ETHANOL

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The large-scale production and use of ethanol as a motor fuel in the United States is derived not only from corn, but from technology, markets and policy. The rationales for using ethanol as a fuel additive are based on both national security and environmental concerns. Energy independence has been a goal of the United States since the oil embargo imposed by OPEC in 1973, and the use of domestically-produced ethanol is seen as enhancing this objective. Both the *Energy Policy Act of 2005* and the *Energy Security and Independence Act of 2007* have mandated a production quota of biofuels to help achieve this goal, while subsidies to corn growers and tariffs on sugar imports (also used to produce ethanol) have supported domestic producers. In addition, the use of ethanol is an important part of meeting the air pollution targets mandated by the *Clean Air Act Amendments of 1990*, as it helps to mitigate the emissions of carbon dioxide and other pollutants harmful to air quality.

The production of ethanol in the United States has dramatically increased over the last decade, when biofuel production goals became mandated by law as part of the Renewable Fuel Standard. Whereas only 1.6 billion gallons of ethanol were produced in 2000, about 14 billion gallons were produced in 2011 (almost all of it used domestically), making the United States the world's largest producer of ethanol.[1] This level of ethanol production involves a significant undertaking. In 2011, roughly 40% of the 93 million acres devoted to growing corn in the US were destined for ethanol, not food (though cattle feed is a by-product in ethanol production, so the net acreage going solely to fuel is less), while 209 biorefineries were in operation processing this corn into fuel.[2]

A Look at The Numbers

Total US Ethanol Production (2011): 14 billion gallons

Total Conventional Gasoline Consumed in US (2011): 134 billion gallons

Percentage of US Fuel Supply Met by Ethanol (2011): 9%

Acres of corn planted (2011): 92 million

Percentage of acres planted used for ethanol: 40%

Number of ethanol biorefineries in the US in 2000/2011: 54/209

Price of corn per metric ton in 2005/2012: $98/$332

Today, most of the fuel used for cars and light trucks in the US contains a blend of up to 10% ethanol, and this blend is known as E10. While a small number of cars can operate on an E15 blend (containing 15% ethanol), it is expected that this number will increase in the coming years, and that a growing number of new “flex-fuel” cars will run be able to run on an E85 fuel mix.

This rapid expansion of ethanol production and use is not without its drawbacks. Critics have suggested that a strong agricultural lobby has allowed for public support of an industry that would not otherwise exist at the levels it does. These arguments have become even more salient in light of recent scientific scholarship suggesting that the energy savings and carbon dioxide reductions thought to result from ethanol may not be as large as originally thought, and in some instances may even result in setbacks. At the same time, the use of ever more land to produce fuel instead of food appears to be driving an increase in the price of corn and other staples around the world.

It is expected that many of these concerns can be addressed by the development of advanced biofuels, especially cellulosic ethanol, which is found in all plants and can be derived from wood chips, grass clippings, agricultural waste and by products (think corn husks instead of kernels of corn), and the inedible parts of plants. Cellulosic ethanol, which is not yet available for large-scale commercialization, can potentially provide more energy per gallon than ethanol, while better combatting climate change, without diverting as much land or food sources toward fuel production.

SCIENTIFIC BACKGROUND

The scientific considerations involving the production and use of ethanol as a motor fuel are many. There are numerous studies that have been conducted (and that continue to be carried out) that examine its energy and environmental impacts. The major issues that tend to define the scientific discourse on ethanol revolve around four areas:

- The energy inputs required to produce ethanol and the energy outputs ethanol provides
- The carbon dioxide reductions available from using ethanol as opposed to gasoline
- The amount of water and fertilizer used to produce ethanol
- The increased use of land to produce fuel instead of food

Energy Inputs and Outputs

The key property of ethanol that makes it suitable as a motor fuel is that it provides the energy levels required to power vehicles, and that this is technically feasible at a cost that consumers and governments are willing to pay.

First of all, in understanding energy output, one important consideration is that a gallon of corn-based ethanol does not have the same energy content as a gallon of gasoline – it only contains about 2/3 of the energy, so in order to do the same amount of work as gasoline, 1.5 gallons of ethanol are needed. Ethanol generates about 76,000 Btu (British thermal units) of energy per gallon, as compared to 114,000 Btu for gasoline. This has important implications for understanding the "net energy" that can be derived from ethanol, and for considering the emission of greenhouse gases.

Energy outputs, however, are only part of the equation. What determines the relative effectiveness of ethanol is consideration of the inputs required to produce it. (One such input, which is addressed more fully in a separate section below, is the land required to produce ethanol – in the United States, one acre of land can yield 320 to 420 gallons.) The key input addressed here is energy. In other words, how much energy must be expended in order to produce or acquire more energy? This concept is understood in two ways, as both "net energy" and as the "energy return on energy invested," or EROEI. In its most basic sense, EROEI is can be thought of as:

$$\text{EROEI} = \frac{\text{Energy gained}}{\text{Energy required to get that energy}}$$

This can expressed as a ratio, for example, 10:1 or ten to one, for any particular energy resource. If the ratio falls above a level of 1:1 for a given resource, then it would represent a net energy yield. If the ratio falls below a level of 1:1, the resource would be considered a net energy drain. In the case of oil, the average EROEI over the years has declined, but oil still provides a net positive with regard to inputs and outputs. It still "pays for itself."

