APPENDIX I

Ethanol Supply Model

Appendix I. Ethanol Supply Model

I.1   Model Purpose

The objective of the ethanol supply model is to provide the NEMS Petroleum Market Model (PMM) with supply curves for corn and cellulose based ethanol, thus allowing the PMM to forecast transportation ethanol demand throughout the NEMS forecast period. To be consistent with the market clearing mechanism adopted for NEMS, the model provides ethanol prices in the form of annual price-quantity curves. The curves, derived from an ethanol production cost function, represent the prices of ethanol at which associated quantities of transportation ethanol are expected to be available for production of E85 and ETBE, and for blending with gasoline.

The delivered ethanol prices are provided to the PMM linear program in the form of a separate supply curve for each of the nine U.S. Census Divisions. The majority of ethanol currently produced in the United States is made from corn and is produced in the East North Central and the West North Central Census Divisions (NEMS regions 3 and 4, respectively). Smaller amounts are available in the South Atlantic, East South Central, West South Central, Mountain, and the Pacific Census Divisions (NEMS regions 5, 6, 7, 8, and 9, respectively). The PMM also models planned cellulose-based ethanol production in all Census Divisions beginning in 2009. Cellulose ethanol is produced from regionally-available agriculture residues, forestry waste, and energy crops such as switchgrass and hybrid poplar.

I.2   Corn-Based Ethanol

Fundamental Assumptions

The cost of corn ethanol is subdivided into capital cost, feedstock cost, operating cost, energy cost, and a credit for marketable coproducts of ethanol production. Energy cost includes the energy needed to grow and transport corn to market and the energy needed to run the ethanol plant. Each of the above factors contributes a part of the total price of ethanol.

Conversion of corn to ethanol is accomplished by either a wet milling or dry milling process. The coproducts produced from the wet milling process are corn gluten feed (CGF), corn gluten meal (CGM), and corn oil, while the dry milling process produces distillers' dried grains with solubles (DDGS).   Coproduct credits for wet mills and dry mills are estimated from ethanol industry financial data.

The price of corn is projected from *The U.S. Farm Economic Effects of a 6 Billion Gallon Renewable Fuel Standard, a 8 Billion Gallon Renewable Fuel Standard, and Elimination of the Federal Ethanol Tax Credit*, Department of Agriculture, July 2005. This paper estimates the effect on agricultural markets of expanding ethanol production by 6 or 8 billion gallons over baseline levels by 2012. For each case, the authors constructed two agricultural market forecasts, one with a baseline level of ethanol production from corn and another with higher levels of ethanol production from corn. The forecasts include corn prices and quantity of corn input to ethanol production for each forecast year. Since PMM models corn ethanol production levels as high as 12 billion gallons, the results of the 8-billion-gallon case are used in PMM. The difference between corn prices and the difference between quantities of corn used for ethanol production gives the rate of change of corn prices with respect to quantity of corn input to ethanol production. The most current baseline corn prices and corn ethanol production were obtained from *USDA Agricultural Baseline Projections to 2014* (http://www.usda.gov/oce/waob/commodity-projections/USDA%20Agricultural%20Baseline%20Projections%20to%202014.pdf) The baseline forecast and the estimated rate of change are used to construct a cost curve of corn to ethanol production.

Energy cost of corn production is estimated from *The Energy Balance of Corn Ethanol: An Update*. Fuel and chemical use per acre of land, fuel use in chemical production, acres planted, and average yields per acre were estimated for nine major corn-producing States. The majority of fuel ethanol is produced in Census Division 4, so estimates for this region were assumed for all other regions. The *USDA Agricultural Baseline Projections to 2014* include energy costs in its corn price estimates. Estimates of delivered industrial energy prices from *Annual Energy Outlook 2005* were deducted in order to estimate the price of corn to ethanol producers excluding the energy needed to grow the corn. The quantities of fuel and current industrial energy prices are used to estimate the energy cost of corn production within NEMS.

Wet milling accounts for about 31 percent of current ethanol production, while new ethanol facilities are projected to be dry milling plants.[1] PMM can choose to produce up to 782 Mbbl/day of corn ethanol in any forecast year. The variability of the market price for the feedstock corn and the conversion by-products and the variable influences of competitive uses for corn (e.g., for producing corn syrup) give rise to broad fluctuations in net corn feedstock prices. As ethanol production from corn increases, land becomes scarcer, causing both land and feedstock costs to increase. These factors are included in the Agriculture model. The Agriculture projections end in 2014, so net feedstock prices for 2015 to 2030 were set equal to the 2014 estimates. The net feedstock costs were then converted to 1987 dollars .

