Appendix B – GPRA05 Biomass Program Documentation

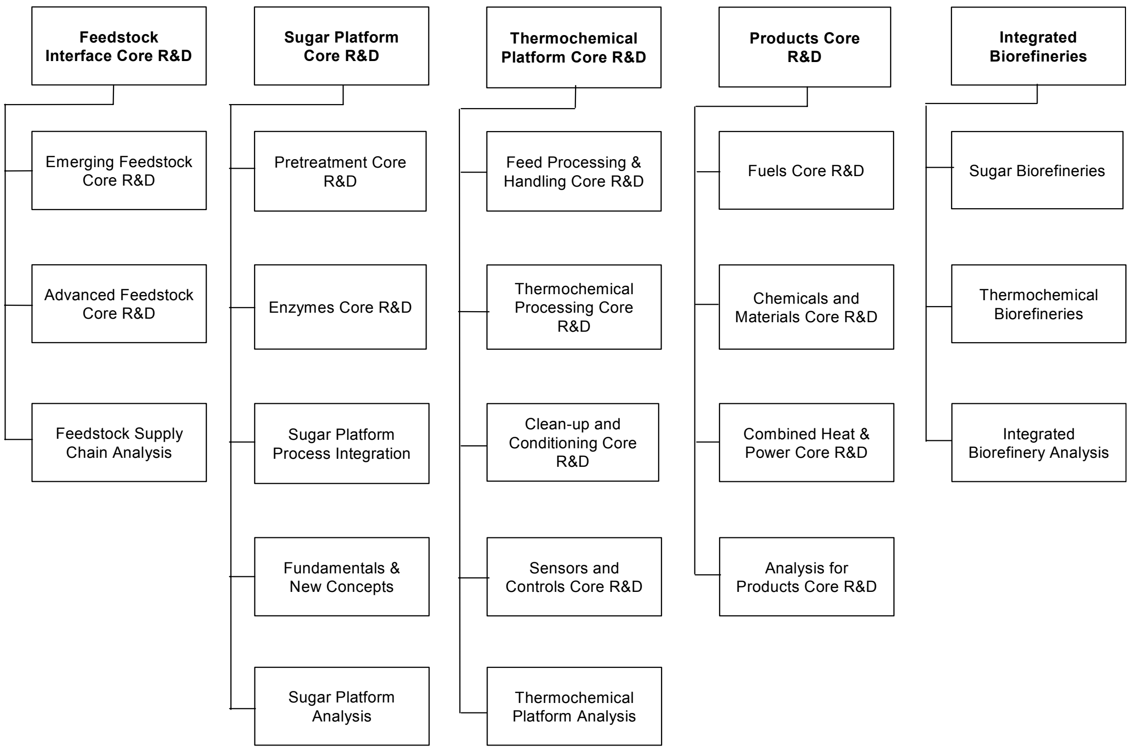

Figure 1. The Biomass Program Hierarchy

Introduction

This report discusses the assumptions and methods employed in the analysis that provided inputs to the process of estimating the benefits of EERE's Biomass Program. There were two separate analyses conducted for the Biomass Program, one for bioproducts and one for biofuels.

The major focus of the Biomass Program is to establish the economic viability of biorefineries producing fuels and high-value bio-based products, i.e., chemicals and/or materials from biomass feedstock, along with heat and power for internal biorefinery use. The biorefinery configuration may vary as a function of site-specific conditions, including feedstock availability and price, local market demand, and other factors. This analysis is based on two types of biorefineries: biorefineries producing primarily fuel ethanol and high-value chemical coproducts; and biorefineries producing chemicals and materials other than fuels. Technical research data that can support analyses of integrated, multiproducts biorefineries are being developed by the government and industry. Consequently, the market penetration estimate for bio-based products from nonfuel biorefineries was calculated separately from biorefineries producing primarily ethanol. As additional research is completed, new fuels and coproducts and other biorefinery concepts may be added to the biorefinery analysis. Both the bioproducts and the biofuels analyses focus on benefits of future achievements by the EERE biomass program and specifically exclude any future or past benefits resulting from historical technology improvements.

As bio-based products increasingly penetrate markets, they will displace petroleum feedstocks traditionally used in the production of such products. However, more important, as bio-based products are produced in biorefineries, they will serve as enabling agents that reduce the costs of the coproduced energy products. This will occur through production synergies and the allocation of capital and operating costs across a broad array of energy and nonenergy biorefinery products. The bio-based products analysis was based on generic bio-based products.

