Appendix B – GPRA06 Biomass Program Documentation

1. Introduction

This appendix discusses the assumptions and methods employed in the biomass benefits analysis that is part of the fiscal year 2006 GPRA benefits analysis for all of the Department of Energy's Energy Efficiency and Renewable Energy (EERE) research and deployment programs. The biomass benefits analysis focuses on the benefits of future achievements by the program and excludes retrospective benefits and benefits resulting from industry's own initiative and funding.

The major program focus is to enable integrated biorefineries producing a slate of products including fuels, chemicals, materials, and/or heat and power. The heat and power may be for internal biorefinery use, but may also be sold externally. Biorefineries process biomass into these products using biochemical processes (such as hydrolysis of biomass to sugars followed by fermentation of sugars to fuels and/or chemicals) or thermochemical processes (such as gasification of biomass to syngas followed by conversion of syngas to fuels or chemicals). Biorefinery configurations may vary as a function of site-specific conditions, including feedstock availability and price, local and regional market demand, and other factors. In addition to facilitating the development of future biorefineries, the program is collaborating with existing ethanol plants in evaluating the feasibility of enhancing their economic viability through increasing their ethanol output. This can be achieved with technology that converts the fibrous component of the corn kernels to ethanol, and, in the process, also convert the starch that is tightly bound by this fiber and so far, not available for conversion to ethanol in existing corn ethanol plants ("residual starch"). As an interim step leading to future biorefineries, the program is working with ethanol production plants (which are less-advanced, limited-capability biorefineries) on near-term technologies aimed at increasing the ethanol that these plants can produce from their traditional feedstock (corn kernels), while enhancing the value of the plants' non-ethanol coproducts such as animal feed additives.

In recent years, the National Renewable Energy Laboratory's (NREL) design of a cellulosic ethanol plant has been a primary source of data for estimates of costs and environmental effects related to the conversion of lignocellulosic feedstock to fuels. With respect to nonfuel products, the Cargill Dow Company is operating the first U.S. bio-based plastics plant in Blair, Nebraska, with the feedstock being the starch from corn kernels. This analysis is consequently based on the concept of enhanced corn ethanol plants with the added production of corn fiber ethanol, residual starch ethanol, and eventually stover-based ethanol, and two interim concepts of biorefineries. The two concepts are "Ethanol Biorefineries" (E-biorefineries) that produce primarily ethanol and a small volume of high value coproducts (chemicals and materials), and "nonfuel biorefineries" that produce chemicals and/or materials, but not fuels. The Biomass Program is conducting midterm and long-term research, development and demonstration (RD&D) that will lead to better defined integrated biorefinery concepts. Because it will take some time for RD&D work to bear fruit, this analysis does not include the benefits that could be estimated once the integrated biorefinery concepts are defined and, therefore, likely underestimates the probable benefits of the program.

A biorefinery industry is expected to result in biomass displacing most petroleum and natural gas feedstocks traditionally used in the production of fuels, chemicals, and materials. The biorefinery concept allows the cost of production to be reduced through synergies associated with feedstock handling and processing, and the allocation of capital and fixed O&M costs across multiple products. While the current analysis assumes that ethanol is the major output of E-biorefineries, future analyses could include additional fuels that the program may identify in the longer term.

The E-biorefinery is envisioned to biochemically process cellulosic biomass into ethanol (the lignin residues from this process are used to make electricity that will be sold externally, reducing the net ethanol cost) and a small quantity of nonfuel chemicals whose economic benefits were modeled as a "credit" that reduces the ethanol production cost. EERE used the Ethanol Long Range Systems Analysis Spreadsheet with Biorefinery Advantages (ELSASBioref) to integrate ethanol supply/demand data with biorefinery synergy credit and "current law" tax incentives to estimate market penetration for ethanol. EERE used these results as input to the NEMS-GPRA06 and MARKAL-GPRA06 models to estimate benefits.

In view of the large number of potential chemical products and materials that could be produced from biomass, this analysis did not assume specific nonfuel products, but instead assumed a category of "generic/composite" product for which EERE made assumptions based on a wide range of possible bio-based products (polymers, solvents, etc.).

Bio-Based Products from Nonfuel Biorefineries

The FY2006 analysis focuses on the benefits associated with a generic/composite bio-based product rather than specific products. This approach was adopted because there are too many potential bio-based chemicals and materials, and the markets for those are quite diverse, unlike transportation fuels where a few commodities account for most of the national market.

