World Biofuels Production Potential

Understanding the Challenges to Meeting the U.S. Renewable Fuel Standard

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Executive Summary

This study by the U.S. Department of Energy (DOE) estimates the worldwide potential to produce biofuels including biofuels for export. It was undertaken to improve our understanding of the potential for imported biofuels to satisfy the requirements of Title II of the 2007 Energy Independence and Security Act (EISA) in the coming decades[1]. Many other countries' biofuels production and policies are expanding as rapidly as ours. Therefore, we modeled a detailed and up-to-date representation of the amount of biofuel feedstocks that are being and can be grown, current and future biofuels production capacity, and other factors relevant to the economic competitiveness of worldwide biofuels production, use, and trade.

The Oak Ridge National Laboratory (ORNL) identified and prepared feedstock data for countries that were likely to be significant exporters of biofuels to the U.S. The National Renewable Energy Laboratory (NREL) calculated conversion costs by conducting material flow analyses and technology assessments on biofuels technologies. Brookhaven National Laboratory (BNL) integrated the country specific feedstock estimates and conversion costs into the global Energy Technology Perspectives (ETP) MARKAL (MARKet ALlocation) model. The model uses least-cost optimization to project the future state of the global energy system in five year increments. World biofuels production was assessed over the 2010 to 2030 timeframe using scenarios covering a range U.S. policies (tax credits, tariffs, and regulations), as well as oil prices, feedstock availability, and a global CO_2 price.

All scenarios include the full implementation of existing U.S. and selected other countries' biofuels' policies (Table 4). For the U.S., the most important policy is the EISA Title II Renewable Fuel Standard (RFS). It progressively increases the required volumes of renewable fuel used in motor vehicles (Appendix B). The RFS requires 36 billion (B) gallons (gal) per year of renewable fuels by 2022[2]. Within the mandate, amounts of advanced biofuels, including biomass-based diesel and cellulosic biofuels, are required beginning in 2009. Imported renewable fuels are also eligible for the RFS. Another key U.S. policy is the $1.01 per gal tax credit for producers of cellulosic biofuels enacted as part of the 2008 Farm Bill[3]. This credit, along with the DOE's research, development and demonstration (RD&D) programs, are assumed to enable the rapid expansion of U.S. and global cellulosic biofuels production needed for the U.S. to approach the 2022 RFS goal[4]. While the Environmental Protection Agency (EPA) has yet to issue RFS rules to determine which fuels would meet the greenhouse gas (GHG) reduction and land use restrictions specified in EISA, we assume that cellulosic ethanol, biomass-to-liquid fuels (BTL), sugar-derived ethanol, and fatty acid methyl ester biodiesel would all meet the EISA advanced biofuel requirements. We also assume that enough U.S. corn ethanol would

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[1] EISA is also known as Public Law 110-140.

[2] The 36 B gal per year of renewable fuels required by 2022 include 35 B gal of ethanol-equivalent renewable fuel and 1 B gal of biomass based diesel. Renewable fuels that have more or less energy per gal than ethanol are assumed to be given proportionally more or less credit in meeting this requirement. See Appendix B.

[3] "2008 Farm Bill" refers to the Food, Conservation, and Energy Act of 2008 which was enacted in June 2008. It is also known as P.L.110-246 and includes a cellulosic biofuel tax credit (Sec.15321) of $1.01 per gal for cellulosic biofuel producers through 2012. This tax credit is part of a biofuel provisions package in the farm bill that includes substantial RD&D funds (including loan guarantees) as mandatory programs, and a reduction in the corn ethanol volumetric ethanol excise tax credit (VEETC).

[4] See http://www1.eere.energy.gov/biomass/

meet EISA’s biofuel requirements or otherwise be grandfathered under EISA to reach 15 B gal per year.

Primary Results from the Scenario Analysis

Many countries around the world are embarking on ambitious biofuel policies through renewable fuel standards and economic incentives. As a result, both global biofuel demand and supply is expected to grow very rapidly over the next two decades, provided policymakers maintain their policy goals. In the reference case presented here, total biofuel production increases more than six-fold from 12 B gal in 2005 to 83 B gal in 2030. The infrastructure challenges are daunting, will require considerable investment, and will test the innovation systems in countries with nascent biofuel industries. The ability to transfer technology and trade in biofuels is essential to meeting new biofuels goals.

Sugar-based ethanol is now the least expensive biofuel and its production is mainly constrained by the availability of feedstock. Thus we see significant increases in production for scenarios where feedstock availability is high. Grain-based ethanol is hampered by higher feedstock prices and competition with food markets, which leads to declining volumes in the long term. Cellulosic biofuels hold great promise if the necessary technology advances are made and these fuels can be produced at competitive prices. The potential for global cellulosic biomass production is sufficient to ensure that the resource base is not a constraining factor in the medium term, although the ability to bring the biomass to markets might limit access to these resources.

The results from the ETP global model show biofuel production dominated by the U.S., Brazil, and Europe. Combined, they supply more than 90% of all biofuels in 2010, although this decreases over time to about 70% in 2030. The majority of biofuel production is in the form of ethanol throughout the period. Sugar-based ethanol gradually loses market share as resource limitation prevents growth at the average rate of the industry.

Biofuel demand is highest in the same regions, but the South American countries are surplus producers and supply most of the internationally traded biofuels. In the reference case, the region exports 8 B gal of biofuels in 2020 and 12 B gal in 2030. The bulk of these volumes are sold to the U.S. and Europe, who are the largest importers.

The ESIA RFS is an ambitious policy that mandates 36 B gal of biofuel consumption in the U.S. by 2022. The challenge to the industry is vast and the scenarios we analyzed indicate that it may be difficult to reach the goal according to the schedule set out in the RFS. Developing the cellulosic resource base, building cellulosic biofuel production facilities, and constructing the ethanol distribution infrastructure quickly enough are the main obstacles to meeting the RFS. In the scenarios modeled, the shortfalls range from 0 to 4 B gal in 2020.

A hypothetical scenario that allows blending of up to 20% ethanol into gasoline[5] illustrates the infrastructure barriers that face ethanol when only 10% blending is allowed. This scenario also shows the competition between cellulosic ethanol and BTL where the former has a cost

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[5] The viability of this scenario is dependent upon resolving issues related to the impact higher blends of ethanol will have on engines and fuel systems. Currently most car manufacturers will only warrant their gasoline engines if they are fuelled with ethanol blends of 10% or less. Blends higher than 10% ethanol are not currently allowed in the U.S.

advantage when ethanol infrastructure constraints are not included and the latter has a cost advantage when ethanol infrastructure is a constraint.[6]

The main constraint to cellulosic biofuel production is infrastructure development rather than the underlying economics; thus, additional incentives such as growers' payments or an extension of the ethanol blenders' tax credit do little to increase overall biofuel supply. The blenders' tax credit would be paid to marketers for volumes already mandated by law and as policy tool would be inefficient to encourage biofuel supply. If increasing biofuel supply is the main policy goal, a targeted subsidy for cellulosic biofuels would have a larger impact and also be less expensive to implement.

In markets without biofuel mandates, the price of biofuels is determined by the price premium it can achieve over gasoline or diesel due to subsidy regimes. Higher oil prices will therefore lead to a stronger price signal for biofuel production and consequently the high oil price scenarios show higher worldwide demand for biofuels. In markets with mandates however, demand volumes are fixed through policy and changes in price signals do little to raise or lower demand. This is the case in the U.S. where biofuel demand is not very responsive to changes in oil price, because the buy-out from the cellulosic biofuels mandate adjusts to oil price and there are no relief-valve mechanisms for the other mandated volumes. This means that higher oil prices tend to lead to domestic production substituting for imports, because the oil price increase raises biofuel demand and thereby results in stronger competition in international markets.

A carbon price has a similar effect to that of a higher oil price. The carbon price can in fact be seen as a price premium on fossil fuels. A carbon policy will thus promote the production and use of biofuels worldwide. While higher oil prices are neutral as far as feedstock and conversion technologies are concerned, a carbon price will favor cellulosic and sugar-based biofuels production over grain-based production, which has higher carbon emissions per gal. A carbon policy will thus tend to increase the share of cellulosic biofuel and sugar ethanol at the expense of grain-derived ethanol.

In comparisons with the EIA's 2008 AEO biofuel projections under the new RFS, this study shows larger biofuel imports and therefore, larger U.S. supply. This is explained by two differences. First, this study focused on an in-depth analysis of the feedstock potential of biofuels exporting countries. Therefore, these results show a much larger supply of imports compared to the AEO. Second, the AEO assumes that the cellulosic technology is adopted at a much slower pace due to higher capital costs, whereas this study includes in its assumptions the provisions of the 2008 Farm Bill through a cellulosic production tax credit that reduces the cost of cellulosic biofuels production until it is competitive with corn ethanol production. This study also shows the benefits of U.S. policies to develop and commercialize cellulosic biofuels technologies since technology transfer results in the spread of cellulosic technology throughout the world.

This study provides an insight into why the U.S. is projected to have difficulty in meeting all of the mandates of the new RFS. The reference scenario, as well as analysis in EIA's *2008 Annual Energy Outlook* (AEO), shows that the U.S. is not projected to completely satisfy the biofuels requirements of the new RFS in 2015. A compliance gap is estimated to persist through 2030 in

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[6] Both cellulosic ethanol and BTL fuels are qualified cellulosic biofuels as defined by EISA. It is not yet certain whether BTL diesel fuel would also qualify as biomass-based diesel under EISA.

EIA’s analysis. Our reference scenario shows a significantly smaller compliance gap through 2025. There are three main constraints to meeting the requirements of the new RFS: 1) ethanol infrastructure cost, 2) limits to cellulosic biofuels production growth in the early years of technology development, and 3) large demand operating at the inelastic limit of the sugarcane supply curve. These challenges were discovered through the use of various policy and market scenarios.

Introduction

Record high oil prices as well as concern over potential threats to energy security and the global environment have made biofuels an urgent national priority (IPCC, 2007)[7]. In response, the President proposed and Congress enacted a greatly expanded Renewable Fuel Standard (RFS) in 2007. Title II of the Energy Independence and Security Act of 2007 (EISA) mandates a total of 36 billion (B) gallons (gal) of renewable fuels by 2022—more than five times U.S. 2007 production[8]. The RFS does not allow more than 15 B gal per year of starch-derived ethanol (e.g., corn ethanol) to satisfy the mandates, a figure that is not substantially higher than current and planned U.S. production capacity. Consequently, the RFS essentially mandates second-generation biofuels or biofuels with lower greenhouse gas (GHG) emissions than corn ethanol (and even lower emissions compared to the petroleum fuels they displace). Also, second-generation biofuels are not derived from food crops and consequently pose much smaller ecological risks (land use intrusion and biodiversity).

The Energy Information Administration (EIA) has projected that the mandate of 36 B gal of biofuels will not be met by 2022 (AEO, 2008). This global study extends EIA's analysis by estimating worldwide potential to produce and supply biofuels to the U.S. market in the EISA timeframe, and determining the constraints under which the RFS might not be met. While U.S. production of biofuels is more desirable from the perspective of the national security, biofuel imports (because they come from different parts of the world than oil) also increase fuel source diversity and U.S. energy security. Both domestic and international production of second-generation biofuels can benefit the global environment.

World biofuels potential depends on the amount of biofuels feedstock that can be grown on available land, biofuels production capacity, and the economic competitiveness of biofuels compared with other options. We identified eight regions[9] that have the largest resource potential to produce biofuels for export to the U.S. Supply curves for selected feedstocks[10] and conversion costs for selected technologies were estimated in each relevant country. The results were used to update the global Energy Technology Perspectives (ETP) model. The ETP model was then used to project the volume of biofuels on the world market through 2030 including production, consumption, and trade within and among the fifteen world regions of the ETP model (biofuels production was also estimated for several specific countries within the "Central and South American" ETP region). A range of scenarios were considered to examine the impacts of policies and market conditions on biofuels production and exports.

A key result of this assessment is the importance of promoting the rapid commercialization of cellulosic biofuels if the EISA RFS requirements are to be met. One important factor for

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[7] In 2008, the United States imported 72% of the crude oil and petroleum products it consumed. The Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2008 reference scenario projects that U.S. petroleum imports will increase for the foreseeable future. From a global perspective, energy security is far from assured because most of the world's long-term supplies of accessible crude oil deposits are in one place – the Middle East.

[8] According to the Renewable Fuels Association, in 2007 U.S. ethanol production was 6.5 B gal. Biodiesel production was about 91 million gal in 2005, based on data from the USDA Commodity Credit Corporation which ended its program and its data collection on March 31, 2006.

[9] The countries are Argentina, Brazil, Canada, China, Columbia, India, Mexico, and, collectively, the nations in the Caribbean Basin Initiative.

[10] See Table 2 in the section on Methodology for feedstocks studied in each country (or region).

promoting the rapid commercialization of cellulosic biofuels is the $1.01 per gal production tax credit (net) for cellulosic biofuels provided under the 2008 Farm Bill[11]. We conclude that it would be much less likely that the RFS requirements would be met without this production tax credit. Cellulosic biofuels are being encouraged in the U.S. as the mainstay of future biofuels supply because they are more sustainable in several respects than ethanol derived from grain. First, feedstocks for this form of production do not have an alternative use such as food or feed. Increased production would therefore not affect food markets directly, although competition for land, labor, and capital could generate indirect impacts. Second, the resource base is potentially enormous; and third, lower water and fertilizer requirements and a significant reduction in carbon emissions could make cellulosic ethanol more environmentally friendly than starch based ethanol.

Scenarios

Scenarios were developed to understand the impact of different policies, technology prospects, and market uncertainties on global biofuel production, imports, and exports. All scenarios modeled include the RFS mandates, as well as existing biofuels policies in other countries. In all scenarios the RFS mandate after 2022 is modeled such that the renewable fuel requirements grow in proportion to the projected baseline petroleum demand growth. All scenarios include the aforementioned cellulosic biofuels tax credit and, implicitly, many other Farm Bill programs which are likely to be reauthorized in the 2012 and subsequent Farm Bills. Thus, in the reference scenario and all other scenarios, the cellulosic tax credit is represented as a continuing but declining production tax credit until cellulosic biofuels are cost competitive with corn ethanol. The incentive applies to both cellulosic biomass-to-liquids (BTL) and cellulosic ethanol.

Reference Scenario: Similar to the AEO 2008, the reference scenario is a projection of the current policy and market environment. As detailed later, it includes all biofuels relevant policies in the U.S. and worldwide.[12]

Full descriptions of all scenarios can be found in Appendix A. Descriptions of key scenario variables follow:

Policy Scenarios: The policy scenarios explore possible U.S. and global policies:

- <u>E20:</u> This scenario assumes that E20 is a certified[13] fuel for conventional gasoline vehicles allowing up to 20% ethanol blending in gasoline.

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[11] "2008 Farm Bill" refers to the Food, Conservation, and Energy Act of 2008 which was enacted in June 2008. It is also known as P.L.110-246 and includes a cellulosic biofuel tax credit (Sec.15321) of $1.01 per gal for cellulosic biofuel producers through 2012. This tax credit is part of a biofuel provisions package in the farm bill that includes substantial research, development, and deployment (RD&D) funds (including loan guarantees) as mandatory programs, and a reduction in the corn ethanol volumetric ethanol excise tax credit (VEETC) from $0.51 to $0.45 per gal in 2009-10—which pays for the cellulosic credit as well as the RD&D programs.

[12] Because the MARKAL model works in five year time increments, intermediate year policy changes that came with the 2008 Farm bill—such as the 2009 reduction in the corn ethanol VEETC to $0.45 per gal, and the extension to 2012 of the $0.54 per gal ethanol import tariff cannot be explicitly modeled but are not expected to affect the results significantly.

- <u>\$50 per t CO_2:</u> There is an implicit global carbon value that reaches \$50 per tonne (t) of CO_2 emitted in 2030 (Figure 1).
- <u>Credit and Tariff Extension</u>: The blenders' tax credit of \$0.51 per gal of ethanol and the U.S. tariff of \$0.54 per gal on ethanol imports are continued indefinitely.[14]

Market Scenarios: These scenarios explore market possibilities that will influence biofuels production and trade.

- <u>High and Low Feedstock Availability</u>: These scenarios are based on historical variations in feedstock production as described in the sections of the report on Methodology and Feedstock Assessment Results.
- <u>High and Low Oil Price:</u> These scenarios include potential high and low oil prices (Figure 2). The oil prices are OECD import basket prices and will generally be significantly lower than spot prices for reference crude oils like West Texas Intermediate or Brent. The reference, high, and low prices are endogenous values from the model itself. The higher oil price reflects the prices currently prevalent in the market and is discussed as a separate scenario (Alfstad, 2008).

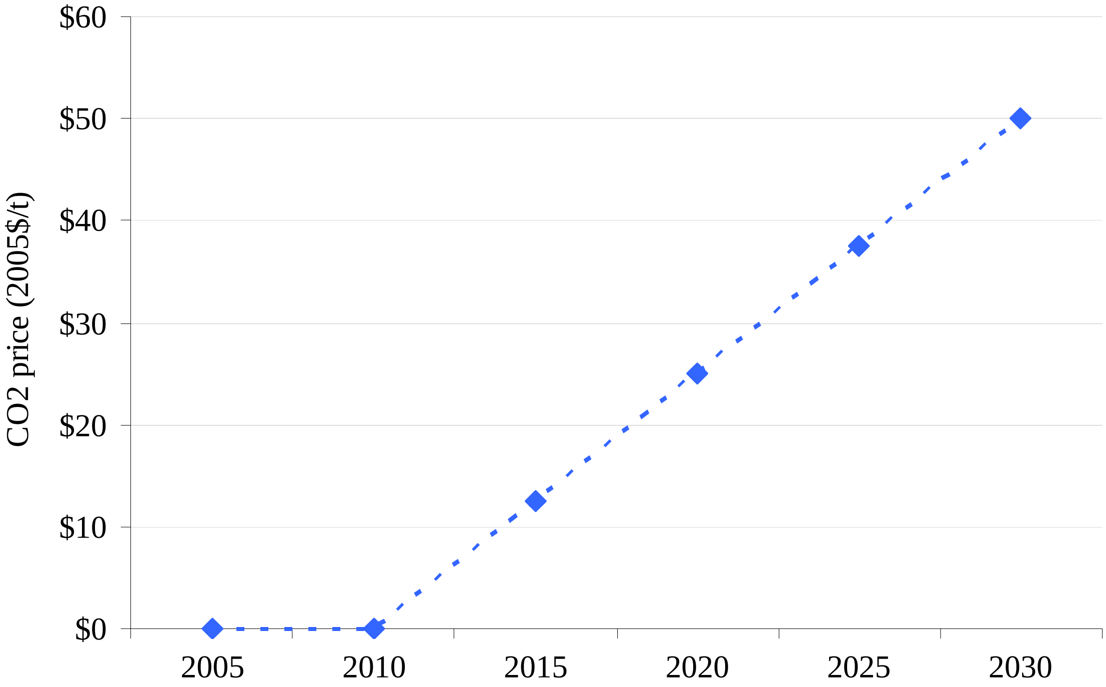

Figure 1: Global price per tonne of carbon dioxide in the CO_2 price scenario

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[13] The viability of this scenario is dependent upon resolving issues related to the impact higher blends of ethanol will have on engines and fuel systems. Currently most car manufacturers will only warrant their gasoline engines if they are fuelled with ethanol blends of 10% or less. Blends higher than 10% ethanol are not currently allowed in the U.S.

[14] This study analyzed the \$0.51 per gal tax credit given for blending ethanol into gasoline and the \$0.54 per gal import tariff that is charged to ethanol producers outside NAFTA and certain other agreements. These two polices are considered in tandem as the main purpose of the tariff is to cancel out the subsidy for foreign producers. The policies are currently due to expire in 2009 and 2010 but in this scenario an extension is explored.

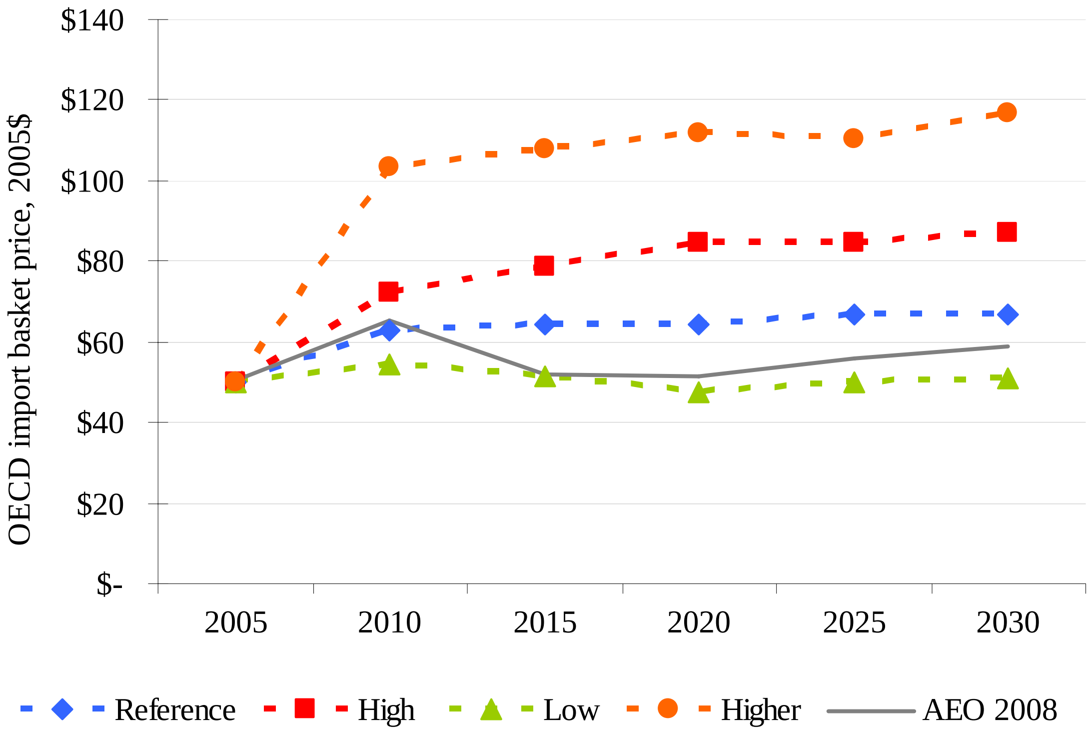

Figure 2: Price of oil in the AEO, reference, low, high, and higher oil price scenarios

Sensitivity and Uncertainty

The model results are relatively sensitive to some of the key assumptions. One of the most important is the cost at which ethanol can be produced from cellulosic feedstocks. At the conversion costs reported in the NREL study (Bain, 2007), cellulosic ethanol is highly competitive and penetrates the market very rapidly. If this low production cost cannot be achieved, because the assumed technology investment due to the U.S. cellulosic biofuels subsidy does not achieve rapid technology learning, then cellulosic biofuels production will be less than estimated.

There is also great uncertainty in the rate at which cellulosic ethanol can gain market share even if low production costs are achieved. The available historical data is insufficient to determine appropriate market penetration rates for this technology at different ethanol prices.

Assumptions regarding biofuels policies in Europe are also important, especially in early years. Europe attracts a large share of imports in early years because of high subsidies. The assumption here is that when the European Union (E.U.) goal under the current policy (10% by 2020) is met, the subsidies are no longer available and any additional ethanol is available on the global market. This assumes that Europeans are willing to pay these subsidies even if a large share of their supply comes from abroad. It also assumes that infrastructure to accommodate these imports is put in place as well as clear customs regulation. If these conditions are not met, considerable amounts of additional biofuels (1-2 B gal) could be available to U.S. markets.

Another note on the European subsidy regimes is that they are generally in the form of tax exemptions. If biofuels achieve substantial market shares (which they do in all scenarios) this leads to a considerable loss of revenue. To make up for this loss, the tax exemptions either need to be phased out as they are currently in the ETP model (although not necessarily at the same rate), or European governments will have to find an alternative source of revenue to pay for roads. There is great uncertainty regarding these subsidy provisions as they generally expire after a few years and there is little clarity as to what will replace them. A faster phase-out than what has been assumed here is a distinct possibility, which could significantly impact trade flows.

Another issue regarding the representation of Western Europe in the model is that it is modeled as a single region. While the region has a range of fuel taxes and exemption levels, it is represented as a single market with one average fuel tax and one tax exemption level in the ETP model. This means that the model exhibits some “knife-edge” behavior, in which U.S. importers are either competitive against all European importers or not. In reality they could be competitive against some of the European markets but not others.

Reducing or removing tariffs and other barriers to international trade of biofuels would yield several benefits. Most importantly, it will allow the most cost-effective producers to expand production and more easily market their products abroad. This should reduce the overall cost of supplying biofuels to markets. It should also limit the political pressure to maintain subsidies provided these also benefit imported biofuels. A well established international trade network would also lessen the impact of bad harvests. If supply falls short in a region one year, countries with mandates can shop for biofuels in international markets. Risks are thus shared among a larger number of participants.

