feedstocks.

Green Biologics, a U.K.-based biotechnology company, has received $1.1 million in funding to support development of its fuel biobutanol product — Butafuel — from cellulosic biomass. The U.K. Department of Trade and Industry is providing nearly half the funding, while shareholders are providing the rest.[61]

U.S. government agencies are also supporting the development of this technology. In 2007 the U.S. Environmental Protection Agency (EPA) awarded a Small Business Innovation Research contract to **Integrated Genomics Inc.** to develop a method for producing butanol from biomass that is competitive with the ethanol now being produced for fuel.[62] Scientists at the USDA Agricultural Research Service are exploring the production of cellulosic biobutanol from wheat straw.

Conversion pathways

The leading biofuel conversion pathway is **biochemical**, which involves a two-fold process that uses enzymes to break down the cellulose to sugars and converts the sugars to fuel. In the initial stage, the non-lignin portions of the plant material must be broken down into fermentable sugars. This process, called **saccharification**, is more complex than breaking down starch into sugar; a variety of pathways, including chemical, thermal, and biological, are still under exploration. Once the saccharification process is complete, the sugars must be fermented to ethanol, as in today's ethanol production.

Many saccharification technologies are currently in development and not yet available at commercial scale. Much of today's research involves developing the exact enzymes for each feedstock that will reduce the conversion costs to a level that will allow for large-scale commercialization. Substantial progress has already been made: since 2001, private and publicly funded research labs have reduced the cost of enzymes required to produce a gallon of cellulosic ethanol from $5 per gallon to less than $0.20 per gallon.[63]

Another process under development for converting cellulose into fuel is **thermochemical**; this pathway is often referred to as biomass-to-liquid (BTL). There are three main thermochemical conversion processes: gasification, pyrolysis, and direct hydrothermal liquefaction.

Gasification involves heating biomass with a limited amount of oxygen to create a synthesis gas, or syngas. In the gasification process, the lignin (the non-fermentable portion of the plant material), which is typically 25-30 percent of the biomass, can also be used, greatly expanding the resource base.[64] Syngas is converted to fuel through **Fischer-Tropsch** synthesis, which uses catalysts to convert the syngas into a range of liquid hydrocarbon fuels. After conversion, the products must be refined, but these fuels require no additional infrastructure; the diesel produced can be used in current distribution systems and the gasoline produced is suited as a petrochemical feedstock.

[60] BP. "BP, ABF and DuPont Unveil $400 Million Investment in UK Biofuels." BP Global Press Release. June 26, 2007. Available online at: http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7034350.

[61] "Green biologics awarded £560,000 to boost 'green' fuel development." Government News Network. January 22, 2007. Available online at: http://www.gnn.gov.uk/content/detail.asp?NewsAreaID=2&ReleaseID=258179.

[62] "Chicago Company Wins EPA Innovation Research Contract." PRNewswire. March 1, 2007. Available online at: http://www.prnewswire.com/cgi-bin/stories.pl?ACCT=104&STORY=/www/story/03-01-2007/0004537868&EDATE=.

[63] "Novozymes Wins Technology Leadership Award for Biofuels Achievement." Press release from Novozymes website. July 25, 2005. http://www.novozymes.com/en/MainStructure/PressAndPublications/PressRelease/Novozymes+Wins+Technology+Leadership+Award+for+Biofuels+Achievement.htm.

[64] Environmental and Energy Study Institute. *Cellulosic Ethanol State-of-the-Art Conversion Processes*. January 8, 2006. Available online at: http://www.ef.org/documents/ce_conversion_factsheet_ef_eesi_final_1-08-07.pdf.

Fischer-Tropsch conversion is an established technology. In South Africa, for example, Johannesburg-based Sasol built Fischer-Tropsch coal-to-oil plants to secure the country's fuel supply during the trade boycotts of the apartheid years and has been producing fuel ever since. In recent years, European governments and companies have pioneered research on this process (see Box 8), but the cost — particularly the high capital outlays — is still a major barrier.[65] Widespread commercial availability of gasification systems suitable for integration with fuels synthesis has not yet been realized.

The other thermochemical conversion pathways, **pyrolysis** and **direct hydrothermal liquefaction**, are less likely to yield significant contributions to the fuel mix given that their products are better suited to stationary power production, but are still worth noting as BTL processes.[66]

Box 8: NExBTL

Finland-based **Neste Oil** has developed a process to convert vegetable oil or animal fat into a synthetic diesel fuel.[67] This next-generation biofuel, called NExBTL, has fuel characteristics similar to Fischer-Tropsch fuels. Neste has arranged for the supply of animal fat and rapeseed oil from Finnish companies to begin production of NExBTL at a rate of 170,000 metric tons per year.

Neste Oil is working with the city of Helsinki and several private companies to run tests of the fuel's application. Neste is also developing biodiesel using gasification and Fischer-Tropsch synthesis of cellulosic materials. While the company expects that the fuel product will not differ from their current product, the technology will enable conversion of the whole plant, thereby widening the feedstock base. Neste estimates having a commercial-scale production facility built by 2015.

None of these processes is yet available at commercial scale, and they remain quite capital intensive. It is, in fact, quite difficult to know the status of these technologies as the companies developing what they hope will be *the* fuel of the future are not especially keen to divulge much information about their proprietary processes or products. Despite these barriers, however, conversion of cellulosic feedstocks is widely believed to be the future of the biofuels industry, because it offers so many benefits and so few drawbacks as compared to today's technologies.

Expected advantages of next-generation fuels

The primary advantage of next-generation fuels is their reduced environmental footprint relative to today's technologies. Preliminary analyses indicate more substantial environmental benefits from cellulosic than from grain-based ethanol. Corn is an energy-intensive and soil-depleting crop, while cellulosic ethanol can be produced from native crops (e.g., switchgrass) that generally require less fertilizer and are far easier to grow and maintain between harvests. These feedstocks have lower well-to-wheel GHG emissions and less negative impact on water quality in surrounding areas due to reduced soil erosion and nutrient runoff. Moreover, in some next-generation processes, the lignin that cannot be converted to ethanol can be burned to power the production facilities, just as bagasse is burned to provide process energy for ethanol produced from sugarcane in Brazil. Estimates suggest that the use of cellulosic ethanol instead of conventional gasoline would reduce net GHG emissions by between 70 and 90 percent— a significant reduction.[68]

Further, because the food and biofuels industries currently use the same parts of the plant, they are in competition over crops. Cellulosic-based fuels are derived from the leaf and stalk portions of plants or from dedicated energy crops, neither of which are part of animal diets, meaning that biofuels production will compete less directly with food supply. However, simply because the food and fuel markets will no longer be in direct competition once cellulosic technologies are commercially available, the "food versus fuel" problem will not be fully resolved. As cellulosic feedstocks must still be grown on arable land, competition over land use will remain an issue, and any expansion of biofeedstock production will likely put pressure on land used for food production. One advantage of cellulosic biomass, however, is the higher yields per acre versus corn, which may alleviate some of this land-use pressure.

[65] Worldwatch Institute, 2007.

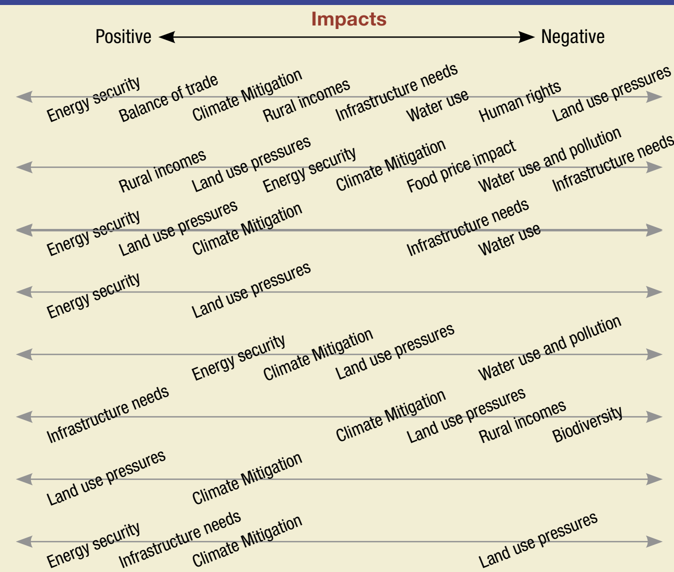
[66] For further information on these processes and fuels, please see: Worldwatch, 2007; and Kavalov, B. and S.D. Peteves. *Status and Perspectives of Biomass-to-Liquid Fuels in the European Union*. EUR 21745. Petten, the Netherlands: European Commission DG Joint Research Center. 2005.

[67] Neste Oil. *Annual Report 2006*. Available online at: http://2006.nesteoil-webannualreport.com/web/pdf/annualreport2006.pdf

[68] Fulton, et. al. 2004.

Table 1: **Impacts of Selected Biofuels Technologies**

Feedstock	Process	Fuel	Cost
Sugar (sugar beets, sugarcane, sorghum)	Crushing and fermentation		$
Starch (corn, wheat, cassava)	Conversion to sugar and fermentation		$$
Agricultural residues (stover)			
Energy crops (switchgrass, miscanthus)	Saccharification and fermentation	Ethanol (or biobutanol)	$$$
Oilseed (canola, jatropha)			
Palm oil	Transesterification	Biodiesel	$$
Algae			
Biomass	Fischer - Tropsch	synthetic gasoline and diesel	$$$



Source: World Resources Institute

The challenge of getting to scale

Today's technology for grain- and oilseed-based "first generation" biofuels production is well understood and available. Countries around the world are blending biofuels into gasoline and diesel with the hopes of reducing petroleum imports and GHG emissions, and supporting rural incomes. But the scale of this deployment is still relatively small. To meet the challenge of climate change and displace large proportions of carbon emissions from fossil fuels, biofuels would need to significantly expand their role. Is this feasible?

The wedges concept is rooted in the idea that multiple technologies, rather than a single "silver bullet", are required to address climate change. However, biofuels are the only technology considered that addresses energy supply for transportation (though others are based on technologies that moderate transport energy demand through greater efficiency and reduced vehicle mileage). The key question for this report, therefore, is not whether biofuels can or should be promoted for marginal contributions to energy security or environmental sustainability. Rather, the key question is whether or not biofuels can actually achieve a significant (wedge-sized) emissions reduction by 2050, as envisioned by Pacala and Socolow, and what types (and acceptability) of impacts this scale of production would entail.

In the Princeton analysis, it is possible to produce enough biofuels to reduce emissions by one gigaton of carbon with several key assumptions. An emissions reduction of this scale implies replacing a fleet of two billion cars running on conventional fuels with cars running on ethanol. This would require an ethanol program producing more than 250 billion gallons (1,000 billion liters) of ethanol per year, roughly 50 times larger than either the Brazilian or U.S. program, or 20 times larger than today's total global production.[69]

How plausible is this? First, it assumes productivity of 100-150 GJ per hectare of land (1,200 – 1,700 gallons of ethanol per acre or 5,000 – 7,000 liters of ethanol per hectare) — roughly equivalent to what is currently achieved for sugarcane-based ethanol in Brazil, but twice today's conversion rate for ethanol from corn in the U.S. Doubling the energy conversion efficiency of grain-based ethanol production would require advances in production and conversion that are certainly plausible. As discussed, there are companies, university researchers, and government agencies seeking to realize these efficiency improvements for corn-to-ethanol conversion through genetic engineering and process improvements, and dedicated energy crops will also contribute significantly. But these improvements over a given timeframe are uncertain.

[69]Carbon Mitigation Initiative (CMI). *The Wedge from Substituting Biomass Fuel for Fossil Fuel*. Princeton University, Princeton Environmental Institute. August 16, 2005. Available online at: http://www.princeton.edu/~cmi/resources/Wedges/Biomass%20fuel%20for%20fossil%20fuel8.16.pdf.

Second, the calculations assume that vehicles are optimized for ethanol, meaning they are specifically engineered to take advantage of ethanol's high octane rating, and can therefore convert the fuel into energy for driving with greater efficiency than engines designed for conventional fuel. In the Princeton analysis, ethanol vehicles get 80 miles per gallon in 2054, compared with their reference vehicles which get 60 mpg. While this kind of improvement is technically feasible, achieving efficiencies of 80 mpg on ethanol is an enormous increase from today's ethanol-powered vehicles, which frequently do not get over 20 mpg. Today's vehicles are optimized to run on conventional fuel. Current flex-fuel models are not designed to take advantage of the fuel properties of ethanol; in fact, due to ethanol's lower heat content, they are 25 percent less fuel efficient when filled with E85 rather than gasoline, as discussed above.

Finally, the Princeton analysis does not include the "full lifecycle" carbon emissions of biofuels production, meaning the CO_2 emissions resulting from the fossil fuel inputs associated with feedstock production, including fertilizer production and application, or from the conversion process.[70] Accounting for these additional GHG emissions in the life-cycle analysis of biofuels would decrease the GHG benefit achieved from one mile driven on biofuels instead of gasoline. This means that even more displacement would be required to achieve a wedge than originally calculated.

Despite these optimistic assumptions and calculations, the biofuels wedge, as envisioned by Pacala and Socolow, still requires the equivalent of one-sixth of the world's agricultural land (around 618 million acres, or 250 million hectares). Given the constraints seen even today on diverting arable land and food crops for fuel production, it is not clear that this would be a viable long-term strategy. To some extent, new biofuels crops capable of growing on marginal lands less suitable for traditional agriculture will help alleviate this concern. However, land-use competition does not disappear. Biofuels production will compete for land with agriculture, human developments, forests, and other natural habitats. All of these present an opportunity cost.

As technologies improve and as food markets and land-use practices adjust, biofuels may still be able to make a major contribution to reducing GHG emissions. Biofuels are likely to be one component of a solution to transport needs, rather than the whole or even the most important component of such a solution. That said, maximizing benefits and minimizing disadvantages associated with large-scale biofuels use requires significant and integrated input from the policy and financial worlds.

[70]Carbon Mitigation Initiative (CMI). *The Wedge from Substituting Biomass Fuel for Fossil Fuel*. Princeton University, Princeton Environmental Institute. August 16, 2005. Available online at: http://www.princeton.edu/~cmi/resources/Wedges/Biomass%20fuel%20for%20fossil%20fuel8.16.pdf.

Policy

Generally speaking, policies based on promoting a single, government-chosen technology have an unenviable track record. Biofuels represent a case in which a particular technology, or set of technologies, has been selected for achieving several intertwined policy goals. The result is that some biofuels policies do little or no good for — and sometimes even harm — the environmental, economic, and energy security goals they are supposed to advance.

This section approaches this challenge by first asking what problems biofuels are supposed to help us fix. It then looks at the track record of some of today's policy frameworks and where they fall short. It considers some of the perverse impacts that these policies can have, and in some cases are already having. Finally, this section examines some ways in which policy can be driven more explicitly by the public good that it is supposed to serve.

What is the purpose of biofuels policy?

Biofuels policy lies at the intersection of many overlapping and occasionally competing policy priorities, including energy security, trade, agriculture, and transport. Each of these policy arenas relates to biofuels and affects the industry's development. Policies intended to promote certain interests in one area can at times be inconsistent with policies conceived in another, and can have competing influences or unintended consequences in the development of biofuels. Given this complexity, policy makers must take a broad perspective when approaching biofuels policy.

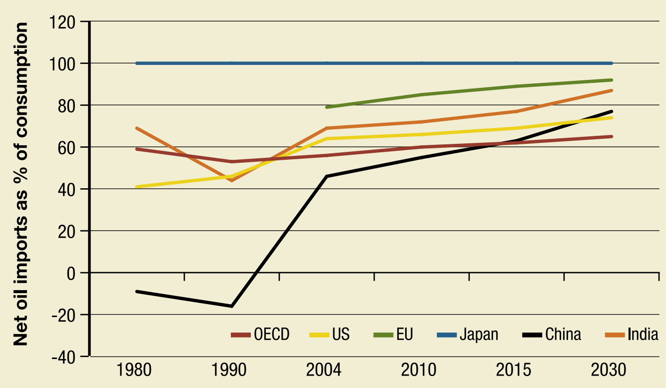
Improving energy security by reducing oil dependence

The cost and security of oil supplies occupy the top rank of policy concerns for many countries, and this pressure is likely to increase over time. Some commentators believe that the world is at the point of "peak oil," beyond which production will inevitably decline as economically exploitable reserves are exhausted.[71] Others reject this idea, but nevertheless consider that the world may be headed for a crunch in available oil supplies due to political constraints and underinvestment, coupled with rapidly growing demand in emerging economies. Either way, measures to limit the dependence of advanced and rapidly emerging economies on oil appear likely to be important priorities, as such reductions can stimulate markets for alternative energy sources, thereby diversifying risk and improving energy security.

