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by

Bill Jackson
jackson_bill@bah.com

Leslie Moeller
moeller_leslie@bah.com

Eric Spiegel
spiegel_eric@bah.com

Praneet Gupta
gupta_praneet@bah.com

The Bounty of Biofuels

Perception versus Reality

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In the flood of media attention that biofuel technologies have received, it's difficult to distinguish the facts from the fanfare. Biofuels have been hailed as a panacea that will arrest global climate change, ensure energy security, and turbocharge agricultural economies. They have also been denounced as a scourge by some critics who claim they will do more harm than good to the environment and are not economically sustainable absent government protection. These critics maintain that biofuels drive up food prices while consuming already scarce water resources in populous areas such as India and northern China. In this article, we will dispel some of the misperceptions regarding biofuels while illuminating the emerging realities, to facilitate a sensible discussion of next steps.

"[I am] gravely concerned that biofuels will bring sudden hunger in their wake. …[The practice of using food crops for biofuels] is a crime against humanity."
– Jean Ziegler, UN Special Rapporteur on the Right to Food[1]

"The apocalyptic statements made by the special rapporteur…are not only unjustified but also unacceptable to those of us who contribute to this emerging industry, and millions of people around the world who benefit from renewable biofuels every day."
– Bob Dineen, President, Renewable Fuels Association[2]

"The Stone Age came to an end not for a lack of stones, and the oil age will end, but not for a lack of oil."
– Sheik Ahmed Zaki Yamani, Chairman, Centre for Global Energy Studies, United Kingdom; Former Saudi Oil Minister[3]

Great minds may think alike, but they often arrive at starkly different conclusions. Before embarking on a discussion of biofuels' potential implications, it's useful to review where great minds both agree and disagree when it comes to biofuels today. To develop that comprehensive overview, we spoke to dozens of experts in government, corporate, academic, and non-profit organizations. In addition to these primary interviews, we reviewed the full body of existing research on the growth and viability of the biofuels market. Based on key assumptions regarding agricultural yield, petroleum supply, and biofuel technology development, we tested hypotheses on the future course this market could take, in terms of not only its long-term impact on petroleum prices but also its implications for the global environment and water use.

Greenhouse Gas Impact

PERCEPTION: Substituting biofuels for petroleum will substantially reduce greenhouse gas emissions.

REALITY: The often overlooked land use effects of cultivating biofuels offset the greenhouse gas benefits commonly expected in the short term.

At first glance, biofuels would appear to leave a much smaller carbon footprint than oil. It is true that energy crops extract carbon from the atmosphere, so they

1 Lauren Etter, "U.N. Is Urged to Disavow 'Rogue' Biofuels Remarks," Wall Street Journal, November 13, 2007.
2 Ibid.
3 Richard Mably, "OPEC Speeds End of Oil Era," Reuters, April 9, 2000.

recycle rather than generate atmospheric carbon. However, greenhouse gas (GHG) emissions from the cultivation and processing of biofuel crops partially offset that benefit. The production of corn ethanol, as an example, consumes significant fossil fuels; farmers use fertilizer and diesel to cultivate the corn, coal, or natural gas for distillation, and petroleum to transport it.

"Some studies…suggest that [corn] ethanol is a loser's game, requiring more carbon-emitting fossil fuel than it displaces. Others give it a slight advantage. But however the accounting is done, corn ethanol is no greenhouse panacea."
– National Geographic, October 2007[4]

Even so, most people would point out that biofuels are significantly "greener" than fossil fuels. Published "well-to-wheel" GHG savings range from 20 percent with corn ethanol to 80 percent or higher with cane or cellulosic ethanol (which can be produced far more "cleanly").

However, what these figures, and most experts until quite recently, have failed to take into account is the land use impact of farming land that was, or would otherwise revert to, grassland or forest. Our preliminary analysis of these land use implications casts doubt on the timing and magnitude of biofuels' GHG advantages.

Converting forest or grassland into energy crops results in a substantial deposit of carbon dioxide into the atmosphere from the clearing of the land. The magnitude of that deposit depends on what was growing on the land cleared and the disposition of that vegetation. For example, clear-cutting and burning a forest naturally releases more carbon dioxide into the atmosphere than harvesting grassland. However, even if the land is not actively cleared but simply prevented from going fallow, the deleterious environmental impact is substantial.

Research on the land use impact of biofuels production is only now emerging, but it strongly validates our findings. Two studies recently published in the peer-reviewed journal Science confirm our preliminary estimates that it could take anywhere from a couple of decades to a few centuries for ethanol to "break even" with petroleum in terms of greenhouse gas emissions because of this initial carbon dioxide deposit (see Exhibit 1).

Although these are only rough calculations, it is clear that the climate change benefits anticipated from biofuels are unlikely to appear soon, at least with current technologies. No matter the crop, the type of land, or the manner in which it is cleared, the one-time land use "cost" of cultivating biofuels is simply too high. That said, there are emerging biofuel technologies that require less-active cultivation of land (e.g., cellulosic and algae based), so the environmental promise of biofuels is not a complete chimera.