Table 1: Energy Return on Energy Invested for Oil [3]

Resource	Year	EROEI
Domestic Oil	1930	100:1
Domestic Oil	1970	30:1
Domestic Oil	2005	11 to 18:1
Imported Oil	1990	35:1
Imported Oil	2007	12:1
Domestic Shale Oil	2010	2:1

With respect to ethanol, the EROEI is dependent upon a variety of energy inputs, such as the fuel used to plant and harvest the corn, the production and use of fertilizer, processing the corn into fuel in biorefineries, and transporting the fuel to the point of use. In light of all these energy needs to produce ethanol, its EROEI is not unambiguously considered to be positive. Some published studies indicate that ethanol has an EROEI below one energy unit returned for every unit of energy invested.[4] There are others suggesting that ethanol has a positive EROEI, including the Renewable Fuels Association, which argues that the energy balance of ethanol is close to an average ratio of 2:1.[5] A meta-analysis published in 2011 looked at previous studies, seeking to account for 1) statistical variation in different analyses; 2) spatial variation with regard to ethanol production in different parts of the U.S.; and 3) the sensitivity of variation in initial assumption to how they impact EROEI results. The analysis of inputs was then measured against the actual production of ethanol to determine net energy. The study found that, when accounting for statistical and regional variation, the net energy returned to society from ethanol ranged from an EROEI value of .64 to 1.18. This means that in some of the cases examined, it took more energy to produce the ethanol than the ethanol delivered to consumers. As the authors stated, "to deliver one liter of ethanol as net energy at an EROEI of 1.18, 7.5 liters of ethanol must be produced; 1 liter as net energy and 6.5 liters (or its energy equivalent) to be reinvested to produce more ethanol." What's more, the analysis suggested that, in light of actual production, of 31.6 billion liters of ethanol produced in the United States in 2009 at 127 biorefineries, only 1.6 billion liters, about 5%, could be considered net energy. By contrast, 122 billion of the 136 billion liters of gasoline used in 2009, (90%) were net energy. The conclusion was that even in the best scenario, the country is "gaining an insignificant amount of net energy" from ethanol.[6]

Greenhouse Gas Emissions

One of the motivations for using ethanol and other biofuels is the potential benefit to be derived regarding climate change. The use of ethanol in place of gasoline has been thought to provide a reduction in the emission of greenhouses gases (GHG). In theory, biofuels can be considered carbon neutral. The logic is that while there are emissions of carbon dioxide into the atmosphere from burning ethanol, the corn used to produce the ethanol originally absorbed that carbon dioxide from the atmosphere, so no new net emissions are being produced in its use.

As the use of ethanol has increased in recent years, this logic has come to be increasingly questioned and extensively studied. The problem with the carbon neutral argument, researchers have found, is that this approach does not take into account the full life cycle in the production and use of ethanol. When one considers the carbon dioxide emissions that result from growing corn, converting it into fuel, and transporting the fuel to consumers, along with tailpipe emissions (which are impacted by the fact that a gallon of ethanol only delivers two-thirds the energy of a gallon of conventional gasoline), the carbon dioxide balance sheet does not always appear to be favorable.

The calculation of how much carbon dioxide is emitted in the manufacture and use of ethanol is complex. Nor is it exact, as it is dependent on the method of producing ethanol and a set of assumptions that have to be made in the process. Most calculations of greenhouse gas emissions associated with ethanol include the carbon costs of:

- Growing the feedstock
- Transporting the feedstock to the biorefinery
- Processing the feedstock into ethanol
- Transporting the ethanol from the biorefinery to its point of use
- The amount of CO_2 produced at the tailpipe
- The reduction of emissions from ethanol compared with standard gasoline

Some calculations also include 1) the carbon dioxide effect from the change in land use from some other activity to corn production; and 2) the emissions benefits due to the production of useful bi-products, such as electricity or cattle feed.

The scientific literature suggests that there are, in general, reductions in greenhouse gas emissions that can be achieved from using ethanol, but like the calculation of energy outputs vs. inputs, much depends upon the particulars of how the ethanol is produced and how far it is transported. A study conducted by the Argonne National Laboratory found that the greenhouse gas emissions associated with ethanol over the full life cycle depend significantly upon the way in which the ethanol is processed in biorefineries. If coal is the fuel used to provide power to the refinery, then the GHG impact from using ethanol represents a 3% increase over gasoline. By contrast, the use of wood chips as an energy source for the same plant would yield a 52% reduction in emissions.[7] Another well-cited study from *Science* suggests that GHG emissions derived from ethanol result in a 13% reduction compared to using gasoline, but that this value will vary from place to place. The authors also suggest that policy incentives designed to reduce emissions could have a positive impact on further reductions. They also point out that there is great potential from biofuels in GHG reductions, but that it is not yet being realized – significant reductions in emissions will only come from large scale use of cellulosic ethanol.[8] The Renewable Fuels Association suggests that the GHG reductions are larger than the literature suggests, pointing out that an additional consideration must be taken into account, namely, "the bottom line is fossil fuel producers are going farther and deeper—and using more energy and emitting more GHGs—to extract new sources of oil. These are the marginal sources of oil against which ethanol should be compared, since both unconventional oil and ethanol are the newest entrants into the fuel pool."[9] Such an approach would be likely to yield a more favorable GHG balance for ethanol.