<u>Target Markets for Nonfuel Biorefineries</u>

A wide variety of chemicals and materials could potentially be produced at nonfuel biorefineries. Sugar and starch products derived through fermentation and thermochemical processes include alcohols, acids, starch, xanthum gum, and other products. Oil- and lipid- based products include fatty acids, oils, alkyd resins, glycerine, and a variety of vegetable oils. Gum and wood chemicals include tall oil, alkyd resins, rosins, pitch, fatty acids, turpentine, and other chemicals. Cellulose derivatives, fibers and plastics include products derived from cellulose, including cellulose acetate (cellophane) and triacetate, cellulose nitrate, alkali cellulose, and regenerated cellulose. Industrial enzymes are used as biocatalysts for a variety of biochemical reactions in the production of starch and sugar, alcohols, and oils; and are also used in laundry detergents, tanning of leathers and textile sizing.

Some of these chemicals and materials represent end products, while others represent "intermediates" used in the production of other products. The potential target markets are even more diverse than the list of potential products. Therefore, EERE did not characterize or analyze specific target markets for this benefits analysis.

Key Factors in Shaping Market Adoption for Nonfuel Biorefineries

Price will be the key factor in market adoption of products from nonfuel biorefineries. Most of these chemical and material products are commodity-based; and, as such, price will be the overriding factor in their penetration of their respective markets. In view of the "generic products" approach, meaningful comparisons of prices or other market factors for biobased products with competing hydrocarbon-based products are not possible.

Methodology and Calculations for Nonfuel Biorefineries

The methodology was based on an "averaged" bio-based product. EERE averaged the energy-use profile from the FY 2004 GPRA estimates to estimate the FY 2006 GPRA profile for the average generic bio-based product. The profile, which included a wide range of products (polymers, solvents, and other chemicals and materials), was averaged by summing the energy savings from the FY 2004 analyses and dividing the total by the volume of products it represented. The result is approximately 20,000 Btus of fossil energy displaced per pound of bio-based product, with the displaced energy distributed between feedstock and processing requirements. This is conservative because it does not include the use of biomass for on-site energy generation, which would result in even greater fossil energy displacement. Starch/cellulose-based products will involve handling dilute aqueous streams throughout the production process, requiring considerable electricity for processes such as separation and purification. This fact and the conservative approach previously noted account for the negative electricity saving coefficient in **Table 2.**

Based on the Biomass Program's plans, bio-based products will enter the market with the first starch-based biorefinery starting up in 2007. The program's experts assumed that the annual starch-based growth rate will be approximately 8% to 9% for the first 28 years, and gradually decrease to nearly 6% after 2035. They also assumed technical challenges will delay market entry for cellulose-based products until 2018, and that the annual growth rate for cellulosic products will be approximately 11% through 2030, 8.5% for 2031-2037, 6.5% for 2038-2044, and 5.5% for 2045 and thereafter. Initially high growth rates moderate as the industry matures, consistent with what one can observe in other industries.

Table 1 shows the growth of bio-based products from nonfuel biorefineries.

Table 1. FY 2006 Bio-Based Products from Nonfuel Biorefineries
(Billion pounds per year)

Year	2020	2025	2030	2035	2040	2045	2050
Products from starch	0.61	0.96	1.44	2.12	2.91	3.99	5.20
Products from cellulose	0.28	0.47	0.79	1.19	1.68	2.30	3.02

Table 2 presents energy-related input that the program's analysts provided to the EERE integrating models in the FY 2005 analysis, which serves as the basis for the current analysis[1].

Table 2. FY 2005 Input to Integrating Models – Energy Savings for Bio-based Products (Energy-saving coefficients per billion lbs of bioproducts)

Natural Gas	T Btu/billion lbs	4.5
Coal	T Btu/billion lbs	-0.6
Electricity	B kWh/billion lbs	-0.6
Distillate Oil	T Btu/billion lbs	4.5
Feedstock	T Btu/billion lbs	11

Ethanol and Bio-Based Products from Enhanced Corn Ethanol Plants and E-Biorefineries

The discussion in this section will focus on describing target markets and technical characteristics used in the analysis of the market penetration and benefits attributable to enhanced corn ethanol plants and E-biorefineries.

Target Markets for Corn Ethanol Plants and E-Biorefineries

Corn ethanol plants, both dry mills and wet mills (to learn more about these plants, use search feature at www.ethanolrfa.org), currently use corn kernels (no cellulosic feedstock) to produce ethanol and some coproducts such as animal feed additives (both dry and wet mills), or corn oil and high-fructose corn syrup (wet mills). Ethanol Biorefineries, or E-biorefineries, will use cellulosic biomass to produce ethanol fuel, high-value specialty chemicals and materials, and combined heat and power. The analysis for this type of biorefinery is limited to the benefits associated with ethanol because they will comprise most of the benefits of E-biorefineries. Thus, this analysis included only ethanol used as a transportation fuel for light-duty vehicles (passenger vehicles, mostly). While it is possible to envision an E-biorefinery using both cellulosic biomass and corn kernels as feedstock, it is outside the scope of this benefits analysis.