Environmental and Social Issues

Biofuel feedstock production can have negative or positive environmental and social effects depending upon the local situation and factors. These include the crop type, the methods used to cultivate and harvest the crop, and what the alternative land use would be. Biofuel feedstock production could lead to deforestation, and raise issues of land tenure, water use, and pollution, representing important and politically delicate issues in many countries. The capacity for long-term land use planning and enforcement is important to avoid or minimize the detrimental impacts of unsustainable expansion. Using food crops for biofuels production can also disrupt food markets.

Most countries in this study have established biofuels targets or mandates[15], partly in response to high crude oil prices. These targets provide investors with increased security based on assurances of local market demand. Many nations (including Brazil, Argentina, Colombia, and several CBI nations) also encourage investment through reduced tariffs and tax-credits. China and India have discouraged the use of food crops and prime farm land for biofuel production. Use of food crops, however, allows producing countries to build domestic biofuel industries and gear up for a transition to other technologies and feedstocks when they become available.

Carbon emissions related to biofuel feedstock production is also a contentious issue. Emissions from land use changes and from diesel combustion in farm equipment, water pumping, and

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[15] See Methodology section for further discussion of worldwide biofuels policies.

production of fertilizer all erode the carbon benefits of biofuels. Different methodologies for estimating life cycle emissions produce different results. Most appear to arrive at estimates that show modest to significant emission benefits (Armstrong et al., 2002; Wang et al., 2007; Macedo et al., 2008; Sheehan et al., 1998). The net carbon loss of land conversion needs to be considered and is one of the greatest sources of debate and uncertainty. Soils and plant biomass are the two largest biologically active stores of terrestrial carbon and hold about 2.7 times more carbon than the atmosphere. If land is cleared to allow for cultivation of food or energy crops, the carbon contained in the standing biomass and some of the carbon stored in the soil will be released to the atmosphere. A "carbon debt" is thus incurred when native ecosystems are converted to cropland. This carbon debt is the difference between the amount of carbon stored in standing biomass and soil before land clearing and that of the crop grown in its place. The actual carbon debt is thus highly dependent on the type of ecosystem that is being cleared and the crop that replaces it.

One study (Searchinger et al., 2008) produced estimates for this pay-back. The actual pay-back will vary between scenarios, but even under their most optimistic assumptions it was over 30 years for corn, and under their base assumptions it was well over 100 years. Another study on the issue (Fargione et al., 2008) points out that the pay-back is highly dependent on the type of land being converted and the type of crop grown in its place. Their results indicate that clearing tropical or peatland rainforest to grow palm oil or soybean incurs large carbon debts with paybacks of several hundred years, while using abandoned or marginal cropland to grow prairie grasses incurs little to no carbon debt.

A recent World Resources Institute analysis (Bradley et al., 2007) of potential climate impacts of biofuels noted:

> 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 emissions 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 lands.

In Europe, a proposal for a directive on the promotion of the use of energy renewable sources has been presented. This proposal calls for a binding 10% minimum target for biofuels in transport to be achieved by each Member State. In a public consultation of interested parties, the proposal suggested three sustainability criteria which were generally supported: a) land with high carbon stocks should not be converted for biofuel production; b) land with high biodiversity should not be converted for biofuel production; c) biofuels should achieve a minimum level of GHG savings (carbon stock losses from land use change would not be included in the calculation).

The EISA RFS contains specific requirements for the lifecycle GHG emissions[16] of each renewable fuel type (a minimum GHG reduction of 20% for all qualifying renewable fuel[17] compared to the fossil fuel it replaces; a reduction of 50% for advanced biofuels; a reduction of 60% for cellulosic biofuels; and a reduction of 50% for biomass-based diesel). Furthermore, this calculation must include “significant indirect emissions such as significant emissions from land use changes,” as well as emissions from “all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential,” thereby addressing the contentious issue of indirect land use. Feedstocks may include crops from previously cleared, non-forested land, biomass from private forest lands, managed plantations, algae, or separated yard and food wastes (Appendix B). The Environmental Protection Agency (EPA) will be releasing a notice of public rulemaking in the near future to determine which fuels would meet the GHG reduction and land use restrictions specified in EISA. Furthermore, the 2008 Farm Bill established a $1.01 per gal tax credit for cellulosic biofuels, incentivizing cellulosic biofuels, which have a smaller impact on land than crops.

Emission factors for feedstocks are shown in Table 1.

Feedstock	**Change from gasoline or diesel**	**Source**
Sugar	-81%	Macedo et al, 2008
Corn (current average)	-19%	Wang et al., 2007
Cellulose	-86%	Wang et al., 2007
Wheat	-47%	Armstrong et al., 2002
Soy bean	-78%	Sheehan et al., 1998

Table 1: Change in lifecycle GHG emissions per mile traveled by replacing gasoline or diesel with biofuels

The concerns discussed are observed in specific instances, and there appears to be a growing consensus that if best practices for socially and environmentally sound development can be applied, then appropriate biofuel feedstock crops could offer farmers enhanced employment and incomes (Kline et al., 2007). Such practices also could help reduce the burden of foreign oil imports on developing nations and avoid the worst potential negative impacts. Indeed, recent growth in biofuel feedstock production has been accompanied by greatly increased attention to what are often long-standing social and environmental challenges.

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[16] This study does not model lifecycle greenhouse gas emissions explicitly but does address the associated issues qualitatively.

[17] Existing corn ethanol plants will likely be grandfathered but the rulemaking process is currently ongoing.

Methodology

This section describes the selection of countries for the study, generation of feedstock supply curves, and development of conversion technology costs. It also discusses the incorporation of the data for the selected countries into the ETP model[18].

Selection of Countries

Geographic areas were selected according to future biofuels production capacity for export to the U.S. market. The criteria used were:

- Current feedstock availability
- Current biofuels production
- Export infrastructure
- Processing capacity
- Proximity to the U.S.
- Forecast production potential

Seven countries and one region were selected as areas to be updated in the ETP model (Table 2). Data from a variety of sources were analyzed to identify the major biofuel feedstock crops in each country as well as other considerations affecting the feedstock supply available for conversion to biofuels[19].

Generation of Feedstock Supply Curves

For each potential feedstock in each area, Oak Ridge National Laboratory (ORNL) produced high, low, and base supply curves for 2012, 2017, and 2027. ORNL's base supply curves are projections of historic data within each country updated for the study. Changes in crop varieties, farming practices, weather, prices, government policies, and other variables led to historical variation in the area planted, yields, and total production. In the high case, growth is constrained to the upper limit of the trends based on historic yields and land use. The percentage of land allocated for a single crop in each state is not allowed to exceed 30% of that state's total land area, while the maximum yield in 2027 is set at twice the corresponding maximum yield reported in the U.S. The proportions of feedstocks allocated to food, fiber, and fuel in the model are based on historic fractions of production used to meet domestic needs.

ORNL compiled average production cost and projected supply data for each state in a country (or each country in a region) into supply curves from least to highest cost (see Figure 4 in Feedstock Assessment Results section)[20]. ORNL's report also discussed environmental, social,

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[18] A more detailed discussion of the ETP model is presented in the report by Alfstad.

[19] Data sources include U.S. Department of Agriculture (USDA), the Food and Agriculture Organization of the United Nations (FAO), DOE, International Energy Agency (IEA), and other regional and national sources.

[20] Where data were not readily available to develop a meaningful supply curve to update the model, the existing average point estimates in the ETP model were used. (Table 2)

and policy considerations affecting, and affected by, feedstock production in each priority country. (Kline et al., 2007).

	Sugar, starch, and oil crops					Cellulosic feedstocks		
	Sugarcane	Corn	Wheat	Palm	Soybeans	Bagasse	Agricultural residue	Other
Argentina	(✓)	(✓)	✓		✓	✓	✓	✓
Brazil	✓	✓			✓	✓	✓	✓
Canada		✓	✓				✓	✓
China	(✓)	(✓)	(✓)		(✓)	✓	✓	✓
Colombia	(✓)			(✓)		✓		✓
India	✓					✓		✓
Mexico	✓	✓				✓	✓	✓
Caribbean Basin (CBI)	✓			✓		✓		✓
Share of world production (excluding U.S.)	73%	55%	27%	3%	81%	-	-	-

Table 2: Countries and feedstocks selected for study. A parenthetical checkmark [(✓)] denotes countries and feedstocks that have only a single data point, rather than a stepped supply curve projection. Cellulosic feedstocks also generally have limited price points.

Development of Conversion and Transportation Costs

Updated transportation and country-specific conversion cost estimates were prepared by the National Renewable Energy Laboratory (NREL) for the feedstocks and technologies shown in Table 3. For most inputs, NREL used a statistical data reduction technique that accounts for observed variability among plants and the cost of each process used to convert a given biomass feedstock to fuel[21]. NREL also drew upon its previous process design studies (Spath et al., 2005), which included cost estimates for most components of typical facilities. Extensive discussion of this analysis and the data is presented in the NREL report prepared as part of this project (Bain, 2007).

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[21] The known cost in one location, generally the U.S. in this study, is adjusted to account for the relative capital and operating costs in each other location. The feedstock cost estimates and tax laws for each country are also incorporated in the result. The actual costs are typically between 90% and 140% of the estimate generated by this type of analysis.

	Sugar, starch, and oil crops					Cellulosic feedstocks		
Fuel and technology	Sugarcane	Corn (dry mill)	Wheat	Palm oil	Soybean	Bagasse	Agricultural residue	Other
Ethanol by conventional fermentation	✓	✓	✓					
Ethanol by biochemical conversion						✓	✓	✓
Ethanol by thermochemical conversion[22]						✓	✓	✓
Biomass-based diesel by transesterification				✓	✓			
Renewable diesel by hydrotreatment					✓			
Residual fuel oil by pyrolysis						✓	✓	✓
Biomass-to-liquids (BTL) by Fischer-Tropsch catalysis						✓	✓	✓

Table 3: Biofuel feedstock conversion technologies updated.

Integration of Feedstock and Conversion Cost Update into ETP Model

Brookhaven National Laboratory (BNL) used the results of the feedstock and conversion technology studies to update the fifteen-region, global ETP model. For the countries studied, ORNL's biomass feedstock supply curves replaced or supplemented the ETP model's representation of biomass. Similarly, NREL's more detailed cost and performance data for biomass handling and conversion technologies, as well as for transport and distribution of biofuels within and among regions, replaced older, less complete data in the ETP model. As detailed in the BNL report prepared as part of this project (Alfstad, 2008), this updated ETP model was then used to evaluate the impact of technological progress and alternative fuel pathways on international energy markets under various scenarios.

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[22] Ethanol by thermochemical conversion is not explicitly separated from ethanol by biochemical conversion in the ETP model because the costs are similar and both produce ethanol.

General Description of the MARKAL/Energy Technology Perspectives (ETP) Model

The ETP model[23] was updated to include the feedstock and technology data gathered for this study. ETP is a fifteen-region, global MARKAL (MARKet ALlocation) energy model. MARKAL-based models are partial equilibrium models that incorporate a representation of a physical energy system. Figure 3 shows how components of the energy system are represented and linked together in a network, where the technologies form the nodes and are linked by flows of energy carriers. It has a representation of the flow of energy carriers through the physical infrastructure from the resource base through the various energy conversion technologies to the end-user. An unlimited number of technology types can be represented; therefore, the MARKAL framework allows a full comparison of technology options from resource extraction to service demand.

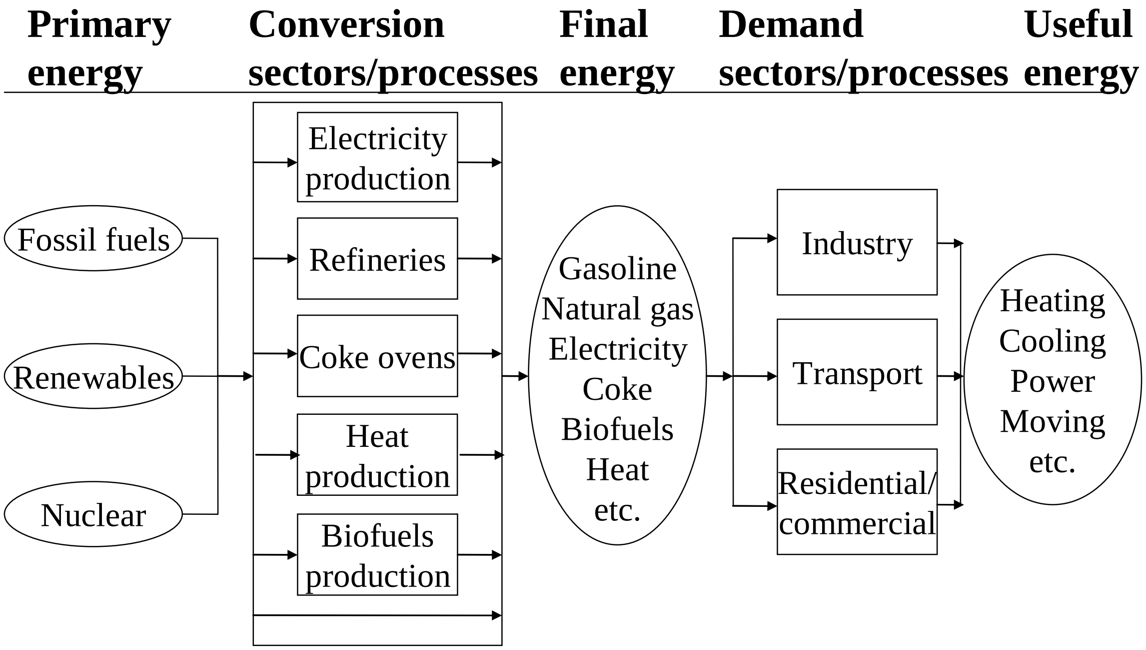

Figure 3: Energy flow diagram in ETP model

The MARKAL model is solved as a cost minimization problem where future states of the energy system are determined by identifying the most cost-effective pattern of resource use and technology deployment over time, discounted over the planning horizon. The MARKAL objective is thus to minimize the total cost of the system. Each year, the total cost includes the following components:

- Annualized investments in technologies
- Fixed and variable annual operation and maintenance costs of technologies

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[23] The ETP model developed by the International Energy Agency is the basis for the DOE's ETP model. The DOE and IEA collaborate to continually refine the ETP model and exchange respective data that define the reference energy system for each of the fifteen world regions: Africa, Australia and New Zealand, Canada, Central and South America, China, Eastern Europe, Former Soviet Union, India, Japan, Mexico, Middle East, Other Asia, South Korea, United States, and Western Europe.

- Costs of exogenous (external) energy and material imports and domestic resource production (e.g., mining)
- Revenue from exogenous (external) energy and material exports
- Fuel and material delivery costs
- Welfare loss resulting from reduced end-use demands
- Taxes and subsidies associated with energy sources, technologies, and emissions

MARKAL-type models are demand driven, which means that for any feasible solution, exogenous demands (externally calculated and projected) are satisfied. The model then determines the least cost configuration of capital stock and utilization rates that will meet these demands, while obeying a set of user defined constraints such as natural resource availability, technology and capital availability, and environmental limitations.

The model is dynamic and tracks capital stock, so that the capital stock in any period is equal to the capital stock in the preceding period plus or minus any additions or retirements. The solution in one period is thus directly linked to the solution for other periods. Optimization is performed for all periods simultaneously, giving decision makers foresight or planning capability. As MARKAL models are defined by the performance, cost, and availability data for hundreds of energy technologies, any change in the data used for input parameters such as feedstocks or technologies will result in a MARKAL model that is different from its predecessor. Each region listed has a unique set of demands specified for all major energy services as well as energy intensive materials industries such as metals, ammonia, cement, and pulp and paper. Demands can be met with internal production or through trade with other regions.

The ETP database contains representations of hundreds of different technologies covering all stages of the energy system from extraction of primary energy to end use devices. This includes information on capital stock already in place as well as new technologies thought to be available now or at a future date. The general approach is that all technologies can be deployed in all world regions. To reflect real-world limitations, some of the following additional characterizations have been made:

- Region- and sector-specific constraints;
- Region- and sector-specific discount rates;
- Region-specific investment costs and fixed and variable costs;
- Region-specific supply curves for renewables;
- Region-specific lengths of seasons; and,
- Region-specific starting years.

As discussed above, the ETP model was expanded for this project. A new set of biomass supply curves developed by ORNL (Kline et al., 2007) for this study were added for selected feedstocks and countries (see Generation of Feedstock Supply Curves section above for details) in place of the existing representation. For Central and South America this also meant breaking up the aggregate supply curves for the entire region into sub-regional curves representing individual countries. The updated biofuels feedstock and technology data resulting from this study represents a significant update of the fuel sector in the ETP model.

The new representation is more detailed and yields smoother price response and behavior. Through interaction with the rest of the energy system these new supply curves can be used to predict the volume of feedstock that will be available for conversion to biofuels at a given price. Both volumes and prices can therefore be determined (endogenously) within the model. Cost curves for capital equipment have been included in the model. If the capital stock of a given technology is to expand faster than a predefined normal rate, a price premium must be paid for it. These new cost curves represent the added cost of outbidding competitors for labor, materials, and contractors. A given technology will thus take market share from competing technologies more rapidly if it has a greater cost advantage. These cost curves have been introduced for the various biofuel production technologies and are particularly important for the market penetration of cellulosic ethanol.

Policies Incorporated into the ETP Model Baseline

The principal U.S. policy covered in this study is Title II of EISA 2007 which mandates increasing amounts of renewable fuel use, reaching 36 B gal per year in 2022. This study focuses on the role of various biofuels in meeting this mandate. The U.S. also has a $1.00 per gal tax credit for producers of biodiesel. This study assumes that this tax incentive is extended throughout the study period[24]. In addition, with the passage of the 2008 Farm bill cellulosic biofuels receive a $1.01 per gal inclusive of any credits that may already be given, such as the credit of $0.51 per gal to blend ethanol with gasoline.

Since this is a study of global biofuel markets, policies that are in place in other countries were also accounted for. These policies are often in the form of tariffs and exemptions from fuel taxes. The policies modeled for key countries according to ETP defined regions are summarized in Table 4 below.

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[24] The biomass-based diesel portion of the new RFS is a small share compared to the other renewable fuel type; therefore, this study did not analyze biodiesel market dynamics in detail. The biodiesel tax credit is assumed to continue to 2030 in the model, but it will likely expire at the end of 2008 and not be renewed. This is not expected to change the results of this study significantly because of the small role that biodiesel plays compared to other fuels.

Country/ region	Gasoline tax (2006$/gal)	2010 biofuel tax exemption	Ethanol tariff	Other
Australia	1.40	100%	90 ¢/gal	
Canada	0.25	100%	20 ¢/gal	
China	0.15	100%	0	
Central and S America	0.70	50%	27 ¢/gal	Subsidy for hydrous ethanol and flexible fuel vehicles. Brazil blending requirement of 20-25%
Europe	2.80	90%	90 ¢/gal	5.5 % market share in 2010, 10% market share in 2020
India	1.90	0%	200%	
Japan	1.85	90%	17%	500 million liters gasoline equivalent by 2010
S Korea	3.00	90%	0	
USA	0.42	51 ¢/gal	54 ¢/gal	36 B gal of renewable fuels[25] by 2022. A declining $1.01 per gal[26] cellulosic biofuel credit is modeled until cellulosic biofuels become cost competitive with corn ethanol.

Table 4: Biofuels policies in key countries and regions in the ETP model[27]

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[25] As defined in EISA.

[26] This is extrapolated from a provision of the Food, Conservation, and Energy Act of 2008.

[27] Biofuels mandates and incentives continue to change around the world. This study attempted to use the most recent policies possible.

Feedstock Assessment Results

The supply curves generated by ORNL for each country, feedstock, time period, and growth case replaced point estimates for supply and price in ETP. Table 2 (in the Methodology section of this report) lists the feedstocks studied. As an example, Figure 4 shows the cost and production potential of sugarcane in Brazil in 2017 in the baseline growth case. Historic production trends and the structure of average production costs were analyzed by state (or province) to develop supply curves for each selected crop-country combination. Future supply was projected for 2012, 2017, and 2027 based on compound growth rates in yields and area harvested by state over the past seven years. The methodology assumes that recent growth trends for yield and harvested area at a state level will continue into the future within a set of defined parameters. Additional details of the methodology as well as data and supply curves for all feedstocks considered are provided in the ORNL report (Kline et al., 2007).

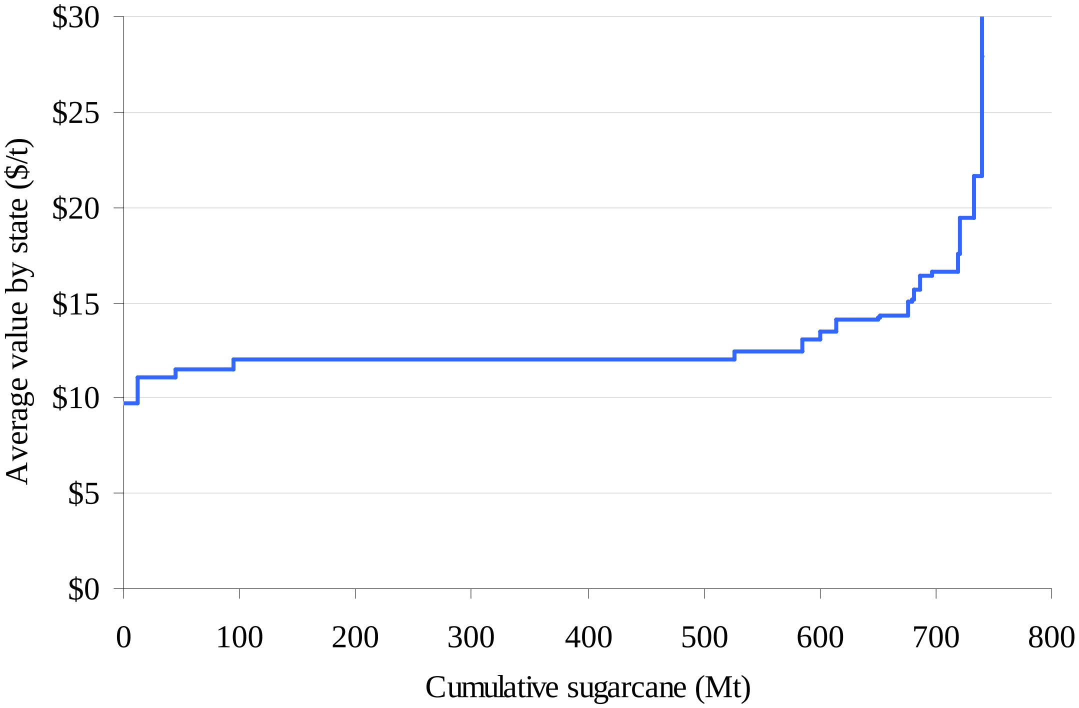

Figure 4: Supply curve example: Brazilian sugarcane in 2017 in the baseline case[28]

ORNL Study Findings

Supplies of all potential feedstock crops are expected to increase in the countries studied. Future growth in production is a result of increasing yields and expanding areas under cultivation. Feedstock growth rates vary widely, as does the portion of production available after meeting

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[28] Each step on the supply curve represents the average production cost for a state or province, while the horizontal length of the step reflects the additional supply projection for that state. Thus, any given point on the curve will represent a cumulative supply for all states producing at or below a corresponding average cost.

domestic demands for food, feed, and fiber. While one factor—the capacity to increase yields through improved crop varieties, technology, and production practices—is applicable to all feedstock crops and countries, the other factor, the capacity for expansion of area under cultivation, is limited to varying degrees across the countries studied.

Among the countries studied, Brazil has the greatest potential for expanded production, mostly from underutilized pasture. Much of its available, previously-cleared, and underutilized land is ideal for rain-fed sugarcane production. Argentina and Colombia also have relatively large amounts of underutilized arable land, along with capital and agricultural production technology which could enable them to quickly respond to policies and market signals for production. Figure 5 presents the 2017 projected available supply for export or biofuel use by feedstock in ethanol equivalent units, while Figure 6 presents similar data by country.

Sugarcane and soybeans provide more than 80% of the crop feedstock potential in the 2017 baseline case. The total crop feedstock potential is slightly smaller than the cellulosic feedstock potential in the 2017 baseline case[29]; however, there is greater uncertainty in the cellulosic feedstock potential compared to that of conventional feedstocks.