Improving balance of trade

Apart from security and other concerns over oil, many major economies are heavily dependent on oil imports (see Figure 7). At sustained high oil prices, these imports will impact their balance of trade.[72]

Figure 7: **Oil Import Dependence of OECD and Select Countries, 1980-2030**



Source: OECD/IEA[73]

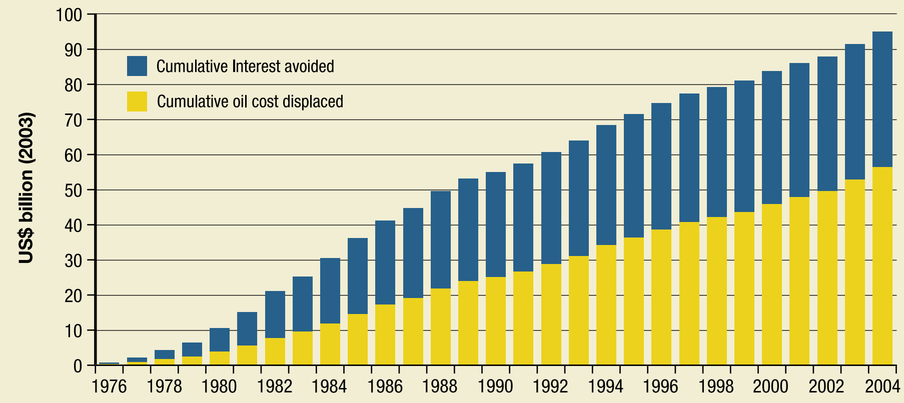
[71]See *The End of Cheap Oil*, National Geographic Magazine, June 2004 for a review of this issue. Matthew Simmons is perhaps the best known voice in arguing that declared oil reserves are gravely overstated. See Matthew Simmons. *Twilight in the Desert: the Coming Saudi Oil Shock and the World Economy*. Hoboken, NJ: Wiley. 2005.

[72]U.S. Energy Information Administration (EIA). *Annual Energy Outlook 2007: With Projections to 2030*. DOE/EIA-0383(2007). February 2007.

[73]OECD/IEA. *World Energy Outlook*. 2006.

Many look to the experience of Brazil. Since 1975, Brazil's ethanol program has greatly reduced the country's oil imports. During much of this period, oil imports were financed through external debt, so reduced spending on imports has also reduced debt service costs. In all, Brazil's external debt is approximately $100 billion lower today than it would have been in the absence of its biofuels production (see Figure 8).[74]

Figure 8: **Cumulative Savings from Avoided Oil Imports and Debt Service**



Source: World Resources Institute[75]

Balance of trade concerns are also important for wealthy countries such as the U.S. and E.U., which import more than 60 and 80 percent of their oil, respectively. While large regional trade imbalances are not inherently problematic, with fluctuating oil prices the impact on balance of trade is a political concern. Moreover, in some political environments, tough talk of reducing reliance on foreign suppliers or dangerous and unfriendly regimes also holds sway.

Raising rural incomes

Biofuels production can contribute significantly to the incomes of investors, land owners, and workers in certain rural areas. In Brazil, the biofuels sector is a major employer. While evidence on net employment impacts is largely anecdotal, advocates claim that the sector provides one million jobs in all, one third of which are seasonal.[76] Although working conditions on sugar plantations can be hard, sugarcane workers in the state of São Paulo on average receive wages that are 80 percent higher than the agricultural sector average, and are roughly equal to the median wage in the service or industrial sectors.[77]

This ability to create jobs in rural areas, most of them for unskilled workers, has made sugarcane plantations attractive, particularly in developing countries. Enhancing rural incomes is particularly appealing in countries experiencing a large-scale migration from rural communities into the cities and struggling to stem the tide.

The addition to rural incomes is not confined to developing countries. The powerful farm lobbies in the E.U. and U.S. also give strong support to biofuels as a boost to incomes. In 2006, for instance, U.S. farm income from corn was up $3.2 billion from the previous year and income from soybean remained steady due to strong demand for biofuels.[78] The boost may not all go to rural communities; large agro-industrial corporations have also benefited from the support for biofuels. Nevertheless, the concept of producing biofuels to support farm income retains a powerful political appeal.

Reducing greenhouse gas emissions

Particularly in the European Union, biofuels are considered an important component of climate change policy. Indeed, the E.U.'s biofuels policy stems from the European Climate Change Programme. However, as noted earlier (see Figure 3), the GHG emissions profiles of different biofuels vary widely.

One popular way to power new ethanol plants is with coal, which is a major reason why much grain ethanol is barely less GHG-intensive than gasoline. Brazilian ethanol, which has a far better GHG profile than U.S. grain ethanol, is charged a hefty import tariff by several countries, including Australia, the E.U., and the United States. Hence, a policy based on lifecycle GHG emissions performance would look vastly different from what is seen in practice today.

The political justification for biofuels policy has shifted slightly in recent years. The rising profile of climate change in policy considerations has meant that policies initially implemented to enhance energy security and support agriculture are now increasingly

[74]Moreira, et. al. 2005.

[75]Moreira, et.al. 2005.

[76]Guilhoto, J.M.M. Geração de emprego nos setores produtores de cana de açúcar, açúcar e álcool no Brasil e suas macro-regiões; Relatório Cenários para a produção de açúcar e álcool. São Paulo: MB Associados e FIPE. 2001.

[77]Smeets, Edward, Martin Junginger, André Faaij, Arnaldo Walter, Paolo Dolzan. *Sustainability of Brazilian Bioethanol.* Study commissioned by SenterNovem, The Netherlands Agency for Sustainable Development and Innovation. August 2006. Available online at: http://www.bioenergytrade.org/downloads/sustainabilityofbrazilianbioethanol.pdf.

[78]U.S. Department of Agriculture, Economic Research Service. 2006. Available online at: http://www.ers.usda.gov/Briefing/FarmIncome/2006incomeaccounts.htm.

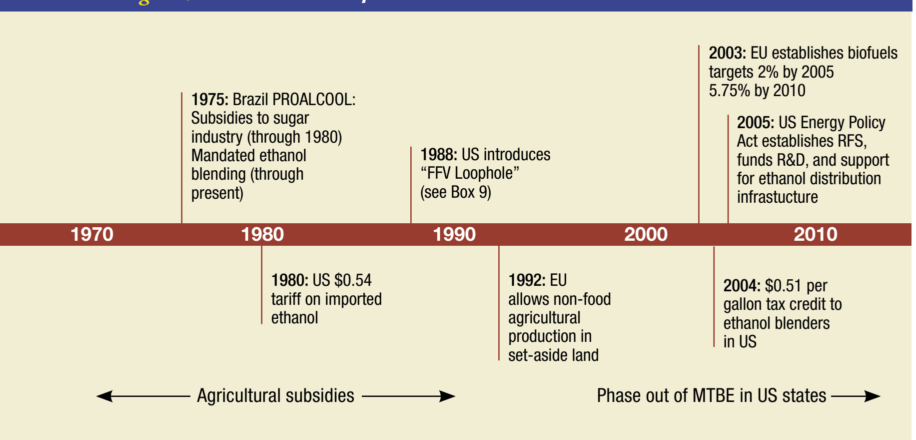
rationalized and defended on the basis of their climate mitigation potential. Policy makers who justify support for biofuels on the grounds that they help to combat climate change then must ensure that they are supporting biofuels that actually achieve this aim.

Biofuels policy today

As noted, the primary drivers of government support for biofuels are growing increasingly strong. Many countries are looking to biofuels to help address these issues. In the OECD, the estimated value of the total support to agricultural producers in 2005 was $280 billion.[79] Consumption gets a boost as well. Argentina, Australia, Brazil, Canada, China, Colombia, the European Union, India, Indonesia, Malaysia, New Zealand, the Philippines, Thailand, and the United States have all adopted targets — some binding — aimed at offsetting growing petroleum demand with increased biofuels consumption.

Despite widespread support, there are only three major markets for biofuels today: Brazil, the E.U., and the U.S. These countries' regulations and subsidies shape the global development of biofuels (see Figure 9). Each country's policy has evolved primarily as a function of the particular circumstances of the local agricultural sector.

Figure 9: **Timeline of Key Biofuels Policies**



Brazil

The Brazilian biofuels industry has a long history, dating as far back as the introduction of the automobile. The industry expanded, however, during the mid-1970s when Brazil faced two seemingly unrelated challenges. At the time, the country was heavily dependent on foreign oil, importing 80 percent of its supply. The OPEC oil embargo of 1973 highlighted a precarious dependence on oil imports and high prices were straining Brazil's external trade balance. At the same time, Brazil's domestic sugar industry was suffering as the international market price for sugar was at historic lows. Sugarcane farmers were seeking an alternative — and more lucrative — market for their crops.[80]

In response, the government formed a National Alcohol Program, PROALCOOL, in 1975. PROALCOOL provided agricultural subsidies to the ailing sugar industry and allowed surplus sugarcane to be converted into ethanol, which was to be blended with gasoline to lessen dependence on foreign oil. Through PROALCOOL, the government offered low-interest loans and credit guarantees to sugarcane producers to encourage construction of distilleries in existing mills and development of new refineries. Brazil also used its national oil company, PETROBRAS, to ensure favorable prices for sugar-based ethanol over gasoline. PETROBRAS artificially inflated gasoline prices to keep ethanol competitive. In the early 1980s, PROALCOOL expanded its support of the ethanol industry by signing contracts with various automakers to produce cars that could run on ethanol. Taxi drivers were granted tax breaks for converting their vehicles to run on pure ethanol and federal fleets were required to run on ethanol as well.[81] The government further supported the industry by requiring that ethanol be available at all filling stations and by barring ethanol imports.

In the late 1980s, however, economic hardship forced the government to reduce subsidies for the ethanol industry, and as part of sweeping political reforms in the early 1990s, all ethanol subsidies were repealed. However, the government continued to require that all gasoline be blended with at least 20 percent ethanol, which sustained the industry. In 2002, when Ford and Volkswagen introduced flex-fuel vehicles, the ethanol market experienced a second boom. Today, Brazil does not subsidize ethanol production as it did at the industry's inception. Aside from reductions in fuel and motor vehicle taxes, the only government support for ethanol is the provision that all gasoline be blended with 20-25 percent ethanol, which is effectively a price guarantee.

Brazil also supports a burgeoning biodiesel industry. The first Brazilian biodiesel plant became operational in 2005, and since 2006 the government has guaranteed the purchase of all biodiesel produced by family enterprises in the northeast of the country

[79]Kojima, Masami, Donald Mitchell, and William Ward. *Considering Trade Policies for Liquid Biofuels*. Energy Sector Management Assistance Program (ESMAP). June. Washington, DC: The World Bank. 2007.

[80]Moreira, et. al. 2005.

[81]Xavier, Marcus Renato. *The Brazilian Sugarcane Ethanol Experience*. Competitive Enterprise Institute. February 15, 2007.

up to a ceiling of 2 percent of total diesel use. The government has also mandated that all diesel sold in 2008 must contain 2 percent biodiesel, with this amount increasing to 5 percent in 2013. Brazil is on track to achieve these goals ahead of schedule.

European Union

With mounting energy security concerns and a commitment to reduce emissions, the European Union also continues to promote greater use of biofuels. In May 2003, the E.U. adopted the Biofuels Directive, which advocated replacing fossil fuels with bio-based fuels and established indicative targets (i.e., not legally binding on member states) for biofuels penetration in the transportation fuel market: a 2 percent target by the end of 2005, rising to 5.75 percent by the end of 2010, and 10 percent by 2020.[82] To achieve these targets the E.U. member states offer various incentives, such as exempting biofuels from the generally high taxes on conventional fuels, subsidizing construction of biofuels infrastructure, and mandating the blending of biofuels into all fuel sold at the pump. Analysis by the International Institute for Sustainable Development reveals that the cost of GHG reductions achieved through government support for biofuels from domestic crops ranges from €200 per metric ton for biodiesel from used cooking oil, to as high as €4,400 per metric ton for grain based ethanol. This level of investment per ton of avoided emissions could have purchased more than 20 tons of CO_2-equivalent offsets on the European Climate Exchange.[83]

Biodiesel, produced in particular from crops such as rapeseed (known as canola in North America), sunflower, and soy, is the dominant biofuel in Europe. This is partly due to the government-backed push in recent decades to make diesel a significant part of the fuels mix for passenger vehicles. Diesel accounts for 55 percent of transport fuels in the European Union, as opposed to 24 percent in the U.S.[84]

Support for biofuels is also maintained by the far-reaching subsidies provided to agriculture in the E.U. through the Common Agricultural Policy (CAP). The CAP subsidizes agricultural production throughout the E.U. and, in response to the overproduction that this encourages, mandates leaving some land as "set aside", under which farmers are paid to keep it out of food production. In 1992 the CAP was amended to allow non-food crops to be planted on set-aside land while maintaining the set-aside payments. Currently about one million hectares of set-aside land is used for non-food production, mostly (more than 75 percent) for growing oilseeds for biodiesel. In September 2007, E.U. agricultural ministers approved a plan to set the mandatory set-aside rates at zero percent for the autumn 2007 and spring 2008 sowings, meaning that farmers will not be required to leave any of their land fallow, to increase the next year's harvest.[85]

Planting energy crops earns farmers a subsidy as well. This subsidy was put in place to encourage farmers to shift production toward biofeedstocks. However, in October 2007, the Commission announced that this subsidy (€45 per hectare or $26 per acre) will be reduced because it was oversubscribed: the policy was intended to raise the amount of land devoted to biofuels crops to 2 million hectares in 2007, but the Commission had received applications for the subsidy for nearly 3 million hectares of land when they decided to cut back the program.[86]

Despite strong governmental support, the European biofuels industry has been unable to reach its ambitious objectives. The E.U. failed to reach its target of 2 percent of transport fuels by 2005 (actual market penetration was 1.4 percent), and in 2007 the European Commission stated that it is unlikely they will reach the 2010 target either.[87] The E.U. biofuels market, however, is still in a nascent stage. Despite protest from the NGO community over its adverse impacts, and industry complaints over competition from heavily-subsidized U.S. biofuels, production had grown to more than 1.3 billion gallons (4.8 billion liters) of biodiesel and more than 400 million gallons (1,600

[82]These are energy replacement targets, not volumes.

[83]Kutas, Géraldine, Carina Lindberg and Ronald Steenblik. *Biofuels – At What Cost? Government support for ethanol and biodiesel in the European Union*. Prepared for the Global Subsidies Initiative of the International Institute for Sustainable Development. October 2007. Available online at: http://www.globalsubsidies.org/IMG/pdf/Global_Subsidies_Initiative_European_Report_on_support_to_Biofuels.pdf.

[84]U.S. figure from: Davis, Stacy C. and Susan W Diegel. *Transportation Energy Data Book: Edition 26*. Oak Ridge National Laboratory prepared for U.S. Department of Energy. 2007. Available online at: http://cta.ornl.gov/data/tedb26/Edition26_Full_Doc.pdf.
E.U. figure from: Jank, Marcos J., Géraldine Kutas, Luiz Fernando do Amaral, and André M. Nassar. *EU and US Policies on Biofuels: Potential Impacts on Developing Countries*. Washington, D.C.: The German Marshall Fund. 2007. Available online at: http://gem.sciences-po.fr/content/research_topics/trade/ebp_pdf/GMF%20paper.pdf.

[85]Press release from the European Commission. "Biofuels Strategy: Background Memo." MEMO/06/65. February 8, 2006. Brussels. Available online at: http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/06/65&format=HTML&aged=0&language=EN&guiLanguage=en.
This policy change came in response to tightening of the cereals market. EU harvests were lower than expected in 2006, which has led to historically high prices. Intervention stocks are down from 86% since the 2006/2007 season. The zero percent set-aside for the 2007/2008 sowings is expected to increase next year's cereal harvest by at least 10 million tonnes. (Press release from the European Commission. "Cereals: Council approves zero set-aside rate for autumn 2007 and spring 2008 sowings" IP/07/1402. September 26, 2007. Brussels. Available online at: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/07/1402&format=HTML&aged=0&language=EN&guiLanguage=en).

[86]Press release from the European Commission. "EU cuts back on biofuel crop subsidy." October 18, 2007. Brussels. Available online at: http://www.euractiv.com/en/sustainability/eu-cuts-back-biofuel-crop-subsidies/article-167713.

[87]Commission of the European Communities. *Communication from the Commission to the Council and the European Parliament: Biofuels Progress Report*. January 2007.

million liters) of ethanol in 2006.[88] Meanwhile, the European Council is considering revised targets of 8 percent by 2015 with a long-term goal of 25 percent by 2030.[89] With such rapid growth and strong governmental support, the European biofuels industry offers plenty of opportunity for investment.