Economic Viability

PERCEPTION: Biofuels are not economically viable as a substitute for petroleum.

REALITY: Biofuels are well on their way to presenting a competitive, long-term alternative to petroleum.

"Second-generation biofuels have a future and are currently being developed, but it will take 10 to 15 more years to develop cost-effective processes at the required scale."
– Dr. Greg Stephanopolous, Bayer Professor of Chemical Engineering, Massachusetts Institute of Technology[5]

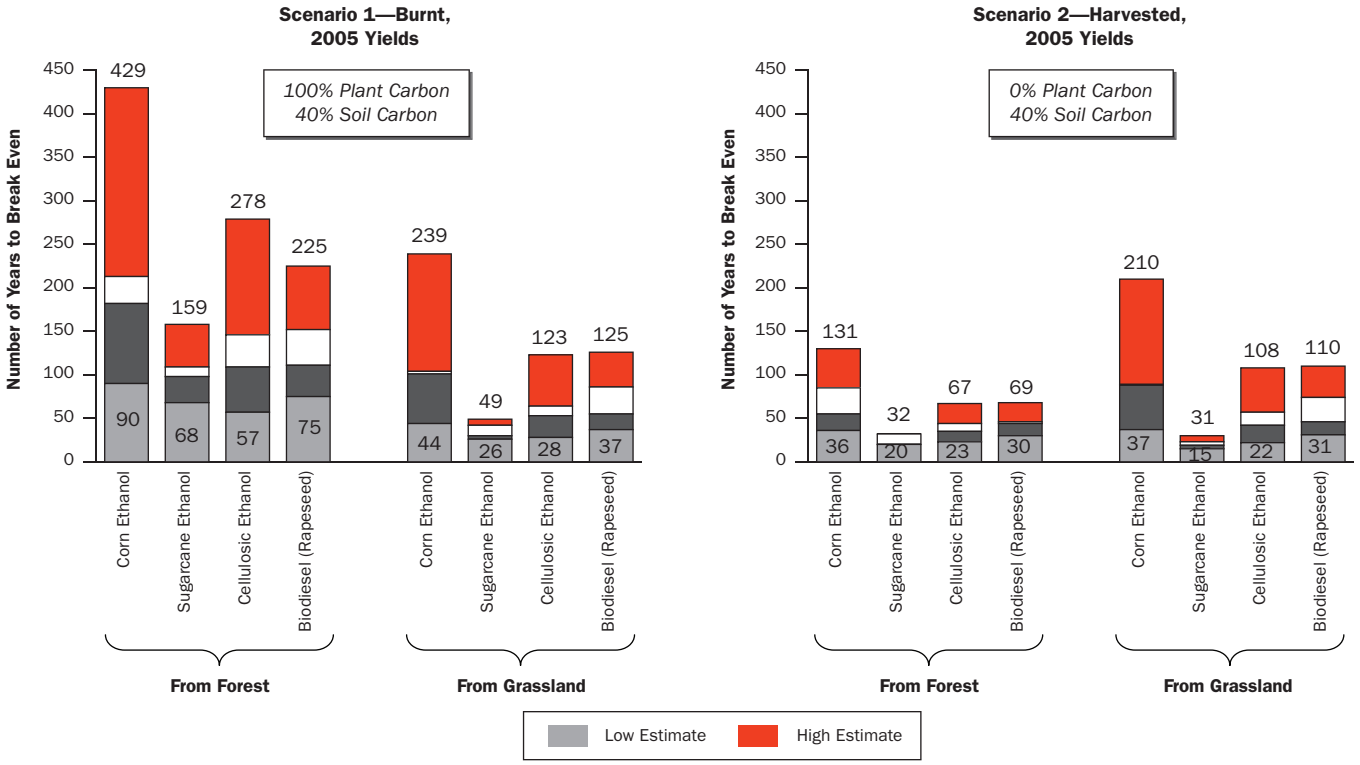
"At current energy prices, some agricultural feedstocks have indeed already become competitive sources of energy, at least under certain production environments."
– Dr. Josef Schmidhuber, Senior Economist, Food and Agricultural Organization[6]

Although the break-even costs for different biofuel technologies vary significantly, sugarcane ethanol in Brazil is already commercially viable (see Exhibit 2).

Introduced with heavy government subsidies in the 1970s, cane ethanol was nurtured as an infant industry in Brazil for many years. The government financed new ethanol plants, directed the state-owned oil company Petrobras to install ethanol tanks and pumps around the country, and mandated that carmakers design and manufacture cars that could run on pure ethanol.