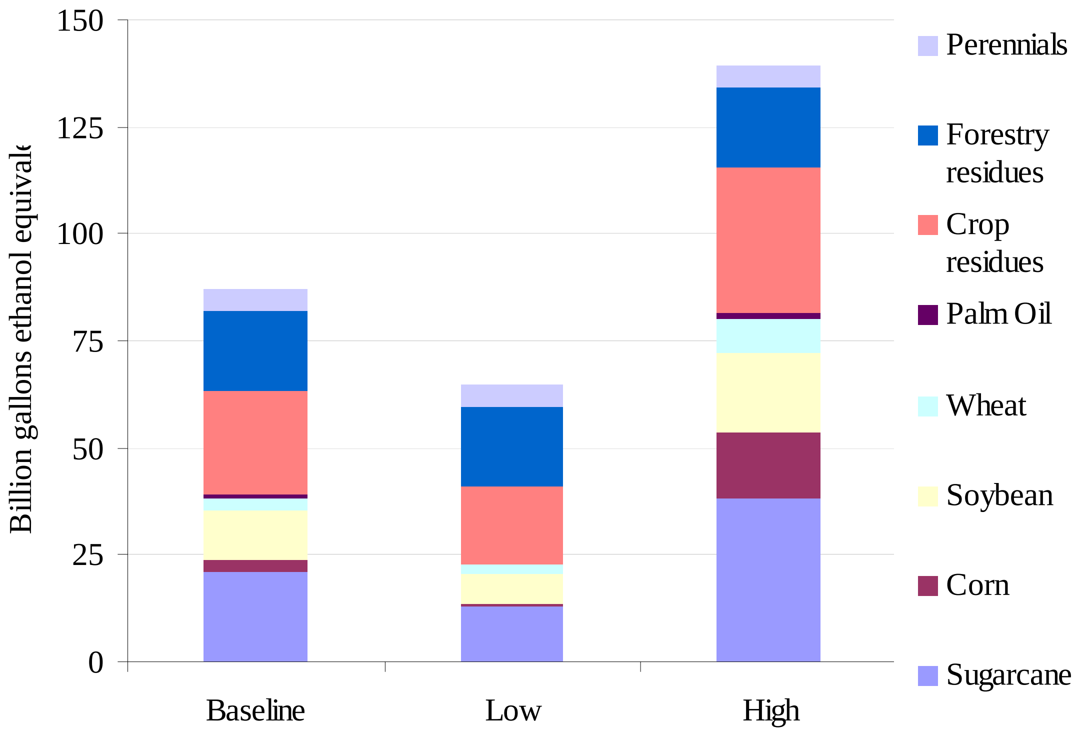

Figure 5: Feedstock available for export or use in biofuel production by source in 2017 in countries analyzed

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[29] This represents total projected cellulosic supplies converted at a rate of 60 gal per dry t.

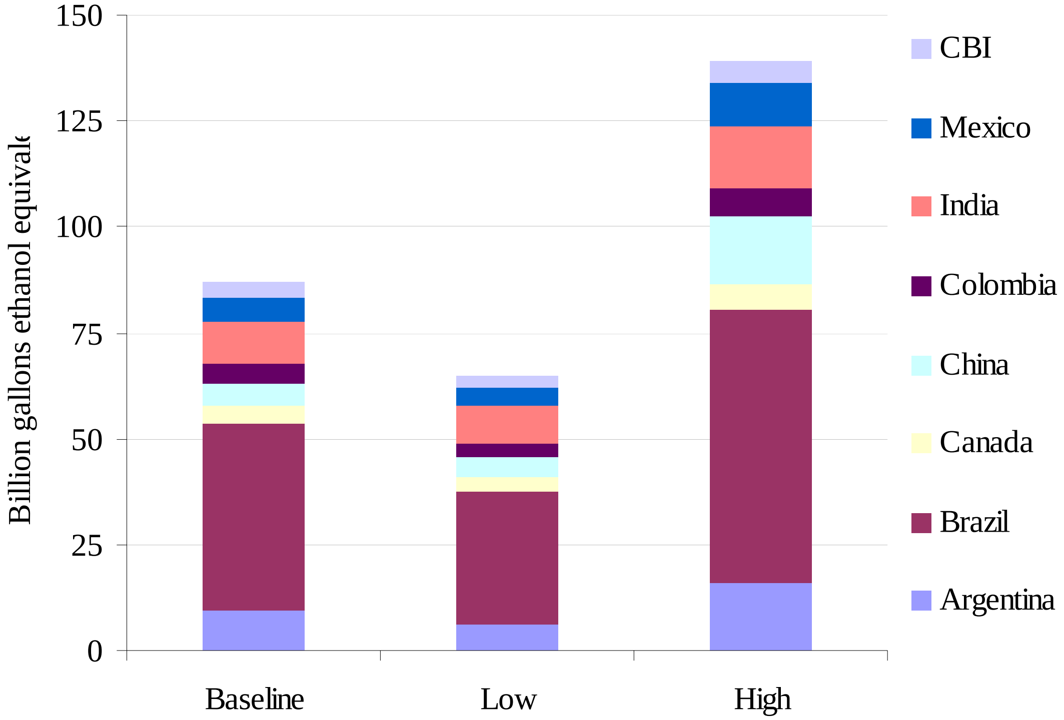

Figure 6: Feedstock available for export or use in biofuel production by country in 2017[30]

Conventional Feedstocks

Sugarcane production history and projections are presented in Figure 7. Other crops are presented in the report by Kline et al. Sugarcane output in the countries studied could grow from 999 million tonnes (Mt) in 2006 to about 1,460 Mt in 2017 and nearly 2,000 Mt by 2027 in the baseline[31] case. In the high growth case supplies could more than double by 2017, exceeding 2,000 Mt - ten years earlier than in the baseline case. Of current, widely cultivated crops, sugarcane has the highest yield of ethanol at the lowest cost and it represents over half of potential future supply available for export to global markets and/or conversion to ethanol over the next two decades. Growth in sugarcane production is led by Brazil where, compared to 2006 production, supply is projected to increase by 75% by 2017 in the baseline case and more than 130% in the high growth case. While Colombia and some CBI countries are expected to have similarly high growth rates in percentage terms, their total available supplies are small relative to those in Brazil.

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[30] Since the rate of conversion to fuel (gal per t) varies widely among feedstock types, it is preferable to make any aggregate comparisons in terms of a common energy equivalent. Conversion rates assumed for each feedstock in gal per dry t are 18.2 for sugarcane; 52 for soybeans; 76 for corn; 63 for wheat; 280 for palm oil; and, 60 gal per dry t for cellulosic feedstocks. These conversion rates will vary from the results of the NREL study and those used in the ETP model.

[31] The feedstock assessment's baseline case is defined in the Introduction Section of Kline, 2007.

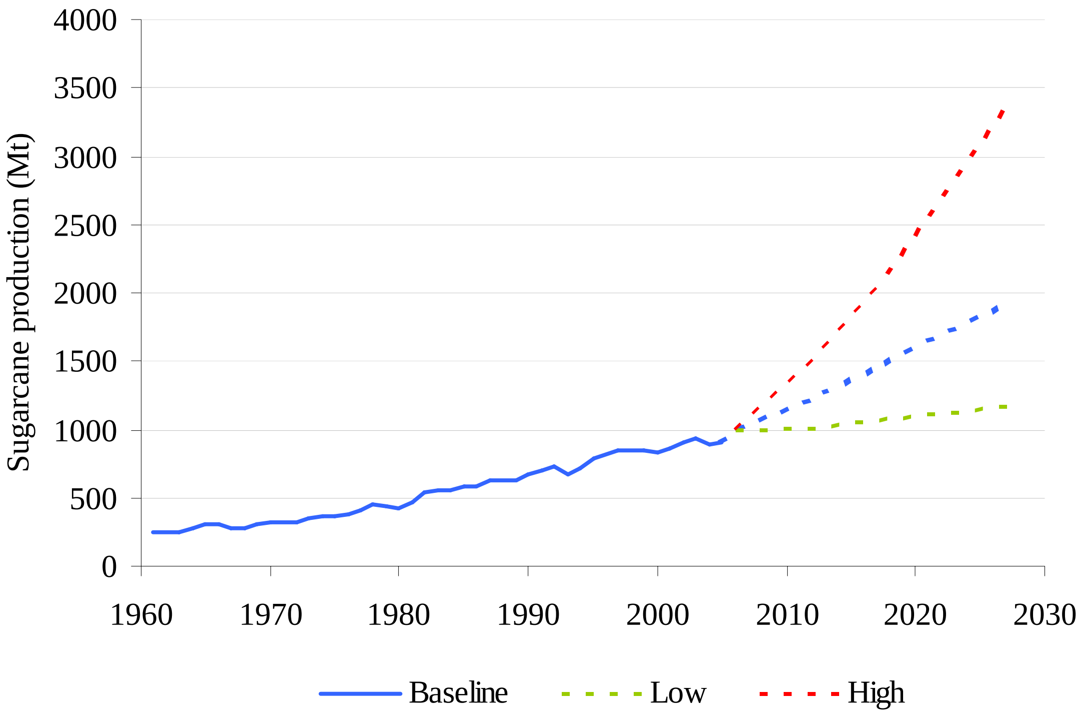

Figure 7: Actual and projected sugarcane production; total aggregate supply from countries studied

The amount of sugarcane available for export or conversion to biofuels is only about half of the total supply because of its dual use as food sugar. Brazil is able to export more than three-quarters of its much larger production amounts while the CBI exports around half of its supply. Other countries export smaller shares of their production. In the baseline case, Brazil provides 86% of a total global projected available supply of 706 Mt, while CBI provides 6%, India 3%, and the other countries studied less than 2%. In the low growth scenarios, only Brazil and CBI are projected to have significant supply available for export or biofuel production, whereas in the high growth case, all sugarcane producing countries studied could contribute to biofuel supplies in the global market. Further, in the model it is assumed that Brazil, the country with an abundance of sugarcane feedstock, uses 60% of the sugarcane for fuel and 40% for sugar production. The only exception is in the high feedstock and increased Brazilian sugar ethanol scenarios where this ratio is 70 to 30. These cases (discussed in the report by Alfstad) assume that food sugar demand will grow more slowly than biofuel sugar demand, and that increasing sugarcane production will allow a larger share to be used for biofuels. Sugarcane production is restricted by climate and soils to certain geographic areas, which is why Argentina, Canada, and the U.S. are not major producers. Brazil, by contrast, has available land suitable for sugarcane estimated at several times greater than the present land area used for this crop.

Soybeans have the second highest production potential of the feedstocks studied in the selected countries, particularly in Argentina, Brazil, and China. The baseline case estimate for total soybean production in the selected countries shows a rapid increase from 2006 levels of about 108 Mt to more than 200 Mt in 2017 – an 87% increase. The other 2017 estimates range from 147 Mt in the low growth case to 288 Mt in the high growth case. Most of the increase is in Brazil and Argentina, the world's two top exporters of soybeans and soy products, respectively.

Given relatively limited domestic demand for soy in these countries, most of the increased production in these countries will be available for export markets and/or biofuel production.

Corn production is projected to increase steadily in the five countries in this study that grow it (Argentina, Brazil, Canada, China, and Mexico). Corn output is projected to increase in the baseline case by 39% from 2006 to 2017, less than the increase for sugarcane or soybeans. Furthermore, after domestic demand for food and feed is accounted for, only a small amount of projected corn production is expected to be available for export or biofuel production; about 7% in the baseline case and 1-2% in the low growth case. Of the countries studied only Canada is likely to use corn as a primary ethanol feedstock.

Wheat output in the three countries studied (Argentina, China, and Canada) is projected to grow even more slowly than corn. The baseline case's growth of about 10% from 2006 to 2017 is similar to worldwide growth in recent years with declining or stagnant production in the nations studied due to poor weather, low relative prices, and government policies. The high growth case's growth rate is more in line with rates for other feedstocks, with potential for supply to increase by as much as 43% above 2006 levels. Thus the low to high range by 2017 is 136 Mt to 208 Mt. The historical supply from these three countries represents only about 27% of global, non-U.S. wheat production, but the factors that affect these countries' growth also affect other producers so this fraction stays relatively constant.

Wheat is primarily grown as a food staple and it has seen very limited use as a biofuel feedstock to date. An exception is in the western provinces of Canada where about 9% of the national supply of wheat could be used for ethanol by 2012 in the baseline case. Canadian wheat ethanol plants benefit from the availability of low cost, lower quality (downgraded) varieties of feed wheat that might otherwise go to waste. The majority (72% in 2006) of the wheat supply in the countries studied comes from China, where a policy against making biofuels from food is likely to prevent any future ethanol production from wheat there.

Palm oil is by far the most rapidly growing biofuel feedstock in this study, though the share of total supply from the countries studied (Colombia and CBI region) is small relative to other feedstock crops. By 2017, palm oil production in Colombia and CBI is projected to increase by 150% over 2006 levels in the baseline case, and by as much as 250% in the high growth case.

Cellulosic Feedstocks

Cellulosic feedstock can be derived from three broad categories of resources including:

1. Recoverable residues from field or plant processing operations, where availability can be calculated from the projected feedstock crop supplies in this study
2. Waste and biomass associated with current forestry and fuel wood supply activities
3. Potential dedicated energy crops – perennials which can be harvested regularly once established. The output of such biomass crops is a function of the estimated productivity of the species and arable land availability.

Given the scarcity of data for the latter two categories, the projections for the countries studied are very preliminary. Estimated cellulosic feedstock availability within the range of costs assumed in the study (generally under $100 per dry t) sum to 488 Mt, with just over half of this total derived from crop processing residues, primarily bagasse. Sugarcane-ethanol and palm oil biodiesel are the two fastest growing biofuel sectors identified in the study and their on-site endowments of low or no cost biomass wastes could facilitate the transition to cellulosic-based production with relative ease in the future.

Bagasse – the crushed stalk residue from sugarcane processing – is by far the most important single cellulosic resource identified for the countries studied, representing about 75% of all available agricultural crop residues in 2017 and about 40% of total cellulosic supplies estimated in that year. More importantly for a cost minimizing analysis, bagasse accounts for 78% of the low-cost cellulosic supply (241 Mt) that costs less than U.S.$36 per dry t (2017 baseline case). This is because bagasse is readily available at sugar-ethanol refineries and therefore (along with similarly available but smaller supplies of palm oil processing wastes and on-site wood mill residues).

The fact that a waste product such as bagasse costs anything is due to the fact that its use as a biofuel feedstock is a lost opportunity for its use as a fuel (direct combustion for process heat and/or electricity) and as a fiber. Most bagasse is currently burned as boiler fuel for sugar processing, but the expected steady increase in efficiencies of boilers over the coming decade means that an increasing portion of bagasse may be allocated to other uses, including biofuel, at an even lower cost. The use of bagasse for ethanol will also contribute to improving sugar-ethanol plant profitability.

Palm plant residue – As with sugar ethanol plants, palm oil processing plants already generate substantial cellulosic waste. With palm, however, the cost as a feedstock is likely low or even negative as the residue has a volume of 1-2 times palm oil output. Palm plant wastes already far exceed thermal process needs and even present disposal costs, making them ideal candidates as a biofuel feedstock. However, palm wastes do not contribute significantly to the biofuel feedstock potential of the countries included in this study. This resource would be more important to consider in other countries with significant palm production, for instance in Southeast Asia.

Other Cellulosic Supplies – Estimated costs for other cellulosic supplies vary significantly depending on assumptions related to productivity and collection and transportation costs. These other feedstock supplies generally have estimated average prices above $36/dry t. These include sustainable recovery of

- corn stover;
- wheat straw;
- fuelwood;
- wastes associated with industrial forestry; and
- perennials[32] – dedicated energy crops harvested for biofuel.

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[32] Brazil, Colombia and Argentina represent about 90% of the total estimated perennial supplies, illustrating the differences in relative scale amongst the countries studied.

Conversion Processes and Fuel Types

NREL developed a complete set of plant gate price curves for each conversion technology in each country in the study (Bain, 2007). Table 5 describes the range of technologies and fuels integrated into the ETP model using results from the NREL study, as well as Fischer-Tropsch synthesis costs already in the ETP model.

Source	Feedstock	Conversion	Product	Distribution/Consumption
Sugarcane	Sugar	Sugar-ethanol	Ethanol	• New distribution infrastructure required • Consumption limited to E10 for most of existing U.S. vehicle fleet • Higher blends (i.e. E85) can be used in a currently small portion of the U.S. fleet
Corn	Starch	Dry mill		
Wheat				
Bagasse/other agricultural residue	Cellulose	Biochemical conversion		
Forestry residues		Thermochemical conversion		
Energy crops		Fischer-Tropsch synthesis	Distillates, naphtha	• Products are refining feedstocks • Compatible with conventional fuel
Oil palm	Oil	Transesterificiation	Biomass-based diesel (fatty acid methyl esters)	• Can be blended with diesel at high ratios in most areas of the U.S.
Soybean				

Table 5: Biofuels conversion processes included in the analysis

NREL Study Findings

For biofuels derived from crops, feedstock cost is generally the largest piece of the plant gate price and shows the most variation among countries, while capital and non-feed operating costs show little variation among countries (Figure 8). For the more complex and capital intensive cellulosic conversion technology, capital and operating costs are proportionately larger, but feedstock costs may still be an important factor in determining cost-effectiveness. A comparison of thermochemical[33] cellulosic ethanol plant gate prices is presented in Figure 9.

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[33] Ethanol by thermochemical conversion is not explicitly separated from ethanol by biochemical conversion in the ETP model because the costs are similar and both produce ethanol.

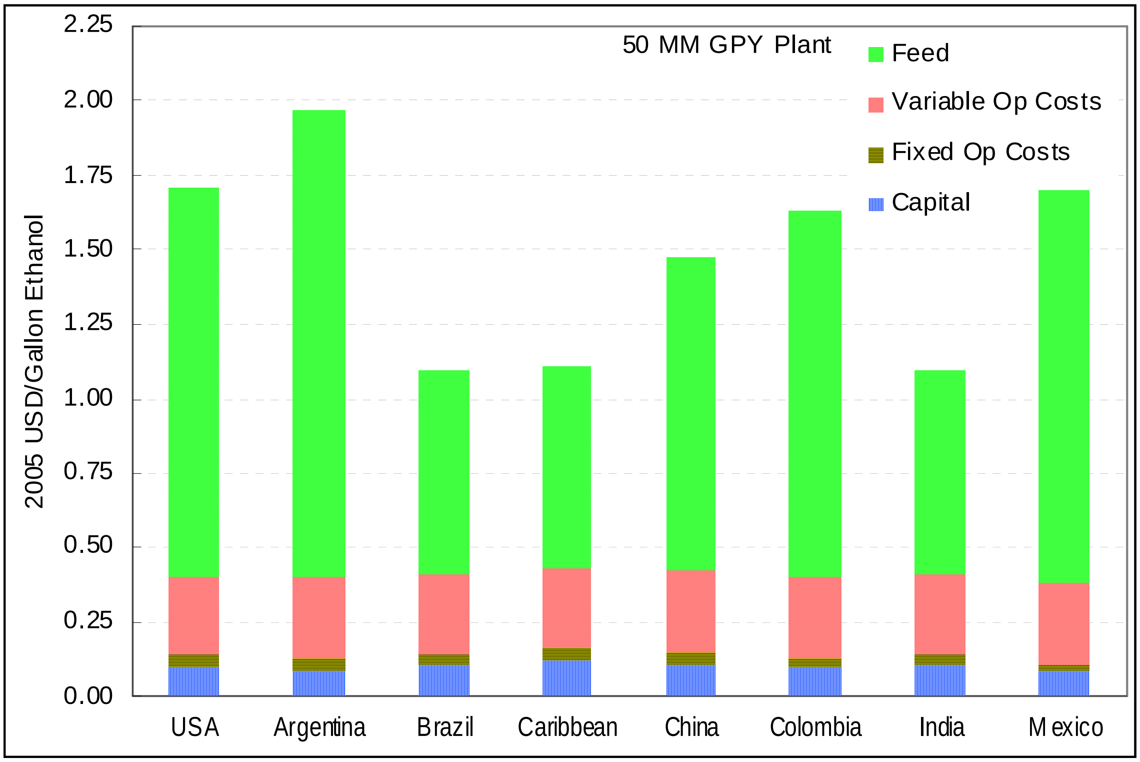

Figure 8: Comparison of sugar cane ethanol plant gate prices[34] (Bain, 2007)

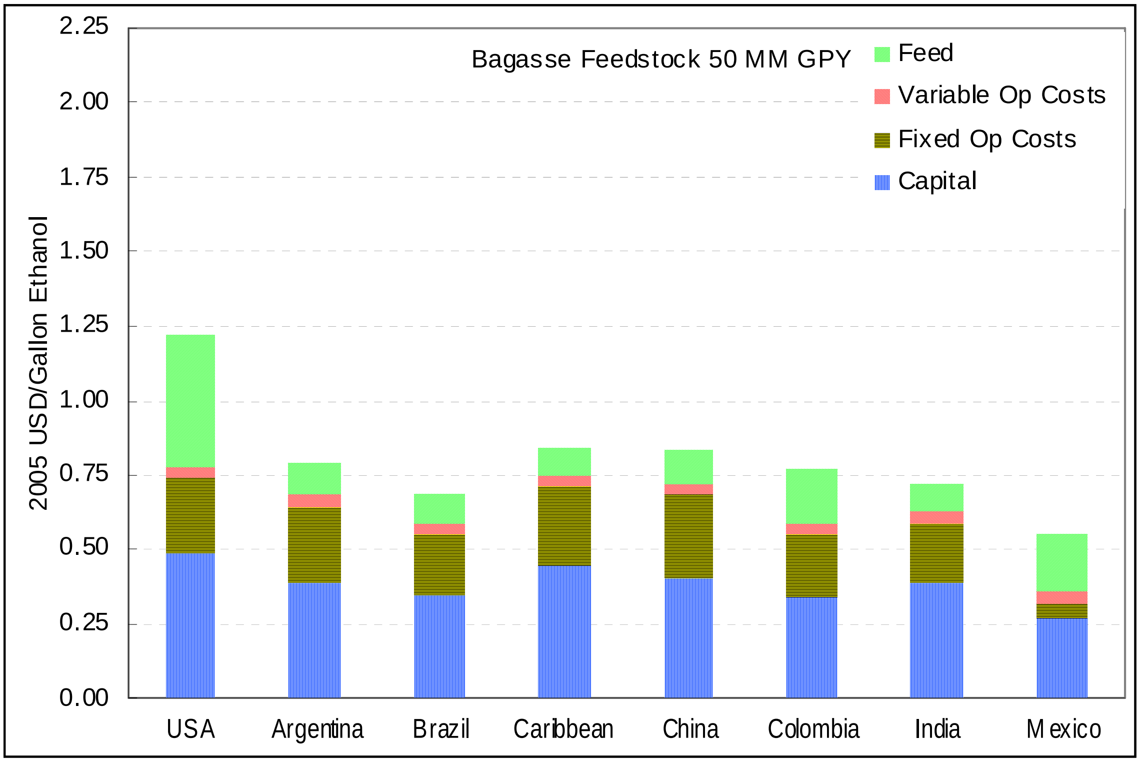

Figure 9: Comparison of thermochemical cellulosic ethanol plant gate prices (Bain, 2007)

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[34] Feedstock price is assume to be at 50% of the 2017 potential supply curve or the single point value if a supply curve is not available.

Results and Discussion of Scenarios

The following results are intended to inform the biofuels policy debate by exploring the dynamics of the biofuels market and the relative impact of various policy and market uncertainties. This study is not intended as a forecast of future biofuels supply. The ETP model solves in five-year time periods; therefore, projections for 2022 are inferred from model results for 2020 and 2025. Detailed results are available in the BNL report (Alfstad, 2008).

World Biofuels Supply

Worldwide, we project 54 billion (B) gallons (gal)[35] of ethanol-equivalent biofuels production in 2020 and 83 B gal in 2030 as shown in Figure 10. The 2020 production projection is a four-fold increase over 2005. In all of the model years, biofuels from the U.S. and Brazil account for more than half of world production. For the range of production in each model year, the high value represents a scenario with high feedstock availability combined with a high oil price, and the lower value represents a scenario with low feedstock availability combined with a low oil price.

Consumption of biofuels worldwide is dominated by the U.S., surpassing half of worldwide consumption by 2015 and growing by almost 10% per year from 2005 to reach a ten-fold increase by 2030 (Figure 11). Western Europe is the second largest consumer of biofuels, followed by Central and South America as a region. Brazil is a net exporter of biofuels and Chinese and Indian consumption is relatively small because their biofuels targets are assumed to not be met.