United States

In contrast to the E.U., the market for transport fuels in the U.S. is dominated by gasoline, making ethanol the most popular alternative fuel option. This ethanol is produced from grain, particularly corn, meaning it is entangled in a system of subsidies and regulations even more complex than in the E.U. In contrast to Brazil, U.S. air quality standards would not allow ethanol blends in gasoline as high as 20-25 percent in today's vehicle fleet; therefore, the ethanol market has taken two approaches: standard low-level blends of under 10 percent ethanol in many markets for use in conventional vehicles, and E85 for use in flex-fuel vehicles. These two approaches do not necessarily compete with each other — it is perfectly possible to sell both low- and high-level blends. But they do potentially create redundancy, as discussed below.

Currently, U.S. policy supports both the supply and demand sides of the ethanol industry. On the supply side, subsidies for agriculture enable production of low-cost feedstocks (mainly corn) for ethanol. These subsidies are linked to commodity prices, so when prices increase, support decreases. On the demand side, blending mandates and consumption tax incentives promote uptake of the fuel. The Global Subsidies Initiative estimates that the aggregate support for biofuels in the U.S. is as high as $7 billion per year, or over $500 per metric ton of CO_2 equivalent removed for corn-based ethanol.[90]

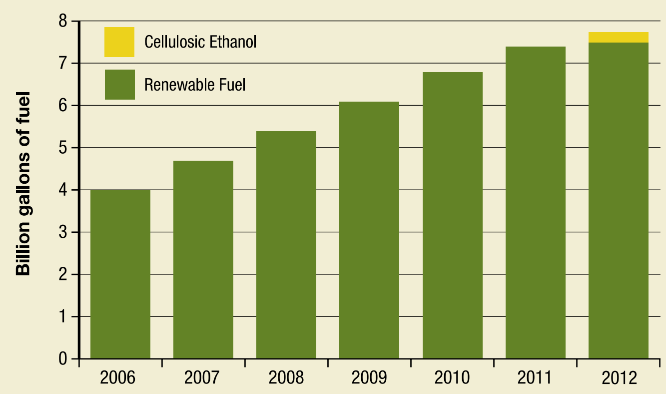
As today's biofuels are produced from crops, any policy support for the agriculture sector indirectly supports the ethanol industry as well. It is no coincidence that 95 percent of the ethanol produced in the U.S. comes from corn; aside from the fact that it grows well in U.S. climates and converts relatively easily to fuel, corn is also one of the most heavily subsidized crops in the U.S. Through a variety of programs, corn received over $50 billion in federal subsidies from 1995 to 2005 (compared to roughly $20 billion each for wheat and cotton, the second and third most subsidized crops, respectively).[91]

More direct support to ethanol producers comes from the *Energy Policy Act of 2005* (EPAct), which extended through 2008 the Volumetric Ethanol Excise Tax Credit (VEETC), including a tax credit of $0.51 per gallon of ethanol blended into gasoline. The statute also broadened the scope of other production incentives and authorized loan guarantees and grants for constructing facilities that convert cellulosic materials and municipal solid waste to ethanol.

Protectionist trade measures are also used in the U.S. to shield the nascent ethanol industry from more fully developed foreign competitors, particularly Brazil's established sugar-based ethanol program. Under the Ethanol Import Tariff of 1980, a $0.54-per-gallon tariff is levied on imported ethanol. This measure was intended to offset the VEETC so that American taxpayers are not subsidizing foreign ethanol production. However, this duty and an additional ad valorem tax seriously limit the penetration of Brazil's cheaper and more energy-efficient ethanol in the U.S. market, meaning it essentially puts the more attractive and beneficial fuel at a competitive disadvantage to the less attractive domestically produced fuel.

EPAct was crucial to the development of today's U.S. ethanol industry, as it also contains many demand-side promotion measures: a fuels standard, tax incentives, incentives for infrastructure stimulation, government preferential purchasing for market guarantee, and funding for research and development as well as education and outreach.

Figure 10: **Renewable Fuel Standard in the U.S. Energy Policy Act, 2005**



Source: World Resources Institute

[88]Steenblik, Ronald. *Biofuels – At What Cost? Government support for ethanol and biodiesel in selected OECD countries*. Geneva: Global Subsidies Initiative of the International Institute for Sustainable Development. September 2007. Available online at: http://www.globalsubsidies.org/IMG/pdf/biofuel_synthesis_report_26_9_07_master_2_.pdf.

[89]USDA Foreign Agricultural Service. *GAIN Report E36122*. Global Agricultural Information Network. November 7, 2006.

[90]Koplow, Doug. *Biofuels — At What Cost? Government support for ethanol and biodiesel in the United States*. Geneva: Global Subsidies Initiative of the International Institute for Sustainable Development. October 2006. Available online at: http://www.globalsubsidies.org/IMG/pdf/biofuels_subsidies_us.pdf.

[91]Environmental Working Group's Farm Subsidy Database. Available online at: http://farm.ewg.org/farm/region.php?fips=00000#topprogs.

Table 2: **U.S. State Biofuels Policies**

State	Level	Date	Enacted?
Hawaii	10% of highway fuel use	by 2010	yes
	15% of highway fuel use	by 2015	
	20% of highway fuel use	by 2020	
	E10 (85% of unleaded gasoline)	Current	
Louisiana	2% of total sales (ethanol and biodiesel)	when state demonstrates sufficient local production	yes
Minnesota	B2	Current	yes
	B20	by 2015	no*
	E10	Current	yes
	E20	by 2013	
Missouri	E10	by 2008, if ethanol is less costly than gasoline	yes
Montana	E10	once producing 40M gal.	yes
New Mexico	B5	by 2012	yes
Oregon	E10	once producing 40M gal.	yes
	B2	once producing 5M gal.	
	B5	once producing 15M gal.	
Washington	B2	by 2008	yes
	E2	by 2008	
	B5	when state demonstrates sufficient local production	
	E10	if does not jeopardize Clean Air Act standards	no**

*Governor Pawlenty will bring his plan to the state legislature during the 2008 session.

**The ethanol requirement could be increased to 10% if the Director of the Department of Ecology determines that this would not jeopardize continued attainment of federal Clean Air Act standards.

Source: World Resources Institute, based on several sources[92]

The primary industry promotion measure in EPAct is the Renewable Fuel Standard (RFS). This measure phases in a renewable fuels standard, driving the market by requiring that gasoline sold by refiners, blenders, and importers contains an increasing amount of renewable fuel, specifically ethanol and biodiesel. The requirement started at 4 billion gallons (15 billion liters) in 2006 and increases each year until reaching 7.5 billion gallons (28 billion liters) in 2012. From then on, the minimum applicable volume of renewable fuel in gasoline will grow in proportion with gasoline production. The RFS requirements also include cellulosic ethanol — in fact, through 2012, one gallon of cellulosic or waste-derived ethanol counts for 2.5 gallons (9.5 liters) of the RFS volume. By 2012, cellulosic ethanol's contribution to the fuel mix must be at least 250 million gallons (or 946 million liters) (see Figure 10). The U.S. industry is already producing more ethanol than the RFS currently requires, and it will likely achieve the 2012 target well ahead of schedule, even as early as 2008.

EPAct also seeks to develop a market for ethanol by accelerating deployment of the necessary supporting infrastructure. One major challenge to expanding the ethanol industry is the lack of distribution infrastructure, discussed on page 13. EPAct begins to address this obstacle by offering tax credits for purchasing alternative fuel vehicles and installing clean vehicle refueling equipment. In addition to this support, there are currently over 80 policy proposals around Congress that relate to biofuels, many of which aim to accelerate the market by adding E85 pumps and encouraging FFV production.

There is significant interest in biofuels promotion at the state level as well. Many U.S. states have already enacted a blending mandate requiring that all marketed fuel contain a specific percentage of biofuels, generally E10 or B2 (a 2 percent blend of biodiesel), or both (see Table 2).

Thus far, federal policies — combined with the enthusiasm from companies that are invested in the industry, state and local governments, and consumers — have had some success in expanding E85-compatible infrastructure. In fact, the number of E85 filling stations quadrupled in two years, from fewer than 300 stations in August 2005 to approximately 1,200 stations in September 2007.[93] This now amounts to about one percent of gas stations in the U.S.[94] The National Ethanol Vehicle Coalition (NEVC) expects this number to continue increasing, reaching 1,500 to 2,000 gas stations by the end of 2007. This is a downward revision from growth estimates from 2006, but the industry predicts accelerating penetration rates in 2008.[95] However, there is still a long way to go before all FFV drivers have convenient access to E85 refueling stations (see Figure 11). FFVs provide no benefit to the country's energy security or to the environment if E85 is not available in the regions where FFVs are driven, or if their drivers choose gasoline instead of ethanol at the pump (as most do).

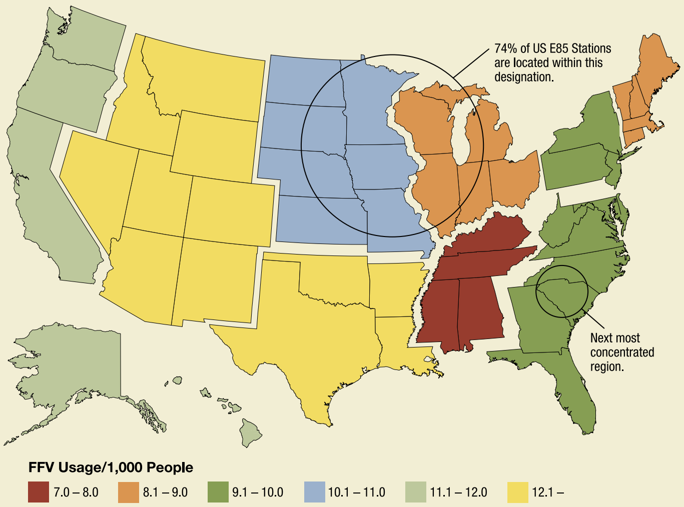
[92]Adapted from Green Car Congress; Policy information from U.S. Department of Energy. Energy Efficiency and Renewable Energy. Alternative Fuels and Advanced Vehicles Data Center. Available online at: http://www.eere.energy.gov/afdc/.

[93]U.S. Department of Energy. Energy Efficiency and Renewable Energy. Alternative Fuels and Advanced Vehicles Data Center. Available online at: http://www.eere.energy.gov/afdc/fuels/stations_counts.html.

[94]GAO. 2007.

[95]Mayne, Eric. "E85 Pace Expected to Pick Up in Q4." April 2, 2007. Available online at: http://wardsauto.com/ar/e85_pace_expected/.

Figure 11: **E85 Stations versus FFV Use by Region**



Source: World Resources Institute, based on several sources[96]

A policy to promote FFV production in order to reduce oil consumption has been on the books since 1988. However, because this policy allows automakers to trade off their FFV production against their Corporate Average Fuel Economy (CAFE) requirements, U.S. oil dependence has actually increased by at least 80,000 barrels per day more than it would have been without this measure (see Box 9).[97] This is equivalent to the level of oil consumption that the EIA initially predicted would be offset by the 7.5 billion gallon ethanol production minimum set in the RFS.[98] U.S. biofuels policy therefore appears to have had little net impact on the nation's oil use — perhaps not a spectacular return on the estimated $5-7 billion per year that the policy costs.[99]

Nevertheless, questioning the value of corn ethanol in Washington D.C. is a challenge. In one U.S. Senate hearing on the subject, the suggestion from one witness that "there are good biofuels and bad biofuels" was vigorously denounced by representatives of the corn lobby, prompting one senator to ask gently whether at least they could concede that there are "good biofuels and better biofuels."[100] However, as the Natural Resources Defense Council recently pointed out, the vast majority of biofuels-related bills are aimed simply at driving the production of *more* biofuels rather than taking care to promote *better* biofuels.[101]

It is axiomatic to the rationale for biofuels support that today's investments are shaping a market for more beneficial fuels in the future. The prospects for more advanced biofuels will be explored

Box 9: Closing the CAFE / FFV Loophole

The current emphasis in the U.S. on promoting E85 infrastructure has had unintended and perverse impacts. The Alternative Motors Fuels Act, enacted in 1988, was intended to promote alternative fuels in order to reduce oil consumption. Under the Act, automakers can get credit toward their CAFE requirements, capped at 1.2 mpg, for producing dual-fuel vehicles, including FFVs. Lawmakers devised a formula (see below) for calculating an adjusted fuel economy rating for FFVs that would take into account the benefits derived from operating the vehicle on alternative fuels, and therefore would not penalize the manufacturers under CAFE for the reduced efficiency that results from using biofuels in today's vehicle fleet, which is not optimized for ethanol use.

$$\frac{1}{\left(\dfrac{0.5}{\text{Fuel economy (mpg) on gasoline}}\right) + \left(\dfrac{0.5^{*}}{\dfrac{\text{Fuel economy (mpg) on E85}}{0.15^{**}}}\right)}$$

* This figure represents the assumption that the vehicle is fueled 50% of the time by gasoline and 50% of the time by E85.

** This figure represents the amount of gasoline in E85.

However, the assumptions used in the formula are not applicable in practice. The formula assumes that FFVs are operated on alternative fuels 50 percent of the time, when in reality they are fueled with regular gasoline more than 99 percent of the time. Thus, the formula incorrectly classifies FFVs as having better fuel economy than they actually do. In calculating the FFV fuel economy ratings for CAFE, the government only counts the 15 percent of E85 that is gasoline, resulting in a fuel economy rating for FFVs that is more than 65 percent higher than the actual fuel economy of the vehicle.

Several lawmakers have proposed amendments that would narrow (although not eliminate) this FFV loophole. These proposals suggest altering the formula used to arrive at the fuel economy ratings for FFVs so that they more accurately reflect reality. Under current ethanol use patterns, however, even these modifications might still considerably overestimate actual ethanol consumption in these vehicles.

[96]EIA. *Annual Energy Outlook Supplement* and U.S. Department of Energy. Energy Efficiency and Renewable Energy. Alternative Fuels and Advanced Vehicles Data Center.

[97]Bedsworth, Louise, David Friedman, and Don MacKenzie. *Fuel Economy Fraud: Closing the Loopholes That Increase US Oil Dependence*. Union of Concerned Scientists. Cambridge: UCS Publications. August 2005.

[98]Energy Information Administration, cited in "Ethanol 101." American Coalition for Ethanol. Available online at: http://ethanol.org/index.php?id=34&parentid=8.

[99]Koplow. 2006.

[100]United States' Senate Energy & Natural Resources Committee. "Transportation Biofuels Conference." February 1, 2007.

[101]Natural Resources Defense Council (NRDC). *Getting Biofuels Right: Eight Steps for Reaping Real Environmental Benefits from Biofuels*. May 2007. Washington, DC: NRDC. Available online at http://www.nrdc.org/air/transportation/biofuels/right.pdf.

in a later section on investment (see page 45). In the meantime, however, biofuels policy should distinguish between good and bad biofuels, supporting only the former. Today's biofuels policy is already coming up against some serious concerns that may threaten public support for them altogether, and in turn threaten the prospects for next-generation fuels as well.

A backlash against biofuels?

The exuberance that characterized the expansion of biofuels through 2006 has been somewhat checked recently as concerns mount regarding some of their potential downsides. The attraction is certainly still present — the energy security community and large parts of the farming and environmental communities remain strongly supportive of biofuels — but some of the "silver bullet sheen" may have started to rub off. Concerns about the sustainability of biofuels are growing, including land-use and deforestation issues, water use, human rights concerns, and the "food versus fuel" question. These concerns are likely to heighten as production grows and as biofuels are increasingly traded internationally, not least because for some of these issues, the impact may grow disproportionately as fuel production reaches scale.

Food, fuel, and international trade

Though it is difficult to pinpoint the precise impact that increased biofuels demand is having on the food market, negative impacts of expansion of the biofuels market globally are already beginning to appear. For instance, in the U.S., ethanol production accounted for 17 percent of the corn crop in 2006, up from 13 percent just one year earlier. This increase in demand for corn has already caused an enormous increase in its price. Historically the ethanol industry's demand for corn has been relatively low. The price of corn hovered consistently around $2 per bushel through most of 2006. In 2007, however, due in no small part to ethanol industry growth, corn prices rose dramatically to more than $3.50 per bushel.[102]

There is a great deal of confusion and uncertainty regarding the impact of increased biofuels production and consumption on food markets. Even the producers of these fuels find it hard to be lucid on the subject: the U.S.-based National Corn Growers Association (NCGA) asserts that "the production of ethanol does not translate into less grain available for food, since farmers do not grow more or less corn based on ethanol production."[103] However, it is clear that there is an impact on food and other markets: the more corn that is used for fuel, the less that is available for other uses until farmers expand production or increase crop yields. There are clearly limits to expanding production, however, before it starts having negative consequences.

