APPENDIX C – BIOMASS PROGRAM
INPUTS FOR FY 2008 BENEFITS ESTIMATES

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Introduction

Program Summary

On February 20, 2006, in his State of the Union Speech, President Bush announced the Advanced Energy Initiative. The Biofuels Initiative, a key component of the President's Initiative, is designed "to foster the breakthrough technologies needed to make cellulosic ethanol cost-competitive with corn-based ethanol by 2012, enabling greater use of this alternative fuel to help reduce future U.S. oil consumption" (White House 2006). The U.S. Department of Energy (DOE)'s Biomass Program is working to meet the ethanol-related goal of displacing up to 40 billion gallons of gasoline per year by 2030. Fuel ethanol is being targeted for the domestic gasoline market because gasoline vehicles are already using gasoline containing up to 10% ethanol. Furthermore, the automobile industry has produced and sold several million flexible fuel vehicles that can use either gasoline or any gasoline/ethanol mixture containing up to 85% ethanol by volume.

As an interim step leading to future biorefineries, the Office of the Biomas Program (OBP) is working with ethanol production plants (current biorefineries) on near-term technology aimed at increasing the ethanol production from corn kernels and enhancing the protein quality of the cattle feed co-product. The cattle feed is called distillers dried grain with solubles (DDGS). The current ethanol plants convert only the starch portion of the kernels to ethanol. The unconverted cellulosic fiber in the kernels and the small amount of "residual" starch (that is firmly bound to the fiber) show up in the DDGS, diluting its protein content and reducing its quality. Each ethanol biorefinery's output would increase if the program and its partners succeeded in converting the kernel fiber to ethanol. After the removal of the fiber and residual starch, the DDGS will be higher in protein content, making it more valuable as feed for poultry and swine. Success with the conversion of kernel fiber and residual starch will facilitate the industry's decision to partner with DOE and develop technology for other cellulosic feedstocks such as corn stover. The United States has considerable quantities of cellulosic biomass, including corn stover, wheat straw, rice straw, forest residues, the biomass component in urban wastes, etc. Future energy crops, e.g., fast-growing trees and grasses, would also be of increasing importance as cellulosic resources in the long term.

In summary, current dry mills use starch crops to produce ethanol and DDGS. By 2010**,** these corn biorefineries would convert some of the kernel fiber and residual starch to ethanol. By 2012, some of the dry mills would also produce chemicals or materials as co-products (Jechura 2005).

The existing corn ethanol biorefineries use natural gas and coal for process heat and power. In future biorefineries, the ethanol conversion process is expected to use waste biomass as a heat and power source such that natural gas requirements would be reduced. While the current analysis assumes that ethanol is the major output of biorefineries, future analyses could include additional fuels that OBP may identify later. In FY 2008 and future years, OBP plans to continue FY 2007 collaboration and enter into new partnerships with industry and others to advance the state of cellulosic ethanol production technology.

Significant Changes from Previous Analysis

There are no significant changes from the prior-year analysis for corn ethanol. For cellulosic ethanol, the current analysis uses a slightly more conservative schedule for achieving plant cost targets. Updated cellulosic supply curves were used to estimate benefits in the post-2030 time frame. The additional feedstock availability offsets somewhat the effect of the more conservative schedule for achieving conversion cost targets.

The Baseline ("without DOE RD3" case)

Without OBP's resources, industry would rely on loan guarantees and other applicable policies in the Energy Policy Act when building up the biorefinery industry. These policies are aimed at demonstration and implementation, not research and development. Research and development activities are needed to continue to decrease the cost of converting cellulosic feedstocks to ethanol if the large volumes envisioned by 2030 are to be achieved. Although small volumes of cellulosic ethanol may be produced with niche, low-cost feedstocks, it would be difficult to foster a major bio-industry within two decades without the DOE support for RD3. The ethanol industry would continue RD3 on the production of ethanol from corn fiber/residual starch, but work on agricultural residues and forest residues would be greatly reduced. Some of the technologies could come from other countries' R&D organizations. However, the deployment process for cellulosic ethanol requires the testing of new technology in costly pilot plants and demonstration plants. The investors would also want to see adequate progress made in feedstock production and collection before providing capital, because a pilot plant can cost up to $9 million and a demonstration plant up to $30 million. Farmers, i.e., feedstock producers, and farm equipment manufacturers must also actively participate before such projects can go forward. Therefore, it is anticipated that technological advances would be delayed by at least seven years for corn fiber/residual starch, 12 years for bio-based products technologies for dry mills, and 15 years for ethanol production technologies using cellulosic feedstock. The riskier cellulose conversion technologies would see a longer delay relative to the more near-term technology for corn fiber conversion.

