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ETHANOL PATHWAYS IN THE 2050 NORTH AMERICAN TRANSPORTATION FUTURES STUDY

By Elyse Steiner
National Renewable Energy Laboratory
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1 Introduction

Ethanol, starch-based and cellulosic, has been included in varying amounts in the 2050 North American Transportation study scenarios. Phase 1 of the 2050 Transportation Study developed two future scenarios that relied on as much as 5 Quads of ethanol in light vehicles in 2050. In Phase II, we have modeled the volume of ethanol required to meet demand and all of the costs that would be incurred under the base case and three additional scenarios defined in the second phase. Ethanol costs include the feedstock, capital and operating costs associated with production, as well as storage, blending, transportation and distribution costs. These costs were calculated using two sources, the TMS ELSAS model and a recent Downstream Alternatives, Inc. report for the DOE Biomass Program[1] on ethanol infrastructure requirements. Explanations of the ethanol models and results are in the following sections of this paper.

2 Supply Pathways

The pathway that bioethanol takes over the next several decades will be determined by several factors including the rate of technological progress, national energy policy, and the world price of oil. Growing concerns over gasoline additive methyl tertiary butyl ether (MTBE) and possible enactment of a renewable fuels standard (RFS) as part of the pending U.S. Senate energy bill would have the effect of increasing demand for ethanol fuels over the next decade. Other factors that would add to the demand for ethanol would include efforts to diversify energy resources, reduce carbon emissions, and decrease dependence on foreign oil. However, conversion costs for ethanol, particularly cellulosic ethanol, must be reduced through increasing technological improvements for ethanol to compete and play a significant role in the fuel market.

2.1 Supply Curves

Data from DOE laboratories and other sources were compiled and analyzed by TMS to construct a model for estimating production cost of cellulosic ethanol over time between 2010 and 2050. The Ethanol Industry Evolution Long-Range Systems Analysis Spreadsheet (ELSAS) model is flexible and allows the amount of ethanol production to vary depending on the assumptions about the future. Required model inputs include Production Year, Production Quantity in that Year, and Cumulative Production in Prior Years. ELSAS contains proposed default values for most key variables, but that the user is free to change these. This is particularly important with respect to feedstock supply curves.

For any year, starting in 2010, the model will calculate the total feedstock needed for the production quantity. The production yield is determined by the year and increases over time from 72 to 106 gallons of ethanol per dry ton of feedstock. The feedstock prices remain constant in year 2000 U.S. dollars. There are three price regimes for feedstock: below $40/ dry ton, $40-55/ dry ton, and over $55-$70/ dry ton. The prices are as delivered to the conversion facility. There is only a finite amount available within each regime. When that quantity has been

[1] Reynolds, R. January 2002. “Infrastructure Requirements for an Expanded Ethanol Industry.” http://www.afdc.doe.gov/pdfs/6235.pdf

exceeded, the price increases as the next price regime is tapped for resources. At production levels above 35 - 40 billion gallons per year, the feedstock cost becomes increasingly more expensive (over $50 per dry ton) and the overall production costs also tend to rise, not fall, as seen in the curves in Figures 2-1 and 2-2 below. The feedstock price component per gallon for the initial ethanol before denaturing is given by the model as the feedstock cost per gallon divided by the yield. The model does not explicitly identify the feedstock composition for each level of production. Agricultural residues, forest residues, urban wood residues, mill residues, and energy crops are all part of the feedstock mix. The denaturing process adds about 5% to the volume of ethanol, which is accounted for in the model.

This model does consider competing uses for biomass feedstocks and does not assume that all available biomass will be used for ethanol fuels. Biopower is another emerging energy technology that will consume many of the same cellulosic feedstocks. The default process allocates about 1/3 of the total to biopower and about 2/3 of the total to biofuels. There is a finite amount of feedstock available beyond which the model will not produce output.

The next step in the model is to determine the non-feedstock costs of production. This step takes into account the capital costs of the production facility and process improvements from learning over time. In the earlier years, this non-feedstock component may be more than double the feedstock portion of the total ethanol cost. This initial non-feedstock cost of $0.86 per gallon is based on a plant processing 2,000 dry tons of feedstock per day at a price of $35 per ton and yield of 72 gallons per ton. For a plant under these conditions, the total production cost is figured to be $1.35 per gallon with $0.49 spent on feedstock.

In later years, the non-feedstock cost declines to $0.16 per gallon according to this model. This is based on a total production cost of $0.557 per gallon of which $0.397 is feedstock. This assumes a plant with an initial cost of $297 million and capacity to produce 295 million gallons of ethanol annually. The plant processes 2.7 million dry tons of feedstock each year and the yield is 106 gallons per ton.

It has been estimated that by 2012, there will be 5 billion gallons per year (bgy) of ethanol produced from corn, rather than cellulosic, resources. This volume is expected to remain constant into the future because the production process is considered to be close to maturity and new production will not use corn. Another assumption about the future in the model is that government subsidies (incentives) for ethanol will continue until at least 2030 in both the base and aggressive cases. Were the subsidy to end sooner, the supply curve would also have to be revised.