Water and Fertilizer

One of the unintended environmental consequences of accelerating corn production for ethanol is the impact on water use and quality that result from actually growing the corn. First of all, corn requires a great deal of water to grow -- every acre produced needs an average of 391,000 gallons of water.[10] This is similar to many other crops, including potatoes, soybeans, wheat, oats and tomatoes.[11] Nonetheless, it is a large amount in and of itself. American farmers are estimated to harvest almost 88 million acres of corn in the 2012-13 growing season, up from 79 million in 2009-10, with about 40% of the total going to ethanol production (to get a sense of the increase, in 2006 only 18.5% of 78 million acres planted in the US went to ethanol production).[12] This large increase in corn cultivation means that the amount of water consumption required to produce ethanol, as opposed to food, is growing, from 5.6 trillion gallons of water in 2006 to a potential 13.7 trillion gallons in 2012-13.[13]

The amount of water that goes into corn cultivation represents a major concern over ethanol, but there is an additional downstream impact (literally): the use of fertilizer and its runoff into streams and rivers. Corn requires more fertilizer than any other major crop grown in the United States.[14] When fertilizer runs off into waterways, it adversely impacts aquatic ecosystems, as nitrates from the fertilizers cause large blooms of algae to flourish. These algae blooms deplete the oxygen in the water, creating large "dead zones" where no other plants or animals can live. Currently, huge dead zones are present in the Gulf of Mexico at the mouth of the Mississippi River, and in the Chesapeake Bay, where runoff from farms gathers in concentrated areas. The dead zone in the Gulf of Mexico extends to almost 8,000 square miles in the summer months, an area about the size of the state of New Jersey.[15] This and other environmental impacts have led environmental organizations such as the Environmental Working Group and the Natural Resources Defense Council, which had originally been more supportive of ethanol, to rethink their positions. As ethanol production increases, so too is the expected the runoff from fertilizer and its subsequent environmental impacts, which is projected to cause a 10 to 18 percent increase in the Gulf of Mexico dead zone once the US meets its goal of 15 billion gallons of corn ethanol production in 2015.[16]

Land Use

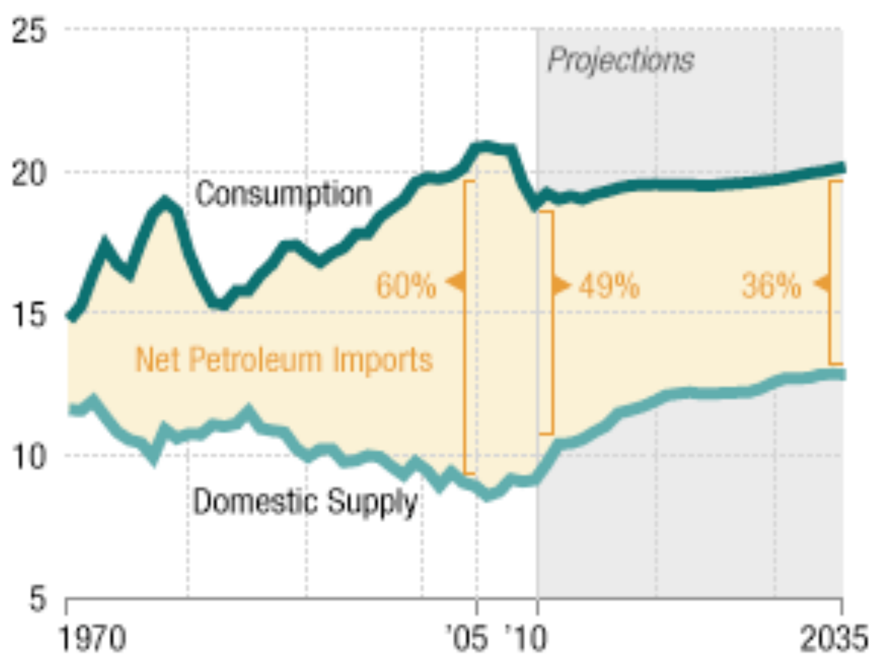
With regard to the last issue identified, the amount of land used to produce ethanol, the problem is inherently both a scientific and a political problem at the same time. Moreover, it is currently the most significant and publicly debated problem regarding the production and use of ethanol. For these reasons, the issue of land use is addressed separately below after the discussion on policy and politics.