Target Market Description

The dominant U.S. highway fuels are gasoline for light-duty vehicles (cars, minivans, vans, sports-utility vehicles, and certain light trucks), and diesel for buses and larger trucks. Gasoline accounts for approximately three-quarters of the oil used in this country's transportation sector. OBP focuses mostly on gasoline displacement at this time. Alcohol fuels are the most logical replacement fuels for light-duty vehicles because current gasoline engines could use various blends of alcohol fuel and gasoline with minimal modifications. Ethanol is the alcohol that has been approved by the U.S. Environmental Protection Agency (EPA) and car manufacturers for blending with gasoline up to 10% ethanol by volume. Ethanol is also the alcohol fuel approved for use in several other nations. Minor engine and vehicle modifications resulted in flexible fuel vehicles (FFVs) that can run on any blend of ethanol and gasoline, up to 85% ethanol.

Corn ethanol biorefineries, both dry mills and wet mills, currently use solely the corn kernels (no cellulosic feedstock) to produce ethanol and some co-products such as animal feed additives (both dry and wet mills), or corn oil and high-fructose corn syrup (wet mills), and a number of fermentation products such as lactic acid and lysine.

According to the Renewable Fuels Association, as of August 2006, ethanol plants operating in the United States had a total production capacity of 4.5 billion gallons, with an additional capacity of 1.89 billion gallons under construction or in expansion (Renewable Fuels Association 2006). Ethanol competes in transportation fuel markets for light-duty vehicles. In 2005, the U.S. consumed approximately 140 billion gallons of motor gasoline (EIA 2006). Nearly 80 companies operate approximately 100 plants in the United States. A few are large agri-businesses such as ADM and Cargill, but many are smaller producers focusing on ethanol as their main product. Nearly half of the plants belong to farmers' cooperatives. The plants obtain corn feedstock from local growers, several of whom may also be part owners of the ethanol plants through the cooperative arrangement.

In 2004, the majority of the ethanol consumed was used as an oxygenate component for gasoline, and the remainder was used as a gasoline additive to improve octane. The primary market where ethanol is used as an oxygenate component consisted of approximately 36 billion gallons of reformulated gasoline (RFG) in 2003 (Reynolds 2004). Within this oxygenate market, in early 2004, methyl-tertiary-butyl-ether (MTBE) and ethanol each provided approximately 50% of the volume. MTBE in RFG is approximately 11% by volume, whereas ethanol is between 5.7% and 10% by volume. This cleaner-burning gasoline, called reformulated gasoline or RFG, is required by the Clean Air Act in metropolitan areas that the U.S. Environmental Protection Agency (EPA) identified as having the worst smog pollution. Other cities with lesser smog problems may choose to "opt in" and use RFG also. The Federal RFG Program was introduced in 1995. RFG is currently used in 17 states and the District of Columbia. About 30% of gasoline sold in the United States is reformulated. Each oil company prepares its own formula that must meet federal emission reduction standards (Environmental Protection Agency 2006). To illustrate the size of this market, assuming an average ethanol concentration of 8.5% in the RFG market, 36 billion gallons of RFG would include 3 billion gallons of ethanol once ethanol completely replaces MTBE. By 2005, MTBE use declined to about 2 billion gallons, whereas ethanol demand increased to 4.0 billion gallons per year for both RFG and conventional gasoline (Schremp 2006). Ethanol has taken a larger share of the RFG market because MTBE has been or is being phased out in many states due to environmental concerns. Furthermore, EPACT 2005 did not contain language protecting MTBE sellers from liability. Some refiners have announced that they will cease using MTBE, and some pipeline operators have announced that they will not ship gasoline containing more than trace amounts of MTBE (Wheeler 2006).

Refinery operators do not blend ethanol with gasoline at the refinery. Instead, they produce a sub-grade, "base" gasoline, called reformulated blendstock for oxygenate blending (RBOB). The RBOB or base gasoline is not yet suitable for direct use in vehicles. Refinery operators ship this base gasoline, and ethanol plants ship ethanol to bulk terminals. The operators at bulk terminals blend the ethanol into the base gasoline to make RFG. Outside of California, RFG typically contains 10% ethanol by volume. California RFG is made with less ethanol, typically 5.7% by volume. Outside of the RFG market, ethanol is also blended with conventional regular gasoline, i.e., gasoline that is not RFG, to make “gasohol.” Unlike RBOB, conventional regular gasoline is suitable for direct use in vehicles. The addition of ethanol results in gasohol with higher octane relative to conventional gasoline without ethanol. Gasohol consists of 90% gasoline and 10% ethanol by volume, with the ethanol serving as an octane enhancer and gasoline extender (i.e., ethanol increases the volume of fuel used in the light-duty vehicles segment). Gasohol is primarily marketed in the Midwest as mid-grade gasoline. Both gasohol and RFG (made by adding ethanol) contain ethanol. However, gasohol and RFG have somewhat different emissions characteristics. As discussed earlier, EPA or state environmental agencies require several metropolitan areas to use RFG because this cleaner-burning fuel helps reduce smog problems. A number of regions that do not face smog problems chose to use gasohol (not as clean burning as RFG) for supply and economic development reasons, not because of problems with smog.

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 have not been routinely shipped via pipeline. Consequently, ethanol is shipped by rail, truck, and/or barge to bulk terminals, where it is blended into gasoline.