Already, food markets have begun to see some of these negative consequences (see Figure 12), though it is hard to isolate the impact of biofuels on food prices. According to analysis commissioned by the NCGA, sustained high corn prices (in the $3.50-$4.00 per bushel range) will cause an increase in prices for food products, primarily meat, poultry, eggs and dairy. They estimate that inflation over the next few years on these products will be 4 to 11 percent higher annually than without the price impacts from increased corn demand for biofuels production in the U.S.[104]

More broadly, as the area of arable cropland that is used for biofuel feedstock production increases, this expansion will have to come at the expense of land area used for other purposes.[105] The additional demand for biofuels production is an important factor in the forecast 20-50 percent increase in food prices by 2016.[106]

The political repercussions are already being seen, causing social unrest — the so-called "tortilla riots" in Mexico in early 2007 — as the skyrocketing price of corn made life particularly difficult for the urban poor. Increasing demand for oils to produce biodiesel is having a similar result. In July 2006 the Malaysian government imposed a moratorium on licensing of new palm oil refineries amid concerns about the impact on food production.[107] These concerns arise at a time when global food reserves are increasingly strained.[108] Commentators on both the political left and right have expressed serious concern about the social and economic impacts of biofuels.[109]

[102]Global food demand and drought-induced shortfalls in some regions have, of course, also contributed to this price increase.

[103]National Corn Growers Association. "Food versus Fuel." June 2005. Available online at: http://www.ncga.com/ethanol/economics/foodVsFuel.asp.

[104]National Corn Growers Association. 2007. *Understanding the Impact of Higher Corn Prices on Consumer Food Prices*. March 26, updated April 18. Available online at: http://www.ncga.com/ethanol/pdfs/2007/FoodCornPrices.pdf.

[105]Doornbosch, Richard and Ronald Steenblik. "Biofuels: Is the Cure Worse Than the Disease?" Organization for Economic Co-operation and Development (OECD). Report SG/SD/RT(2007)3. Prepared for Round Table on Sustainable Development, Paris, September 11-12, 2007.

[106]Doornbosch and Steenblik 2007.

[107]Kojima, et. al. 2007.

[108]Food and Agriculture Organization of the United Nations (FAO). *Food Outlook*. June 2007. Available online at: http://www.fao.org/docrep/010/ah864e/ah864e01.htm.

[109]Fidel Castro, who has had a very quiet year otherwise, has spoken out vigorously condemning the US push for biofuels. In spring 2007 he wrote several articles in which he accused George W Bush of condemning three billion people to premature death by hunger and thirst and called the political support for "converting food into combustibles" a "sinister idea" and "international genocide." The Economist, noting that "it is not often that we find ourselves in agreement" with Mr. Castro, largely supported his critique. See two articles in BBC News: "Castro Hits Out at US Biofuel Use." March 27, 2007. Available online at: http://news.bbc.co.uk/2/hi/americas/6505881.stm; "Castro in New US Biofuel Attack." April 4, 2007. http://news.bbc.co.uk/2/hi/americas/6525059.stm. See also The Economist article: "Castro Was Right." April 4, 2007. http://www.economist.com/opinion/displaystory.cfm?story_id=8960412.

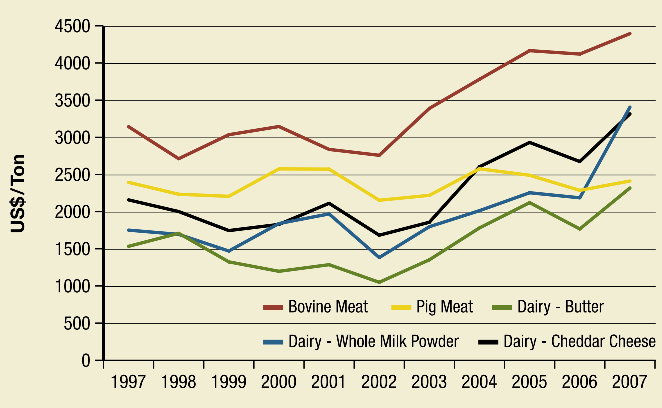
The impacts of sudden changes in food prices are clearly severe, and cause real human suffering. It is less clear what the longer-term role of biofuels is in keeping crop prices up. Both the E.U. and the U.S. have been repeatedly criticized for the effect of their agricultural policies in *depressing* agricultural commodity prices.[110] While the urban poor suffer from high food prices, low prices hit the incomes of agricultural producers. In the poorest developing countries, agriculture is the main source of income, which would make the recently high international commodity prices a boon. However, price increases on food commodities *imported* by developing countries are expected to be steeper than the increases on the commodities they export.[111] Moreover, timing is crucial: if years of low prices have caused developing country producers to leave their farms or switch to other crops, then a spike in prices now will be detrimental, as these populations will not be able to capitalize on the increased prices but will have to pay them in order to eat. High food commodity prices are not an inherently bad outcome, but the issue is without a doubt complex and further work is needed to understand this dynamic.

Land-use pressures

In developed countries such as the U.S. and E.U., biofuels compete for land principally with other forms of agriculture. In the tropics there is additional pressure on forests, which are being rapidly cut down in many tropical countries to make way for agriculture. Forests are a major store of carbon, so where biofuels are being promoted as a means to reduce GHG emissions there is a potentially perverse impact as the carbon stored in these forests is released into the atmosphere when they are cleared.

These dynamics are not straightforward. Where biofuels feedstock plantations are developed on already deforested or degraded lands and generate income, it is clearly a positive development. However, in tropical Asia forests are often cleared directly to grow oil palm for biofuels production, meaning that the impact in terms of direct carbon emissions (e.g., clearing by fire) can be calculated relatively simply. When peat is drained the emissions occur over several years, so calculation is more challenging, but a country-level value can be assigned. Brazilian sugarcane, on the other hand, is generally grown far from the forests, so its planting does not lead directly to deforestation. However, it takes up land that might be used for other purposes, and thus could increase pressure on forested land elsewhere (see Box 10).

Figure 12: **Selected Food Commodity Prices, 1997-2007**



Source: FAOSTAT[112]

Box 10: Calculating Direct and Indirect Emissions[113]

Calculating GHG emissions from land-use conversion related to different types of biofuels production can be challenging, particularly in developing countries where adequate data are not readily available.

When calculating the emissions from land-use change, two main categories are considered: direct and indirect conversion. *Direct* conversion refers to when land is converted directly from another use to agricultural land to grow biofuel feedstocks. In some cases site-specific data may be available, and in these instances relatively detailed calculations can be made for the direct impacts of biofuels production. Where site-specific information is not available, a default value can be used based on conservative assumptions about how biofuels would likely be produced in the country in question.

Indirect conversion refers to the displacement of other land uses by biofuels production, which in turn encroach on forested areas. For example, forests may be cleared for soy production because current soy fields are being converted to sugarcane production for biofuels. The likely impacts from indirect conversion have the potential to be large, but they are also much more difficult to quantify than direct conversion. Land-use activities may be displaced to other countries — for instance, as world soy prices increase in response to displacement of production in Brazil, additional production may arise elsewhere. Conversely, rising soy prices may result in non-soy crops displacing soy for some uses. Finally, responses may not be immediate, and tracking market responses over time means that quantification of such impacts will need to rely on projections rather than historical information.

[110] Food and Agriculture Organization of the United Nations (FAO). *The State of Agricultural Commodity Markets 2006.* Rome: FAO. 2007.

[111] Kojima, et. al. 2007.

[112] Food and Agriculture Organization of the United Nations. Statistics Division. FAOSTAT. Available online at: www.faostat.fao.org.

[113] See Daviet, Florence and Liz Marshall. *Quantification Methodologies for Emissions from Direct and Indirect Land-Use Change: Biofuels Production in Brazil* (working title). Washington, D.C. World Resources Institute. (forthcoming). This paper will present some of the issues related to identifying the GHG emissions from indirect land conversion, and some initial thoughts around how to include these in a credible and helpful manner.

While methodologies can be developed to approximate the additional emissions from deforestation associated with biofuels production, this does not cover all of the potential impacts of displacing forests. In many developing countries forests provide a range of ecosystem services of significant value to the poor, including income generation from harvesting or tourism, watershed regulation, protection from extreme weather conditions, and timber. In many cases it is easy to trample on the land and access rights of communities ill-equipped to defend themselves as land passes from natural forest to managed plantation. In addition, plantations are frequently owned by international corporations, rather than the local populations that might have benefited from the additional income. Finally, tropical forests are incomparably rich havens of biodiversity, which suffers when palm monocultures pervade. For instance, the orangutans in Indonesia's natural forests are already endangered, but the species is at even greater risk when their habitat is burned and replaced with a plantation.

Water

The Millennium Ecosystem Assessment identified freshwater resources as one of the clearest examples of the intense pressure humans are putting on nature, saying the "signs are flashing red" that current patterns of use and abuse cannot be sustained.[114] As water concerns rise up the global agenda, it is important to recognize that biofuels impact water supply and quality, from growing of the feedstock through processing of the fuel.

Water impacts of feedstock production are highly dependent on particular crop needs, but generally irrigation depletes water supplies. Worldwide, agriculture accounts for roughly 70 percent of global freshwater use. Certain crops are more water intensive than others. Sugarcane, for instance, is a very thirsty crop. In Brazil, cane production has historically been mostly rain-fed, but the use of irrigation is increasing.[115] Jatropha can grow under semi-arid conditions, so it is a promising feedstock in places like India and parts of Africa where water availability is already a pressing issue. However, even these less-thirsty crops do require, or at least grow better with, some irrigation. As demand for biofeedstocks for fuel continues to rise, so too will the pressures on global freshwater supplies for irrigation.

In addition to agriculture's impact on water supplies, application of agrochemicals such as herbicides, pesticides, and nitrogen fertilizers during crop production damages water quality in surrounding areas. Again, the severity of the impact varies by crop. Corn, for instance, requires more nitrogen fertilizer than many other crops. Moreover, chemical fertilizers are often over-applied, or applied at times when crops cannot effectively absorb them. This leads to a significant amount of nutrient loss: on average, about 20 percent of nitrogen fertilizer worldwide is lost through surface runoff or leaching into groundwater.[116] Nutrient runoff is a major cause of surface-water eutrophication and ecosystem damage (see Box 11).

Between 1960 and 1990, global use of synthetic nitrogen fertilizer increased more than sevenfold, while phosphorus use more than tripled.[117] As biofuels production reaches scale, increased demand for feedstocks will incentivize farmers to reduce field rotation and bring marginal lands into production. This more intensive agriculture on less fertile lands will require increased use of agrochemicals, causing further damage.

Box 11: Eutrophication

One of the leading causes of water quality impairment around the world is eutrophication, or the over-enrichment of water by nutrients such as nitrogen (N) and phosphorus (P). Eutrophication can lead to a number of symptoms that are harmful to freshwater and marine ecosystems. Increased nutrients can cause phytoplankton and macroalgae blooms, which can block sunlight and lead to a loss of subaquatic vegetation. Eventually, species diversity can be reduced to systems dominated by gelatinous organisms such as jellyfish.

Eutrophication can also lead to "hypoxic" or "dead" zones; that is, vast regions of oxygen-depleted waters. Hypoxia is caused when algae die, sink to the bottom, and are digested by bacteria, in the process using up the available dissolved oxygen. These oxygen-starved areas stress aquatic ecosystems and can lead to fish kills and ecosystem collapse: fish, shrimp, and crabs generally flee to more oxygenated waters, but bottom-dwellers such as snails, worms, and starfish eventually die.

Sources of nutrients in coastal waters are diverse and include agriculture, aquaculture, septic tanks, urban wastewater, urban stormwater runoff, industry, and fossil fuel combustion. The relative importance of each of these sources varies by region. For example, in the United States and the European Union, agricultural sources are generally the primary contributors to eutrophication, while in Asia and Africa nutrient pollution is primarily attributed to sewage discharges.

WRI has identified 375 hypoxic coastal zones and 175 hypoxic lakes around the world, concentrated in coastal areas in Western Europe, the Eastern and Southern coasts of the U.S., and East Asia, particularly in Japan.[118]

[114] Statement from the Board of the Millennium Ecosystem Assessment. *Living Beyond Our Means: Natural Assets and Human Well-Being*. March 2005. Available online at: http://www.millenniumassessment.org/documents/document.429.aspx.pdf.

[115] Smeets, Edward, Martin Junginger, André Faaij, Arnaldo Walter, Paolo Dolzan. *Sustainability of Brazilian Bioethanol*. Study commissioned by SenterNovem, The Netherlands Agency for Sustainable Development and Innovation. August 2006. Available online at: http://www.bioenergytrade.org/downloads/sustainabilityofbrazilianbioethanol.pdf.

[116] Millennium Ecosystem Assessment (MA). Ecosystems and Human Wellbeing: Policy Responses Volume 3. Chapter 9: Nutrient Management: pp. 295-311. Primary Authors: Howarth, R. and K. Ramakrrshna. Eds. K. Chopra, R. Leemans, P. Kumar, and H. Simons. Island Press. Washington, DC 2005.

[117] Selman, Mindy. "Eutrophication: An Overview of Status, Trends, Policies, and Strategies." August 2007. Washington, DC: World Resources Institute.

[118] Selman. 2007.

Genetically modified fuels?

If there is one sure-fire way to make biofuels more controversial, genetically modified feedstocks would seem to be it. Given the importance of developing plant strains that can obtain high yields on low-fertility soils and with low rainfall or irrigation, the chances are that genetically modified organisms (GMOs) will play an important role in the next generation of biofuels, and indeed in improving the productivity of existing technologies (see Box 4). GMOs may surface in two places: in the enzymes used for chemical processing, and in the feedstock crops themselves.

GMOs are widespread in the world's food crops, but have been controversial in many places. The European Union, Brazil, and many African countries have historically maintained heavy restrictions on the use of GM technology, and using GMOs in feedstock crops may result in restrictions on international trade.[119] The potential for public backlash against new GM crops may make companies cautious about deploying new feedstocks in field trials. Conversely, using GMOs to improve dedicated energy crops such as switchgrass or designing enzymes for use in production facilities may prove less controversial.

How these factors might be reflected in a broader sustainability standard is a challenging question. But it must be answered if biofuels are truly going to deliver on underlying policy goals. What might an improved biofuels policy look like?

Improving biofuels policy

Fix transport policy first

The optimal way to deal with such a broad set of challenges is through a policy structure that provides broad incentives to cut fossil fuel use and carbon emissions. Better transportation policy — combining efficiency, modal shifts, urban design, and alternative fuels — could be driven by price signals (e.g., an economy-wide tax on carbon or higher fuel taxes) combined with other measures. The advantage of such a comprehensive approach is that it would allow rational trade-offs between different means of reducing oil use and emissions, and leave maximum scope for innovation.

A full examination of a comprehensive policy framework including a price for carbon and accounting for other externalities is beyond the scope of this report, but there are signs, particularly in some European countries, that such an approach is politically feasible. Many European countries apply significant taxes to transport fuels to reflect security and greenhouse gas concerns, as well as account for other externalities. Generally these costs are broadly reflected rather than specifically calculated. However, Sweden adds the cost of maintaining strategic oil reserves to its taxes on oil, meaning that oil consumers pay for the service they receive. In the United States, as in most countries, this burden is shouldered by the general taxpayer rather than the motorist.

With or without a more comprehensive approach to transportation energy use and emissions, biofuels will likely be part of the policy frameworks intended to address these concerns. There is a growing awareness, therefore, that if biofuels are going to be a part of the solution, a framework is needed to ensure that their production and consumption do not do more harm than good.

Two key themes have emerged within the burgeoning debate on the sustainability of biofuels: concerns about the sustainability of feedstock production and questions regarding full accounting for the carbon content of biofuels. The two themes are related, but often handled separately in the policy arena. The first theme recognizes that many environmental and social impacts of biofuels production occur as a result of feedstock production, and asks whether biofuels feedstocks can be grown sustainably, and at what scale. Questions related to feedstock production are generally discussed in the context of agricultural policy. The second theme concerns the life-cycle carbon content of biofuels and asks whether, given that biofuels are promoted as a carbon-friendly alternative to petroleum fuels, they are in fact effective at displacing carbon emissions in the transport sector, and to what extent. Discussions on carbon content usually surface in the context of energy policy. Both discussion threads ultimately lead back to the question of how to identify and quantify the impacts of biofuels production and combustion, and how to incorporate such impacts into policies that provide the correct incentives for the evolution of feedstock and fuel conversion technologies.

Addressing these aspects of biofuels sustainability will require several distinct types of policy interventions:

- policies that influence farmers' decisions about what, where, and how feedstocks will be grown;
- broader land-use policies that reflect the value of ecosystem services provided by land, minimize leakage of environmental impacts beyond the biofuels system boundary, and remain consistent with national priorities for balancing production of food, fuel, and ecosystem services; and
- domestic policies and international initiatives that mitigate the extent to which developed countries are able to export the environmental impact of their energy demand.