The biofuels analysis was limited to ethanol, because it is the current focus of the biofuels element of the biomass program. Other biofuels may be included in the future when more data are available.

The biofuels analysis is based on a sugar-based biorefinery configuration that will produce primarily ethanol, along with side-streams (in smaller quantities) of high-value, generic bio-based products. The biofuels analysis did not estimate the benefits from the coproduction of bio-based products, other than what is inherent in their role of increasing ethanol market penetration through the synergistic affects (as discussed above) of biorefinery credits. The credit for bio-based coproducts is based on 1 cent per gallon of ethanol produced in 2020 and gradually increasing to 14 cents per gallon by 2050, as biorefinery technology matures. Additional biorefinery configurations will be defined and analyzed as new data and analytic tools become available.

For the biofuels analysis, the Ethanol Long Range Systems Analysis Spreadsheet (ELSAS) was used to integrate ethanol supply and demand data to determine market penetration. The ELSAS results were then used as input to the NEMS-GPRA05 and MARKAL-GPRA05 models to determine benefits.

Section 2 presents the documentation of the analysis for bio-based products. **Section 3** presents the documentation of the analysis for biofuels.

Bio-based products

In prior years, energy and environmental benefits analyses were performed for each industrial bio-based product (chemicals and materials) R&D project using a Microsoft Excel spreadsheet originally developed by Energetics, Inc., and later modified by Arthur D. Little and other consultants for the Industrial Technologies Program. The metrics were projected approximately 20 years into the future using an experience-based market-penetration model. Variables such as commercialization years, target-market sizes, and market-penetration rates were estimated using input from the principle investigator, industry experts, and the project manager.

At this time, data are insufficient to support a truly integrated biorefinery approach to the analysis. Instead, the industrial bio-based products analysis methodology for the GPRA FY 2004 analysis was modified for GPRA FY 2005 to focus on the energy savings from "generic" industrial bio-based products and to be more closely aligned with the industrial bio-based products goal: "through 2010, establish the technical and market potential of at least three new commodity-scale chemicals and/or materials." This goal is from the FY 2005 budget request submitted to the Interior and Related Agencies Subcommittee.

Because the Biomass Program has not identified specific targeted bio-based products at this point, the benefits analysis is based on generic products. The energy-use profile from the FY 2004 GPRA estimates for 2005 was averaged to estimate the energy-use profile for the average generic industrial bio-based product. The profile, which included a wide range of bio-based products (polymers, solvents, and other chemicals and materials), was averaged by summing the energy savings from the GPRA FY 2004 bio-based products analyses and dividing the total by the volume of products it represented. This resulted in a profile of approximately 20,000 Btu of fossil energy displaced per pound of generic bio-based product, with the displaced energy distributed between feedstock and processing requirements. It should be noted that the energy-use profile below does not consider the use of biomass materials for on-site energy generation through co-firing or other methods. Bio-based products may consume more electricity than conventional chemicals and materials. Starch/lignocellulosic-based products will involve handling dilute aqueous streams from the pretreatment step and through the final processing step, requiring considerable electricity for processes such as separation and purification (negative electricity saving in the table of energy savings below).

Near-term (2005-2010) energy and environmental benefits were estimated, based on the progress of current Biomass Program-funded industrial bio-based product R&D toward commercialization in a biorefinery. From 2010 to 2015, the market for industrial bio-based products developed with Biomass Program support was projected to grow 4% annually as those bio-based products that are commercialized in the next few years increase their market share and additional biorefineries are constructed.

As the market share and consumer awareness and acceptance of industrial bio-based products increases, it is projected that the subsequent commercialization of new products and market growth of established bio-based products will proceed at a slightly faster rate. Beyond 2015, the annual growth was increased to 6% to reflect the accelerated commercialization/market growth of industrial bio-based products produced in integrated biorefineries. **Table 1** presents energy-related inputs to the NEMS-GPRA05 model related to bio-based products. The final table in this section provides estimates of the current production of bio-based products compared to the sizes of the markets in which these products compete.