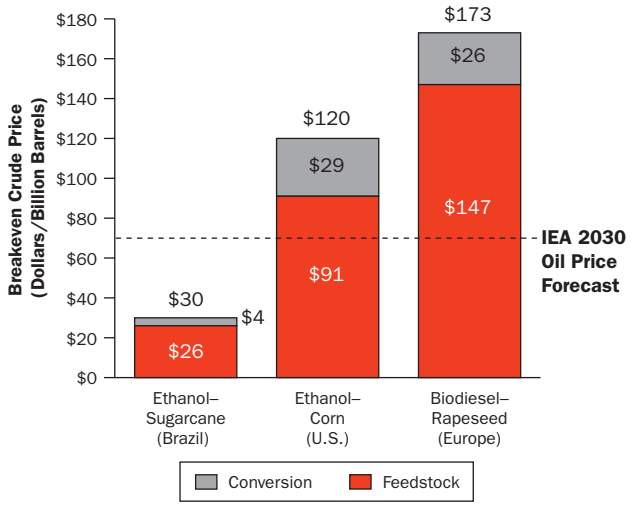
4 Joel K. Bourne, Jr. "Green Dreams," National Geographic, October 2007.
5 Phone interview with Dr. Greg Stephanopolous, Fall 2007.
6 Panos Konandreas and Josef Schmidhuber, "Global Biofuel Production Trends and Possible Implications for Swaziland," Food and Agricultural Organization of the United Nations, July 2007. Also phone interview with Dr. Josef Schmidhuber, Fall 2007.

Exhibit 1
Biofuels' Impact on Land Use All but Eliminates GHG Advantages



Note: Assume temperate forestland and grassland for corn, cellulosic, and rapeseed biodiesel, and tropical forestland and grassland for sugarcane. Assume 40% of soil is organic carbon and 100% of plant biomass is lost to the atmosphere when land is converted to cropland
Sources: "Biofuels for Transport," International Energy Agency; "Inventory of U.S. GHG Emissions," Environmental Protection Agency; Intergovernmental Panel on Climate Change (IPCC) Third Assessment; Booz Allen Hamilton

Exhibit 2
Breakeven Crude Price for Biofuels



Note: Feedstock cost assumptions account for most of the difference in estimates; corn price = $4.35 per Bu (U.S. corn indices); rapeseed price = $423/ton (Hamburg commodity price)
Source: Booz Allen Hamilton

By the early 1990s, low oil prices prompted the government to phase out the cane ethanol subsidies, generating short-term trauma for ethanol purveyors and drivers, but also a long-term solution. Car manufacturers were compelled to find an inexpensive way to make cars that could burn both fuels. Today 85 percent of cars sold in Brazil feature these flex-fuel power trains, and cane ethanol is the clear winner based on sheer economics—without policy support.[7]

Cellulosic ethanol—produced from grass, woody crops, plant residues, and even waste—is a leading contender among second-generation biofuels. Our calculations suggest that as the technology matures, cellulosic ethanol will break even with petroleum at around $55 per barrel—without government incentives. Moreover, it can be produced outside tropical zones and, as mentioned, is significantly greener than other established biofuels.

7 "Global Biofuel Production Trends and Possible Implications for Swaziland," Food and Agricultural Organization of the United Nations, July 2007. Also phone interview with Dr. Josef Schmidhuber, Fall 2007, National Geographic.

Other technologies are currently in development, including biomass-to-liquids, biobutanol, and biodiesel from algae. Although it is still unclear which of these specific technologies holds real promise, there may well be other viable alternatives to petroleum.

In short, biofuels are not a pipe dream; cane ethanol is already a proven and economically viable technology, and cellulosic ethanol is maturing rapidly. Other technologies may follow. Much will depend on the pricing of biofuel material costs (inputs) relative to petroleum pricing. In fact, input costs are likely to become more volatile because they move with oil prices.

Perhaps the biggest endorsement of biofuels as an economically viable alternative to petroleum has come from OPEC itself. Abdalla El-Badri, secretary-general of the Organization of the Petroleum Exporting Countries (OPEC), noted in June 2007 that the consortium was considering cutting its investment in new oil production in response to moves by the developed world to create and use more biofuels.

"If we are unable to see a security of demand…we may revisit investment in the long term."
– Abdalla El-Badri, secretary-general of OPEC, June 2007[8]

Energy Market Impact

PERCEPTION: The global energy markets are so vast that biofuels cannot hope to shift the petroleum supply/demand balance.