Vehicle fleets can be a source of additional demand for ethanol fuel. These include alternative-fuel vehicles that have been either modified or manufactured to accommodate the use of E85, i.e., 85% ethanol and 15% gasoline by volume. The E85 vehicles are flexible-fuel vehicles that can use either gasoline or E85 or any gasoline blend containing up to 85% ethanol. As of late 2006, the National Ethanol Vehicle Coalition estimated that there are approximately 6 million FFVs on the road, both as fleet and non-fleet vehicles (National Ethanol Vehicle Coalition, 2006). However, only a small number of FFVs use E85, because E85 is not widely sold and it is usually not as cheap as gasoline for the same driving distance. 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.). In 2004, the U.S. Department of Energy determined that a regulation requiring private and local government fleets to acquire alternative fuel vehicles (AFVs) is not necessary and, therefore, would not be promulgated. This ruling was pursuant to the investigation required by the Energy Policy Act of 1992, which revealed that an AFV requirement on private and local fleets would not appreciably increase the percentage of alternative fuel and replacement fuel used in motor vehicles (EERE 2004). The use of alternative fuels by government fleets would not displace a significant share of our gasoline consumption because the number of vehicles in government fleets is not significant. For example, the General Services Administration reported that the federal fleet included approximately 630,000 vehicles in 2005 (GSA 2006).

The market penetration of E85 has been much lower than for E10 because: (1) E85 has been frequently more expensive than gasoline on an energy-equivalent basis; (2) the availability of E85 refueling stations is limited; and, (3) an investment of approximately $50,000-60,000 per gasoline station is required for installing a new 12,000 gallon underground storage tank for E85 (Morris 2003, Raabe 2006). This cost would be reduced with the EPAct tax credit of up to $30,000 per gasoline station. Once sufficient ethanol is available at reasonable prices, the infrastructure barriers are not excessively difficult to overcome. For example, an automobile manufacturer can now produce a flexible-fuel version of any vehicle with only modest modifications to the engine. To minimize the cost of adding E85 storage capability, gasoline station owners could convert the existing mid-grade storage/dispensing system to E85 while retaining the capability to sell mid-grade gasoline. The owner may choose to upgrade the two dispensing systems for regular gasoline and premium gasoline such that he can still offer premium and regular, but has the option of mixing these two gasoline types to create mid-grade gasoline on demand. In this way, a gasoline station would be able to sell E85, and premium, mid-grade, and regular gasoline.

Baseline Adjustments to the *AEO2006* Reference Case

The Energy Information Administration (EIA) assumed that cellulosic ethanol will enter the market beginning in 2010, ramp up to 250 million gallons per year by 2012, and will grow no further (Radich 2006). This view of cellulosic ethanol growth appears to be too conservative. Technology can cross national boundaries through licensing and subsidiaries, and therefore one should not discount technological developments in other countries. Iogen, a Canadian enzymes manufacturer and biofuels technology developer, has built a small demonstration plant in Ottawa, Canada. At full capacity, Iogen's demonstration plant is designed to process about 30 metric tons per day of feedstock, and to produce approximately 2.5 million liters of ethanol per year. The plant uses wheat, oat, and barley straw as raw materials (Iogen 2004). Abengoa, a Spanish technology and engineering firm, plans to open a demonstration facility that makes ethanol out of wheat straw in Babilafuente (Salamanca), Spain. Commissioning is expected to start by the end of 2006. This plant will process 70 metric tons of agricultural residues, such as wheat straw, per day for producing more than 5 million liters of ethanol per year (Abengoa Bioenergy 2006). Japanese automaker Honda’s research and development division and the Research Institute of Innovative Technology for the Earth (RITE) are developing technology to produce ethanol from soft biomass such as leaves and plant stalks (World Refining & Fuels Today 2006). Within the United States, New York State is seeking proposals under a new $20 million grant program to develop and construct a pilot cellulosic ethanol facility (NYSERDA 2006). There may be other organizations planning to commercialize cellulosic ethanol technology. To account for these developments, EERE modelers partially modified the constraints in the NEMS model to allow additional ethanol expansion through 2030 in the baseline but did not increase the number of FFV models (Wood 2006).

Representation of Program-Relevant Technologies in the AEO Reference Case

EIA’s *Annual Energy Outlook* (*AEO2006*) includes corn ethanol technology and cellulosic ethanol technology but do not include the Biomass Program’s effects. The Energy Policy Act of 2005 requires the use of 250 million gallons of cellulosic ethanol starting in 2012. In a personal communication, Tony Radich said that EIA does not believe that much capacity would be built at once, so they assumed that cellulosic ethanol will enter the market beginning in 2010 and ramp up to 250 million gallons per year by 2012. EIA estimated a rather slow reduction in production costs, which limited the penetration of cellulosic ethanol to the required 250 million gallons in the *AEO2006* Reference Case. In the High Oil Price Case, cellulosic ethanol would grow to 1.9 billion gallons per year by 2030 (Radich 2006).