Table 1. FY05 Bio-based Products NEMS-GPRA05 Inputs
Energy Savings due to Bio-based Products Market Penetration

		2005	2010	2015	2020	2025
Natural Gas	T Btu	3.37	7.49	9.12	12.20	16.33
Coal	T Btu	0.22	-0.82	-1.00	-1.34	-1.80
Electricity[1]	B kWh	-0.38	-0.66	-0.80	-1.07	-1.44
Distillate	T Btu	2.80	7.88	9.59	12.84	17.18
Oil Feedstock	T Btu	7.67	18.27	22.22	29.74	39.80
Total	**T Btu**	**10.04**	**26.87**	**33.29**	**44.96**	**60.16**
Annual Growth from previous period				4%	6%	6%

Current (1999-2001 depending on data source) Market Size

Lubricants and greases[1]	19.6 Billion lbs
Organic chemical (including polymers)[2]	175.2 Billion lbs
Polymers[3]	100.1 Billion lbs
U.S. Bio-based products[4]	12.4 – 21.1 Billion lbs (depending on study)

Biofuels (Ethanol)

Target Markets

Market Description

In 2003, U.S. fuel ethanol production reached 2.8 billion gallons, an increase of 32% from the previous year.[5]

EERE targets ethanol technology for the gasoline additive market in the midterm and as a gasoline substitute in the longer term. In 2002, approximately 99% of the ethanol consumed in the United States was for the gasoline additive market and 1% was for gasoline substitute.[6] 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 as MTBE is phased out in many states due to environmental concerns (see discussion of MTBE later in this section for additional detail). As recently as 2002, MTBE accounted for approximately 70% of the oxygenate market.[7] In 2002, MTBE accounted for approximately 2.39% and ethanol 1.16% of the U.S. on-highway motor fuel (gasoline plus diesel).

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

[1] Negative electricity savings represent greater electricity consumption in converting biomass feedstocks to products compared to converting petroleum feedstocks to similar products.

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 barges 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 the MTBE consumption.

The 2003 production level for ethanol was more than 2.8 billion gallons per year. The consumption of MTBE in 2002 was approximately 4 billion gallons, but MTBE consumption will decline as California, New York, Connecticut and other states transition 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.

To promote a stronger role for ethanol and other biofuels in the U.S. fuels market, Congress has debated a Renewable Fuels Standard (RFS), which would require that gasoline sold or dispensed to consumers in the United States contain a certain volume of renewable fuel. The proposed requirement for renewable fuel volume would ramp up to 5.0 billion gallons per year within approximately 10 years. Thereafter, the RFS volume would increase proportionately to the increase in total motor fuel consumption. This program has provisions for a credit-trading system that would give refiners flexibility for implementing the RFS in the marketplace. Other biofuels besides ethanol, such as biodiesel (a biologically derived fuel from soybeans, rapeseed, or used cooking oil) for blending with diesel fuel can be used to satisfy the RFS requirement. The proposed legislation also called for repealing the RFG oxygen requirement. Congress is still debating the RFS requirement, but many analysts believe it will be enacted during FY 2004.

Vehicle fleets 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 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, (2) it is generally more costly than gasoline on a BTU 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 parity between the value of 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

In its AEO2003 Reference Case, the Energy Information Administration (EIA) assumed a growth scenario for cellulosic ethanol. EERE analysis uses EIA's reference case as the basis for calculating its baseline—a scenario in which there is no EERE R&D. After evaluating the technical and market barriers to the development of ethanol biorefineries using cellulosic feedstock, EERE concluded that without Federal investment in RD&D, the cellulosic ethanol industry would grow at only 25% (at best) of the rate postulated in the EIA Reference Case. The rationale for this assumption 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. This development will require active public/private collaboration before cellulosic ethanol can effectively compete in fuel markets.

Baseline Market Acceptance

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 on a Btu basis. 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 a Btu basis. 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 rapidly accept nearly pure ethanol such as E85 because of its environmental characteristics and indigenous supply basis. Increases in market penetration for ethanol also will 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

Price

The price of biomass-based fuels is sensitive to biomass feedstock costs, the impacts on production costs of biorefinery synergisms, 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).

Non-price Factors

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, including 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, etc.

A 2002 study[8] 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 also are 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 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, the National Renewable Energy Laboratory (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.

Biorefinery configurations with integrated production of fuels, heat and power, and bio-based products need to be defined in more detail as soon as additional research data are available. While the relevant manufacturing factors are not fully understood, the need and overall process for contamination control in a sugar-based fermentation plant can be derived from the experience of current pharmaceutical and ethanol plants.

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

Inputs to Base Case

Table 2 contains the products of the analysis documented in this report, which serve as inputs to the NEMS-GPRA05 and MARKAL-GPRA05 integrated benefits analyses. NEMS-GPRA05 analysis extends through 2025, while MARKAL-GPRA05 analysis extends through 2050. The methodology employed to derive these inputs is described below.