In addition to feedstock prices and quantities, the model requires capital cost, feedstock conversion cost (non-energy operating cost), and energy cost data. The cost data were derived from several sources which are documented in the Inventory of Variables, Data, and Parameters section of this report. Note that with this theoretical approach, only the agricultural, or feedstock production costs are modeled as a function of the total quantity of ethanol produced. The conversion plant process costs, (capital, operating, and process energy) are independent of production quantities.

Capital and conversion costs were assumed to be constant across all Census Divisions and for all forecast

1 Renewable Fuels Association online ethanol plant list and internet search for wet-mill ethanol producers.

years. Energy costs vary across Census Divisions as a function of industrial-sector coal, natural gas, and electricity prices. Natural gas prices are obtained from the NEMS Natural Gas Transmission and Distribution Model, coal prices are from the NEMS Coal Market Model, and electricity prices are from the NEMS Electricity Market Model.

There are currently two Federal tax incentives for blending ethanol into gasoline. One is a reduced rate of Federal excise tax on ethanol-blended gasoline, and the other is a business income tax credit for ethanol blended into gasoline. The excise tax reduction and income tax credit are of equal value, 51 cents per gallon of ethanol

Key Computations and Equations

Corn ethanol costs net of energy and subsidies are calculated in a separate spreadsheet (NEMScornsupplycurve.xls, maintained by Tony Radich of EIA). These costs are tabulated as a function of ethanol production quantity in the PMM input file WETOHIN. This file also contains natural gas, coal, and electricity use as a function of ethanol production quantity. Once the data are read, the ethanol price is calculated from the following equation:

$$WPETOH_{1,cd,t,e} = [\, FC_{t,e} + CAPCST_{e} + OPCST_{e} + PEN_{cd,t,e} - (STSUB_{cd} + ETHCRD_{t}) / MC\_JPGDP_{t}]*42$$

where:

$WPETOH_{1,cd,t,e}$	=	Delivered price of corn ethanol produced in Census Division *cd* in year *t* for volume step *e* (1987 \$/barrel),
$FC_{1,t,,e}$	=	Feedstock corn production cost, exclusive of energy, in year *t* for volume step *e* (1987 \$/gal),
$CAPCST1_{e}$	=	Capital cost for corn conversion technology for volume step *e* (1987 \$/gal),
$OPCST_{e}$	=	Operating costs, exclusive of energy, for volume step *e* (1987 \$/gal),
$PEN_{cd,t,e}$	=	Cost of energy used in the corn-to-ethanol conversion process in Census Division *cd* in year *t* on volume step *e* (1987 \$/MMBtu),
$STSUB_{cd}$	=	State incentive for corn ethanol production in Census Division *cd* (nominal \$/gal).
$ETHCRD_{t}$	=	Federal motor fuels excise tax credit for ethanol production in year *t*

(nominal \$/gal)

MC_JPGDP_t	=	GDP chained price index in year *t* (1987=1)
42	=	number of gallons per barrel

Capital cost is calculated as follows:

$$BNDRET1_e = (1 + MC\_RMCORPBAA_t/100 + BNDPREM1_e/100)/(MC\_JPGDP_t/MC\_JPGDP_{t-1}) - 1$$

$$BNDCRF1_e = BNDRET1_e/(1 - 1/(1 + BNDRET1_e)**CRNLIFE_e)$$

$$EQRET1_e = (1 + MC\_RMTCM10Y_t/100 + BETA1_e*EQPREM1_e/100)/(MC\_JPGDP_t/MC\_JPGDP_{t-1}) - 1$$

$$EQCRF1_e = EQRET1_e/(1 - 1/(1 + EQRET1_e)**CRNLIFE_e)$$

$$CAPCST_e = (BNDCRF_e*CRNDEBT_e/100 + EQCRF_e*(100 - CRNDEBT_e)/100)*CRNCAP_e$$

where:

$BNDRET1_e$	=	*Real return on debt required for corn ethanol plants on volume step e*
$MC\_RMCORPBAA_t$	=	*Nominal yield of BAA-rated corporate bonds in year t*
$BNDPREM1_e$	=	*Bond premium required for corn ethanol plants on volume step e*
$BNDCRF1_e$	=	*Bond capital recovery factor on volume step e*
$CRNLIFE_e$	=	*Economic life of ethanol plants on volume step e*
$EQRET1_e$	=	*Real return on equity required for corn ethanol plants on volume step e*
$MC\_RMTCM10Y_t$	=	*Nominal yield on 10-year treasury note in year t*
$BETA1_e$	=	*Multiplier applied to equity risk premium on volume step e*
$EQPREM1_e$	=	*Market risk premium for equity on volume step e*
$EQCRF1_e$	=	*Equity capital reconvery factor on volume step e*
$CRNDEBT_e$	=	*Debt fraction of corn ethanol plant finance on volume step e*
$CRNCAP_e$	=	*Capital cost per annual gallon of capacity for corn ethanol plant on volume step e*

The price of energy in each case is calculated as follows:

$$PEN_{cd,t,e} = CRNDS* PDSIN_{cd,t} + CRNMG* PMGIN_{cd,t} +CRNLG* PLGIN_{cd,t} +(CRNNG+QNG_{t,e})*PNGIN_{cd,t} + QCL_{t,e}*PCLIN_{cd,t}+(CRNEL+QEL_{t,e})* PELIN_{cd,t}$$

where:

CRNDS	=	Distillate needed to grow corn (MMBtu/gal)
CRNMG	=	Motor gasoline needed to grow corn (MMBtu/gal)
CRNLG	=	Liquefied petroleum gas (LPG) needed to grow corn (MMBtu/gal)
CRNEL	=	Electricity needed to grow corn (MMBtu/gal)
CRNNG	=	Natural gas needed to grow corn (MMBtu/gal)
$PDSIN_{cd,t}$	=	Industrial price of distillate for Census Division *cd* in year *t* ($/MMBtu)
$PMGIN_{cd,t}$	=	Industrial price of motor gasoline for Census Division *cd* in year *t* ($/MMBtu)
$PLGIN_{cd,t}$	=	Industrial price of LPG for Census Division *cd* in year *t* ($/MMBtu)
$PNGIN_{cd,t}$	=	Industrial price of natural gas for Census Division *cd* in year *t* ($/MMBtu),
$PCLIN_{cd,t}$	=	Industrial price of coal for Census Division *cd* in year *t* ($/MMBtu).
$PELIN_{cd,t}$	=	Industrial price of electricity for Census Division *cd* in year *t* ($/MMBtu).
$QNG_{t,e}$	=	Quantity of natural gas in year *t* on volume step *e*, MMBtu/gal
$QCL_{t,e}$	=	Quantity of coal in year *t* on volume step *e*, MMBtu/gal
$QEL_{t,e}$	=	Quantity of electricity in year *t* on volume step *e*, MMBtu/gal

Inventory of Variables, Data, and Parameters

MODEL INPUT: $MC\_RMCORPBAA_t$, $MC\_RMTCM10Y_t$

DEFINITION: Nominal yields of BAA-rated corporate bonds and 10-year treasury notes, respectively, in year *t*

SOURCE: Generated by the Macroeconomic Model. Located in Macroecnomic common block MACOUT.

MODEL INPUT: MC_JPGDP_t

DEFINITION: GDP chained price index in year *t*. 1987=1.

SOURCE: Generated by the Macroeconomic Model. Located in Macroecnomic common block MACOUT.

MODEL INPUT: $CRNLIFE_e$

DEFINITION: Capital recovery period for corn ethanol plants on volume step *e*. Value is 10 years.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls, by Thomas Lee of OIAF.

MODEL INPUT: *BNDPREM1*$_e$

DEFINITION: Bond premium required for corn ethanol plants on volume step *e*. Value is 0.25 percent for all steps.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: *EQPREM1*$_e$

DEFINITION: Market risk premium for equity investment. Value is 6.75 percent for all equity investments.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: *BETA1*$_e$

DEFINITION: Corn ethanol-specific multiplier applied to equity risk premium on volume step *e*. Value is 1.5 for dry mills.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: *CRNDEBT*$_e$

DEFINITION: Debt fraction of corn ethanol plant finance on volume step *e*. Value is 40 percent for all steps.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: *CRNCAP*$_e$

DEFINITION: Capital cost per annual gallon of capacity for corn ethanol plant on volume step *e*. Value is 0 for existing plants and $0.885 (1987 $) for dry mills that are not yet built.

SOURCE: Conversation with John Urbanchuk of LECG Consultants, July 19, 2005.

MODEL INPUT: *$OPCST_e$*

DEFINITION: Operating cost, exclusive of energy, for corn ethanol plants on volume step *e*.