The *AEO2006* Reference Case projects that corn ethanol will grow rapidly to 9.2 billion gallons per year by 2013, and grow very slowly thereafter to 11 billion gallons per year by 2030. Furthermore, the *AEO2006* Reference Case showed that no ethanol would be used in E85 through 2030. The reasons include the higher cost of ethanol relative to gasoline on an energy basis, and the cost of adding E85 refueling capabilities.

Removing Effects of Program Activities

In the non-program baseline, commercial cellulosic ethanol production was assumed to begin 15 years after the start of such production in the Program Case. EIA's 2012 start date for commercial production was removed.

Other Program-Relevant Adjustments to AEO Reference Case

The DOE Office of Energy Efficiency and Renewable Energy updated a number of cellulosic feedstock supply curves (agricultural residues, forest residues, and switchgrass) to reflect better analytic techniques used by the University of Tennessee in early 2006.

Program Outputs

This section shows the connection between the Biomass Program's budgets, activities, milestones, outputs, outcomes, and benefits.

Assumed Budget Projections

The FY 2008 budget request for the Biomass Program is confidential until after the budget submission to Congress. A summary of the recent and requested budgets, by major area, is shown in **Table C-1**. The House and Senate have not yet met in conference on the FY 2007 budget request as of late CY 2006.

The budget request for FY 2009 through 2011 is confidential until after the budget submission to Congress. We assumed also that annual budgets through FY 2019 would be at 80% of 2009-2011 funding level.

Table C Error! No text of specified style in document.**-1 Biomass Program Budget**

(dollars in thousands)

	FY 2006 Current Appropriation	FY 2007 Request	FY 2007 House Mark	FY 2007 Senate Mark	FY 2008 Request[a]
Biomass and Biorefinery Systems R&D					
Feedstock Infrastructure	505	9,967	9,967	4,280	10,000
Platforms Research and Development	19,907	50,530	50,530	50,530	59,400
Utilization of Platform Outputs R&D	23,479	89,190	89,190	139,190	109,163

Congressionally Directed Activities	46,827	0	TBD	19,000	0
Operating Total, Biomass and Biorefinery Systems R&D	90,718	149,687	149,687	213,000	178,563
Capital Projects	0	0	0	0	15,700
Total, Biomass and Biorefinery Systems R&D	181,436	299,374	149,687	213,000	194,263

a. The amount of the request is confidential until after the budget submission to Congress.

Description of Key Activities

The Biomass Program focuses primarily on enabling integrated biorefineries that produce ethanol as the main output and, where possible, valuable co-products such as electricity and chemicals. Biorefineries use biochemical or thermochemical processes to convert feedstock into fuels and chemicals. A biochemical process involves the hydrolysis of biomass to sugars and subsequent fermentation of sugars to fuels or chemicals. The lignin residues that cannot be biochemically converted would be used as a fuel for the electricity and steam needed by the biorefinery. A thermochemical process involves the gasification of biomass to synthesis gases and subsequent conversion of the synthesis gases to fuels, chemicals, or heat and electricity. Additional information is in the Biomass Program's Multiyear Program Plan (Department of Energy 2005).

When processing lignocellulosic biomass, the biochemical biorefinery will convert the cellulosic portion of the biomass into ethanol and use, at least initially, the remaining lignin residues to generate process heat and electricity. Excess electricity will be sold to the grid, thereby reducing the net ethanol cost. The program assumed the co-production of a small quantity of non-fuel, bio-based chemicals or materials in corn ethanol biorefineries. For corn ethanol, these bio-based products were modeled as a "credit" that reduces the ethanol production cost.

Feedstock Infrastructure

Feedstock Infrastructure activities support the targets shown in **Table C-2.** The activities consist of: (1) R&D on future energy crops; (2) biomass collection and storage systems, including harvester development for the collection of agricultural residues and other cellulosic resources; and (3) development of supporting infrastructure and supply. DOE is establishing regional partnerships on feedstock development in collaboration with the United States Department of Agriculture (USDA), land grant universities, and private-sector consortia to ensure that the biorefineries will have access to plentiful feedstock supplies (including energy crops) at reasonable prices. The DOE Office of Science will also fund basic research to support this work, effectively increasing the probability of R&D success.

Platforms Research & Development

OBP is accelerating research on conversion technologies and process integration. OBP will expand partnerships to further improve the integration of pretreatment and enzyme operations that would lead to cheaper biomass-based sugars. This effort is required to support biorefinery validation projects with technology packages delivered to pilot plants and demonstration plants beginning in FY 2010 as shown in Table C-2. The Office of Science will also fund appropriate enabling research to increase the probability of achieving cost targets.

Utilization of Platform Outputs

These activities consist of cost-shared projects to validate integrated biorefinery designs that will focus on pathways with feedstocks such as corn fiber, corn stover, and oilseeds for converting biomass to fuels, chemicals, and/or materials. OBP will accelerate the validation of industrial-scale projects, an essential step in reducing technical risks associated with first-of-a-kind biorefineries. This acceleration will result in industrial-scale demonstrations whose dates are listed in Table C-2. Efforts will continue to integrate and test handling, pretreatment, hydrolysis, and fermentation operations to evaluate performance and costs of converting biomass to fuels and co-products.