2.2 Reference Supply Curves

Figure 2-1 below shows the results from the model's reference case. These cellulosic ethanol supply curves show the production cost for the quantity and production year. In addition to this amount, there are 5 billion gallons of ethanol produced from starch available in the U.S. market.

Therefore, for example, if there is 11.5 billion gallons of cellulosic ethanol in 2025, there are actually 16.5 billion gallons of ethanol produced that year.

Figure 2-1: ELSAS Reference Case Supply Curves

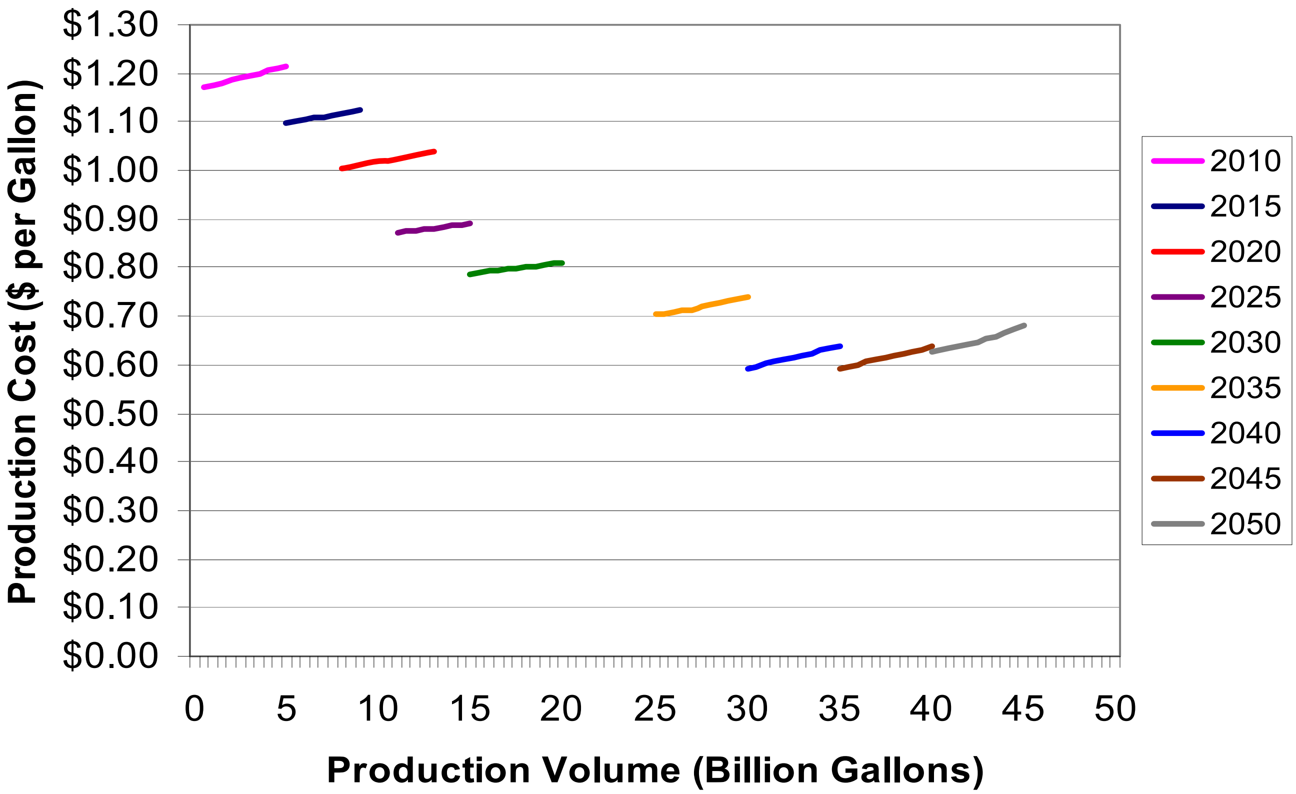

Table 2-1: Cellulosic Ethanol Production and Prices (Reference)

YEAR	CELLULOSIC PRODUCTION (BILLION GAL)	ANNUAL GROWTH RATE[2]	MKT PRICE ($/GAL)	INCENTIVE ($/GAL)	PRODUCTION COST ($/GAL)[3]	CUMMULATIVE PRODUCTION (BILLION GAL)
2010	1.5	-	-	-	$1.18	5.3
2020	9.2	8%	$0.69	$0.32	$1.01	56.7
2030	18.1	5%	$0.61	$0.19	$0.80	178.0
2040	32.6	5%	$0.61	$0.01	$0.62	434.5
2050	40.8	2%	$0.63	$0.00	$0.63	831.6

[2] Annual growth rate calculated using total (starch and cellulosic) ethanol production volume.
[3] Production cost is the plantgate cost and does not include transportation from conversion facility to market.

2.3 Aggressive Supply Curves

The more aggressive, high innovation case increases the availability of energy crops over time, and accelerates production cost reductions achieved through R&D and learning. It also phases out the government subsidy earlier. The primary impacts from high innovation are felt in the 2020-2040 mid-period.

