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Dairy Analytics and Nutrient Analysis (DANA) Prototype System User Manual

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CENTER FOR AVANCED ENERGY STUDIES

Dairy Anaerobic Digester Market Assessment Model

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Contents

Introduction

This document is a user manual for the Dairy Analytics and Nutrient Analysis (DANA) model. DANA provides an analysis of dairy anaerobic digestion technology and allows users to calculate biogas production, co-product valuation, capital costs, expenses, revenue and financial metrics, for user customizable scenarios, dairy and digester types. The model provides results for three anaerobic digester types; covered lagoons, modified plug flow, and complete mix, and three main energy production technologies; electricity generation, renewable natural gas generation, and compressed natural gas generation. Additional options include dairy types, bedding types, backend treatment type as well as numerous production, and economic parameters.

DANA's goal is to extend the National Market Value of Anaerobic Digester Products analysis (informa economics, 2012; Innovation Center, 2011) to include a greater and more flexible set of regional digester scenarios and to provide a modular framework for creation of a tool to support farmer and investor needs. Users can define scenarios from combinations of existing parameters or add new parameters, run the model and view a variety of reports, charts and tables that are automatically produced and delivered over the web interface.

DANA's approach uses server-based data processing and web-based user interfaces, rather a client-based spreadsheet approach. This offers a number of benefits over the client-based approach. Server processing and storage can scale up to handle a very large number of scenarios, so that analysis of county, even field level, across the whole U.S., can be performed. Server based databases allow dairy and digester parameters be held and managed in a single data repository, while allowing users to customize standard values and perform individual analysis. Server-based calculations can be easily extended, versions and upgrades managed, and all changes are immediately available to all users.
This user manual describes how to use and/or modify input database tables, run DANA, view and modify reports.

DANA is based in the INL's analysis architecture entitled Generalized Environment for Modeling Systems (GEMS) [1], which offers extensive collaboration, analysis, and integration opportunities and greatly speeds[2] the ability construct highly scalable web delivered user-oriented decision tools. Thus, DANA has the capability to leverage pre-existing models that can be used to calculate all aspects of dairy operation. Existing government and commercial models can be used directly without reprogramming and lend credibility to national planning efforts or local development analysis. DANA has been designed to be extended and modified in multiple ways to suit multiple analysis goals.

[1] GEMS will be described in section "GEMS Component Architecture"
[2] This prototype version of DANA was completed in 3 weeks.

Gaining Access to the Model

Access to the DANA model is provided through secure login to the dairy analytics web site. To obtain access you first must be approved by Innovation Center for U.S. Diary and must complete the following steps:

1. **Request user credentials** by clicking on the link below.
   a. **Dairy Analytics User Request**[3]
2. Select "**Dairy Analytics"** from the **Application** drop-down list if it is not already selected.
3. **Fill out** the rest of the information on the form.
4. **Within** 24 hours you will receive an email response with your new login credentials. Follow the additional instructions exactly as specified.
5. Once your account is established you will be added as a user to the dairy analytics web portal (https://dairyanalytics.inl.gov) and will receive an email with the proper link.
6. If you have any issues please contact Dave McGrath (david.mcgrath@inl.gov).

Using DANA for Dairy Anaerobic Digestion Analysis

DANA can be run using predefined scenarios or by creating your own. This section will go through be basic process for creating scenarios, running the model and viewing reports.

Using the Web Interface

Figure 1 shows the main DANA Market Model web page. The left panel provides links to documents, input databases, and collaborative discussion. The center panel area has a brief introduction, followed by a link to execute the model and links that open four predefined web reports. To perform new calculations simply modify or specify predefined regional scenarios, execute the model (click "Run Anaerobic Digester Market Model"), and view the reports (i.e., Capital Cost Analysis, Co-product Valuation, Expense and Revenue, or Investment Metrics). Simply open the reports if you are only interested in previously calculated results.

[3] https://secure.inl.gov/caims/default.aspx?AppID=a9ced862-24bf-44fb-9e8c-897983245855

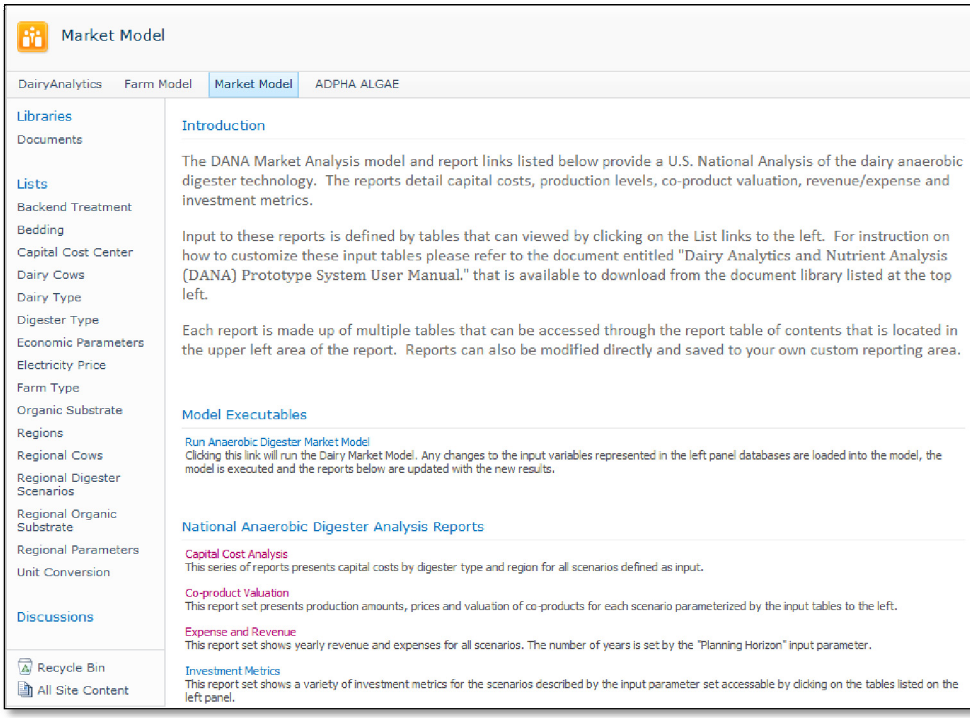


Figure 1. DANA Market Model Web Interface.

Input Scenario Data

This section will describe each of the input data tables and demonstrate how to go about linking them together to create scenarios. A detailed description of each parameter will not be provided here, but can be found associated with the two spreadsheets that were source information for the DANA model (informa, 2012; Innovation Center, 2011).

The web interface to the input data tables is crafted using Microsoft SharePoint 2010. This means that no custom developed web coding has been done to provide editable access and viewing of these tables. A SharePoint user manual will act as a handy auxiliary user manual to help you manipulate these tables and will also show you the many useful capabilities and features that are available in SharePoint 2010.

Regions

The concept of "regions" is fundamental to the overall level and scale of the analysis. The term "region" simply means any geospatial area. For example, states, EPA regions, hydrologic basins, or farms are all valid "regions". Thus, regions can be created to represent any geospatial area you choose. There are many parameters in the model that are specified by region so it is important to remember,

1. Parameters are held constant over the whole region and
2. The finer the division into regions the greater the amount of input parameters needed.

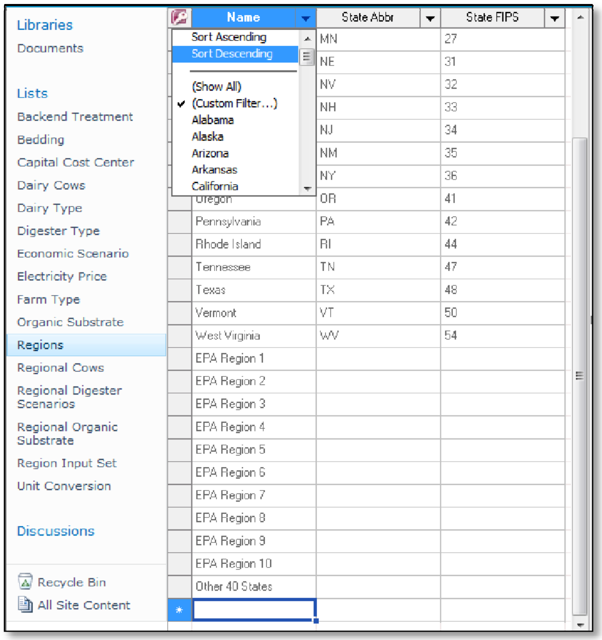


Figure 2. Regions table custom filtered and opened for editing and adding new regions.

The informa (2012) regions are U.S. States, whereas the Innovation Center model (2011) ran its analysis by EPA regions. DANA extends the ability to conduct analysis by any type of region without any reprogramming of the model, only input data setup is needed.

Tables in the left panel of the web site are accessed by simply selecting their names. The table is opened for editing[4] and allows the user to add new rows and/or edit existing rows. The last table row, indicated by *, is blank and is used to type or paste new rows. The table headers provide capability to filter and sort the data.

Figure 2 shows the Regions table open for editing with a custom filter defined to show only region names that contain, for example, an 'e'. The region table is simply a lookup table that is accessed by an automatic dropdown menu in many of the other tables, thus all it requires is the region name. Each region name should be unique.

The input data tables are linked into relationships that allow many scenarios to be calculated in a single model run. The hierarchical relationships shown in Table 1 depict how the overall run time scenarios are constructed. Sub-items show linkage of table columns to tables. Users can add new parameters and link tables to create scenarios of any level of complexity. Executing DANA will run all scenarios and return the results to web reports.

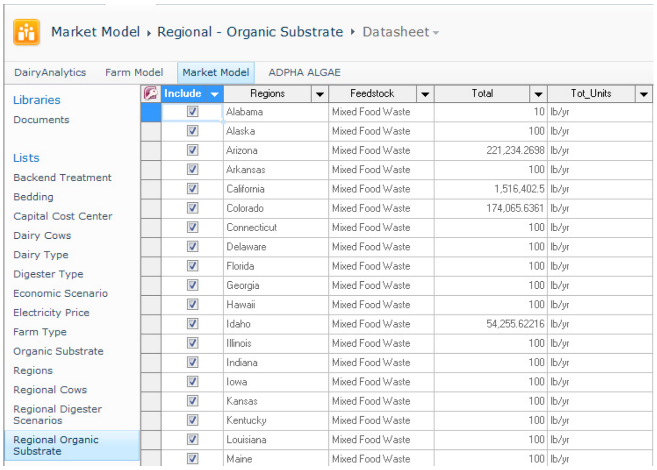
Table 1. Hierarchical relationships among DANA input tables.

1.	Regional Organic Substrate – Defines organic substrate availability by region			
	a.	Regions		→ "Regions" Table
	b.	Feedstock		→ "Organic Substrate" Table
2.	Regional Cows – Defines the number of cows per region			
	a.	Cows		→ "Dairy Cows" Table
	b.	Regions		→ "Regions" Table
3.	Electricity Price – Defines yearly electricity price by region			
	a.	Regions		→ "Regions" Table
4.	Regional Digester Scenarios – Defines the overall scenario name and associated parameters			
	a.	Farm Type - Defines the farm type name and parameters)		
		i.	Dairy Type	→ "Dairy Type" Table
		ii.	Bedding Type	→ "Bedding" Table
		iii.	Backend Treatment	→ "Backend Treatment" Table
		iv.	Digester Type	→ "Digester Type" Table
	b.	Regional Input Set– Defines the Regional Parameter Set		
		i.	Regions	→ "Regions" Table
	c.	Economic Scenario - Defines the Economic Parameter Set		
		i.	Capital Cost Centers	→ "Capital Cost Center" Table
	d.	Regions - Defines the Regions		
5.	Unit Conversion – Defines unit conversion used throughout the calculations.			

[4] Adding and editing tables is only possible if the user has adequate privileges.

1. Regional Organic Substrate

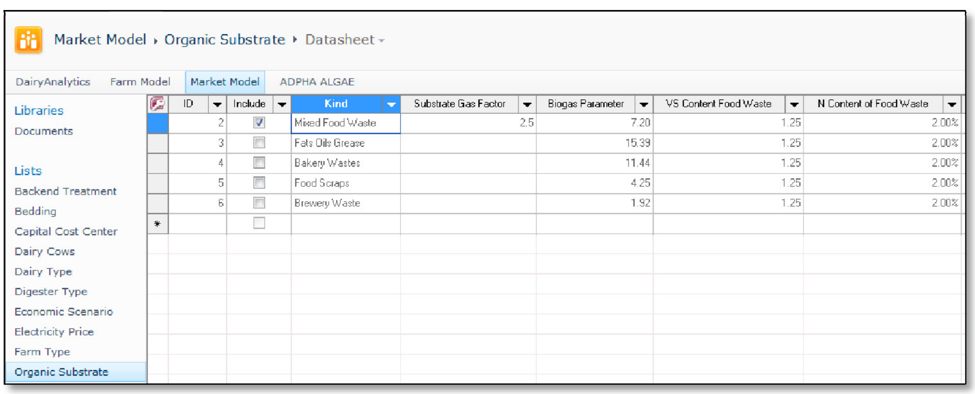
The regional organic substrate table (Fig. 3) defines for each region (Fig. 2), one or more feedstock types (i.e., Organic Substrates, Fig. 4) and the total amount produced for that region.



Include	Regions	Feedstock	Total	Tot_Units
☑	Alabama	Mixed Food Waste	10	lb/yr
☑	Alaska	Mixed Food Waste	100	lb/yr
☑	Arizona	Mixed Food Waste	221,234.2698	lb/yr
☑	Arkansas	Mixed Food Waste	100	lb/yr
☑	California	Mixed Food Waste	1,516,402.5	lb/yr
☑	Colorado	Mixed Food Waste	174,065.6361	lb/yr
☑	Connecticut	Mixed Food Waste	100	lb/yr
☑	Delaware	Mixed Food Waste	100	lb/yr
☑	Florida	Mixed Food Waste	100	lb/yr
☑	Georgia	Mixed Food Waste	100	lb/yr
☑	Hawaii	Mixed Food Waste	100	lb/yr
☑	Idaho	Mixed Food Waste	54,255.62216	lb/yr
☑	Illinois	Mixed Food Waste	100	lb/yr
☑	Indiana	Mixed Food Waste	100	lb/yr
☑	Iowa	Mixed Food Waste	100	lb/yr
☑	Kansas	Mixed Food Waste	100	lb/yr
☑	Kentucky	Mixed Food Waste	100	lb/yr
☑	Louisiana	Mixed Food Waste	100	lb/yr
☑	Maine	Mixed Food Waste	100	lb/yr

Figure 3. Regional Organic Substrate table.

The column entitled "FeedStock" shown in Figure 3 is automatically linked to the Organic Substrate table (Fig. 4) as well as the "Regions" column (Fig. 3) linked to the regions table (Fig. 2). To add or edit rows in the Regional Organic Substrate table scroll to the last row of the table, select a region from the dropdown menu, select a feedstock from the dropdown menu, type in the total amount of that feedstock for the region and select the units from the dropdown provided. The "Include" column is used to indicate this row should be included in the analysis.



ID	Include	Kind	Substrate Gas Factor	Biogas Parameter	VS Content Food Waste	N Content of Food Waste
2	☑	Mixed Food Waste	2.5	7.20	1.25	2.00%
3	☐	Fats Oils Grease		15.39	1.25	2.00%
4	☐	Bakery Wastes		11.44	1.25	2.00%
5	☐	Food Scraps		4.25	1.25	2.00%
6	☐	Brewery Waste		1.92	1.25	2.00%

Figure 4. Organic Substrate "Feedstock" table.

New substrates can be added or existing substrates edited in the organic substrate table. You simply give the new substrate any name and enter the parameters in each column. Parameter units can be found either by right clicking on the column header and selecting "edit/delete column" or by changing the table view from datasheet to standard[5] and opening the line editor (Fig. 5). A definition of the parameter and its units are provided in these views. Each substrate kind should be unique.