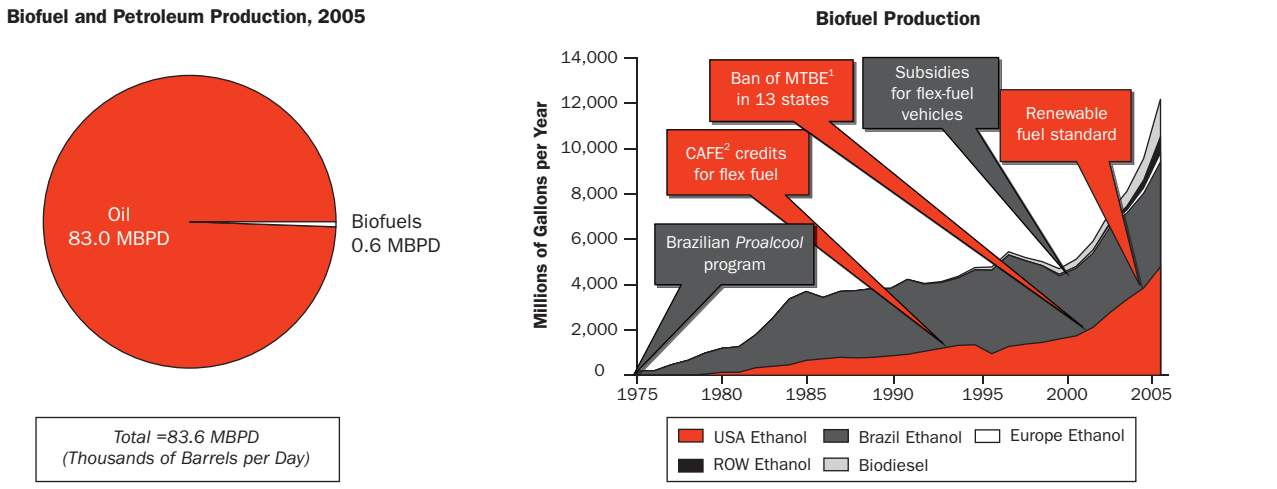
REALITY: If agricultural supply expands at historical rates, biofuels can make a significant contribution to the transportation fuel pool, resulting in a potential oversupply of petroleum.

"The new fuel option does not pose a threat to OPEC as it will only supply a small proportion of growing global energy demands over the coming years."
– Claude Mandil, Executive Director, International Energy Agency (IEA), June 2007[9]

"Some [biofuels] will work, and some will fail, but we suspect the world will be well on its way to solving its oil dependency crisis within a decade, if not within five years."
– Vinod Khosla, founder and partner, Khosla Ventures[10]

It's important to note that although biofuels are the best and most cost-efficient hope for an alternative to petroleum, biofuel production is still miniscule in terms of total fuel demand—less than 1 percent. Still, biofuel volumes have grown significantly over the last five years, primarily driven by positive policy actions in regions and countries the world over (see Exhibit 3).

Exhibit 3
Still Relatively Small, Biofuel Volumes Are Growing Significantly



1 Methyl tert-butyl ether
2 Corporate average fuel economy
Sources: "Table of Ethanol Production," BP; "Biofuels for Transport," International Energy Agency (IEA); F.O. Licht; World Energy Outlook 2006, IEA; Booz Allen Hamilton

8 Javier Blas and Ed Crooks, "Drive on Biofuels Risks Oil Price Surge," Financial Times, June 5, 2007.
9 Clare Watson, "IEA Tells OPEC that Biofuels Will Not Affect Oil Production," Energy Business Review, June 11, 2007.
10 Vinod Khosla, "Biofuels Trajectory to Success: The Innovation Ecosystem at Work," www.khoslaventures.com. Also phone interview with Vinod Khosla, Fall 2007.

Worldwide production of ethanols and biodiesel exceeded 12 billion gallons in 2005, the last year for which complete data is available.

Most forecasts of biofuel volumes are conservative; they predict a very modest contribution to the total fuel pool. They assess current agricultural resources and conclude that they are insufficient for the dual purpose of feeding the world's population and producing significant biofuel volumes.

However, if agricultural supply improvements (both in terms of crop yields and input productivity) continue at historical rates, then biofuels can, over time, contribute significant volumes (similar or even larger than current OPEC exports) without jeopardizing the world's food supply.

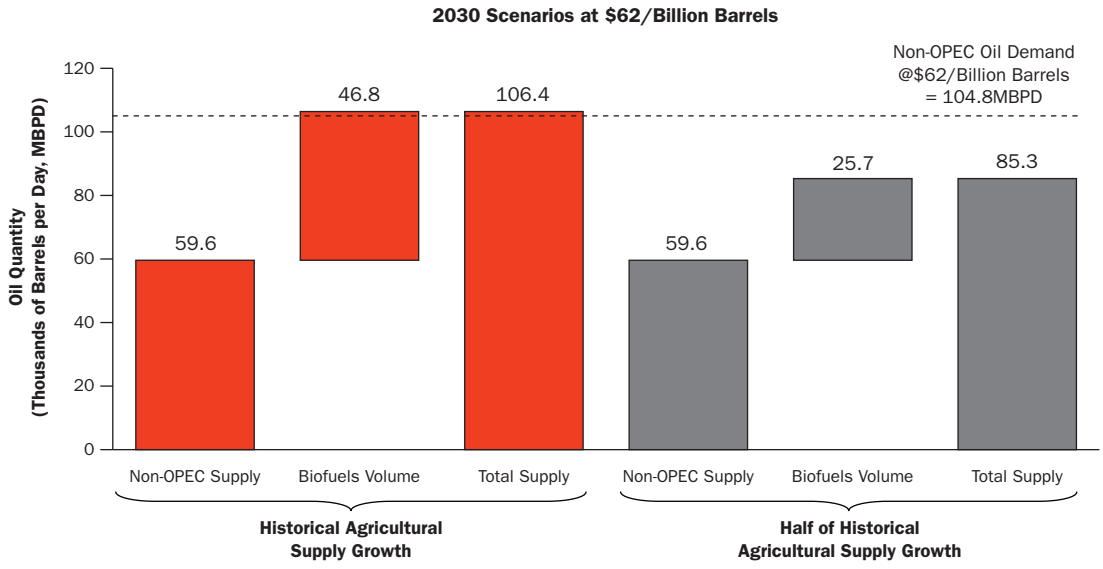
Here history is our witness. Agricultural supply has been steadily increasing for the last half century with rare exception. Advances in plant breeding, soil study and fertilizer use, water management, weed and pest control, and infrastructure development have increased crop yields and agricultural productivity. At the same time, the cost of inputs has declined. Today's farming utilizes less labor, capital, chemicals, and land to produce more food.

