ECONOMIC AND TECHNICAL ANALYSIS OF ETHANOL DRY MILLING: MODEL USER'S MANUAL

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Staff Paper # 06-05

April 2006

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Model Users Manual

Using the DM model is not complex: the user changes input values of interest (plant size, conversion rates, etc.) and examines the effect of these changes on output values (annual profits, feed stock requirements, etc.). There are nine worksheets in four modules in the excel workbook: assumptions, process, economics, and technology assessment. All user inputs are entered in the assumptions module of the model, which consists of three worksheets denoted with bright yellow tabs: process assumptions, economic assumptions and physical assumptions. The values that are entered on this page are then used in each of the subsequent modules to calculate hourly flow rates, equipment size and cost, total costs, loan terms, and annual profits. At the top of each page is a title bar which describes the page, the color coding of the cells, and pertinent information from the other pages. Before each of the pages is discussed, an explanation of the different types of cells in the model is in order.

There are several different types of cells in the model; each of which is color coded as either an: input (direct and constant), value holder, information, calculation, look up table, flow rate, or function cell. Any of the cells can be changed to suit the specific needs of a user, but caution should be exercised when changing any cell value that is not a direct user input, bright yellow with black text. Cells that are not yellow with black text should only be changed for very specific reasons. To mitigate against accidental user input in non-input cells, they have been password protected. The function of each cell is indicated by its color. Table 1 shows the different types of cell colors and their corresponding function. A detailed explanation of cell nomenclature directly follows. This explanation precedes a description of each module of the DM model and how it is to be used.

Table 1 Description of Cell Color Coding

Variable Color Coding	
Direct Input	Constant Input
Calculation	Value Holder
Trigger	Function Value
Information	Information
Input Flow	Output Flow
Flow Rate	
Look Up Table	

Source: DM Model

Description of Cells and their Function

Direct User Input Cells (Yellow / Black Text)

These cells are where the user enters or changes values. These cells are designed to be manipulated by the user to change the assumptions of the model. Changes in values of these cells will directly change the quality and amount of output and financial situation of the modeled dry mill. Direct input cells important in determining the profitability of the dry mill include: plant capacity, physical conversion rates, economic rates, etc. These are the only cells in the model that are not protected.

Direct User Constant Cells (Yellow / Red Text)

These cells are readily manipulated by the user just as 'direct input cells' are. However, it is not recommended that these cells be changed because their values do not vary much across time or plants. The values in these cells are generally accepted, and changing these values is not recommended. These cells include the densities of materials, indices, molecular weights, minimum reflux values, etc. To protect against user error, these cells are protected.

Value Holder Cells (Light Blue)

These cells are the values from other cells in other modules or sheets. They take values, inputs or calculations, from one part of the model and return them in another part of the model to be used or lend clarification. They are used to connect the individual sheets together and increase the transparency of the model. These cells have labels describing where they come from.

Function Trigger Cells (Pink)

The function cells allows the user to choose to either input a value as a function of other variables (by entering a 1 in the trigger cell) or input the value independent of other variables (by entering a 0). Functions exist and can be used to calculate conversion rates, plant utilization percentage, and prices for distiller's dried grains with solubles (DDGS), ethanol, and a jet cooker. The bright pink cells are used to turn the function on (1) or off (0) and light pink cells describe or are the products of functions.

Information Cells (Tan / Light Green)

These cells simply explain what unit, variable, or process is being used in the other types of cells. These cells are used to describe excel names, and also appear in the title page. These cells should not be changed. Descriptor cells include row and column headings, units for other cells, and other general information.

Calculation Cells (Light Yellow)

These cells carry out the calculations that take place in the model. Using values from other cells (input, function, or other calculation cells), calculations are carried out in these cells. Calculation cells return values for densities, equipment sizing, financing, etc. These cells are the same for all plant capacities but will return different values according to their functional form and input values. In general these cells should not be changed unless there is a specific reason, for example, to indicate an industry-wide change.

Hourly Flow Rates (Blue, Purple, and Orange)

Hourly flow rate cells are used in the process module to differentiate between input, output, and process flows. Orange cells represent hourly process flow rates where no output or input takes place, purple cells indicate hourly rates of inflow, and blue cells signify hourly rates of outflow. In the process module the anhydrous ethanol flow into storage tanks rate is blue, the flow of grain to be milled is purple, and the flow of mash to the fermentation vessels is orange.

Look Up Table (Bright Green)

These cells always occur in tabular form and are used to give the user a range of values for an input. Look up tables are intended to be used in conjunction with direct user input cells, and for this reason these cells only appear in the assumptions module of the model. Look up tables appear directly next to the input cell that they provide values for. Look up tables are used to give constants for different distillation tray heights, as well as jet cooker price suggestions.

Description of the DM Model Pages and Their Use

The DM model contains four modules indicated by the color of their tab: assumptions, process, economic, and technology assessment. The assumptions module demarked by yellow tabs is made up of three separate worksheets: process (Asmp1), physical (Asmp2), and economic (Asmp3) assumptions. The process module, indicated by the tab color light yellow, consists of two pages: process flows (Proc1) and equipment sizing / pricing (Proc2). The economic module, signified by blue tabs, consists of three worksheets: revenues and costs (Econ1), financing (Econ2), and benefit cost analysis (Econ3). The technology assessment module consists of one worksheet (Tech1) and is denoted by the tab color of red. When the DM model is opened, the screen displays the process assumptions worksheet by default. Users can then enter values for direct user inputs and move from worksheet to worksheet by clicking on the tabs at the bottom of the worksheet. The following will briefly describe how each page of the model was constructed, and how the user is to manipulate it.

All user inputs are entered into the DM model on one of the three assumptions worksheets. In the assumptions module every type of cell is utilized excepting flow rate cells. This module and the values entered by the user drive the rest of the model. Users enter values pertaining to three categories: the dry mill production process, physical properties of inputs and outputs, and economic parameters.

Process Assumptions

The process assumption worksheet is the first worksheet in the assumption module. This worksheet is composed of three tables and four diagrams that together cover almost all the decisions that a production manager and/or owner of a dry mill plant must make in production. The user may enter values for plant capacity, plant utilization, retention times, process temperatures, enzyme usage, and moisture percentages of different streams. The most important variables, and most likely to be changed, are found in the plant operation table.

Plant Operation Input Table

Variables found on the plant operation table drive the model. Two of the most critical variables are annual production capacity and the percentage of utilization. As can be seen below in Table 2 the plant operation input table also allows for the user to set values for the backset rate, percentage solids in the fermentation, and the denaturant percentage of denatured ethanol. The user should first enter a value for total plant capacity into the first input cell of the table. This is the maximum number of gallons of anhydrous ethanol the plant can produce in a single year. Most dry mills are within the capacity range of 10 and 100 million[1] gallons of anhydrous ethanol per annum. It is suggested that users enter capacities within this range because the DM model has been validated at these production levels.

Ethanol production facilities run continuously with scheduled shut down periods for maintenance. In the DM model there are two ways in which less than full capacity utilization can be entered using a function trigger. The user can either enter a utilization of full capacity percentage or enter the number of operational days per year. The user should enter a 1 into the function cell and enter the percentage of full capacity utilization or enter a 0 and enter the number of days of plant operation. Directly to the right of the trigger tells the user which method is being used. BBI's Ethanol Handbook states that the planned number of days of operation should not be more than 360 days of full utilization, corresponding to a 99% utilization rate [**2**]. Operational hours are calculated by multiplying days of operation by the number of hours in a day[2], 24. The user can also change the percentage solids of the mash- changing the alcohol content of the beer, backset rate- changing the water balance, and the necessary denaturant percentage- changing the denaturant input.

Process Assumption Diagrams

Biotic and other parameters of the ethanol production process are entered in the process assumptions diagrams. In the theoretical process diagram (Figure 1) the user enters parameters for the amount of enzymes, yeasts, and antibiotics required per pound of corn input. This diagram shows theoretical conversion rates per pound of dry weight corn. All values are in dry pounds excepting gallons of ethanol.

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[1] Most new ethanol plants are within the range of 30 – 100 MGY.