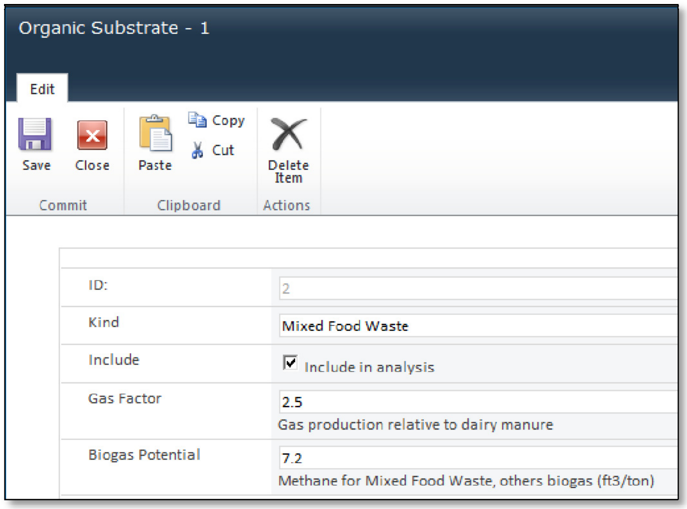


Figure 5. Organic substrate table opened in SharePoint standard view

2. Regional Cows

The regional cows table (Fig. 6) defines a scenario name, links multiple dairy cow kinds to regions and defines the number of cows of that type within the region. The “Region Cow Scenario” column is a text name input by the user that names the scenario. The “cows” column presents a dropdown linked to the dairy cow table (Fig. 7) and the regions column is a dropdown linked to the regions table (Fig. 2). The combination of Cows and Regions should be unique. The scenario name groups cow / region combinations into a particular scenario.

[5] This is capability of the Microsoft SharePoint portal. A user manual for SharePoint can be found here or purchased at any bookstore.

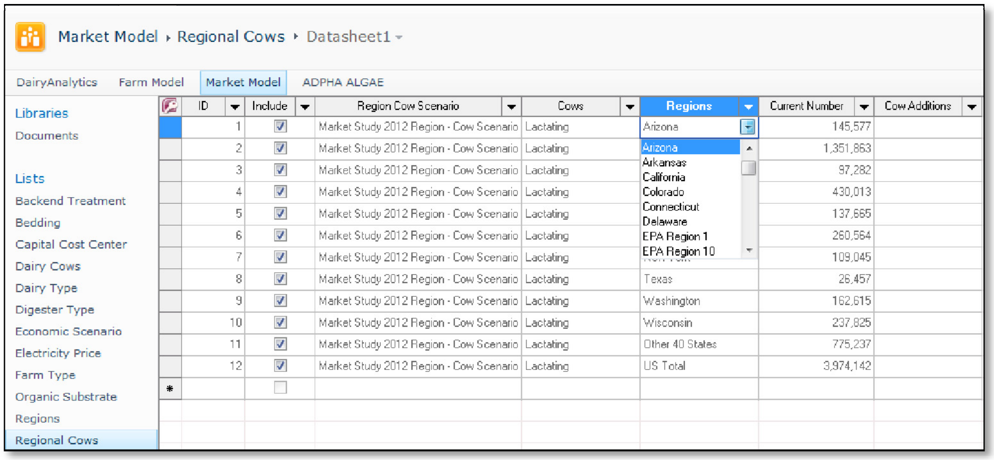


Figure 6. Regional Cows table with Regions table dropdown open.

The Dairy Cows table (Fig. 7) can be used to identify many cow types as defined by unique combinations of the parameters available. Each row should have a unique name.

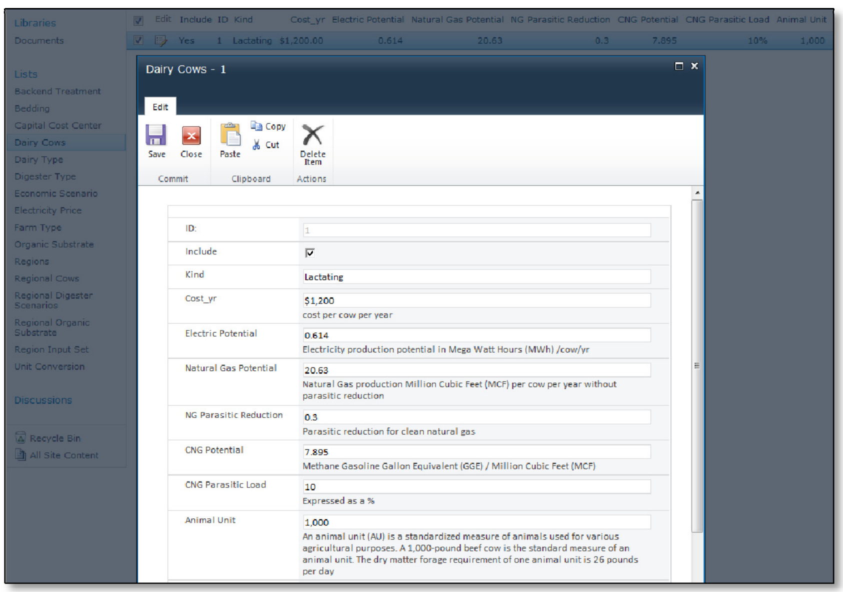


Figure 7. Dairy Cows table open in standard SharePoint view

3. Electricity Price

The Electricity Price table provides the average electricity price by region and year[6]. The region column is linked to the regions table by dropdown menu access. Additional years (columns) or regions (rows) can be added by the user.

[6] Currently, only the 2011 price is used in the calculations. Future versions will incorporate a time series forecast model to predict future electricity prices.

Figure 8. Electricity Price table.

4. Regional Digester Scenarios

The Regional Digester Scenarios table (Fig. 9) links four tables, three of which link other tables. This hierarchical structure can be used to create many scenarios with many parametric combinations. Users can also perform a basic sensitivity analysis by altering parameters systematically and extending the number of scenarios. The main integrating table (Fig. 9) names the scenario and defines the unique combinations of farm types, regional input sets, economic scenarios and regions. Finally, the proportion of the three primary anaerobic digester types is defined (Fig. 9, Lagoon Percent, Plug Flow Percent, Complete Mix Percent) for the scenario row. Note that the scenario name is unique to 1 or more, (i.e., a set) of rows and each row combination of farm type, regional input set, economic scenario and region should be unique to its row within the scenario set.

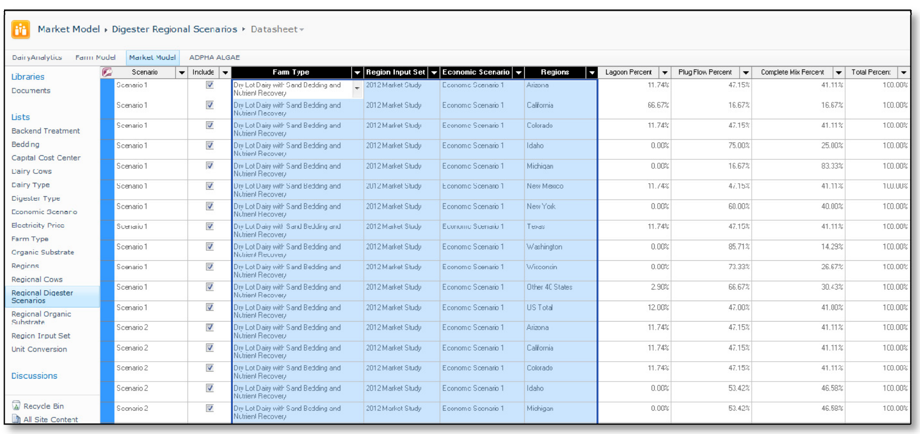
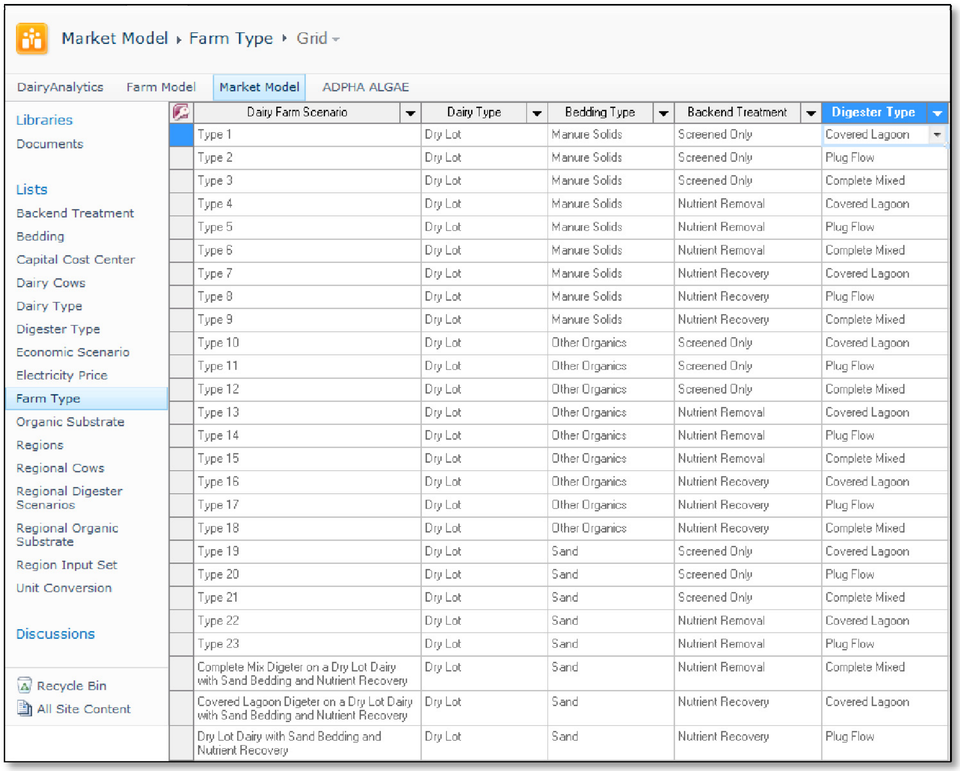


Figure 9. Regional Digester Scenario table.

The Farm Type column (Fig. 9) is linked by a drop down menu to the Farm Type table (Fig. 10). Likewise Region Input Set column to a table of the same name (Fig. 15), Economic Scenario to the Economic Scenario table (Fig. 16) and finally Regions to the Regions table (Fig 2).

Farm Type Table

The Farm Type table (Fig. 10) defines a Dairy Farm scenario name that is made up of a Dairy Type, Bedding Type, Backend Treatment, and a Digester Type, each of which is a separate table linked to the Farm Type table by a dropdown menu.

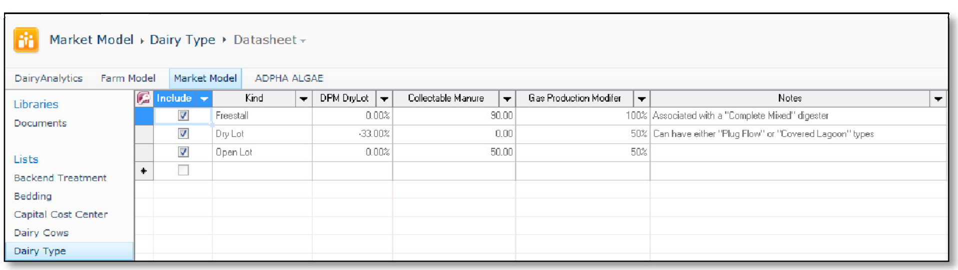


Dairy Farm Scenario	Dairy Type	Bedding Type	Backend Treatment	Digester Type
Type 1	Dry Lot	Manure Solids	Screened Only	Covered Lagoon
Type 2	Dry Lot	Manure Solids	Screened Only	Plug Flow
Type 3	Dry Lot	Manure Solids	Screened Only	Complete Mixed
Type 4	Dry Lot	Manure Solids	Nutrient Removal	Covered Lagoon
Type 5	Dry Lot	Manure Solids	Nutrient Removal	Plug Flow
Type 6	Dry Lot	Manure Solids	Nutrient Removal	Complete Mixed
Type 7	Dry Lot	Manure Solids	Nutrient Recovery	Covered Lagoon
Type 8	Dry Lot	Manure Solids	Nutrient Recovery	Plug Flow
Type 9	Dry Lot	Manure Solids	Nutrient Recovery	Complete Mixed
Type 10	Dry Lot	Other Organics	Screened Only	Covered Lagoon
Type 11	Dry Lot	Other Organics	Screened Only	Plug Flow
Type 12	Dry Lot	Other Organics	Screened Only	Complete Mixed
Type 13	Dry Lot	Other Organics	Nutrient Removal	Covered Lagoon
Type 14	Dry Lot	Other Organics	Nutrient Removal	Plug Flow
Type 15	Dry Lot	Other Organics	Nutrient Removal	Complete Mixed
Type 16	Dry Lot	Other Organics	Nutrient Recovery	Covered Lagoon
Type 17	Dry Lot	Other Organics	Nutrient Recovery	Plug Flow
Type 18	Dry Lot	Other Organics	Nutrient Recovery	Complete Mixed
Type 19	Dry Lot	Sand	Screened Only	Covered Lagoon
Type 20	Dry Lot	Sand	Screened Only	Plug Flow
Type 21	Dry Lot	Sand	Screened Only	Complete Mixed
Type 22	Dry Lot	Sand	Nutrient Removal	Covered Lagoon
Type 23	Dry Lot	Sand	Nutrient Removal	Plug Flow
Complete Mix Digeter on a Dry Lot Dairy with Sand Bedding and Nutrient Recovery	Dry Lot	Sand	Nutrient Removal	Complete Mixed
Covered Lagoon Digeter on a Dry Lot Dairy with Sand Bedding and Nutrient Recovery	Dry Lot	Sand	Nutrient Recovery	Covered Lagoon
Dry Lot Dairy with Sand Bedding and Nutrient Recovery	Dry Lot	Sand	Nutrient Recovery	Plug Flow

Figure 10. Farm Type table made up of a dairy farm scenario name and four linked tables; Diary Type, Bedding Type, Backend Treatment, and Digester Type.

The Diary Type table

The Dairy Type table (Fig. 11) defines a variety of dairy types. The "kind" column is a text value that names the dairy type row. The remaining columns define parameters for the diary type based on the Innovation Center model (2011).

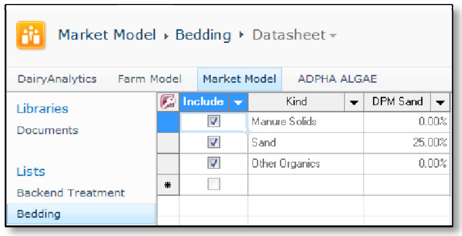


Include	Kind	DPM DryLot	Collectable Manure	Gas Production Modifer	Notes
☑	Freestall	0.00%	90.00	100%	Associated with a "Complete Mixed" digester
☑	Dry Lot	-33.00%	0.00	50%	Can have either "Plug Flow" or "Covered Lagoon" types
☑	Open Lot	0.00%	50.00	50%	

Figure 11. Dairy Type table

The Bedding table

The Bedding Table (Fig. 12) defines bedding % sand as defined in the Innovation Center model (2011).

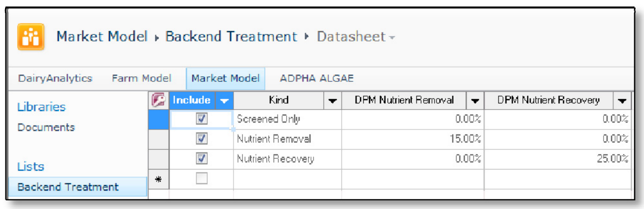


Include	Kind	DPM Sand
☑	Manure Solids	0.00%
☑	Sand	25.00%
☑	Other Organics	0.00%

Figure 12. Bedding table

The Backend Treatment table

The Backend Treatment table (Fig. 13) defines types of backend treatment as defined by the Innovation Center model (2011).