[119] Baumuller, Heike. *Domestic Import Regulations for Genetically Modified Organisms and their Compatibility with WTO Rules Some Key Issues*. International Institute for Sustainable Development (IISD) and the International Centre for Trade and Sustainable Development (ICTSD). 2003. Available through Trade Knowledge Network at http://www.tradeknowledgenetwork.net/publication.aspx?id=587.

Applying carbon standards to fuels

In January 2007, California Governor Arnold Schwarzenegger signed into law a path-breaking executive order called the "Low Carbon Fuel Standard" (LCFS), which mandates a 10 percent reduction in the carbon content of California's transport fuels by 2020. Unlike the federal Renewable Fuel Standard, which mandates a volumetric target for certain types of biofuels regardless of their environmental impact, the LCFS mandates the desired environmental outcome but leaves flexible the fuel pathways with which to get there. Subsequent technical feasibility analysis describes this objective as "ambitious but attainable" using a number of possible technologies, including plug-in hybrid vehicles, battery electric vehicles, and biofuels with various levels of GHG reductions.[120]

These two different policy approaches create vastly different sets of incentives that are critical in influencing how the biofuels industry evolves. The RFS, while an important signal to the industry that has effectively encouraged production of alternative fuel, does not provide incentives for production to move in a way that improves environmental performance (with the exception of indirect support for cellulosic ethanol, which receives 2.5 times the renewable fuel credit that grain-based ethanol does). In fact, ethanol producers receive the same RFS credits regardless of the emissions profile of the fuel produced. Emissions-intensive biofuels may further national objectives related to farm support and domestic energy security, but they do so at the expense of the environment.

To ensure that environmental objectives are met as well, fuel incentives should be tied explicitly to the fuel's environmental performance, as does the LCFS, in part. Such policies also provide ongoing incentives to develop new technologies with improved environmental performance, whereas technology-based policies such as the RFS can entrench current technologies and disadvantage emerging technologies that did not yet exist when the support frameworks were determined. The Natural Resources Defense Council describes such fuel policies as "technology neutral and performance based."[121] This kind of policy structure would provide further incentive to developers of next-generation biofuels. Investment in these fuels will be worthwhile, even if the improved environmental performance has a premium, because fuels that do not meet these standards will not qualify for support.

The downside of such policies arises because, whereas gross categories of fuel technologies are easy to observe, document, and reward, the life-cycle environmental performance associated with those technologies is not. There are significant problems with identifying and measuring impacts (such as the impact of removing stover on soil quality, or of displacing cattle ranching that pushes farther into the Amazon). These uncertainties are then compounded by the logistical difficulties associated with tracing and aggregating such impacts through the supply chain to ensure that markets and policymakers can differentiate between "green" and "brown" biofuels, and reward producers and suppliers accordingly.

To establish a consistent methodology for tracking and reporting such impacts, reporting standards for biofuels sustainability and carbon content are being developed and ground-tested for the U.K.'s Renewable Transport Fuel Obligation. This reporting program is seen as a stepping stone toward "a mandatory assurance scheme that would reward biofuels based upon their carbon intensity and penalise [sic] those that came from feedstocks produced unsustainably."[122] Carbon reporting standards have also been developed for California's LCFS, which draw largely from the E4Tech framework.[123]

Certification and international trade

To advance sustainable development of the biofuels industry, several groups have convened to identify and establish sustainability criteria for biofuels production and to advocate for their application in national and international policy. In the U.S., a coalition of environmental groups has called for establishing an independent certification process for feedstock production, much like the Forest Stewardship Council's certification for sustainable forest practice. Establishing sustainability criteria, as well as a certification process to verify achievement of those criteria, would set the stage both for mandatory policies that tie eligibility for support programs to achievement of those criteria and, when combined with product labeling, for niche markets that — even in the absence of mandatory policies — would allow consumers to selectively participate in and support "green" biofuels markets.

Global trade in biofuels has been quite small to date, and most markets have been satisfied with domestic production. This is largely because of specific trade barriers, such as the $0.54 per

[120]Farrell, Alexander E., Daniel Sperling et al. *A Low Carbon Fuel Standard for California Part II :Policy Analysis*. UC Berkeley Transportation Sustainability Research Center. Paper UCB-ITS-TSRC-RR-2007-3. August 2007.

[121]NRDC. 2007.

[122]Low Carbon Vehicle Partnership. "RTFO Carbon and Sustainability Reporting Requirements." Available on the Low Carbon Vehicle Partnership website at: http://www.lowcvp.org.uk/assets/reports/Summary%20of%20RTFO%20C&S%20reporting%20requirements.pdf.

[123]Farrell, Sperling et al. 2007.

gallon ($0.14 per liter) tariff the U.S. imposes on imported biofuels, and because agriculture is generally a highly protected sector in most markets. However, international trade in biofuels is expected to increase substantially in the coming years, with import demand in countries such as the U.S., the E.U., and Japan likely to be met with exports from countries in Latin America, sub-Saharan Africa, and Southeast Asia, which have tropical climates suitable for high crop productivity and more land available for feedstock production.[124] In the United States, ethanol imports have increased dramatically since 2002 despite the tariff, with more than 50 percent of imports coming from Brazil. International trade, and trade policy, will therefore play a critical role in determining the pattern and magnitude of impacts from biofuels use.[125] To avoid international displacement of significant environmental impacts, importing countries must proactively develop sustainability standards for biofuels products and trade-compliant methods of applying them. There are several efforts underway internationally to establish certification or sustainability standards for biofuels (see Box 12).

Validation of carbon and sustainability claims throughout the fuel lifecycle will be critical to the effectiveness of any policy premised on performance. The U.K. reporting guidelines call for suppliers to engage independent auditors to verify the veracity of their carbon and sustainability reports. An independent international certification body could perform the same function.

Although individual countries have free reign to tie their domestic policies to these sorts of sustainability criteria for biofuels and biofeedstocks produced domestically, linking a "green index" for biofuels to trade policy may not be as straightforward. There are restrictions on the types of standards and regulations that can be imposed on international trade and remain WTO-

Box 12: Certification Efforts

Several initiatives seek to establish certification and sustainability standards for biofuels. Some of these initiatives overlap heavily, but they are all broadly consistent in their principles. As of yet, none of these has established itself as the leading forum for this activity, and none is backed by the force of law. However, the U.K.'s **Renewable Transport Fuel Obligation** (RTFO) has perhaps gone the furthest in developing operational standards, with pilots going forward in 2007.

RTFO was introduced in 2005 with the intent to ensure inclusion of biofuels and other renewable fuels in the U.K. fuel mix. It also includes a requirement that producers report the GHG balance and environmental impact of their biofuels. RTFO has established reporting guidelines for biofuels sustainability that attempt to lay the groundwork for practical application of such criteria. To determine "qualifying standards" of sustainability, the guidelines benchmark the criteria against the following "meta-standards" that RTFO has identified as relevant criteria for sustainability.[126]

- Biomass production will not destroy or damage large above or below ground carbon stocks.
- Biomass production will not lead to the destruction of or damage to high biodiversity areas.
- Biomass production does not lead to soil degradation.
- Biomass production does not lead to the contamination or depletion of water resources.
- Biomass production does not lead to air pollution.
- Biomass production does not adversely affect worker's rights and working relationships.
- Biomass production does not adversely affect existing land rights and community relations.

Some of the major initiatives include:

The **Roundtable on Sustainable Biofuels** is a stakeholder initiative led by the Swiss EPFL (École Polytechnique Fédérale de Lausanne) Energy Center. This group seeks to develop sustainability standards for biofuels that are simple, generic, adaptable, and efficient. They hope to have global consensus on the broad principles by the end of 2007, and draft criteria by mid-2008.

The Global Bioenergy Partnership (GBEP), coordinated by the FAO headquarters, is a political forum for promoting bioenergy. The Secretariat seeks to encourage the production, marketing, and use of "green" fuels, with particular focus on developing countries. It will help members identify and implement projects for sustainable bioenergy development and support the formulation of guidelines for measuring reductions in greenhouse gas emissions due to the use of biofuels.

The **IEA** supports several initiatives. **Bioenergy Task 38** analyzes information on bioenergy, land use, and GHG mitigation to support policy and industry decision makers in selecting efficient and effective mitigation strategies that optimize GHG benefits. **Task 40** focuses on sustainable bioenergy trade.

The **Roundtable for Sustainable Palm Oil (RSPO)** is a multi-stakeholder group of organizations, producers, and industries that represent the entire supply chain of palm oil and biofuel production. The group developed a set of principles and criteria for sustainable palm oil production, including ecological, social, economic, and more general criteria. They are studying the supply chain in order to establish whether a track-and-trace standard would be a viable option for the industry.

[124]Kojima, et. al. 2007.

[125]Dufey, Annie. *Biofuels production, trade and sustainable development: emerging issues*. September. London: International Institute for Environment and Development. September 2006.

[126]Low Carbon Vehicle Partnership. "RTFO Carbon and Sustainability Reporting Requirements." Available on the Low Carbon Vehicle Partnership website at: http://www.lowcvp.org.uk/assets/reports/Summary%20of%20RTFO%20C&S%20reporting%20requirements.pdf.

compliant.[127] WTO member countries can adopt domestic policies related to trade as long those policies do not directly or indirectly discriminate between imported and domestically produced "like" products, or between "like" products imported from different countries.[128] If such a policy were challenged under the WTO, any trade distortion that resulted from the different treatment would have to be justified as necessary to achieving the intended environmental goal, and would have to be applied in a rational manner, which would likely provoke lively debate.

The process of establishing WTO-compliant import standards for biofuels and biofeedstock production is likely to be complex. There a wide variety of crops that qualify as feedstocks. Many have multiple uses, and for many of the crops, information is scarce regarding the types of practices likely to be used for large-scale production, or on the best management practices available to producers. Establishing comparable standards for such a wide variety of feedstocks, which come from many regions and with a spectrum of social and environmental impacts, will be difficult and require a vastly improved understanding of various production methods and their impacts. The institutional process used to evaluate and negotiate export countries' compliance with those standards will be equally difficult to design and establish, but, as history has demonstrated, will be equally important in determining the compatibility of subsequent regulations with the existing trade policy regime.

Surely, the development of the biofuels industry is not waiting, for example, until broad principles of sustainability can be implemented in practical rules of certification. It will take time to find solutions and develop consensus to integrate biofuels protections into the WTO and other international trade regimes.Yet this report has highlighted several backlashes that have already emerged, even when the scale of the biofuels industry is still relatively minuscule compared to the current global energy market and, more importantly, compared to the future global biofuels market, as its growth accelerates.

As the industry grows, the global fuel mix will incorporate biofuels at significantly larger scales than today's fuel mix. However, for biofuels markets not to cause more substantial harm to people and ecosystems, the need for sustainability standards must be widely acknowledged among multiple stakeholders and constituencies, including the vulnerable and the powerful. The backlashes are real and will certainly worsen as a result of industrial scale development of biofuels. It is necessary and possible, however, to minimize the negative impacts. Consequently, the development of safeguards in multiple forms, including standards and certification, must go hand-in-hand with the development of the biofuel industries themselves.

[127]Turner, Brian T., Richard J. Plevin, Michael O'Hare, and Alexander E. Farrell. "Creating Markets for Green Biofuels: Measuring and Improving Environmental Performance." April 13. *UC Berkeley Transportation Sustainability Research Center*. Paper UCB-ITS-TSRC-RR-2007-1. 2007. Available online at: http://repositories.cdlib.org/its/tsrc/UCB-ITS-TSRC-RR-2007-1

[128]Lancaster, Christine. "Biofuels Assurance Schemes and Their Compatibility with Trade Law." Piper Rudnick Gray Cary. PowerPoint Presentation. Brussels. June 7, 2007. Available at http://www.eeb.org/activities/agriculture/documents/Lancaster_Presentation_pdf.pdf.

Investment

The policy challenges discussed in the previous section can appear daunting. Investments in biofuels are uniquely risky because they put investors at the mercy of not one but two commodity cycles: agriculture and oil. Moreover, there are other uncertainties related to the additional infrastructure requirements, the sustainability of fuel production processes, and the prospects for new technologies. However, despite such uncertainty, both private and public sector investment is flowing into biofuels technologies at all stages. In 2006, biofuels attracted $2.3 billion in venture capital and private equity dollars, with approximately 80 percent of this capital going toward expansion projects for mature technologies, and the remainder, primarily venture capital financing, going toward development of next-generation technologies.[129] The majority of this interest was in the U.S., where the market has seen strong growth over the past few years. Venture capital investment in biofuels in the U.S. totaled $740 million in 2006, compared to $110 million in 2005, and was led by such high-profile investors as Bill Gates, Vinod Khosla, and Richard Branson.[130]

The number of publicly traded biofuels companies has grown remarkably, with $3.1 billion in IPOs in 2006, compared to only $204 million in 2005.[131] Indeed, 2006 was an incredible year for biofuels companies. Several companies went public, including three U.S. companies (see Box 13) and German company CropEnergies, which raised $224 million. Moreover, the biofuels companies in The WilderHill New Energy Global Innovation Index (NEX) outperformed all other technology companies in the index during 2006, increasing 83 percent during the year.[132] Top performers in the index have included those companies that specialize in enzyme production for next-generation fuels.

By the summer of 2007, enthusiasm for biofuels companies had cooled slightly, and the market saw fewer IPOs. However, biofuels projects are attracting more debt financiers, rather than financing from internal balance sheets, indicating that investors are beginning to see biofuels as a more mainstream investment.[133]

The playing field

The biofuels supply chain is characterized by uncertainties of which investors need to be aware. From feedstock production to fuel distribution, there are new and shifting dynamics that will impact the profitability of companies and investments, particularly as the industry reaches greater scale.

Growing

Global demand for farm products is increasing rapidly. Biofuels have opened a new and lucrative market for agriculture, particularly for corn in the U.S., sugarcane in Brazil, canola in Europe, and palm oil in Southeast Asia and Latin America, but elsewhere as well. As the scale-up of demand for biofuels continues and pushes the limits of what today's farmland can provide, there will be increased pressure on land prices worldwide.

Already certain regions are witnessing this upward pressure. In 2006 the price of farmland in Iowa rose faster than the price of Manhattan or London real estate for the first time in more than a

[129]Greenwood, C., Hohler, A., Liebreich, M., Sonntag-O'Brien, V., Usher, E. *Global Trends in Sustainable Energy Investment 2007*. United Nations Environment Programme. 2007. Available online at: http://www.unep.org/pdf/SEFI_report-GlobalTrendsInSustainableEnergyInverstment07.pdf.

[130]"Venture Capital Powering Renewable Energy Investment, Totaling $1.6 Billion in 2006." Originally published at www.businesswire.com. January 24, 2007. Available online at: http://www.allbusiness.com/finance/equity-funding-private-equity-venture-capital/3998434-1.html.

[131]Greenwood, et. al. 2007.

[132]Greenwood, et. al. 2007.

[133]Greenwood, et. al. 2007.

Box 13: Ethanol IPOs

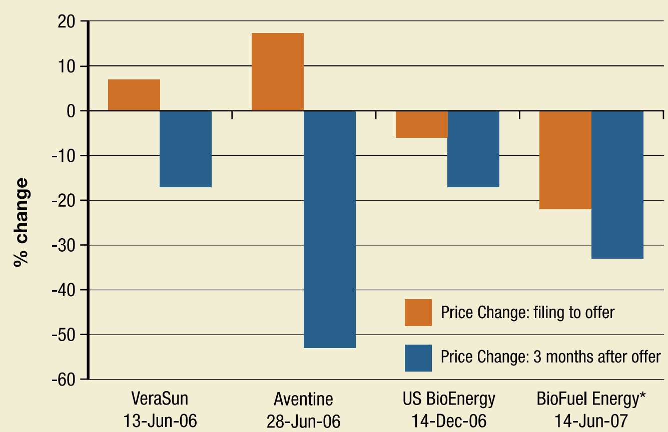
Much of the proliferation of publicly traded biofuels companies in 2006 can be traced to passage of the Energy Policy Act of 2005. This mandate, coupled with the continued substitution of ethanol for MTBE as a gasoline additive, caused demand for ethanol to explode. As high demand caused ethanol prices to rise, producers rushed to increase their productive capacity to take full advantage of the booming ethanol market. However, this wave of enthusiasm was not long sustained; the companies that cashed in early seem to have caught the crest of the wave, while those that held out may have missed an opportunity (see Figure 13).

Aside from **Archer Daniels Midland**, the industry leader, which produces over a billion gallons of ethanol a year, the majority of ethanol producers operate at a much smaller scale. To meet growing demand, new companies have emerged, and existing companies have pursued aggressive expansion strategies.