Value is $0.261/gallon for wet mills and $0.167/gallon for dry mills (1987 $) for 2000 thru 2030. Located in the spreadsheet NEMScornsupplycurve.xls.

SOURCE: *USDA's 2002 Ethanol Cost-of-Production Survey*, Agricultural Economic Report Number 841

MODEL INPUTS: *CRNDS, CRNMG, CRNLG, CRNEL, CRNNG*

DEFINITION: Distillate, motor gasoline, LPG, electricity, and natural gas, respectively , needed to grow corn.

SOURCE: Shapouri, Hosein; Duffield, James A.; Wang, Michael. *The Energy Balance of Corn Ethanol: An Update*. Agricultural Eocnomic Report Number 814.

MODEL INPUT: $PDSIN_{cd,t}$, $PMGIN_{cd,t}$, $PLGIN_{cd,t}$

DEFINITION: Prices of distillate, motor gasoline, and LPG, respectively, for industrial use in Census Division *cd* in year *t*.

SOURCE: Generated by the Petroleum Market Model. Located in the Price common block MPBLK.

MODEL INPUT: $PCLIN_{cd,t}$

DEFINITION: Price of coal for industrial use in Census Division *cd* in year *t*.

SOURCE: Generated by the Coal Market Model. Located in the Price common block MPBLK.

MODEL INPUT: $PNGIN_{cd,t}$

DEFINITION: Price of natural gas for industrial use in Census Division *cd* in year *t*.

SOURCE: Generated by the Natural Gas Transmission and Distribution Model. Located in the Price common block MPBLK.

MODEL INPUT: $PELIN_{cd,t}$

DEFINITION: Price of electricity for industrial use in Census Division *cd* in year *t*.

SOURCE: Generated by the Electricity Market Model. Located in the Price common block MPBLK.

MODEL INPUT: $QNG_{t,e}$, $QCL_{t,e}$; e=1

DEFINITION: Quantity of natural gas and coal needed to convert corn to ethanol in year *t* on volume step 1.

Ethanol production on this step is assumed to come from wet mills, which consume 0.051 million Btu of process energy and electricity per gallon of output. Wet mills generate their own electricity, so their only energy inputs are coal and natural gas. Natural gas is 20% of the energy input per gallon, and coal is 80% of the energy input per gallon.

SOURCE: *USDA's 1998 Ethanol Cost-of-Production Survey*, Agricultural Economic Report Number 808

MODEL INPUT: $QNG_{t,e}$, $QCL_{t,e}$; e=2-4

DEFINITION: Quantities of natural gas and coal needed to convert corn to ethanol in year *t* on volume steps 2-4.

Ethanol production on these steps is assumed to come from dry mills. Process energy consumption values, in million Btu per gallon, are as follows: 0.050 in 1990, 0.041 in 2000, 0.037 in 2005, 0.035 in 2020 and 2025. This decreasing trend is based on the assumption that energy required decreases linearly over time. Existing dry mills, on step 2, use natural gas for 50% of their process energy and coal for 50% of their process energy. New dry mills, on steps 3 and 4, use natural gas for 100% of their process energy. Located in the spreadsheet NEMScornsupplycurve.xls.

SOURCE: Marland, G. and A.F. Turhollow. 1991. "CO_2 Emissions From the Production and Combustion of Fuel Ethanol from Corn." *Energy*, 16(11/12):1307-1316.

MODEL INPUT: $QEL_{t,e}$; e=2-4

DEFINITION: Quantity of electricity needed to convert corn to ethanol in year *t* on volume steps 2-4.

Ethanol production on these steps is assumed to come from dry mills, which consume 1.1 kwh (0.0037 million Btu) per gallon. Located in the spreadsheet NEMScornsupplycurve.xls.

SOURCE: *USDA's 1998 Ethanol Cost-of-Production Survey*, Agricultural Economic Report Number 808

MODEL INPUT: $ETHCRD_t$

DEFINITION: Value of Federal tax incentive in year *t*, in nominal dollars. The incentive is 52 cents per gallon in 2004 and 51 cents per gallon thereafter.

Located in the WETOHIN data input file.

I.3 Cellulose-Based Ethanol

Theoretical Approach

The cost of cellulose ethanol is subdivided into capital cost, feedstock cost, operating cost, and a credit for excess electricity generated at the ethanol plant. As with the corn model, each of the above factors contributes a part of the total price of ethanol.