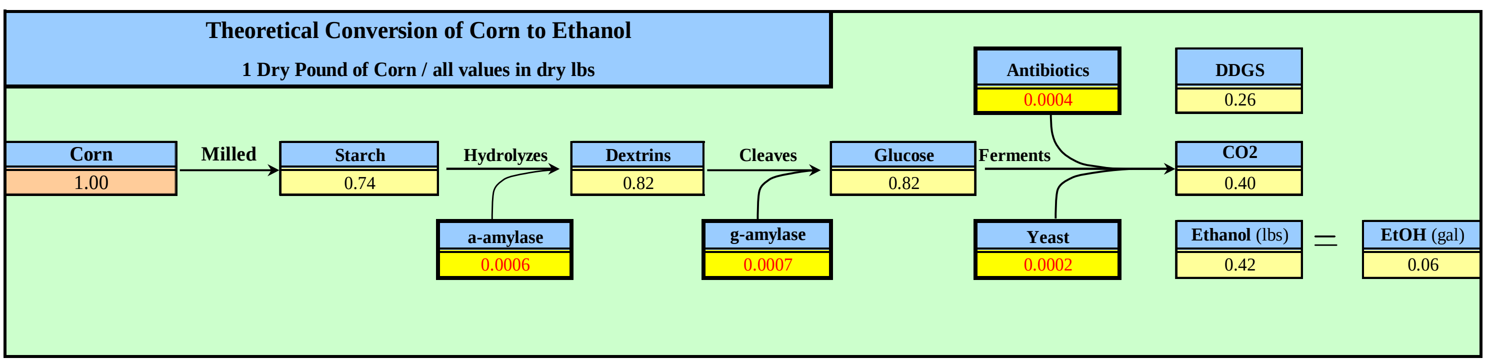
[2] It should be noted that there are huge energy requirements in shutting down and restarting a plant, especially in distillation systems.

Table 2 Dry Mill Process Assumptions: Plant Operation

Dry Mill Process Assumptions: Plant Operation			
Variable		**Description**	**Value**
Production	Name Plate	gal / year	**40,000,000**
1	**% Utiliz. Method: ON**		
	% Capacity Method	95%	(trigger = 1)
	Op Hours Method	360	(trigger = 0)
	Actual	gal / year	**38,000,000**
	Plant Utilization	% NP Cap	95%
Operational			
		hours / day	24
		days /year	365
		hours/year	8322
Paramaters			
	Backset Rate	% of H2O	20%
	Mash Solids	% of Mash	30%
	Denaturant	% of EtOH	5%

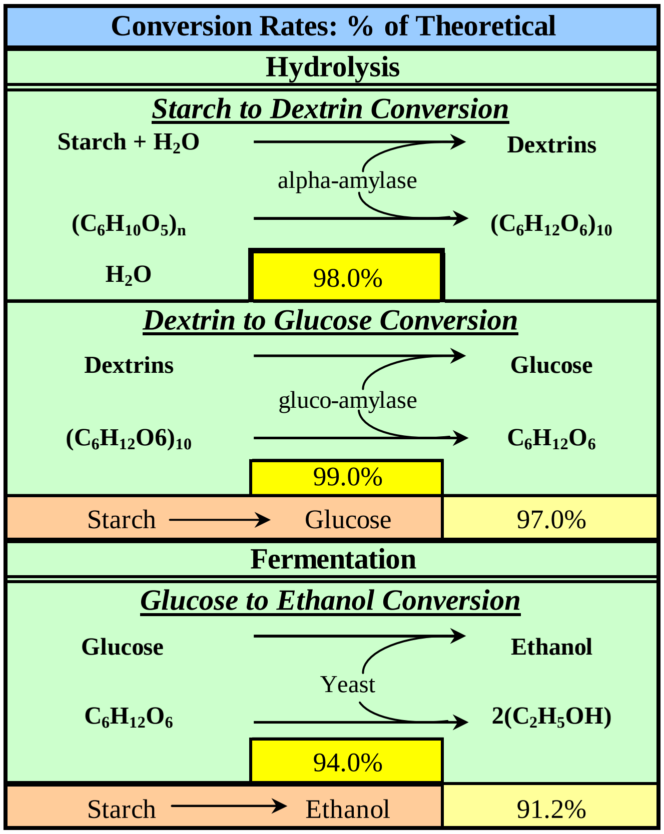
Source: DM Model

Figure 1 Theoretical Conversion of Corn to Ethanol



Theoretical yields are not realized in production. To take this into account the user enters conversion percentages in the conversion rate diagram (Figure 2). Conversion rates are entered for the hydrolysis of starch to dextrins and dextrins to glucose, as well as fermentation. Conversion rates are entered as a percentage of theoretical.

Figure 2 Conversion Rates as a Percentage of Theoretical Yield Figure



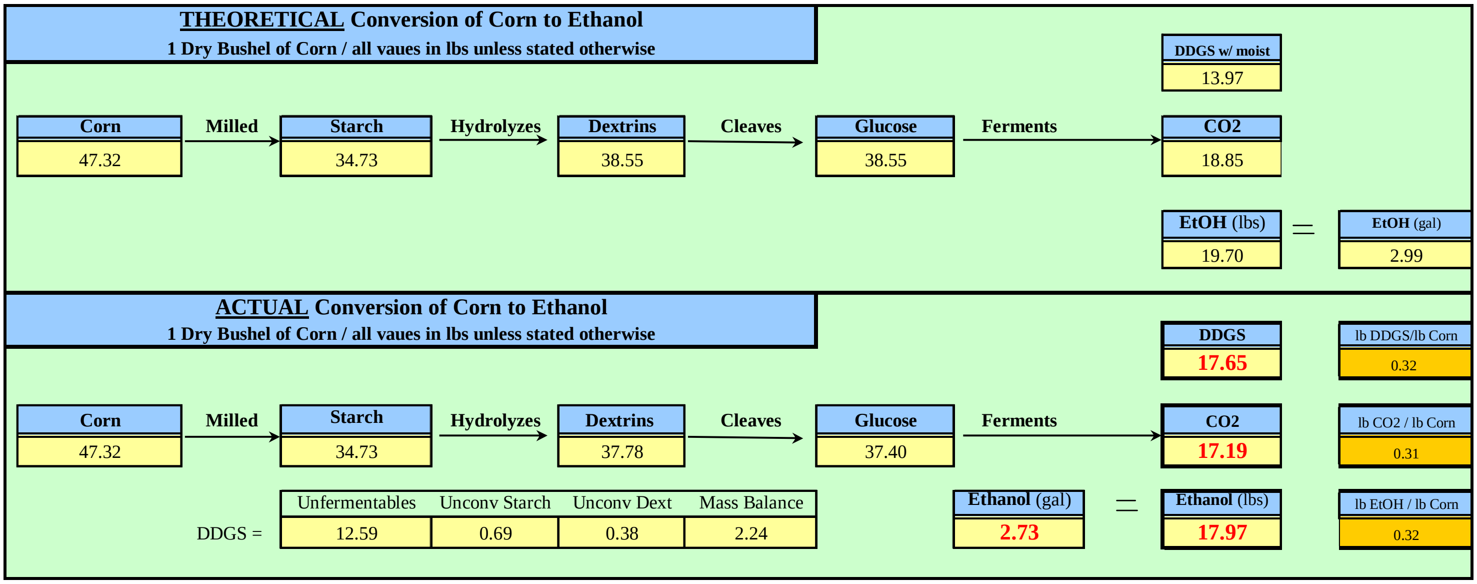
Source: Authors Estimates

The conversion rates entered and other process assumptions are used to calculate the yields of products per bushel of grain input. These calculations are carried out in the theoretical versus actual yield diagram on the process assumptions page. This diagram is Figure 3. To preserve mass balance both actual and theoretical product yields were necessary in calculation and values are in dry weight pounds. Ethanol and CO_2 yields were calculated as a function of the corn composition and conversion rates while DDGS was calculated as the remainder. The actual pounds of product per pound of grain input was calculated and used in flow rate estimation.