Table 2. FY05 Ethanol Inputs (millions gallons per year)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Corn	1600	1770	2130	2700	2725	2750	2800	2850	2900	2950	3000	3050	3100
Cellu	0	0	0	0	0	0	0	20	40	60	90	120	150
Total	1600	1770	2130	2700	2725	2750	2800	2870	2940	3010	3090	3170	3250
Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Corn	3150	3200	3200	3200	3200	3140	3140	3140	3080	3080	3080	3020	3020
Cellu	200	250	300	370	440	510	610	710	810	950	1090	1230	1410
Total	3350	3450	3500	3570	3640	3650	3750	3850	3890	4030	4170	4250	4430
Year	**2026**	**2027**	**2028**	**2029**	**2030**	**2035**	**2040**	**2045**	**2050**				
Corn	3020	2970	2970	2970	2920	2800	2680	2540	2380				
Cellu	1650	1930	2250	2610	3010	4610	6400	8300	10200				
Total	4670	4900	5220	5580	5930	7410	9080	10840	12580				

Technical Characteristics

For the sugar-based biorefinery concept, the analysis is based on a plant whose main product is fuel ethanol with coproduction streams of electricity and high-value chemicals and/or materials, which result in a reduced cost of ethanol due to the allocation of plant capital and operating costs across several products. The effect of the coproduction of electricity is inherent in the NREL cost estimates used in this analysis. A biorefinery credit was employed to account for the effect of other coproducts (chemicals and/or materials). The credit is 1 cent per gallon of ethanol produced in 2020 and gradually increases to14 cents per gallon by 2050. The high-value chemicals and/or materials that will be coproduced are not yet identified. The biorefinery credit is based on a moderate rate of technical success with respect to coproducts manufacturing and is considered by the analysts to be conservative.

Although the analysis considered competition for raw feedstocks (see discussion in next section), it did not explicitly consider the possible competition –between ethanol and chemical and materials coproducts – for the sugar stream within the biorefinery. Such competition can affect the ethanol production volume and conversion efficiency. This consideration will be included in future analyses, once biorefinery configurations and processes are better defined and understood.

The analysis is based on a biorefinery with a throughput of 2,000 dry tons of feedstock per day and with a conversion efficiency (in gallons of ethanol per dry ton of feedstock) increasing from 82 in 2020 to 101 in 2050 as a result of technological advances contemplated by the Biomass Program. This compares with current conversion efficiency of 70 gallons per dry ton.

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 ELSAS model (for near-term conditions) are presented in **Table 3.**

Table 3. Farm-gate Biomass Quantities Supplied vs. Price Range (millions dry tons per year)

Feedstock excluding mill residues and black liquor	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	6	65	80
Potential Energy Crops	0	5	120	280
Other Wastes	0	17	25	35
Total	0	40	230	465

The total is 465 million dry tons per year, at up to $50 per dry ton, before adding transportation costs to the biorefinery.

Some of the biomass likely will be used for fiber products, power, and chemicals. The fraction of feedstock evaluated for biofuels is shown below:

Forest Residues	0.4
Agricultural Crops Residues	0.8
Potential Energy Crops	0.8
Other Wastes	0.7

While forest residues and some of the "other wastes" may not be optimal for fermentation-based ethanol production, we recognized that future syngas-based fuels production may use forest residues and certain "other wastes" as feedstock. Therefore, the analysis is not deemed to be overly optimistic in spite of this year's focus on fermentation-based biorefineries for the GPRA analysis. After adding transportation costs from the source, such as the crop field or forest, the near-term supply for biofuels as a function of price per dry ton at the biorefinery gate is shown in **Table 4.** (Note that the maximum 465 million dry tons were reduced due to the fact that not all biomass will be used for biofuels production)

Table 4. Biorefinery-gate Quantities Supplied vs. Price Range (millions dry tons per year)

Feedstock excluding mill residues and black liquor	Up to $27.5/dt	Up to $40.0/dt	Up to $52.5/dt	Up to $65.0/dt
Agricultural Crops Residues	0	4.8	52	64
Potential Energy Crops	0	4.0	96	224
Forest and Other Wastes	0	17	25	52
Total	0	26	173	340

The annual quantity available to ethanol production, at up to $65 per dry ton (including costs of transportation to the biorefinery), is now 340 million dry tons. About 120 million dry tons per year at this price range would be available for other uses. In the longer term (2040, for example), crop yields increasing at the rate of 1% per year will result in additional biomass residues and the supply will be as shown in **Table 5.**

Table 5. Long-term Supply for Biofuels (millions dry tons per year)

Feedstock excluding mill residues and black liquor	Up to $27.5/dt	Up to $40.0/dt	Up to $52.5/dt	Up to $65.0/dt
Agricultural Crops Residues	0	7.1	77	95
Potential Energy Crops	0	4.0	96	224
Forest and Other Wastes	0	17	25	52
Total	0	28	198	371

At approximately 95-100 gallons of ethanol per dry ton of feedstock, the potential supply in the long term is at least 35 billion gallons per year.