Biomass feedstock supply is not modeled in the Petroleum Market Model ethanol model. Biomass price/quantity data are obtained from the Renewable Fuels Model of NEMS and are used as input to the ethanol model. The Model Documentation: Renewable Fuels Module of the National Energy Modeling System", DOE/EIA-M069(2005) contains a complete description of the approach and assumptions used in generating the biomass feedstock supply functions.

Briefly, the biomass use in NEMS is modeled as two distinct markets, the captive and non-captive biomass markets. The captive market pertains to users with dedicated biomass supplies that obtain energy by burning biomass byproducts resulting from the manufacturing process. The noncaptive market is defined to include the commercial, transportation, and electric utility sectors, as well as the resources marketed in the industrial sector. There is an additional noncaptive market serving residential uses of biomass.

EIA developed a fairly simple model structure consisting of one supply schedule per region. This schedule defines the quantity and cost relationships of biomass resources accessible by all noncaptive, non-residential consumers. It is based on an aggregation of supply/price information from U.S. Forest Service and forest product experts. The wood portion of the cost-supply schedule is static throughout the model period. Energy crop cost-supply schedules are also developed and superimposed onto the wood total.

Fundamental Assumptions

A basic assumption for the biomass feedstock is that the supply price for noncaptive biomass energy is the same across all sectors. Biomass feedstock costs are input from the NEMS Renewable Fuels Model at the Census Division level. Biomass usage by the PMM ethanol model is fed back to the Renewable Fuels Model. At lower prices, the NEMS biomass supply is mostly urban wood waste. Cellulose ethanol technology, however, is being developed for agricultural residue, forestry residue, and purpose-grown energy crops. These sources of supply are assumed to be available only at higher biomass prices. A feedstock cost premium, estimated by region and by ethanol quantity, was applied to cellulose ethanol to reflect this.

An important modeling consideration for cellulose ethanol production is the imposition of a constraint on the amount of ethanol production capacity assumed for the early years of the forecast. Ethanol from cellulose is relatively new technology and ethanol production from cellulose is currently at the demonstration level. By assumption, commercial cellulose ethanol production begins in 2010 in the *AEO2005* reference case. Commercial production is assumed to begin 2 years earlier in the *AEO2005* High Renewables side case. A constraint on cellulose ethanol production prevents unrealistically large increases in production capacity from occurring suddenly in response to favorable market prices. Cellulose ethanol production capacity is allowed to grow by 50 million gallons per year per region after 2010 (2008 in the High Renewables case)...

In addition to feedstock prices and quantities input from the Renewable Fuels Model, the ethanol model requires feedstock conversion and energy cost data, and capital and operating cost data. The conversion and capital cost data were derived from a joint study by the Dept. of Agriculture and the Dept. of Energy, *Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks.*,

Ethanol production costs are assumed to be constant across the United States. However, feedstock availability and price varies from Census Division to Census Division. Ethanol production in Census Divisions 2 and 7 is expected to be based on forest residue. Census Divisions 3 and 4 have corn stover in large volume. The feedstocks available in Census Division 9 are forest residue and rice straw The Federal tax incentives for blending ethanol also apply to ethanol from cellulose.

Key Computations and Equations

The main computations performed by the cellulose portion of the ethanol model involve the derivation of an ethanol supply-price curve for each Census Division. The computations consist of three major steps:

1. Reading in ethanol component cost data from the PMM input file WETOHIN.
2. Obtaining biomass feedstock prices at the census division level from the Renewable Fuels Model.
3. Derivation of delivered ethanol prices, calculated as a function of the biomass feedstock price and the ethanol conversion costs.

The delivered ethanol price equation is as follows:

$$WPETOH_{2,cd,t,e} = [CAPCST2_e + FC_{2,t,,e} + OPCSTCL_e - PWRCDCL_e - ETHCRD_t / MC\_JPGDP_t]*42$$

where:

$WPETOH_{2,cd,t,e}$ = Delivered price of cellulose ethanol in Census Division *cd* in year *t* for volume step *e* (1987 $/barrel)

$CAPCST2_e$ = Capital cost for cellulose conversion technology for volume step *e* (1987 $/gal)

$FC_{2,t,,e}$	=	Cellulose feedstock cost, exclusive of energy, in year t for volume step e (1987 $/gal),
$OPCSTCL_e$	=	Operating cost for volume step e (1987 $/gal),
$PWRCDCL_e$	=	Power credit for co-products combusted and sold as power for volume step e
$ETHCRD_t$	=	Federal motor fuels excise tax credit for ethanol production in year t (nominal $/gal)
MC_JPGDP_t	=	GDP chained price index in year t (1987=1)
42	=	number of gallons per barrel