Process Parameters Table

Parameters including, retention time (rtd), number of pieces of equipment, and process temperatures, are entered for each step of the production process. These are entered in the table titled ‘Equipment RTD / Number / Temperature’ as shown in Table 3. These parameters are important in calculating equipment size, thermal energy use, and process flow rates. Many dry mill processes, such as hammer milling, have no specific rtd. These processes operate at whatever flow rate is necessitated by the rest of the system. Process stages which do operate at system speed have the number 60 entered as their rtd. The longest rtd in the dry mill process is the fermentation process. Due to the relatively extensive residence time in this step, dry mills commonly employ four fermentation vessels. The beer well is a large storage tank in which fermentation continues. Beer wells are commonly designed to hold twice the volume of the fermentation vessels.

Figure 3 Theoretical and Actual Product Yields



Source: Authors Estimates

Table 3 Dry Mill Process Assumptions: Equipment RTD / Temperature / Number

Dry Mill Process Assumptions: Process Equipment Specification			
Equipment	**RTD**	**Number**	**Temp. (F)**
Hammer Mills	60	1	110
Slurry Tank	90	1	180
Jet Cooker	60	1	180
HP Hold Tube	15	1	180
Liquification Tank	90	1	210
Fermenters	3000	4	95
Beer Well	6000	1	95
Rectifier	60	1	180
Stripper	60	1	180
Mol Sv Clmns	60	2	180
Centrifuge	60	1	180
Evaporators(1)	60	3	160
2	-	-	200
3	-	-	240
Drum Dryer	60	1	160
Storage Tanks	17280	1	70

Source: DM Model / RFA [**15**]

Moisture / Solid Percentages

The user must decide on the moisture / solids percentages for each stage of the production process. The user can input values for the moisture content of the mash, WDG, WDGS, DDGS, and the soluble syrup. The moisture content of these flows are important in estimating how much water is needed in the production process and in finding the amount of thermal energy necessitated in the recovery of co-products. The DM model is closed in its water balance. This balance requires that some of the moisture / solids percentages be derived from the calculations based on other moisture levels and flows. The moisture content of the beer, whole stillage, and thin stillage are calculated using flow rates and the co-product moisture percentages. Corn, mash, and DDGS moisture percentages are transferred from user input cells in other tables. The mash moisture comes from the user input of the percent solids in the mash, while the corn and DDGS moisture percentages come from the physical properties table. This input table, shown below as Table 4, is used in the calculation of hourly flow rates, water balance, and input requirements.

Physical Properties

There are three tables in which physical properties are entered into the model: the grain composition table, distillation and evaporation table, and the densities, indices, and conversions table. These physical assumption values are used in the calculations of flow rates, conversion rates, and finances.

Table 4 Dry Mill Process Assumptions: Solid / Liquid Percentages

Dry Mill Process Assumptions: Solid / Liquid Percentages		
Product	**Moisture %**	**Solids %**
Corn	15.5%	84.5%
Mash	70%	30%
Beer	89%	11%
Whole Stillage	66%	34%
WDG	40%	60%
WDGS	60%	40%
Thin Stillage	93%	7.0%
Syrup	60%	40%
DDGS	11%	89%

Source: DM Model / Authors Estimates

Grain Composition

The grain composition table allows users to input assumptions about the macronutrient components of grain and DDGS. The starch, fiber, protein, ash, moisture, and glucose percentages of grain are entered into the table. The percentages are summed and subtracted from 100% to obtain the "other" percentage. DDGS nutrient content is calculated as the amount of starch, dextrin, and glucose that was not converted to alcohol in the fermentation process. These values are used along with conversion rates to determine the theoretical and expected yield of co-products from grain. Table 5 shows the grain composition table as it appears in the DM model, these values are in dry weight percentages.

Table 5 Physical Property Assumptions: Grain Composition

Physical Assumptions: **Grain Composition**		
Grain:	Corn	DDGS
Starch+Sol Sugar	74%	6.1%
Cellulose / Hemi-	8.1%	26%
Lipids	4.3%	13.6%
Protein	10.3%	33%
soluble	20%	
insoluble	80%	
Ash	1.4%	4.4%
Other	1.6%	18%
Moisture	15.5%	11%
Total	100.0%	100%

Source: Corn Chemistry and Technology [**18**] / DM Model

Densities / Indices / Identities

The physical properties of water, alcohol, grain and gasoline are entered in the DII table (Table 6). This includes their densities and relative densities which are important in converting hourly flow rates in terms of weight into hourly flow rates in terms of volume. The table also allows for entering the Marshall Swift index number. This allows for the inflationary rate of chemical equipment to enter the model. The energy index used in calculating electrical energy use appears in this table as well. Several convenient excel variables are also listed in this table. These include the values of 1,000,000 and 60 that are used frequently in conversions in the DM model.

Table 6 Physical Property Assumptions: Densities / Indices / Identities

Physical Property Assumptions: Densities / Indices / Identities			
	Variable	Unit	Value
Indices			
	Marshal Swift		1107
	Energy		8
Densities:			
	Water	lbs / gal	8.33
	Anhydrous EtOH	lbs / gal	6.59
	Mash	lbs / gal	8.58
	Beer	lbs / gal	7.79
	Grain	lbs / bush	52.11
	Hydrous EtOH	lbs / gal	6.67
	Reltv (EtOH / H2O)	%	0.791
Identities			
	One Million		1000000
	Minutes per Hour		60
	Btu's evaporate 1 lb H2O		1000
	Grams per Pound		453.592
	Liters per Gallon		3.785
	Ideal Gas Law		22.4
	R		0.0821
	BP for EtOH		173
	BP for H2O		212
Molecular Wgt:			
	Starch / Dextrins		162
	H2O		18
	Glucose		180
	EtOH		46
	CO2		44

Sources: [13], [4], [5]

Distillation and Evaporation Table

Even though the distillation and evaporation table contains some process assumptions, it was included in the physical properties page because it contains more physical assumptions. The design of the distillation and evaporation equipment is more complex than other stages of the production process in which only a tank is needed. The complexity of these systems required a separate table for input value entry. It should be noted from a quick examination of this input table, shown in Table 7, that a direct user input cell only appears for heat exchange and dryer efficiencies. The variables of distillation and evaporation that appear in this table are similar across dry mill plants and should not be changed by the user unless there is a specific reason to do so. This table includes a look-up table / function combination that is used to determine distillation tray sizes. The user decides on which tray size to use from the look-up table and enters a 1 in the corresponding function cell and a 0 in the other function cells. This table also has the specific heats for water and ethanol which are important in determining the thermal heating requirements of the dry mill process.

Table 7 Dry Mill Process Assumptions: Distillation / Evaporation

Dry Mill Process Assumptions: Distillation / Evaporation						
Variable		**Unit**	**Values**	**Thermal**	**Specific Heat (Btu's)**	
Distilate	EtOH	%	95.6%	**Variable**	**Sensible**	**Latent**
	H_2O	%	4.4%	Water	1	1,100
Reflux	Minimum	m3/sec	1.75	Anhyd EtOH	0.63	800
	Pressure	lbs/in	1.2	Hyd EtOH	0.65	815
	Ratio	#	2.625	**Efficiencies**		
Evaporator	Passes	#	3	Of Heat Exchange Max		80%
	Avg Delta T	F	30	Of Drum Dryer Max		80%
	Avg U Temp	F	220	Spacing (in)		Constant
Trays	Spacing	in	24	0	12	0.0229
	Rectifier	#	50	0	18	0.0427
	Stripper	#	30	1	24	0.0537

Source: DM Manual / Alcohol Distillation: Basic Principles [**19**]

Economic Variables

There are three tables in the variables page of the DM model that deal directly with the economics of the dry mill production process. The first of these pages is a price table in which prices for all inputs and outputs are entered. The second deals with the finances of the ethanol plant, and the third table allows the user to turn three price functions on or off. These functions are for the price of ethanol, DDGS, and one piece of equipment for which no data exists, the jet cooker.

Price Table

In the price table, Table 8, the user simply enters prices for all inputs, outputs, and governmental subsidies. The user is also asked to enter the price of one good that is neither an input nor an output, soybean meal, but is used in the DDGS price function. The prices that the user enters are either in dollars per volumetric unit (gas and water), dollars per weight unit (corn and CO_2), or as a percentage of revenue, net revenue, and capital costs (taxes, labor, license fees and miscellaneous expenses).