Figure 2-2: ELSAS Aggressive Case Cost Curves

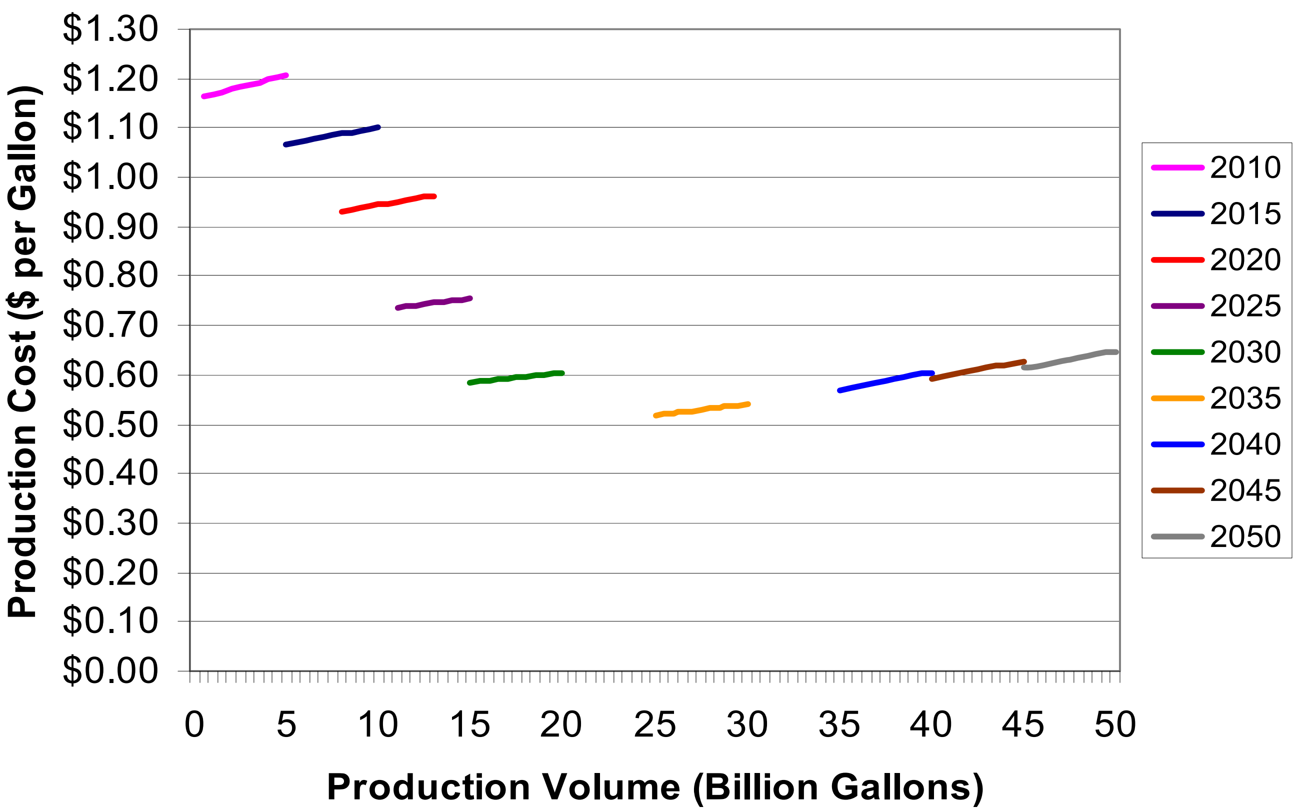

Table 2-2: Cellulosic Ethanol Production and Prices (Aggressive)

YEAR	CELLULOSIC PRODUCTION (BILLION GAL)	ANNUAL GROWTH RATE	MKT PRICE ($/GAL)	INCENTIVE ($/GAL)	PRODUCTION COST ($/GAL)	CUMMULATIVE PRODUCTION (BILLION GAL)
2010	1.5	-	-	-	$1.17	5.3
2020	9.9	9%	$0.67	$0.27	$0.94	58.1
2030	19.3	5%	$0.60	$0.00	$0.60	187.9
2040	38.5	6%	$0.59	$0.00	$0.59	460.3
2050	50.6	2%	$0.65	$0.00	$0.65	904.0

3 Distribution Infrastructure

A recent study by Downstream Alternatives, Inc. (DAI) for the U.S. Department of Energy Biomass Ethanol Program estimates the infrastructure requirements and costs for the future fuel ethanol industry in the United States. The study analyzed two cases: ethanol production of 5.1 bgy and 10.0 bgy. The analysis is not associated with any particular year or timeline, but did include geographical and regional (PADD) differences. Both E-10/E-5.7 and E-85 fuels were included in the scenarios. The study concluded that no major infrastructure barriers exist, although considerable investments for terminal operators and retailers will be required. In addition, freight charges to move ethanol will be considerably higher than pipeline shipments for gasoline (Reynolds, 2002).