Capital cost is calculated as follows:

$$BNDRET2_e = (1 + MC\_RMCORPBAA_t/100 + BNDPREM2_e/100)/(MC\_JPGDP_t/MC\_JPGDP_{t-1}) - 1$$

$$BNDCRF2_e = BNDRET2_e/(1 - 1/(1 + BNDRET2_e)^{**}CLLLIFE_e)$$

$$EQRET2_e = (1 + MC\_RMTCM10Y_t/100 + BETA2_e{*}EQPREM2_e/100)/(MC\_JPGDP_t/MC\_JPGDP_{t-1}) - 1$$

$$EQCRF2_e = EQRET2_e/(1 - 1/(1 + EQRET2_e)^{**}CLLLIFE_e)$$

$$CAPCST2_e = (BNDCRF2_e{*}CLLDEBT_e/100 + EQCRF2_e{*}(100 - CLLDEBT_e)/100){*}CLLCAP_e$$

where:

$BNDRET2_e$	=	*Real return on debt required for cellulose ethanol plants on volume step e*
$MC\_RMCORPBAA_t$	=	*Nominal yield of BAA-rated corporate bonds in year t*
$BNDPREM2_e$	=	*Bond premium required for cellulose ethanol plants on volume step e*
MC_JPGDP_t	=	*GDP chained price index in year t*
$BNDCRF2_e$	=	*Bond capital recovery factor on volume step e*
$CLLLIFE_e$	=	*Capital recovery period for cellulose ethanol plants on volume step e*
$EQRET2_e$	=	*Real return on equity required for corn ethanol plants on volume step e*
$MC\_RMTCM10Y_t$	=	*Nominal yield on 10-year treasury note in year t*
$BETA2_e$	=	*Cellulose ethanol specific multiplier applied to equity risk premium on volume step e*
$EQPREM2_e$	=	*Market risk premium for equity on volume step e*
$EQCRF2_e$	=	*Equity capital recovery factor on volume step e*

$CLLDEBT_e$	=	*Debt fraction of cellulose ethanol plant finance on volume step e*
$CLLCAP_e$	=	*Capital cost per annual gallon of capacity for cellulose ethanol plant on volume step e*

Feedstock cost is evaluated as follows:

If $PBMET_{cd,t}<=1.601$ *then* $FC_{2,t,,e}=1.601*17.2/ CONEFF_t$
If $PBMET_{cd,t}<=1.689$ *then* $FC_{2,t,,e}=1.689*17.2/ CONEFF_t$
If $PBMET_{cd,t}<=1.93$ *then* $FC_{2,t,,e}=1.93*17.2/ CONEFF_t$
If $PBMET_{cd,t}<=2.758$ *then* $FC_{2,t,,e}=2.758*17.2/ CONEFF_t$

Where

$PBMET_{cd,t}$	=	Biomass feedstock cost for Census Division *cd* in year *t* (1987 $/MMBtu)
17.2	=	MMBtu of biomass per short ton of biomass.
$CONEFF_t$	=	Feedstock conversion rate, gallons of ethanol per ton of biomass. Yield increases from 79.8 gallons per ton of feedstock in 2010 to 85 gallons per ton in 2014.

Inventory of Variables, Data, and Parameters

MODEL INPUT: $MC\_RMCORPBAA_t$, $MC\_RMTCM10Y_t$

DEFINITION: Nominal yields of BAA-rated corporate bonds and 10-year treasury notes, respectively, in year *t*

SOURCE: Generated by the Macroeconomic Model. Located in Macroecnomic common block MACOUT.

MODEL INPUT: MC_JPGDP_t

DEFINITION: GDP chained price index in year *t*. 1987=1.

SOURCE: Generated by the Macroeconomic Model. Located in Macroecnomic common block MACOUT.

MODEL INPUT: $CLLLIFE_e$

DEFINITION: Capital recovery period for cellulose ethanol plants on volume step *e*. Value is 20 years.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls, by Thomas Lee of OIAF.

MODEL INPUT: $BNDPREM2_e$

DEFINITION: Bond premium required for corn ethanol plants on volume step *e*. Value is 0.5 percent for all steps.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: $EQPREM2_e$

DEFINITION: Market risk premium for equity investment. Value is 6.75 percent for all equity investments.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: $BETA2_e$

DEFINITION: Cellulose ethanol-specific multiplier applied to equity risk premium on volume step *e*. Value is 1.75.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: $CLLDEBT_e$

DEFINITION: Debt fraction of cellulose ethanol plant finance on volume step *e*. Value is 20 percent for all steps.