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 3.2 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.

Corn ethanol plants are projected to develop and improve their ability to process corn fiber, a cellulosic feedstock, into ethanol (in addition to their continuing production of ethanol from corn starches) in the 2007-2022 time frame. Beginning in 2007, some municipal solid wastes also will be converted into ethanol (the Masada project in New York and similar projects). Beginning in 2019, biorefineries producing ethanol as a major product (along with high-value coproducts) from biomass wastes and residues will begin operation. Note that a number of other, non-ethanol biorefineries would have started producing before 2019, as described in the previous section on bio-based products analysis for input to NEMS-GPRA05. Eventually bio-energy crops, such as fast growing grasses, also will supply the biorefineries.

The analytic tool ELSAS was used to estimate ethanol market penetration, based on a moderate biorefinery credit resulting from coproducts that would enhance biorefinery economics. The following section describes the ELSAS tool 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 lab personnel and their subcontractors, employing different specialized tools. ELSAS served as the integrating tool.

The following discussion provides a brief overview of ELSAS and the integration methodology.

Integration of Component Analyses

Three components of biomass ethanol analysis are integrated using ELSAS. These components are feedstock supply data, conversion technology data, and ethanol demand data. These three components are described in greater detail in the following sections.

ELSAS is a spreadsheet-based economic equilibrium analysis tool that integrates these three sets of data – along with additional technical, economic, policy, and financial variables – to derive ethanol supply and demand curves and determine market penetration (see **Figure 2,** depicting the inputs and outputs of ELSAS).

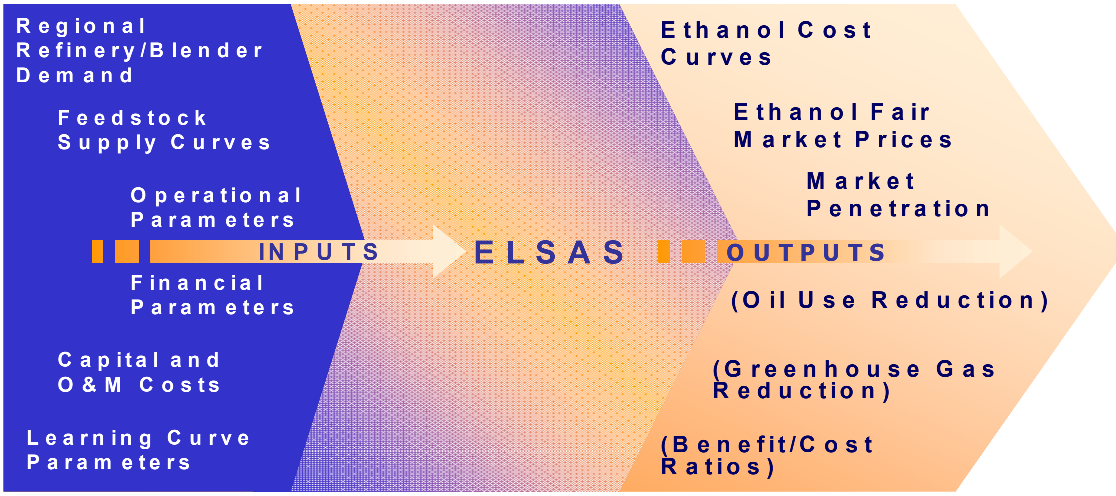

Figure 2. ELSAS Input and Output Parameter Categories

The model depends on an estimate[9] of near- to mid-term technology development by NREL as the starting point for a learning-curve cost-reduction algorithm for the technology used to convert feedstocks into ethanol. Dartmouth University professor Lee Lynd's estimates[10] of the expected long-term improvement in cellulosic technology were adapted to bound the other end of the learning curve. Using these boundaries, the learning curve equation was developed through the use of a curve-fitting process applied to various estimates made by NREL of the cost of ethanol from production facilities of increasing sophistication, with some modification by the Department of Energy. The learning curve provides the cost of the non-feedstock components of ethanol cost for each given year in the analysis period. The model combines this data with feedstock cost and supply-availability 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), ELSAS 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 (which generally decline in the analysis due to the operation of the learning curve) and feedstock costs (which can increase with increasing volumes of feedstock use).