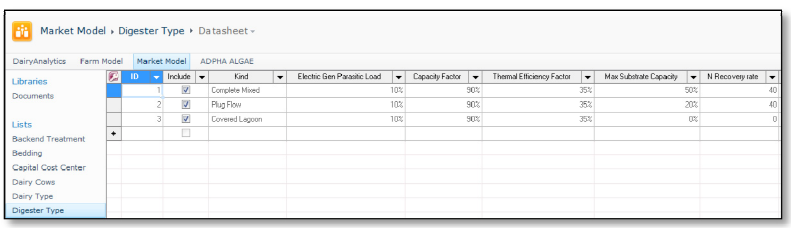


Include	Kind	DPM Nutrient Removal	DPM Nutrient Recovery
☑	Screened Only	0.00%	0.00%
☑	Nutrient Removal	15.00%	0.00%
☑	Nutrient Recovery	0.00%	25.00%

Figure 13. Backend Treatment table

The Digester Type table

The Digester Type table (Fig. 14) defines parameters for different digester types.



ID	Include	Kind	Electric Gen Parasitic Load	Capacity Factor	Thermal Efficiency Factor	Max Substrate Capacity	N Recovery rate
1	☑	Complete Mixed	10%	90%	35%	50%	40
2	☑	Plug Flow	10%	90%	35%	20%	40
3	☑	Covered Lagoon	10%	90%	35%	0%	0

Figure 14. Digester Type table

Regional Input Set Table

The Regional Input Set table (Fig. 15) has a large number of variables (Table 2) that are defined for each region of interest. The Input Data Set name defines the overall scenario name (Fig. 15; "2012 Market Study"), the region which is linked to the regions table (Table 2) and 30 additional parameters. Future versions of DANA will attempt to reduce the number of parameters by estimating values regionally from data sets and farm records.

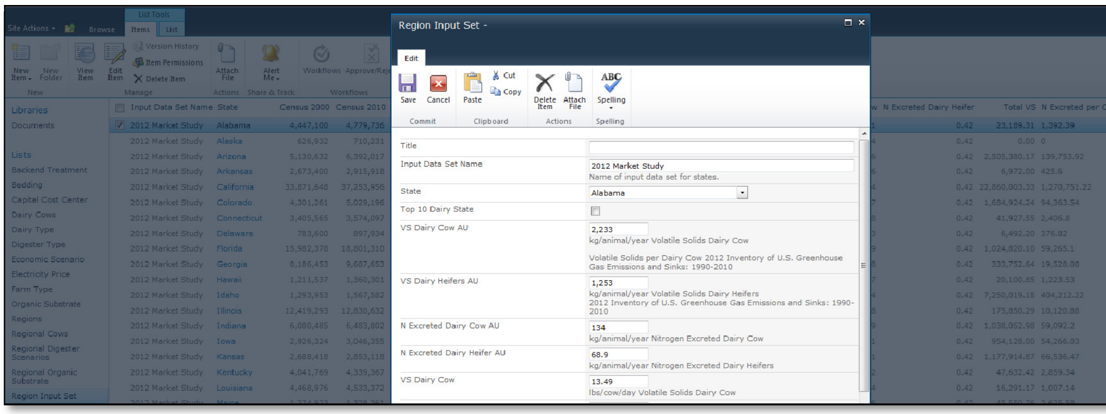


Figure 15. Regional Input Set table shown in standard output to show parameter descriptions

Table 2. Complete set of the Regional Input Data table parameters.

Name	Type	Length	Label
ID	Numeric	8	ID
Input_Data_Set_Name	Character	25	Input_Data_Set_Name
Region	Character	25	Region
Census_2000	Numeric	8	Census_2000
Census_2010	Numeric	8	Census_2010
Top_10_Dairy_State	Numeric	8	Top_10_Dairy_State
Number_of_Animals	Numeric	8	Number_of_Animals
Number_Farm_with_Digesters	Numeric	8	Number_Farm_with_Digesters
VS_Dairy_Cow	Numeric	8	VS_Dairy_Cow
VS_Dairy_Heifer	Numeric	8	VS_Dairy_Heifer
N_Excreted_Dairy_Cow	Numeric	8	N_Excreted_Dairy_Cow
N_Excreted_Dairy_Heifer	Numeric	8	N_Excreted_Dairy_Heifer
Total_VS	Numeric	8	Total_VS
N_Excreted_per_Cow	Numeric	8	N_Excreted_per_Cow
Methane_Conversion_Factor	Numeric	8	Methane_Conversion_Factor
Methane_Production	Numeric	8	Methane_Production
Tipping_Fees	Numeric	8	Tipping_Fees
Pipeline_Biomethane_Price	Numeric	8	Pipeline_Biomethane_Price
CNG_Price	Numeric	8	CNG_Price
Diesel_Price	Numeric	8	Diesel_Price
Recovered_Nitrogen_N_Price	Numeric	8	Recovered_Nitrogen_N_Price
Recovered_Phosphorus_P_Price	Numeric	8	Recovered_Phosphorus_P_Price
Recovered_Potassium_K_Price	Numeric	8	Recovered_Potassium_K_Price
Nut_Enr_Fiber_Pr_Covered_Lagoon	Numeric	8	Nut_Enr_Fiber_Pr_Covered_Lagoon
Nut_Enr_Fiber_Pr_Plug_Flow	Numeric	8	Nut_Enr_Fiber_Pr_Plug_Flow
Nut_Enr_Fiber_Pr_Complete_Mix	Numeric	8	Nut_Enr_Fiber_Pr_Complete_Mix
GHG_Offset_Credit_Price	Numeric	8	GHG_Offset_Credit_Price
REC_Price	Numeric	8	REC_Price
RIN_Price	Numeric	8	RIN_Price
VS_Dairy_Cow_AU	Numeric	8	VS_Dairy_Cow_AU
VS_Dairy_Heifers_AU	Numeric	8	VS_Dairy_Heifers_AU
N_Excreted_Dairy_Cow_AU	Numeric	8	N_Excreted_Dairy_Cow_AU
N_Excreted_Dairy_Heifer_AU	Numeric	8	N_Excreted_Dairy_Heifer_AU

Economic Scenario Table

The Economic Scenario table (Fig. 16) is the third table linked to the Regional Digester Scenario table (Fig. 9). The Capital Cost Center column is linked by dropdown to the capital cost center table (Fig. 17).

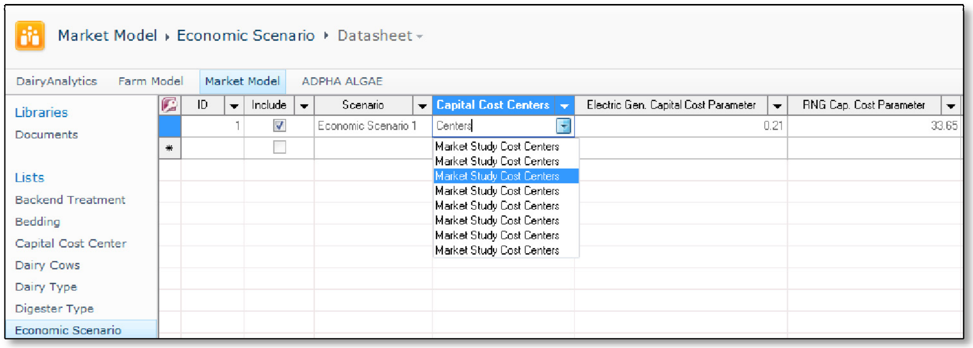


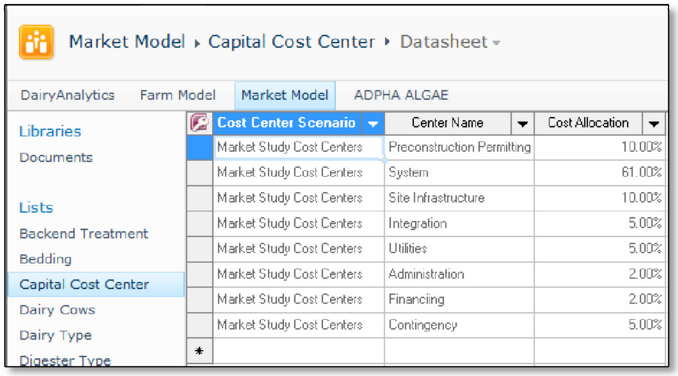
Figure 16. Economic Scenario table

This table also contains an additional 30 parameters (Table 3) many of which are cost related.

Table 3. Complete set of Economic Scenario table parameters.

Name	Type	Length	Label
ID	Numeric	8	ID
Include	Numeric	8	Include
Scenario	Character	255	Scenario
Capital_Cost_Centers	Character	255	Capital_Cost_Centers
Electric_Gen_Capital_Cost_Parame	Numeric	8	Electric_Gen_Capital_Cost_Parameter
RNG_Cap_Cost_Parameter	Numeric	8	RNG_Cap_Cost_Parameter
CNG_Cap_Cost_Parameter	Numeric	8	CNG_Cap_Cost_Parameter
Operation_Cost_Parameter	Numeric	8	Operation_Cost_Parameter
Equity	Numeric	8	Equity
Debt	Numeric	8	Debt
Loan_APR	Numeric	8	Loan_APR
Grants	Numeric	8	Grants
Third_Party_Funds	Numeric	8	Third_Party_Funds
Depreciation_Parameter	Numeric	8	Depreciation_Parameter
Tax_Rate	Numeric	8	Tax_Rate
NG_Spot_Price	Numeric	8	NG_Spot_Price
CNG_Spot_Price	Numeric	8	CNG_Spot_Price
Electricity_Inflation	Numeric	8	Electricity_Inflation
Natural_Gas_Inflation	Numeric	8	Natural_Gas_Inflation
Inflation_Diesel	Numeric	8	Inflation_Diesel
CNG_Inflation	Numeric	8	CNG_Inflation
OPEX_Inflation	Numeric	8	OPEX_Inflation
Carbon_Credit_Inflation	Numeric	8	Carbon_Credit_Inflation
Inflation_Env_Credits	Numeric	8	Inflation_Env_Credits
Inflation_Other	Numeric	8	Inflation_Other
Planning_Horizon	Numeric	8	Planning_Horizon
GHG_Offset_Credit_Price	Numeric	8	GHG_Offset_Credit_Price
REC_Price	Numeric	8	REC_Price
RIN_Price	Numeric	8	RIN_Price
VS_Dairy_Cow_AU	Numeric	8	VS_Dairy_Cow_AU
VS_Dairy_Heifers_AU	Numeric	8	VS_Dairy_Heifers_AU
N_Excreted_Dairy_Cow_AU	Numeric	8	N_Excreted_Dairy_Cow_AU
N_Excreted_Dairy_Heifer_AU	Numeric	8	N_Excreted_Dairy_Heifer_AU

Capital cost centers (Fig. 17) define how the distribution of total capital costs are apportioned to cost centers. The market study cost centers were taken from the Innovation Center model (2011), but alternate sets can be defined as needed.

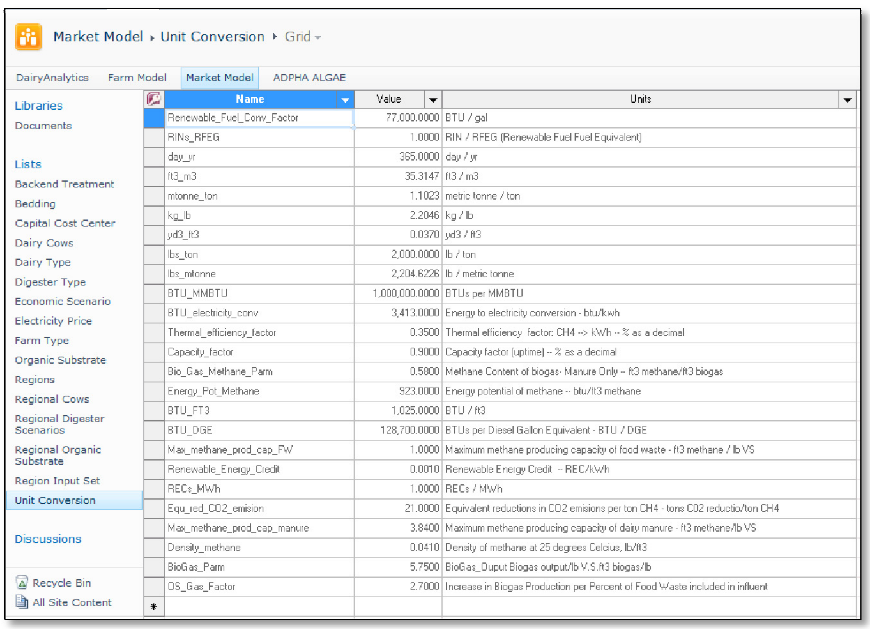


Cost Center Scenario	Center Name	Cost Allocation
Market Study Cost Centers	Preconstruction Permitting	10.00%
Market Study Cost Centers	System	61.00%
Market Study Cost Centers	Site Infrastructure	10.00%
Market Study Cost Centers	Integration	5.00%
Market Study Cost Centers	Utilities	5.00%
Market Study Cost Centers	Administration	2.00%
Market Study Cost Centers	Financing	2.00%
Market Study Cost Centers	Contingency	5.00%

Figure 17. Capital Cost Center table

5. Unit Conversion Table

The Unit Conversion table (Fig. 18) defines conversion factors that are used throughout the calculations. Often conversions like these are left undocumented in equations within the code. Placing conversions in a database allows them to be referred to by name in the code, which provides self-documentation. Also, errors can be corrected in the table without need to edit code.



Name	Value	Units
Renewable_Fuel_Conv_Factor	77,000.0000	BTU / gal
RINs_RFEG	1.0000	RIN / RFEG (Renewable Fuel Fuel Equivalent)
day_yr	365.0000	day / yr
ft3_m3	35.3147	ft3 / m3
mtonne_ton	1.1023	metric tonne / ton
kg_lb	2.2046	kg / lb
yd3_ft3	0.0370	yd3 / ft3
lbs_ton	2,000.0000	lb / ton
lbs_mtonne	2,204.6226	lb / metric tonne
BTU_MMBTU	1,000,000.0000	BTUs per MMBTU
BTU_electricity_conv	3,413.0000	Energy to electricity conversion - btu/kwh
Thermal_efficiency_factor	0.3500	Thermal efficiency factor: CH4 --> kWh -- % as a decimal
Capacity_factor	0.9000	Capacity factor (uptime) -- % as a decimal
Bio_Gas_Methane_Parm	0.5800	Methane Content of biogas- Manure Only -- ft3 methane/ft3 biogas
Energy_Pot_Methane	923.0000	Energy potential of methane -- btu/ft3 methane
BTU_FT3	1,025.0000	BTU / ft3
BTU_DGE	128,700.0000	BTUs per Diesel Gallon Equivalent - BTU / DGE
Max_methane_prod_cap_FW	1.0000	Maximum methane producing capacity of food waste - ft3 methane / lb VS
Renewable_Energy_Credit	0.0010	Renewable Energy Credit -- REC/kWh
RECs_MWh	1.0000	RECs / MWh
Equ_red_CO2_emision	21.0000	Equivalent reductions in CO2 emisions per ton CH4 - tons C02 reductio/ton CH4
Max_methane_prod_cap_manure	3.8400	Maximum methane producing capacity of dairy manure - ft3 methane/lb VS
Density_methane	0.0410	Density of methane at 25 degrees Celcius, lb/ft3
BioGas_Parm	5.7500	BioGas_Ouput Biogas output/lb V.S.ft3 biogas/lb
OS_Gas_Factor	2.7000	Increase in Biogas Production per Percent of Food Waste included in influent

Figure 18. Unit Conversion table

This completes a description of all the input tables. In the prototype model only limited access is given to modify these tables. Future version will implement setup wizards to help users assemble new scenarios. Also, note that the model run in market assessment mode ignores the Digester Type specified in the Farm Type table since all three digesters are always calculated during a national assessment. This specification will be used when the model is run for farm analysis.

Running the DANA Model

To run the DANA model simply click on the link shown in Figure 19. This will cause the input files to be read, calculations performed and a variety of reports, tables and graphs to be created.