SOURCE: Spreadsheet AEO2006 Final Discount Rates.xls.

MODEL INPUT: $CLLCAP_e$

DEFINITION: Capital cost per annual gallon of capacity for cellulose ethanol plant on volume step *e*. Value is $5.02/gal (1987 $) for all plants.

MODEL INPUT: $FC_{2,t,,e}$

DEFINITION: Cellulose feedstock cost in year *t* for volume step *e* (1987 $/gal). The prices for biomass were chosen to reflect adequate supplies of higher-quality biomass for the step quantity of cellulose ethanol. Cellulose ethanol plants are assumed to use forest wastes, crop residues, and energy crops. It is assumed that they will not use urban wood waste, because its quality is too variable.

MODEL INPUT: $OPCSTCL_e$, $PWRCDCL_e$

DEFINITION: $OPCSTCL_e$ is $0.428 per gallon, and $PWRCDCL_e$ is $-0.082 per gallon (1987 $).

SOURCE: McAloon, Andrew; Taylor, Frank; Yee, Winnie. *Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks.* National Renewable Energy Laboratory, October 2000. Located in the WETOHIN input data file.

MODEL INPUT: $PBMET_{cd,t}$

DEFINITION: Biomass feedstock cost for Census Division *cd* in year *t*.

Input from the Renewable Fuels Model.

SOURCE: National Energy Modeling System common block WRENEW.

MODEL INPUT: $ETHCRD_t$

DEFINITION: Value of Federal tax incentive in year *t*, in nominal dollars. The incentive is 52 cents per gallon in 2004 and 51 cents per gallon thereafter.

Located in the WETOHIN data input file.

I.4 Ethanol Transportation Costs

The most comprehensive work regarding ethanol distribution infrastructure and costs is a report by Downstream Alternatives, Inc. (DAI), *Infrastructure Requirements for an Expanded Ethanol Industry,* June 2002, performed for the Department of Energy Office of Energy Efficiency and Renewable Energy. This source was used to develop cost estimates for transporting ethanol between and within Census Divisions (CD's).

The DAI study estimates the infrastructure investment costs and the transportation costs that would likely be incurred if ethanol demand reached 5.0 billion gallons per year (BGY) by 2012. The infrastructure costs are incremental and represent additional expenditures from an established baseline level of 1.5 BGY. Transportation costs are the largest category of costs, far larger than the amortized costs of modifications to petroleum terminals and retail stations for blends of 10 percent ethanol or less. Rail and water are the modes of ethanol transport that are considered, as pipeline shipment is not currently considered a cost-effective method of transport due to special handling requirements of ethanol.

The DAI study examines the costs and ethanol demand by PADD. The links needed for PMM, as shown in Table I1, are based on Census Divisions for demands. There are some discrepancies between the PADD and CD mapping in terms of states; however, for the purpose of ethanol transportation cost estimates between the CD's, the following table is not expected to introduce significant error to the modeling results.

Table I1. DAI Regions and NEMS Regions

DAI Regions		**NEMS/PMM Regions**	
Code	Locations	Code	Locations
1	PADD 1	1, 2, 5	CDs 1, 2, and 5
2	PADD 2	3, 4	CDs 3 and 4
3	PADD 3	6, 7	CDs 6 and 7
4	PADD 4	8	CD 8
5	PADD 5	9	CD 9

Most ethanol is produced in either CD 3 or 4, and transported by rail, barge, ship, or truck. Ethanol produced and consumed in the same CD is assumed to be shipped by truck at a freight cost of 4 cents/gallon. Starting with the baseline of existing ethanol sales from year 2000, the DAI study examines the costs and ethanol demand for the years 2004, 2007, and 2012. The corresponding demands in the PMM model for each mode of transportation and the estimated freight costs are shown for these 3 years in Tables I2, I3, and I4.