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 corn 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.

While ELSAS is an ethanol market-penetration analysis tool rather than a biorefinery market analysis tool, the inclusion of a biorefinery credit effectively creates the first step in the direction of an integrated market model for various biomass applications. While presenting results primarily in terms of cellulosic ethanol, it provides for the economic consequences of other uses of biomass feedstock, and models the economic impacts on ethanol production of generic (or nonspecific) biorefinery technology. This biorefinery credit is described above in the section on Technical Characteristics.

The time frame used in this analysis and the relative immaturity of biorefinery technology creates considerable uncertainty in this analysis. Numerous unforeseen advances in technology are likely to impact these projections. However, the results indicate long-term economic value based on the successful achievement of EERE's goals for biomass technologies, with adequate feedstock at economically viable costs in the long term to support multiple uses.

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

Feedstock Supply

Oak Ridge National Laboratory (ORNL) developed cellulosic feedstock supply curves with the aid of BIOCOST[11], POLYSYS[12], 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 ELSAS at a national level of aggregation. The current ELSAS GPRA case uses data developed by Arthur D. Little, Inc.,[13] which was adapted from ORNL feedstock data. These data were modified based on more recent ORNL work on agricultural residue availability and cost[14].

Within ELSAS, the feedstock costs were adjusted to include transportation charges from the farm gate to the conversion facility, and feedstock supplies were allocated among different competing uses as described above in the Technical Potential section. In addition, the analysis assumes that agricultural residues 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 370 million dry tons of agricultural residues, forest wastes, energy crops and other biomass wastes, after excluding potential competing uses.

Ethanol Conversion Cost

Ethanol conversion technology characterizations, in conjunction with feedstock costs, determine ethanol production cost. NREL, which conducts research and development work (in partnership with industry and universities) aimed at developing cost-competitive processes for producing ethanol from cellulosic feedstocks, develops estimates of production costs. Sale of electric power as a by-product of plant operations is also a factor for some cases. Surveys by the U.S. Department of Agriculture[15], industry publications, and other sources are used to estimate costs for corn grain-based ethanol.

Production-cost calculations in ELSAS make use of several different elements. First, an estimate of the conversion efficiency of feedstock into ethanol is derived. This efficiency is a function of date, which increases in the future as a result of R&D success envisioned by the program. This allows the feedstock component to be converted into one of the components of cellulosic ethanol cost. Next, near-term to mid-term estimates of the non-feedstock cost component are selected by the user, based on the Biomass Program's input. The default conversion efficiency and non-feedstock component of production cost are based on the program's studies published by NREL.[16] Then, a long-term, lower-bound estimate of the same component cost is selected, consistent with long-term goals. Cost reductions are modeled over time with a learning curve methodology, which projects technology improvements with increasing, cumulative industry production. The non-feedstock cost component is not allowed to fall below the lower bound. The user may modify the default values for conversion efficiency if new data are available. The parameters of the learning curve equation also can be varied by the user if new data suggest the need for doing so.

Ethanol Demand

Demand curves for ethanol (for use as a blending component with gasoline) are developed by ORNL under the direction of Jerry Hadder. The value of ethanol to refiners based on its blending characteristics (octane rating, toxic dilution, sulfur dilution, effect on Reid vapor pressure in summer RFG, etc.) is considered, along with crude oil and gasoline price projections, public policy variables, and numerous technical and economic factors relating to oil refinery operations. Analyses are developed with the use of the ORNL Refinery Yield Model (ORNL-RYM), a linear programming tool that simulates oil refinery operations. For a given set of input assumptions, the results of the ORNL analysis show 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. When complete RYM data has not been available, other analytical results (from a similar refinery linear program operated by MathPro) were used along with RYM outputs. Ethanol intra- and inter-regional transportation costs also are considered.

Benefits Estimation

The factors used by NEMS-GPRA05 and MARKAL-GPRA05 for calculating reductions in fossil energy use and carbon emissions were derived from the EERE Environmental Benefits Model GREET. The **G**reenhouse gases, **R**egulated **E**missions, and **E**nergy use in **T**ransportation (GREET) model is maintained by Argonne National Laboratory and is widely used within EERE, by industry, universities, and other government agencies, including those in several other countries. 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.

Endnotes

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