The result is significantly reduced food prices over the past 40-plus years even as food consumption has grown and people have adopted richer diets (owing to population and GDP growth). New techniques, such as marker-assisted breeding, may well accelerate the rate of improvement in agricultural productivity.

Now, let's look forward about 25 years to determine what impact biofuels might realistically have on the global fuel pool in 2030. First, let's assume that agricultural supply continues to grow at historical rates. Leaving biofuels out of the equation for the moment, we could anticipate crop yields increasing by some 55 percent. Food crop prices would drop to roughly half of 2005 levels.

Further, let's assume the IEA's forecasted price for crude oil—$62 per barrel—in 2030. (Many major oil companies use a price range of $55 to $60 per barrel). Supposing that the agricultural supply base develops as we've assumed and the biofuel infrastructure continues to expand, we can anticipate that more available crop land will be cultivated and more of it utilized to produce biofuels. In the scenario we've just described, we expect biofuel production would offset 47 million barrels of oil per day (see Exhibit 4). If

Exhibit 4
Biofuels Can Contribute Significant Volumes at Reasonable Oil Prices



Note: Booz Allen Hamilton built a detailed equilibrium model to determine the estimated biofuel opportunity.
Sources: World Energy Outlook 2007—China and India Insights, International Energy Agency; Booz Allen Hamilton

agricultural supply increases at half the rate we expect, then biofuel volumes would drop to roughly 26 million barrels per day, according to our model.

We recognize that this is an "optimistic" scenario as far as the development of biofuels, but we believe the economics are compelling as determined by our economic model that determines the equilibrium between food and fuel. This model takes into account elasticities of demand and supply for food and fuel, linking output and prices based on biofuel demand. There will likely be some form of government regulations and infrastructure constraints that were not considered in the equilibrium model, but the economics will serve as a forcing function, driving further biofuel development.

Effect on Food Prices

PERCEPTION: Biofuel crops will crowd out food crops, driving food prices up and food consumption down in the developing world.

REALITY: If crop yields and agricultural productivity improve at historical rates, food prices need not be higher than today.

"Food, feed, and fuel prices are now linked."[11]
—Ruth Rawling, VP Public Affairs, Cargill

Regardless of crop and land type, the production of biofuels inevitably links food and petroleum prices. As Exhibit 5 demonstrates, biofuels act as a bridge between oil prices and agricultural commodity prices. Energy crops such as switchgrass (used in cellulosic ethanol) serve as a substitute for petroleum. They also compete for the same agricultural resources (i.e., land and water) as food crops. As such, biofuels effectively link the markets for crude oil and food. There is now an alternative to petroleum—and for the utilization of crop land.

Many fear that in a world of biofuels, the oil tail will wag the food dog in terms of pricing, but with agricultural improvements, the food dog may well wag the oil tail.

"When crop demand for biofuel use is strong enough to consume a large proportion of the supply, the floor price of the crop will be set by petroleum. However, biofuels would have to have a much bigger share of the transportation fuel market before they could influence petroleum prices."
– Mike Edgerton, Ethanol and Quality Traits Technical Lead, Monsanto[12]

Whatever happens, there is no disputing that biofuels link the prices of crude and food. As a result, some point to the recent run-up in food prices—corn in the U.S., tortillas in Mexico, pasta in Italy—and blame biofuels. Although biofuels are a contributor, current biofuel volumes are simply too small to account for these recent regional commodity price spikes. Other factors such as droughts and inventory levels had a significant impact.

As biofuel volumes grow, the link between fuel and food prices will only strengthen. As we noted in the previous section, we anticipate a future in which agricultural supply improvements generate significant enough biofuel volumes to effectively "cap" petroleum prices.