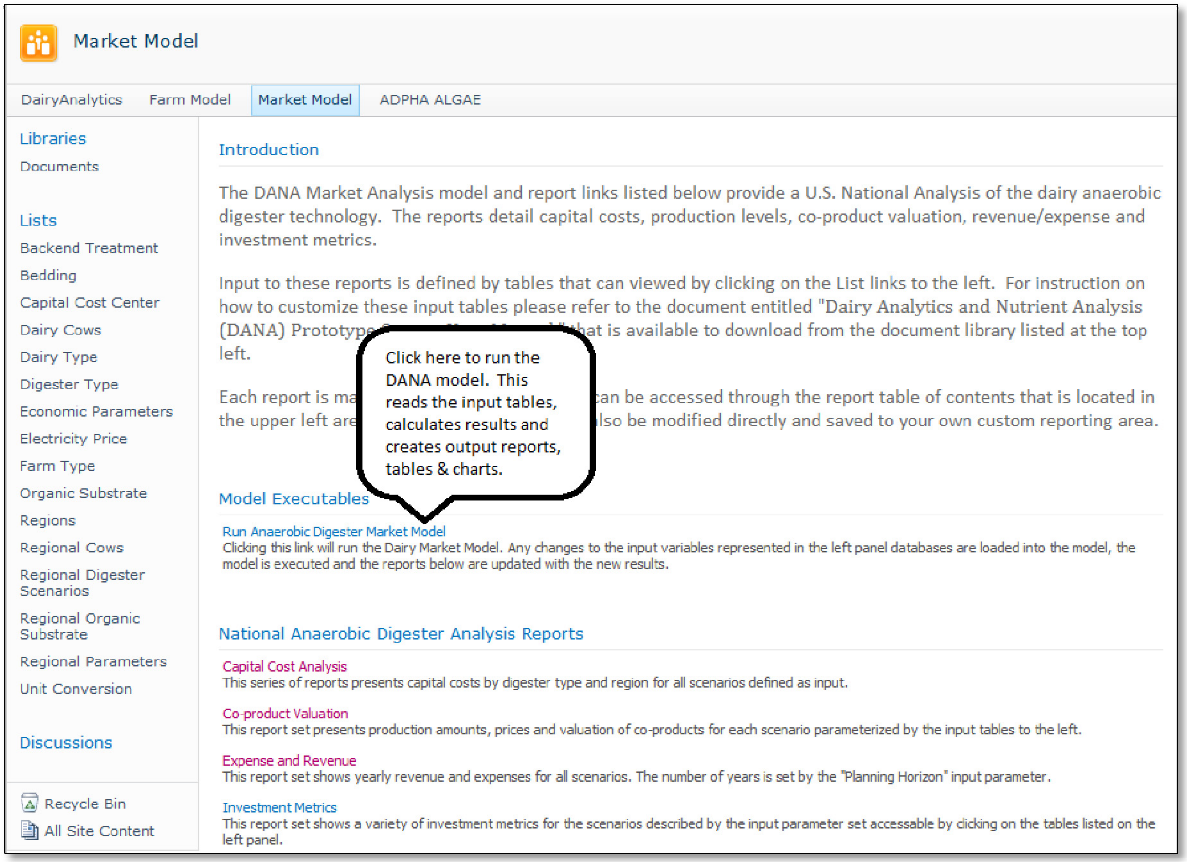


Figure 19. Link to run the DANA model.

DANA combines the equations used in the informa (2012) and Innovation Center (2011) spreadsheet models. In addition to integrating both these models, the main difference is that rather than a spreadsheet approach (where the same equation is copied to many spreadsheet cells), a single set of equations are used to process all the input data. DANA is written the SAS programming language and the main equations are listed in the Appendix 1. The SAS programs can also be downloaded from the dairy analytics web site and can be run on any SAS system.

The model provides results for three anaerobic digester types; covered lagoons, modified plug flow, and complete mix, and three main energy production technologies; electricity generation, renewable natural gas generation, and compressed natural gas generation. Additional options include different dairy types, bedding types, backend treatment type as well as numerous production, and economic parameters as described in the prior sections of this report.

Model Result Reporting

Reports are viewed and customized using the SAS web report studio (WRS) product that is launched from links on the dairy analytics web site (Fig. 20). A user manual for this product is available online[7] and will not be duplicated here. SAS WRS is a web-based report viewing and report writing tool. It fully web based and does not require any software be installed on the user's computer. It implements a virtual workspace for each user to modify and create reports that contain tables, charts, explanatory notes, maps, etc. Here we will describe the standard set of reports created for this project. Keep in mind many more reports can be easily created to support individual reporting needs. Also, please note that the scenario results reported here, though similar to the informa report (2012), may be different due to two factors. First, the DANA system was completed prior to publication of the informa report. Any changes to equations and/or parameters may not have been updated in the DANA databases or code. Additionally, DANA integrates both the informa (2012) spreadsheet and its precursor the Innovation Center (2011) spreadsheet, which may cause altered results, especially when values from the two sources interact to generate results[8].

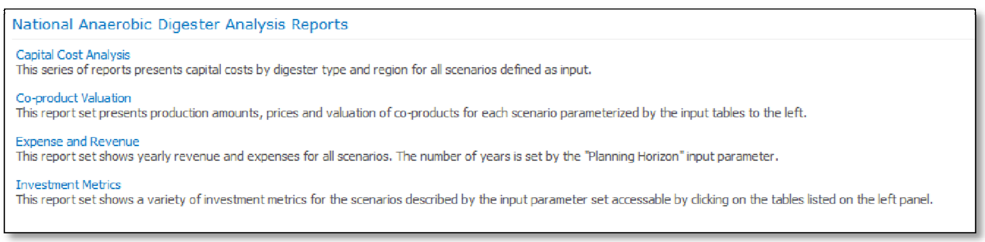


Figure 20. Reports available from the Dairy Analytics web site

Capital Cost Analysis

The result of clicking on "Capital Cost Analysis" (Fig. 20) is a cross tabulation table that presents region and scenario by digester type and generation type. Appearing on the left in figure 21 is the data source or "multidimensional OLAP cube[9]" that provides data to generate the report table on the right. Variables with a green and yellow set of rectangles next to them are called "dimensions" and those with a yellow ruler are called "measures". Essentially, dimensions are categories used to organize the measures for reporting. On the right side (Fig. 21) of the report the row and column headers are dimensions and the table values are measures.

Figure 21 shows only one of the many possible views available as each dimension individually or together can be used to organize any set of measures. Currently, DANA generates three cubes. The first contains capital cost information (Fig. 21) the remaining two contain time based income and expense estimates and finally investment measures.

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[7] http://support.sas.com/documentation/onlinedoc/wrs/index.html

[8] DANA results were identical to the Innovation Center DMI model results for the default case. Since DANA was completed prior to the final informa (2012) report, comparison between DANA and informa has not been completed.

[9] A multidimensional on-line analytical processing (OLAP) cube is commonly used business reporting tool (http://en.wikipedia.org/wiki/Online_analytical_processing)

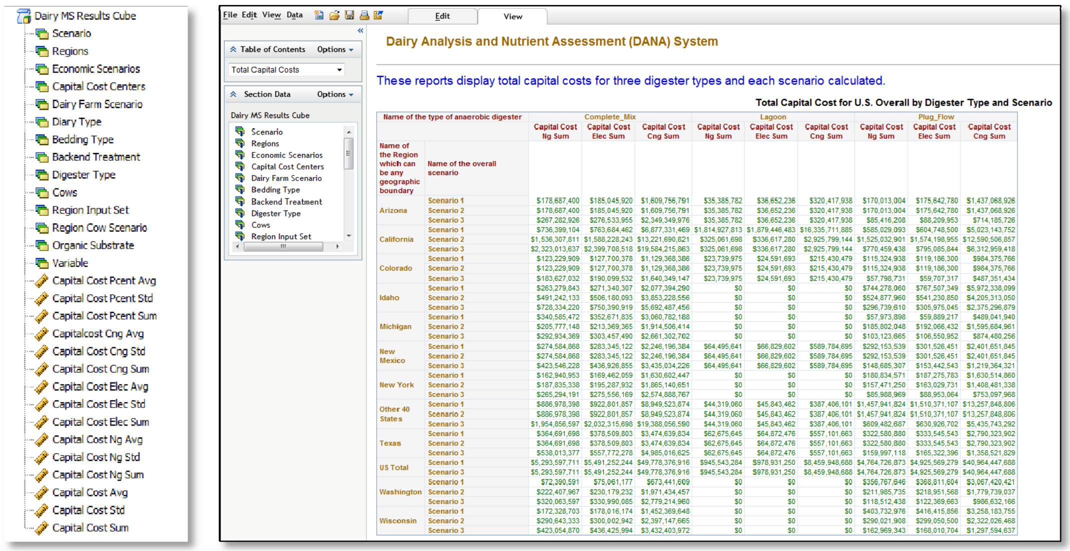


Figure 21. Dairy anaerobic digester capital cost report, region and scenario by digester type and generation type.

The cube dimension values automatically change along with their corresponding measures when changes are made to the input data scenarios (i.e., regions, production and economic parameters, etc.). For example, if we created scenarios that used EPA regions, like was done in the original Innovation Center model (2011), we would see EPA region names appear in figure 21 rather than U.S. States. If we created scenarios where regions were names of farms then those names would appear as the list of regions in the results generated by DANA, stored in the resulting cubes and displayed in reports like figure 21.

Each user has the ability to modify the standard reports and save them in a personal workspace. The SAS Web Report Studio manual[10] will describe how to customize reports. Briefly, you many have noticed an "edit" tab in the header of the report shown in figure 21. Clicking the edit tab switches the report to edit mode (Fig. 22) and allows you to change tables and add graphics, maps, text explanations and many more customizations. Figure 22 depicts how data is assign to a crosstab table by assigning dimensions and measures to table rows and columns. The icons displayed below the edit tab gives you an idea of the kinds of graphs that can be added by the user.

[10] http://support.sas.com/documentation/onlinedoc/wrs/index.html

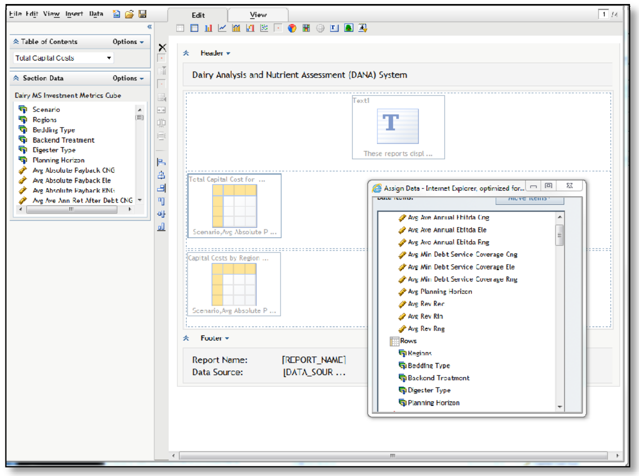


Figure 22. User customization of a standard DANA report.

Co-Product Valuation

Figure 23 show the standard co-product valuation table that is displayed initially upon clicking the "Co-product Valuation" link (Fig. 20).

Dairy Analytics and Nutrient Analysis (DANA) System

Co−Product Valuation Report

Name of the overall scenario	Scenario 1																		
Name of the type of anaerobic digester	Complete_Mix												Lagoon						
	Sum Value Elec And Recs Annual	Sum Value Cng And Rin Annual	Sum Tot Value Prod And Coprod Annual	Sum Rin Value Annual	Sum Renewable Energy Credits	Sum Rec Value Annual	Sum P Recovered Value	Sum Organic Substrate Value Annual	Sum Nutr Enrich Fiber Value Annual	Sum N Recovered Value	Sum Ghg Offset Credit Value	Sum Value Elec And Recs Annual	Sum Value Cng And Rin Annual	Sum Tot Value Prod And Coprod Annual	Sum Rin Value Annual	Sum Renewable Energy Credits	Sum Rec Value Annual	Sum P Recovered Value
Name of the Region which can be any geographic boundary																			
Arizona	$9,410,341	$16,349,543	$718,568,087	$8,472,023	0.0065	$140,873	$12.62	$8,274,455	$2,582,041	$18.95	$0.16	$1,874,297	$3,256,408	$4,507,132	$1,687,409	0.0044	$28,058	$0.00
California	$67,160,911	$58,798,097	$2,775,926,217	$36,354,716	0.0072	$604,509	$12.62	$72,206,269	$11,003,624	$18.56	$0.12	$158,807,983	$139,033,363	$212,464,694	$85,963,979	0.0043	$1,429,415	$0.00
Colorado	$7,150,940	$9,996,734	$484,121,748	$5,956,405	0.0068	$99,043	$12.62	$8,244,738	$1,725,452	$19.15	$0.11	$1,362,404	$1,904,588	$2,502,240	$1,134,820	0.0044	$18,870	$0.00
Idaho	$9,393,309	$18,747,804	$1,254,603,038	$10,808,080	0.0046	$178,580	$12.62	$1,496,215	$5,147,256	$18.56	$0.15	$0	$0	$0	$0	0.0043	$0	$0.00
Michigan	$19,975,945	$28,377,264	$1,385,663,513	$16,103,740	0.0064	$267,774	$12.62	$41,653,742	$3,199,335	$18.75	$0.09	$0	$0	$0	$0	0.0044	$0	$0.00
New Mexico	$12,052,611	$18,432,958	$1,278,972,091	$11,672,067	0.0050	$194,084	$12.62	$3,102,116	$4,621,519	$19.35	$0.16	$3,211,132	$4,911,024	$6,821,726	$3,109,745	0.0045	$51,709	$0.00
New York	$11,413,562	$15,310,737	$549,000,857	$8,688,651	0.0091	$144,475	$12.62	$43,597,679	$2,286,892	$17.96	$0.05	$0	$0	$0	$0	0.0041	$0	$0.00
Other 40 States	$80,160,747	$94,235,114	$2,969,529,802	$48,034,807	0.0093	$793,671	$12.62	$280,068,224	$27,317,801	$17.57	$0.06	$3,411,096	$4,010,005	$5,020,254	$2,044,034	0.0040	$33,773	$0.00
Texas	$19,715,474	$26,409,380	$1,301,303,402	$18,411,094	0.0077	$306,141	$12.62	$37,610,750	$5,230,764	$18.16	$0.11	$3,134,407	$4,198,618	$6,139,791	$2,927,034	0.0042	$48,671	$0.00
US Total	$442,283,784	$469,759,738	$19,879,597,313	$265,030,169	0.0074	$4,379,047	$12.62	$730,737,122	$191,389,115	$18.36	$0.11	$74,710,940	$79,352,200	$104,516,023	$44,769,114	0.0042	$739,712	$0.00
Washington	$2,408,097	$7,056,665	$281,016,628	$3,558,261	0.0071	$59,167	$12.62	$9,665,072	$1,090,041	$18.95	$0.10	$0	$0	$0	$0	0.0044	$0	$0.00
Wisconsin	$9,374,865	$13,122,446	$745,970,350	$7,577,925	0.0054	$126,006	$12.62	$12,214,485	$1,797,957	$17.96	$0.08	$0	$0	$0	$0	0.0041	$0	$0.00

Figure 23. Co-Product valuation results by scenario, digester type and region.

The following is a list of dimensions (italicized) and measures available in the cube entitled "Dairy MS Valuation Cube" that can be used to construct reports.