Table 8 Economic Assumptions: Prices / Values

Economic Assumptions: Prices / Values			
Variable		**Unit**	**Value**
Ag Goods	Dent Corn	$ / Ton	$85
	Milo	$ / Ton	$120
	Soy Bean Meal	$ / Ton	$150
Chemicals	Brewers Yeast	$ / lb	$2.50
	Alpha Amalayse	$ / lb	$3.00
	Gluco Amalayse	$ / lb	$3.00
	SO2 / Antibiotic	$ / lb	$2.50
	CO2	$ / Ton	$6.00
Utilities	Electricity	$ / kWh	$0.03
	Natural Gas	$ / Mbtu	$8.00
	Water	$ / K gal	$1.00
	Gasoline	$ / gal	$2.00
Operation C	Total Labor	% Capital	5.0%
	Taxes	% Net Rev	15.0%
	Liscence Fees	% Rev	2.0%
	Misc.	% Rev	2.0%

Source: USDA / Authors Estimates

Financial

The financial information table is where users enter values for variables pertaining to the yearly finances of the dry mill plant. This table is where users enter values for rates (interest, inflation) and loan term (repayment years, equity percentage). This table also permits the user to decide how profits will be used and in what proportion. The user enters values for the percentage of profits that will be paid to shareholders, managers, or pay down equity. The sweep payment is calculated as the share of profits that are not used in all other pursuits. The sweep payment allows the plant to use a percentage of the profits to pay more than the required loan payment. The sweep payment allows the loan to be paid off in less than the agreed upon number of years. Table 9 shows the financial table as it appears in the DM model.

Table 9 Economic Assumptions: Financial

Economic Assumptions: Financial Information			
	Variables	Unit	Value
Terms:	Wrkng Cap Req.	% Op Cost	8%
	Sweep Factor	% Profits	40%
	Initial Equity Req	% TCI	40%
	Loan Factor	% TCI	60%
Timing:	Loan Length	Years	15
	Plant Operational	Year	3
	Plant Life Span	Years	25
	1st year TCI	% TCI	60%
	2nd year TCI	% TCI	40%
Rates:	Inflationary		3.0%
	Discount		12.0%
	Interest		8.7%
	Real Discount		8.7%

Source: Authors Estimates

Price Functions Table

The last input table that deals with the economic parameters of the dry mill plant is a price functions table. This table is shown below as Table 10. The prices of ethanol, DDGS, and the jet cooker are calculated as a function of other prices or capacity. In this table the user must decide whether to enter the prices of these goods manually, by turning the function off, or allow these prices to be calculated as a function of other prices / capacity, by turning the function on. The price function is turned on by the user entering a 1 in the adjacent pink cell; and it is turned off by the entering a 0 in the same cell.

The ethanol and DDGS price functions were calculated through regression analysis of their respective markets and substitutable goods. The table lists the commodities that were used as explanatory variables in the analysis and their corresponding p-values. The over all model fit is also listed in the table as the R^2 value. The ethanol price per gallon is a function only of the price per gallon of gasoline:[3]

Price Ethanol = 19.37 + .792 [Price Gas] + e

t-stat:	***(2.0)***	***(11.8)***
P-value:	***(.05)***	***(0)***

Adj R^2 = .62

[3] Price data for gasoline, ethanol, corn, and soybean meal come from Bloomberg's Electronic Database. DDGS prices come from USDA.

Table 10 Economic Assumptions: Price Functions- Ethanol, DDGS, and Jet Cooker

Economic Assumptions: Price Function / Manual Entry:								
Ethanol Price ($ / gal): f[price of Gas (cents / gal)] / Manual Entry								
1								
1) Manually	If N36 = 0 Then Price(EtOH) =							EtOH Manl Price
not in use							*entered here:*	$1.90
2) Functionally	If N36 = 1 Then Price(EtOH) =					*Regression (R-Sqd = .62)*		
IN USE								
EtOH Fnct Price	=	*Bo*	+	*B1*	*	Price Gas	+ *error*	
$1.78	=	(19.4)	+	(.79)	*	200	+ N(u,s)	

DDGS Price ($ / Ton): f(price of SBM, price of YDC) / Manual Entry								
0								
1) Manually	If N36 = 0 Then Price(EtOH) =							DDGS Manl Price
IN USE							*entered here:*	$90
2) Functionally	If N36 = 1 Then Price(EtOH) =					*Regression (Adj R-Sq = .73)*		
not in use								
DDGS Fnct Price	= *Bo* + *B1* *	Price SBM	+ *B2* *	Price YDC	+ *error*			
$90	= (-9.2) + (.135)	150	+ (1.04) *	85	+ N(u,s)			

Jet Cooker: f (Capacity) / Manual Entry							
1							
1) Manually	If N36 = 0 Then Price(EtOH) =						Jet Ck Manl Price
not in use						*entered here:*	$100,000
2) Functionally	If N36 = 1 Then Price(EtOH) =			f(Price of Gas)			
IN USE			*Function:*				
Cooker Fnct Price	= *F* (	Total Capacity	^(2) ,	Total Capacity	)		
$118,531	= 38,000 + 10^(-12) *	40,000,000	^(2) + .0024 *	40,000,000			

Source: DM Model

The price function of DDGS was calculated in the same manner using the price of corn and soybean meal as the explanatory variables for the price of DDGS:

$$\textbf{Price DDGS} = -9.205 + 1.037\,[\text{Price Corn}] + .135\,[\text{Price SBM}] + e$$

t-stat:	*(-2.2)*	*(10.9)*	*(4.6)*
P-value:	*(.03)*	*(0)*	*(0)*

$$\text{Adj } R^2 = .73$$

The jet cooker is a piece of equipment used in the dry mill process for which no cost correlations could be found. A discussion with representatives of a company which sell jet cookers led to the addition of a look up table included with the price function for a jet cooker. The jet cooker price was constructed as a function of plant capacity. If the user chooses not the use the price function the user may enter any value for the price of the jet cooker in the manual price cell, with or without the assistance of the look-up table. The jet cooker function is as follows:

$$\textbf{Price Jet Cooker} = 38{,}500 + .0024 * (\text{Capacity}) - 10^{-9} * (\text{Capacity})^2$$

The price of the jet cooker appears in the price function table regardless of whether its function is used or whether a manual price is entered.