In 2004, U.S. ethanol fuel production reached approximately 3.4 billion gallons, an increase of 21% from the previous year. As of October 2004, 81 ethanol plants were producing and 11 additional plants were under construction. Ethanol competes in transportation fuel markets for light-duty vehicles. In 2003, the U.S. prime supplier sales volume of motor gasoline was approximately 134 billion gallons[2].

EERE targets ethanol technology for the gasoline additive market in the midterm and as a gasoline substitute/additive in the longer term. In 2003, approximately 99% of the ethanol consumed in the United States was for the gasoline additive market and 1% was for use as a gasoline substitute.[3] In 2004, the majority of the ethanol consumed in the additive market is used as an oxygenate component (additive) for gasoline, and the remainder is used as a gasoline additive to improve octane in conventional gasoline. Within the oxygenate market, in early 2004, methyl-tertiary-butyl-ether (MTBE) and ethanol each provided approximately 50% of the volume. However, ethanol is expected to take a much larger share of this market because MTBE has been or is being phased out in many states due to environmental concerns (see discussion of MTBE later in this section for additional detail).

The Clean Air Act requires a minimum level of oxygen content in both reformulated gasoline (RFG) and oxygenated gasoline. RFG, which is required in ozone nonattainment areas, and oxygenated gasoline, which is required in carbon monoxide (CO) nonattainment areas, are not the same. Ethanol competes with MTBE in both of these oxygenate market segments. Most of the MTBE (and an increasing share of ethanol) are used in RFG, which is the most important market segment for oxygenates. Both ethanol and MTBE are used in the smaller oxygenated gasoline market segment, with ethanol being the dominant oxygenate. In a third market segment, ethanol is blended with conventional gasoline to make gasohol, which is primarily marketed in the Midwest. Gasohol consists of 90% gasoline and 10% ethanol by volume, with the ethanol serving as an octane enhancer and gasoline extender.

After adjusting for its Federal excise tax exemption, the price of ethanol has historically tracked with the price of gasoline, whereas MTBE is normally priced at a premium relative to gasoline. However, MTBE used to be the oxygenate of choice in RFG for most refiners outside the Midwest because of its wider availability, more favorable blending characteristics for summer Reid Vapor Pressure, and ease of distribution. When blended into gasoline, ethanol raises the vapor pressure of the mixture, while adding MTBE to gasoline has only a minor effect on vapor pressure. Because ethanol absorbs water, which is typically present in small quantities in the U.S. petroleum products pipeline system, ethanol and ethanol blends are not routinely shipped via pipeline. Consequently, ethanol is shipped by rail, truck, and/or barge to distribution terminals, where it is blended into gasoline. MTBE is blended into gasoline at the refinery, and MTBE blends do not require any special handling compared with gasoline that has no MTBE.

MTBE is currently the subject of environmental concern in several communities, due to its leakage and contamination of groundwater. It imparts a turpentine odor to water at low concentrations. There have been several efforts at the national level to completely phase out MTBE’s use in gasoline. At this time, these efforts have not succeeded. Eighteen states, however, have issued their own limits on MTBE use. The states that have enacted MTBE bans account for more than 60% of historical MTBE consumption.

The 2003 production level for ethanol was 2.81 billion gallons per year. The consumption of MTBE in 2002 was approximately 4 billion gallons, but MTBE consumption has been declining as California, New York, Connecticut and other states transitioned from MTBE to ethanol. A national ban on MTBE would increase the demand for ethanol because ethanol, like MTBE, is a high-octane content, virtually sulfur-free additive that reduces toxic air emissions. Ethanol also will help solve the problem of fuel volume loss that would accompany an MTBE ban because oxygenates such as MTBE (or ethanol or other oxygenates), when blended in gasoline, also are used by the automobile engine as a fuel. Reformulated gasoline typically contains 11% MTBE.

Vehicle fleets provide additional demand for ethanol fuel. These include alternative-fuel vehicles that have been either modified or manufactured to accommodate the use of E85 (85% ethanol and 15% gasoline) or E95 (95% ethanol and 5% gasoline). Many of these vehicles are flexible-fuel vehicles, enabling their use with gasoline or E85. The vehicle fleet market is dominated by government agencies, but also includes fleets owned by corporate entities and other organizations (taxi cabs, utilities, airport authorities, etc.). The use of green fuels in

Federal Government fleets is driven largely by the alternative-fuel vehicle requirements under the Energy Policy Act (EPACT) of 1992. The market penetration of E85 has been much lower than for E10 because (1) only a limited number or vehicles can use E85 (and fleet rules under EPACT do not necessarily require the use of alternative fuels in these vehicles), (2) E85 is generally more costly than gasoline on an energy-equivalent basis, and (3) the required investment for refueling infrastructure is greater for E85 and E95 than for E10.