The average cents per gallon in Tables I2 through I4 are provided on an amortized, cost per gallon of ethanol basis. Costs for capital improvement are included in the PMM model but are not included in the freight costs shown below. (Amortized capital improvement costs range from 0.52 cents per gallon to 0.87 cents per gallon, with a nationwide average of 0.66 cents per gallon)

Table I2. 2004 New Ethanol Shipments and Freight Costs by Census Divisions

From	To	Mode of Transport	Amount of New Ethanol Shipped (mgy)	Freight Costs (cents/gallon)
CD 3	CD 1	Rail	44.8	9.0
CD 3	CD 1	Ship	25.1	11.0
CD 3	CD 2	Rail	160.5	8.0
CD 3	CD 2	Ship	89.9	11.0
CD 3	CD 3	Barge	103.2	4.0
CD 3	CD 5	Rail	44.7	8.0
CD 3	CD 5	Ship	25.0	11.0
CD 4	CD 3	Rail	52.0	4.0
CD 4	CD 3	Truck	52.0	4.0
CD 4	CD 4	Truck	103.3	4.0
CD 4	CD 9	Rail	84.0	13.0
CD 4	CD 9	Ship	70.0	13.0

Source: Based on data from Downstream Alternatives Inc., *Transportation and Infrastructure Requirements for a Renewable Fuels Standard*, (June 2002), and personal communication with author (Robert Reynolds, August 2002

Note: Costs shown reflect 2000 dollars.

Table I3. 2007 New Ethanol Shipments and Freight Costs by Census Divisions

From	To	Mode of Transport	Amount of New Ethanol Shipped (mgy)	Freight Costs (cents/gallon)
CD 3	CD 1	Rail	34.8	9.0
CD 3	CD 1	Ship	18.8	11.0
CD 3	CD 2	Rail	124.5	9.0
CD 3	CD 2	Ship	67.4	11.0
CD 3	CD 3	Truck	38.6	4.0
CD 3	CD 5	Rail	34.7	9.0
CD 3	CD 5	Ship	18.8	11.0
CD 3	CD 6	Barge	12.2	3.5
CD 3	CD 6	Rail	24.9	7.0
CD 4	CD 3	Truck	38.6	4.0
CD 4	CD 4	Truck	38.6	4.0
CD 4	CD 6	Barge	4.1	3.5
CD 4	CD 6	Rail	8.3	7.0
CD 4	CD 7	Barge	43.7	3.5
CD 4	CD 7	Rail	88.8	7.0
CD 4	CD 9	Rail	195.0	13.0
CD 4	CD 9	Ship	105.0	13.0

Source: Based on data from Downstream Alternatives Inc., *Transportation and Infrastructure Requirements for a Renewable Fuels Standard*, (June 2002), and personal communication with author (Robert Reynolds, August 2002

Table I4. 2012 New Ethanol Shipments and Freight Costs by Census Divisions

From	To	Mode of Transport	Amount of New Ethanol Shipped (mgy)	Freight Costs (cents/gallon)
CD 3	CD 1	Rail	71.8	9.0
CD 3	CD 1	Ship	43.1	11.0
CD 3	CD 2	Rail	256.8	9.0
CD 3	CD 2	Ship	154.1	11.0
CD 3	CD 3	Barge	16.8	4.0
CD 3	CD 3	Truck	146.3	4.0
CD 3	CD 3	Rail	10.0	4.0
CD 3	CD 5	Rail	71.5	9.0
CD 3	CD 5	Ship	42.9	11.0
CD 3	CD 6	Barge	20.6	3.5
CD 3	CD 6	Rail	11.4	7.0
CD 3	CD 9	Rail	25.0	14.0
CD 3	CD 9	Ship	15.0	14.0
CD 4	CD 1	Rail	17.9	11.0
CD 4	CD 1	Ship	10.8	12.0
CD 4	CD 2	Rail	64.2	11.0
CD 4	CD 2	Ship	38.5	12.0
CD 4	CD 3	Barge	33.6	4.0
CD 4	CD 3	Rail	20.0	4.0
CD 4	CD 3	Truck	36.6	4.0
CD 4	CD 4	Truck	36.6	4.0
CD 4	CD 5	Rail	17.9	11.0
CD 4	CD 5	Ship	10.7	12.0
CD 4	CD 6	Barge	20.6	3.5
CD 4	CD 6	Rail	11.4	7.0
CD 4	CD 7	Barge	110.1	3.5
CD 4	CD 7	Rail	61.0	7.0
CD 4	CD 8	Rail	35.0	4.5
CD 4	CD 9	Rail	225.0	13.0
CD 4	CD 9	Ship	135.0	13.0

Source: Based on data from Downstream Alternatives Inc., *Transportation and Infrastructure Requirements for a Renewable Fuels Standard*, (June 2002), and personal communication with author (Robert Reynolds, August 2002