An expedient method of raising funds to scale up ethanol production is to undertake an Initial Public Offering (IPO). **VeraSun Energy**, one of the largest U.S. ethanol producers, went public in June 2006. Originally offering shares at $21 to $22 each, VeraSun priced above the top end of its range, at $23, and raised $420 million. Proceeds from the IPO helped fund the construction of new plants in Iowa and Minnesota, bringing VeraSun's capacity to approximately 560 million gallons (2,120 million liters) per year by 2008. **Aventine Renewable Energy Holdings, Inc.** also went public in June 2006. Aventine raised $390 million, pricing at the top of its range ($43) and also upsizing the offering size from its initial filing. VeraSun also planned to expand production with its IPO proceeds. Following the success of VeraSun and Aventine's offerings, a number of other ethanol producers announced their intention go public shortly after. By the end of the summer, however, ethanol supply was catching up to demand.

When Chicago spot market ethanol prices reached a high of $3.91 per gallon in July 2006, **Hawkeye Holdings** announced that it too would raise equity in the public markets. Hawkeye's timing was poor, however. Sustained high ethanol prices had lured new firms into the industry and encouraged existing firms to increase their capacity. As projected supply rose to meet forecast demand, ethanol prices began to fall. By September 2006, Chicago spot market prices fell to $1.90 per gallon. At the same time, rising ethanol production was inflating corn prices, reducing producers' profit margins. Hawkeye withdrew its plans to go public, but remained committed to expanding production.

Figure 13: **Ethanol Companies' IPO Performance 2005-2006**



Note: all figures exclude underwriters' allotment.

* On 22-May-07, BioFuel Energy initially filed at $16.00 -$18.00 per share. Range was revised downward on 12-Jun-2007 to $13.00 - $14.00 per share. Graph represents differential from 12-Jun-2007 offer range.

Source: World Resources Institute, based on several sources [134]

Not all companies that filed for IPOs in the wake of VeraSun and Aventine's success retreated when faced with signs of a slowing market, however. **U.S. BioEnergy Corp.** went public in December 2006, hoping to raise up to $150 million to expand production. The IPO raised $140 million, a sizeable amount of capital, but below initial projections as the offering priced below the filing range.

In 2007, the biofuels market has seen sustained high corn prices and supply appears to roughly match demand. There has been some IPO activity in 2007; however, expectations and proceeds are down. In June, Biofuel Energy Corp. went public. Between the company's initial filing with the Securities and Exchange Commission and the issuance of the offering, the number of shares being publicly offered was nearly halved and the filing range was reduced from an initial $16-$18 to a subsequent range of $13-$14. The IPO finally priced at $10.50, raising only $55 million.

quarter of a century.[135] As feedstock costs account for more than half of the cost of biofuels production (60 percent for ethanol and 70-80 percent for biodiesel),[136] rising land prices will impact production costs. In the short term, it appears that increased feedstock demand will be met largely by bringing set-aside and fallow land back into production and shifting production away from other crops (e.g., soybean). However, in the long term, those options will dwindle as the industry continues to scale-up, meaning land premiums will increasingly impact the cost profiles of producers as well as other investments.

Producing

Biofuel producers have experienced a rollercoaster market for the past few years but have continued to thrive. The years 2005 and 2006 were boom times for the industry. A combination of policy enthusiasm, low input prices (corn), and high oil prices drove investor interest in biofuels. The boom started to slow down in 2007, having tripped over its own success. For instance, expanded biofuels production has caused steep increases in the price of corn, soy oil and rapeseed oil, as well as tightening rail capacity, which has severely cut into producers' profit margins.

[134]Data are drawn from companies' SEC filings, available online at: http://www.sec.gov/edgar.shtml, and publicly available information from Yahoo Finance, available online at: www.finance.yahoo.com.

[135]Wilson, Jeff. "Farmland the New Hot Property." Bloomberg News. February 21, 2007. Available online at: http://www.theglobeandmail.com/servlet/story/LAC.20070221.RCORN21/TPStory/RealEstate.

[136]U.S. Energy Information Administration (EIA). *Annual Energy Outlook 2007: With Projections to 2030*. DOE/EIA-0383(2007). February 2007.

Estimates of the total production cost for ethanol are between \$1.60 and \$2.00 per gallon (\$0.42- 0.53 per liter), and \$2.50 per gallon (\$0.66 per liter) of biodiesel.[137] As stated above, feedstock cost accounts for a large majority of a biofuels facility's operating costs (other costs include natural gas or power costs, water, chemicals, labor, marketing and distribution, etc.). However, the majority of the capital required for biofuels production is for constructing the processing facility. New plants in the U.S. require over \$2 per annual gallon of a capacity (189 million liters) in capital costs.[138] Capital costs for biodiesel facilities are less than for ethanol plants because their minimum efficient scale is smaller. However, for next-generation biofuels, estimated capital costs can be in the hundreds of millions of dollars (see Box 14).

Box 14: Iogen

Based in Ottawa, Canada, Iogen Corporation is the world leader in cellulosic ethanol biotechnology. Iogen pioneered the biomass-to-ethanol field, building the first demonstration facility to convert biomass (wheat straw) into cellulosic ethanol in 2004. Their process uses steam explosion pre-treatment as well as fungal enzymes to convert biomass into sugars that will be fermented to create ethanol.

In 2006, Iogen received a CAD\$30 million investment from Goldman Sachs to accelerate commercialization of their process. Iogen is now ready to expand to commercial-scale production in a new US\$300 million plant to be built in Shelley, Idaho beginning in 2008. The new facility will use straw from wheat, barley, and rice, as well as corn stover and switchgrass, and is expected to produce 20-50 million gallons (76-189 million liters) per year.

To finance construction of the new plant, Iogen has been awarded a DOE grant of \$80 million, and they are also seeking a \$250 million DOE loan.[139] Iogen is also partnered with **Royal Dutch Shell, Petro-Canada, Goldman Sachs**, and the Canadian government.

The original demonstration plant, located in Ottawa, is also due for a CAD\$25.8 million upgrade – 7.7 million of which will come from a Canadian government loan.

Thinking about these capital costs in terms of a wedge, the magnitude of the necessary investment is clear. Assuming a capital cost of \$4 per gallon of annual capacity, for the global biofuels industry to achieve a wedge (described above as approximately 250 billion gallons or 1,000 billion liters), the processing facilities alone would cost at least \$1 trillion. As technology changes and economies of scale are realized within the industry, these costs should come down.

Nevertheless, providing this capital will be challenging for the biofuels industry. Today investors still see biofuels as a fairly risky undertaking, particularly relative to industries that are hundreds of years old. Given the exposure of biofuels investments to the risks and fluctuations of two commodities markets, investors remain hesitant. For plant developers, loans are still difficult to secure. Given this greater perceived risk, developers may have to provide a greater share of the project's total cost than is normally required, and the repayment rate may be shorter than most loans.[140]

Next-generation biofuels bring another set of players into the game as well: the enzyme producers. Generally these players are biotech firms that have begun to specialize in enzymes for biofuels production. These companies have developed interesting business models for capitalizing on their technologies as the biofuels market continues to expand (see Box 15).

Distributing

Deploying biofuels at scale will not only require the feedstock and the conversion facilities to produce the fuel, but could also require massive investment in associated distribution infrastructure. The infrastructure requirements for an expanded biofuels market can be grouped into three stages: 1) storage and delivery of feedstock from point of production to biorefinery, 2) transport of fuels from biorefinery to blender to retail outlet, and 3) distribution of fuel from retailer to consumer.

Agricultural feedstocks present new challenges for the fuels industry. For instance, while it varies depending on the feedstock, crops are harvested periodically, which generally means that the supply of feedstock to the refineries is not as consistent as petroleum, which is pumped year-round. The surplus of feedstock during one season must be stored for delivery to the biorefineries on a regular basis to smooth out fluctuations in feedstock supply. Feedstock is generally delivered by truck from the farm to a nearby storage or processing facility (within 50 miles or 80 kilometers). The storage facilities must ensure that the biomass does not perish before it is delivered to the refinery, which can present additional costs.

Once the fuel emerges from a processing plant, it must be moved in volume to the point of blending into the fuel mix; this is easier for some biofuels than for others, and can pose some additional challenges, particularly with ethanol. Crude and processed oil products are moved throughout the U.S. using a dedicated pipeline system that cost-effectively transports a variety of products in succession. However, as discussed above, certain characteristics of ethanol make it incompatible with the existing pipeline infrastructure. Given these characteristics and the new geographic distribution of fuel producers — e.g., ethanol biorefineries concentrated in the

[137]Singhai, Mansi and Paul Y. Cheng, CFA. Lehman Brothers. *U.S. Ethanol: Surplus Capacity Healthy*. April 12, 2007.

[138]Singhai and Cheng, 2007; and GAO. 2007.

[139]Ellis, Sean. "Plans for Cellulosic Ethanol Facility Inching Along." Idaho Farm Bureau Federation. Available online at: http://www.idahofb.org/news/news.aspx?n=n&id=15421.

[140]Petre, Peter. "Understanding Ethanol, CSFB Banker Bottomlines It: 'Ethanol Is Interesting but Risky'." Fortune. January 31, 2006. Available online at: http://money.cnn.com/2006/01/30/markets/biofuel/index.htm.

Box 15: Biotechnology Cashing In with Cellulosic Ethanol

Aside from Iogen (discussed above), several other biotechnology companies are involved in the rush to cellulosic ethanol.

In 2001, DOE issued a $16.1 million grant to **Novozymes**, a leading biotech-based enzyme and microorganisms manufacturer, and the National Renewable Energy Laboratory (NREL), to research ways to reduce the cost of enzymes used to convert cellulosic biomass into sugars for producing fuel ethanol.[141] Using corn as the feedstock and pretreatment technology from NREL, Novozymes identified new enzymes, increased catalytic activity, and improved sugar yields. By 2005, these innovations led to a thirty-fold decrease in the cost of enzymes, from $5 to $0.10-$0.18.

In October 2006, the biotechnology firm **Dyadic International, Inc.** signed a three-year agreement with **Abengoa Bioenergy R&D, Inc.**, a subsidiary of Abengoa Bioenergy Co., to research ways to reduce the cost and improve the yield of converting cellulosic biomass into sugars for ethanol fuel. Abengoa, one of the world's largest ethanol producers, will invest $10 million in Dyadic through a stock purchase agreement. Dyadic will use this funding and their patented Chrysosporium lucknowense fungus (C1) enzyme platform to attempt to deliver an enzyme mixture tailored to Abengoa's biomass feedstocks. Under the agreement, if Dyadic is successful, they may be entitled to royalty payments on Abengoa's ethanol sales.

Genencor, the second largest enzyme producer worldwide, has recently signed multiple agreements to provide its advanced enzyme technology to developmental cellulosic ethanol projects. In January 2007, Genencor announced it will partner with **Mascoma Corporation**, which just received $14.8 million from New York state, as part of a consortium to build a biomass-to-ethanol demonstration plant in Rochester. Mascoma's plant intends to use a variety of forest and agricultural feedstock including wood chips, corn stover, and switchgrass. In September 2007, Genencor announced that it would also be teaming with energy provider, **DONG Energy**, to provide enzymes for a demonstration facility near Kalundborg, Denmark. Using straw as the feedstock, the plant hopes to produce 4,500 tons of cellulosic ethanol per year.

Greenfield Ethanol Inc., Canada's largest fuel ethanol producer, signed a joint venture agreement with the biotechnology firm **SunOpta Inc.** in December 2006 to develop a commercial-scale cellulosic ethanol operation using wood chips. The joint venture will match Greenfield's expertise in building ethanol plants with SunOpta's proprietary enzyme technology to establish one or more commercial-sized plants. The venture's first plant, which is slated to produce 10 million gallons of cellulosic ethanol, will be the world's first commercial cellulosic ethanol plant using wood chips as a feedstock.

At the start of 2007, **Syngenta**, a global agribusiness company, and the biotechnology firm **Diversa Corporation**, announced a restructuring of their research and development collaboration to focus on biofuels production. Originally focused more broadly on plant genomics, this collaboration will now concentrate on developing enzymes that will break down biomass into sugars used to produce ethanol fuel. Under the new deal, Syngenta will pay Diversa $16 million over the next two years to develop enzymes primarily aimed at converting bagasse, a residual from sugarcane production, into fuel.

In June 2007, Diversa and **Celunol Corp.**, an ethanol producer based in Dedham, Massachusetts, announced they would merge to form **Verenium Corporation**. Verenium becomes the first cellulosic ethanol operation to boast a fully integrated production process, from pretreatment and novel enzyme development to fermentation, engineering, and project development. With cost still the central concern in producing cellulosic ethanol, Verenium's vertically-integrated structure gives it a competitive advantage by removing the need to pay technology transfer fees to obtain enzyme technology for converting biomass into sugars.

U.S. Midwest rather than petroleum refineries concentrated at the coasts — delivering biofuels to the consumer is much more complex and therefore more costly than petroleum distribution. NREL estimates that ethanol transport in the U.S. costs $0.13 to $0.18 per gallon (or $0.03 - $0.05 per liter), while gasoline delivery costs only $0.03 to $0.05 per gallon (or $0.01 per liter).[142]

Biofuels today are transported by rail, tanker truck, or barge. In the U.S., rail dominates ethanol shipping, having accommodated 60 percent of ethanol production in 2005, while trucks shipped 30 percent and barges 10 percent.[143] Tanker trucks provide greater flexibility but are twice as expensive as rail, while rail is certainly the cheapest for long-distance transport, such as from Midwest biorefineries to the demand centers on the coasts. Transport by barge is also a cost-effective mode of transport, but it requires that the facility be located on a navigable waterway, which is not always an option.

Currently, outside of Brazil no ethanol is shipped via pipeline, but the U.S. pipeline industry is actively researching the feasibility of developing a national ethanol distribution infrastructure that does not rely on the already strained rail and highway infrastructure (see Box 16). Pipeline distribution may ultimately be a cost-effective means of distributing biofuels, as it is for petroleum-based fuels; however, this is not evident. Pipelines are cost effective for petroleum products as production is concentrated in a relatively small number of refining centers, which allows for efficient use of a hub-and-spoke system. For biofuels, production today is dispersed among a large number of relatively small plants that are widely distributed (in the U.S., primarily in the Corn Belt). Next-generation fuels are likely to make production even more dispersed as biomass feedstocks are more widely distributed than today's fields, and field-to-mill transportation cost is critical to mill economics.

This widely dispersed production makes the likely cost of biofuel pipelines very high. The capital investment required to build *new* dedicated pipelines for ethanol distribution would be very expensive: in 2006 NREL estimated pipeline construction costs at roughly $1 million per mile (or $620,000 per kilome-

141"Novozymes Wins Technology Leadership Award for Biofuels Achievement." Novozymes Press Release. July 25, 2005. Available online at: http://www.novozymes.com/en/MainStructure/PressAndPublications/PressRelease/Novozymes+Wins+Technology+Leadership+Award+for+Biofuels+Achievement.htm.

142National Renewable Energy Laboratory cited in GAO. 2007.

143U.S. Department of Agriculture. *Ethanol Transport Backgrounder*. Agricultural Marketing Service. September 2007. Available online at: http://www.ams.usda.gov/tmd/TSB/EthanolTransportationBackgrounder09-17-07.pdf.

ter).[144] However, once built, a pipeline network could significantly reduce the costs of transporting the fuel to market.

Box 16: Kinder Morgan's Ethanol Infrastructure

Kinder Morgan is one of North America's largest pipeline transportation and energy storage companies. In 2006, Kinder Morgan handled 1.5 billion gallons of ethanol (5.7 billion liters), which accounted for approximately 30 percent of the domestic market. This market presence, however, is currently confined to ethanol blending and storage. Realizing that current transport infrastructure will not support a major expansion of ethanol use beyond the Midwest, Kinder Morgan has begun considering dedicated ethanol pipelines. Construction of a dedicated ethanol pipeline from the Midwest to the East coast would be expensive, however, with cost estimates of between $1-2 billion. Therefore, Kinder Morgan is also considering conversion of an existing pipeline to ethanol transport, potentially in relation to their East coast Plantation product line, which runs from Baton Rouge, Louisiana to Washington, D.C. As with shipment of other products, Kinder Morgan would then charge ethanol producers for using the pipeline to deliver their ethanol from refineries to regional storage terminals based on a set fee scale. This would insulate the company from fluctuations in the price of ethanol.

At the distribution end of the supply chain, ethanol is blended with gasoline and, regardless of the blend of ethanol, moved from bulk storage to retail outlets in tanker trucks, as gasoline is now. At high-level ethanol blends (e.g., E85), new infrastructure is needed including new or extensively cleaned tanks, valves, hoses, and pumps. This distribution infrastructure upgrade can cost anywhere from $3,000 to more than $60,000 per pump.[145] Costs are at the lower end of this range if the station offering E85 merely cleans and replaces some dispenser parts from existing fueling equipment. However, to do a thorough retrofit, the costs will be at the higher end of the range, and if all new retail site equipment has to be installed, costs can be as high as $200,000 per site. Currently there are no components that are fully approved and compliant, so it is unclear what the cost of a fully compliant system would be.