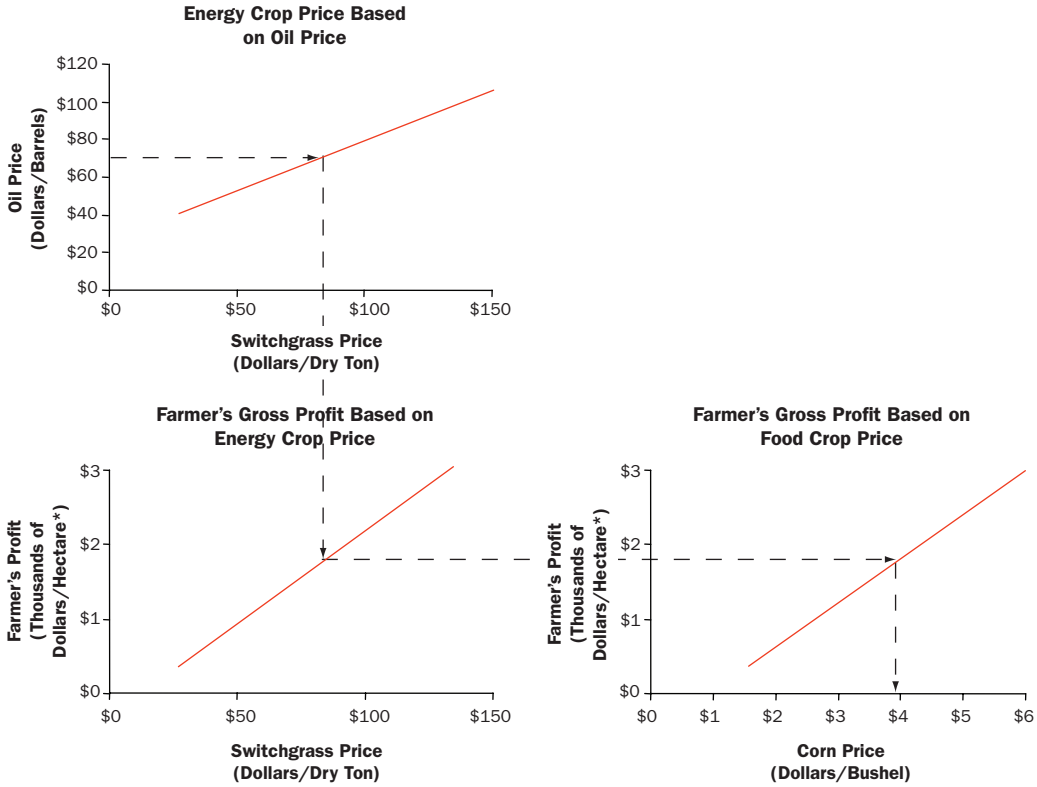
Meanwhile, biofuel production will likely temper continued food price declines. However, the doomsday scenarios that some critics paint are exaggerated and can be mitigated through sound policy. Critics argue that biofuel production will crowd out food crops, resulting in escalated food prices that will disproportionately affect the developing world. Their arguments are persuasive, but the developing world's food woes cannot be laid entirely at biofuels' door. Farmers in these markets are already at a disadvantage when it comes to accessing the latest agricultural practices and yield improvements.

Governmental policies, the lack of infrastructure, political instability, and cheaper imports from the U.S. and Europe depress crop yields in these areas, denying global consumers up to 30 percent of potential agricultural production today. Government protections and incentives that encourage the production and consumption of energy crops exacerbate the upward pressure on food prices.

Replacing the world's appetite for petroleum with a taste for biofuels would consume substantial agricultural resources, that is true. However, there is significant additional rain-fed land in the world available for agricultural production, according the Food and

11 Phone interview with Ruth Rawling, Fall 2007.
12 Phone interview with Mike Edgerten, Fall 2007.

Exhibit 5
Scale Production of Biofuels Links Food and Crude Prices



* One hectare equals 10,000 square meters or 2.47 acres
Note: All dollar figures are in 2007 US$, based on 2030 yields
Sources: "Biofuels: Growing Energy," Ceres Inc.; Booz Allen Hamilton

Agricultural Organization (FAO) of the United Nations and other global authorities.

Moreover, assuming continued agricultural productivity improvements, our models suggest biofuels can be a sizable part of the transportation energy supply without consuming excessive land. Although increased production of energy crops for biofuels will increase food prices in the short term, that increase will be mitigated by continued increases in agricultural supply.

In a world with biofuels, food prices will be higher than in a world without biofuels, but they will not necessarily be higher than they are today.

Those most negatively affected will be the urban poor, who cannot grow their own food and do not enjoy the concomitant fuel price benefit of increased energy crop production.

In summary, biofuel production will put upward pressure on food prices, but as long as agricultural supply and productivity continue to grow steadily, food prices should not exceed today's prices, even if significant land is devoted to biofuel production.

Water Stress

PERCEPTION: Biofuel development robs water-stressed countries of their most precious natural resource: water.

REALITY: Although biofuel development does place additional strain on water resources, there are major agricultural zones in the world that suffer water stress regardless.

"The impact of biofuels would be drastic for the poor in the developing world who have to buy their food, and increased agriculture would further add to water shortage and pollution."
– Herbert Oberhaensli, Head of Economics and International Relations, Nestlé[13]

[13] Phone interview with Herbert Oberhaensli, Fall 2007.

Contrary to prevailing wisdom, most of the world has plenty of water. The vast majority of the globe's agricultural regions can rely on the natural rain cycle for water. There are two rather urgent exceptions: India and northern China suffer severe water stress (see Exhibit 6).

There are other, less agriculturally intensive areas that need to irrigate to meet their water needs (e.g., Kazakhstan and the Southwestern United States), but these regions do not have the populations—and hence the need for local agriculture—found in India and China.