Table C-2 shows the OBP outputs and associated activities and milestones. **Table C-3** links the OBP outputs with eventual outcomes.

Table C-2. Biomass Program: Outputs, Activities, and Milestones

Outputs	Associated Activities	Associated Milestones
Enable first corn biorefinery with corn fiber and residual starch	RD&D for corn fiber pathway at corn ethanol biorefineries	Conclude commercial demonstration with industry partner to increase ethanol output by at least 4% for each biorefinery by 2009
Enable first pilot-scale project with corn stover	RD&D with industry on pretreatment, hydrolysis and fermentation, and integrated validation at pilot scale	Deliver technology package to pilot-scale project by 2010. By 2012, evaluate process against target selling price of $1.07 per gallon of ethanol with a $35/ton feedstock cost or $1.22 per gallon with a $45/ton feedstock cost
Assist with legislation favorable to cellulosic ethanol, vehicles and fueling stations	Provide White House with analyses and position papers as needed	Enactment in 2012 through re-authorized Farm Bill and Energy Policy Act
Enable first demonstration-scale project with corn stover	Conduct RD&D with industry for stover cost reduction	By 2013, deliver technology for stover collection and storage to demonstration-scale project at a cost of $35 to $45 per dry ton (depending on region and tillage)
	Scale up stover-based ethanol technology with industry partners	By 2015, evaluate demonstration-scale production against target yield of 90 gallons of ethanol per ton of feedstock
Enable switchgrass commercialization	RD&D with Office of Science, universities and USDA to improve switchgrass varieties in multiple regions	Increase switchgrass yield per acre by 10% at test sites by 2015 from current regional levels Increase yield per acre by an additional 5% at test sites by 2019
Enable first pilot-scale projects with switchgrass and forest residues	RD&D with Office of Science and industry, leading to integrated validation at pilot scale	Deliver technology packages to two pilot-scale projects by 2016. By 2017, evaluate production at pilot scale against target yield of 90 gallons per dry ton
Enable first demonstration-scale project with switchgrass and/or forest residues	Scale up switchgrass-based ethanol technology with industry partners	By 2020, evaluate production at demonstration scale against target yield of 90 gallons per dry ton of feedstock
Enable next-generation cellulosic biorefineries for ethanol production	RD&D with Office of Science, USDA, and industry on production, collection, and storage of additional biomass resources. Partner with industry on demonstrations for longer- term feedstocks	Deliver improved switchgrass and more competitive technologies for biomass production, collection, and storage to demonstration facilities. Industry partners construct, operate, and evaluate subsequent demonstration-scale projects. New biorefineries start up - 2023 through 2028

Currently, the ethanol conversion efficiency is approximately 70 gallons per dry ton of biomass. The maximum theoretical conversion efficiency is more than 110 gallons per dry ton for several cellulosic materials, as shown on the National Renewable Energy Laboratory (NREL)'s theoretical yield calculator Web site (http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html). However, the targets in this analysis were kept below this limit. The current average switchgrass yield is nearly 5 dry tons per acre, per year; and expected improvements in yield are between 7% and 11% in 2015 relative to current varieties (Walsh 2006a). The cost range for cellulosic ethanol is reported by NREL at approximately $1.00 to $1.40 per gallon (Aden 2002) for a range of enzyme and fermentation performances and costs.

Table C-3. Biomass Program: Linkage of Outputs with Outcomes

Outputs	Associated Immediate Outcomes and dates	Associated Interim Outcomes	Associated Ultimate Outcomes
Enable first corn biorefinery with corn fiber and residual starch	Corn ethanol costs 2% less by 2010 thanks to DOE co-funding and collaboration	Ethanol industry deploys corn fiber and residual starch technology between 2010 and 2015	Benefits, e.g. increased energy security, reduced emissions, etc.
Enable first pilot-scale project with corn stover	Pilot-scale validation in 2012 helps improve the design of demonstration plants, thereby reducing risks	Facilitate industry's decision on demonstration projects after 2010. Farm equipment manufacturers accelerate R&D on residue harvesting and storage systems	Keep subsequent commercialization dates on target for benefits estimation
Assist with legislation favorable to cellulosic ethanol, vehicles and fueling stations	Appropriate policy helps to accelerate RD3	Accelerate commercialization over the next 15 years	Benefits, e.g. increased energy security, reduced emissions, etc.
Enable first demonstration-scale project with corn stover	Demonstrate technology at $1.07 selling price per gallon of ethanol with a $35/ton feedstock cost or $1.22 per gallon with a $45/ton feedstock cost. Lead to commercialization beginning in 2015	Industry deploys stover conversion beginning in 2015, spurring deployment of wheat straw and similar residues. Farm equipment manufacturers begin production of efficient harvesting and storage systems. Spurred by success with residues, farmers and industry begin to cost-share switchgrass demonstrations	Keep commercialization date on target
Enable switchgrass commercialization	Improved switchgrass varieties allow farmers and industry to collaborate on deployment beginning in 2019	New biorefineries plan on using switchgrass in selected regions beginning in 2019. Farmers incorporate switchgrass in their decision process for future plantings	Keep switchgrass commercialization date on target
Enable first pilot-scale projects with switchgrass and forest residues	Pilot-scale validation by 2017 helps improve the design of larger demonstration plants, thereby reducing risks for ethanol cost targets	Farm equipment and logging equipment manufacturers accelerate R&D on their respective harvesting and storage technologies	Keep subsequent commercialization dates on target
Enable first demonstration-scale projects with	Successful demonstration leads to commercialization beginning in 2019	Industry deploys ethanol from switchgrass and/or forest residues beginning in 2019.	Keep subsequent commercialization dates on target