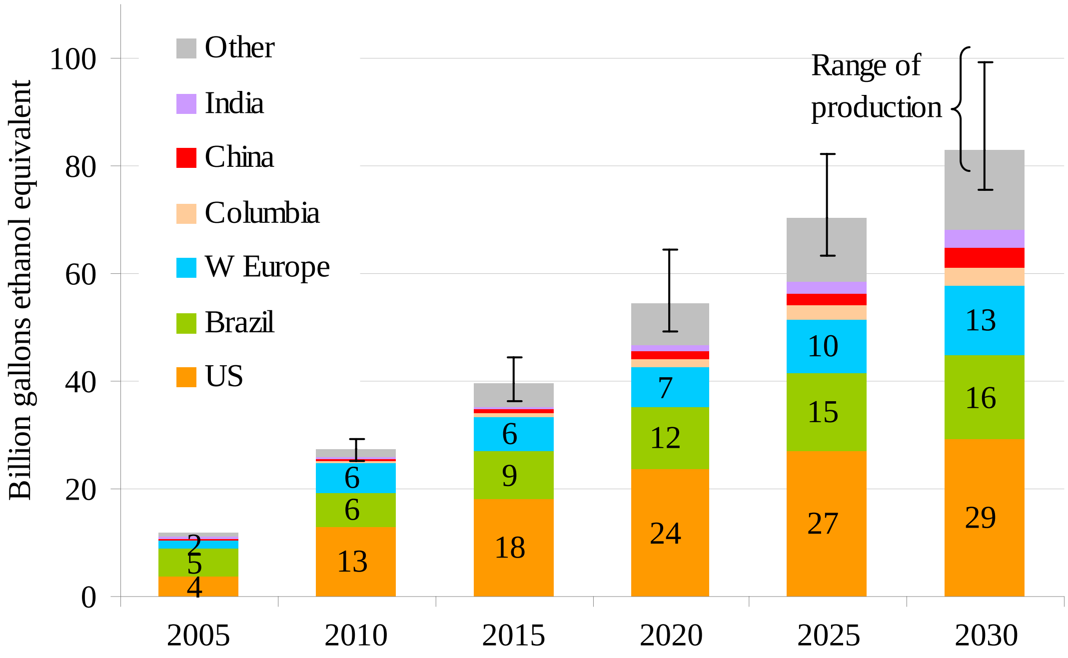

Figure 10: World biofuels production by country in the reference scenario

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[35] The model results throughout this discussion are presented in ethanol equivalent volumes.

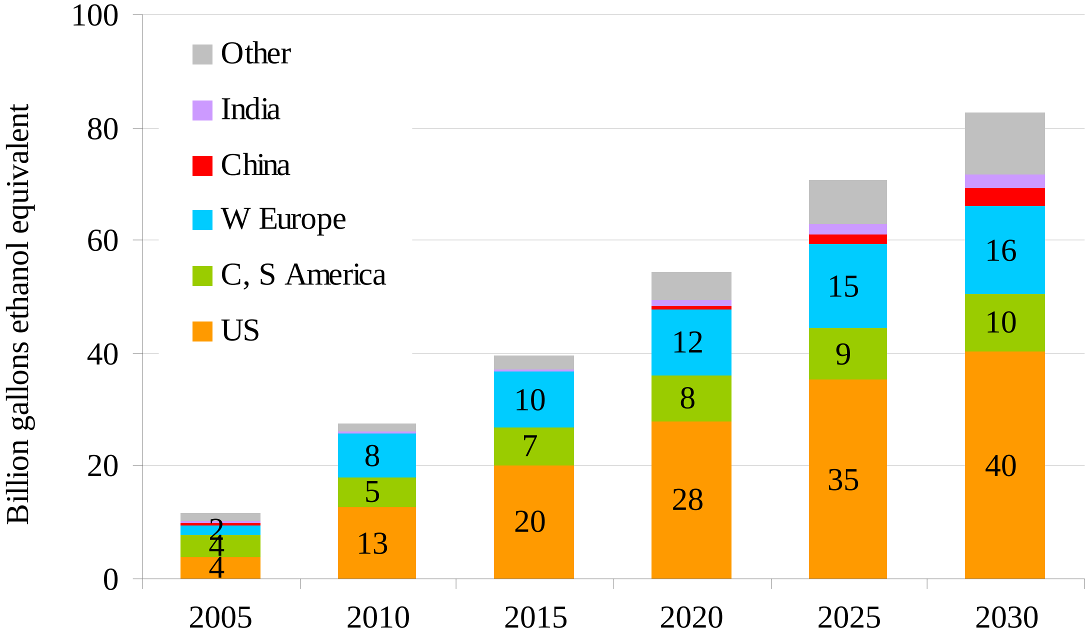

Figure 11: World biofuels consumption by country in the reference scenario

Grain and sugar-based ethanol dominate world biofuels production until 2020 when cellulosic biofuels begin to grow significantly in share (Figure 12). More than 75% of grain ethanol production occurs in the U.S., accounting for 15 B gal of the world production of 19 B gal (79%) in 2015; however, grain production levels off and declines by 2030 mainly due advanced renewable fuel requirements in the EISA RFS. Brazil is projected to maintain a greater than 80% market share of sugar ethanol production through 2030.

While domestic consumption is significant in Brazil, the country is capable of producing large volumes to satisfy world demand. Under the high feedstock availability scenario, Brazil can increase sugar ethanol production in 2020 from almost 10 B gal in the reference to over 16 B gal (Figure 13). While Brazilian sugar ethanol can satisfy the 4 B gal of the U.S. RFS advanced biofuels requirement that need not be biomass-based diesel fuel or cellulosic biofuels by 2022, if Brazil is to export larger volumes of fuel to the U.S. it will have to develop cellulosic biofuels production. Because of the ready supply of bagasse associated with sugar ethanol production, Brazil is well positioned to provide low-cost cellulosic biofuels, especially in light of the U.S. RFS requirement of 16 B gal per year of cellulosic biofuels by 2022. For this reason, Brazil and other countries will have a high incentive to invest in second-generation technologies to convert bagasse or other cellulosic feedstocks to biofuels.

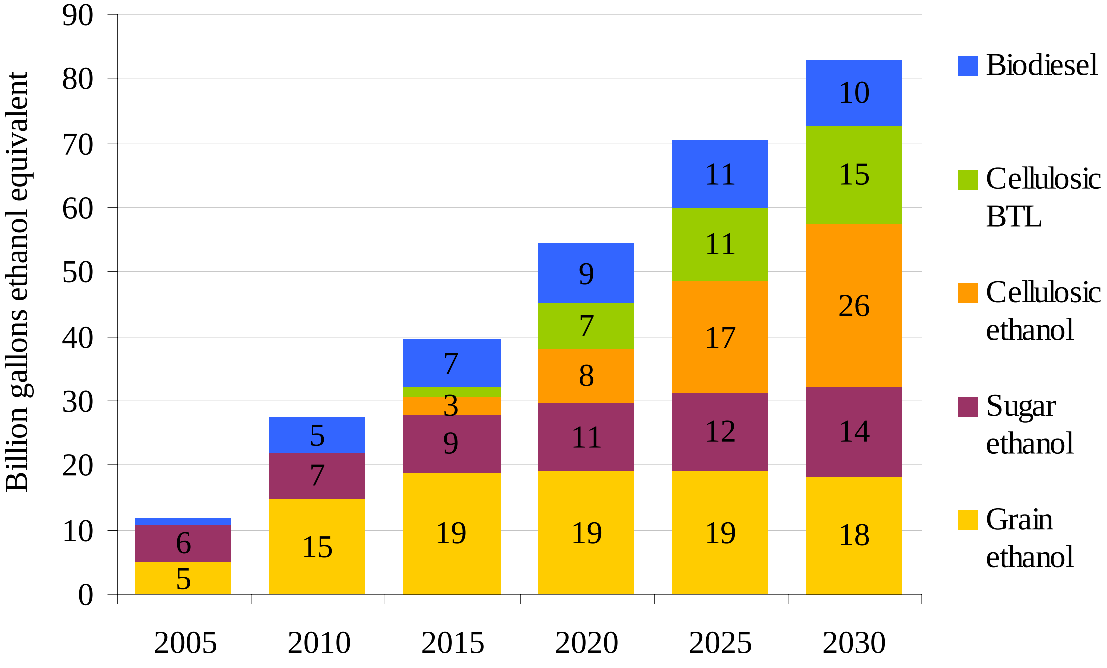

Figure 12: Total biofuels production by type in the reference scenario

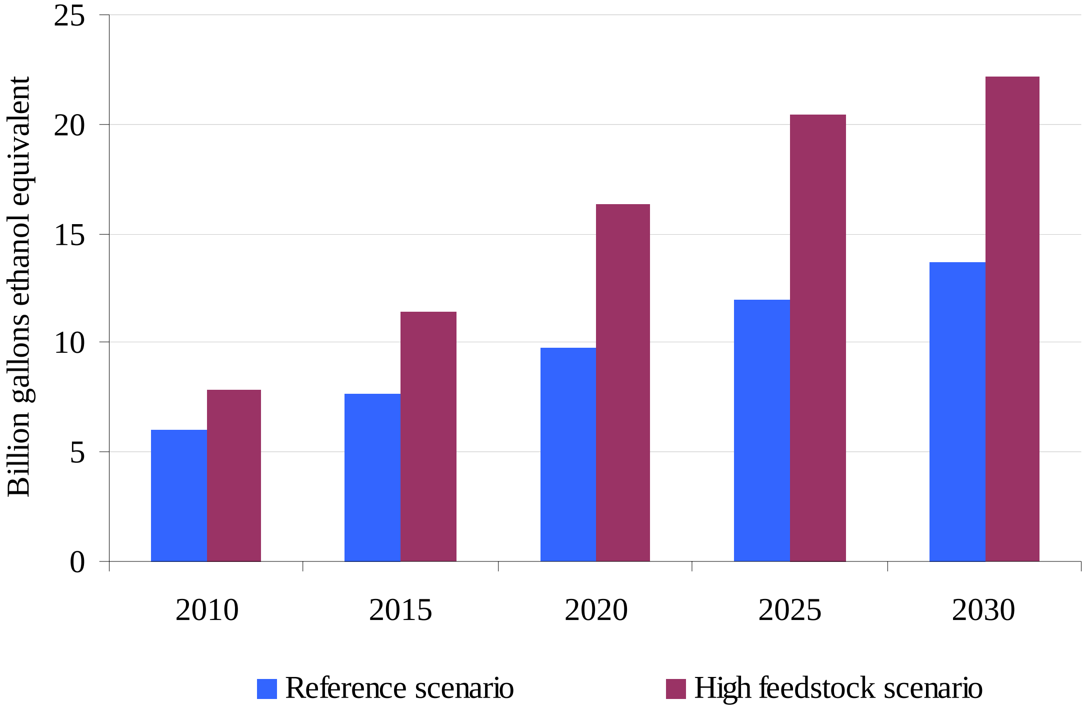

Figure 13: Brazilian ethanol production in the reference and high feedstock scenarios

Cellulosic biofuels are estimated to play an increasingly crucial role in meeting world demand for renewable transportation fuels. In the model, cellulosic feedstocks can produce ethanol via bio-chemical conversion as well as BTL via Fisher Tropsch catalysis. They are driven in particular by cellulosic advanced renewable fuel mandates in the U.S. RFS of 10.5 B gal by 2020, reaching 16 B gal in 2022. As a result of the demand set by this mandate, cellulosic ethanol production steadily increases in volume from the time the technology is adopted in the 2010-2015 timeframe and exhibits an average annual growth rate of almost 16% between 2015 and 2030 (Figure 12). With the demand created for cellulosic biofuels under the U.S. RFS, a significant portion of total biofuels supply in the latter years (2020-2030) is met through cellulosic technology. In 2030 more than 40 B gal of cellulosic biofuels (49% of total biofuel supply) are produced through either biochemical or Fischer-Tropsch BTL conversion. While more than 30% of cellulosic biofuel production occurs in the U.S. from 2015 onwards, there is also a substantial amount produced in countries that have an abundance of cellulosic feedstocks (such as Brazil). Investments in the U.S. (such as the tax credit in the 2008 Farm bill) to bring this technology to the marketplace leads to technology learning that can be transferred throughout the world.

Biodiesel is also an important component of world biofuel supply and increases to 10 B gal by 2030. A major portion of this is used in European countries where subsidies are the highest (Table 4).

U.S. Biofuels Supply

The main driver impacting biofuels supply in the U.S. is the EISA RFS requirement. The EISA RFS has specific mandates for each type of biofuel: renewable fuels, advanced renewable fuels, cellulosic advanced renewable fuels, and biodiesel advanced renewable fuels (described in Appendix B). Corn and wheat ethanol are assumed to qualify as renewable fuels and sugar ethanol is assumed to qualify as an advanced renewable fuel. Both cellulosic ethanol and cellulosic BTL are assumed to qualify as cellulosic advanced renewable fuels.

In the reference case, total U.S. biofuel supply undergoes significant growth to reach 28 B gal in 2020 and 35 B gal in 2025; however, this is less than the RFS requirement of 30 B gal in 2020 and 36 B gal in 2022 (Figure 14) with shortfalls in each of the biofuels categories except biodiesel and renewable fuel (e.g. corn ethanol). The EIA has also projected the impact of the new RFS on U.S. biofuels supply in its 2008 AEO. The AEO projects the RFS will not be met. It assumes that the U.S. Environmental Protection Agency exercises its authority to lower the mandate as necessary.

This study differs from the AEO in that it projects higher levels of biofuels supply in the U.S. due to more imports, reaching more than 35 B gal in 2025, whereas the AEO projects only 32.5 B gal by that year. The differences in these two models arise from two major underlying assumptions – the potential for other countries to export biofuels to the U.S. and the costs and availability of cellulosic biofuels. First, this study focused on an in-depth analysis of the feedstock potential of biofuels exporting countries. Therefore, our results show a much larger supply of sugar ethanol (mostly from Brazil) in U.S. biofuels supply (Figure 14) compared to the AEO. Second, the AEO assumes that the cellulosic technology is adopted at a much slower pace due to higher capital costs, whereas this study includes a cellulosic production tax credit similar to the Farm Bill provision[36] that reduces the cost of cellulosic biofuels production until it is competitive with corn ethanol production. This study also assumes that technology learning and transfer results in the availability of cellulosic technology throughout the world when economic. As a result, the cellulosic biofuels are produced in countries (such as Brazil) that have an abundance of cellulosic feedstocks and exported as cellulosic biofuels to the U.S. As expected, the AEO results show no imports of cellulosic biofuels, whereas this study shows larger volumes of cellulosic biofuels in U.S. supply when imports are added to domestic production.[37]

Various policy and market scenarios were modeled in order to understand why the U.S. may have difficulty in meeting the mandates of the new RFS.

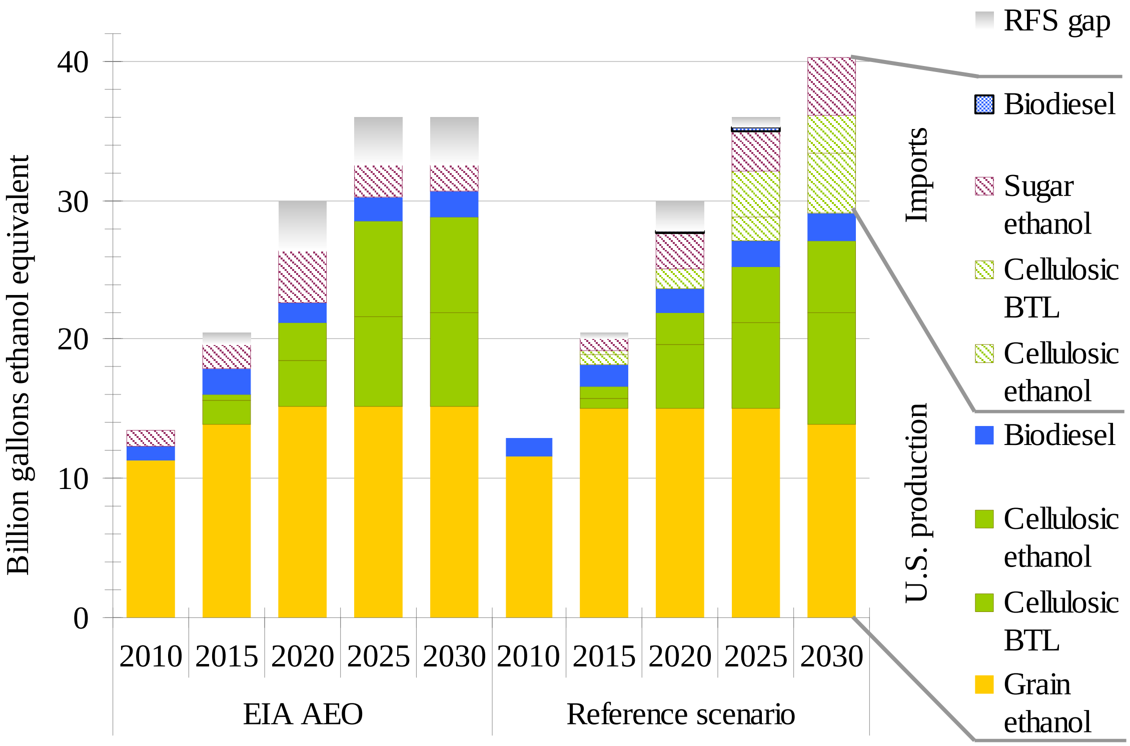

Figure 14: U.S. biofuels supply by type and source in the EIA AEO 2008 and the reference scenario

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[36] The 2008 Farm Bill refers to the The Food, Conservation, and Energy Act of 2008 (P.L.110-246) and includes a cellulosic biofuel tax credit (Sec.15321) of $1.01 per gal for cellulosic biofuel producers through 2012. This tax credit is part of a biofuel provisions package in the farm bill that includes substantial RD&D funds (including loan guarantees) as mandatory programs, and a reduction in the corn ethanol volumetric ethanol excise tax credit (VEETC).

[37] U.S. production of cellulosic biofuels in some years is slightly lower in this study compared with the AEO results due to competition with imported cellulosic biofuels, even though the total of domestic production and imports is greater in all years in this study.

Policy Scenarios

None of the policy scenarios in this study, with the exception of E20 scenario, significantly change the dynamics of biofuel production and imports to the U.S. As discussed below, the policy scenarios, with the exception of E20 scenario, have limited effect because the RFS is a strong policy in itself, ethanol faces infrastructure constraints, and feedstock demand (mainly for sugarcane) begins to operate at the inelastic regions of the supply curves.

E20 Scenario

The E20 certification scenario allows blending of up to 20% ethanol into gasoline. By assuming E20 certification, this scenario tests the hypothesis that ethanol infrastructure constraints prevent greater penetration of ethanol and attainment of the RFS. In this scenario ethanol infrastructure constraints are significantly reduced and more ethanol can be supplied to markets, allowing the U.S. to meet the mandates of the RFS. This not only leads to an increase in cellulosic and sugar ethanol but also a decrease in cellulosic BTL fuels. (Figure 15 and Figure 16)

Meeting the RFS not only requires the production of sufficient volumes of fuel with the available biomass but also the infrastructure necessary to bring this fuel to customers. Currently the U.S. blends up to 10% ethanol in gasoline. In 2020, gasoline demand is projected to reach 137 B gal (AEO, 2008) and the total ethanol required for blending in gasoline for E10 is much less that the mandated 30 B gal of biofuels under the RFS. To sell the mandated volumes retailers will need to market the excess ethanol as E85. Consuming large amounts of E85 requires dedicated infrastructure, including pipelines for transport of ethanol, fuel stations that can dispense E85, and flexible fuel vehicles to use the E85. Under an E20 scenario, these infrastructure requirements are not necessary because larger volumes of ethanol can be blended into gasoline using existing infrastructure.

Cellulosic feedstocks can be converted to synthetic distillates or naphtha via Fisher-Tropsch catalysis or ethanol via biochemical conversion. Both types of cellulosic biofuels are assumed to qualify as cellulosic advanced renewable fuels under the RFS. Cellulosic BTL fuels are more expensive than cellulosic ethanol (on an energy equivalent basis) but also more valuable because they can be refined and distributed with petroleum-based fuels in the existing pipeline infrastructure and can be used by the current fleet of light duty vehicles and trucks. Consequently, BTL fuels do not suffer from the same infrastructure constraints as E85. Suppliers (as represented in the model) will therefore prefer to meet the mandates with lower cost ethanol as long as it can be distributed at reasonably low costs. As the sales of ethanol increase, the cost of distribution goes up as the ability to expand ethanol infrastructure and sell E85 is limited. Above a certain volume of ethanol sales, the production cost advantage of cellulosic ethanol is negated by the escalation of distribution costs, and additional cellulosic biofuel supply will tend to be in the form of cellulosic BTL. These infrastructure constraints are the main reason for the significant supply of cellulosic BTL, as opposed to cellulosic ethanol only, in the reference scenario. Under the E20 scenario, infrastructure constraints on ethanol are relaxed, ethanol sustains its economic advantage over cellulosic BTL, and the mandated levels in the RFS are met. The E20 scenario is the only scenario where the RFS is met (Figure 15 andFigure 16).

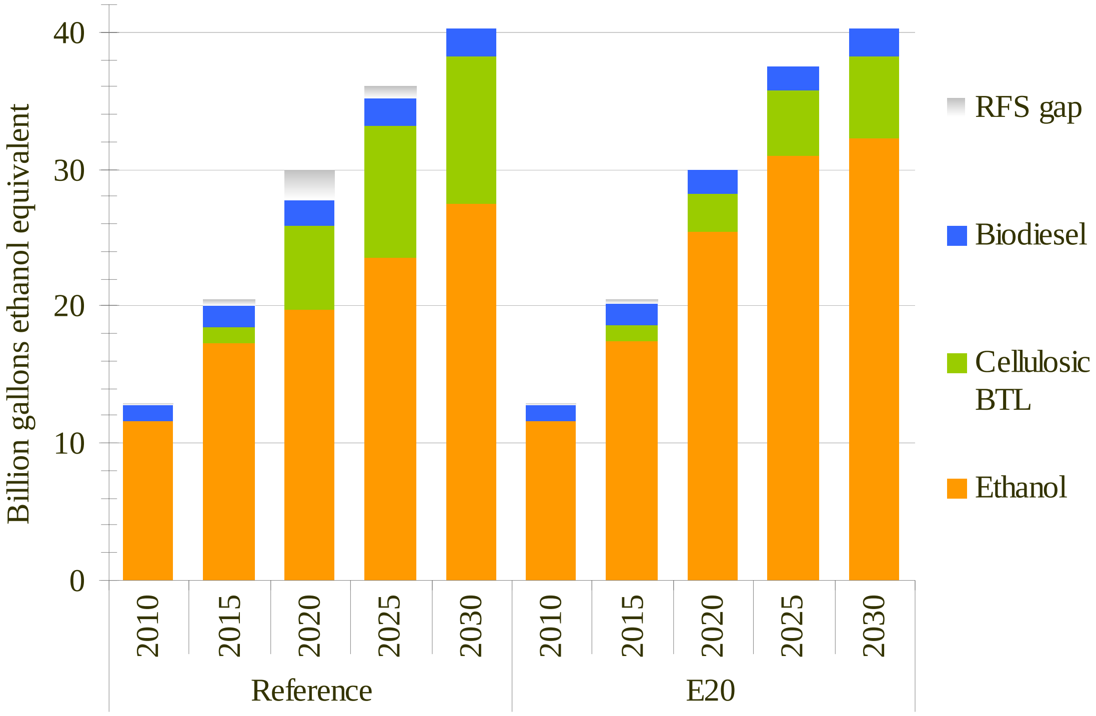
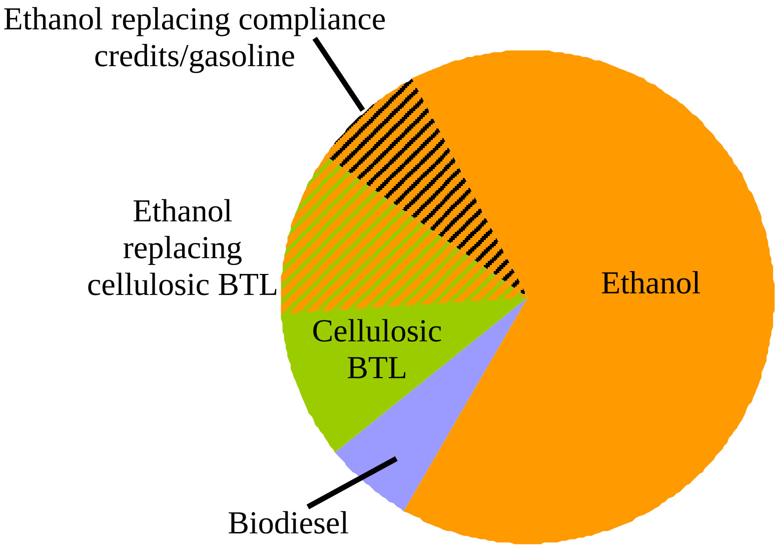


Figure 15: U.S. biofuels supply by type in the reference and E20 scenario



Total in 2020: 28 B gallons in the reference scenario
30 B gallons in the E20 scenario
30 B gallons required by the RFS

Figure 16: U.S. biofuels supply by type in 2020 in the E20 scenario

$50 per t of CO_2 Scenario

This CO_2 policy scenario assumes a global implicit price of $50 per t of CO_2 (Figure 1). Under this scenario the requirements of the RFS are met after 2025 but not by 2020 (Figure 17), because this scenario has only a moderate effect on U.S. imports. This policy tends to provide a greater incentive for domestic consumption in producing countries as opposed to production for export. This policy also provides an incentive to increase the production of cellulosic biofuels and sugar-based ethanol as these emit less lifecycle CO_2 than biofuels from grain. As a result, U.S. grain ethanol consumption is lower than in the reference scenarios. The largest increase is for U.S. imports of sugar ethanol (almost doubling in 2025 compared to the reference scenario). U.S. cellulosic ethanol production increases by 40% between the two scenarios in 2025, but it is offset by a decline in imported cellulosic ethanol. Domestic and imported cellulosic BTL show small increases of 10% on average between scenarios in 2025. By 2030, cellulosic biofuels are a much more mature technology, and combined with its fewer CO_2 emissions than sugar ethanol, cellulosic biofuels growth outpaces that of sugar ethanol (Figure 18).