Dairy Valuation Cube Content	*Digester_Type*	Adj_Electricity_Value
Scenario	*Region_Input_Set*	Adj_Electricity_Value_Annual
Regions	*Region_Cow_Scenario*	NG_Price
Economic_Scenario	*Cows*	Natural_Gas_Prod
Capital_Cost_Centers	*Organic_Substrate*	Natural_Gas_Prod_MMBTU
Dairy_Farm_Scenario	Electricity_Price	Adjusted_NG_Value
Dairy_Type	Electricity_Prod_Full	Adj_NG_Value_Annual_Annual
Bedding_Type	Electricity_Prod_Adj	CNG_Price
Backend_Treatment	Electricity_Prod_kW_yr	CNG_Prod

CNG_Prod_MMBTU
CNG_Value
CNG_Value_Annual
REC_Price
Renewable_Energy_Credits
Annual_RECs
REC_Value
REC_Value_Annual
RIN_Price
Renewable_ID_Num_Prod
Annual_RINs
RIN_Value
RIN_Value_Annual
GHG_Offset_Credit_Price
GHG_Offset_Credits
GHG_Offset_Credits_yr
GHG_Offset_Credit_Value
Annual_GHG_Offset_Credit_Value
Fiber_Production
Fiber_Production_yr
Fiber_Price
Nutr_Enrich_Fiber_Value
Nutr_Enrich_Fiber_Value_Annual
Recovered_Nitrogen_N_Price
N_Prod_Codigest
N_Recovered
N_Recovered_yr
N_Recovered_Value
N_Recovered_Value_Annual
Recovered_Phosphorus_Price
P_Prod_Codigest
P_Recovered
P_Recovered_yr
P_Recovered_Value
P_Recovered_Value_Annual
Organic_Substrate_Added
Pot_Org_Sub_Need
Region_Pot_Org_Sub_Need
FW_Avail_Pct
Organic_Substrate_Added1
OS_cow_added
FW_Pct_Tot
Tipping_Fees
Organic_Substrate_Value
Organic_Substrate_Value_Annual
Value_Elec_And_RECs
Value_Elec_And_RECs_Annual
Value_CNG_And_RIN
Value_CNG_And_RIN_Annual
Max_Value_Sum
Max_Value_Sum_Annual
Max_Value_Prod_And_CoProd
Max_Value_Prod_And_CoProd_Annual
Tot_Value_Prod_And_CoProd
Tot_Value_Prod_And_CoProd_Annual

Time Based Revenue and Expense

Figure 24 shows the relationship among three investment metrics for renewable natural gas (RNG) and the complete mix digester type across all regions by year. This lattice graph shows another way view information with DANA. Diagonal elements are a histogram of each of the investment metrics. Symbol marks show values by years 1 through 15. Ellipses represent 95% confidence intervals. Each matrix element is a chart of the row value versus the column value. This graph when viewed online shows data values when graph points are selected. This information is also available in a cross tabular report.

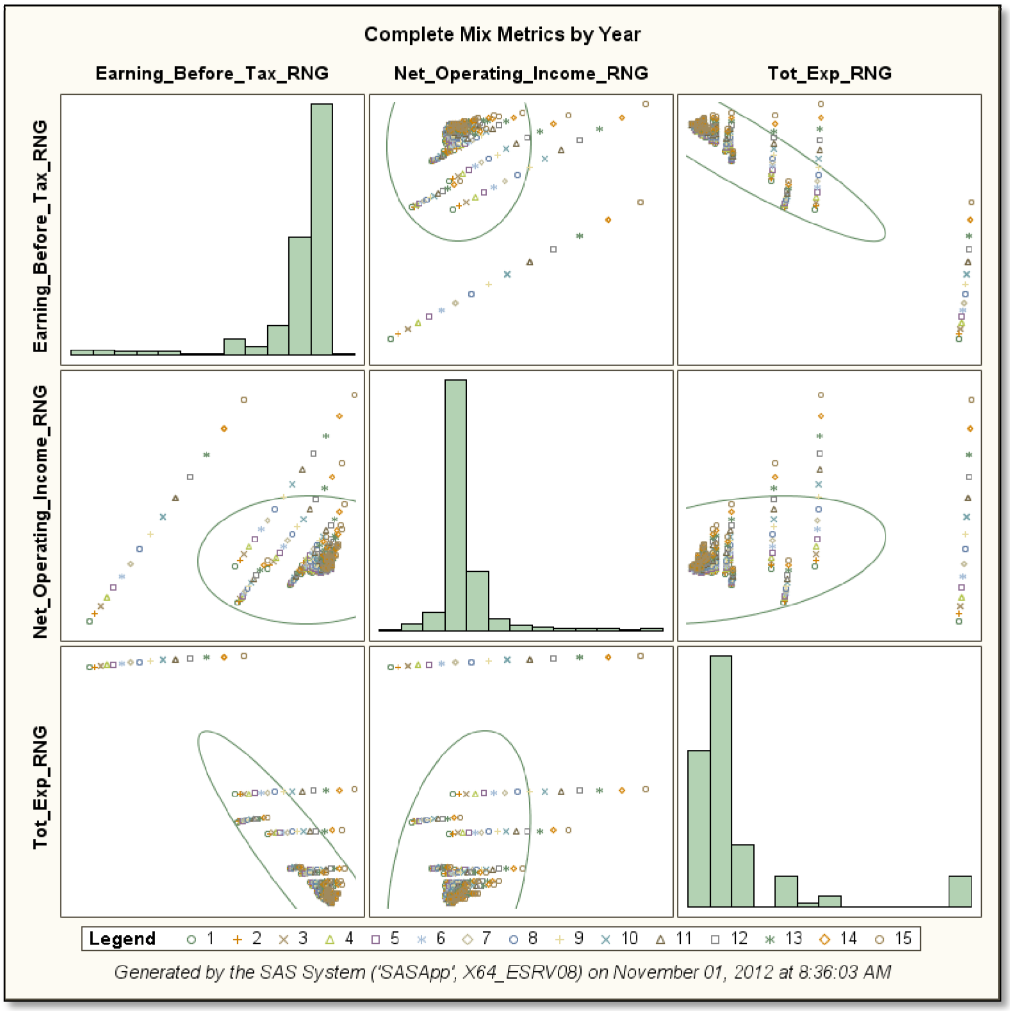


Figure 24. Investment metrics for renewable natural gas (RNG) for the complete mix digester type across all regions.

Investment Metrics

Figure 25 shows the earnings before interest, taxes, depreciation, and amortization (EBITDA) metric by region, digester type and scenario. Other metrics (APR, debt, equity, etc.) can similarly be presented in cross tabular reports or in graphic form (Fig. 26).

Dairy Analysis and Nutrient Assessment (DANA) System

These reports displays investment measures for three digester types and each scenario calculated.

Name of the overall scenario			Scenario 1			Scenario 2			Scenario 3		
			Avg Ave Annual Ebitda Cng	Avg Ave Annual Ebitda Ele	Avg Ave Annual Ebitda Rng	Avg Ave Annual Ebitda Cng	Avg Ave Annual Ebitda Ele	Avg Ave Annual Ebitda Rng	Avg Ave Annual Ebitda Cng	Avg Ave Annual Ebitda Ele	Avg Ave Annual Ebitda Rng
Name of the Region which can be any geographic boundary	Name of the type of anaerobic digester	Number of years for planning horizon									
Arizona	Complete_Mix	15	$-25,281,926	$-8,890,996	$4,901,414	$-25,281,926	$-8,890,996	$4,901,414	$-35,438,320	$-11,591,107	$8,475,510
	Lagoon	15	$-3,756,765	$-492,114	$2,254,979	$-3,756,765	$-492,114	$2,254,979	$-3,756,765	$-492,114	$2,254,979
	Plug_Flow	15	$-18,989,996	$-4,477,614	$7,734,061	$-18,989,996	$-4,477,614	$7,734,061	$-9,213,296	$-2,011,606	$4,048,370
California	Complete_Mix	15	$-119,469,713	$-49,133,785	$10,051,503	$-207,113,681	$-73,273,703	$39,348,083	$-297,908,286	$-100,204,974	$66,155,634
	Lagoon	15	$-214,999,116	$-48,683,521	$91,265,390	$-38,507,304	$-8,719,437	$16,346,040	$-38,507,304	$-8,719,437	$16,346,040
	Plug_Flow	15	$-75,031,609	$-24,199,115	$18,574,699	$-176,210,523	$-49,470,750	$57,176,455	$-87,181,082	$-23,699,373	$29,718,323
Colorado	Complete_Mix	15	$-19,711,299	$-8,187,368	$1,509,628	$-19,711,299	$-8,187,368	$1,509,628	$-27,874,357	$-11,189,610	$2,850,036
	Lagoon	15	$-3,093,018	$-897,467	$950,014	$-3,093,018	$-897,467	$950,014	$-3,093,018	$-897,467	$950,014
	Plug_Flow	15	$-15,308,167	$-5,354,386	$3,021,381	$-15,308,167	$-5,354,386	$3,021,381	$-7,455,417	$-2,535,482	$1,604,476
Idaho	Complete_Mix	15	$-29,409,637	$-8,631,453	$8,852,681	$-54,041,153	$-15,534,227	$16,868,042	$-79,379,048	$-22,521,505	$25,322,181
	Lagoon	15	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Plug_Flow	15	$-82,306,408	$-22,426,176	$27,961,000	$-57,801,470	$-15,647,152	$19,824,272	$-32,596,698	$-8,789,686	$11,243,105
Michigan	Complete_Mix	15	$-54,606,999	$-23,450,890	$2,765,915	$-35,119,470	$-15,548,329	$920,121	$-47,904,474	$-20,778,075	$2,047,867
	Lagoon	15	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Plug_Flow	15	$-8,011,784	$-3,074,493	$1,080,069	$-26,622,342	$-10,474,074	$3,114,144	$-14,403,892	$-5,569,064	$1,865,143
New Mexico	Complete_Mix	15	$-31,907,967	$-9,325,871	$9,676,195	$-31,907,967	$-9,325,871	$9,676,195	$-48,095,909	$-13,603,459	$15,420,764
	Lagoon	15	$-7,831,939	$-1,815,476	$3,247,173	$-7,831,939	$-1,815,476	$3,247,173	$-7,831,939	$-1,815,476	$3,247,173
	Plug_Flow	15	$-32,523,869	$-8,362,469	$11,968,526	$-32,523,869	$-8,362,469	$11,968,526	$-16,439,442	$-4,176,288	$6,142,739
New York	Complete_Mix	15	$-32,066,056	$-15,256,014	$-1,110,936	$-36,508,107	$-17,296,884	$-1,131,293	$-49,702,385	$-23,249,158	$-989,668
	Lagoon	15	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Plug_Flow	15	$-29,386,542	$-12,782,450	$1,189,329	$-25,226,110	$-10,897,511	$1,159,517	$-13,262,732	$-5,621,917	$807,569
Other 40 States	Complete_Mix	15	$-175,323,864	$-82,978,503	$-5,273,026	$-175,323,864	$-82,978,503	$-5,273,026	$-375,170,233	$-175,496,923	$-7,478,630
	Lagoon	15	$-5,700,079	$-1,770,489	$1,536,127	$-5,700,079	$-1,770,489	$1,536,127	$-5,700,079	$-1,770,489	$1,536,127
	Plug_Flow	15	$-234,012,689	$-98,860,996	$14,864,552	$-234,012,689	$-98,860,996	$14,864,552	$-94,181,986	$-38,903,813	$7,610,887
Texas	Complete_Mix	15	$-61,844,559	$-26,224,384	$3,748,781	$-61,844,559	$-26,224,384	$3,748,781	$-85,890,773	$-34,956,472	$7,903,009
	Lagoon	15	$-7,066,926	$-1,403,957	$3,361,239	$-7,066,926	$-1,403,957	$3,361,239	$-7,066,926	$-1,403,957	$3,361,239
	Plug_Flow	15	$-42,068,809	$-13,804,210	$9,979,489	$-42,068,809	$-13,804,210	$9,979,489	$-19,872,686	$-6,145,236	$5,405,947
US Total	Complete_Mix	15	$-891,940,090	$-382,428,174	$46,308,757	.	.	.	$-891,940,090	$-382,428,174	$46,308,757
	Lagoon	15	$-117,414,946	$-31,347,776	$41,074,819	.	.	.	$-117,414,946	$-31,347,776	$41,074,819
	Plug_Flow	15	$-640,951,752	$-226,333,777	$122,553,135	.	.	.	$-640,951,752	$-226,333,777	$122,553,135
Washington	Complete_Mix	15	$-12,062,513	$-5,178,301	$614,529	$-33,701,281	$-13,668,590	$3,188,238	$-46,508,389	$-18,342,195	$5,358,699
	Lagoon	15	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Plug_Flow	15	$-49,110,184	$-18,063,388	$8,061,435	$-27,667,922	$-9,711,466	$5,398,281	$-15,173,539	$-5,230,423	$3,136,372
Wisconsin	Complete_Mix	15	$-25,537,927	$-10,876,820	$1,460,002	$-41,444,956	$-17,317,849	$2,984,291	$-58,561,209	$-24,093,257	$4,910,351
	Lagoon	15	$0	$0	$0	$0	$0	$0	$0	$0	$0
	Plug_Flow	15	$-53,830,370	$-21,136,565	$6,374,159	$-38,083,130	$-14,809,314	$4,774,809	$-21,171,550	$-8,175,979	$2,759,352

Figure 25. Earnings before Interest, taxes, depreciation, and amortization (EBITDA) metric by region, digester type and scenario.

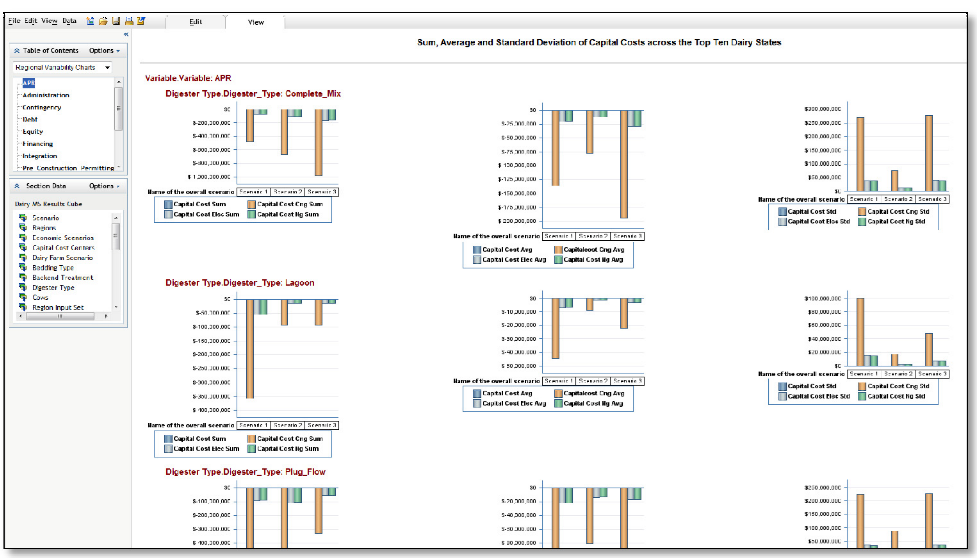


Figure 26. APR digester type by scenario variability chart for sum (left column), average (center column) and standard deviation (right column).

GEMS Component Architecture

DANA was implemented within the INL's Generalized Environment for Modeling Systems (GEMS) component architecture, which includes a unique integration of Microsoft SharePoint, SAS Analytics and Business Intelligence, and Phoenix Integration's ModelCenter and AnalysisLibrary. As mentioned previously, SharePoint provides the customer information deliver point and enables many collaboration capabilities. SAS's systems provide business intelligence and extensive statistical analysis capability in a form that is accessible by analysts and researchers without the need for extensive programming skills. ModelCenter provides a point-and-click model integration environment that relieves modelers of extensive error-prone scripting tasks needed to connect models.

The remainder of this section will describe a GEMS application entitled OASIES. Though not related to directly to dairy farms, the example provides concepts that demonstrate what is possible for extending DANA to integrate existing models, add alternate user control interfaces and to perform optimization studies. In this example, OASIES conducts a planning and an optimization study to determine a set of most attractive combinations of hybrid energy equipment combinations.

Future versions of DANA may include digester process models and environmental models of nutrient movement on the landscape. Rather than coding these models anew, the GEMS component architecture can be used to integrate already existing codes available from DOE, USDA and EPA into DANA. This integration uses the same input databases and same SAS web report studio reporting tools to handle the data produced by new models.

OASIES Overview

OASIES provides scenario analysis capability, like DANA, but was developed to provide understanding of the technical and regulatory viability of integrated energy solutions (i.e., hybrid energy systems). Conventional, renewable, and alternative integrated energy systems are synthesized and analyzed for viability within the boundaries of a community of interest. OASIES allows for a flexible and site-specific identification of available energy resources, allowing decision makers to make more informed decisions about hybrid energy systems.