switchgrass and/or forest residues		Farmers make planting decisions focusing on switchgrass. Farm equipment and logging equipment manufacturers begin production of efficient harvesting and storage equipment. Forest industry and Forest Service develop new forest management approaches	
Enable next-generation cellulosic biorefineries for ethanol production	Pilot and demonstration-scale projects enable additional biorefineries to use a wider variety of biomass resources	Biorefineries can keep production cost increases to a minimum even as higher demand pushes up biomass prices from 2020 on	Benefits, e.g. increased energy security, reduced emissions, etc.

Key Factors in Shaping Market Adoption of EERE technologies

Price – Ethanol subsidies are currently an important component of the market dynamics. Corn ethanol can compete in the high-value E10 market at current oil prices ($61-$64 as of late 2006). Refineries are willing to pay a higher price per gallon of ethanol for each 0.1 gallon of ethanol that will be blended with 0.9 gallon of base gasoline, because the ethanol fraction increases the octane of the gasoline/ethanol blend and helps reduce toxic emissions when E10 is used in vehicles. Beyond this first 10% volume in gasoline, additional ethanol would not contribute any more to the octane increase or toxic emissions reduction. In other words, the refiners will not pay the same high price for the next increment of ethanol. The additional ethanol would have to compete with gasoline strictly on the ability to deliver energy to drive a number of miles. The paradox is that ethanol fetches higher prices when used in E10, but would have to be priced much lower for a larger volume of ethanol to be used in E85. If ethanol could be produced much more cheaplyand its supply became much greater—ethanol prices might come down sufficiently so that this paradox no longer exists.

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

Vehicle compatibility

Essentially all gasoline vehicles in the United States can use the low-blend ethanol gasoline mixture (E10 or less). For high blends such as E85, automobile manufacturers have considerable experience in producing vehicles that meet the Environmental Protection Agency's requirements (Environmental Protection Agency 2000). Six million flex-fuel vehicles 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, and other models (General Motors Corp. 2006). U.S. car manufacturers have recently announced plans to increase E85 FFV production and to increase consumer awareness of these vehicles with beefed-up marketing campaigns (AFDC 2006, Detroit Free Press 2006). Manufacturers are making the FFV option standard on an increasing number of models. Therefore, there is no “non-FFV” option for those models. The issue of price differences between the FFV version and gasoline-only option does not arise.

Infrastructure Requirements

A 2002 logistics study (Reynolds 2002) did not foresee any major infrastructure barriers to a substantial expansion of the ethanol industry in a set of scenarios that were analyzed. The scenarios included substantial movement of ethanol among and within different regions of the country by several different modes of transport. The study revealed that investments in transportation, storage, terminal upgrades, and retailing are possible without encountering significant “growing pains” for up to 10 billion gallons per year. The study looked primarily at the blend or E10 market. Existing pumps at retail stations could be converted from dispensing pure gasoline to E10 with only minor modifications and cost. However, new pumps would have to be installed to dispense E85, and the amortized costs to the retail station would depend on E85 throughput. The study assumed that E85 use is expected to be small compared to E10.

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, 0.1 cent per gallon of E10, on an amortized basis. 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 2002 study found that 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 the 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 appropriate vessels and potential restrictions on 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 (Reynolds 2002).

When the ethanol market greatly exceeds 10 billion gallons per year, some of the aforementioned barriers could become constraining. The benefits analysis assumed that the United States, through the DOE Transportation Posture Plan and resulting roadmaps, would have implementation measures that would minimize the effects of these barriers. Initial coordination activities would be identified in a Posture Plan to be developed by the Biomass Program in FY 2007. Subsequently, EERE will develop a Transportation Posture Plan combining planning information from the Office of Science; the Vehicle Technologies, Biomass, and Hydrogen programs; and other federal agencies such as the departments of Transportation and Agriculture. It is reasonable to expect that the USDA will play a key role in R&D on energy crops and overall sustainability analysis, OBP will continue to lead the RD&D efforts with respect to biochemical and thermochemical conversion, the Vehicle Technologies Program will be the lead sponsor of automotive technology R&D aimed at taking advantage of biofuels properties, and the Office of Science will sponsor basic R&D that underpins the USDA and OBP research.