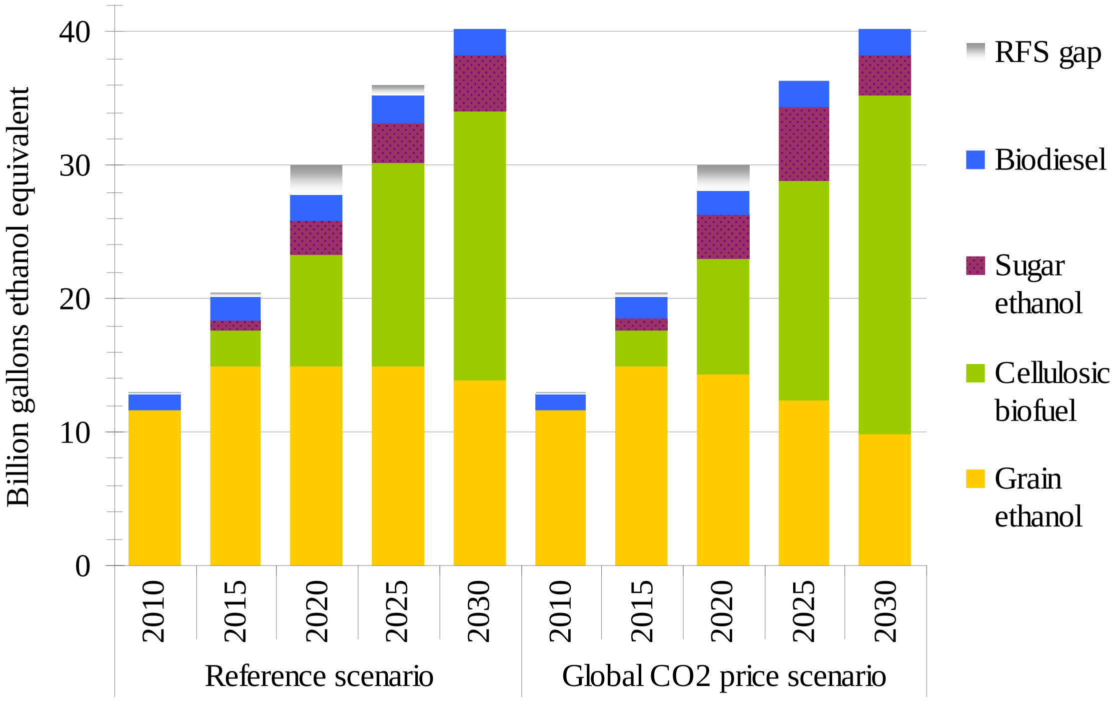


Figure 17: U.S. biofuels supply by type in the reference scenario and global CO_2 price scenario

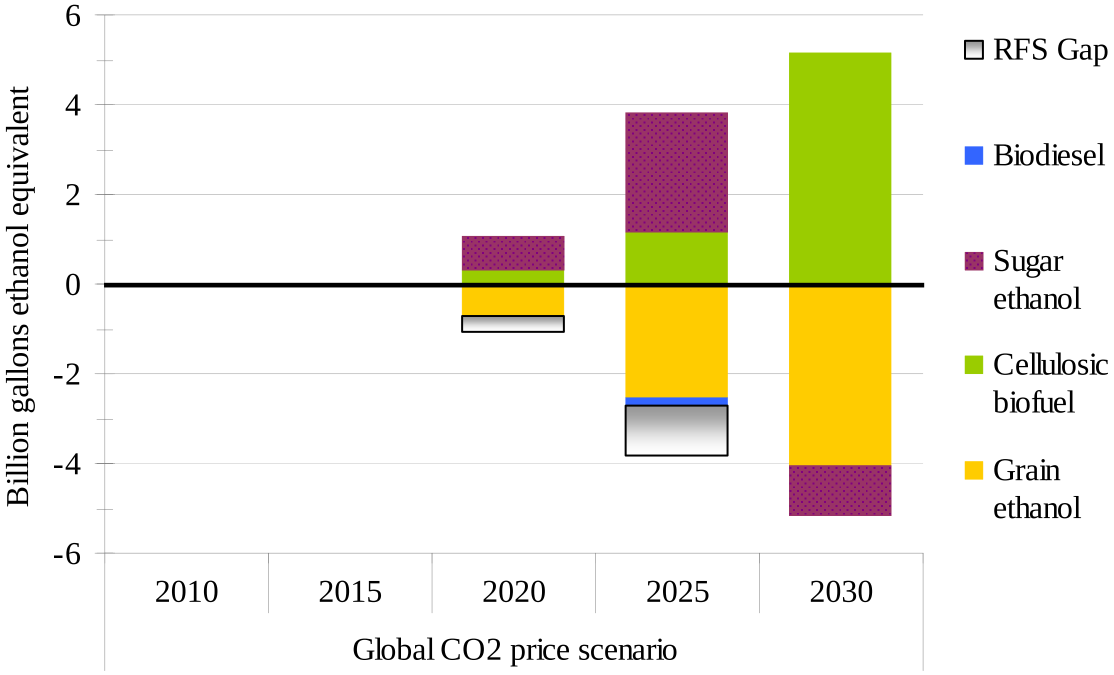


Figure 18: Change in U.S. biofuels supply by type in the global CO2 price scenario compared to the reference scenario

<u>Credit and Tariff Extension Scenario</u>

Extending both the blenders' ethanol credit and tariff has marginal benefits on overall biofuel supply. This policy protects domestic producers from foreign imports and U.S. production is boosted at the expense of foreign supply, with declines in imported sugar ethanol in 2020 and 2030[38] (Figure 19). Even on its own, the credit has limited impacts on biofuels supply and the tariff further diminishes the effect.

The blenders' ethanol credit is an incentive for a fuel that is limited by infrastructure constraints rather than poor economics. Corn ethanol production remains high and infrastructure constraints make it difficult to introduce more ethanol into the market, so the credit does not encourage significant amounts of additional cellulosic ethanol production. For corn and sugar ethanol, this scenario results in a shift in cost from consumers to taxpayers. For cellulosic ethanol, this scenario results in a transfer of funds from taxpayers to biofuel suppliers until the cellulosic advanced renewable fuel mandate in the RFS is met.

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[38] Sugar ethanol imports increase in 2025 compared to the reference scenario because domestic cellulosic biofuels are not widely available yet to meet the large increases in the RFS mandate in the 2020 to 2025 timeframe.

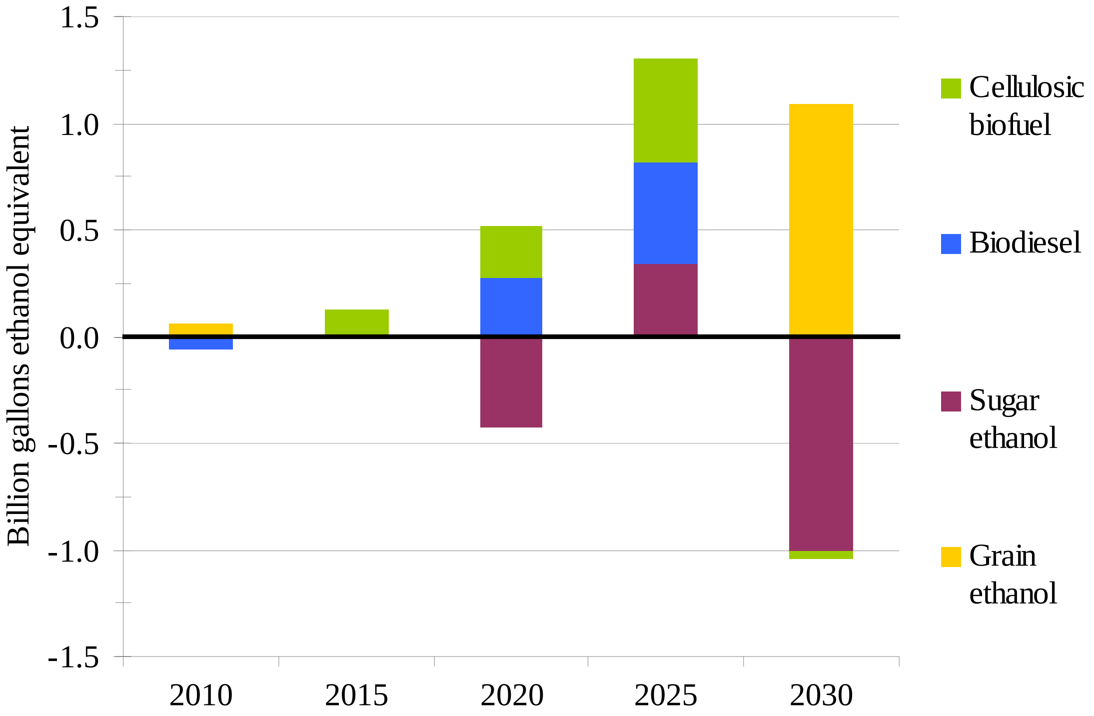

Figure 19: Change in U.S. biofuels supply by type in the blenders' credit and tariff scenario compared to the reference scenario

The RFS in itself is a strong policy so additional incentives do little to increase overall biofuels supply or cellulosic renewable fuels in particular. The main constraints for greater cellulosic biofuels production are the time needed to develop the cellulosic resource base, build production facilities, and improve the infrastructure for ethanol distribution, rather than the underlying economics. In the E20 scenario, where RFS mandates are met in 2020, E20 certification significantly reduces the ethanol distribution infrastructure constraints. The exact limitation on how quickly the infrastructure can be put in place is uncertain but is an issue that needs attention.

Market Scenarios

The market scenarios explore the market possibilities that could influence biofuels production and trade. In particular, this section explores the impact of high and low biofuels feedstock availability and high and low oil prices. Other scenarios are discussed in the BNL report (Alfstad, 2008).

High and Low Feedstock Availability

The high and low feedstock availability scenarios illustrate how sugar ethanol production in the reference scenario is mainly limited by its supply curve, where the large requirements of the RFS cause production to reach the inelastic portion of the curve preventing further growth in production at economic cost. Figure 20 illustrates how cumulative sugarcane production in Brazil in the reference scenario eventually reaches the inelastic portion of the supply curve where further increases in production result in significantly higher feedstock costs. This figure also shows how the high feedstock availability scenario relaxes this economic constraint and how the low feedstock availability scenario exacerbates it. In the high feedstock availability scenario, feedstock availability of sugar for both food and fuel is assumed to increase compared to the reference scenario and the ratio of fuel to food for Brazilian sugar application is assumed to be 70:30 compared to 60:40 in the reference scenario. As a result there are larger amounts of low-cost sugar ethanol available in world markets, along with cellulosic biofuels from the bagasse that accompanies sugar ethanol production, which displace significant amounts of domestically produced corn ethanol in the U.S. (Figure 21). The high feedstock availability scenario meets the requirements of the RFS by 2025 but not in earlier years. In the low feedstock availability scenario the opposite effect occurs; meeting the overall advanced biofuels target is much more difficult and costly (Figure 20).

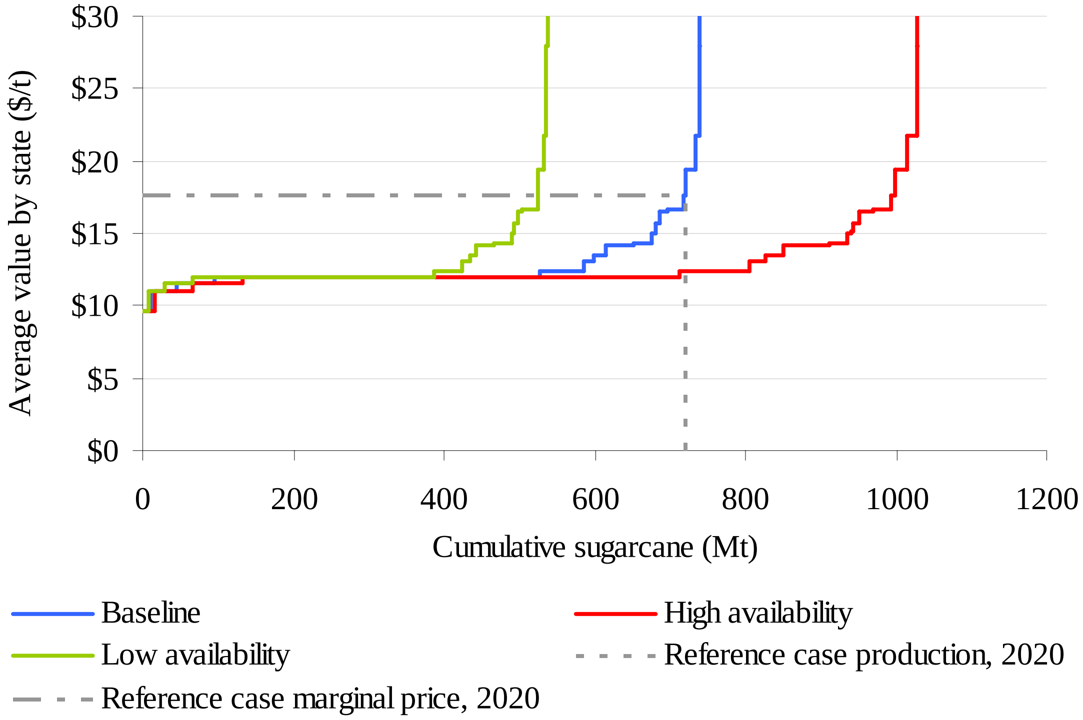

Figure 20: Brazil sugarcane feedstock supply curve in the baseline, low, and high feedstock availability cases in 2017. Superimposed is Brazilian sugar ethanol production in the reference scenario and the associated marginal price.

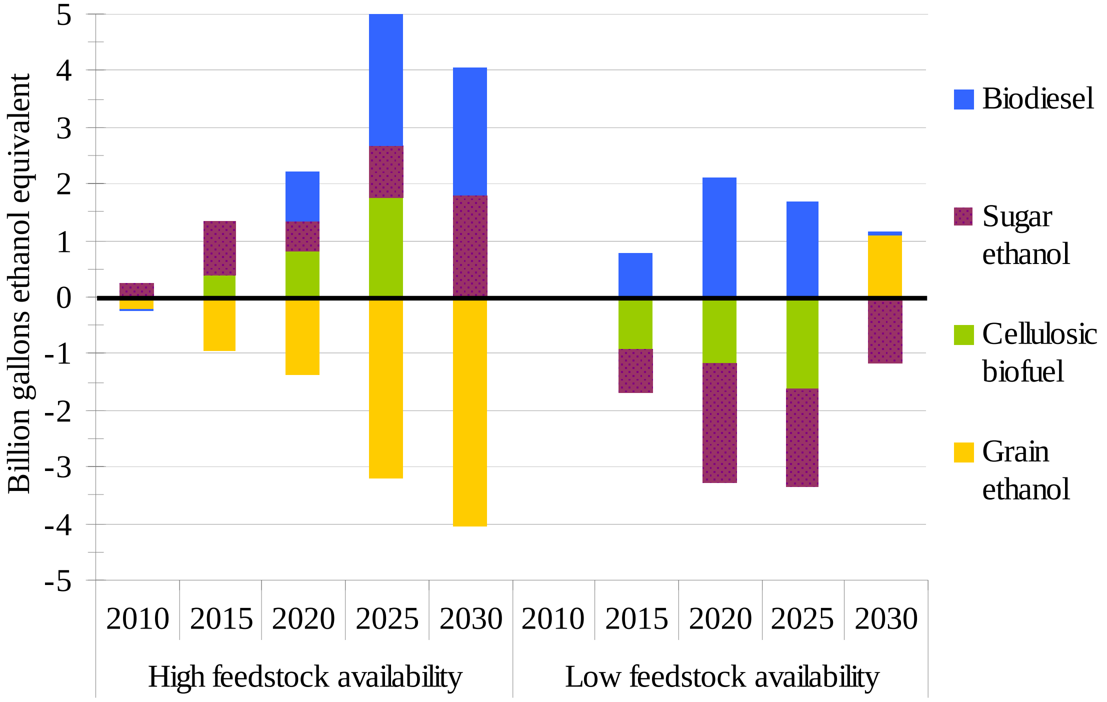

Figure 21: Change in U.S. biofuels supply by type in the high and low feedstock availability scenarios compared to the reference scenario

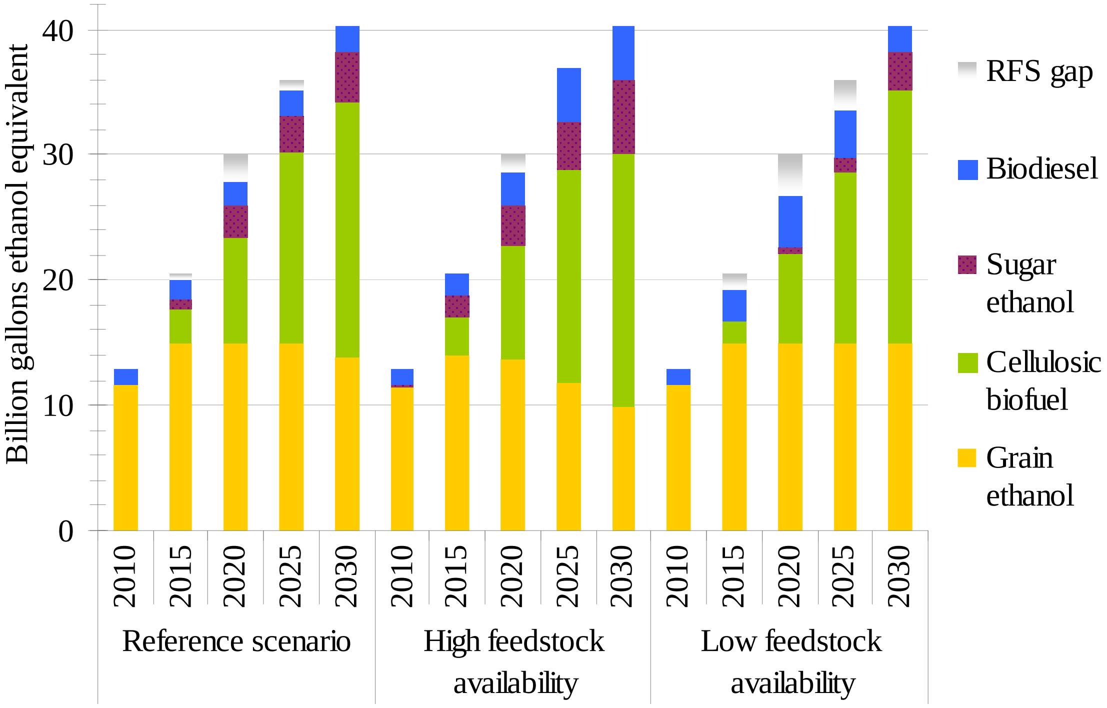

Figure 22: U.S. biofuels supply by type in the reference, high, and low feedstock availability scenarios

High and Low Oil Prices

Changes in oil prices (Figure 2) have limited impact on U.S. biofuels supply because demand volumes are fixed through policy. Since the buy-out from the cellulosic biofuels mandate adjusts to oil price and there are no relief-valve mechanisms for the other mandated volumes, U.S. biofuel demand is largely unaffected by oil prices. The law removes the risk of falling oil prices to suppliers since the credit price will adjust to keep price incentives at levels that are presumed to be sufficient to ensure supply. Conversely, it reduces credit prices in the event of rising oil prices to ensure that the industry is not taxed needlessly in an environment where price incentives for biofuel supply should be adequate. Globally, high oil prices lead to higher demand for biofuels, which become more competitive with gasoline and diesel, particularly in subsidized biofuel markets. For the high and low oil price scenarios, U.S. renewable fuel consumption does not differ significantly from the reference scenario in quantity but does differ in the types of fuel consumed (Figure 24). Since higher oil prices increase biofuels demand in countries without fixed mandates, higher prices lead to a reduction in U.S. imports of sugar ethanol and a corresponding increase in U.S. production of grain ethanol (Figure 23). Low oil prices reduce demand in other world regions, increasing the supply competing in U.S. markets.

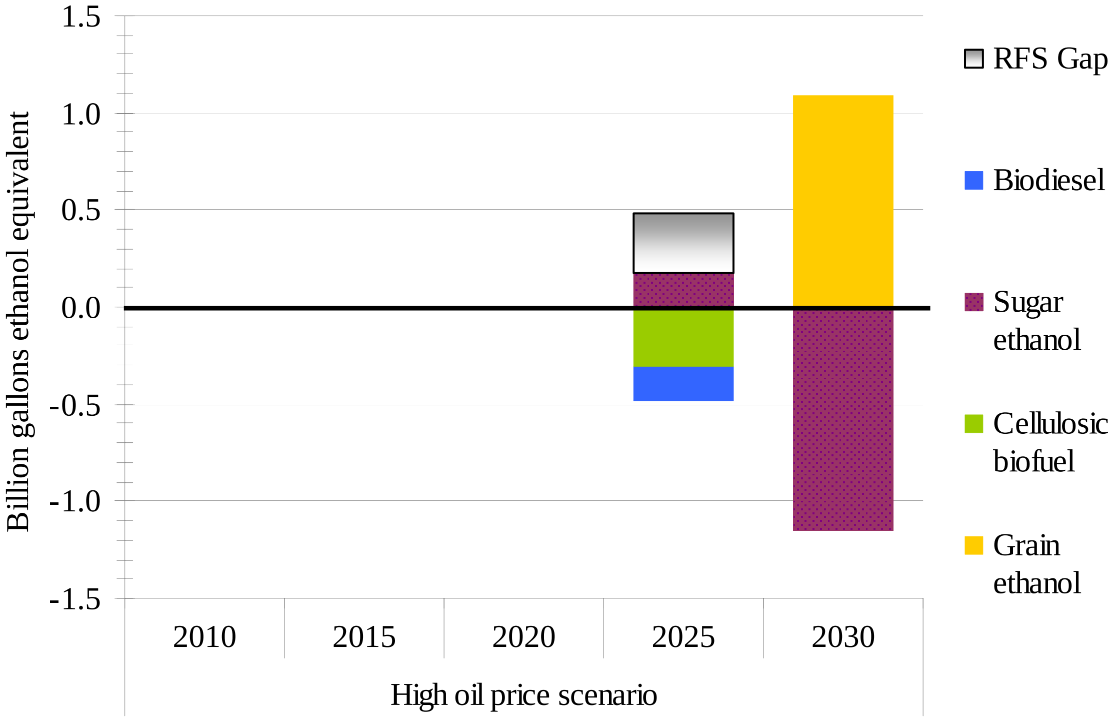

Figure 23: Change in U.S. biofuels supply by type in the high oil price scenario compared to the reference scenario

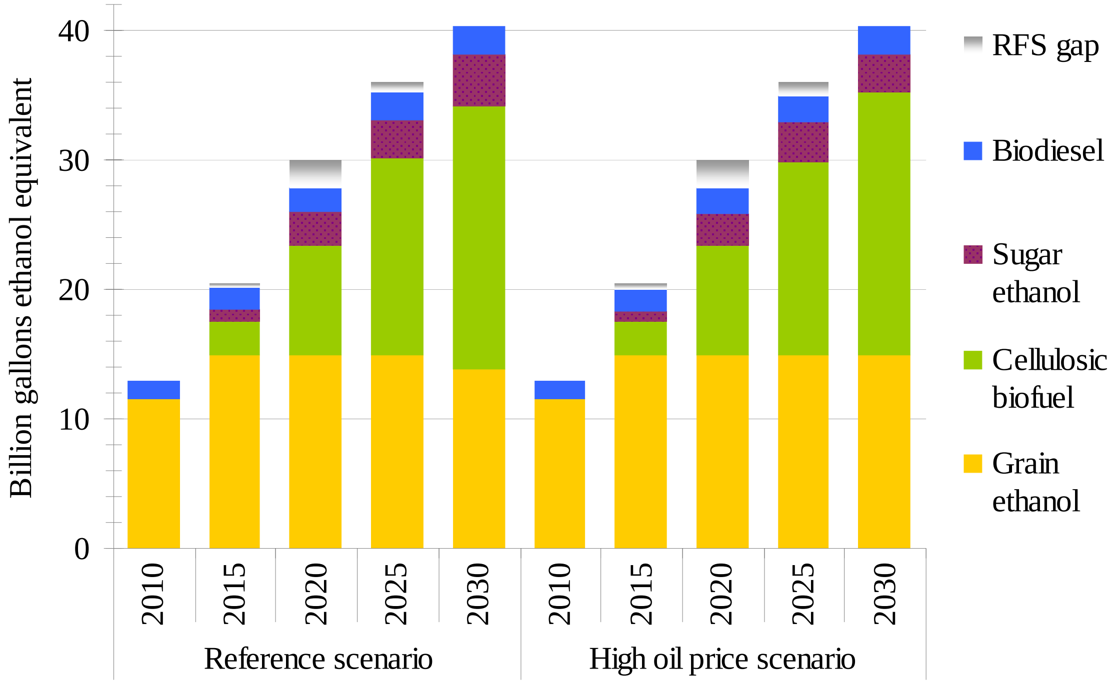

Figure 24: U.S. biofuels supply by type in the reference and high oil price scenarios

Conclusions and Recommendations

This study projects that the U.S. may not meet the full mandates of the new RFS from 2015 through 2025, but the estimated gap is significantly smaller than that estimated by the EIA. There are three main constraints to meeting the requirements of the new RFS: 1) ethanol infrastructure costs, 2) limits to cellulosic biofuels production growth in the early years of technology development, and 3) large demand operating at the inelastic limit of the sugarcane supply curve. These challenges are illustrated through the use of various policy and market scenarios, and in particular the E20 certification scenario and the high feedstock availability scenario. The E20 scenario also shows the competition between cellulosic ethanol and cellulosic BTL where the former has a cost advantage when ethanol infrastructure constraints are not included and the latter has a cost advantage when ethanol infrastructure becomes a limiting factor. The results from scenarios like the global price on CO_2 also illustrate the interaction between grain ethanol and cellulosic biofuels which emit different amounts of CO_2. Results from the oil price cases reveal trade dynamics between producing and consuming countries and countries with and without biofuels mandates; however, both show little impact on U.S. biofuels supply because the RFS is a very strong policy in itself and mitigates the impacts of oil prices.