POLICY AND POLITICS

The major driver behind the significant growth of ethanol production and use in the United States has been the development of policies designed to meet environmental and energy security challenges. Energy independence has long been a goal of the US, ever since the oil embargo imposed by OPEC in 1973. Offsetting foreign oil with domestically produced fuel such as ethanol has been a stated objective of U.S. policy since this time, as this could have favorable impacts on energy security, economic growth, and environmental protection. When the US became involved in wars in Iraq and Afghanistan, the national security implications of oil dependence became even more apparent. As Secretary of the Navy Ray Mabus said in 2011, "There are great strategic reasons for moving away from fossil fuels. It's costly. Every time the cost of a barrel of oil goes up a dollar, it costs the United States Navy $31 million in extra fuel costs. But it's costly in more ways than just money. For every 50 convoys of gasoline we bring in, we lose a Marine. We lose a Marine, killed or wounded. That is too high a price to pay for fuel."[17]

In spite of its objective to enhance energy security, the US has been unable to diminish the level of oil it imports until the last few years, with net imports reaching a high of 60% of total consumption in 2005 (and falling to 45% in 2011 due to the increase in domestically produced oil, especially in North Dakota).[18] At the same time, as the environmental impacts of oil use became increasingly evident, most notably air pollution and global warming, the idea of developing alternative fuels or additives to gasoline became even more attractive. To combat American dependence on foreign oil, shift the supply of liquid fuels away from imports, and combat environmental degradation, Congress passed subsidies for the production of domestically-produced ethanol as a motor fuel. Soon after, it placed an import tariff on ethanol produced in other countries, and late began to mandate the use of oxygenate additives and biofuels such as ethanol in gasoline.

Figure 1: Consumption and Supply of Liquid Fuels in the US (in millions of barrels per day)[19]



Policy

Congress first approved subsidies to producers of ethanol in 1978 with the Energy Tax Act, which provided a tax exemption of $.40/gallon. From this time through 2011, when the subsidy was eliminated, producers of ethanol received anywhere from 40 to 60 cents a gallon, as subsequent legislation (the Alternative Motor Fuels Act, the Energy Policy Act of 1992, the Energy Policy Act of 2005, among others) both extended the subsidy and revised the amount of the tax credit. In 2011, the tax credit was $.45/gallon for corn ethanol (and up to $1.01 for cellulosic ethanol, for which the subsidy remains). According to a 2010 study by the Congressional Budget Office, biofuel tax credits cost $6 billion a year in foregone revenue, which meant that taxpayers paid $1.78 per gallon of reduced use of conventional gasoline.[20]

In addition to providing tax incentives, Congress has also protected the domestic market by placing a $.54/gallon tariff on ethanol imported from other countries. This measure, passed in 1980, was largely designed to curb imports of sugarcane ethanol produced in Brazil (see the sidebar on Brazilian ethanol). This measure was not without controversy, as it diminished the potential use of a product that can provide more energy content than corn ethanol at lower cost, while offering greater greenhouse gas reductions.

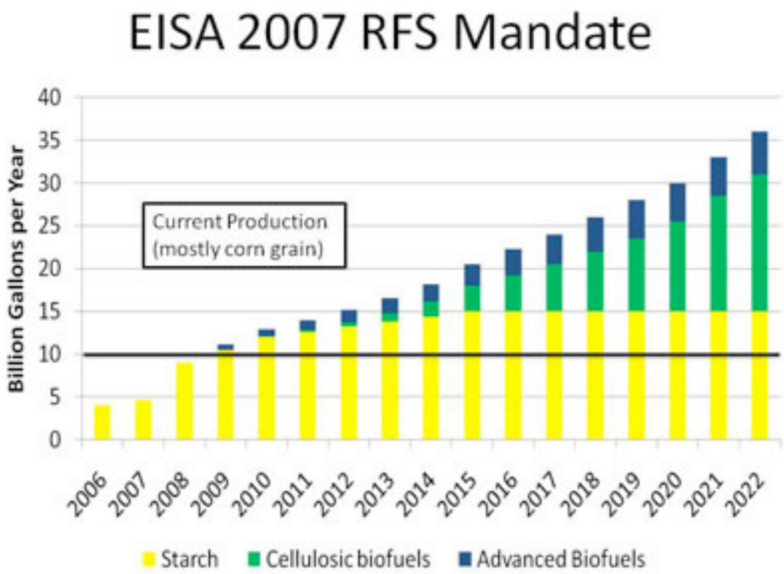
At the end of 2011, both the ethanol subsidy and the tariff were allowed to expire, as Congress refused to extend them. The elimination of Congressionally approved benefits targeted toward a particular industry is a rare event in American politics, but in this case, the industry did not need to fight for these measures, because other provisions in US law have ensured a growing market. These other provisions, which involve mandates to 1) use oxygenate additives to reduce air pollution, and 2) increase the production and use of renewable biofuels, mean that "most farmers haven't even realized it [the subsidy] is gone, because the price of corn has been so high, and it continues to be high with or without the subsidy."[21]

The use of oxygenate additives in gasoline – which results in what is known as reformulated gasoline – is mandated by the *Clean Air Act*. This is because fuel that contains an oxygen additive will burn more efficiently. When more of the fuel burns, fewer pollutants, such as carbon monoxide, are released into the air. The *Clean Air Act Amendments of 1990*, which are enforced by the EPA, introduced the mandate for oxygenated additives in the U.S. gasoline supply. Metropolitan areas that exceeded a particular level of carbon monoxide in the air – mostly in California and the East Coast, along with big cities like Houston and Chicago – were required to use reformulated gasoline. For many years the compound MTBE (Methyl Tertiary Butyl Ether) was used as a fuel additive to meet these EPA requirements, as it was an effective remedy to combat high levels of air pollution. However, MTBE came to be found in aquifers throughout the country, as it seeped into groundwater supplies through leaky gasoline pipelines and underground storage tanks (the problem of leaking storage tanks is widespread). The result was that, even though MTBE improved air quality, it diminished water quality, and so its use was subsequently limited or subjected to an outright ban. California and New York, the largest users of MTBE, banned its use beginning in 2004.