Key Consumer Preferences or Values

E10 consumption has historically been concentrated in the Midwest. In recent years, ethanol use in coastal RFG increased dramatically as state bans on MTBE began taking effect. As a result, some coastal states are beginning to adopt policies to promote in-state ethanol production. E85 is likely to penetrate markets more easily in the Midwest where most of the ethanol is produced and consumers have a long history of using ethanol fuels. 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. However, ethanol production costs must be lower than those of current corn ethanol and more competitive with gasoline in order for E85 infrastructure and acceptance to grow rapidly.

Manufacturing Factors

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 number of fuels (including ethanol) and chemicals may be derived. Pioneer plants will cost more because the technology would be new. With experience, the 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. This is also a result of the cost-reduction opportunities associated with the fast pace of biotechnology advances. 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

When NEMS and MARKAL analysts estimated the rate of market adoption, they assumed the continuation of existing laws, regulations, and policies (such as the ethanol tax incentive and the Renewable Fuels Standard) and continuing USDA and DOE investment in biomass technology RD&D at current levels, consistent with current energy policy legislation. The incentives are expected to play a key role in reducing the costs and financial risks of pioneer cellulosic ethanol plants.

Immediate Outcomes

The immediate outcomes resulting from OBP activities include pilot-scale and demonstration-scale validation of new biorefinery technologies, industry's development of novel biomass harvesting and storage subsystems, and the availability of cost-competitive biomass resources when new biorefineries start up. Cost targets are in 2004 dollars. The cost data that OBP provided to EERE modelers are capital and operating costs (not prices) as required by NEMS and MARKAL. OBP assumed that three years are needed between the completion of a demonstration and the first year of commercialization.

Interim Outcomes

At this time, there are two fuel ethanol markets, the low-blend market (up to 10% ethanol in gasoline) and the high-blend market (85% ethanol in gasoline). The value of ethanol changes significantly from the first market to the second market because its valuation is based on two entirely different factors.

The low-blend market exists because reformulated gasoline is being produced by adding up to 10% ethanol to a base gasoline that is made of petroleum constituents. In the low-blend market, refineries are willing to pay a higher price per gallon of ethanol for each 0.1 gallon of ethanol that will be blended with 0.9 gallon of base gasoline because the ethanol fraction increases the octane of the gasoline/ethanol blend and helps reduce toxic emissions when E10 is used in vehicles. Blending ethanol with gasoline in higher concentrations (beyond the 10% needed for octane and environmental benefits) becomes less competitive because a gallon of ethanol has only two-thirds the energy of a gallon of gasoline. In 2006, however, the price of oil reached new highs, and the cost of producing corn ethanol compared favorably with the cost of producing gasoline on an energy-equivalent basis. Production capacity constrains the amount of ethanol that can enter the market, and the current production capacity for ethanol from corn is still significantly less than U.S. motor gasoline demand.

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 would become competitive with gasoline on an energy basis. At that point, fuel markets would likely accept nearly pure ethanol such as E85 because of its environmental characteristics and indigenous supply basis. In Brazil, for example, both E22 and E100 are readily available and most new car sales are flex-fueled vehicles that can use either fuel or any blend in between these limits. Increases in market penetration for ethanol will also be affected by competition from other alternative transportation fuels and success in building a nationwide E85 transportation and distribution infrastructure. Eventually, increases in market penetration may be constrained by the availability of feedstock, rather than market demand.

Summary of Inputs

The input that OBP provided to the EERE benefits models are discussed below.

Biomass Supply

The University of Tennessee (UT) and Oak Ridge National Laboratory (ORNL) developed cellulosic feedstock supply curves with the aid of POLYSYS (UT 2006) and other regionally detailed models (Walsh 2006). The supply curves represent quantities of different categories of feedstocks available at different prices and time periods. In NEMS and MARKAL, feedstock costs are adjusted to include $10.50 per dry ton for transportation from the farm gate to the conversion facility, and feedstock supplies are allocated among different competing uses, e.g., biopower. In addition, the MARKAL analysis assumes that agricultural residues and bio-energy crops will increase at an annual rate of 1% and 1.4%, respectively, during the analysis period, due to increasing agricultural productivity. NEMS has not yet incorporated the postulated productivity increases (Lavoie 2006).

While forest residues and urban wood wastes may not be optimal for sugar-based ethanol production, we recognize that future syngas-based fuels production may use forest residues and some urban wood wastes as feedstock. Therefore, these resources were assumed available to ethanol biorefineries along with the more appropriate resources (agricultural residues and switchgrass).

Fossil Fuels and Carbon Calculations

Energy and carbon benefits were calculated as the difference between the fossil energy use and carbon emissions in the Program and Baseline cases. Fossil energy use includes the fossil energy embedded in the final product, e.g., in gasoline, as well as the upstream fossil energy consumption, e.g., the fossil energy used to extract and transport oil, and refine the oil into gasoline.