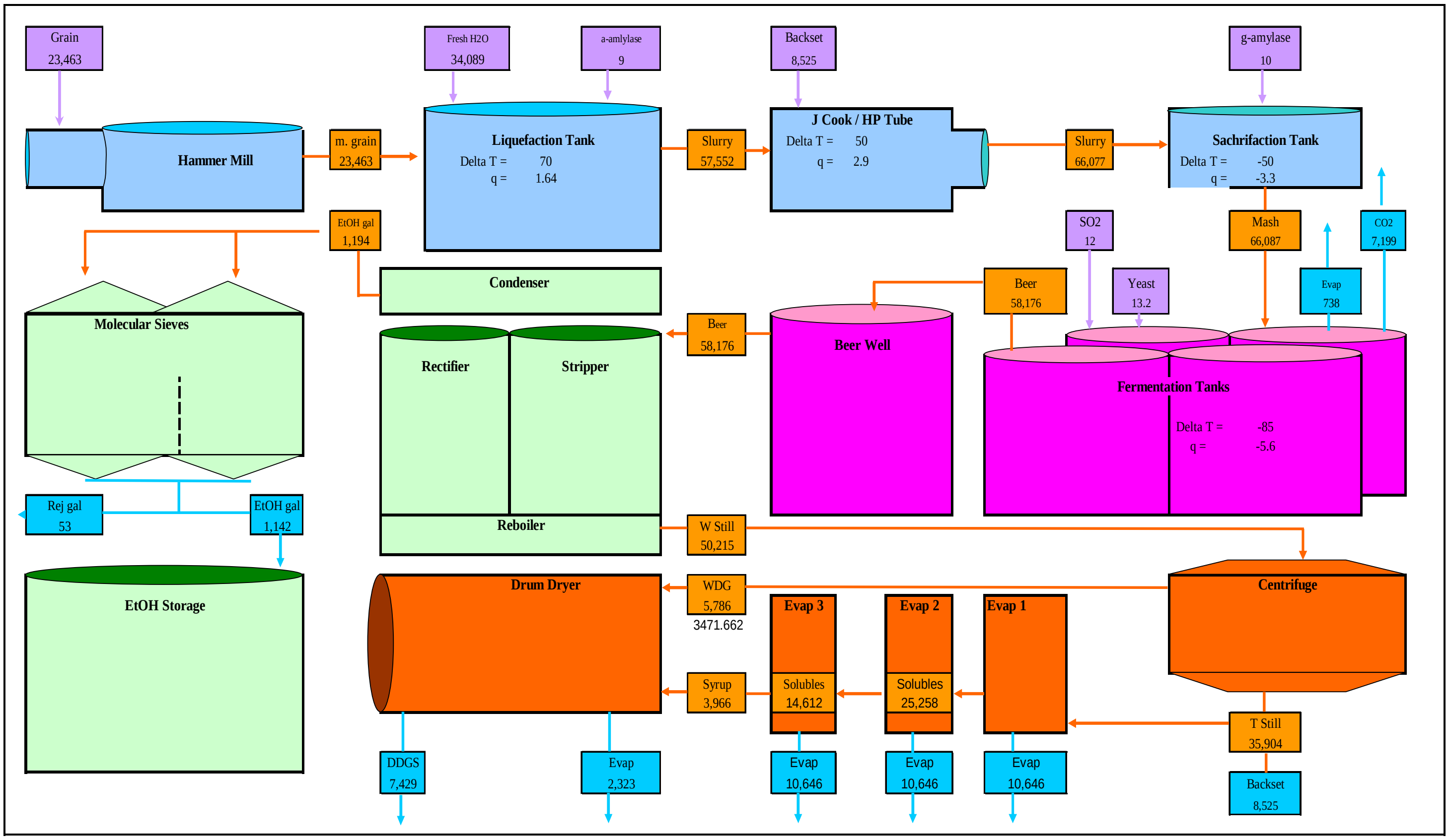
Process Module: Process Flows

The process page is where the user inputs from the variables page are used to calculate the hourly flow rates. The annual ethanol output and yield rates from the process assumptions page are used to calculate flow rates of grain, ethanol, water, CO_2, and DDGS. The theoretical yield of co-products and the yearly plant capacity are used to calculate the hourly flow rates of inputs and outputs in each stage of the dry mill process. These flow rates are calculated in terms of weight, dry weight, and volume when possible. Hourly flow rates were calculated for full capacity as well as for average actual capacity utilization. Flow rates were calculated using the dry mill process assumptions as well as physical property input values. Hourly flow rates are displayed in two ways: diagrammatically and in table form.

The flow diagram (Figure 4) better expresses the flow of streams while the table form allows for more manipulation of the flows (Table 11). Streams of outflows are streams in blue, inflows in purple, and process in orange. The diagram shows flows in pounds at full capacity.

Table 11 shows the tabular flow rates for the fermentation process. The two pieces of equipment utilized in this process are the fermenters (4) and the beer well. The flow rates are found for dry weight, pounds, and volume when applicable. The flow rates of the inputs are shown in purple, outputs in white, and when output flow is equal to input flow it is shown in orange. Densities and energy flows are also calculated when applicable.

Figure 4 Process Flow Diagram: Hourly Flows for a 40 MGY at Full Capacity



Source: DM Model

Table 11 Hourly Flow Rates for Fermentation

Equipment			Hourly Flow Rates								
Name	Number Used	RTD min	Input / Output	Dry Weight lb	Full Capacity lb	Full Capacity gal	Densities lbs / gal	Actual / Average lb	Actual / Average gal	Energy MMBtu	Energy kWh
Fermenters	4	3000									1504
			Mash	81274	270,914	31,361		257,368	29,793		
			Antibiotics		13			12			
			Gluco Amylase	-	48	6		45	5		
			Yeast	-	14	2		13	2		
			CO2		28,796	1,930,349		27,356	1,833,831		
			H2O Evap		738.0	89		701	84		
			Beer	25487	232,335	30,185	7.70	220,719	28,676		
Beer Well	1	6000									632
			Beer		232,335	30,185	7.70	220,719	28,676		

Source: DM Model Estimates

Energy and mass balances are also calculated on the process page. These tables are found below the process flow diagram. The per gallon of ethanol energy and water results are shown in Table 12. These averages were found by summing the hourly flow rates for all processes, multiplying the sum by the number of operational hours per year, and dividing by the number of gallons of ethanol produced in a year.

Table 12 Average Energy and Water Usage per gal of EtOH Produced

Annual (Utility Use / EtOH Production)		
Utility	Unit	Value
Energy (Avg Use gal EtOH)		
Thermal	Mbtu's	31,879
Electrical	kWh's	1.14
Total	Mbtu's	31,880.5
Water (Avg Use gal EtOH)		
fresh	gal	4.9
recycled	gal	1.2
Total	gal	6.1

Source: DM Model Estimates

Table 13 shows how the calculation of solubles and insolubles was carried out. This information was used to calculate the flow of whole stillage into thin stillage and WDG.

Table 13 Calculation of Solubles and Insoluble Solids %

Solubles and Insolubles Table				
Stch to Dxtrn		Dxtrn to Gluc		Gluc to EtOH
96%		99%		85%
Substance		Theoretical	Actual	Remaning Solids
Insloubles	Non-Starch			14%
	Starch	0.750	0.720	3%
Solubles	Glucose	0.825	0.784	1%
	Protein			2%
	Alcohol	0.421	0.340	6%
Total				**26%**
	Insolubles	**66.4%**		17%
	Solubles	**33.6%**		9%

Source: DM Model / Authors Estimates

Process Module: Equipment Sizing and Cost Estimation

The third page of the DM model calculates the necessary equipment size for the given flow rates and also estimates the cost of the sized equipment. The flow rates that were calculated in the process page and physical property values are used to calculate equipment sizing. Equipment size is found in horse power, volume, area, or height. The estimated cost of individual pieces of equipment is calculated using their respective size estimates. The sum the equipment cost is then used to estimate fixed capital investment associated with the plant. In Table 14, we see that the total cost of equipment estimate equals $10,006,438 for a 40 MGY plant. This estimate is used to calculate total fixed costs for the plant.

Table 14 Equipment Size and Cost Estimation for 40 MGY Plant

Process	Equipment	Equipment Size					Price	
	Description	HP	gal	ht (ft)	Diam (ft)	Area (ft2)	(+/-)	Equipment
1) Milling	Grain Handling							
	Hammer Mill	610					50%	$162,690
2) Liquification & Sacharification	Slurry Tank		15,112				20%	$164,535
	Jet Cooker		30,524				20%	$118,531
	HP Hold Tube		7,632		4.07		40%	$180,168
	Liq. Tank		45,794				20%	$92,392
3) Fermnt	Fermenters		381,617				20%	$1,066,846
	Beer Well		2,936,072				20%	$739,795
4) Distilltn	Rectifier (dstlt FR)			100	14.0		15%	$826,507
	trays			24			30%	$452,623
	Stripper (Evap rate)			60	14.0		15%	$444,325
	trays			24			30%	$271,574
	Mol. Sieve Beads			25.6	12.8	128	5%	$422,052
	Sieve columns						15%	$572,982
5) Co-Prod Recovery	Cetrifuge	1,928					20%	$830,306
	Evaporator					773	30%	$662,243
	Drum Dryer					5024	40%	$1,908,848
	Storage Tanks		1,380,822				20%	$318,444
6) Utilities	Boiler						15%	$771,580
Total								$10,006,438

Source: DM Model Estimates / *Plant Design and Economics for Chemical Engineers* [**13**]

Economic Module: Revenue and Cost Estimation

The sum of all major equipment is then used to estimate the direct and indirect capital costs associated with a dry mill plant of this magnitude. This is done with two different methods, FCI and RDE, which return different estimates. Working capital is then added to the capital costs and an estimate of fixed capital investment is returned. Table 15 shows how these costs are estimated, note that the same purchased equipment cost that was calculated in Table 14 appears in Table 15. The DM-TCC is then calculated using values of plant capacity and FCI and RDE TCC estimates. This is shown on the bottom of Table 15.