As MTBE was phased out, ethanol has come to take its place as the most widely used oxygenate additive in gasoline. The EPA has allowed a fuel blend of 90% gasoline/10% ethanol, known as E10, to be used in any gasoline powered automobile. Currently, about 95% of all gasoline sold in the US contains up to 10% ethanol – not only to comply with the law, but also to boost octane levels and meet the Renewable Fuel Standard (discussed below).[22] The EPA has also allowed the use of a 15% ethanol blend (E15), but because it can have corrosive effects on engines, its use is limited by both regulation and the inability of most cars to use it. Overall, the use of oxygenated additives is considered to be a success in meeting the original objectives of enhancing air quality, as levels of smog, carbon monoxide and particulate matter have reduced in cities throughout the US over the last two decades.

While the oxygenate requirements resulted in greater use of ethanol, there is a more recent federal mandate, the Renewable Fuel Standard (RFS), that has more significantly impacted the production and use of ethanol, prompting a massive expansion of the industry. The RFS, administered by the EPA, was established by the *Energy Policy Act of 2005*, and then revised in the *Energy Independence and Security Act (EISA) of 2007*. The law requires the use of biofuels at continually increasing levels, with a minimum of 9 billion gallons of renewable biofuels to be blended into the gasoline supply by 2008, 15 billion gallons by 2012, and finally 36 billion gallons by 2022.

Figure 2: Renewable Fuel Standard Targets[23]



The RFS applies to refiners, importers, and blenders of gasoline. EPA sets a minimum percentage of fuel that must be displaced with renewable fuels in order to meet the standard for the year, and in effect, this largely means ethanol. Over time, it is expected that cellulosic ethanol and other advanced biofuels will be more readily available at an affordable price, and therefore the law places a cap on the amount of corn ethanol that can be used to meet the RFS. Beyond 2015, all increased use of biofuels is expected to come from cellulosic and advanced biofuels. The EPA has periodically raised the percentage of total fuel volume that must be renewable – currently at 9.23% in 2012 – in order to meet the law's overall production requirement. The minimum level will continue to increase until the US reaches the level of 36 billion gallons of renewable fuel use.

The effect of the RFS mandate has been a significant expansion of biofuel production, with 14 billion gallons produced in 2011.[24] The RFS also has led to growing demand in the market for corn, and an increase in the price of corn, which rose to an average of $7.63 a bushel in August 2012, a record high. Rising prices help small farmers and agribusiness interests. They also promote the growth of the biofuel industry. But at the same time, there are other impacts, particularly on the price of food and animal feed (these are addressed below).

Ethanol in Brazil

Brazil is the second largest producer of ethanol in the world, after the United States, with 5.5 billion gallons produced in 2011. In Brazil, however, ethanol is derived from sugar, and this has significant implications for costs, energy output and environmental impact. Sugar ethanol costs about 30% less to produce than corn ethanol because the corn starch must first be converted to sugar before it can be processed into alcohol. With respect to output, less land is needed to produce the same volume of ethanol – in Brazil about 800 gallons of ethanol are produced per acre of land, while in the US only about 320-420 gallons are derived per acre corn planted. Moreover, sugar ethanol has a better energy balance – the "energy return on energy invested" is six to seven times greater than that of corn ethanol. The environmental benefits of sugar ethanol are better too, as it offsets a greater amount of greenhouse gases than corn ethanol.

The development of the ethanol industry in Brazil began almost 40 years ago as a response to the 1973 oil crisis. Seeking to reduce oil imports, the government launched the "Pro Alcool" program. This guaranteed that the state-owned oil company, Petrobras, would purchase the ethanol produced. It also provided low-interest loans to sugarcane growers, and set a fixed price for both gasoline and ethanol so that ethanol sold for less than gasoline at the pump. These measures allowed the industry to grow significantly, and then were eventually phased out. With the introduction of flex fuel cars and filling stations in recent years, Brazil now uses more ethanol than gasoline to meet its needs. In fact, it imports ethanol from the United States.

The Politics of Ethanol

The politics of ethanol production and use are extensive. One of the major political drivers for increasing the use of ethanol over the years has been the strength of the U.S. farm lobby, which has for decades been successful in securing federal support for the production of corn, the most widely grown crop in the United States. This support comes in the form of direct payment to farmers, price supports, and crop insurance, with direct payments totaling about $5 billion per year, and other support costing approximately $1 billion each year, according to the National Corn Growers Association and the Congressional Budget Office.[25] Direct payments are made to corn growers based on acreage planted, without regard to yields or market prices, which has prompted two significant critiques. First of all, it is the largest farms, many of which are owned by commercial firms and not family farmers, which receive the biggest benefits. Therefore those in the least economically vulnerable position are gaining the greatest support. According to the Environmental Working Group, a strong critic of US farm subsidies, "the top 10 per cent of farmers collected 74 per cent of all subsidies between 1995 and 2010 (not only direct payments), amounting to nearly $166 billion."[26] A second critique of direct payments revolves around the point that payments are made annually without regard to crop yields or prices. At a time when corn and other food prices are high and have been rising around the world (this article was written in 2012), when the production and use of ethanol in the US fuel supply is mandated by federal laws, when corn producers in the US are profitable, and when the United States has a huge budget deficit, it makes little sense, according to critics, to continue to subsidize corn growers with billions of dollars of taxpayers' money.