Biorefinery Costs

NEMS-GPRA08 analysis extends through 2030, while MARKAL-GPRA08 analysis extends through 2050. The Biomass Program analyst at NREL provided costs and other input through 2050. OBP based their cellulosic biorefinery concept on a plant whose main product is fuel ethanol, with electricity as a co-product. Excess electricity is sold to the grid and is modeled as a reduction in the cost of producing ethanol. 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 90 gallons of ethanol per dry ton of feedstock in 2015 to 94 gallons per dry ton in 2035, as a result of technological advances (Jechura 2005).

Table C-4. Cellulosic Ethanol Production Costs and Conversion Efficiency Targets

Costs in 2004$ per Gallon (Without Feedstock Costs)
(2012 costs: nominal $1.07/gallon if added $35/ton feedstock cost
2035 costs: nominal $0.60/gallon if added $35/ton feedstock cost)

Year	Operating $/gal EtOH	Annualized Capital $/gal EtOH	Ethanol Yield gal/ton	Electricity Usage kWh/gal	Nat Gas Usage MMBtu/gal
2015	$ 0.330	$ 0.430	90.1	-2.06	0
2016	$ 0.317	$ 0.419	90.3	-2.06	0
2017	$ 0.305	$ 0.407	90.5	-2.06	0
2018	$ 0.292	$ 0.396	90.8	-2.06	0
2019	$ 0.279	$ 0.384	91.0	-2.05	0
2020	$ 0.267	$ 0.373	91.2	-2.05	0
2021	$ 0.254	$ 0.362	91.4	-2.05	0
2022	$ 0.241	$ 0.350	91.6	-2.05	0
2023	$ 0.229	$ 0.339	91.8	-2.05	0
2024	$ 0.216	$ 0.328	92.1	-2.05	0
2025	$ 0.203	$ 0.316	92.3	-2.04	0
2030	$ 0.140	$ 0.259	93.4	-2.04	0
2035	$ 0.102	$ 0.225	94.0	-2.03	0
2040	$ 0.102	$ 0.225	94.0	-2.03	0
2045	$ 0.102	$ 0.225	94.0	-2.03	0
2050	$ 0.102	$ 0.225	94.0	-2.03	0

Source: John Jechura , *Adv Dry Mill Curve 8-25-2005 - DA changes.xls* , National Renewable Energy Laboratory, after acceleration to be consistent with the Initiative's goal.

Consistent with current ethanol plants' financial practices, a real capital cost recovery factor of 15% is used in NEMS and MARKAL to calculate the per-gallon capital costs in each year. Cellulosic ethanol plants combust the lignin portion of the lignocellulosic feedstock to produce heat and electricity. The plants produce excess electricity that is sold into the grid. The negative numbers in the electricity use column represent the sale of the excess electricity. The electricity credit is computed by multiplying the price of electricity times the excess electricity production.

In addition to the benefits associated with cellulosic biorefineries, a smaller subset of benefits is associated with OBP's corn ethanol R&D. Dry mills process corn into ethanol, distillers dried grain with solubles (DDGS), and carbon dioxide (CO_2). DDGS is sold into the animal feed market. Some dry mill operators sell their CO_2 output, but the CO_2 market is limited and therefore not considered in this analysis. As dry mills begin to deploy the technology to convert the fiber and residual starch in kernels to ethanol, there will be less fiber and starch in the DDGS co-product. The corn fiber and residual starch conversion process does not change the protein amount in the DDGS. This increases the value of the DDGS in the market place because pound for pound, its protein content is higher than before. Therefore the revenue to the ethanol producer from DDGS sales remains constant, while the plant makes more ethanol from the recovered fiber. The ethanol (denatured) yield per bushel will increase from 2.8 gallons in 2010 to more than 3.4 gallons in 2030.

The degree to which ethanol technologies would progress in the absence of EERE's biomass RD3 has not been studied in detail. Instead, EERE adopted the methodology recommended by the National Research Council (NRC) to estimate how EERE RD3 funding would accelerate technology improvements. The NRC recommended using an N-year rule, in which technology deployment would be accelerated by N years with EERE or conversely delayed by N years in the absence of EERE. OBP assumed that without federal investment in RD&D, technological advances would be delayed seven years for corn fiber/recalcitrant starch and 15 years for ethanol production technologies using cellulosic feedstock.

The reason for a moderate delay for the corn fiber/recalcitrant starch process is that industry has shown interest and willingness to cost-share R&D in this area, and the estimated development time is short compared to that for cellulosic ethanol technology. OBP has already catalyzed work in this area, as indicated by several projects that are underway. It seems reasonable that, absent any further OBP involvement, industry would continue to build on work already accomplished, albeit at a slower rate.

The rationale for assuming a 15-year delay for standalone cellulosic ethanol biorefineries is industry's reticence to underwrite cellulosic ethanol research, because of its greater 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 is necessary before cellulosic ethanol can become competitive.

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