In the longer term, once production technology improvements achieve cost parity between ethanol and gasoline, ethanol will compete directly with gasoline in broader automotive fuel markets. In this instance, the growth of ethanol consumption eventually will become limited by the availability of biomass feedstocks, rather than by ethanol market demand.

Baseline Technology Improvements for E-Biorefineries

The degree to which this technology would progress in the absence of EERE's biomass R&D has not been studied. Alternatively, EERE evaluated the technical and market barriers to the development of E-Biorefineries using cellulosic feedstock, and concluded that without Federal investment in RD&D, the cellulosic ethanol industry would grow at only 20% of the rate postulated in the EIA Reference Case for the Annual Energy Outlook 2004. The rationale for this conclusion is industry's reticence to underwrite cellulosic ethanol research because of its risk and cost. For example, for a decade, the enzyme industry failed to show interest in partnering with EERE to develop low-cost enzymes for cellulosic ethanol production. Only in 2000-2001 did they make the strategic decision to become key players in the development of the new ethanol industry. Feedstock collection infrastructure is another critical area in which industry has neglected to invest in the development of new technology. Sustained public/private collaboration continues to be needed before cellulose-based chemicals and ethanol can become competitive.

Baseline Market Acceptance for E-Biorefineries

Gasoline is a mix of both high- and lower-value petroleum-based components, with the high-value components comprising only a small fraction of the total volume. With current ethanol tax incentives and ethanol's value to refiners due to its environmental and octane characteristics, corn-based ethanol is competitive with the small fraction of high-value petroleum-based constituents of gasoline that give gasoline acceptable octane and emissions levels. Therefore, a small amount of ethanol (10% or less) can be blended with 90% or more gasoline to produce a fuel that is competitive with conventional gasoline. However, blending ethanol with gasoline in higher concentrations becomes less competitive because a gallon of ethanol has only two-thirds the energy of a gallon of gasoline, and it cannot compete with gasoline on an energy-equivalent basis.

Ethanol is already widely used in gasoline and accepted as a component of transportation fuel in the target market. As the technology for producing cellulosic ethanol matures in the longer term, the retail value of cellulosic ethanol will become competitive with gasoline on an energy basis. At that point, fuel markets will likely accept nearly pure ethanol such as E85 because of its environmental characteristics and indigenous supply basis. Increases in market penetration for ethanol will also be affected by competition from other alternative transportation fuels and success in overcoming the lack of an established nationwide E85 transportation and distribution infrastructure. Eventually, increases in market penetration may be constrained by the availability of feedstock, rather than market demand.

Key Factors in Shaping Market Adoption for E-Biorefineries

Price - The price of biomass-based fuels is sensitive to biomass feedstock costs, the decrease in net ethanol production costs resulting from integration with bio-based products in a biorefinery, and prices of competing fuels, such as gasoline. The previous section discussed the value of ethanol in the low-blend market (E10) versus the high-blend market (E85 or higher blends).

Nonprice Factors – These include vehicle compatibility, infrastructure requirements, key consumer preferences/values, manufacturing factors, and policy factors.

***Vehicle Compatibility* -** In the E10 market, virtually all gasoline vehicles can use this low-blend ethanol gasoline mixture. For high blends such as E85, automobile manufacturers have considerable experience in producing vehicles that meet the Environmental Protection Agency's requirements, due to a few million flex-fuel vehicles that have been sold in the United States; these include models of the Ford Taurus, Chevrolet S10 pickup truck, GMC Sonoma pickup truck, Isuzu Hombre pickup truck, Chrysler Voyager minivan, Dodge Caravan minivan, Chevrolet Silverado, and other models.

***Infrastructure Requirements* -** A 2002 study[4] on logistics barriers, sponsored by EERE, foresees no major infrastructure barriers to a substantial expansion of the ethanol industry in the scenarios it analyzes, which include substantial movement of ethanol among and within different regions of the country by several different modes of transport. The study reveals that a large number of investments in transportation, storage, terminalling, and retailing are possible without encountering significant "growing pains."

Although petroleum terminal improvements anticipated by the study represent significant capital investments for terminal operators, they amount to less than 1 cent per gallon of new ethanol volume on an amortized basis. In addition, with some assurance of increased throughput volumes at terminals (such as that provided by a Federal renewable fuel standard), terminal operators could be expected to make the improvements.