The question of mandates and subsidies has been further complicated by the way in which the United States nominates presidential candidates. The Iowa caucuses lead the way in the primary election season every four years, and success in the state is considered to be crucial for a candidate to remain viable for subsequent contests as they seek nomination. To that end, candidates from both parties have routinely touted their support for ethanol mandates and subsidies as a way to garner electoral support in the state, where a great deal of corn is grown (2.3 billion bushels on 14 million acres of land in 2011).[27] Barack Obama and Mitt Romney both provided their support in 2012, and they have been part of a long succession of presidential hopefuls offering support for ethanol. Even John McCain, an opponent of ethanol production and subsidies, changed his stance when he ran for president in 2008. As a longtime critic of ethanol who argued that ethanol didn't improve energy security or air quality, he didn't actively complete in Iowa in 2000 during his first presidential run. He stated at the time that "ethanol subsidies should be phased out, and everybody here on this stage, if it wasn't for the fact that Iowa is the first caucus state, would share my view that we don't need ethanol subsidies. It doesn't help anybody."[28] As McCain was beginning his 2008 presidential campaign, the temptation to win votes seemed to prompt a change in his position, as he came out in support of ethanol production as a solution to energy security and GHG emissions (though he remained opposed to subsidies, which made him unpopular enough to again avoid competing heavily in the caucuses). By 2012, surprisingly, things seem to have changed a bit. In light of the growth and strength of the ethanol industry, it appeared that unflinching support for ethanol in Iowa was considered a bit less important to voters. Polls conducted at the time of the 2012 Iowa caucus found that fewer voters than before considered support for ethanol production to be a major issue in their voting behavior.[29]

FOOD OR FUEL?

The most significant issue involving ethanol that has emerged in recent years has been the impact on land use and the production of food. As more of the US corn crop has come to be used for ethanol, a robust and ongoing debate has emerged on both the impacts and the wisdom of increasing the use of arable land to produce fuel instead of food.

The amount of land that is used to produce ethanol is quite large. As noted above, in 2011, 93 million acres in the United States were devoted to growing corn, and 40% of that total was used in producing ethanol. In the United States, one acre of land can generate anywhere from 320 to 420 gallons of ethanol, and such levels of productivity may be problematic. One study, conducted in 2005, suggested that maximum productive capacity at current yields is not far away.

> For the US production of ethanol, even without considering the environmental impacts, the results show that this option is not a realistic alternative. The major constraint is the amount of land area required for corn plantations…Assuming an annual increase of 4% in the US automobile fleet, we determined that by the year 2012, all the available cropland area of the United States would be required for corn production. This scenario assumed that the whole automobile fleet would use E85 as fuel. In the same scenario, by the year 2036, not only the entire US cropland area but also the entire land area now used for range and pasture would be required. Finally, by 2048, virtually the whole country, with the exception of cities, would be covered by corn plantations.[30]

While E85 is not widely used, it is available and its widespread use is envisioned as a laudable goal for future use in a growing fleet of flex-fuel cars. Even if an assumption of 100% use of E85 in the auto fleet is unrealistic (conventional vehicles, electric cars, and natural gas engines, along perhaps with other technologies not yet developed are potential competitors), the analysis cited above demonstrates the scope of the need for land to produce corn for ethanol.

Another impact of using land to produce ethanol is the rising price of corn and other staples, which have increased rapidly in recent years, particularly in 2012, when a drought in parts of the United States resulted in a lower-than-expected yield in agricultural output. In 2005, the average price of a bushel of corn sold in the United States was $1.96; and a market high was reached in August 2012 with a monthly average of $7.63 a bushel.[31]

This increase appears to have had an inflationary impact on the price of food in general, in the US and around the world, with multiple rippling effects. With less corn available, consumers have turned to other commodities such as wheat, rice and soybeans, causing the price of these goods to more than double in price since 2005.

Table 2: Commodity Prices, in Dollars per Metric Ton[32]

Commodity	August 2005	August 2012
Corn	$98	$332
Wheat	$149	$349
Rice	$283	$582
Soybeans	$230	$622

In 2012, the UN Food and Agriculture Organization reported that food prices overall rose 6% in a single month (July 2012), and that corn prices rose 23%, wheat was up 19% and sugar 12% compared to the previous month.[33] This increase seemed to have been driven largely by drought in the United States, but the severe weather only served to underscore the criticism of U.S. biofuel policy, which is blamed for generating tight food supplies and increased market volatility. (Biofuels policy in the EU also comes under fire for adversely impacting global food prices.)