The actual flow rates from the process flow pages are used to calculate the yearly output of co-products and the yearly requirement of inputs for this output. Yearly revenue is calculated by multiplying the yearly amount of each co-product by its price. Yearly variable costs are calculated in the same manner, multiplying the inputs by their costs. Yearly avoidable fixed costs are calculated also on this page. These costs include taxes, labor, and licensing fees. The yearly variable cost and avoidable fixed cost are summed to return the total yearly cost of operation.

Table 16 shows the annual real revenue that the dry mill plant receives form the sale of their co-products and government subsidies. These are revenues are summed to return an estimate of total annual revenue in real dollars.

Table 15 Capital Cost Estimation for 40 MGY Plant

Corn to Ethanol Capital Cost Estimation (Peters et al, 2003 Plant Design and Econ. for Chm Eng (251)					
		Methods			
		Fixed Cap Invst (FCI) *Error: (+ or - 30%)*		Ratio Delvd Equip (RDE) *(Error + or - 20% to 25%)*	
Cost	**Itemized Expenditures**	**Cost Estimate**	**% of FCI**	**Cost Estimate**	**% of Eq. Cost**
Direct Fixed Costs	Purchased Equip	$10,006,438	22.9%	$10,006,438	100%
	Instrumentation	$4,107,446	9.4%	$3,602,318	36%
	Piping	$3,189,825	7.3%	$6,804,378	68%
	Electrical	$2,010,027	4.6%	$1,100,708	11%
	Buildings	$2,010,027	4.6%	$1,801,159	18%
	Yard Improvement	$786,532	1.8%	$1,000,644	10%
	Service Facilities	$6,030,081	13.8%	$7,004,507	70%
	Total Direct Capital Costs	$31,636,075	72.4%	$36,023,177	360%
Indirect Fixed Costs	Engineering & Sprvsn	$3,277,218	7.5%	$3,302,125	33%
	Construction Expense	$4,020,054	9.2%	$4,102,640	41%
	Legal Expense	$786,532	1.8%	$400,258	4%
	Contractors Fee	$786,532	1.8%	$2,201,416	22%
	Contingency	$3,189,825	7.3%	$4,402,833	44%
	Total Indirect Capital Costs	$12,060,161	27.6%	$14,409,271	144%
Tot Capt Cost (TCC)		**$43,696,236**	100.0%	**$50,432,448**	504%
Working Capital		$3,277,218		$3,782,434	
Tot. Capt Invst (TCI)		**$46,973,454**		**$54,214,882**	
DM Model		= FCI Estmt if Plant Capacity > 85 mgy		= RDE Estmt if Plant Capacity > 85 mgy	
		per gal (FCI-TCC) =	$1.09	per gal RDE-TCC) =	$1.26
Total Capital		If Plant Capacity < 85 mgy and > 40 mgy then TCC is a linear fnct of the two			
		Tot Cap (M gal)	40	Functional Value	1
Estimate		**DM Total Capt Cost (DM-TCC)**		**$50,432,448**	
		Working Capital		$4,799,620	
(DM-TCC)		**DM Total Capt Invst (DM-TCI)**		**$55,232,068**	
		TCC / Total Cap		1.26	

Source: DM Model Estimates / *Plant Design and Economics for Chemical Engineers* [**13**]

Table 16 Yearly Real Revenue for 40 MGY Plant

Yearly Revenues					Revenue	
Product		**Dollars**	**per**	**Yearly Output**	**Annual**	**per gal**
Ethanol	*denatured*	$1.78	gal	39,900,000	**$70,930,230**	**$1.87**
	hydous	$1.69	gal	41,841,004		
	anhydrous	$1.78	gal	38,000,000		
DDGS:	*dry*	$90.00	ton	123,024	**$11,072,195**	**$0.29**
CO2 and Subsidies:	CO2	$6.00	ton	252,251,272	**$756,754**	**$0.02**
	Subsidies	$0.00	gal	38,000,000	$0	**$0**
Total Annual Revenue					**$82,759,179**	**$2.18**

Source: Factors Associated with Success of Fuel Ethanol Producers [**15**] / DM Model Estimates

Similar to the annual revenue the annual operating costs are also calculated as shown in Table 17. The hourly flow rates of all inputs are multiplied by the number of yearly operational hours to give an estimate of operational costs. Indirect costs are found as a percentage of revenue, net revenue, and total capital costs. This table also calculates the average costs per gallon of ethanol produced in a year. Working capital is calculated as a percentage of total annual operating cost seen at the bottom of Table 17.

Table 17 Annual Real Operating Costs

Annual Direct / Indirect Operational Costs							
Annual Direct Operational Costs							
						Costs	
Direct Input		**$**	**Per**	**Amnt Used**	**Annual**	**per gal**	**Total**
Grain:	*Yellow Dent*	$85.00	Ton	390,259	$33,172,039	$0.873	$33,172,039
Utilities:							
	Electricity	$0.03	Kwh	47,795	$1,433,837	$0.038	
	Natural Gas	$8.00	MBTU	1,314,389	$10,515,110	$0.28	
	Denaturant	$2.00	gal	1,900,000	$3,800,000	$0.100	
	H2O	$1.00	K gal	133,231	$133,231	$0.0035	$15,882,178
Chem's / Enzyms:							
	A-amalayse	$3.00	lb	343,740	$1,031,221	$0.027	
	G-amalayse	$3.00	lb	401,030	$1,203,091	$0.032	
	Yeast	$2.50	lb	462,834	$1,157,085	$0.030	
	SO2 / Antibiotic	$2.50	lb	254,065	$635,163	$0.017	$4,026,560
Total Direct Operational Cost						$1.40	**$53,080,777**
Annual Indirect Operational Costs							
						Costs	
Indirect Input		**As a %**	**Of**		**per Annum**	**per gal**	**Totals**
Labor		5.0%	DM-TCC		$2,521,622	$0.066	$2,521,622
Other:							
	Taxes	15.0%	Net Rev		$4,073,517	$0.11	
	Liscence Fees	2.0%	Rev		$1,655,184	$0.04	
	Maintenance	2.0%	Rev		$1,655,184	$0.044	
	Miscelleneous Expenses	2.0%	DM-TCC		$1,008,649	$0.03	$8,392,533
Total Indirect Operational Cost						$0.29	**$10,914,156**
Total Operational Cost						**$1.68**	**$63,994,932**

Source: Factors Associated with Success of Fuel Ethanol Producers [**15**] / DM Model

Economic Module: The Finance Page

Project financing of a fuel ethanol plant is one of the greatest challenges for a prospective dry miller. Not only is the ethanol market volatile but so too are the markets for the inputs used in the ethanol production process, grain and boiler fuel [**6**]. This causes venture capitalists to shy away from dry mill projects because they face a great deal of uncertainty on the expected rate of return from investment. Compounding this capital scarcity is the difficulty that investors would have in liquidating the dry mill's assets. For these reasons, farmer co-operatives have become major players in ethanol plant building. Grain farmers join the co-operative and lend not only capital support but also pledge a portion of their grain harvest to the dry mill. This reduces the risk to both the farmer and dry mill from volatile grain markets. The building of ethanol plants has also been supported by rural local communities because of the expected benefits that accrue to the community, such as increased employment. Financers require a large equity payment on a dry mill plant, generally 40% of the total capital cost or greater. Investors also may require the plant to be quite conservative in their management of risk.

Information from each of the preceding pages is used to calculate the annual finances that are displayed on page 6 of the DM model. This page contains a yearly break down of the loan payments figured with and without a sweep payment included. All the pertinent financial information is also displayed on this page. The annual profits are now able to be calculated with the available information. Table 18 shows the financial table as it appears on page 6 of the model.