Further, in comparisons with the EIA's biofuels projections under the new RFS, this study shows larger biofuel imports and therefore, larger U.S. supply. This is explained by two differences. First, this study focused on an in-depth analysis of the feedstock potential of biofuels exporting countries. Therefore, these results show a much larger supply of imports compared to the AEO. Second, the AEO assumes that the cellulosic technology is adopted at a much slower pace due to higher capital costs, whereas this study includes in its assumptions the provisions of the 2008 Farm Bill through a cellulosic production tax credit that reduces the cost of cellulosic biofuels production until it is competitive with corn ethanol production. This study also assumes that technology learning and transfer results in the availability of cellulosic technology throughout the world.

Further analysis is needed to assess biofuels production and export potential from countries not included in this study (regions of the world where original ETP biofuels data was used). This might not show any significant difference from our estimate of U.S. biofuel imports but would provide a better picture of how biofuels are produced and consumed throughout the world, especially in the Asian countries. Countries with biofuel production potential in Asia include Indonesia, Thailand, and Malaysia; and in Africa, countries such as South Africa, which have generally greater economic and political stability than other parts of the continent, could become major biofuel producers. New feedstocks that are not used for food, such as the jatropha plant, could be used to produce biofuels in these and other countries.

Appendix A: Results for all Policy and Market Scenario

A detailed description of all the scenarios modeled is included in this appendix. The main features of the fourteen scenarios are described in Table 6.

Scenario	**Ethanol blenders' tax credit**	**Ethanol import tariff**	**Feedstock availability**	**Oil price**	**Other**
Reference case	-	-	Reference	Reference	60:40 fuel:food split
Credit and tariff extension	Extended	Extended	Reference	Reference	
Credit extension	Extended	-	Reference	Reference	
E20	-	-	Reference	Reference	Up to 20% blending of ethanol in gasoline is allowed
$20 per tonne (t) growers' payment	-	-	Reference	Reference	$20 per dry t of biomass feedstock
$50 per t of carbon dioxide	-	-	Reference	Reference	Global price of $50 per t of CO_2 by 2030
70:30 fuel:food split			Reference	Reference	70% of sugarcane in Brazil available for biofuels
High oil price	-	-	Reference	High	
Low oil price		-	Reference	Low	
Extra high oil price	-	-	Reference	Extra high	
High feedstock availability	-	-	High	Reference	70:30 fuel:food split
Low feedstock availability	-	-	Low	Reference	
High feedstock availability and high oil price	-	-	High	High	
Low feedstock availability and low oil price	-	-	Low	Low	

Table 6: List of scenarios

Scenario Analysis

Reference Scenario

The reference scenario forms the base against which other scenarios are compared. The reference scenario includes worldwide biofuel policies (see Table 4) including the U.S. new Renewable Fuel Standard (RFS). Particular attention was paid to the economic incentives required to commercialize cellulosic ethanol plants. We relied on the NREL cost estimates for these plants but accounted for the fact that these estimates were for the “nth of a kind” plant, not the first several plants. While the “nth of a kind” plant was estimated to be competitive, these earlier plants were not. Consequently it was necessary to assume some kind of learning investment that could come from a variety of public and private sources. The subsidy could be in the form of production tax credits, co-funding or other support or a subsidy scheme that improves the economics of cellulosic biofuel production for the investor. We had estimated, prior to the enactment of the 2008 Farm Bill, that an initial learning investment subsidy of about $1.00 per gallon[39] (gal) would be needed to achieve rapid uptake of cellulosic biofuels technology. In the later stages of our quantitative analysis, the 2008 Farm Bill was enacted which included a $1.01 per gal cellulosic ethanol production tax credit; this was included in our reference scenario. We assumed that the cellulosic ethanol production tax credit would be extended past 2012 at declining levels sufficient to keep new cellulosic ethanol plants competitive. We also assumed that the blenders’ tax credit and ethanol import tariffs both expire in 2010.

Potential Future Policies

Since ethanol distribution infrastructure limitations and the ability to deliver sufficient volumes of ethanol to consumers is one of the main obstacles to reaching the RFS mandate, a policy scenario where E20 (gasoline blended with up to 20% ethanol by volume) is certified was considered. This would alleviate some of the infrastructure concerns, but the viability of this policy is dependent on resolving issues related to the impact higher blends of ethanol will have on engines and fuel systems. Currently most car manufacturers will only warrant their gasoline engines if they are fuelled with ethanol blends of 10% or less.

Another potential subsidy considered in this study is a growers’ payment for U.S. farmers cultivating renewable cellulosic biomass. A $20 per dry tonne (t) payment would be offered to farmers starting in 2010 and expires in 2022. It is not adjusted for inflation.

Carbon Prices

In the carbon scenarios a carbon price of $50 per t of CO_2 is gradually phased in. It starts at $12.5 per t in 2015 and is increased by $2.5 per t annually until it reaches $50 per t in 2030. The carbon price applies to all sectors of the economy and to all regions. It is adjusted for inflation.

Oil Prices

Oil prices are determined endogenously in the model and are thus an outcome for a given model run and not an input assumption. Many factors influence the oil price, including supply curves, demand, end-use efficiency, and fuel switching. Another important variable is Organization of the Petroleum Exporting Countries (OPEC) rent-seeking, which can be manipulated in the model. This study used this rent-seeking behavior as the market driver for oil prices. A high oil price scenario is thus a case where OPEC follows a more aggressive policy and restricts supply to world markets by demanding higher economic rent on each barrel it produces. Low oil prices conversely occur when OPEC reduces their rent-seeking and produces more crude oil for world markets.

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[39] The model results throughout this discussion are presented in ethanol equivalent volumes unless otherwise noted.

In this study high oil prices indicate an additional $18 per barrel economic rent sought by OPEC producers, while in the low price case it is $18 per barrel lower. It is worth noting that this does not mean that oil prices will be exactly $18 per barrel higher and lower respectively for these two scenarios, since non-OPEC producers will respond to price changes. There is also an extra high oil price case where OPEC rent-seeking is raised by $43 per barrel. Oil price outcomes are shown in Figure 2.

The oil prices referred to in Figure 2 and in the rest of this report are the average U.S. imported prices of crude oil, also known as refiners' acquisition costs. Average import prices are generally significantly lower than the oil prices reported in the press. Reported oil prices are usually spot or future prices (*i.e.* WTI Cushing spot or NYMEX future price). These refer to reference crudes (light sweet crude oil), which are of higher quality than the average traded crude and thus receive a higher price. The difference between spot prices and contract prices varies widely, as shown in Figure 25. In its 2008 *Annual Energy Outlook* (AEO) the EIA projects this gap to range between $8 and $12 per barrel over the next 20 years (EIA, 2008a).

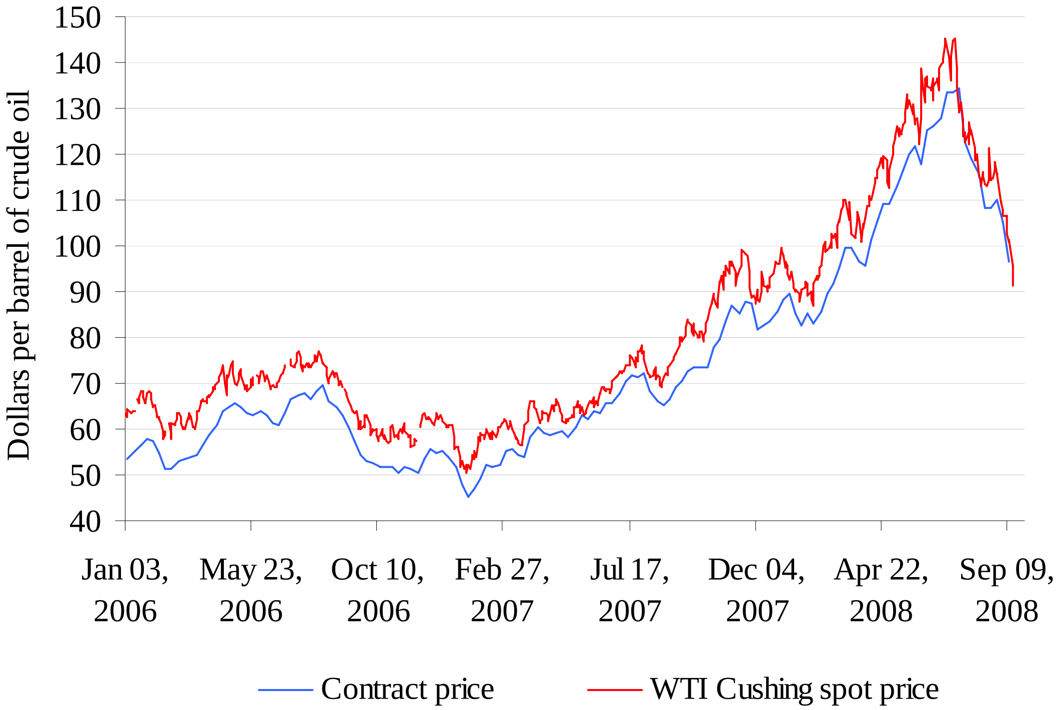

Figure 25: Historical oil prices by type

Results and Findings

Note on results and findings

Results from this study should not be read as forecasts. There are too many uncertainties and unknowns to make accurate predictions about future production and traded volumes of biofuels. This has been an exploratory scenario analysis that is meant to inform the biofuels policy debate. It is thus intended to address the dynamics of the biofuel markets and the relative impact of policies and market uncertainties rather than forecast future biofuel supply. Numbers should not be viewed in isolation but in the context of the study and underlying assumptions. For instance, an adjustment of supply curves would change produced volumes but the overall dynamics of the markets and the relative impact of the various policies should not change. In this section the focus is therefore mainly on these issues rather than on absolute numbers. That said, every effort has been made to ensure that the reported volumes are as reasonable as possible. Furthermore, the overall spread of outcomes from the analysis probably gives a fair estimate of the range of import volumes that are feasible in the medium term. This caveat is meant to emphasize the inherent uncertainty in this type of forward-looking exercise and encourage the reader not to attach too great an importance to individual values but rather view them in context of the overall range of results.

Results

This section covers the results of the scenario analysis. A total of fourteen scenarios were analyzed. To limit the page count and ensure readability, only selected data have been included here. Data tables for each of the scenarios can be found in the BNL report (Alfstad, 2008) for readers who wish to access the full results.

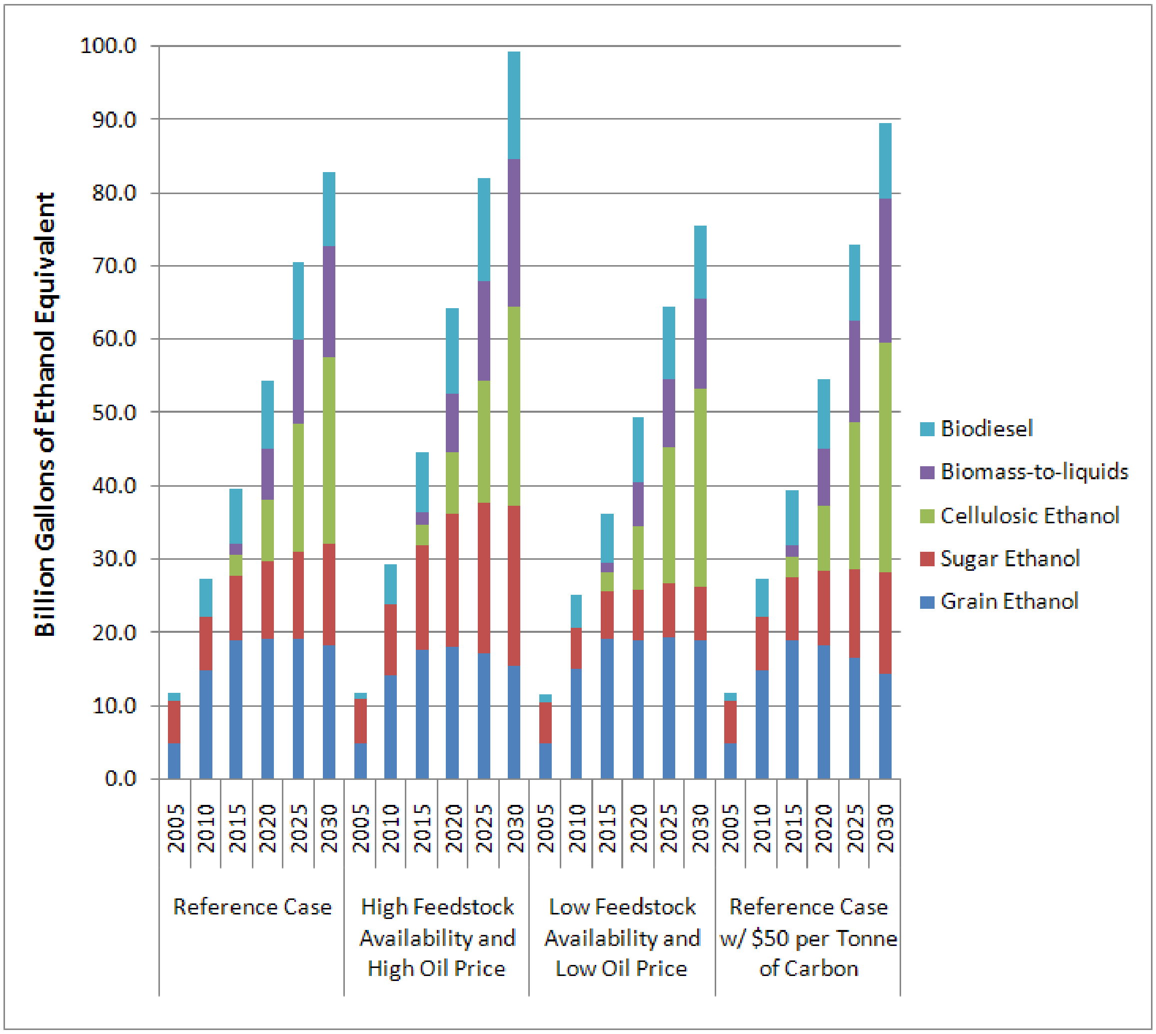

Figure 26: World biofuels supply by type for various scenarios

World biofuel supply for selected scenarios is shown in Figure 26. The reference case total biofuel production increases from 12 billion (B) gallons (gal) of ethanol equivalent in 2005 to 54 B gal 2020 and 83 B gal in 2030. The scenarios analyzed showed volumes ranging from 49 to 64 B gal in 2020 and from 75 to 99 B gal in 2030. The highest production worldwide occurs in the scenario with high feedstock availability combined with high oil prices. The lowest global production is found in the scenario with low feedstock availability and low oil prices.

Initially, the majority of biofuels are produced from food crops. In the longer run, growth rates for grain and sugar ethanol slow down. This is mainly due to limits of feedstock availability, but also because the U.S. RFS does not mandate higher volumes for these fuels. Cellulosic biofuels quickly gain significant market share after they are introduced on a commercial scale in 2012. In the reference case cellulosic biofuels have a market share of 28% in 2020 and this grows to almost 50% by 2030.

Feedstock availability mainly impacts sugar ethanol and biodiesel production, as can be seen by comparing the high and low feedstock cases to the reference case. This is because grain ethanol is not competitive outside the U.S. and cellulosic expansion is not constrained by the overall resource availability under any scenario.[40] Again, it is worth noting that the scenarios exploring sensitivity to feedstock availability only adjust the supply curves for the countries covered in the feedstock assessment part of this study. Worldwide sugar ethanol production in the reference case is about 11 B gal in 2020, while in the high feedstock growth case this rises to 18 B gal and in the low growth case it is as low as 7 B gal. The majority of sugar cane ethanol is produced in Brazil, which maintains a market share of more than 80% in all years for all scenarios. There is some feedback to grain ethanol production, as it is displaced when more inexpensive sugar ethanol is supplied to world markets.

Cellulosic biofuel production is more dependent on technology cost and limits to infrastructure roll-out than feedstock availability, as can be seen in Figure 26. Cellulosic ethanol production remains virtually unchanged by the shifts to high and low feedstock availability. It is in fact slightly higher for the low feedstock cases because of reduced competition from sugar ethanol. This is an indication that feedstock availability is not the constraining factor for cellulosic ethanol production but rather infrastructure constraints and competition from less expensive sources of biofuel.

Another reason for the lack of response from cellulosic biofuels to changes in feedstock supply is the fact that a large share of the overall cellulosic biofuel potential is in countries not covered by the feedstock analysis part of this study. Thus, the cumulative global shift in supply curves is smaller between scenarios for cellulosic feedstocks than for sugarcane or oil seeds, where a much larger share of total supply is from the studied countries (see Table 7). This is partly because cellulosic feedstocks are more evenly distributed geographically and because the country screening process mainly focused on potential for first generation biofuels (see section on Feedstock Assessment Results).

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[40] Here, feedstock availability refers to the physical presence of biomass resources in the region. Availability at conversion plants depends on the ability to harvest, collect, and transport the feedstocks, and this is treated as an infrastructure constraint in this study.

Feedstock	**Countries Assessed in Present Study**	**2006 Output (Mt)**	**Share**
Sugarcane	Argentina, Brazil, China, Colombia, India, Mexico, CBI	999	73%
Soybeans	Argentina, Brazil, China	108	81%
Corn	Argentina, Brazil, China, Canada Mexico	234	55%
Wheat	Argentina, Canada, China	146	27%
Palm Oil	Colombia, CBI	1.3	3%

Table 7: Share of world (non-U.S.) production of crop feedstocks represented by the assessed countries (Kline et al., 2007)

The introduction of carbon prices raises global biofuel production. Total biofuel supply is 7 B gal higher in 2030 after the introduction of a carbon price. The increase in cellulosic biofuel supply is higher at 10 B gal, while grain ethanol production drops about 4 B gal. There is also a small increase in sugar ethanol production. The reason for the low response in sugar ethanol production has to do with the shape of the supply curves. Sugar is the cheapest source of ethanol and supply is mainly constrained by feedstock availability.

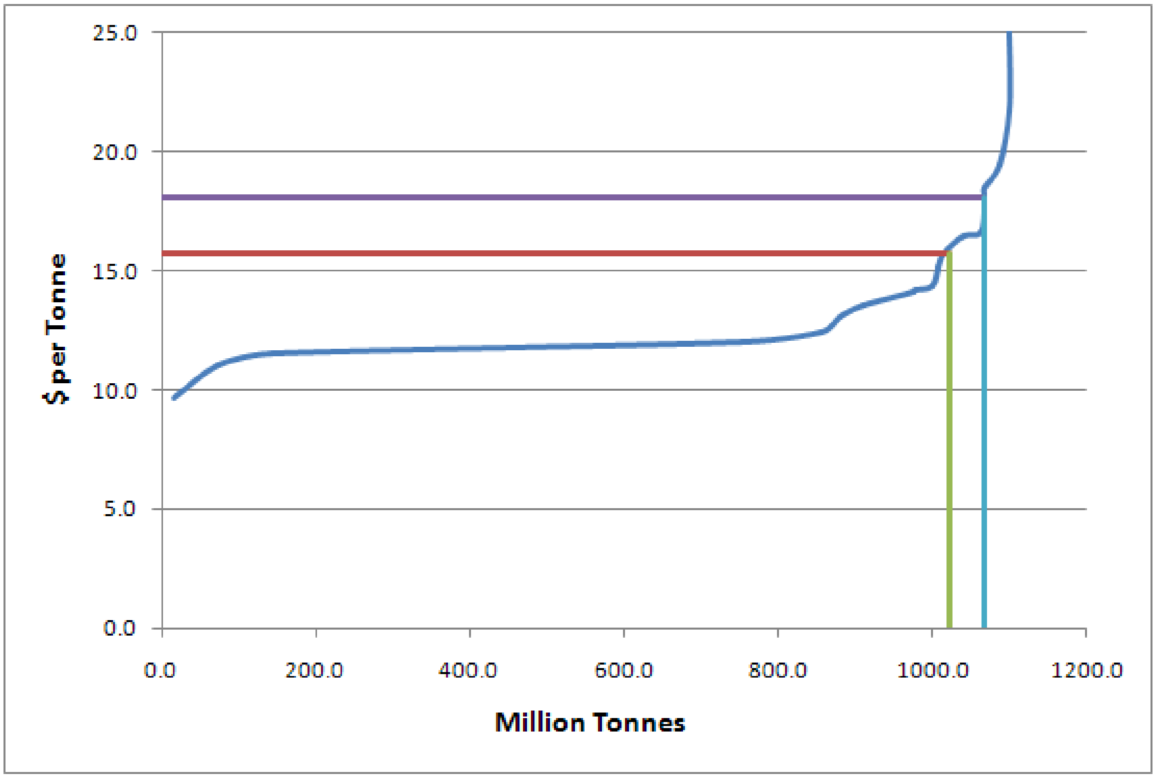

Figure 27: Effect of carbon price on Brazilian sugarcane supply in 2030

Figure 27 shows the sugar cane supply curve for Brazil in 2030 in million t (Mt) produced at a given price per t. The carbon price results in a significant increase in the feedstock market price from $15.7 to $18.1 per t for the reference case. Since most of the ethanol is economic at prices below $15.7, we are at the inelastic part of the supply curve where response to price signals is relatively small. As a result the increase in production is quite limited from 1,020 to 1,067 Mt. The same argument explains why other price signals, such as higher oil prices, also have a limited impact on sugar ethanol production and why an outward shift in the supply curve (the high feedstock growth case) has a much larger impact.

The reason why grain ethanol production is going down in spite of stronger price signals has to do with the limits on overall ethanol sales. U.S. and Europe, the biggest markets, are driven by mandates. The carbon price is not sufficient to encourage demand beyond the mandated levels and thus, competition is in a market of fixed size. Since the economics of cellulosic biofuels relative to grain ethanol improves, the former takes market share from the latter.