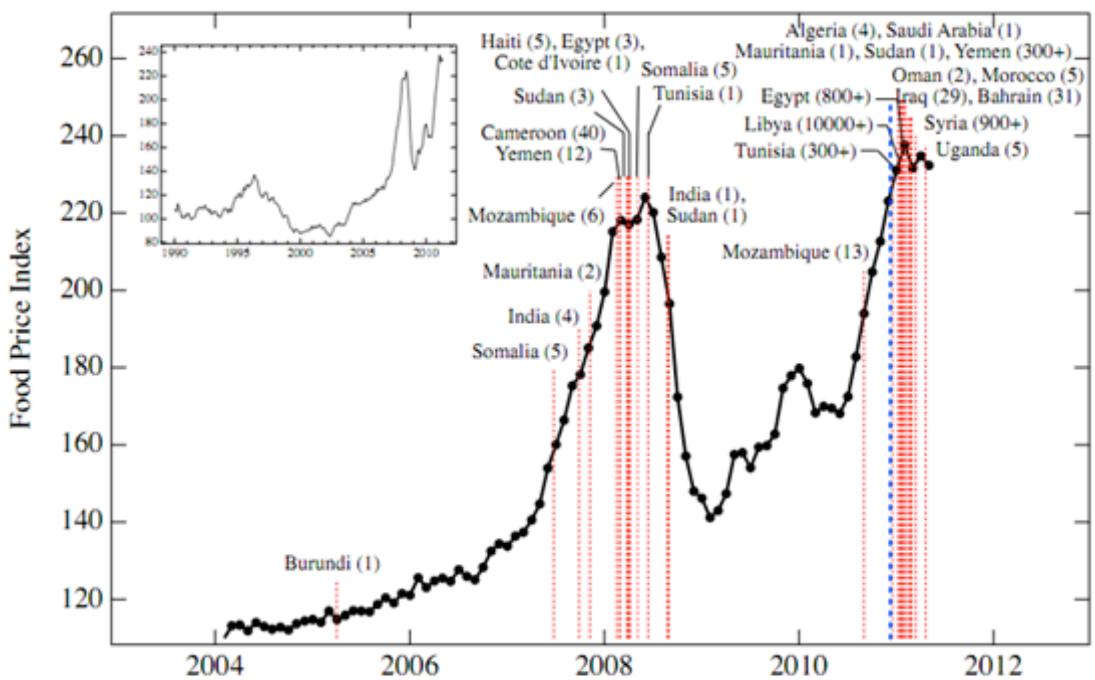
There is debate over the exact price impact that the production of biofuels has had on rising food prices, but there is for the most part some agreement that there has been an effect. A 2008 study by the National Academy of Sciences estimated that the expanded production of biofuels accounted for 20-40% of the worldwide increase in food prices in 2007-8, when food prices began to rise sharply.[34] A World Bank report in the same year stated that “the most important factor was the large increase in biofuels production in the U.S. and the EU. Without these increases, global wheat and maize stocks would not have declined appreciably, oilseed prices would not have tripled, and price increases due to other factors, such as droughts, would have been more moderate.”[35] The Global Development and Environment Institute in 2011 released an analysis stating that “the United States is by far the world’s largest producer and exporter of corn, so this diversion of something on the order of 15% of global corn production from food and feed to fuel has created a demand shock in global markets." The study estimated that the increased cost to corn importing countries from 2006-2011 was $11.6 billion, with more than half of that amount being absorbed by developing countries.[36] Other studies report similar findings, arguing that there is a clear and convincing relationship between U.S biofuel policy and the price of food worldwide, but there is far from unanimous agreement on the issue.[37]

The spillover effects of growing corn for food extend to other commodities as well. Most corn grown in the US is not sweet corn of the corn-on-the-cob variety, but feed corn, which is used for animals. Therefore the rising price of corn means that the cost of animal feed has gone up too. This has had an effect on livestock and poultry producers, who have seen their costs jump, leading to higher consumer costs. High corn prices led the Governors of ten states (Texas, North Carolina, Georgia, Virginia, New Mexico, Arkansas, Maryland, Delaware, Utah and Wyoming), along with 34 U.S. Senators and 156 House members, to request a temporary waiver of the Renewable Fuel Standard in 2012. As Governor Rick Perry of Texas stated, "Good intentions and laudable goals are small compensation to the families, farmers and ranchers who are being hurt by the federal government's efforts to trade food for fuel. Any government mandate that benefits one industry to the detriment of millions of consumers is bad policy."[38] While the EPA can waive the RFS if meeting the targets cause severe economic or environmental harm, the agency denied the request, stating that, "The agency recognizes that this year's drought has created significant hardships in many sectors of the economy, however, the agency's extensive analysis makes clear that Congressional requirements for a waiver have not been met and that waiving the RFS would have little, if any, impact on ethanol demand over the time period analyzed."[39] Indeed, a waiver from the mandate might not ease the rise in corn prices. The use of ethanol to meet clean air rules is not changing, and no other available substance can oxygenate gasoline as effectively. Moreover, ethanol is as much as a dollar cheaper than other types of octane boosters. Finally, a relaxation in the RFS would not immediately offer an economic case against the use of ethanol, as producers, refiners and blenders, would still see an economic benefit to maintaining the ethanol production chain that they have established. So even if a reduction in the mandate were allowed, there would still be an economic rationale for the widespread use of ethanol.