Currently the oil majors are not involved in distributing and branding E85 on a large scale. However, several policy proposals suggest requiring that major oil companies[146] operate at least one E85 pump at a mandated percentage of their stations, beginning at 5 percent in 2008 and increasing to 50 percent by 2017.[147] These stations with E85 pumps must be geographically distributed such that at least one would be available in each state in which the company operates. If the oil majors become significantly involved in marketing E85, and once approved components are available and required, the cost of the necessary distribution infrastructure will likely be toward the high end of this range.

Requiring that oil companies sell E85 would at least start to address the chicken-and-egg infrastructure problem, but it would be very costly. Today nearly 40 percent of approximately 170,000 stations in the U.S. operate under the brand of one of the five majors (Exxon, BP-America, Chevron, ConocoPhillips, and Shell).[148] Requiring half of these stations to install an E85 pump would likely cost more than $2 billion and could cost as much as $6.8 billion. If E85 were not adopted nationally, and if consumers were not compelled to fill up with ethanol over gasoline, billions of dollars in E85 pumps and infrastructure would be a lot of stranded investment.

In addition, the vehicle technology requirements of these high blends of ethanol must also be considered. As discussed above, high blends of ethanol would also require FFVs. This technology is relatively simple, costing vehicle manufacturers an estimated additional $100 - $150 per vehicle. However, automakers may have to significantly retool production lines to scale up production of FFVs to the scale that would be required to match projected biofuels consumption. Any retooling would likely be costly for the automakers. However, for the American Big Three (General Motors, Ford, and DaimlerChrysler), retooling for FFV production is likely an attractive option. These automakers are increasingly under pressure to contribute to efforts to reduce oil consumption and GHG emissions. This pressure comes in the form of higher CAFE standards and interest in hybrid and plug-in hybrid electric vehicle technology. Biofuels and FFVs afford these companies the opportunity to "Live Green" — to participate in oil and GHG reduction efforts — while avoiding the even costlier retooling that increased efficiency and manufacturing hybrids would require. The Big Three are currently faced with poor credit ratings and consequently a high cost of capital; therefore, any strategy that reduced their capital requirements — which a cheaper retooling would do — would be better for their balance sheets.

Issues of concern

As the previous section shows, investors are putting significant quantities of capital into biofuels technology and the huge range of associated infrastructure, from FFVs to feedstock transport. With so much at stake, some private sector investors have started putting on the brakes, increasingly wary of the potential for an essentially policy-based market to succumb to a backlash. Companies providing the fuels are well aware that if the fuels they sell are associated with high food prices and damage to rainforests, their brands will quickly lose valuable customer good will.

[144] National Renewable Energy Laboratory cited in GAO. 2007.

[145] GAO. 2007.

[146] Defined as those who introduce gasoline into commerce in the U.S. through wholly-owned or branded stations, and having 'an affiliate relationship or significant ownership interest' in more than 4,500 retail station outlets

[147] S23 (Harkin): Biofuels Security Act of 2007 and S162 (Lugar): National Fuels Initiative would create increasing mandate for % of major oil co. stations that have E85 pumps. Mandate increases from 5% in 2008 to 50% in 2017.

[148] GAO. 2007.

At the same time, the push toward next-generation fuels and feedstocks mean that policy and the markets are closely intertwined: biofuels policy will only deliver results if companies come up with better fuels and deploy them quickly; investors in biofuels will likely see returns only if they correctly anticipate the shape of policy in the years ahead.

There are three major areas of concern:

- Policy structures today in some cases give incentives to invest in what may become redundant infrastructure. Investors should avoid following policy enthusiasm down a path that will result in stranded investments if political winds should change. How might investors guard against this uncertainty?
- How do emerging impacts from biofuels production affect the prospects for a sustained market for these fuels, and what can companies do to address these impacts?
- How well understood are the prospects for next-generation biofuels to make a meaningful contribution to the fuel mix in major economies in the near term?

Building a bridge to nowhere?

Despite long-term competition from next-generation fuels, new first-generation biofuels plants continue to be built. The market for biofuels may be a policy-driven market (as described above), but it is still a market. Where there are bottlenecks in the supply chain, there are opportunities to invest in solutions. For instance, if the government mandates widespread availability of E85, then investing in E85 infrastructure is likely to be a money-making prospect. However, as no single biofuel has the potential to displace all fossil fuels for transportation in the major markets, the way in which biofuels are adopted will depend largely on how they fit into the broader fuel mix, which will be dominated by fossil fuels for the foreseeable future. Blending biofuels into the existing fuel mix presents a set of infrastructure-related challenges, given the different fuel qualities of the varieties biofuels. These present both opportunities for investment and risks and uncertainties for the whole range of stakeholders.

Given the distinctions in infrastructure requirements noted above, E85 deployment in the U.S. would raise numerous challenges. Expecting E85 to become the sole transport fuel nationwide is not realistic, given the magnitude of biofeedstocks and the sheer scale of the land-use requirements. At present, however, both existing and proposed federal legislation in the U.S. supports E85 indiscriminately across the country. This policy push means that investments in E85-related infrastructure are likely to be profitable in the short-term. This will not be the first time policy incentives have created a market opportunity where there was not one before. However, a longer-term bet on this infrastructure could founder if, for example, states require E10 and find that they have no need for a separate E85 infrastructure.

Policy makers should avoid creating incentives for investment in poorly planned short-term fixes, and industry players need to be wary of these policy-driven opportunities. A piecemeal and uncoordinated approach to meeting the needs of the expanding biofuels industry does not serve anyone well. However, basing support on policy goals such as lower carbon intensity offers a potentially constructive way to promote fuels that genuinely protect the climate. Even better, more integrated transport policy that raises the cost of emissions will also harness the potential for greater efficiency and modal shifts.

Environmental and social impacts: fearing the backlash

As discussed on page 32, the rapid rise of biofuels has generated increasing concern over impacts on a range of environmental and social concerns, from the forest-dwelling orangutan to the price of a tortilla. For a technology that is so dependent on public policy support, a strong public backlash on the basis of these concerns could be disastrous for the industry. It would not be the first time that a substance has fallen out of favor in the fuels market due to negative environmental impacts (see Box 17). Companies invested in this arena have a strong incentive to ensure that negative impacts of the fuel are minimized, and a handful of companies are already acting on this incentive.

Box 17: MTBE

Methyl tertiary-butyl ether (MTBE) is a chemical compound that has been used as a fuel additive in gasoline in the U.S. since the late 1970s. Originally, low levels of MTBE were added to fuel as an octane enhancer to replace lead as it was phased out. Following the oxygenate requirements set by Congress in the 1990 Clean Air Act (CAA), higher-level blends of MTBE were used, as the increased oxygen content in the fuel causes it to burn more completely, reducing tailpipe emissions regulated by the CAA. MTBE was not mandated, but it was the oxygenate of choice for refiners after 1992, when EPA initiated the Federal RFG (reformulated gasoline) program to meet CAA requirements.

However, MTBE soon was found in groundwater and drinking water around the U.S., sparking an outcry. MTBE contaminates drinking water, causing an unpleasant taste and odor. The health effects of MTBE in drinking water are uncertain, but EPA acknowledges that at high levels it is possibly carcinogenic.[149]

In response to these concerns, several states have banned MTBE, and a federal ban has been considered on several occasions. In 1999 then-governor Gray Davis issued an Executive Order to remove MTBE from all California's gasoline by 2003 (California was the leading consumer of MTBE), and more than half of the states have since banned the additive. In addition, largely in response to the state bans, most of the large petroleum companies began voluntarily phasing out MTBE in the spring of 2006, before the summer driving season.

[149]U.S. Environmental Protection Agency (EPA). *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-butyl Ether (MTBE).* EPA-822-F-97-009. December 1997.

Companies in Europe have started grappling with these challenges perhaps more so than anywhere else, but the issues are complex (see Box 18). Efforts to minimize the negative impacts of palm oil production are hampered by a significant lack of credible and timely data on the environmental, social, and economic values of the land. Palm oil retailers are making sourcing decisions, governments are making allocation decisions, and community groups are making land claims, all based on inadequate data. While some efforts at standards and law enforcement have been made, producing countries have faced a significant lack of credible processes to verify and certify plantation development.

Box 18: European Private Sector Efforts to Promote Sustainable Biofuels

Due in part to advocacy campaigns that brought public scrutiny on the industry, members of the palm oil sector have begun to take steps to reduce their risk of promoting or being associated with these problems. The Swiss retail company **Migros** has adopted a standard for responsible palm oil production that includes supplier performance audits, and screening of palm oil flows from plantation to supermarket.[150] In 2001, three of the four largest Dutch commercial banks (**ABN AMRO**, **RaboBank**, and **FortisBank**) adopted policies to mitigate environmental and social risks when dealing with palm oil companies.[151] **Unilever** identified a set of ten broad indicators of sustainable agriculture and are working with a steering committee of research and non-governmental organizations to apply them to their palm oil activities in Southeast Asia.

In 2006, the Cramer Commission, a group of primarily Dutch private-sector stakeholders convened by the now-Minister of Environment for the Netherlands, unveiled a set of criteria for sustainable biofuels production. These criteria fall into six themes: GHG balance; competition with food, supply, medicine, or building materials; biodiversity; economic prosperity; social well-being; and environment. The group recommended a track-and-trace certification system to ensure the sustainability of biofuels.

Paving the way for tomorrow's biofuels

With increasing political emphasis on cellulosic biomass for biofuels production, it would seem only a matter of time before the next generation of these fuels comes riding in to save the day. But how much time? Today's policy is predicated largely on the assumption that cellulosic feedstocks will play a major role relatively soon. Most scenarios that project significant oil displacement and GHG reductions from biofuels include optimistic outlooks for next-generation technologies.

The European biofuels industry is already reaching maximum domestic or local production capacity, and with all the concerns surrounding first-generation fuels, including imported palm oil from Southeast Asia, Europe is looking to next-generation technologies and feedstocks to enable increased biofuels consumption while minimizing adverse social and environmental impacts.[152]

Similarly, in the U.S. context, biofuels supporters are also looking to next-generation fuels to expand the proportion of biofuels in the fuel mix with fewer negative impacts. Corn and ethanol industry representatives generally acknowledge that with today's technology the maximum potential contribution from corn-based first generation ethanol to the fuel mix is around 15 billion gallons (57 billion liters) per year.[153] Targets and projections, therefore, that call for 25, 35, 65, or more than 100 billion gallons (or up to 380 billion liters) of bio- or alternative fuels in the U.S. fuel mix within the next 50 years, imply assumptions about the speed with which next-generation, non-corn based fuels will become widely available.

Many technology companies claim that next-generation technologies are only a few years away from commercialization, and all that is needed is capital for demonstration and commercial-scale plants. How realistic is this assumption? A closer look at the development process suggests that policy makers and investors need to be considerably more cautious. In fact the timing of the deployment of these next-generation technologies *at scale* is highly uncertain.

As of late 2007 there are only 9 demonstration plants for next-generation biofuels in the world, capable at full capacity of producing about 3 million gallons (12 million liters) per year. None of these is a commercial-scale plant (see Table 3). A large number of other plants are under development, and the results of their performance will be an important indicator of the scope for more innovative biofuels.

[150]Press release by Urs Riedener, Head of Marketing Food and Near Food, Federation of Migros Cooperatives. *Palm oil from sustainable production – a Migros pilot project*. January 22, 2002. Available online at: http://www.rspo.org/resource_centre/Migros%20Criteria.pdf.

[151]Van Gelder, Jan Willem. German Banks and Palm Oil and Pulp & Paper in Indonesia. Prepared on behalf of the World Wildlife Fund International by Profundo. December 2001.

[152]Environment Commissioner Stavros Dimas has noted the additional benefits that second generation biofuels offer, including higher potential production and cost and GHG reductions that "second generation biofuels seem to have much lower overall ... environmental impacts than the first generation biofuels that dominate production in the EU today." http://www.euractiv.com/en/environment/biofuels-cure-oil-dependency/article-159043

[153]Renewable Fuels Association. "Energy Bill Provides Growth Opportunity for Ethanol." *Ethanol Report*. Issue #254. June 26, 2007.

Table 3: **Cellulosic Facilities**

	Company	Status	Location	Production Capacity (per year)
In Operation	China Resources Alcohol Corporation	Began operation in October 2006. It is the only cellulosic ethanol pilot demonstration plant in the world which operates continuously, 24 hours per day.	ZhaoDong City, Heilongjiang Province, China	Aims to install 1.7 million gallons by the end of 2007 and 330 million gallons by 2012.
	ClearFuels Technology, Inc.	ClearFuels' first commercial demonstration facility is currently under development	Hawaii	
	Dedini	Demonstration facility began operation in 2002.	São Paulo, Brazil	1.8 million liters at the demonstration facility
	Dynamotive	Pilot plants in operation	Ontario, Canada	
	Iogen Corporation	Operates the world's first and only pre-commercial demonstration facility where clean-burning cellulosic ethanol fuel is made from agricultural residues.	Ottawa, Canada	2.5 million liters of cellulosic ethanol
	Lignol Energy (Lignol Innovations)	Operates a pilot plant in Vancouver, Canada, and is planning a commercially viable demonstration plant		
	Marubeni Corporation/Tsukishima Kikai Corporation (TSK)	Completed January 2007, second phase in 2008	Osaka, Japan	1.3 million liters, with the goal of 4 million liters in the second phase
	PureVision Technology	Currently developing a 3-ton/day pilot-scale reactor followed by a 75-ton/day commercial demonstration biorefinery that is anticipated to be co-located at an existing corn-to-ethanol plant. This commercial demonstration project is anticipated to break ground in 2010.	Fort Lupton, Colorado	
	Verenium (Merger of Celunol and Diversa)	Verenium Jennings Pilot Facility--Opened in 1999	Jennings, Louisiana	Up to 50,000 gallons
Under Development	Abengoa Bioenergy	Pilot cellulosic plant under construction adjacent to Abengoa's existing ethanol facility.	Babilafuente (Salamanca, Spain)	5 million liters
	Abengoa Bioenergy	Permit granted	Lancaster, California	anticipated 3.1 million
	Blue Fire Ethanol, Inc	Technology fully demonstrated, ready for commercial deployment.	Izumi, Japan	300 liters
	Blue Fire Ethanol, Inc	Developing its first commercial facility in California that should be operational by 2010. Also negotiating permits for 3 million gal/yr plant in Lancaster, CA that would use green waste, wood waste, and other cellulosic materials as feedstocks.	Corona, California	Approx. 17 million gallons
	C2 Biofuels	Planning	Georgia	50 million gallons
	Catalyst Renewables	Funding from New York in 2006	Lyonsdale, NY	anticipated 130,000 gallons
	Changing World Technologies (CWT)	First commercial facility commissioned in 2004 and is currently operated by Renewable Environmental Solutions, LLC (RES). Achieved 100% capacity in February 2005.	Carthage, Missouri	

Feedstock(s)	Main Investor(s)	Technology	Other
Local corn stover		SunOpta and Novozymes technologies	China has committed $5 billion to cellulosic ethanol production and recently announced that they would allow no further increase in ethanol production from starch, in response to food security concerns.
Bagasse, crop waste, wood waste, and energy crops	Garage Technology Ventures	Patented steam reformation process developed by Pearson Technologies	
Bagasse	Cooperative agreement with São Paulo's Research Foundation	Dedini Hidrólise Rápida' (DHR) involves pretreating the biomass with organic solvents, and then dilute acid hydrolysis.	
Takes waste construction and demolition wood, and waste sawdust		Fast pyrolysis technology	
Wheat, oat and barley straw	Royal Dutch/Shell Group, Goldman Sachs and Co., Petro-Canada, the Canadian Government and DSM (an animal feed vitamin supplier)	Enzymatic hydrolysis and fermentation	See Box 14
Wood chips		Delignification process first developed by General Electric Corp.	
Wood waste		Liscensed technology from Verenium (Merger of Celunol and Diversa)	
Biomass (evaluating corn stover, sugar cane residues and wood)	PureVision has received over $3 million in U.S. government grants as well as co-funding from industrial collaborators.	Continuous fractionation process	
A wide variety of biomass feedstocks	Publically traded company. Braemer Energy Ventures, Charles River Ventures, Khosla Ventures, and Rho Capital invested in the project	Enzymatic hydrolysis and fermentation	
Wheat straw (lignocellulosic biomass)	Publicly traded company. Abengoa and Ebro Puleva are joint partners of the facility. The project is supported by € 4.5 million from the European Comission.	Abengoa has contracted to use SunOpta's patented steam explosion technology.	
Wood waste			
Solid municipal waste, rice and wheat straws and wood waste	Publicly traded	Blue Fire has exclusive North American license to Arkenol's Concentrated Acid Hydrolysis Technology	BlueFire's goal is to design, develop, and construct 20 biomass-to-ethanol plants in the next 6 years, totaling 1.5 billion gallons in production and approximately $2.7 billion in gross revenue by 2012 with earnings in excess of $1.6 billion. Only cellulose-to-ethanol company worldwide with demonstrated production of ethanol from these materials.
Landfill waste	Publicly traded	Blue Fire has exclusive North American license to Arkenol's Concentrated Acid Hydrolysis Technology	
Wood pulp		C2 signed a deal in December 2005 to work with Georgia Tech researchers to create technologies for their planned facility.	
Wood and willow from the surrounding area	Funding from NY State and New Energy Capital		
Turkey waste	RES is a joint venture between CWT and ConAgra Foods	Thermal Conversion Process (TCP: depolymerization and hydrolysis)	