3.1 Infrastructure Requirements

All aspects of capital investments and infrastructure were considered in the detailed study. To start with, in the low production case, there would be a total of 495 terminals capable of receiving ethanol by water or rail, compared to 908 terminals in the high production case. The terminals would need to install or convert tanks totaling over 2 million barrels in capacity for the 5.1 bgy case and an additional 3.1 million barrels for the 10 bgy case. Up to 76 total railroad spurs would be required in order for terminals to handle ethanol. Also, all terminals handling ethanol for the first time would have to invest in new blending systems and likely miscellaneous expenses.

At the retail level, approximately 35,000 facilities on the low end and up to 96,750 facilities on the high end would be converted. Including the 23,000 existing stations, the total could approach 120,000 outlets in the United States. A small number of E-85 installations would also be added. All together, equipment investments and retail conversions for E-10 and E-85 fuels would amount to $301.5 million for the low production case and $648.8 million for the high production case.

On a per gallon basis, these terminal and retail expenses represent $0.0075 per gallon ethanol in E-10 for the low and high production cases combined. Calculated on a per blended gallon basis for E-10 fuel, the amortized cost would only be one-tenth of the per gallon cost of ethanol. The amortized costs for ethanol in E-85 would range from $0.079 (low production case) to $0.0642 (high production case).

Transporting the fuel also entails additional costs, which will vary by region or PADD (Petroleum Administration for Defense Districts). Cost variations were accounted for in the DAI analysis. The study estimated that the total annual freight charges for 5.1 bgy would be $391 million or $0.0767 per gallon of ethanol shipped. The total annual charges for 10 bgy would be $568 million, equating to $0.0568 per gallon of ethanol shipped, on average.

To handle the additional rail and barge shipments, there may be some additional transportation equipment required. New tractor trailer transports, rail tank cars, and river barges have all been factored into the calculation of overall infrastructure costs. The total equipment cost could be as much as $340.3 million for the combined case.

3.2 Pipelines

The DAI report did not include ethanol movement by pipelines because the volumes analyzed were not sufficient to warrant their use. Pipelines could conceivably be used to transport ethanol if the volumes grew to a level at which it became economically feasible. In fact, pipelines are used to transport ethanol in Brazil and South Africa where ethanol is more commonly used. However, in North America, the volumes would have to increase tremendously and some existing challenges would have to be overcome. One evaluation of the ethanol infrastructure concluded that ethanol would have to reach 20% or higher of all products moved by pipeline or approximately 40% of total gasoline shipments.[4] If volumes did reach this level and were transported by pipelines, it is estimated that the incremental cost of ethanol over other pipeline fuels would be relatively small. At lower volumes, ethanol pipelines may be developed for niche applications only.

Considerations for shipping ethanol by pipeline are both technical and operational. The first technical challenge that comes up is the water intolerance of ethanol and residual moisture from petroleum products in pipelines. Contamination and discoloration from stronger solvent effects of ethanol are also possible. Ethanol products must arrive on specification without contaminants because downgrade options for these fuels do not exist in the market. Corrosion in pipelines is another risk that has not been fully assessed. Concerns remain regarding pH values and the corrosive affect on pipelines. Operational challenges have to do with the volumes, scheduling, logistics, and product losses of ethanol shipments.

If ethanol production volumes do become large enough to warrant pipeline shipments by 2050, it is estimated that dedicated ethanol pipelines could be built along existing routes at a cost in the $500,000 per mile range. The most likely scenario is for a pipeline to originate in St. Louis to transport ethanol from PADD II to other parts of the United States. Pipelines from further north in PADD II do not exist and there may be complications with permitting, environmental impact studies, and rights of way. The additional cost would probably be somewhere in the $0.01 - $0.03 range. Further, tanks have been estimated to cost between $10 and $15 per barrel. For a 25,000-barrel tank, the cost would be around $300,000.

4 Scenarios and Ethanol Use

4.1 Scenario Ethanol Requirements

The three scenarios (Greening the Pump, Rollin' On, and Go Your Own Way) defined in the study will demand different levels of ethanol production based on their unique sets of drivers and mixes of vehicle technologies. It is these drivers that influence which version of the production cost model and supply curves will be used to calculate the specific scenario costs for each of the

[4] Personal communication with Robert Reynolds March, 2002.

three cases. Greening the Pump has early and significant ethanol demand, but the relatively low technical innovation indicates that the standard cost supply curves should be applied. Rollin' On relies much less heavily on ethanol, so it too should use the less aggressive supply curves even though the scenario has high innovation as a driver. The slow development of ethanol production facilities and capacity does not allow the industry to move down the learning curve as quickly as a rapid innovation and high environmental consciousness scenario. Go Your Own Way, a rapid innovation case with high ethanol demand, is the most appropriate candidate for the aggressive supply curves. Table 4-1 below shows the scenarios and the supply curves used to calculate the fuel cost results.

Table 4-1: Scenario Production Curves

	Reference Production	**Aggressive Production**
Greening the Pump	√	
Go Your Own Way		√
Rollin' On	√	

The base case of the study does not include any cellulosic ethanol production. It does account for up to two billion gallons annually of starch-based ethanol by 2005 and continues at that level through 2050. In the three scenarios, starch-based ethanol production increases to five billion gallons per year by 2015 and stays constant at that level through 2050.