The impacts of using more land to produce fuel are felt worldwide, as price spikes have led to food riots and social unrest in recent years throughout the developing world, particularly in 2007, 2008 and 2011.

Egypt, Cameroon, Mozambique, Senegal, Haiti, India, and Bangladesh faced rioting attributed to food price spikes. Even the protests that resulted in the Arab Spring in 2011 seemed to have been triggered in part by a response to the price of food. An analysis in 2011 looked at riots worldwide, whatever the cause, and found that they have been widely correlated with rising food prices. While admittedly, in the Middle East, the spread of social unrest has had other causes, the study, whose focus was the Arab Spring, suggests that while high food prices may not necessarily trigger riots themselves, they are "a precipitating condition for social unrest."[40] The graph below demonstrates the correlation, with the vertical lines representing the beginning of food riots, and the black dots representing the FAO food price index.

Figure 3: Correlation between Food Price Index and Rioting (death toll in parentheses)[41]



The long-term social impacts of trading food for fuel could be significant. Support for ethanol benefits gasoline consumers at the expense of food consumers, and "unlike other alternative energy technologies, the impact of biofuels will be greater on food prices than energy prices."[42] Since food is a necessity while gasoline is more of convenience or even a luxury good, the situation that has evolved is one in which the rich seem to be benefiting at a cost to the poor, especially in the developing world, where people spend a larger proportion of their income on food. "For the 1.2 billion people who make

$1.25 or less a day and spend 50% to 80% of their income on food, price rises mean hunger and less money for education and health care."[43] As one analyst noted, "It may be the case, therefore, that the poor go hungry so the wealthy can drive bigger cars farther…Without adequate safeguards, further expansion of biofuels will mean an unpalatable trade-off between cars for the rich and starvation for the poor."[44]

While the causes of food shortages are multiple and complex, it may be the case that greater flexibility in US biofuels policy could at the very least diminish the volatility in global food prices. Proposed policy changes have included extending the timeframe in the RFS beyond 2022 for meeting the goal of 36 billion gallons of biofuel production. Relaxing the blending mandates to meet the RFS targets when corn production is low is another option. Since ethanol production appears to affect food prices more than fuel prices, and there are sufficient supplies of gasoline in the US for motor fuel, the supply of corn could be used as a benchmark for adjusting EPA's blending requirements. Another alternative is to allow ethanol producers greater flexibility to meet their mandates over multiple years. Under current law, blenders can meet up to 20 percent of their obligations in a given year from banked credits that were earned in previous years by producing more ethanol than was required. Increasing this limit would promote flexibility and potentially limit market volatility, as producers would be able to adjust feedstock purchases in response to supplies and prices. The flipside of this is that under current law, blenders can borrow blending credits from their future obligations as long as they pay back the credit in the following year with higher production. Extending the timeframe in which the credits are paid back could also have a similar calming effect on the market.[45]

CELLULOSIC ETHANOL

As there is a growing awareness that ethanol derived from corn is not producing all the benefits promised, and that its use is causing unintended consequences, the US has developed a policy goal of promoting the development of advanced biofuels such as cellulosic ethanol, which is under development by many companies in the US and overseas.

Cellulosic ethanol is considered to be an improvement over corn ethanol for a variety of reasons. To start, cellulose is found in all plant material. It is the most common organic compound on the planet, and is therefore readily available to be converted into fuel without requiring great effort, expense and resources to grow it. Cellulose can be acquired from agricultural waste products, the output from lawn maintenance and forestry management, and many other sources. The implications of this are significant, as the feedstock used to produce fuel does not have to require the diversion of land, or fertilizer usage, or irrigation. Of course, producing cellulosic ethanol could include all of these impacts, if vast acreage were devoted to the production of a product such as switchgrass, which has a very high concentration of cellulose.

In addition, research into the energy balance and greenhouse gas emissions associated with cellulosic ethanol indicates that its use offers far better returns than corn ethanol. Studies are confirming the potential benefits in terms of net energy and GHG emissions, such as a paper published by the National Academy of Sciences, which found that switchgrass offers an EROEI ratio of 5 to 1, while reducing CO2 emissions by 94% compared to convention gasoline.[46]

These assessments are not without their caveats. Increased use of woody waste for fuel could impact the markets for wood pulp and paper products. The use of arable land to grow plants with a high cellulose yield can impact the production and prices of other crops, as well as the use of water and fertilizer. And the fuel inputs and GHG outputs required to grow/gather, transport, and process biomass into fuel, and then transport the fuel to consumers may not be fully understood until the commercialization of cellulosic biofuels is more fully developed and brought up to a large scale.

In spite of these potential impacts, the use of cellulosic ethanol is considered to be an improvement over corn ethanol. With this in mind, the Renewable Fuel Standard mandates an increase in its use, calling for 15 billion gallons in the US fuel supply by 2022, a level equal to the total amount of corn ethanol called for in the RFS. While it remains to be seen if this ambitious target can be reached, the promise of cellulosic ethanol is considered to be the next major advance in the development of alternative fuels in the United States.

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