Table 3: **Cellulosic Facilities** *continued*

	Company	Status	Location	Production Capacity (per year)
Under Development	Choren	Expecting production at first plant in 2009	Site selection currently underway	
	Flambeau River Biorefinery/American Process Inc.	Production expected as early as 2009	Park Falls, Wisconsin (Next to Flambeau River Biorefinery)	20 million gallons
	Fuel Frontiers, Inc	Secured land, environmental permits, feedstock sources, a ten-year ethanol purchase contract, and preliminary approval for an $84 million bond authorization from the state of New Jersey	Toms River, New Jersey	52 million gallon
	Greenfield Ethanol/SunOpta	Joint venture announced Dec. 2006	Ontario or Quebec, Canada	10 million gallons (40 million litres) of cellulosic ethanol
	Losonoco	Building a proprietary gas-to-liquids process alongside their corn-to-ethanol processing plant during 2008. Expecting production by 2009.	at their Bartow facility, Florida	
	Masada Oxynol	Planning	Middletown, New York	
	Mascoma Corporation	Planned; received funding from New York state in 2006	Rochester, New York, pending local permit approvals; another facility planned in Michigan	500,000 gallons
	POET (formerly Broin Companies)	Converting 50 mgpy dry-mill ethanol plant into commercial cellulosic biorefinery by 2011	Emmetsburg, Iowa	anticipated 125 million gallons
	Potlatch Corporation	Began feasibility study in 2006	Arkansas (adjacent to existing Cypress Bend pulp and paperboard mill)	
	RangeFuels	Phase 1 of the plant is scheduled to be completed in 2008.	Treutlen County, Georgia	100-million-gallons 20 million gallons after Phase 1
	Verenium (Merger of Celunol and Diversa)	Broke ground on the Verenium Jennings Demonstration Facility in February 2007, and the facility is scheduled to be completed by the end of 2007, with operations commencing in early 2008.	Jennings, Louisiana	1.4 million gallons
	Western Biomass Energy	Began operations in March 2007	Upton, Wyoming	
	Worldwide BioEnergy	Licensed the rights to the technology and is working toward commercialization, beginning with construction of a pilot plant.	Illinois	

Feedstock(s)	Main Investor(s)	Technology	Other
Biomass		Fischer-Tropsch gasification and synthesis	
Spent pulping liquor		AVAP: uses alcohol sulfite cooking liquor to fractionate softwood chips into three lignocellulosic components.	
Waste		Startech Environmental Corporation proprietary Plasma Converter(TM) System	Toms River facility will become the prototype for launching additional facilities at other potential sites domestically and internationally, including potentially a 250-million gallon facility in eastern Pennsylvania.
Wood chips		SunOpta's proprietary steam explosion technology	
Yard waste, citrus residues and sugar bagasse	Expecting funding from Florida State	Thermochemical gasification	
Municipal solid waste		Acid hydrolysis	
Wood chips, paper sludge, non-food agricultural products	Investors include Khosla Ventures, Flagship Ventures, General Catalyst Partners, Kleiner Perkins Caufield & Byers, Vantage Point Venture Partners, Atlas Venture, and Pinnacle Ventures	Biochemical conversion. Mascoma has an exclusive license with Dartmouth College.	
Corn fiber and corn cobs	Cooperative agreement with U.S. DOE	Corn fractionation and lignocellulosic technology	By adding cellulosic production to an existing grain ethanol plant, POET will be able to produce 11 percent more ethanol from a bushel of corn, and 27 percent more from an acre of corn, while almost completely eliminating fossil fuel consumption and decreasing water usage by 24 percent.
Forest and agricultural waste		Thermochemical gasification	Potlatch is a real estate investment trust that owns and manages 1.5 million acres of timberlands in Arkansas, Idaho, Minnesota and Oregon. They also operate 15 manufacturing facilities for producing commodity wood products and bleached pulp products.
Wood waste	RangeFuels founded by Khosla Ventures.	Proprietary two step thermo-chemical conversion process called K2.	
Sugarcane bagasse, specially-bred energy cane, and wood	Publically traded. Khosla Ventures is an investor.	SunOpta's proprietary steam explosion technology	First demonstration-scale cellulosic ethanol facility to break ground in the U.S. It is intended to reduce scale-up risk by validating the cost models for Vereniumís first generation of commercial-scale cellulosic ethanol facilities, which are slated for completion by 2010.
Wood waste: local ponderosa pine	Received start-up grants from the Wyoming Business Council and the Wyoming Department of Forestry,	Technology developed by KL Process Design Group, the South Dakota School of Mines and Technology	The technology is expected to be integrated with corn stover and other prairie grasses, but the economics of feedstock transport must first be evaluated.
Swine manure		Thermochemical conversion	

Scaling up may be slower than we think

There has been tangible progress in developing new biofuels technologies, and it is hard not to be infected by the enthusiasm. Undoubtedly the unleashing of venture capital and the interest of creative researchers will produce genuine technological breakthroughs. But there are still grounds for some caution.

First, the fact that the technologies in question are generally proprietary makes their promise and performance hard to evaluate. True, some companies have attempted to address this problem by having their processes and costs verified by government or other third parties, not least because they are mostly seeking investment. Investors have clearly been impressed enough with what they have seen to try their luck — with, in most cases, substantial government support. However, the lack of transparency or proven track records mean that for the foreseeable future, general statements about the progress of these technologies will be approximate, and most investments will rely on governments' continued willingness to support the industry's development.

More fundamentally, the list of demonstration projects now moving ahead cannot be taken as a sign that large-scale deployment of these technologies is near. The demonstration plants now being built are all well below commercial scale. If they are successful, larger-scale demonstration plants will be needed. Investors will need to see these in operation for some time before they invest significant capital in such novel technologies.[154]

The owner of a new technology has a strong incentive to pace this development cycle carefully. Each new scale-up means bringing in new investors, which means that the original owners see their share of ownership diminish. The more the technology has been demonstrated at different scales and over time, the more these owners will be able to hold out for a better deal and realize more of the value of their technology. They have a strong incentive not to immediately join with large partners that might bring large-scale production sooner.

The wedges vision considers timescales of 50 years for deployment of the necessary technologies. What will happen that far into the future is anyone's guess. But in the next ten to twenty years, it may be unrealistic to expect cellulosic ethanol and its fellow high-tech fuels to come gushing out at huge scale.

[154]Similar challenges are common with other technologies of interest in fighting climate change. For instance, see Wellington, Fred, Hiranya Fernando, Clay Rigdon, and John Venezia. *Capturing King Coal* (Working title). Washington, DC: World Resources Institute. (forthcoming).

Conclusions

Although biofuels will likely play a major role in energy and agricultural policy in the years to come, today's policy structures do not maximize the potential advantages — such as reduced GHG emissions and enhanced energy security — that biofuels offer. However, realizing these advantages is far from simple. Unwise policy design choices can not only negate the potential energy and emission benefits of biofuels, but can also impact human welfare through higher food prices, and damage the environment through deforestation and more intensive farming. These impacts may produce a backlash sufficient to undermine public support for biofuels in important markets. Where agriculture is concerned, unwise policy decisions are more the rule than the exception.

This report attempts to place both the advantages and drawbacks of biofuels in context, and to draw lessons for policy makers and investors from humanity's experience to date. Our starting point is the search to implement key climate technology "wedges" that can contribute in a major way to mitigating greenhouse gas emissions. Our conclusions are:

1. Biofuels are not a complete, nor even the primary, solution to our transport fuel needs. Biofuels have the potential to play some role in fulfilling figure transport demand, but carbon displacement on the gigaton scale seems unlikely to be feasible.

In order to displace one gigaton of carbon emissions, the wedges vision assumed both a large improvement in production efficiency and the use of one sixth of global agricultural land for biofuels. It is unlikely that this would be feasible without significant destruction of the world's forests, which would undermine the benefits of biofuels, or impacts on food prices, which would impose politically and morally untenable hardship on the poor. Biofuels will not save policy makers from the uncomfortable but necessary task of using fuel prices, taxation, and mandated efficiencies to restrain transport fuel demand and decarbonize mobility.

2. Today's biofuels policies illustrate the potential for both positive and negative impacts.

Biofuels policy in Brazil has put pressure on forests and agricultural markets, but has also undoubtedly played a major role in enhancing the country's energy security, raising rural incomes, reducing foreign debt and reducing GHG emissions. European Union biodiesel policy and U.S. ethanol policy have effectively been simple financial transfers to the farm sector, contributing to neither energy nor environmental goals. Biofuels policy should not take a one-size fits all approach, as the term 'biofuels' disguises a range of products with varying abilities to achieve policy aims.

3. Biofuels should be rewarded, within a broader policy framework, with support that is in proportion to the specific benefits that they bring.

Short of a world in which externalities such as carbon emissions and energy security are adequately reflected in price signals through taxes or caps, incentives supporting biofuels and other alternatives should be proportional to the actual benefits they offer, such as life-cycle reductions in carbon emissions. At the very least, applying a technology neutral "low-carbon fuel standard" rather than a renewable fuels standard would yield more economically efficient outcomes, and could help spur a number of technology solutions, including, in particular, next-generation fuels.

4. Successful biofuels deployment will depend critically on the emergence of more advanced fuels, feedstocks, and conversion processes. Although these fuels have promise, it is not clear how quickly they can be deployed at meaningful scale.

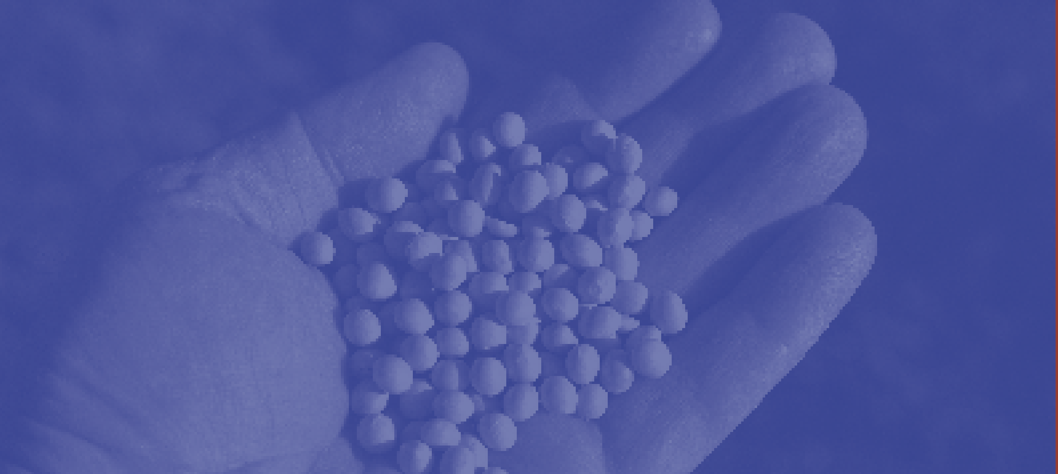
New processes capable of converting feedstocks such as lignocellulose are vital, as is the use of feedstocks that can be grown on land unsuitable for agriculture. Until these are commercially available, governments should refrain from stimulating demand for biofuels. Rather, efforts should be focused on bringing these next-generation fuels to market at scale. This would include enhanced RD&D support for new biofuels technologies and low-carbon fuel standards, rather than large-scale renewable fuels standards.

5. Measures to ensure high environmental and social standards at the point of production, including certification, are essential.

As biofuels become a larger part of the social, economic, and environmental strategies of countries around the world, standards and regulations are needed to ensure that support for biofuels do, in fact, achieve the intended policy goals. Developing standards in an open and participatory manner, devising a transparent system to effectively monitor compliance and ensuring that the standards are not discriminatory or in violation of WTO principles will be challenging.

6. Until next-generation fuels are ready for commercial deployment, policy makers and investors should avoid creating new, parallel infrastructures for ethanol.

Biodiesel, biobutanol, and octanol can all be delivered through standard fuel distribution channels, as can ethanol in low-level blends. The present U.S. policy focus on deploying a national infrastructure for E85, including flex-fuel vehicles and distribution channels, is misguided. If E85 infrastructure is to be deployed at all, it should be on a regional basis in response to market forces. Promoting flex-fuel vehicles by undermining fuel efficiency standards aggravates the very problems of oil dependence and GHG emissions that policy seeks to address.



About WRI

The World Resources Institute (WRI) is an environmental think tank that goes beyond research to find practical ways to protect the earth and improve people's lives.

Our mission is to move human society to live in ways that protect Earth's environment and its capacity to provide for the needs and aspirations of current and future generations.

Because people are inspired by ideas, empowered by knowledge, and moved to change by greater understanding, WRI provides—and helps other institutions provide—objective information and practical proposals for policy and institutional change that will foster environmentally sound, socially equitable development.

WRI organizes its work around four key goals:

- **People & Ecosystems:** Reverse rapid degradation of ecosystems and assure their capacity to provide humans with needed goods and services.
- **Access:** Guarantee public access to information and decisions regarding natural resources and the environment.
- **Climate Protection:** Protect the global climate system from further harm due to emissions of greenhouse gases and help humanity and the natural world adapt to unavoidable climate change.
- **Markets & Enterprise:** Harness markets and enterprise to expand economic opportunity and protect the environment.

Acknowledgments

The authors benefited from the input and insights from numerous colleagues, without whom this report would not have been possible. Our tireless and brilliant colleagues at the World Resources Institute, Manish Bapna, Emily Chessin, Hiranya Fernando, Al Hammond, Liz Marshall, Smita Nakhooda, Jim Perkaus, Jonathan Pershing, Clayton Rigdon, Lee Schipper, Fred Stolle, Fred Wellington, and Jake Werksman generously contributed their time and expertise to improving this analysis. Paul Jefferiss, Sarah Ladislaw, Ron Steenblik, and our partners at the Goldman Sachs Center for Environmental Markets all made important contributions as thoughtful reviewers.

The contributions of Andrew MacBride, Kirk Vizzier, Seth Ort, and Siir Kilkis were invaluable throughout the research and writing process, ensuring that we got our facts straight. Greg Fuhs provided excellent and speedy editing. Kristin Duffy and her colleagues at Dever Designs made it a treat for the eyes.

This report would not have been possible without the financial support of WRI's partners, in particular the Goldman Sachs Center for Environmental Markets, JPMorgan Chase Foundation, BP, Generation Investment Management, and the Government of the Netherlands. WRI also thanks USDA, DOE, and NSF for support of its Biofuels Production and Policy program.

Each World Resources Institute report represents a timely, scholarly treatment of a subject of public concern. WRI takes responsibility for choosing the study topics and guaranteeing its authors and researchers freedom of inquiry. It also solicits and responds to the guidance of advisory panels and expert reviewers. Unless otherwise stated, however, all the interpretations and findings set forth in WRI publications are those of the authors.

About the Authors

Rob Bradley is Director of the World Resources Institute's International Climate Policy Initiative. Prior to joining WRI in 2004, he has worked for 10 years on European and International climate and energy policy for private, public and NGO sector clients. He holds a BSc in Physical Sciences from University College London and an MSc in Environmental Sciences from the University of East Anglia.

Britt Childs is a research analyst in the Climate and Energy Program at the World Resources Institute. Her research focuses on international climate policy, including in particular, sustainable development and clean technology deployment. She holds a bachelor's degree in international politics from Georgetown University's Walsh School of Foreign Service.

WORLD
RESOURCES
INSTITUTE

10 G Street, NE
Washington, DC 20002
www.wri.org

Mixed Sources

Product group from well-managed forests, controlled sources and recycled wood or fiber

FSC

www.fsc.org Cert no. SW-COC-1941

Printed in the United States of America on chlorine-free paper with recycled content of 50%, 30% of which is post-consumer.

WORLD RESOURCES INSTITUTE

Goldman Sachs Center for Environmental Markets

ISBN: 978-1-56973-670-8