4.2 Greening the Pump

The Greening the Pump (GtP) scenario is driven by high environmental concern combined with low technological and social innovation. In the area of fuels, this paradigm translates to an early and increased emphasis on ethanol production in North America. By the year 2020, E-10 is mandatory in all gasoline sold in Canada and the United States and, by 2040, 10% of diesel is ethanol. In addition to E-10 production, the environmental driver increases the demand for E-85 fuels and vehicles. In 2020, E-85 vehicles make up 20% of new vehicle sales and are assumed to run entirely on E-85 fuel. This market share remains unchanged through 2050. These E-85 flex fuel vehicles have a fuel economy of 40.75 mpg for cars and 29.80 mpg for light trucks after 2025. In the U.S., ethanol will be produced from both starch and cellulose throughout the time period of the scenario. In Canada, this scenario envisions cellulosic production replacing corn ethanol production, not supplementing it.

4.3 Go Your Own Way

With both high innovation and high environmental responsiveness, Go Your Own Way (GYOW) emerges as the scenario with the greatest E-85 use and lowest ethanol production costs by 2050. The market penetration of E-85 vehicles peaks at 30% in 2025. All E-85 light vehicles in this scenario are hybrid-electric vehicles. As in Greening the Pump, E-10 eventually reaches 100% market penetration in Canada and the United States. There is no E-diesel in this scenario. After 2005, ethanol will enter the market rapidly and follow the aggressive supply path towards lower costs and high production volumes of nearly 50 billion gallons per year. Sales of conventional vehicles running on E-10 are lower than in the base case and Greening the Pump because of the successful market penetration of hydrogen fuel cell vehicles. Consequently, total ethanol production is slightly lower than in Greening the Pump, most of the ethanol (90%) is used by E-85 vehicles, and very little (10%) is blended in E-10 fuel.

4.4 Rollin' On

In the Rollin' On (RO) scenario there is very little demand for ethanol in the market, especially cellulosic ethanol. The low environmental responsiveness manifests itself in no market for E-85 vehicles and only 50% of gasoline in Canada and the United States sold as E-10 blend. Because of the low production volumes, much of the ethanol will be produced from corn in the United States with only a small amount of cellulosic feedstocks consumed.

5 Ethanol Costs in the Three Scenarios

5.1 Ethanol Production Costs

Ethanol production costs for Greening the Pump and Go Your Own Way are presented in Table 5-1. In the first few years when only corn-based ethanol is produced, we have assumed the current production cost of ethanol. When cellulosic ethanol does enter the market, we use the cellulosic ethanol production costs, which are also applied to corn-based ethanol. ELSAS, the TMS model described in Section 2, was used to generate these estimates. The aggressive production path assumed for Go Your Own way ultimately results in lower costs of ethanol production for comparable production levels.

Table 5-1: U.S. Ethanol Volume and Price

	Greening the Pump			Go Your Own Way		
Year	Ethanol Produced (Billion gallons)	% Cellulosic	Production Cost (US$ / gallon)	Ethanol Produced (Billion gallons)	% Cellulosic	Production Cost (US$ / gallon)
2000	1.6	0	1.09	1.6	0	1.09
2005	3.8	47	1.23	4.3	0	1.22
2010	10.6	65	1.16	10.9	54	1.20
2015	19.5	74	1.03	19.5	74	0.98
2020	32.8	85	0.97	31.1	84	0.79
2025	38.6	87	0.73	34.7	86	0.56
2030	41.1	88	0.63	36.7	86	0.57
2035	43.9	89	0.65	41.9	88	0.60
2040	46.4	89	0.66	44.8	89	0.60
2045	48.4	90	0.68	47.2	89	0.61
2050	50.4	90	0.69	49.3	90	0.61

Table 5-2 illustrates some of the key assumptions underlying the production costs shown above, as well as the disaggregation of the production cost into feedstock and non-feedstock (capital and operating) costs. The calculations also assume a 10% rate of return and 0.178 capital recovery factor. Plant size increases from 55.7 million gallons per year to 295 million gallons per year by 2045.

Table 5-2: Key Assumptions Used in Ethanol Production Cost Calculations

Year	Cellulosic Volume (Billion gallons)	Production Cost ($/gallon)	Feedstock Cost ($/gallon)	Capital Cost ($/gallon)	Tax Credit ($/gallon)	Yield (Gallon/ dry ton)	# of Plants
Greening the Pump							
2010	6.9	$ 1.16	$ 0.42	$ 0.52	$ 0.37	77	123
2030	36.4	$ 0.63	$ 0.47	$ 0.11	$ 0.19	106	162
2050	45.4	$ 0.69	$ 0.53	$ 0.11	$ -	106	154
Go Your Own Way							
2010	5.9	$ 1.20	$ 0.41	$ 0.55	$ 0.37	77	107
2030	31.7	$ 0.57	$ 0.41	$ 0.11	$ -	106	147
2050	44.3	$ 0.61	$ 0.45	$ 0.11	$ -	106	150
Rollin' On							
2010	0.0	$ -	$ -	$ -	$ -	0	0
2030	3.4	$ 0.98	$ 0.28	$ 0.49	$ 0.19	106	15
2050	4.5	$ 0.83	$ 0.28	$ 0.39	$ -	106	15

Table 5-3 presents the total capital costs for cellulosic ethanol production plants in GtP, GYOW, and RO. In every year, the capital cost is higher in Greening the Pump than in Go Your Own Way, and the cumulative capital cost is 26% higher for GtP than GYOW.