Hybrid Energy Analysis Process

The OASIES hybrid energy analysis process, shown in Figure 27, can be used in any order depending on the experience level and comfort of the user. The final step, hybrid energy systems (HES) Design, requires the work of an experienced HES developer. The following subchapters will describe the planning and optimization steps.

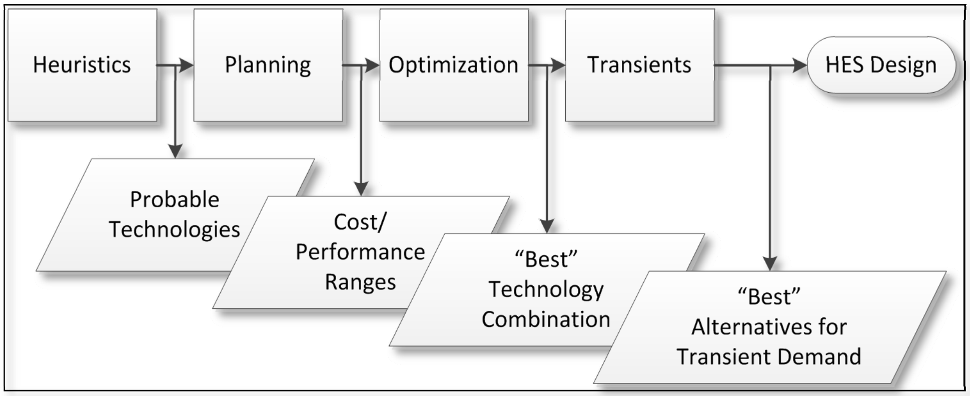


Figure 27. OASIES analysis process

Planning Platform

The OASIES Planning Platform allows the user to select the technology mix from a variety of technologies identified via a site-specific resource evaluation. First, the user inputs required electrical demand levels that the generation mix must match. Then the Planning Platform calculates capital and operational costs, emission levels, power, and energy system resilience.

The OASIES planning model allows users to select the components of the HES and calculate cost and performance values. Results are delivered to the user and are executable from a web portal (Fig. 28, shows the front page). Users make adjustments to controls (slider bars, dropdown boxes, check boxes, etc.) that set model parameters. When the user is ready, clicking the "Run the Model" button (upper left, Fig. 28), executes the model and returns tables and charts of results to the portal. The user can then view charts and graphs that summarize the resulting calculations.

Figure 28. OASIES planning model web portal interface

Figure 29 shows the user input tab that allows specification of a number of model inputs, such as the planning horizon for life cycle cost analysis, discount on money per year over the horizon, potential selling price of electricity, cost of natural gas and diesel fuel, maximum NOx emission levels, and yearly kWh demand. Additionally, the base and variable (peak) power demand can be set independently.

The scenario input tab (Fig. 29) allows the user to input the component mix. The set of components shown here is configurable by the user from the web portal and determines the components presented in Figure 29. In the case shown, a nuclear power option, biomass plant option, diesel generator (prime mover) models and number, and hydro plant models can be chosen. A similar DANA interface will likely be created for farm and investor use.

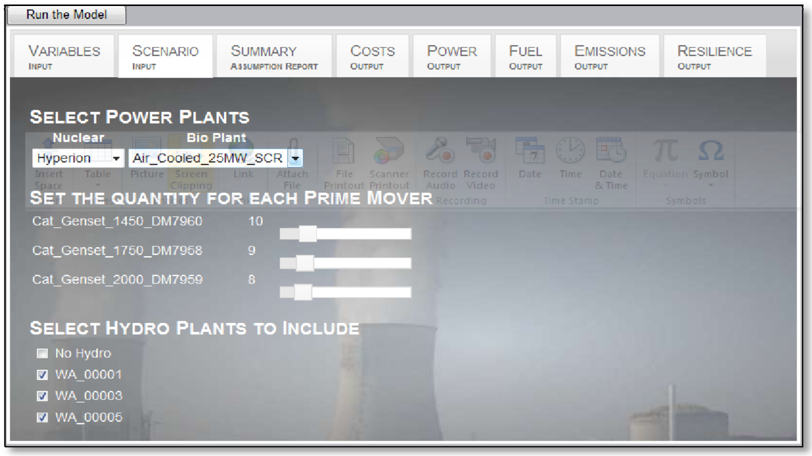
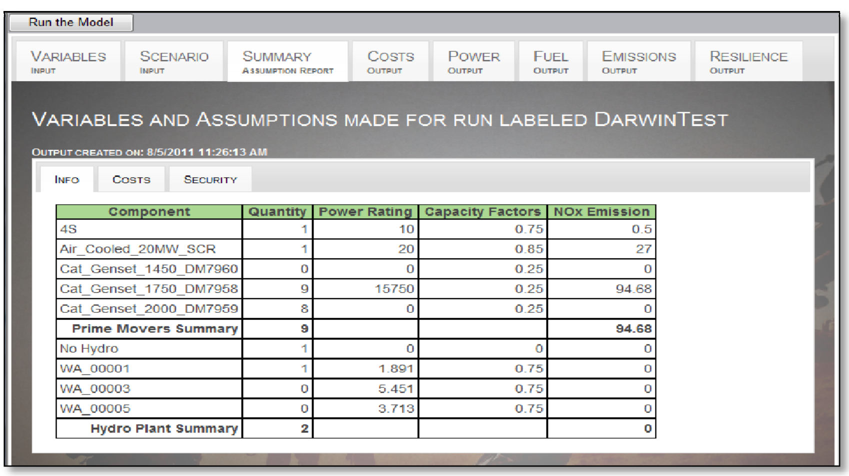


Figure 29. Component input selection screen

This completes the input necessary for the OASIES Planning Model. The remaining tabs contain results obtained from executing the model.

Figure 30 shows information on power, emissions, costs and security metrics by component so the user can understand what components contribute the greatest and least to the overall totals that appear on additional tabs.

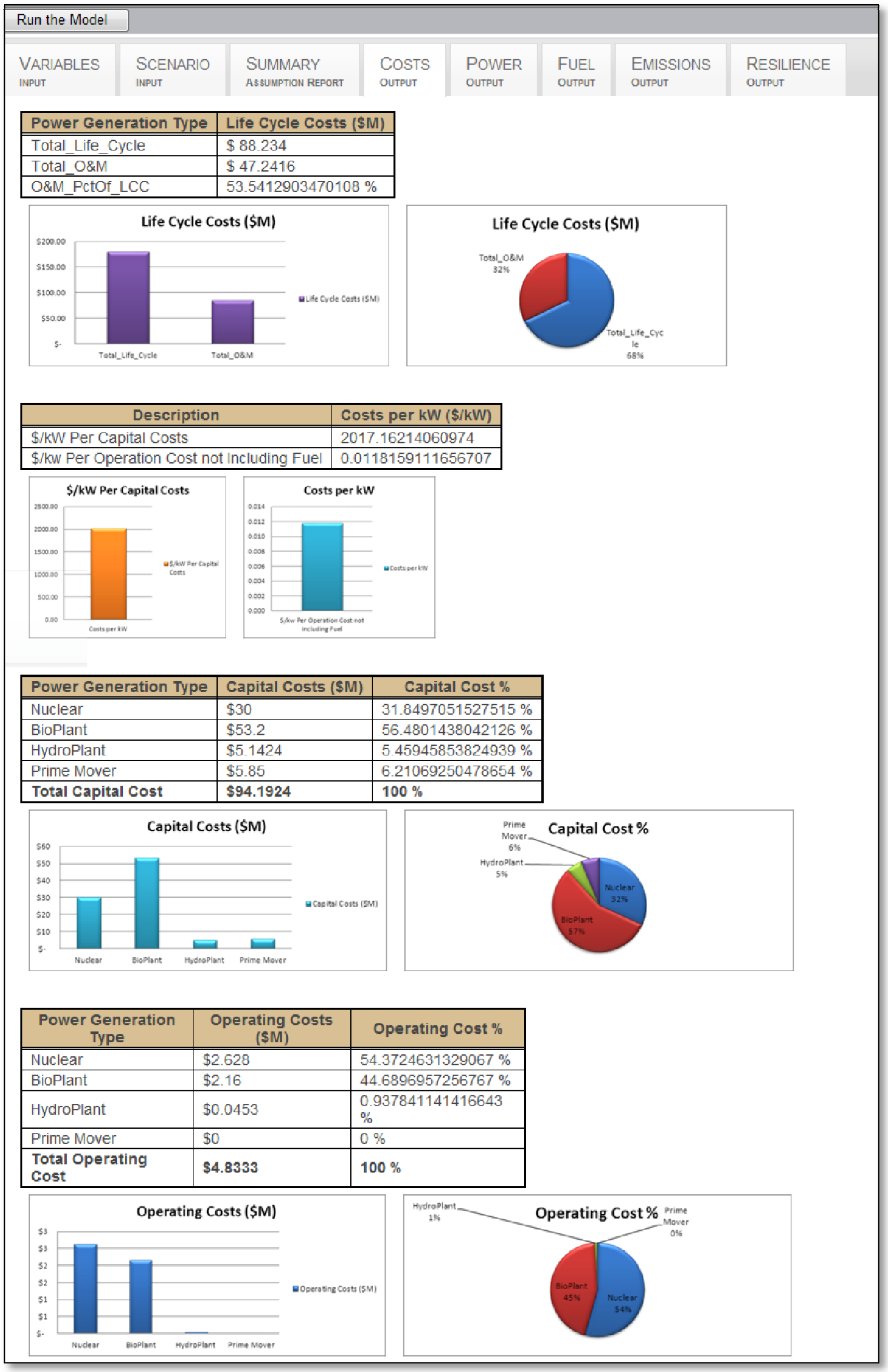


Component	Quantity	Power Rating	Capacity Factors	NOx Emission
4S	1	10	0.75	0.5
Air_Cooled_20MW_SCR	1	20	0.85	27
Cat_Genset_1450_DM7960	0	0	0.25	0
Cat_Genset_1750_DM7958	9	15750	0.25	94.68
Cat_Genset_2000_DM7959	8	0	0.25	0
Prime Movers Summary	**9**			**94.68**
No Hydro	1	0	0	0
WA_00001	1	1.891	0.75	0
WA_00003	0	5.451	0.75	0
WA_00005	0	3.713	0.75	0
Hydro Plant Summary	**2**			**0**

Figure 30. Component summary results

Figure 31 shows the Cost Output Tab. Each contains a variety of tables and charts that describe the overall system costs. Charts can be expanded and viewed in sequence. These charts are extracted directly from an Excel table that can be modified by the user if necessary. The remaining results include:

power, fuels, emissions, and resilience/security outputs. All are presented in a similar format with tables and associated charts in Figures 31–35.



Power Generation Type	Life Cycle Costs ($M)
Total_Life_Cycle	$ 88.234
Total_O&M	$ 47.2416
O&M_PctOf_LCC	53.5412903470108 %

Description	Costs per kW ($/kW)
$/kW Per Capital Costs	2017.16214060974
$/kw Per Operation Cost not Including Fuel	0.0118159111656707

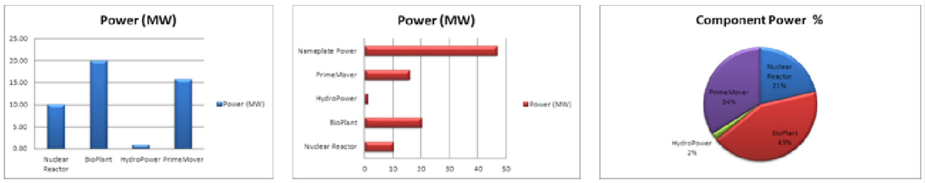
Power Generation Type	Capital Costs ($M)	Capital Cost %
Nuclear	$30	31.8497051527515 %
BioPlant	$53.2	56.4801438042126 %
HydroPlant	$5.1424	5.45945853824939 %
Prime Mover	$5.85	6.21069250478654 %
Total Capital Cost	**$94.1924**	**100 %**

Power Generation Type	Operating Costs ($M)	Operating Cost %
Nuclear	$2.628	54.3724631329067 %
BioPlant	$2.16	44.6896957256767 %
HydroPlant	$0.0453	0.937841141416643 %
Prime Mover	$0	0 %
Total Operating Cost	**$4.8333**	**100 %**

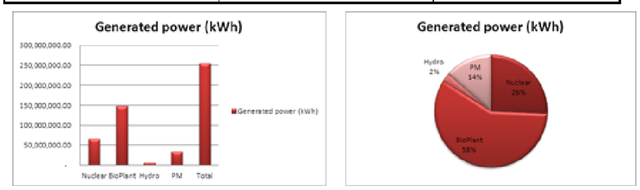
Figure 31. Cost output tab

VARIABLES INPUT | SCENARIO INPUT | SUMMARY ASSUMPTION REPORT | COSTS OUTPUT | POWER OUTPUT | FUEL OUTPUT | EMISSIONS OUTPUT | RESILIENCE OUTPUT

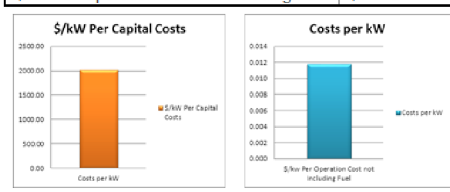
Power Rating	Power (MW)	Component Power %
Nuclear Reactor	10.00 MW	21.42%
BioPlant	20.00 MW	42.83%
HydroPower	0.95 MW	2.02%
PrimeMover	15.75 MW	33.73%
Nameplate Power	**46.70 MW**	**100.00%**



Generated power (kWh)	Generated power (kWh)	Component Power %
Nuclear	65,700,000 kWh	100.00%
BioPlant	148,920,000 kWh	50.9%
Hydro	6,211,935 kWh	7.3%
PM	34,492,500 kWh	21.3%
Total	255,324,435 kWh	100%



Costs per kW	Costs per kW ($/kW)
$/kW Per Capital Costs	$2,017.16
$/kw Per Operation Cost not Including Fuel	$0.012



kW hour (%)	kW hour
Demand (kWhr per year)	$265,985,700
HES (kWhr per year)	$255,324,435
Demand Coverage (%)	96%
Green Power as (%) of Demand	83%

Base Power Goals	Power Goal Differences (MW)
Base Goal Power	40.00
Calculated Base Power	30.00
Diff. Base (Goal-Calc)	30.00
Rel Diff. Base (Calc-Goal)/Goal	-25%

Peak Power Goals	Power Goal Differences (MW)
Peak Goal Power	20.00
Calculated Peak Power	16.70
Diff. Peak (Goal-Calc)	3.30
Rel. Diff. Peak (Calc-Goal)/Goal	-17%

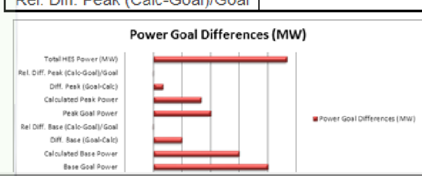
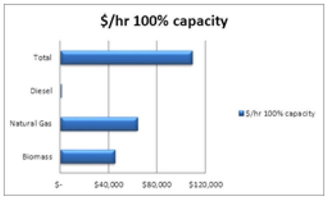


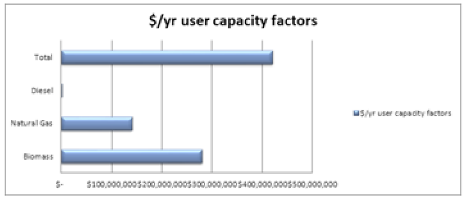
Figure 32. Power output tab

Run the Model

VARIABLES INPUT | SCENARIO INPUT | SUMMARY ASSUMPTION REPORT | COSTS OUTPUT | POWER OUTPUT | FUEL OUTPUT | EMISSIONS OUTPUT | RESILIENCE OUTPUT

Power Generation Type	$/hr 100% capacity	$/yr user capacity factors	Cost per Unit	
Biomass	$45,000	$ 279,225,000	100	$/ton
Natural Gas	$ 63,540	$ 139,152,600	4	$/1000 scf
Diesel	$ 497	$ 1,087,992	4	$/gal
Total	**$ 109,037**	**$ 419,465,592**		