Table 18 Financial Information for a 40 MGY plant

Financial Table: Information		Calculations	
Loan Info: Loan Years	15	DM Total Capital Costs	$50,432,448
Expected Life of Plant	25	(+) Working Capital	$4,799,620
Years till Operational	3	(=) DM Capital Invst	**$55,232,068**
Loan Info: Invst / Total Invst	60%	(+) Accrued Interest	$2,757,128
Year (2) Invst / Total Invst	40%	(=) DM Total Cptl Invst	**$57,989,196**
Initial Equity / Capital Invst	40%	**Lender Equity Requirement**	**$23,195,679**
Initial Loan / Capital Invst	60%	**Total Loan Ammount**	**$34,793,518**
Sweep Pmnt / Profits	40%	Year 1	$20,876,111
Working Capital / Total Invst	15%	Year 2	$13,917,407
Rates: Discount	12.0%	**Scheduled An. Loan Pmnt**	**$4,249,872**
Real Discount	8.7%	**Profits (gross)**	**$18,764,247**
Inflationary	3.0%	Net	$14,514,375
Interest	8.7%	Sweep Payment	$5,805,750
		other	$8,708,625

Source: DM Model Estimates

The information from the financial table is used in to calculate annualized payments (principal, interest, and total) as well as expected profits in both real and nominal dollar amounts. This information is shown in Table 19. The annualized payments are also calculated allowing a sweep payment, shown in Table 20. The annual expected profits are used to calculate how much faster the loan will be paid off than the regular scheduled payment plan. The annual profits are also calculated under the allowance of a sweep.

Table 19 Annual Loan Amortization Schedule (No Sweep) on $34,793,247 Loan

Year	Principal Nominal	Principal Real	Interest Payment Nominal	Interest Payment Real	Principal Payment Nominal	Principal Payment Real	Total Annual Payment Nominal	Total Annual Payment Real	Pre Loan Pmnt Real	Pre Loan Pmnt Nominal	Post Loan Pmnt Real	Post Loan Pmnt Nominal
3	34,793,518	31,840,998	3,040,210	2,782,223	1,209,662	1,107,012	4,249,872	3,889,235	18,764,247	20,504,199	14,875,012	16,254,327
4	33,583,856	29,838,821	2,934,512	2,607,276	1,315,360	1,168,680	4,249,872	3,775,956	18,764,247	21,119,325	14,988,291	16,869,453
5	32,268,496	27,835,088	2,819,577	2,432,192	1,430,294	1,233,785	4,249,872	3,665,977	18,764,247	21,752,905	15,098,270	17,503,033
6	30,838,202	25,826,508	2,694,600	2,256,685	1,555,272	1,302,516	4,249,872	3,559,201	18,764,247	22,405,492	15,205,046	18,155,620
7	29,282,930	23,809,702	2,558,703	2,080,459	1,691,169	1,375,075	4,249,872	3,455,535	18,764,247	23,077,657	15,308,712	18,827,785
8	27,591,761	21,781,191	2,410,931	1,903,211	1,838,941	1,451,677	4,249,872	3,354,888	18,764,247	23,769,987	15,409,359	19,520,115
9	25,752,820	19,737,392	2,250,246	1,724,626	1,999,625	1,532,546	4,249,872	3,257,173	18,764,247	24,483,086	15,507,074	20,233,214
10	23,753,194	17,674,607	2,075,522	1,544,383	2,174,350	1,617,921	4,249,872	3,162,304	18,764,247	25,217,579	15,601,943	20,967,707
11	21,578,844	15,589,016	1,885,530	1,362,147	2,364,342	1,708,051	4,249,872	3,070,198	18,764,247	25,974,106	15,694,049	21,724,234
12	19,214,503	13,476,666	1,678,937	1,177,573	2,570,935	1,803,202	4,249,872	2,980,775	18,764,247	26,753,329	15,783,472	22,503,458
13	16,643,568	11,333,460	1,454,292	990,302	2,795,579	1,903,654	4,249,872	2,893,956	18,764,247	27,555,929	15,870,291	23,306,057
14	13,847,989	9,155,152	1,210,018	799,965	3,039,853	2,009,701	4,249,872	2,809,666	18,764,247	28,382,607	15,954,581	24,132,735
15	10,808,135	6,937,331	944,400	606,175	3,305,472	2,121,656	4,249,872	2,727,831	18,764,247	29,234,085	16,036,416	24,984,214
16	7,502,664	4,675,412	655,573	408,531	3,594,299	2,239,848	4,249,872	2,648,380	18,764,247	30,111,108	16,115,867	25,861,236
17	3,908,364	2,364,625	341,508	206,618	3,908,364	2,364,625	4,249,872	2,571,242	18,764,247	31,014,441	16,193,005	26,764,569

Source: DM Model

Table 20 Annual Loan Amortization Schedule (Sweep)von $39,986,293 Loan

Annual Loan Amortization Schedule with a Sweep — Principle and Payments												Profits	
Sweep Payment		Sweep Principal Paid		Principal Ammount		Principal Payment		Interest Payment		Total Payment		Post Sweep Pmnt	
Real	Nominal	Nominal	Real	Nominal	Real	Nominal	Real	Nominal	Real	Nominal	Real	Nominal	Real
5,805,750	6,344,100	7,553,761	6,912,762	34,793,518	33,780,114	7,553,761	7,333,749	3,040,210	2,951,660	10,593,972	9,694,985	9,910,228	9,069,262
5,805,750	6,534,423	7,849,783	6,974,430	27,239,756	26,446,366	7,849,783	7,621,148	2,380,173	2,310,847	10,229,956	9,089,183	10,889,369	9,675,064
5,805,750	6,730,456	7,774,394	7,039,535	19,389,974	18,825,217	7,774,394	7,547,956	1,694,270	1,644,922	9,468,664	8,167,753	12,284,241	10,596,494
5,805,750	6,932,369	7,899,371	7,108,266	11,615,579	11,277,261	7,899,371	7,669,293	1,014,954	985,392	8,914,325	7,465,607	13,491,167	11,298,640
5,805,750	7,140,340	8,035,269	7,180,825	3,716,208	3,607,969	3,716,208	3,607,969	324,717	315,259	4,040,925	3,285,642	19,036,732	15,478,605
												23,769,987	18,764,247
												24,483,086	18,764,247
												25,217,579	18,764,247
												25,974,106	18,764,247
												26,753,329	18,764,247
												27,555,929	18,764,247
												28,382,607	18,764,247
												29,234,085	18,764,247
												30,111,108	18,764,247
												31,014,441	18,764,247

Source: DM Model

Economic Module: The BCA Page

The information from the annual loan amortization is then used in conjunction with annual revenues and costs to calculate the returns to equity in the plant. The net present value (NPV), internal rate of return (IRR), and benefit cost ratio (BCR) are all calculated as a measure of project worth. This is done in both real and nominal dollar amounts and allows for the allowance of a sweep payment or not. Table 21 shows the valuation of the plant under regularly scheduled payments, and Table 22 shows the valuation of the plant allowing sweep payments to be made.

Table 21 Calculation of Annualized NPV, IRR, and Benefit Cost Ratio (No Sweep)