The volume of product anticipated to be moved by railroad and river barge is a very small fraction of products moved by these industries. Furthermore, both the rail freight car-building industry and the barge-building industry have the capacity to build equipment that would keep pace with the increasing ethanol shipments from new plants.

There are also operational strategies the ethanol industry could employ that would mitigate risk of supply disruptions caused by logistical glitches. Additional inventory levels at terminals and other storage locations could act as a cushion against delayed shipments and help ensure the smooth functioning of a growing market.

While the study did not find any serious logistical impediments to expansion of the ethanol industry, it did identify two areas of potential concern that merit further study. These are the availability of Jones Act/OPA90-compliant vessels and barge movement in some areas of the U.S. inland waterway system as a result of vessel retirements.

Ships that are used to transport ethanol are subject to various regulations and requirements. The Merchant Marine Act of 1920, otherwise known as the Jones Act, requires that all ocean or waterway transportation from one U.S. port to another U.S. port be moved in a vessel built in the United States, owned by a U.S. person or corporate entity, manned by a certified U.S. crew and registered in the United States (U.S. flagged). Tankers meeting these specifications are known as Jones Act tonnage.

Vessels carrying petroleum products between U.S. ports are also subject to the Oil Pollution Act of 1990 (OPA90). This would include ethanol because ethanol is normally transported after having been "denatured," with the addition of a small quantity of a petroleum product such as gasoline. OPA90 requires the use of double-hulled vessels and further requires the retirement of single-hulled vessels from petroleum product service by certain dates, based on their manufacture or rebuild date.

Key Consumer Preferences/Values - Both E10 and E85 are likely to penetrate the market more easily in the Midwest where ethanol already is a familiar fuel. In addition, if the trend of increasing public awareness and environmental concern continues, this could become a significant positive factor in consumer choice in fuel markets in other regions outside of the Midwest.

Manufacturing Factors - Cellulosic ethanol is envisioned as a major product – but not the only one – from a biorefinery. While various biorefinery configurations are possible, the two fundamental platforms are fermentation (sugar-based) and gasification (syngas-based). EERE is working with private industry to further develop these platforms, from which a host of fuels and chemicals may be derived. Initial plants will cost more in view of the perceived technical risks. As experience is gained with new plants, costs for each subsequent plant will decrease as a result of lessons learned and lower cost of capital associated with reduced risk. The Biomass Program has historically focused more on the fermentation platform for cellulosic ethanol, as this path was seen as a logical extension of the more mature starch-based ethanol process. Consequently, NREL and its subcontractors have extensively analyzed the process economics of the fermentation pathway. Because the focus on the syngas-based biorefinery is relatively new, our understanding of this pathway is not as developed as our understanding of the sugar-based pathway. For this reason, our analysis was limited to the sugar-based pathway.

Policy Factors - In estimating the rate of market adoption, the analysis is based on the continuation of existing laws, regulations and policies (such as the ethanol tax incentive) and continuing USDA and DOE investment in biomass technologies RD&D at current levels, consistent with the Biomass R&D Act of 2000.

Methodology and Calculations for E-Biorefineries

Inputs to Base Case - Tables 3 and 4 show the results of the E-biorefinery analysis documented in this report, which serve as input to the integrated benefits analyses. NEMS-GPRA06 analysis extends through 2025, while MARKAL-GPRA06 analysis extends through 2050. The methodology employed to derive these inputs is described below.

Table 3. FY 2006 Ethanol from Corn Ethanol Plants and E-Biorefineries (Billion gallons per year)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Starch-Based Ethanol	3.42	3.73	3.97	4.02	3.92	3.64	3.53	3.53	3.53	3.53
Cellulosic Ethanol from Corn Fiber			0.088	0.34	0.51	0.47	0.46	0.46	0.46	0.46
Cellulosic Ethanol from Corn Stover, Other Wastes, and Energy Crops					1.20	3.60	6.20	9.00	10.2	13.2
Total	3.42	3.73	4.05	4.36	5.63	7.71	10.2	13.0	14.2	17.2

Table 4. FY 2006 Bio-Based Products from E-Biorefineries

Year	2024	2025	2030	2035	2040	2045	2050
Products as % of cellulosic ethanol by weight	1.0	3.0	3.0	5.0	5.0	7.0	7.0
Products from cellulose in billion lbs. per year	0.05	0.24	0.71	2.05	2.97	4.72	6.11

In **Table 3**, corn ethanol growth through 2050 is based on our latest assessment of the industry, not assuming a Renewable Fuels Standard because this has not been enacted in 2004. For cellulosic ethanol based on corn fiber conversion, a near-term technology being developed by the program and industry partners, we assumed success for dry mills only. While the other type of ethanol plants, wet mills, may also succeed in deploying this technology, the benefits from wet mills are not considered in order to make the estimates more conservative. The volume of cellulosic ethanol from corn fiber includes the ethanol resulting from converting the fiber in the corn kernel and the residual starch that can be converted once liberated from the fiber. The total increment in ethanol output would equal 20% of the current dry mill's ethanol output. As previously stated, future E-biorefineries are assumed to use cellulosic biomass such as corn stover and energy crops, and not the corn kernel or its fiber as feedstock.