Table 5-3: Cellulosic Ethanol Production Capital Costs

	Greening the Pump		Go Your Own Way		Rollin' On	
Year	Capital Cost (US$/ gallon)	Annual Capital Cost (million US$)	Capital Cost (US$/ gallon)	Annual Capital Cost (million US$)	Capital Cost (US$/ gallon)	Annual Capital Cost (million US$)
2010	0.52	3,534.36	0.55	3,273.02	0.61	0.06
2020	0.31	8,672.97	0.21	5,583.35	0.56	1,221.36
2030	0.11	4,076.23	0.11	3,545.13	0.49	1,652.32
2040	0.11	4,638.87	0.11	4,455.63	0.44	1,628.58
2050	0.11	5,084.42	0.11	4,961.15	0.39	1,744.56
Cumulative		232,639.69		185,911.47		52,106.25

5.2 Ethanol Blending after Production

Once leaving the production facility, cellulosic ethanol is blended with gasoline at a terminal to form either E-10 or E-85 fuel blends for vehicular use. From the terminal, the blended fuels are transported to retail outlets. Sections 4.2 – 4.4 described the assumptions in each scenario regarding the demand for ethanol blends. Table 5-4 shows the amount of neat ethanol used in E-10 and E-85 blends to satisfy the demand in each scenario.

Table 5-4: Volume of Ethanol in E-10 and E-85

Year	Ethanol in E-10 (Million gallons)	Ethanol in E-85 (Million gallons)	% Total Ethanol in E-10
	Greening the Pump		
2010	7,952	2,601	75%
2030	14,368	27,027	35%
2050	17,418	32,979	35%
	Go Your Own Way		
2010	9,656	1,291	88%
2030	10,465	26,188	29%
2050	5,130	44,166	10%
	Rollin' On		
2010	3,498	-	100%
2030	8,353	-	100%
2050	9,508	-	100%

5.3 Ethanol Distribution Costs

Downstream Alternatives analyzed the distribution requirements and costs associated with the movement of up to 10 billion gallons of ethanol produced annually in a report prepared for DOE (See Section 3). In developing ethanol distribution cost estimates for the 2050 study, we made extensive use of the DAI report. However, we also made a number of assumptions to extend its analysis to the much larger volumes of ethanol use in the scenarios of the 2050 study.

Tables A-1 through A-3 in Appendix A present the ethanol distribution cost estimates developed by DAI for two ethanol cases. Amortized costs per gallon in this report may be slightly different than what DAI developed. In one case, 5.1 billion gallons of ethanol are distributed (Case B1) and in the other 10 billion gallons of ethanol are distributed (Case C). The estimates cover equipment needs at terminals where ethanol is blended with gasoline (tanks, blending equipment, rail spurs for delivery by rail), at service stations dispensing E-85 and/or E-10, and for movement of the ethanol from ethanol production plants to the terminals (by truck, rail, and barge). It appears that the capital cost component of distributing E-10 and E-85 from the terminals where blending occurs to the service stations is not actually estimated but that cost should be very small. One point to note in the tables is that there are differences between the two cases in new equipment requirements per ethanol gallon moved, mode share, and unit costs. Reasons for these differences include the fact that proportionally more existing equipment is used in Case B1 and that where ethanol is moved from and to varies between the cases.

5.3.1 Capital Costs of Distribution

We adopted the DAI estimates directly for the cost of moving up to 10 billion gallons ethanol. For volumes higher than 10 billion gallons, we developed estimates of the new equipment requirements, costs, and mode share for the second 5 billion gallons moved in Case C (see Tables A-1 - A-3). Very little existing equipment is available to move these 5 additional billion gallons. We assumed that these requirements, costs, and mode share would be applicable to all new equipment requirements for ethanol volumes above 10 billion gallons. We recognize that at the much higher production levels assumed in the 2050 scenarios, the movement patterns between producing and consuming regions of the country may change from those assumed in the DAI study. These distribution changes may result in somewhat altered equipment requirements. However, for purposes of this analysis, we believe the DAI estimates serve as a reasonable reference for potential requirements and costs. In our modeling, we assume no differences in the cost of moving different types of ethanol. The distribution costs remain constant across the three 2050 scenarios examined.

We assumed that there would not be any pipeline movement of ethanol fuels. We did assume replacement of trucks after 10 years, blending equipment after 20 years, and E-85 service station equipment after 20 years and incorporated those costs, although this was not part of the DAI analysis. Finally, we limited the number of terminals to which ethanol could be delivered to the current total of 1,063 and the number of stations which could be converted to dispense E-10 or E-85 to the current total of 180,000. Because we limited the number of stations, we increased the volume distributed at each station and the per station capital costs.