System Fuel Requirements	System Fuel Requirements	Unit	Notes
BioPlant.Fuel_Mass_Flow (wet ton/day 20% moisture)	450.0000	wet ton/day 20% moisture	Assumes unit at 100% capacity
BioPlant.Fuel_Mass_Flow (100,000 wet ton/year)	27.9225	1000 wet ton/year	Accounts for user input capacity factor
Diesel.Volume_Flow (gal/hr)	124.2000	gal/hr	Assumes all units at 100% capacity
Diesel.Volume_Flow (1000 gal/year)	271.9980	1000 gal/year	Accounts for user input capacity factor
Natural_Gas.Volume_Flow (1000 scf/year)	15.8850	1000 scf/hr	Assumes all units at 100% capacity
Natural_Gas.Volume_Flow (1,000,000 scf/year)	34.7882	1,000,000 scf/year	Accounts for user input capacity factor

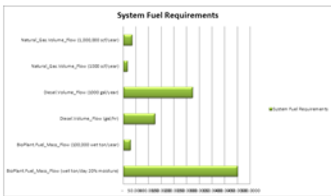
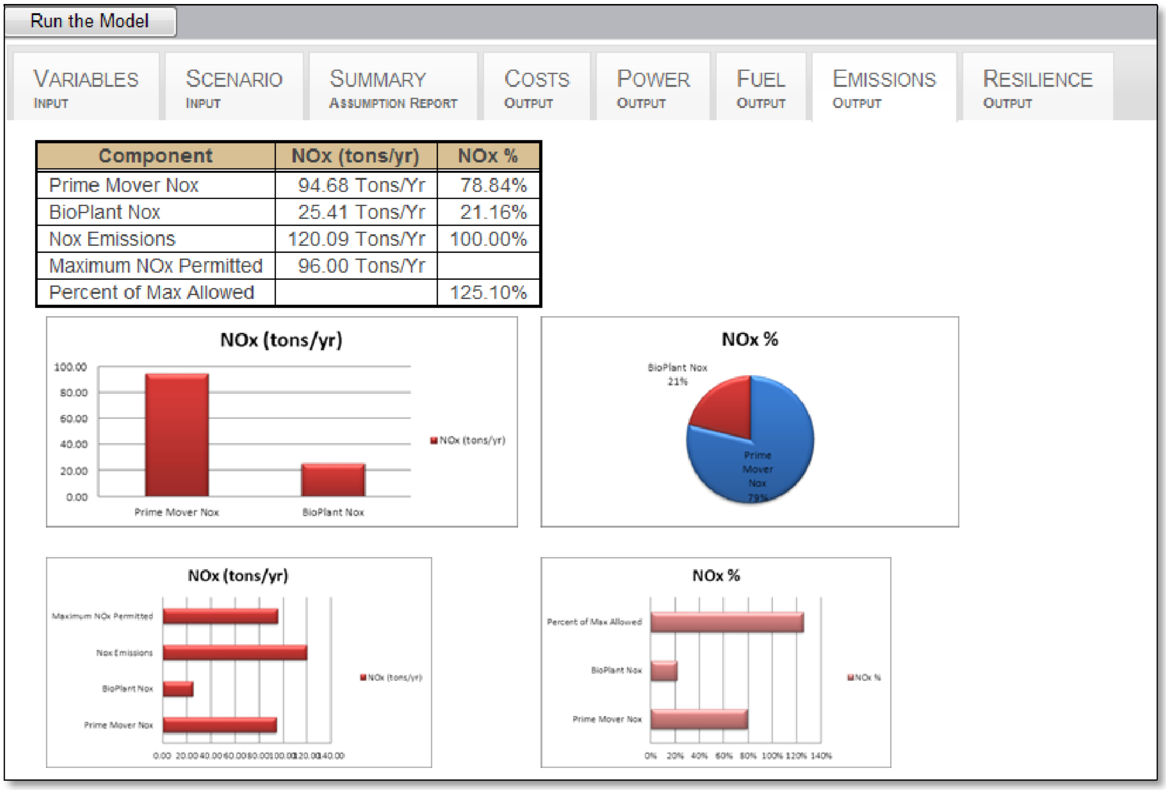
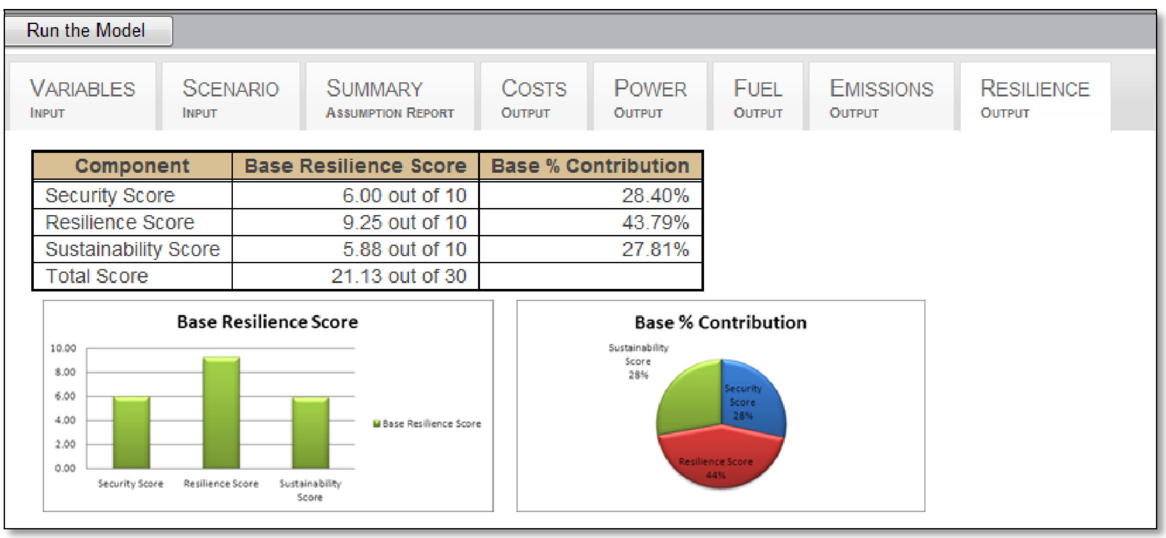


Figure 33. Fuel output tab



Component	NOx (tons/yr)	NOx %
Prime Mover Nox	94.68 Tons/Yr	78.84%
BioPlant Nox	25.41 Tons/Yr	21.16%
Nox Emissions	120.09 Tons/Yr	100.00%
Maximum NOx Permitted	96.00 Tons/Yr	
Percent of Max Allowed		125.10%

Figure 34. Emissions output tab



Component	Base Resilience Score	Base % Contribution
Security Score	6.00 out of 10	28.40%
Resilience Score	9.25 out of 10	43.79%
Sustainability Score	5.88 out of 10	27.81%
Total Score	21.13 out of 30	

Figure 35. Resilience output tab

Overall the planning model provides extensive summary information on a particular hybrid energy technology mix relative to base power and peak demand. Adjusting inputs and components and studying the results will help users obtain a general idea of the types and number of components that are good candidates for further analysis.

Optimization Platform

The OASIES Optimization Platform requires a set of user defined operational goals. Then, using an optimization algorithm, the system selects an appropriate technology mix based on a minimization and/or maximization of the stated goals. The result is a set of alternative, integrated energy system designs.

Optimization is be defined as "the process of making something as fully perfect, functional, or effective as possible." (Merriam-Webster[i]). As such, there are many approaches available to achieve optimization, in fact the overall OASIES process could be said to be a process the leads to optimization, one that uses both qualitative and quantitative methods.

OASIES conducts model execution and optimization using the Phoenix Integration ModelCenter[ii] tool. This is a commercially available product used for product design and trade study analysis primarily in the aerospace and defense industries. ModelCenter provides flexibility for conducting optimization since any of the over 30 gradient and evolutionary-based optimization methods can be used directly, or an independent optimization algorithm can be integrated and used. ModelCenter provides integration for codes developed in virtually any programming language such as Fortran, C++, etc., and commercial tools such as MatLab, Excel, and many others. Additionally, ModelCenter has licensed and integrated Sandia National Laboratories, Dakota nonlinear optimization suite.

Figure 36 shows the OASIES Optimization model. It is constructed from an optimizer component (rainbow icon), the OASIES Planning Model ("Planning" node)[iii], a Pareto front processor, and an Excel spreadsheet that accumulates results and forms tables and graphs that are delivered to the user web portal.

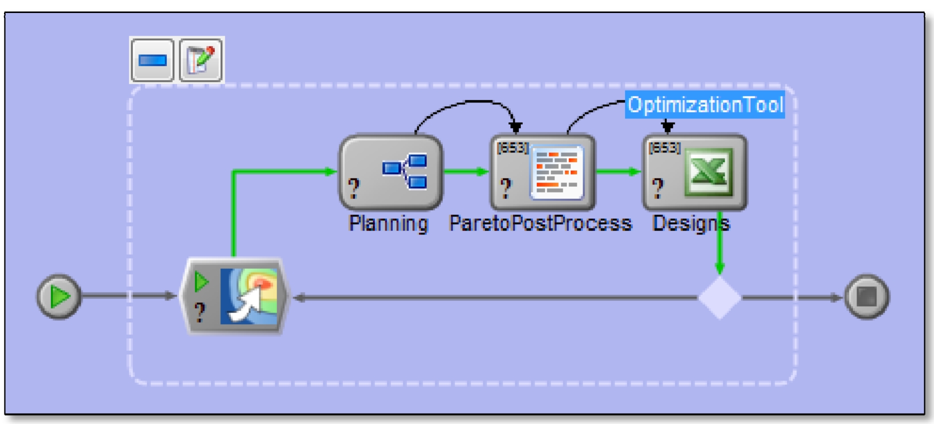


Figure 36. OASIES optimization model

The optimization objectives, constraints and design variables are chosen from the inputs and outputs within the Planning Model. Figure 37 shows the ModelCenter optimization definition window.

This particular optimization is defined to solve for the following:

1. Zero difference between the base power goal input by the user and the calculated total base power output result for the alternative hybrid energy design solution
2. Zero difference between the peak power goal and the calculated peak value for the alternative design
3. Minimize the total NOx emissions
4. Maximize the total resilience score
5. Minimize the total life cycle cost which is discounted over the planning horizon

This is a multi-objective optimization problem with 5 objectives to be met. There are no constraints specified. Constraints, if present, are specified with bounds and any alternative design that falls outside the bounds is discounted.

The Design Variables (Figure 37) are variables that the optimizer changes in an effort to find alternatives that better satisfy the objectives. The design variables chosen for this particular optimization are nuclear reactors, biomass plants, number of three different prime movers (diesel generators), and selection of one or more of three hydropower plants. A selection of a particular value for each of the variables listed, taken together, constitutes one alternative design.

The number of potential alternative designs and thus the search space (i.e, optimization run time) can increase exponentially. In the example shown in Figure 37 there are 127,776 design alternatives available to be selected. This number is derived by calculating the product of all choices i.e., 3 Nuclear X 3 BioPlants X 11 Diesel #1 X 11 Diesel #2 X 11 Diesel #3X 2 Hydro #1 X 2 Hydro #2 X 2 Hydro #3. This shows the value of following the OASIES process and limiting the number of components prior to optimization.

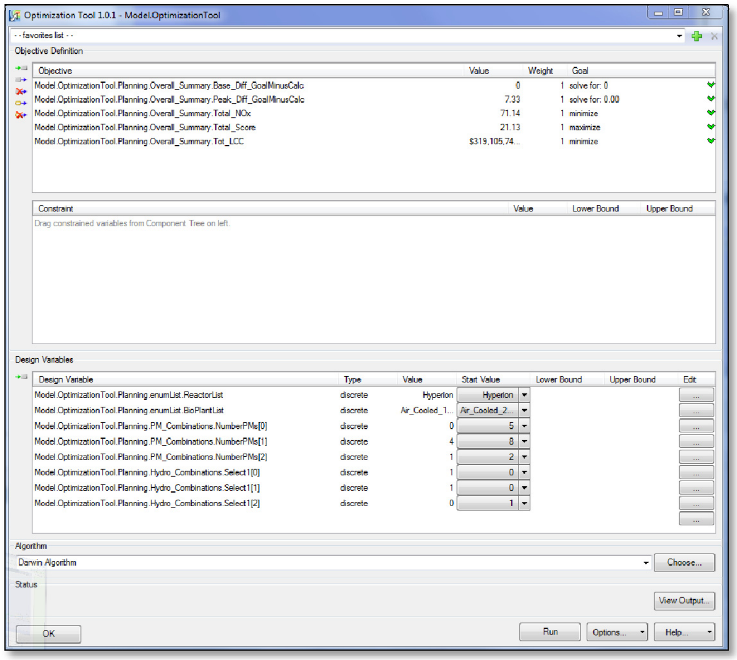


Figure 37. Optimization definition screen

The optimization algorithm chosen is the "Darwin Algorithm," so named because it mimic's the biological breeding genetics process[iv]. The algorithm performs these steps;

1. Generate a generational population of alternative design by random selection
2. Calculate the objectives or "fitness" for each member of the population
3. Create a next generation by cross breeding the "fittest" members using substitution and mutation
4. Evaluate the fitness of the children
5. Repeat until no or little improvement in fitness is found

As this process is running, ModelCenter is collecting Pareto efficient designs and is presenting them to the user. Figure 38 shows a Pareto front made up of 5 alternative system designs. The values of the objectives listed in Figure 37 are shown along an axis for each alternative design. This optimization generated thousands of alternatives and took ~ 4 hours to complete running on a Windows desktop workstation.

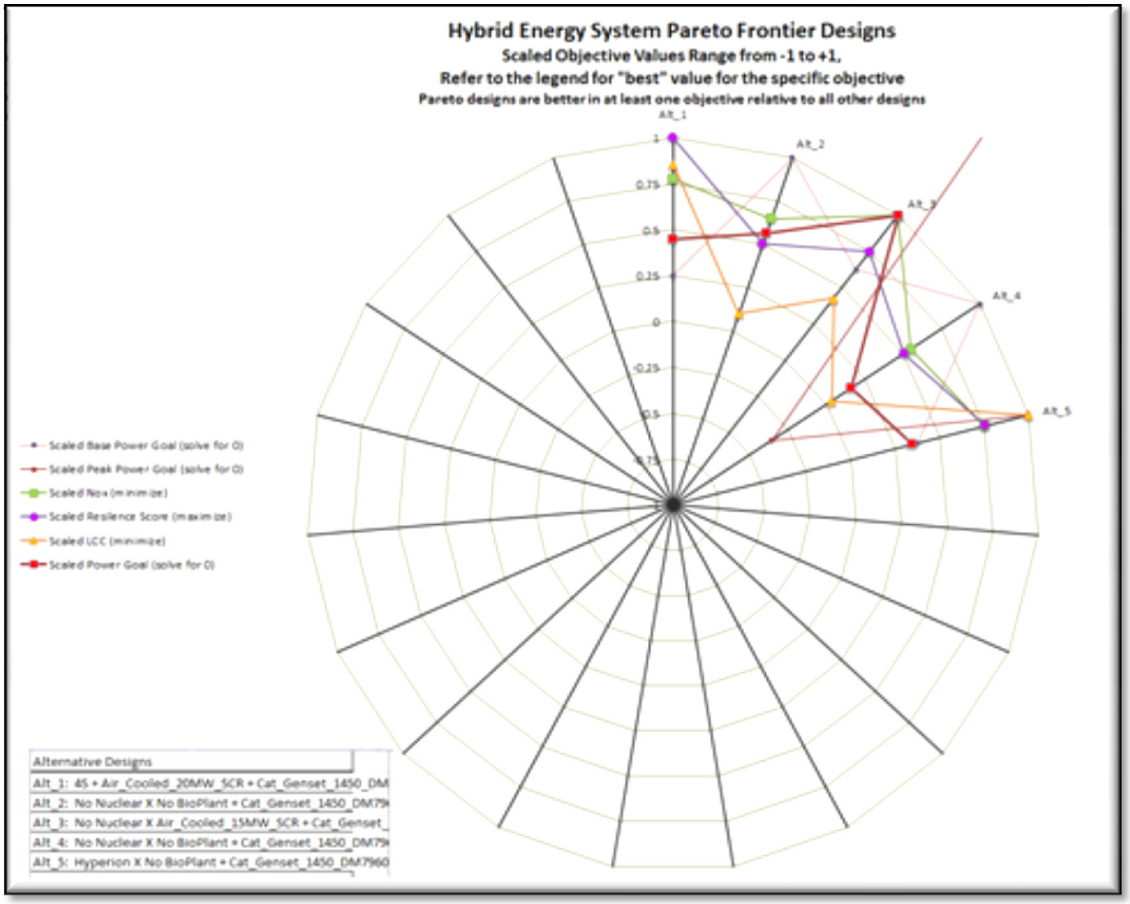


Figure 38. Example Pareto Frontier made up of 5 alternative HES designs.