Not only is water quantity a problem, but so is water quality. China's and India's brisk economic growth will only exacerbate this crisis, as their growth is fed by ever-increasing quantities of food and fuel. Petroleum supply cannot keep up with demand as it is; both countries are already dependent on imported oil. Meanwhile, water availability limits domestic production of food; that is even more true for biofuels. Imports will increasingly be a requirement, forcing a choice between food and fuel security.

Agriculture consumes vast quantities of water; it uses more water than any other sector, by far. Moreover, agricultural practices result in the runoff of fertilizers and chemicals, diminishing water quality. Biofuel production requires water, but growing the feedstock consumes far more. In other words, it is agricultural activity—not biofuel development per se—that diminishes the quantity and quality of available water in India and northern China.

The solution to the water crisis in these regions will be found in sound policy-making and the development of a reliable and diversified portfolio of import sources for both food and fuel.

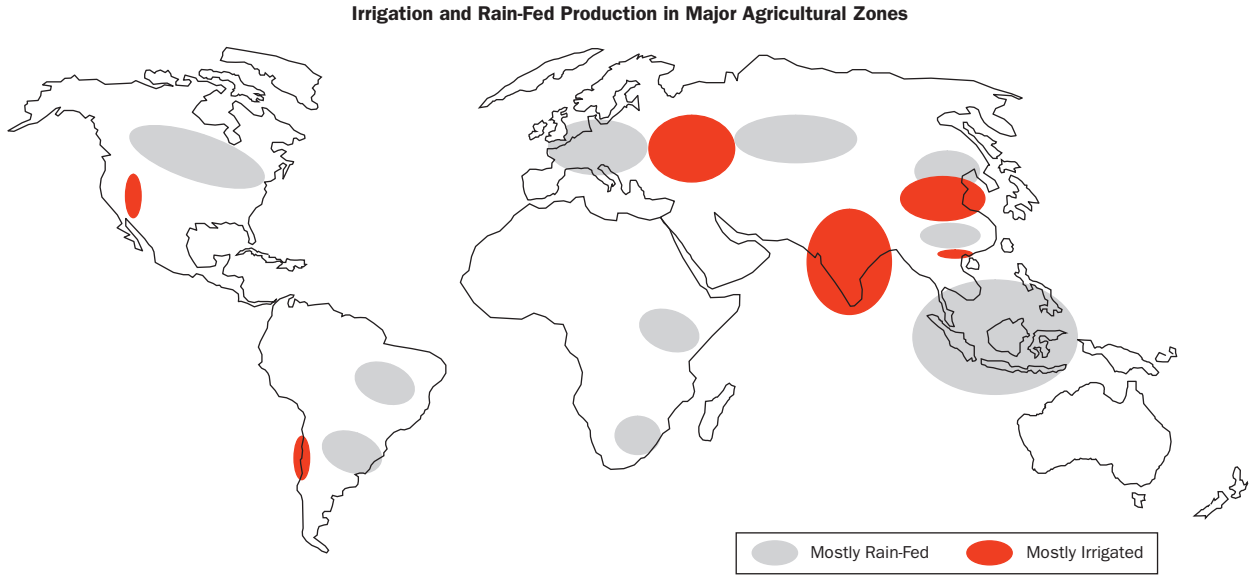
"Food and water issues will be present independent of biofuel development."
– André Faaij, Associate Professor, Utrecht University, task leader of IEA Bioenergy Task Force[14]

The Role of Regulation

PERCEPTION: Government mandates and subsidies provide the foundation and foster the positive development of the biofuel industry.

REALITY: Mandates and subsidies can work, but they can also trigger unintended consequences that negate the intended benefits of biofuels.

Exhibit 6
Agricultural Zones of India and Northern China Are Water Stressed



Note: Rain-fed land is defined as land where more than 50% of the production is from rains. Areas under irrigation are not always in drought conditions; e.g., the southern region of China
Sources: http://www.iiasa.ac.at/Research/LUC/index.html; "Comprehensive Assessment of Water Resources," International Water Management Institute, 2006; Booz Allen Hamilton

14 Phone interview with André Faaij, Fall 2007.

Governments around the world have supported the development of biofuels and a biofuels infrastructure for various compelling reasons: to promote energy security, reduce GHG emissions, and protect domestic agriculture. Toward these ends, governments have subsidized, de-taxed, even mandated biofuel production. These incentives have resulted in the increased cultivation of biofuel crops, the development of a biofuels infrastructure, and increased R&D spending on viable biofuel solutions.

Over time, however, regulatory support for biofuels has also produced some unintended consequences. The emphasis on biofuels has put upward pressure on food commodity prices. Moreover, biofuels that are not economically viable have received undue support. Tariffs and quotas have shut out economically viable biofuels in favor of local alternatives. For example, U.S. tariffs have effectively shut out Brazilian cane ethanol.

In certain instances, regulatory support of biofuels has had the opposite of its intended effect. For example, European mandates supporting biofuel production prompted certain Southeast Asian countries to burn forests and peat lands to produce palm oil for ethanol. The resulting GHG emissions were huge.