Also in **Table 3**, cellulosic ethanol estimates from corn stover, other cellulosic wastes, and energy crops resulted from a market equilibrium analysis that competes ethanol versus petroleum constituents in the low-blend fuel market (E10) and versus corn ethanol. Future biorefineries will produce chemical coproducts from biomass along with the main ethanol output stream to enhance their economic viability. **Table 4** shows the fraction of bio-based products produced in E-biorefineries from cellulosic feedstock.

Technical Characteristics - The E-biorefinery analysis is based on a plant whose main product is fuel ethanol with coproduction of high-value bio-based products and electricity. This results in a reduced cost of ethanol due to the allocation of costs across several products. NREL has designed a narrowly defined biorefinery, i.e., a cellulosic ethanol plant whose products are ethanol and electricity generated from biomass wastes. To be conservative in the current biorefinery analysis, EERE estimated that bio-based coproducts reduce ethanol costs further by a modest 3% to 5%. This estimate will be refined when better data are available as a result of additional R&D and analysis.

The analysis is for a biorefinery with a total throughput of 2,000 dry metric tons of feedstock per day and with a conversion efficiency increasing from approximately 70 gallons of ethanol per dry U.S. ton of feedstock currently to 95 in 2050, as a result of technological advances.

Technical Potential - The biomass feedstock resources discussed here do not include wood waste and black liquor waste from paper mills, an important but captive resource – these resources are typically used within the forest and paper products industry. Under favorable R&D outcome and market scenarios, the upper bound for ethanol supply from U.S. biomass is estimated at 35 billion gallons per year, based strictly on feedstock availability. The farm-gate price and supply relationship for biomass used in the ELSASBioref model (for near-term conditions) are presented in **Table 5.**

Table 5. Farm-gate Biomass Quantities Supplied vs. Price Range Excluding Mill Residues and Black Liquor (Million dry tons per year)

Feedstock	up to $20/dt	up to $30/dt	up to $40/dt	up to $50/dt
Forest Residues	0	12	20	70
Agricultural Crops Residues	0	1	65	80
Potential Energy Crops	0	0	80	187
Other Wastes	0	17	25	35
Total	0	30	190	372

The total is 190 million dry tons per year at prices up to $40 per dry ton, and 372 million dry tons per year at up to $50 per dry ton, before adding transportation costs to the biorefinery. To be realistic, some of the future energy crops are assumed to be used in non-biorefinery applications. Therefore, only 66 percent of energy crops will count toward EERE's benefits. Likewise, some of the forest and agricultural residues and other wastes will be used for fiber products and other non-biorefinery applications. The fraction of each feedstock available for use in biorefineries is shown below.

While forest residues and some of the "other wastes" may not be optimal for sugar-based ethanol production, we recognize that future syngas-based fuels production may use forest residues and certain "other wastes" as feedstock. Therefore, this analysis is not deemed to be overly optimistic in spite of the assumption that biorefineries are sugar-based.

Transportation costs ranging from $7.50 to $15.0 per dry ton (depending on hauling distance) were added to farm-gate prices to account for hauling to the biorefinery. After adding these costs and applying the factors shown in **Table 6**, the near-term supply as a function of price per dry ton at the biorefinery gate is shown in **Table 7**.

Table 6. Fraction of Total Feedstock Assumed To Be Available To Biorefineries

Feedstock	Fraction
Forest Residues	0.4
Agricultural Crops Residues	0.7
Potential Energy Crops	0.66
Other Wastes	0.6

Table 7. Biorefinery-gate Quantities Supplied vs. Price Range Excluding Mill Residues and Black Liquor (Million dry tons per year after transportation)

Feedstock	Up to $27.50/dry ton	Up to $40.00/dry ton	Up to $52.50/dry ton	Up to $65.00/dry ton
Agricultural Crops Residues	0	0.7	45	56
Potential Energy Crops	0	0	53	123
Forest and Other Wastes	0	15	23	49
Total	0	16	121	228

The annual quantity available for ethanol production, at up to $65 per dry ton (including costs of transportation to the biorefinery), has been reduced from 372 to 228 million dry tons after applying the reduction factors from **Table 6**. In the longer term (2040, for example), crop yields increasing at the rate of 1% per year will result in additional feedstock as shown in **Table 8**.