Table 5-5 presents the total capital costs for developing the ethanol distribution infrastructure in Greening the Pump, along with the capital costs of cellulosic ethanol production. Table 5-6 shows the same information for Go Your Own Way. All distribution capital costs assume a 10% interest rate and 10 year payback period. As can be seen, the distribution costs represent 12.4% of the total GtP capital costs. The costs for E-85 stations predominate the distribution costs. In the GYOW case, E-85 station costs are even a greater percentage, 14.7%, of total costs. In both scenarios, plant costs and E-85 station costs combined make up nearly 98% of all capital costs associated with ethanol fuels.

Table 5-5: Capital Distribution Costs for Greening the Pump (Millions)

Year	Bioethanol plants	Vehicles to transport ethanol to terminals	Terminal equipment (tanks, blending equipment, rail spurs, etc)	E-10 stations	E-85 stations	Total
2000	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2010	$3,534.4	$45.23	$47.89	$7.62	$148.53	$3,783.63
2030	$4,076.1	$87.56	$54.86	$0.00	$720.24	$4,938.77
2050	$5,084.4	$78.25	$42.77	$0.00	$489.34	$5,694.77
Cumulative	$232,590.9	$3,495.2	$2,108.0	$165.9	$27,277.6	$265,637.6
Share	87.6%	1.3%	0.8%	0.1%	10.3%	100.0%

Table 5-6: Capital Distribution Costs for Go Your Own Way (Millions)

Year	Bioethanol plants	Vehicles to transport ethanol to terminals	Terminal equipment (tanks, blending equipment, rail spurs, etc)	E-10 stations	E-85 stations	Total
2000	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2010	$3,273.02	$ 41.82	$ 51.85	$ 9.73	$ 73.73	$ 3,450.16
2030	$ 3,545.13	$ 75.11	$ 48.48	$0.0	$ 814.19	$ 4,482.91
2050	$ 4,961.15	$ 82.31	$ 43.50	$0.0	$ 722.57	$ 5,809.53
Cumulative	$185,708.9	$3,351.9	$2,106.9	$ 165.9	$33,031.5	$224,365.1
Share	82.8%	1.5%	0.9%	0.1%	14.7%	100.0%

Table 5-7: Capital Distribution Costs for Rollin' On (Millions)

Year	Bioethanol plants	Vehicles to transport ethanol to terminals	Terminal equipment (tanks, blending equipment, rail spurs, etc)	E-10 stations	E-85 stations	Total
2000	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
2010	$ 0.06	$ 21.07	$ 10.14	$ 1.95	$0.0	$ 33.22
2030	$1,652.32	$ 20.50	$ 21.72	$ 2.09	$0.0	$1,696.63
2050	$1,744.56	$ 18.99	$ 16.04	$ 1.08	$0.0	$1,780.67
Cumulative	$52,106.2	$ 911.9	$ 822.4	$ 101.7	$0.0	$53,942.3
Share	96.6%	1.7%	1.5%	0.2%	0.0%	100.0%

5.3.2 Per Gallon Distribution Costs

Table 5-8 contains selected per gallon distribution cost estimates for Greening the Pump. The transport to terminals estimates are derived from DAI's freight charges as presented in Table A-3. We added capital costs to those charges for the equipment needs to move more than 10 billion gallons ethanol. However, the amount added is on the order of 1/100 of a cent per gallon. The other estimates contained in the table were simply derived by dividing the capital costs at terminals and stations in any year by the volume of ethanol delivered in that year. Thus, we do not have the complete per gallon costs of moving ethanol through terminals, to service stations, and into cars (refueling). The per gallon costs for the new ethanol infrastructure presented in Table 5-8 need to be added to the typical costs of moving liquid fuels (e.g., gasoline and diesel fuel) from terminals to vehicles. That will be done elsewhere in the 2050 analysis.

Table 5-8: Selected Per Ethanol Gallon Distribution Costs in GtP (Cents/gallon)

	Transportation to terminals	**Additional capital costs at terminals**	**Capital costs at stations dispensing E-10**	**Capital costs at stations dispensing E-85**
2000	7.7	0	0	0
2010	3.6	0.5	0.1	5.7
2030	3.6	0.1	0	2.7
2050	3.6	0.1	0	1.5