Policies can often furnish the necessary impetus to develop valuable new technologies and establish new infrastructure; the Brazilian government's promotion of cane ethanol is the perfect example. However, regulation can also trigger counterproductive behavior, as we've noted. Policymakers need to walk a fine line in promoting long-term beneficial behaviors, while avoiding short-term detrimental consequences. They need to pave the way to an orderly transition by introducing incentives that are broad enough to encompass long-term optimal technologies, while being specific enough to focus on those with the most potential.

The Reality Today

The current generation of biofuels may not furnish the strong greenhouse gas benefits commonly expected. However, biofuels are well on their way to presenting a real, long-term alternative to petroleum.

Scale production of biofuels necessarily links agriculture commodity prices to crude oil prices—and food assumes greater pricing power over petroleum. That said, if crop yields and agricultural productivity improve at historical rates, food prices need not be higher than today.

With or without biofuels, India and northern China contend with water shortages and need to address their growing food and fuel needs with sound policy and diversified import sources. Regulation can foster a productive biofuels industry, as demonstrated in Brazil, but it can also trigger unintended consequences.

As we look toward the world's biofueled future, government leaders and economists should be mindful of the consequences and implications of various policy solutions:

- Current agricultural policies in Organisation for Economic Co-operation and Development (OECD) countries lower world food prices and reduce the incentive for developing countries to develop their own agricultural supply.
- Biofuel subsidies, tax exemptions, and blending mandates exacerbate biofuels' upward pressure on food prices.
- Conversely, "infant industry" support may provide the required incentive to establish the infrastructure necessary for biofuels, such as flex-fuel power trains, fueling stations, and transportation infrastructure.
- Political stability, land rights, and infrastructure are necessary prerequisites to developing functioning agricultural markets in the developing countries.
- Availability of capital and know-how is essential for developing countries to establish a biofuels industry.
- Reliable and diversified import sources can address food and fuel security issues in water-stressed countries.

With sound policies in place and healthy innovation in the biofuels sphere, we can expect biofuels to become a viable alternative to fossil fuels in the long term.

Also contributing to this article were Frank Bogaert and Martha Turner.

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Andrea Athanas, senior program officer, World Conservation Union (IUCN)

Rob Bradley, director, International Climate Policy Initiative, World Resources Institute

Ana Maria Bravo, director, Communications and Public Affairs, Genencor

Britt Childs, research analyst, World Resources Institute

Sam Cox, purchasing and commodities director, Bob Evans

Charlotte de Fraiture, International Water Management Institute

Mike Edgerton, ethanol and quality traits technical lead, Monsanto Company

Andre Faaij, associate professor; coordinator research cluster "Energy Supply & System Studies," Utrecht University

Rutger Goethart, manager, EU Public Affairs, Heineken

Penny Healy, group corporate affairs executive, D1 Oils South Africa

Anders Johannesson, vice president, Environmental Issues and Public Affairs, AB Volvo

Gene Kahn, vice president of sustainability, General Mills Inc.

Vinod Khosla, founder and partner, Khosla Ventures

Sabine Klages-Buechner, manager, International Government Affairs, DuPont

Elizabeth Marshall, economist, World Resources Institute

Paul Noe, vice president, Regulatory Affairs, Grocery Manufacturers Association

Herbert Oberhaensli, head, Economics and International Relations, Nestlé Switzerland

Ben Pearcy, vice president, southeast Europe and European biofuels, Bunge

Miguel Pestana, vice president, Global External Affairs, Unilever

Prabhu Pingali, director, Food and Agricultural Organization of the United Nations

Rudy Rabbinge, university professor, Dean Graduate School, Wageningen University

Ruth Rawling, vice president, Corporate Affairs, Europe, Africa, Cargill Inc.

Lex Ronteltap, manager, Research and Innovation, Heineken

Josef Schmidhuber, senior economist, Food and Agricultural Organization of the United Nations

Greg Stephanopolous, Bayer professor of chemical engineering, Massachusetts Institute of Technology

Bart Vandewaetere, European affairs manager, Nestlé Switzerland

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Contact Information:

CHICAGO

Bill Jackson
Senior Vice President
312-578-4745
jackson_bill@bah.com

CLEVELAND

Leslie Moeller
Vice President
216-696-1767
moeller_leslie@bah.com

Praneet Gupta
Senior Associate
216-902-4219
gupta_praneet@bah.com

HOUSTON

Tim Donohue
Vice President
713-650-4125
donohue_timothy@bah.com

LONDON

Viren Doshi
Senior Vice President
+44-20-7393-3572
doshi_viren@bah.com

McLEAN, VA

Eric Spiegel
Senior Vice President
703-902-3813
spiegel_eric@bah.com

SÃO PAULO

Arthur Ramos
Vice President
+55-11-5501-6229
ramos_arthur@bah.com

SHANGHAI

Nick Pennell
Vice President
+86-21-6340-6633
pennell_nick@bah.com

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