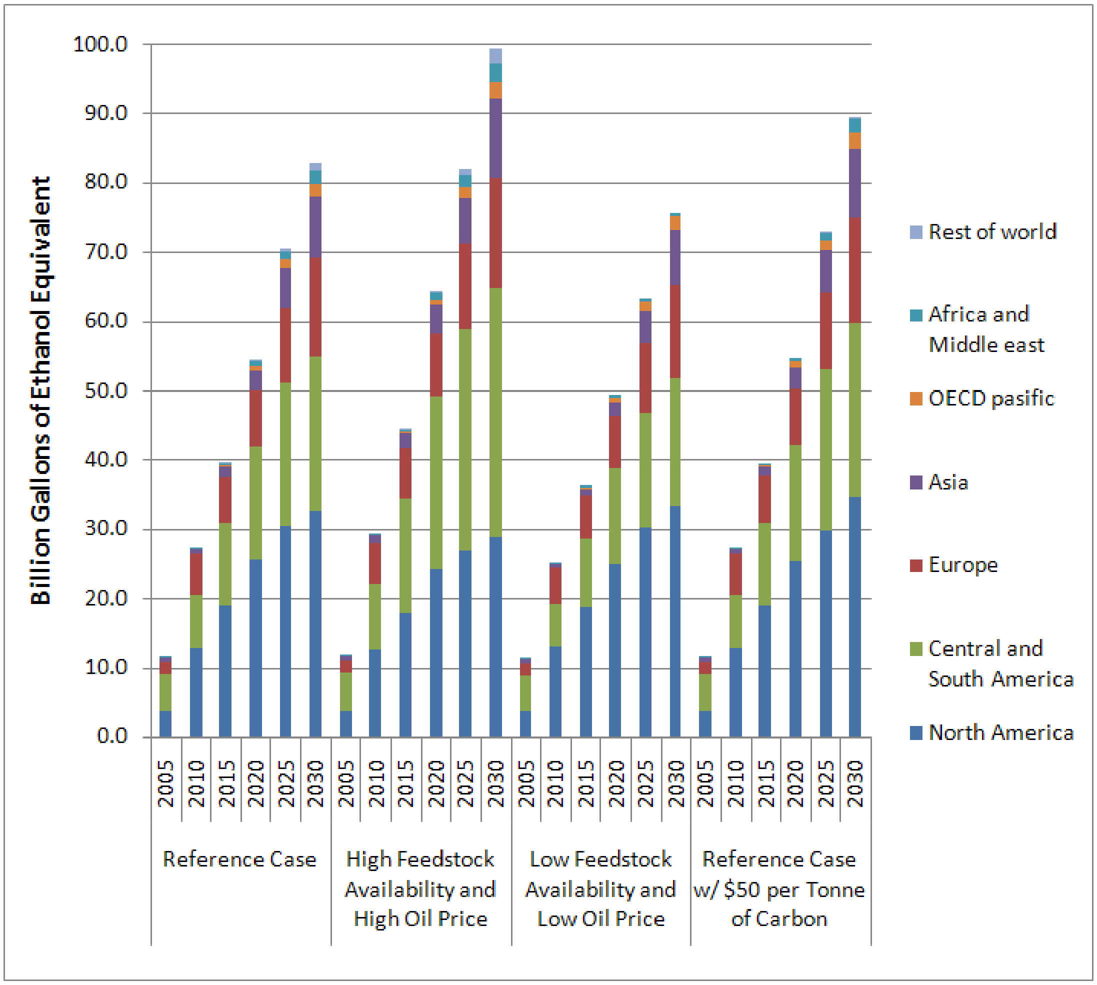

Figure 28: World biofuel supply by producing region for various scenarios

World biofuels production is dominated by North (primarily U.S.) and South (primarily Brazil) America, with significant contribution from Europe and Asia, as seen in Figure 28. In the reference case the U.S. share of total biofuel production grows to over 45% in 2015 but drops gradually to about 35% in 2030. In the high feedstock case the share drops to 26% in 2030.

Figure 29 shows biofuel demand by region. The U.S. is the biggest market for biofuels and it attracts around 50% of total supply for all years in the reference case. Europe and Brazil also attract large quantities of biofuels to satisfy their fuel standards. These three markets all have biofuel mandates, so overall demand changes little between scenarios, although there are some differences in U.S. demand since waivers can be purchased. The majority of the variation between scenarios is thus occurring in regions that have incentives but not mandates, such as Asia and Central and South America (other than Brazil).

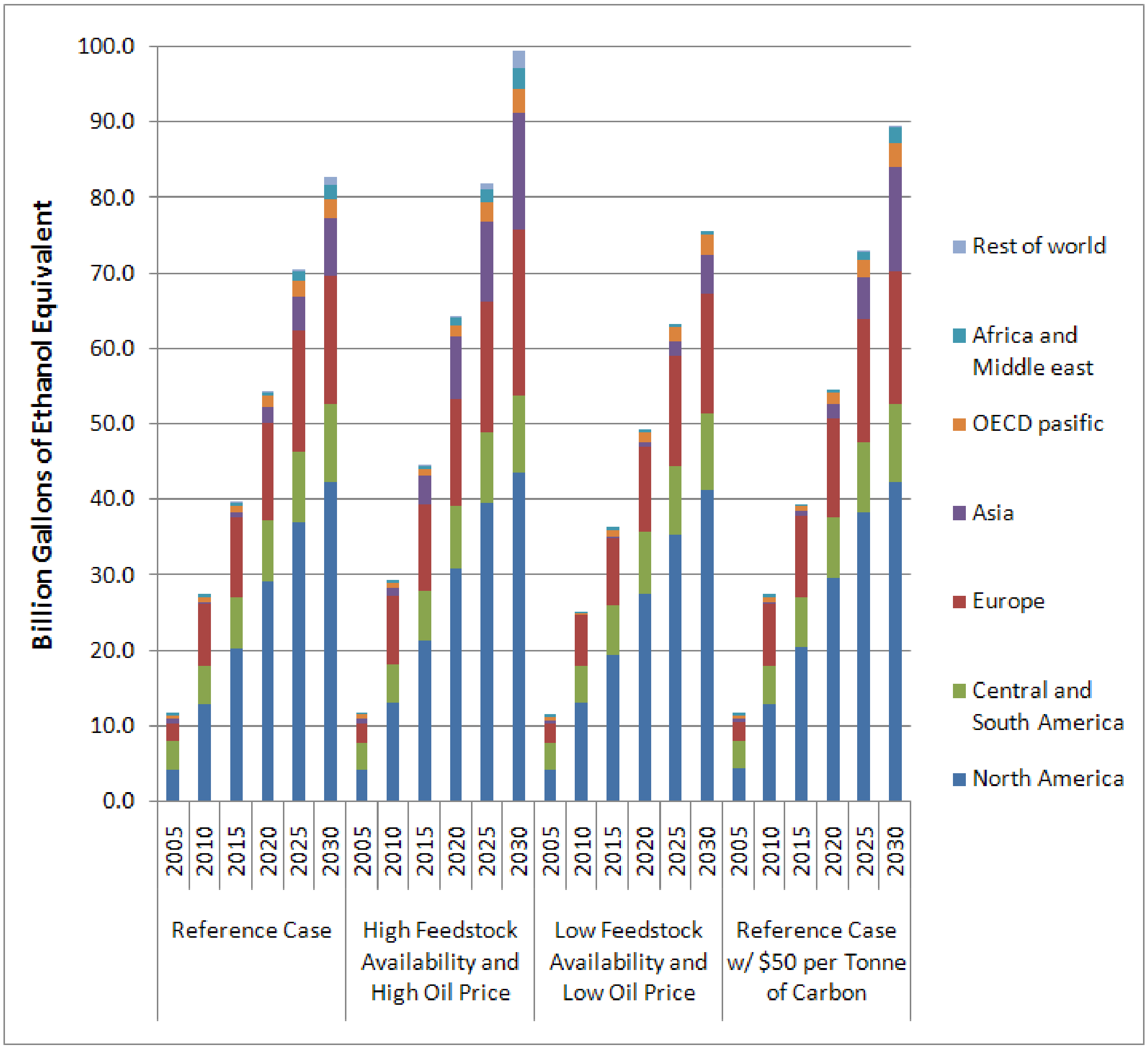

Figure 29: World biofuel demand by region for various scenarios

By comparing the supply side chart (Figure 28) with the demand side it is possible to develop a view of trade flows. A total of 10 B gal of biofuels is traded among regions in 2020 and this grows to 15 B gal by 2030. For the high feedstock growth case, these trade flows are significantly higher at 15 and 26 B gal respectively.

Most of the traded ethanol originates in Central and South America, which exports 8 B gal of biofuels in 2020 and 12 B gal in 2030. The U.S. and Europe are the major importers.

Figure 30 shows biofuel supply to the U.S. This supply is not sufficient to meet the cellulosic biofuel mandates in the early years of the RFS. As a result waivers are purchased to cover the shortfall. Total biofuel supply in the reference case is 28 B gal in 2020, of which about 4 B gal are imported. A little less than 20 B gal of this is ethanol, while the remainder is biomass-to-liquid (BTL) fuels (6 B gal) and biodiesel (1.9 B gal). Since the total RFS requirement for 2020 is 30 B gal, the waiver requirement is 2 B gal.

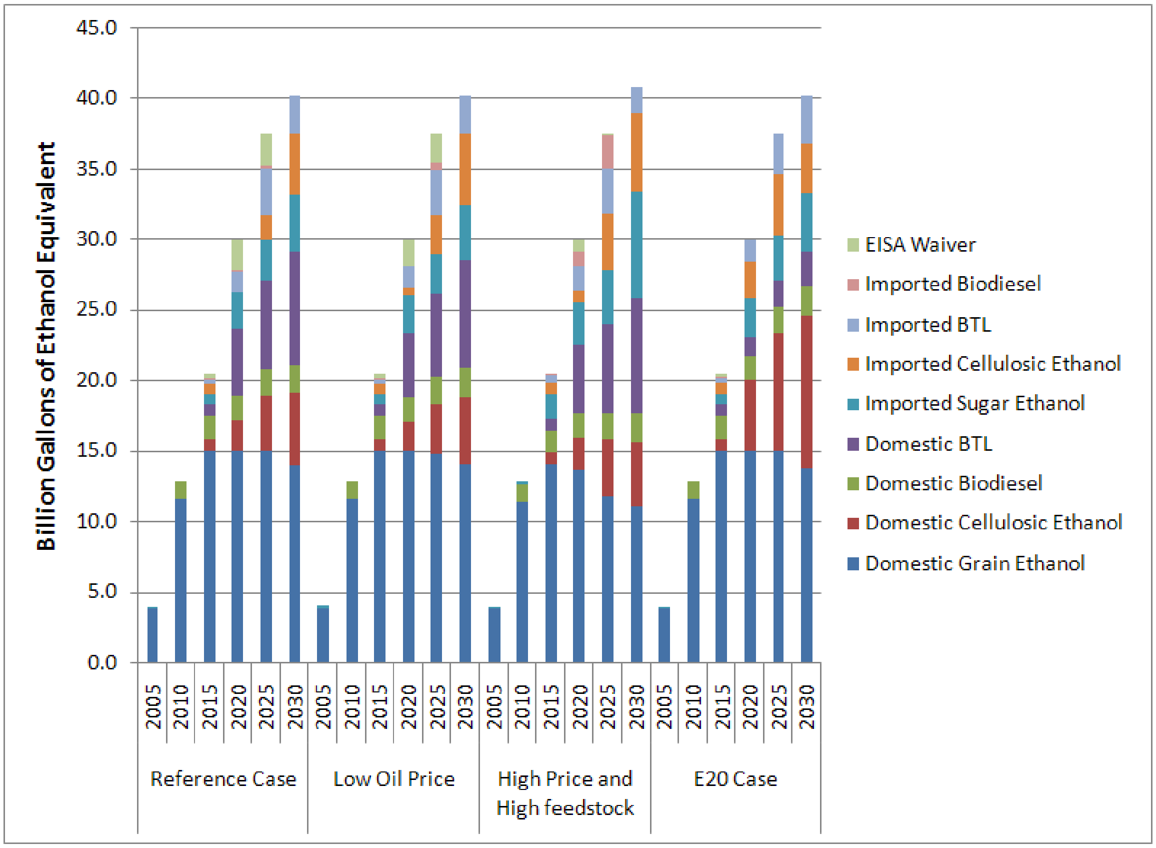

Figure 30: U.S. biofuel supply for the reference technology cases

Allowing E20 greatly increases the share of ethanol and displaces BTL. In the reference case ethanol distribution is restricted by infrastructure constraints and the inability to deliver sufficient volumes of ethanol as E85. This brings BTL into the market to fill the RFS gap. Distributing and selling ethanol as E20 alleviates these restrictions allowing more ethanol to penetrate the market. In fact, the E20 case is the only scenario where the mandate is met in 2020 and as a consequence some BTL is displaced. This is discussed further in the “biofuel market dynamics” section below.

In scenarios where there is abundant sugar ethanol available in the world market, significant volumes of U.S. domestic grain ethanol production are displaced. In these cases the advanced renewable fuels mandate is exceeded and the additional sugar ethanol demand is not driven by the RFS but by price. Extension of the ethanol blenders’ tax credit or other domestic subsidy would protect domestic producers from this foreign competition but come at a significant cost to the U.S. Treasury.

The biodiesel requirement of the RFS is met in all scenarios in all time periods and supply also increases beyond the mandated volumes to help meet the overall advanced biofuels target. This happens in scenarios where sugar ethanol is in short supply and higher prices justify larger imports of biodiesel.

Biofuel Market Dynamics

The market adoption of biofuels worldwide is driven by a combination of mandates and economic incentives. If a mandate is in place the price will rise until supply is sufficient to meet it. Assuming that the targets set are achievable, there is no volumetric risk in this case, but there can be considerable risks associated with the cost of compliance. This cost risk can be mitigated through some form of relief-valve mechanism, but this would reintroduce volume risk. In a market where biofuels demand is driven by economic incentives (*e.g.* tax breaks, direct subsidies) the price of these fuels are determined by the price premium they can realize over gasoline or diesel due to the subsidy regimes. The cost risks are therefore reduced but there is significant volume risk. Therefore, under a mandate regime prices adjust to volumes, while under a subsidy regime volumes adjust to prices. In a region where both types of incentives are present the volumes will be determined by the mandates, while the main impact of subsidies will be to reduce prices for the consumer or increase profits for producers.

In a global market place, where some regions have mandates while others only have subsidies, these dynamics affect how biofuels are allocated among markets. Regions with mandates are willing to take the price risks and therefore tend to carve out a fixed share of the market, regardless of what happens elsewhere[41]. These markets would therefore tend to be served first. The regions that rely purely on policy induced price incentives will compete for whatever is available after all mandates have been met. Producers will sell their product in the market where they realize the highest net-back. The ethanol will thus tend to flow to the markets where price signals are the strongest, net of transport costs and tariffs. As long as there are unmet mandates this will limit the amount of ethanol going to countries without these fixed volumetric targets.

The EISA RFS creates a market place where ethanol is no longer a single commodity but can be separated into several subsets whose value is dependent on the feedstock from which it was produced. The ethanol itself will probably trade at one price but the associated credits will achieve different prices in the market place and thus change the total value of the ethanol. There are essentially four different types of ethanol under this regulation; ethanol that qualifies as renewable fuel (e.g. grain ethanol), ethanol that qualifies as advanced renewable fuel (e.g. sugar ethanol), ethanol that qualifies as cellulosic biofuels (e.g. cellulosic ethanol) and ethanol that does not qualify for any of the credits. It is thus perfectly possible, and in fact highly probable, that the market value (price plus credit value) for each of the types of ethanol will be different. Credit prices are generally determined by the market and will reach the level required to ensure sufficient supply, but for cellulosic ethanol (and other qualifying cellulosic biofuels) the credit value is equal to the waiver price as long as the mandate remains unmet.

The general dynamics of the biofuel markets as represented in this modeling exercise can best be understood by separating it into two stages; before the U.S. mandate is met, and after the mandate is met. Before the mandate is met all production is complementary in the sense that increased production in one part of the world does not come at the expense of production in another. There is little competition among ethanol producers, and ethanol prices are set by the price premium it can realize over gasoline due to the subsidy regimes. Any producer able to deliver ethanol to the market at this price will therefore do so. After the mandate in the U.S. has

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[41] This is how the ETP model behaves; strictly enforcing mandates. In the real world lawmakers and regulators would likely issue waivers, adjust the regulations, or otherwise accommodate markets if the mandates are deemed to have unacceptable adverse impacts.

been met, biofuel markets become much more competitive and prices fall. At this stage (sometime between 2020 and 2030 in most scenarios), most of the subsidies in the rest of the world have been phased out. Producers are in more direct competition and increased production in one region leads to decreased production elsewhere. For instance, this is seen by comparing the high feedstock case to the reference case, where domestic production changes little in the early years but significant amounts are displaced by cheap imports in 2025 and 2030.

Another way to view this situation is to see the early years as a “sellers market” with high prices, where importers, unable to meet domestic biofuel targets, are competing for the fuel available on the open market. In the latter years the market is more balanced, prices fall and producers have to compete for market share.

Meeting the biofuel targets requires not only the production of sufficient volumes of fuel but also the infrastructure to bring this fuel to customers and consumers who actually purchase it. The biofuels mandate in 2022 is 36 B gal[42], roughly equivalent to 22 B gal of gasoline. In 2022 our projected gasoline demand is 139 B gal, so it is not feasible to meet the mandate by selling E10 alone. To sell more ethanol, retailers will be forced to market it as E85; however, sale of E85 requires a dedicated infrastructure.

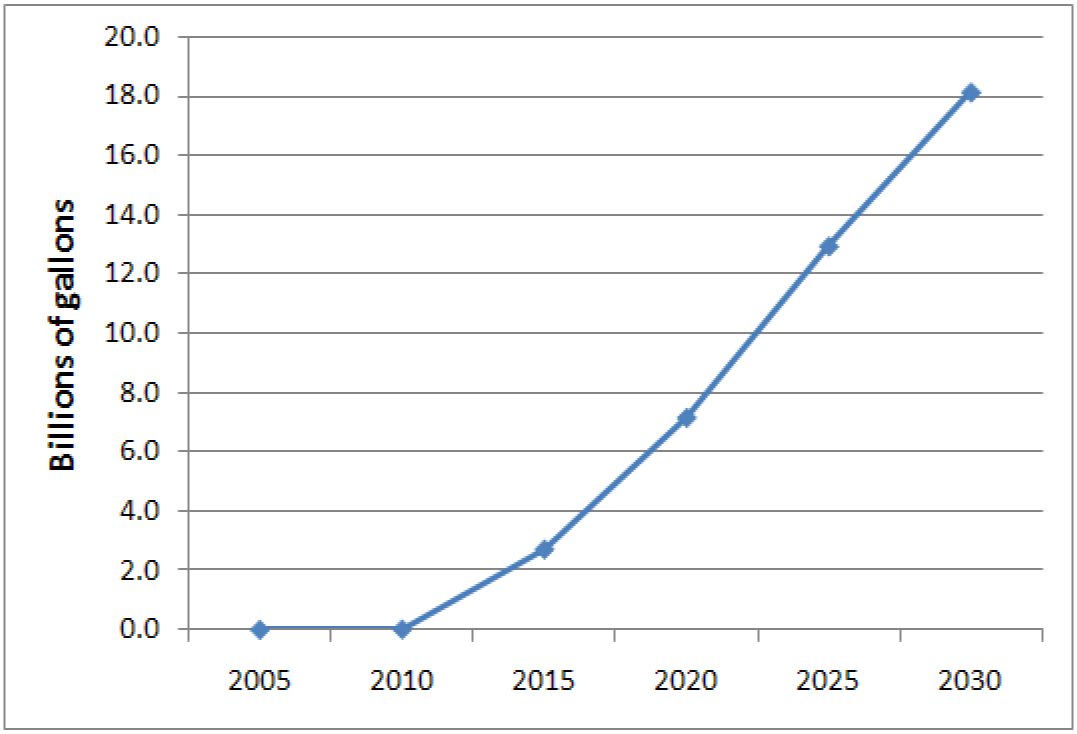

Figure 31: E85 sales in the reference case

Since the responsibility for meeting the mandate under the legislation lies with the “refineries, blenders, distributors, and importers,” it falls on these entities to ensure that consumers actually purchase the fuel. This poses both infrastructure and marketing challenges. In order to sell the fuel to customers, there needs to be an underlying infrastructure to deliver it to them at fueling

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[42] It is not yet clear how the 1 B gal biomass-based diesel requirement will be calculated – in gal of ethanol equivalent or gal of diesel equivalent.

stations. Not only is an expansion of the distribution and fuelling station infrastructure needed to deliver sufficient volumes of E85 to customers, but there also must be enough flexible fuel vehicles on the road to use it. Approximately 1,200 out of almost to 170,000 fueling stations in the U.S. sell E85 currently (National Ethanol Vehicle Coalition, 2008). There are about 6.5 million flex-fuel vehicles on the road (EIA, 2007) but few of these actually run on E85.

Another concern is that consumers not only have to drive a flexible fuel vehicle and refuel at a station where E85 is available, they also need to be willing to buy the fuel. E85 currently trades at a premium to gasoline when adjusted for the loss in fuel efficiency due to the lower energy content for a given volume of fuel. Assuming that the bulk of consumers will buy the fuel that lets them travel at the lowest cost, this means that some form of additional incentive needs to be in place to encourage the adoption of E85. This is likely to require a cross subsidy.

Instead of supplying E85, marketers can meet the mandates by distributing cellulosic Fischer-Tropsch BTL. These BTL fuels can be distributed with petroleum-based fuels in the existing infrastructure and can be used by the current fleet of light duty vehicles and trucks. Consequently, BTL fuels do not suffer from the same infrastructure constraints as E85. Based on the technology assumptions used for this study, cellulosic ethanol production is cheaper per unit of energy than Fischer-Tropsch diesel for a given feedstock price. The suppliers (as represented in the model) will therefore prefer to meet the mandates with ethanol supply as long as it can be distributed at reasonably low costs. As the sales of E85 increase, the cost of distribution increaases as the ability to expand the infrastructure and sell E85 is limited. Above a certain volume of ethanol sales, the production cost advantage is negated by the distribution cost escalation, and additional biofuel supply will then tend to be in the form of BTL.

This effect can be seen by comparing the reference case, and the credit extension case to the E20 case (Figure 32). There is little variation in overall ethanol sales in the two cases with E10 as the maximum blend. Additional incentives, in the form of a blenders' tax credit, have little impact. Since there are no substitutes for grain and sugar ethanol for the renewable and advanced renewable biofuel targets, the ethanol distribution constraints function as a cap on the amount of cellulosic ethanol that can be sold. Additional incentives for cellulosic biofuels will thus tend to lead to increased BTL supply. By allowing E20 to be sold to consumers, the infrastructure constraints are significantly reduced and more ethanol can be supplied to markets. This not only leads to an increase in cellulosic ethanol but also a decrease in BTL fuels.

The buy-out from the cellulosic biofuels mandate adjusts to oil price and there are no relief-valve mechanisms for the other mandated volumes; therefore, U.S. biofuel demand is not very responsive to changes in oil price. The RFS removes the risk of falling oil prices to suppliers since the credit price will adjust to keep price incentives at levels that are thought to be sufficient to ensure supply. Conversely, credit prices are reduced in the event of rising oil prices to ensure that the industry is not taxed needlessly in an environment where price incentives for biofuel supply are already adequate. Therefore, the price signal for U.S. renewable fuel suppliers does not differ significantly from the baseline to the high and low oil price scenarios.