Table 8. Long-term Biorefinery-Gate Supply vs. Prices Excluding Mill Residues and Black Liquor (Million dry tons per year after transportation)

Feedstock	Up to $27.50/dry ton	Up to $40.00/dry ton	Up to $52.50/dry ton	Up to $65.00/dry ton
Agricultural Crops Residues	0	1	68	83
Potential Energy Crops	0	0	78	184
Forest and Other Wastes	0	15	23	49
Total	0	16	169	316

At approximately 93 gallons of ethanol per dry ton of feedstock, the potential supply in the long term is 29 billion gallons per year. This potential would increase significantly with appropriate incentives such as those aimed at reducing carbon emissions.

Expected Market Uptake - Although the proposed Renewable Fuels Standard (RFS) is expected by many to be enacted, this analysis is limited to existing policies and does not include consideration of the RFS. Corn ethanol is projected to continue to expand as a result of various states' phase-outs of MTBE, but only to approximately 4 billion gallons/year by 2014 compared with approximately 5 billion gallons/year under the proposed RFS. Future cellulosic ethanol capacity will slowly replace corn ethanol capacity as the new technology becomes more and more competitive relative to corn ethanol. The tables show corn ethanol continuing at a fairly stable level through 2050.

The Biomass Program estimates that, beginning in 2012, corn ethanol plants will deploy the technologies for processing corn fiber, a cellulosic feedstock, into ethanol. This would be in addition to their continuing production of ethanol from corn starch. Beginning in 2018, a number of the ethanol plants will also convert corn stover to ethanol, if R&D is successful. Beginning in 2024, the first E-biorefineries producing ethanol as a major product (along with high-value coproducts) from biomass wastes and residues will be completed and begin operation. Note that a number of nonfuel biorefineries would have started producing before 2024, as described in the previous section on bio-based products analysis. Eventually energy crops (e.g., fast growing grasses) will supply the biorefineries to augment the residues.

The analytic tool ELSASBioref was used to estimate ethanol market penetration for cellulosic ethanol, including from corn stover, energy crops and other cellulosic residues, but excluding corn fiber and residual starch. The market penetration of corn fiber and residual starch-based ethanol, small quantities in comparison with the other cellulosic ethanol, was determined exogenously with input from the Biomass Program experts. The following section describes ELSASBioref and its use for this analysis.

Methodological Approach - Biomass ethanol market penetration analysis was accomplished through the integration of the results of various analyses conducted primarily by national laboratory personnel and their subcontractors. ELSASBioref served as the integrating tool. The following discussion provides a brief overview of ELSASBioref and the integration methodology.

***Integration of Component Analyses* -** The four principal components integrated with the ELSASBioref tool are corn feedstock and conversion cost and performance estimates, cellulosic feedstock supply curve information, cellulosic ethanol conversion technology data, and ethanol demand curve information. These components are described in greater detail in the following sections.

ELSASBioref is a spreadsheet-based economic equilibrium analysis tool that integrates these four sets of data – along with additional technical, economic, and policy variables – to derive ethanol supply and demand curves and estimate market penetration (see **Figure 1** depicting the input and output).

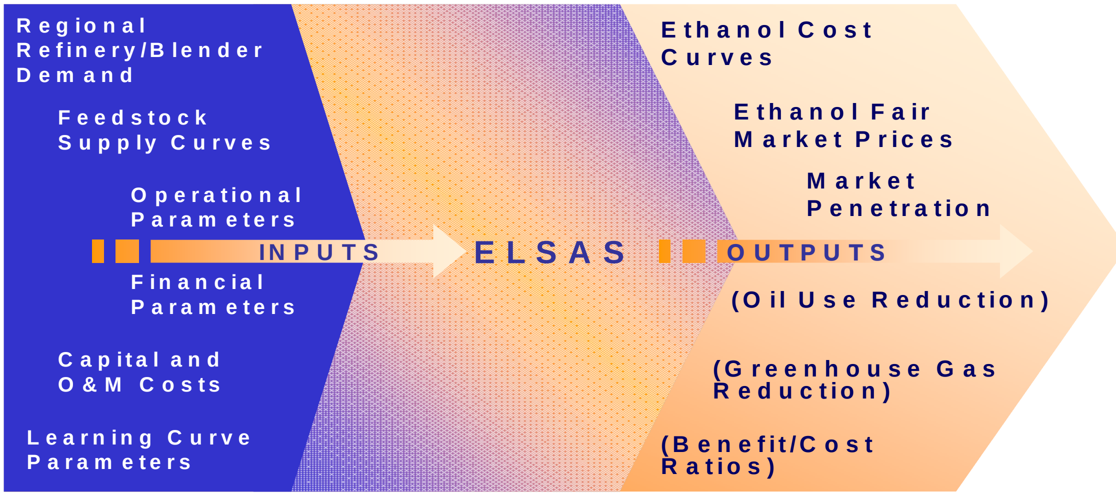

Figure 1. ELSASBioref Input and Output Parameter Categories

The model uses cost projections provided by NREL's design team to characterize the enzyme-based technology used to convert cellulosic feedstocks to sugars and eventually ethanol. The model combines this data with cellulosic feedstock supply data to generate the cost and incremental supply of ethanol available for a given year.