APPENDIX A

Table A-1: Terminal Equipment Costs

	Case B1	Case C (including B)	Case C minus Case B
FUEL VOLUMES			
Total ethanol (billion gallons/yr)	5.1	10	4.9
Old ethanol (etoh)	1.813	1.813	0
New etoh in E-10	2.987	7.487	4.5
New etoh in E-85	0.3	0.7	0.4
TERMINALS			
No. of terminals	495	908	413
Terminals per bgy (old and new)	97	91	84
New tanks at terminals	181	479	298
Total capacity of new tanks (mbbl)	1579	4415	2836
Cost of new tanks	$23,055,000	$63,100,000	$40,045,000
Cost of new tank per terminal requiring new tank	$127,376	$131,733	$134,379
Tank conversions at terminals	63	107	44
Total capacity of converted tanks	471	766	295
Cost of tank conversions	$1,369,000	$2,249,000	$880,000
Cost of converted tank per terminal needing conversion	$21,730	$21,019	$20,000
Share of new volume served by new tanks	0.770	0.852	0.906
Avg. cost of new tank or conversion at terminal requiring either	$103,103	$115,364	$123,602
Terminals with new tanks or converted tanks	244	586	342
Existing terminals with tanks that can store ethanol without new tanks or conversions	251	322	71
Total cost of contingency at terminals with new or converted tanks	$4,880,000	$11,720,000	$6,840,000
Cost of contingency per terminal	$20,000	$20,000	$20,000
Terminals requiring blending equipment for blending	287	666	379
Existing terminals with blending equipment	208	242	34
Total cost of blending systems	$86,100,000	$199,800,000	$113,700,000
Cost per blending system	$300,000	$300,000	$300,000
Terminals requiring rail spurs	49	76	27
Proportion of terminals requiring rail spurs	0.099	0.084	0.065
Total cost of rail spur	$17,395,000	$26,980,000	$9,585,000
Cost per rail spur	$355,000	$355,000	$355,000
Total capital costs of terminals	$132,799,000	$303,849,000	$171,050,000
Amortized cost per gallon	$0.0071	$0.0065	$0.0061

Table A-2: Station Equipment Costs

	Case B1	Case C (including B)	Case C minus Case B
FUEL VOLUMES			
Total ethanol (bgy)	5.1	10	4.9
STATIONS			
Existing E-10 stations	22916	22916	22916
New E-10 stations	35214	96742	61528
Total number of E-10 stations per bgy etoh	12110	12866	18765
Total E-10 station costs for new stations	$20,776,260	$57,078,370	$36,302,110
Cost per new E-10 station	$590	$590	$590
Etoh dispensed in E-10/station (gals/month)	6,881	6,477	4,441
E-10 dispensed per month	68,811	64,768	44,408
E85 stations	2556	5018	2462
Total number of E-85 stations per bgy etoh	8,520	7,169	6,155
Total E-85 station costs	$147,927,000	$287,931,000	$140,004,000
Cost per E-85 station	$57,874	$57,380	$56,866
Amortized cost per gallon	$0.0788	$0.0657	$0.0559
Etoh dispensed in E-85/station (gals/month)	9,781	11,625	13,539
E-85 dispensed per month	11,507	13,676	15,928

Table A-3: Transportation Equipment and Charges

	Case B1	Case C (including B)	Case C minus Case B
FUEL VOLUMES			
Total ethanol (bgy)	5.1	10	4.9
TRANSPORTATION: FREIGHT CHARGES			
Total	$391,070,000	$567,932,750	$176,862,750
Per gallon ultimately delivered	$0.0767	$0.0568	$0.0361
Per gallon of total gallons shipped	$0.0563	$0.0475	$0.0353
TRANSPORTATION: CAPITAL			
Existing trucks	173	173	
New trucks	254	563	309
Cost of new trucks	$29,210,000	$64,745,000	$35,535,000
Amortized cost per gallon	$0.0018	$0.0016	$0.0014
Cost per truck	$115,000	$115,000	$115,000
Total gals moved by truck (bil)			
Imports/exports (Table 6-20 and -21)	0.00	0.00	0
Intra-PADD (Table 6-29 and -30)	3.24	6.44	3.195

Total	3.24	6.44	3.195
Share of total	0.47	0.54	0.64
Trucks/billion gal delivered	84	74	63
Existing rail cars	278	278	
New rail cars	2549	3,472	923
Cost of new rail cars	$152,940,000	$208,320,000	$55,380,000
Amortized cost per gallon	$0.0080	$0.0044	$0.0019
Cost per rail car	$60,000	$60,000	$60,000
Total gals moved by rail (bil)			
Imports/exports (Table 6-20 and -21)	1.31	1.49	0.175
Intra-PADD (Table 6-29 and -30)	0.16	0.71	0.55
Total	1.47	2.20	0.725
Share of total	0.21	0.18	0.14
Rail cars/billion gal delivered	554	375	188
Existing barges	14	14	
New barges	21	42	21
Cost of new barges	$33,600,000	$67,200,000	$33,600,000
Amortized cost per gallon	$0.0017	$0.0014	$0.0012
Cost per barge	$1,600,000	$1,600,000	$1,600,000
Total gals moved by barge (bil)			
Imports/exports (Table 6-20 and -21)	1.93	2.68	0.745
Intra-PADD (Table 6-29 and -30)	0.31	0.66	0.35
Total	2.24	3.33	1.095
Share of total	0.32	0.28	0.22
Barges/billion gal delivered	7	6	4

All modes			
Imports/exports (Table 6-20 and -21)	3.24	4.16	0.92
Intra-PADD (Table 6-29 and -30)	3.71	7.80	4.095
Total gals shipped	6.95	11.96	5.015
Total shares	1.00	1.00	1.00
Total gals shipped relative to total gals delivered	1.362	1.196	1.023