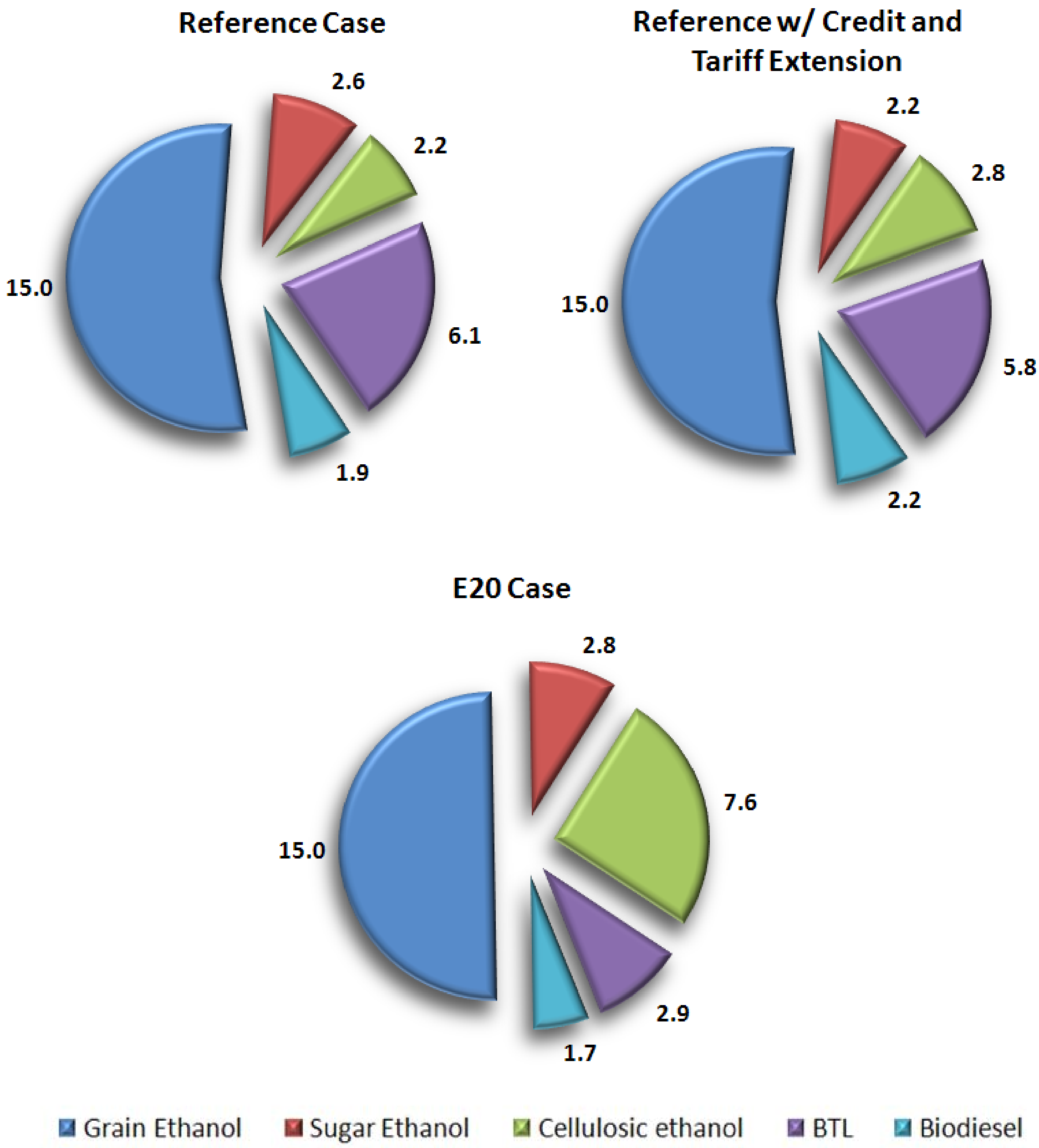

Figure 32: Biofuels sales by fuel type with reference scenario E10 versus E20

While biofuel demand in the U.S. is relatively independent of oil prices, this is not the case in countries that use price incentives rather than mandates. In these regions biofuel prices are determined by the premium that the subsidy regime allows them to achieve over petroleum fuels. Lower oil prices therefore mean lower biofuel prices, which leads to reduced incentives to supply these markets. With lower prices and less biofuel going to international markets the cost of importing biofuels into the U.S. drops and volumes go up. Conversely, higher oil prices mean higher demand internationally, more competition for supply and therefore higher prices and lower volumes imported into the U.S. This dynamic has two significant impacts. The first is the perhaps counterintuitive outcome that increasing oil prices lead to reduced biofuel demand in the U.S. This effect is marginal but might have been more pronounced if not for the constraints on ethanol sales described earlier. The second is that it changes the balance of imports and domestic production. Figure 33 shows that higher oil prices lead to reduced imports and thereby higher domestic production. The reverse would be true for falling oil prices. This relationship is consistent with the price impacts described above. This pattern changes if wholesale gasoline prices rise above $2.75, at which point the credit price decouples from the gasoline price and is held constant at $0.25. Oil prices above this level will increase biofuel demand in the U.S.

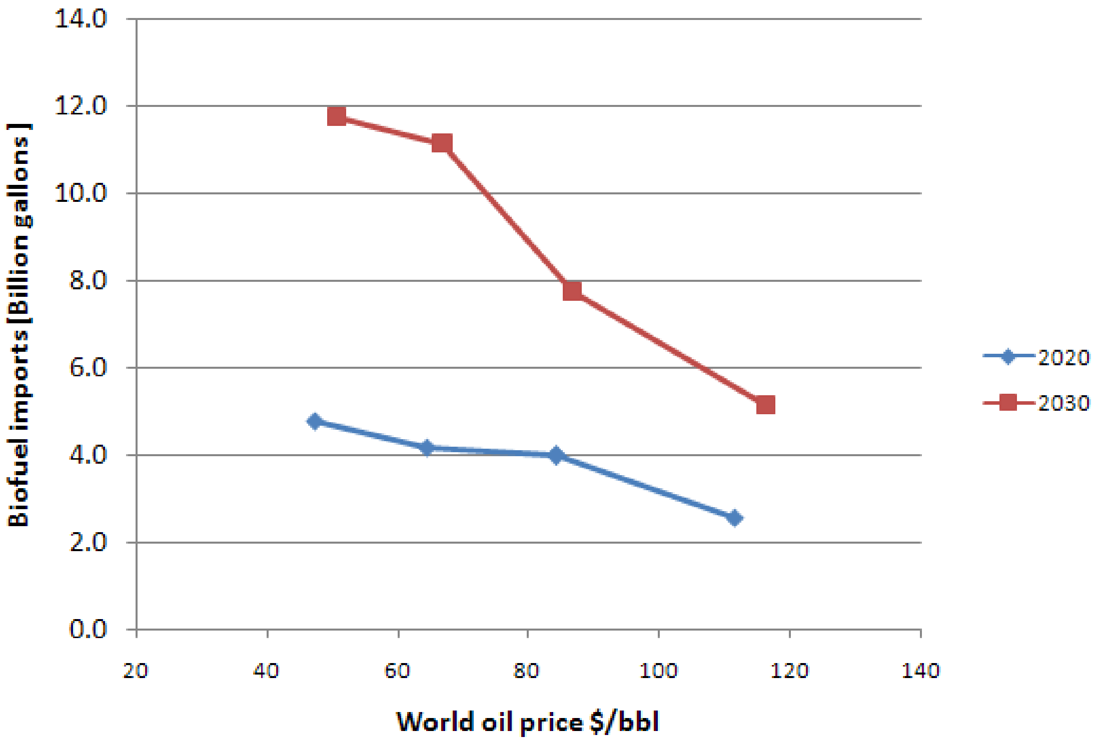

Figure 33: Oil price impact on biofuel imports

Critical to these outcomes is the assumption that producers believe that U.S. lawmakers will stick to this arrangement even if oil prices stay low for an extended period of time. The growth rates in biofuel production seen in these scenarios require strong confidence among investors that biofuel markets will expand and remain strong. Any doubt in the willingness of the U.S. and other governments to continue with their biofuel policies will likely lead to under-investment.

The RFS in itself is such a strong policy that additional incentives such as growers' payments or an extension of the ethanol blenders' tax credit does little to increase overall biofuels supply. The ability to develop the cellulosic resource base, build cellulosic biofuel production facilities, and construction of ethanol distribution infrastructure fast enough is the main constraint rather than the underlying economics. The exact limitation on how quickly the infrastructure can be rolled out is uncertain, and this is an issue that needs attention. The main impact of the credit extension is thus to bring in more domestic production at the expense of imports. Towards the end of the period, when growth rates are lower and infrastructure rollout is less of a concern, it also tends to bring in more cellulosic ethanol in place of BTL fuels. Furthermore, as more subsidies are introduced in the same scenario, diminishing returns to the cost of the policy will be seen.

The relative strength of the carbon value policy as a price signal compared to other policies changes over time. The blenders' tax credit and growers payment are both nominal values (i.e. they stay at a given dollar price and are not adjusted for inflation) and therefore decrease in real terms over time. The carbon price, however, increases over time and is also assumed to be in real dollars (i.e. inflation adjusted). This means that this policy strengthens over time.

Countries in the NAFTA trade-zone such as Mexico and the Caribbean nations currently have preferential access to U.S. markets through import waivers. Producers in these countries can realize higher net-backs to the U.S than other exporting regions can for a given domestic ethanol price. The favored market for ethanol from these countries is therefore the U.S. and they tend to be the first exporters serving U.S. importers. An interesting consequence of this is that extending the current tariff and blenders' tax credit policies will lead to an increase in U.S. imports from these countries. This is because the blenders' tax credit will serve as an additional incentive to producers, while the tariff normally intended to cancel out the benefits of the tax credit to foreign producers does not apply to imports from NAFTA member countries.

India and China are both potentially huge markets for biofuels but neither import much in most of the scenarios presented here. In the case of India this is mainly due to the very high import tariffs charged for imports of fuel ethanol into the country. Currently they are importing ethanol as a chemical feedstock but we assumed that this can be supplied by local producers when the internal infrastructure expands, which it will have to do if current ethanol blending targets are to be met. India thus produces significant amounts of ethanol for domestic consumption but does not import any. China does not currently have any strong economic incentives for ethanol imports. Fuel tax exemptions do not provide strong encouragement because the taxes themselves are so low. Like India, China relies mainly on domestic production in these scenarios. Any change in policy to help meet their ambitious targets might alter this.

Appendix B: Energy Independence and Security Act of 2007

The central policies covered in this study are the provisions enacted under the Energy Independence and Security Act of 2007 (EISA). EISA is designed to improve energy efficiency and increase the supply of renewable energy. The main provisions enacted into law can be summarized as follows:

- **Renewable Fuel Standard (RFS).** EISA mandates the use of additional renewable fuels by modifying the existing fuel standard. The standard now requires the sale of 36 billion (B) gallons (gal) of renewable fuels by 2022.
- **Corporate Average Fuel Economy (CAFE).** The law sets a fuel efficiency target of 35 miles per gal for the combined light duty vehicle fleet by the 2020 model year.
- **Appliance Energy Efficiency Standards.** The bill sets energy efficiency standards for a range of commercial and household appliances, including refrigerators, freezers, and lighting.
- **Repeal of Oil and Gas Tax Incentives.** EISA repeals two tax subsidies. The revenues from these taxes are intended to cover the cost of implementing the CAFE standards.

The focus in this study is on the RFS its impact on biofuel supply and demand. While the CAFE provisions have been included in the analysis, the issues examined in this study relate to biofuels and all scenarios are designed to address this subject.

Under the RFS provision the existing standard under the Clean Air Act is revised and expanded. The EISA amends the RFS in the Energy Policy Act of 2005 to include all transportation fuels. It expands the existing requirement to 9.0 B gal in 2008, increasing to 36 B gal in 2022. It requires renewable fuels produced at new facilities to have at least 20% lower lifecycle greenhouse gas (GHG) emissions than petroleum fuels. Starting in 2009, the RFS requires that an increasing amount of the above mandate be met using advanced renewable fuels, which are defined as biofuels derived from feedstocks other than corn starch with 50% lower lifecycle GHG emissions than the fossil fuel that it replaces. By 2022, it requires 21 B gal per year of advanced biofuel. Of the advanced biofuel mandate, specific carve-outs are made for cellulosic fuels and biomass-derived diesel[43]. (Figure 34) From 2015 onwards all increases in the overall mandated volumes are from advanced renewable fuels. The maximum volume of conventional biofuel (e.g. corn ethanol) for which distributors can receive credits is thus 15 B gal annually. The law does not actually prevent production of corn ethanol above this volume, but the economic incentives to produce it are significantly reduced if no additional credits are available. In general, compliance is required from “refineries, blenders, distributors, and importers” for each of the mandates volumes. The Environmental Protection Agency (EPA) can issue waivers under certain circumstances and may also sell waivers for the cellulosic biofuel mandate at a price which is the higher of $0.25 or $3.00 less the wholesale price of gasoline.

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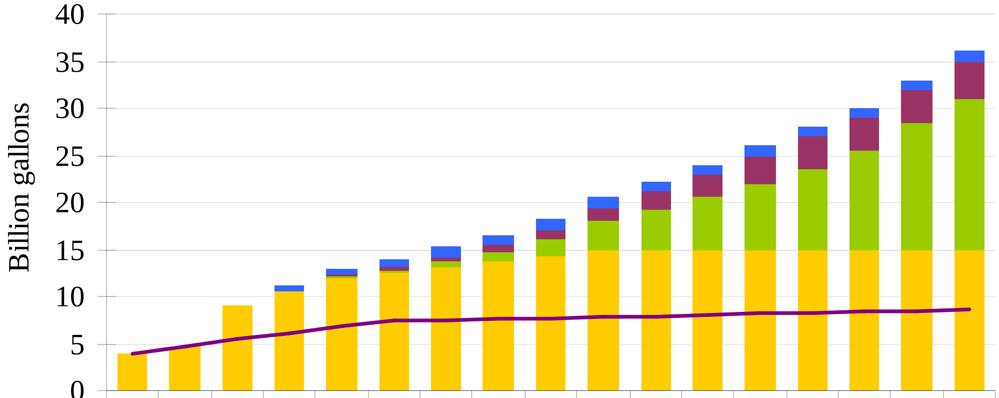
[43] There are further requirements and qualifications for biomass-based diesel as defined in EISA. It is not yet clear whether Fischer-Tropsch BTL diesel would qualify as both a cellulosic biofuel and a biomass-based diesel. Biomass-based diesels are mainly limited to fatty acid methyl esters (FAME) made from oil.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
New RFS total			9	11.1	13	13.9	15.2	16.6	18.2	20.5	22.3	24	26	28	30	33	36
🟦 Biomass-based diesel				0.5	0.65	0.8	1	1	1	1	1	1	1	1	1	1	1
🟪 Any advanced	0	0	0	0.1	0.2	0.3	0.5	0.75	1	1.5	2	2.5	3	3.5	3.5	3.5	4
🟩 Cellulosic advanced					0.1	0.25	0.5	1	1.75	3	4.25	5.5	7	8.5	10.5	13.5	16
🟨 Any renewable fuel	4	4.7	9	10.5	12	12.5	13.2	13.8	14.4	15	15	15	15	15	15	15	15
— Old RFS	4	4.7	5.4	6.1	6.8	7.4	7.5	7.6	7.7	7.8	7.9	8.1	8.2	8.3	8.4	8.5	8.6

Figure 34: EISA 2007 RFS mandated volumes through 2022

Appendix C: Feedstock and Conversion Technology Details

NREL developed a complete set of plant gate price curves for each technology in each country in the study (Bain, 2007). The conversion processes for ethanol included corn dry mills, sugar cane mills, wheat mills, bio-chemical (B-C) conversion of cellulosic feedstocks, and thermo-chemical (T-C) conversion of cellulosic feedstocks[44]. Representative flow diagrams that show the ethanol yields these conversion processes as well as Fisher-Tropsch catalysis to produce BTL[45] are shown in the following figures. Detailed discussion and analysis of the conversion technologies can be found in the report by Bain.

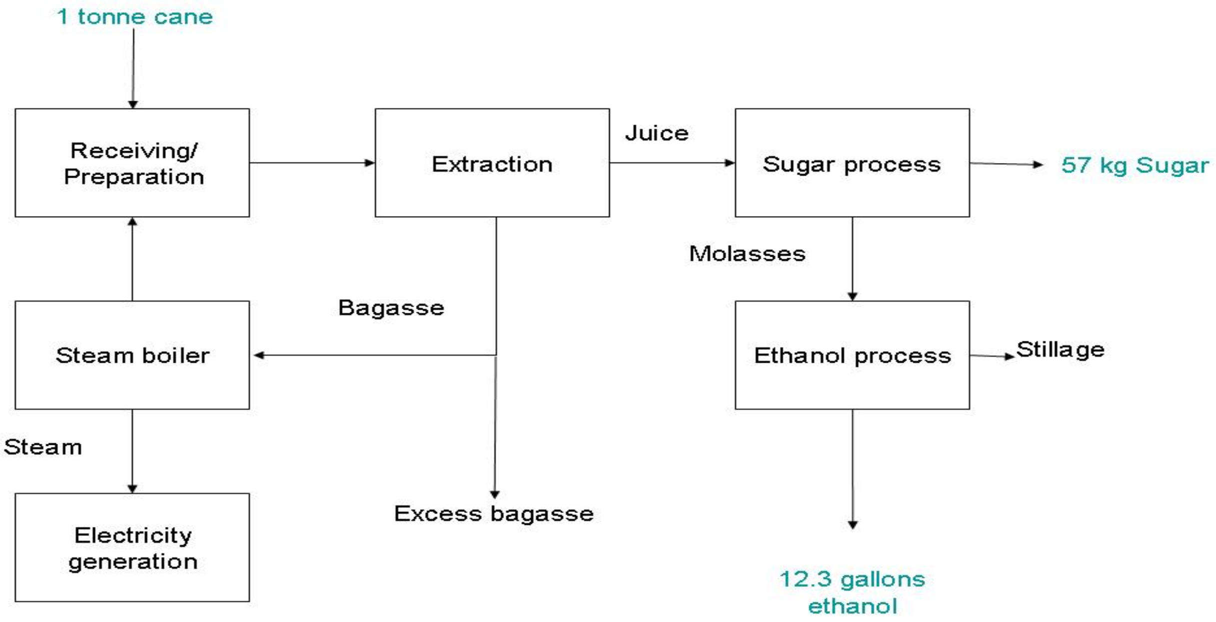


Figure 35: Conversion process to produce sugarcane ethanol

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[44] Ethanol by thermochemical conversion is not explicitly separated from ethanol by biochemical conversion in the integrated assessment because the costs are similar and both produce ethanol.

[45] Conversion costs for cellulosic BTL conversion are from the ETP model.

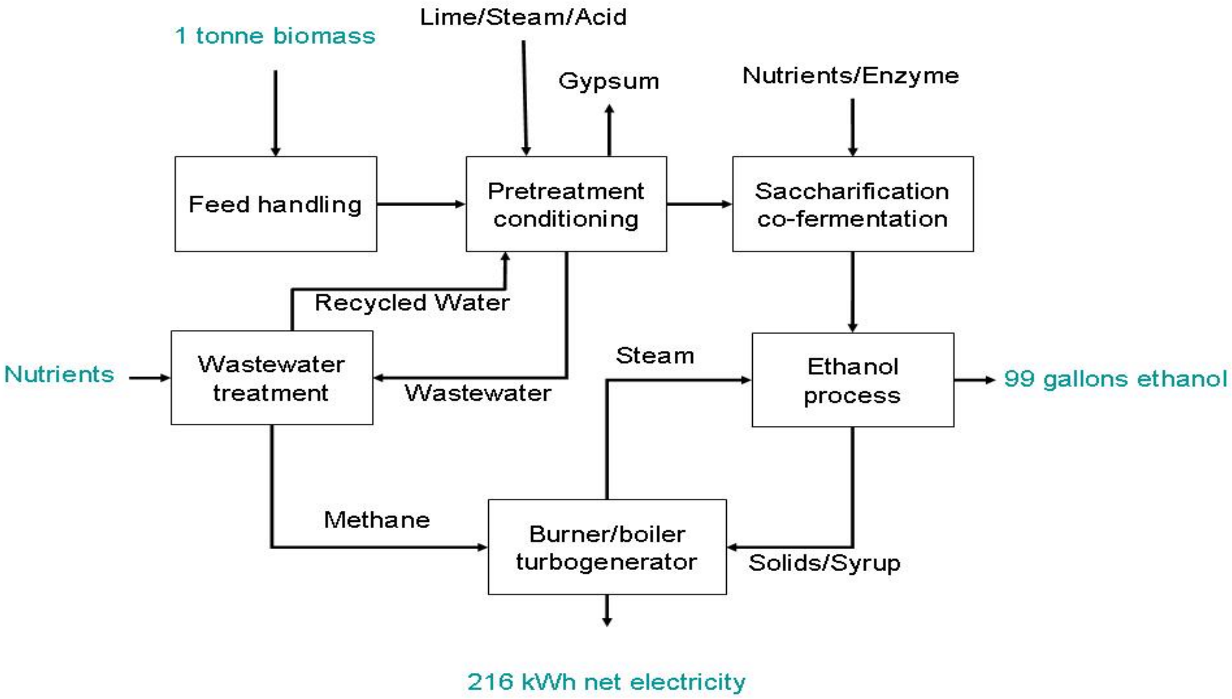

Figure 36: Biochemical conversion process to produce cellulosic ethanol

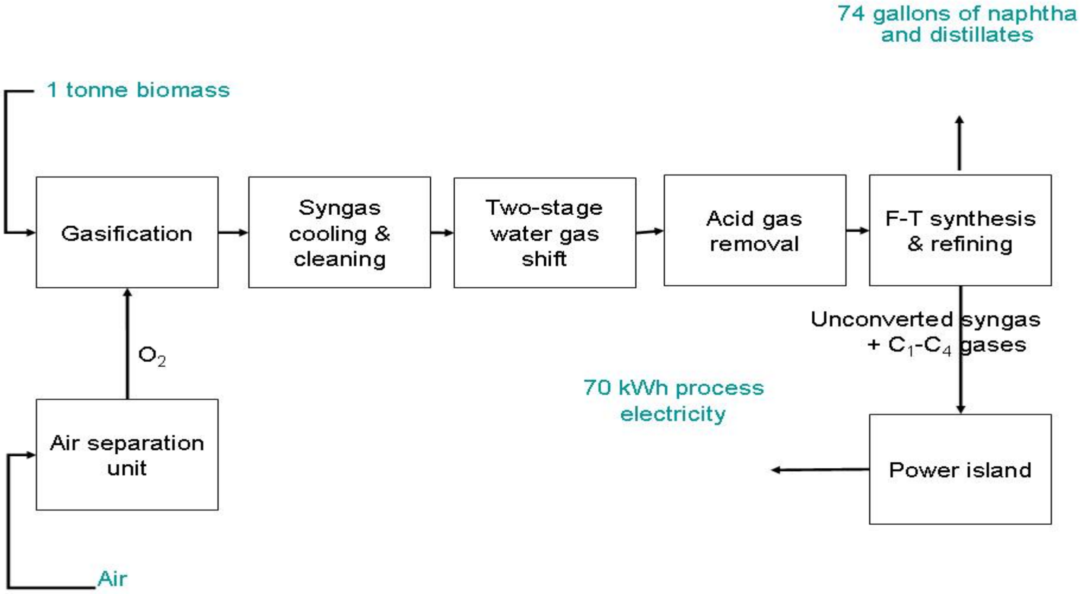

Figure 37: Gasification and Fischer-Tropsch catalysis to produce cellulosic BTL

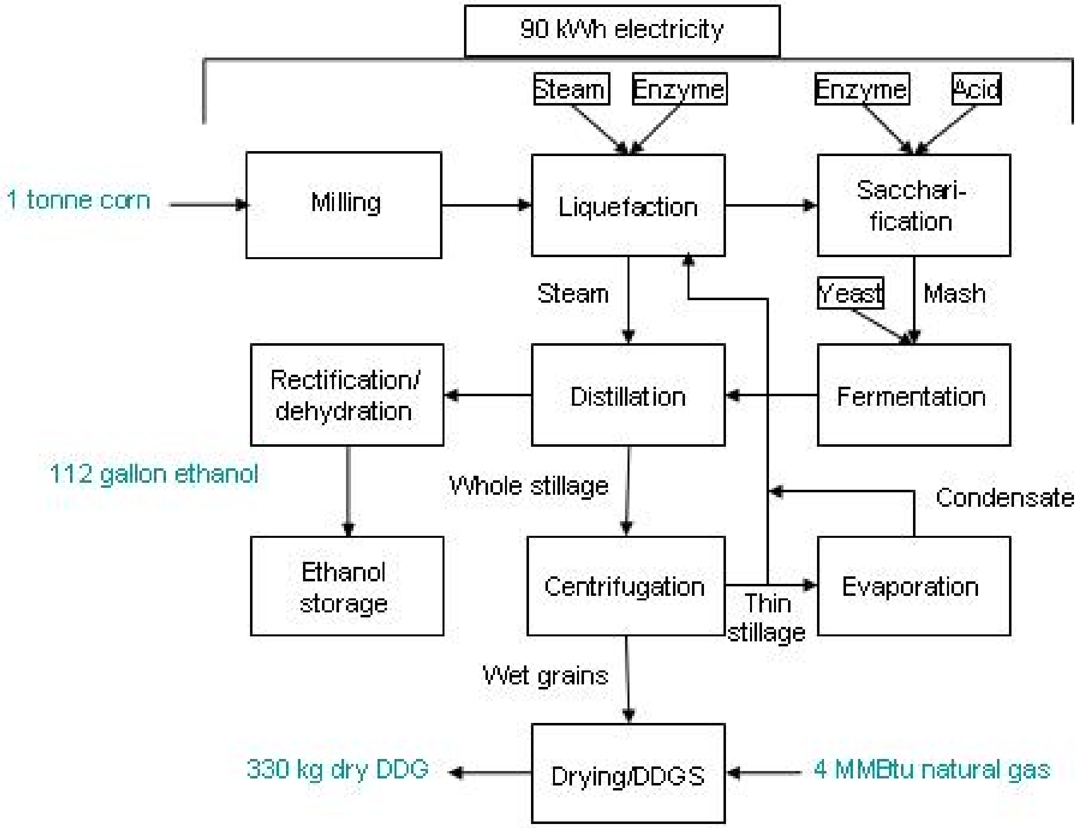

Figure 38: Dry mill conversion process to produce corn ethanol

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