For the last year in each five-year increment (to 2050), ELSASBioref balances supply and demand of ethanol by establishing a market-clearing price. For supply levels greater than the amount of corn starch-based ethanol production, the marginal cost of ethanol supply at each five-year increment is determined by cellulosic ethanol production costs and feedstock costs. Feedstock costs may increase with increasing demand in accordance with supply curves provided by experts at Oak Ridge National Laboratory.

Quantities demanded at different prices are represented in a demand curve for ethanol. For the last year in each five-year increment, supply and demand are balanced through a market-equilibrium price. The production of starch-based ethanol for that year is subtracted from the total demand for ethanol to calculate the total volume of cellulosic ethanol produced. Quantities of cellulosic ethanol produced in the first four years in the five-year increment are determined by interpolation. This process of determining market-equilibrium quantities and prices is performed for each five-year increment to 2050.

Additional details regarding the three primary data-input components and their treatment within ELSASBioref are presented below.

EERE provided estimates of growth rates for conventional corn starch based ethanol supply, and these were incorporated as additional input data in the ELSASBioref model.

Cellulosic Feedstock Supply - Oak Ridge National Laboratory (ORNL) developed cellulosic feedstock supply curves with the aid of BIOCOST[5], POLYSYS[6], and other regionally detailed models. The feedstock supply-curve information shows quantities of different categories of cellulosic feedstocks available at different prices and time periods. This information is used by ELSASBioref at a national level of aggregation. The current GPRA case uses ORNL data reported by Arthur D. Little Inc[7]. These data were modified based on more recent ORNL work on agricultural residue availability and cost[8].

Within ELSASBioref, cellulosic feedstock costs are adjusted to include transportation charges from the farm gate to the conversion facility, and feedstock supplies are allocated among different competing uses as described above in the Technical Potential section. In addition, the analysis assumes that agricultural residues and bio-energy crops will increase at an annual rate of 1% during the analysis period, due to increasing agricultural productivity. This assumption yields a total U.S. feedstock supply in 2040 approaching 316 million dry tons of agricultural residues, forest wastes, energy crops and other biomass wastes, after excluding potential competing uses.

Ethanol Conversion Costs **-** NREL, which is partnering with industry and universities to develop competitive ethanol production technologies, provided estimates of cellulosic ethanol production costs (other than feedstock-related costs) on a per-gallon basis. The NREL estimate of the efficiency of converting feedstock into ethanol is input as a function of date, namely the number of gallons per dry ton of feedstock increases in the future as a result of R&D success. This allows the ORNL-provided feedstock costs to be presented on a per-gallon basis and added to the NREL non-feedstock costs to obtain the cost of producing a gallon of cellulosic ethanol.

Ethanol Demand **-** Demand curves for ethanol (for use as a blending component with gasoline) are developed by ORNL refinery modelers. The value of ethanol to refiners is based on its blending characteristics including octane rating, toxics dilution, sulfur dilution, effect on Reid vapor pressure in summer reformulated gasoline, etc. The refinery model ORNL-RYM uses this value along with crude oil and gasoline price projections, public policy variables, and numerous technical and economic factors relating to oil refinery operations. For a given set of input assumptions, the ORNL analysis generates quantities of ethanol demanded by refineries for blending with gasoline at different prices. Procedures were developed to modify RYM outputs to different world oil price scenarios. Ethanol transportation costs also are used in the analysis.

Benefits Estimation **-** The factors used by NEMS-GPRA06 and MARKAL-GPRA06 for calculating reductions in fossil energy use and carbon emissions were derived from the EERE Environmental Benefits Model GREET. The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model is maintained by Argonne National Laboratory and is widely used within EERE, by industry, universities, and other government agencies. GREET contains characterizations of several biomass feedstock sources, including herbaceous and woody biomass, corn, and soybeans. GREET models many transportation fuels and vehicle technologies and includes representations of major electricity generation sources. GREET can compare energy and emission changes for alternative technologies, relative to a base technology in a unified and consistent way.

Sources

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