Year	Costs							Benefits			
	Investment	Loan		Variable		Total		Total		Net	
	Real	Nominal	Real	Real	Nominal	Real	Nominal	Real	Nominal	Real	Nominal
1	20,876,111					20,876,111	21,502,394			-20,876,111	-21,502,394
2	13,917,407					13,917,407	14,764,977			-13,917,407	-14,764,977
3		4,249,872	3,889,235	63,994,932	69,928,990	67,884,167	74,178,862	82,759,179	90,433,190	14,875,012	16,254,327
4		4,249,872	3,775,956	63,994,932	72,026,860	67,770,888	76,276,732	82,759,179	93,146,185	14,988,291	16,869,453
5		4,249,872	3,665,977	63,994,932	74,187,666	67,660,909	78,437,538	82,759,179	95,940,571	15,098,270	17,503,033
6		4,249,872	3,559,201	63,994,932	76,413,296	67,554,133	80,663,168	82,759,179	98,818,788	15,205,046	18,155,620
7		4,249,872	3,455,535	63,994,932	78,705,695	67,450,467	82,955,567	82,759,179	101,783,352	15,308,712	18,827,785
8		4,249,872	3,354,888	63,994,932	81,066,866	67,349,820	85,316,737	82,759,179	104,836,852	15,409,359	19,520,115
9		4,249,872	3,257,173	63,994,932	83,498,872	67,252,105	87,748,743	82,759,179	107,981,958	15,507,074	20,233,214
10		4,249,872	3,162,304	63,994,932	86,003,838	67,157,236	90,253,709	82,759,179	111,221,416	15,601,943	20,967,707
11		4,249,872	3,070,198	63,994,932	88,583,953	67,065,130	92,833,825	82,759,179	114,558,059	15,694,049	21,724,234
12		4,249,872	2,980,775	63,994,932	91,241,471	66,975,707	95,491,343	82,759,179	117,994,801	15,783,472	22,503,458
13		4,249,872	2,893,956	63,994,932	93,978,716	66,888,888	98,228,587	82,759,179	121,534,645	15,870,291	23,306,057
14		4,249,872	2,809,666	63,994,932	96,798,077	66,804,598	101,047,949	82,759,179	125,180,684	15,954,581	24,132,735
15		4,249,872	2,727,831	63,994,932	99,702,019	66,722,763	103,951,891	82,759,179	128,936,105	16,036,416	24,984,214
16		4,249,872	2,648,380	63,994,932	102,693,080	66,643,312	106,942,952	82,759,179	132,804,188	16,115,867	25,861,236
17		4,249,872	2,571,242	63,994,932	105,773,872	66,566,175	110,023,744	82,759,179	136,788,313	16,193,005	26,764,569
18				63,994,932	108,947,088	63,994,932	108,947,088	82,759,179	140,891,963	18,764,247	31,944,874
19				63,994,932	112,215,501	63,994,932	112,215,501	82,759,179	145,118,722	18,764,247	32,903,221
20				63,994,932	115,581,966	63,994,932	115,581,966	82,759,179	149,472,283	18,764,247	33,890,317
21				63,994,932	119,049,425	63,994,932	119,049,425	82,759,179	153,956,452	18,764,247	34,907,027
22				63,994,932	122,620,908	63,994,932	122,620,908	82,759,179	158,575,145	18,764,247	35,954,237
23				63,994,932	126,299,535	63,994,932	126,299,535	82,759,179	163,332,400	18,764,247	37,032,865
24				63,994,932	130,088,521	63,994,932	130,088,521	82,759,179	168,232,372	18,764,247	38,143,851
25				63,994,932	133,991,177	63,994,932	133,991,177	87,558,799	183,328,681	23,563,867	49,337,504
Net Present Value										**$101,718,453**	**$101,718,453**
Benefit Cost Ratio										**1.45**	**1.47**
IRR										**35.9%**	**40.0%**

Source: DM Model

Table 22 Calculation of NPV, IRR, and Benefit Cost Ratio w/Allowance for Sweep Payment

Year	Costs	Costs (Sweep)				Benefits (Sweep)	
	Investment	Loan Payment		Total		Net	
	Real	Real	Nominal	Real	Nominal	Real	Nominal
1	20,876,111			20,876,111	21,502,394	-20,876,111	-21,502,394
2	13,917,407			13,917,407	14,764,977	-13,917,407	-14,764,977
3		9,694,985	10,593,972	73,689,917	80,522,962	9,069,262	9,910,228
4		9,089,183	10,229,956	73,084,116	82,256,816	9,675,064	10,889,369
5		8,167,753	9,468,664	72,162,685	83,656,330	10,596,494	12,284,241
6		7,465,607	8,914,325	71,460,539	85,327,621	11,298,640	13,491,167
7		3,285,642	4,040,925	67,280,574	82,746,620	15,478,605	19,036,732
8				63,994,932	81,066,866	18,764,247	23,769,987
9				63,994,932	83,498,872	18,764,247	24,483,086
10				63,994,932	86,003,838	18,764,247	25,217,579
11				63,994,932	88,583,953	18,764,247	25,974,106
12				63,994,932	91,241,471	18,764,247	26,753,329
13				63,994,932	93,978,716	18,764,247	27,555,929
14				63,994,932	96,798,077	18,764,247	28,382,607
15				63,994,932	99,702,019	18,764,247	29,234,085
16				63,994,932	102,693,080	18,764,247	30,111,108
17				63,994,932	105,773,872	18,764,247	31,014,441
18				63,994,932	108,947,088	18,764,247	31,944,874
19				63,994,932	112,215,501	18,764,247	32,903,221
20				63,994,932	115,581,966	18,764,247	33,890,317
21				63,994,932	119,049,425	18,764,247	34,907,027
22				63,994,932	122,620,908	18,764,247	35,954,237
23				63,994,932	126,299,535	18,764,247	37,032,865
24				63,994,932	130,088,521	18,764,247	38,143,851
25				63,994,932	133,991,177	23,563,867	49,337,504
Net Present Value						**$99,034,610**	**$99,034,610**
Benefit Cost Ratio						**1.38**	**1.47**
IRR						**30.7%**	**34.6%**

Source: DM Model

References

1) Alexander, R.J. 1994. Corn Dry Milling: Processes, Products, and Applications. Pages 351 – 371 in: Corn Chemistry and Technology. Watson, S.A. and Ramstad, P.E. eds. American Association of Cereal Chemist, St. Paul, MN

2) BBI International, 2003. "The Ethanol Plant Development Handbook," Edition Four.

3) Boyer, C.D., and Shannon, J.C. 1994. Carbohydrates of the Kernel. Chapter 8, Pages 253 – 269 in: Corn Chemistry and Technology. Watson, S.A. and Ramstad, P.E. eds. American Association of Cereal Chemist, St. Paul, MN

4) DOE Energy Information Administration, (http://www.eia.doe.gov)

5) "Chemical Engineering Plant Cost Index," Chemical Engineering, May 2005.

6) Evans, M.K. 1997. The Economic Impact of the Demand for Ethanol. Report to: Midwestern Governors' Conference, Lombard Illinois.

7) Haas, D., Agbara, G. 2000. Tax Incentives for Petroleum and Ethanol Fuels. GAO/RCED-00-301R.

8) Maisch, W.F. 1994. Fermentation Processes and Products. Chapter 19, Pages 553 – 572 in: Corn Chemistry and Technology. Watson, S.A. and Ramstad, P.E. eds. American Association of Cereal Chemist, St. Paul, MN.

9) May, J.B. 1994. Wet Milling: Process and Products. Chapter 12, Pages 377 – 395 in: Corn Chemistry and Technology. Watson, S.A. and Ramstad, P.E. eds. American Association of Cereal Chemist, St. Paul, MN

10) McAloon, A., Taylor, F., Yee, W. Ibsen, K., Wooley, R. 2000. Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks. Report to: National Renewable Energy Laboratory, Golden, CO (NREL/TP-580-28893).

11) Musgrove, D., Dale, M.C. 2004. Feasibility Study for an Integrated Grain/Cellulose Ethanol Plant in Arizona. Report to: USDA, Washington DC, (USDA 02-025-086019322).

12) Orthoefer, F.T. 1994. Corn Starch Modification and Uses. Chapter 16, Pages 479 – 495 in: Corn Chemistry and Technology. Watson, S.A. and Ramstad, P.E. eds. American Association of Cereal Chemist, St. Paul, MN

13) Peters, M.S., Timmerhaus, K.D., and West, R.E. 2003. *Plant Design and Economics for Chemical Engineers*. McGraw-Hill, New York, NY.

14) Pimentel, D. 2003. Ethanol Fuels: Energy Balance, Economics, and Environmental Impacts are Negative. Natural Resources Research, Vol. 12, No 2, June.

15) The Renewable Fuel Association, (**www.ethanolrfa.org**)

16) Shapouri, H., Gallagher, P., Graboski, M.S. 2002. USDA's 1998 Ethanol Cost-of-Production Survey. USDA, Agricultural Economic Report Number 808.

17) Tiffany, D.G., Eidman, V.R. 2003. Factors Associated with Success of Fuel Ethanol Producers. Staff Paper P03-7, Department of Applied Economics, University of Minnesota.

18) Watson, S.A. 1994. Structure and Composition of Corn. Chapter 3, Pages 53 – 78 in: Corn Chemistry and Technology. Watson, S.A. and Ramstad, P.E. eds. American Association of Cereal Chemist, St. Paul, MN

19) Weinkat, P.C., Klaaven, E., McKenzie, B.A. 1984. Alcohol Distillation: Basic Principles, Equipment, Performance Relationships, and Safety. **www.ces.purdue.edu/extmedia/AE/AE-117.html**

20) Zeochem Corporation, 2005. "Molecular Sieve Adsorbents for the Process Industries and Other Markets."