Figure 39 shows a subset of the generated alternatives three dimensionally. Each point represents a separate alternative set of hybrid energy equipment components. Color indicates the alternative preference score and black crossbars mean that the alternative is best in some respect from all others (i.e., it is Pareto efficient)

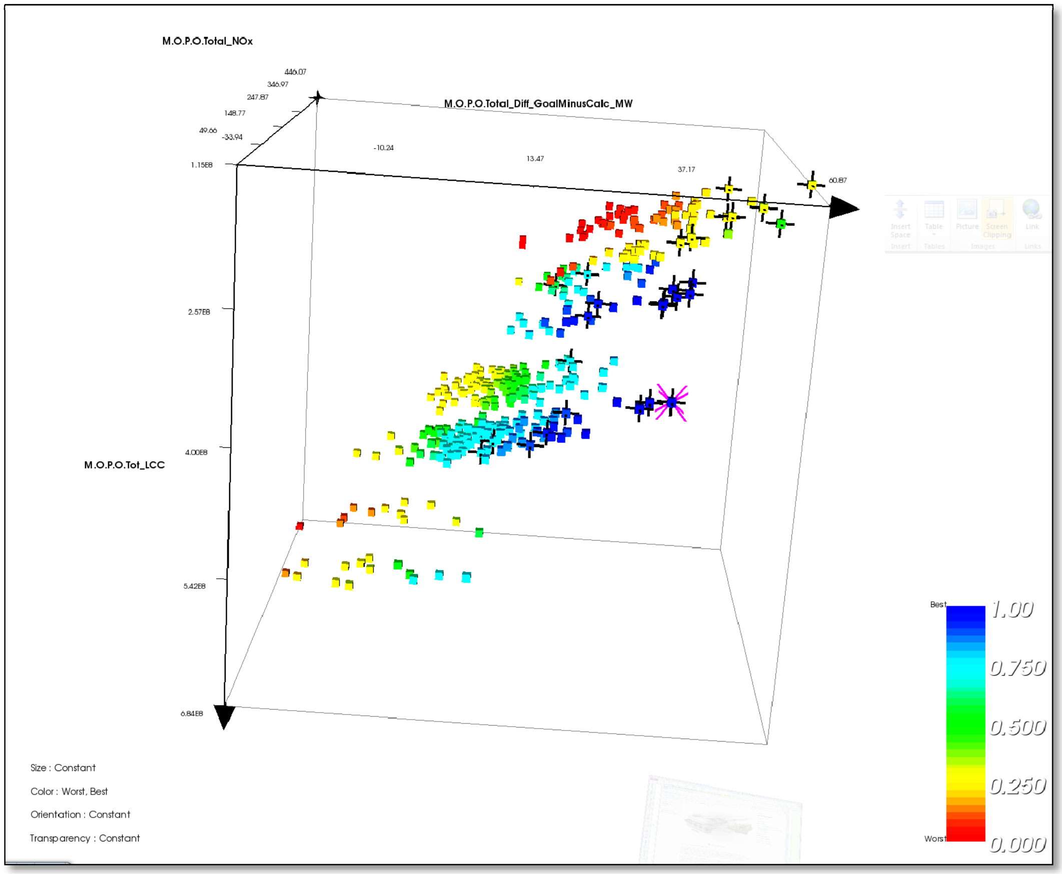


Figure 39. Alternative design solutions and the Pareto efficient designs indicated by black crossbars.

Summary

This document is a user manual for the Dairy Analytics and Nutrient Analysis (DANA) model. DANA provides an analysis of dairy anaerobic digestion technology and allows users to calculate biogas production, co-product valuation, capital costs, expenses, revenue and financial metrics, for user customizable scenarios, dairy and digester types. The model provides results for three anaerobic digester types; covered lagoons, modified plug flow, and complete mix, and three main energy production technologies; electricity generation, renewable natural gas generation, and compressed natural gas generation. Additional options include dairy types, bedding types, backend treatment type as well as numerous production, and economic parameters.

The document explained how to use and modify input data tables, run the DANA model and view and customize results. Only a small fraction of the resulting output was discussed. Requesting access to the system and viewing the reports online is the best way to view the information.

DANA's goal is to extend the National Market Value of Anaerobic Digester Products analysis (informa economics, 2012; Innovation Center, 2011) to include a greater and more flexible set of regional digester scenarios and to provide a modular framework for creation of a tool to support farmer and investor needs. Users can define scenarios from combinations of existing parameters or add new parameters, run the model and view a variety of reports, charts and tables that are automatically produced and delivered over the web interface.

DANA is based in the INL's analysis architecture entitled Generalized Environment for Modeling Systems (GEMS), which offers extensive collaboration, analysis, and integration opportunities and greatly speeds the ability construct highly scalable web delivered user-oriented decision tools. Thus, DANA has the capability to leverage pre-existing models that can be used to calculate all aspects of dairy operation. Existing government and commercial models can be used directly without reprogramming and lend credibility to national planning efforts or local development analysis. DANA has been designed to be extended and modified in multiple ways to suit multiple analysis goals.

References

Informa economics. 2012. National Market Value of Anaerobic Digester products. August 2012.

Innovation Center. 2011. DMI Model. DMI Digester Model (MS 8-24-11) (version 1).xls, Innovation Center for U.S. Dairy

Appendix 1: SAS Code

This appendix lists the main calculations for the DANA model. The full SAS code can be downloaded from the dairy analytics web site.

SAS Models

The SAS model is made up of three SAS Enterprise Guide files (.egp) as follows;

1. Market Model 2012.egp,
2. Market Model 2012 Balance Sheet.egp, and
3. Market Model2012 Cubes.egp

After changes are made to the input, these three files must be executed in order.

Market Model 2012.egp

This model gathers input from the database tables and performs basic calculation related to gas production, co-product valuation and capital cost amounts. All values calculated are stored in a table entitled Dairy.MS_Results.

Capital costs are calculated based on predetermined costs associated the three digester types and are then apportioned by the capital cost centers. Additionally, capital costs associated with electric generation, renewable natural gas generation and compressed natural gas production are apportioned to the cost centers.

Table columns from left to right are arranged as follows;

1. Run Categories
2. Input Parameters
3. Production Amounts
4. Valuation Amounts
5. Capital Cost Amounts

Market Model 2012 Balance Sheet.egp

This model takes data from Dairy.MS_Results and calculates revenue and expense over a planning horizon that can be set by the user (generally 15 to 20 years). The analysis is conducted for anaerobic digestion producing electricity, renewable natural gas, or compressed natural gas. Additionally, co-products that results from the anaerobic digestion process are calculated.

These co-products currently are;

1. nutrient enriched fiber,
2. nutrient N and P,
3. greenhouse gas credits,

4. renewable energy credits (RECs),
5. renewable identification numbers (RINs – transportation / CNG related), and
6. tipping fees.

Market Model 2012 Cubes.egp

This model prepares the data to be reported via the web using the SAS web-based tool entitled Web Report Studio. This tool allows any user to create customized reports containing tables, graphs and explanatory text. Data can be filtered, totaled and flagged based on user specified criteria.

Many other reporting options are available and can be quickly implemented as needed including the following;

1. Microsoft Office – Excel, PowerPoint, Word
2. SAS Reports – List reports, summary reports, distribution/uncertainly reports, frequency reports
3. SAS graphs – report graphs, activex graphs, GTL graphs
4. JMP graphs

SAS Setup Code

```
Data Dairy.iElectric_Calculations;
Set  Dairy.Input_Data;
Renewable_Fuel_Conv_Factor      =77000;
label = "77,000.0000    BTU / gal";
RINs_RFEG             =1;
label = "RIN / RFEG (Renewable Fuel Equivalent)";
day_yr       =365;
label = "day / yr";
ft3_m3       =35.31466;
label = "ft3 / m3";
mtonne_ton              =1.10231;
label = "metric tonne / ton";
kg_lb        =2.2046;
label = "kg / lb";
yd3_ft3      =0.037037;
label = "yd3 / ft3";
lbs_ton      =2000;
label = "lb / ton";
lbs_mtonne=2204.62262;
label = "2,204.6226      lb / metric tonne";
BTU_MMBTU             =1000000;
label = "BTUs per MMBTU";
BTU_electricity_conv   =3413;
label = "Energy to electricity conversion - btu/kwh";
Thermal_efficiency_factor            =0.35;
label = "Thermal efficiency  factor: CH4 --> kWh - % as a decimal";
Capacity_factor          =0.9;
label = "Capacity factor (uptime) -- % as a decimal";
Bio_Gas_Methane_Parm            =0.58;
label = "Methane Content of biogas- Manure Only -- ft3 methane/ft3 biogas";
Energy_Pot_Methane  =923;
label = "Energy potential of methane -- btu/ft3 methane";
BTU_FT3   =1025;
label = "BTU / ft3";
BTU_DGE  =128700;
label = "BTUs per Diesel Gallon Equivalent - BTU / DGE";
Max_methane_prod_cap_FW        =1;
label = "Maximum methane producing capacity of food waste - ft3 methane / lb VS";
Renewable_Energy_Credit          =0.001;
label = "Renewable Energy Credit  -- REC/kWh";
RECs_MWh             =1;
label = "RECs / MWh";
Equ_red_CO2_emision=21;
label = "Equivalent reductions in CO2 emisions per ton CH4 - tons C02 reductio/ton CH4";
Max_methane_prod_cap_manure  =3.84;
label = "3.8400           Maximum methane producing capacity of dairy manure - ft3 methane/lb VS";
Density_methane        =0.041;
label = "Density of methane at 25 degrees Celcius, lb/ft3";
BioGas_Parm             = 5.75; /*    BioGas_Ouput Biogas output/lb V.S.             ft3 biogas/lb */
label = "BioGas_Ouput Biogas output/lb V.S.   ft3 biogas/lb";
OS_Gas_Factor =        2.7; /*        Increase in Biogas Production per Percent of Food Waste included in influent */
```

```
label = "Increase in Biogas Production per Percent of Food Waste included in influent";
/* Informa Spreadsheet Calculations */
/*Number of Cows on Farms with Each Digester Type by State          */
/*Formula:  Number of cows per state * % of each digester type = Number of cows per digester type*/
/*Unit:        Cows*/
AD_Cows    = AD_Percent * Number_of_Animals;
Label AD_Cows = "Number of Cows on Farms with Each Digester Type by State";
/*Manure Production by cows with manure directed to each digester type (tons/year)            */
/*Formula:  Number of Cows * Manure excretion rate (lbs/cow/day) * Days per year * ton/lbs = Manure Production by cows with manure directed to
each digester type (tons/year)*/
/*Unit:        tons/year*/
Tot_Manure_Prod  = AD_Cows * Manure_Excretion_Rate * day_yr / lbs_ton;
Label Tot_Manure_Prod = "Manure Production by cows with manure directed to each digester type (tons/year)";
/* ------------------- START FOOD WASTE CALCULATIONS --------------*/
/* Food Waste 1000 tons / yr */
/* FW_parm_yrxx is food waste based US totals for population and food waste 1000 tons /yr */
/* Values from Informa Economics */
/* 1000 tons /yr */
/*FW_parm_2000 = 17478 / 281421.906 ; */
/* 1000 tons / person */
FW_parm      = 21372 / 308745.538 ;
Label FW_Parm = "FW_parm_yrxx is food waste based US totals for population and food waste 1000 tons /yr";
/*FW_parm_2020 = 23215 / 341387 ;*/
/* 1000 tons / person / day? yr? */
Food_Waste = FW_parm  * Census_2010;
Label  Food_Waste="Food Waste Produced by the Region - 1000 tons / person / yr";
If Tot_Manure_Prod > 0 then Pct_Waste_Manure = Food_Waste / Tot_Manure_Prod;
                  else Pct_Waste_Manure = 0;
                                                                            Label  ="";
/*Maximum Food Waste Allowed by Digester Type (%)      */
/*Formula:  User Input*/
/*Unit:        %*/
/*If DigesterType = "Lagoon"       then Max_Substrate_Capacity = 0.00;*/
/*If DigesterType = "Plug_Flow"    then Max_Substrate_Capacity = 0.25;*/
/*If DigesterType = "Complete_Mix" then Max_Substrate_Capacity = 0.50;*/
Label Max_Substrate_Capacity ="Maximum Food Waste Allowed by Digester Type (%)";
/*Annual Maximum Possible Organic Substrate Used (tons/year)                                  */
/*Maximum Possible Organic Substrate Used                              Note: This table assumes enough food waste is available to meet the maximum
food waste percentage allowed.*/
/*Formula:  Manure Production by cows with manure directed to each digester type (tons/year) / (1 - Maximum Food Waste Allowed by Digester Type
(%)) - Manure Production by cows with manure directed to each digester type (tons/year) = Annual Maximum Possible Organic Substrate Used
(tons/year)*/
/*Unit:        tons/year                   */
Pot_Org_Sub_Need = Tot_Manure_Prod * Max_Substrate_Capacity / ( 1  -Max_Substrate_Capacity);
Label  Pot_Org_Sub_Need="Annual Maximum Possible Organic Substrate Used (tons/year)";
/* ------------------- END FOOD WASTE CALCULTTIONS -------------------------- */
Format
Pct_Waste_Manure PERCENT6.2
AD_Cows        20.
Tot_Manure_Prod  20.2
FW_Parm        Percent6.2
Food_Waste      20.2
Pct_Waste_Manure Percent6.2
```

```
Pot_Org_Sub_Need 20.2
;
run;
Proc Sort;
By Scenario Regions Digester_Type;
run;
```

Digester Gas Production Code

```
Data Dairy.Production;
Set  Dairy.Input_Merge;
/* Notes */
/*25% more VS in Food Waste and 85% Destroyed */
/* Amount of Biogas ft3 / lb VS destroyed = 5.6 ft3 */
/* Don't know how much N volatilizes before it gets to the digester */
/*Annual Organic Substrate Utilized by Digester Type (tons/year)        */
/*Annual Organic Substrate Utilized                */
/*Formula:  If Maximum Food Waste Allowed by Digester Type (%) <= Food Waste Available, use Annual Maximum Possible Organic Substrate Used
(tons/year), otherwise, weight food waste available by Annual Maximum Possible Organic Substrate Used (tons/year)*/
/*Unit:        tons/year*/
if Food_Waste > 0 then FW_Avail_Pct = Region_Pot_Org_Sub_Need / Food_Waste;
If FW_Avail_Pct <= 1.0 then Organic_Substrate_Added = Pot_Org_Sub_Need;
                else
                 do;
  if Region_Pot_Org_Sub_Need > 0 then Organic_Substrate_Added = Food_Waste * Pot_Org_Sub_Need / Region_Pot_Org_Sub_Need; /* lb/cow/day
*/
                                        else Organic_Substrate_Added = 0;
                                                    end;
Label Organic_Substrate_Added = "Annual Organic Substrate Utilized by Digester Type (tons/year)";
/*Organic Substrate Utilized by Digester Type (lbs/cow/day)                                        */
/*Organic Substrate Utilized Note: Assigns available food waste to digester types based on the share of maximum food waste utilized*/
/*Formula:  Annual Organic Substrate Utilized by Digester Type (tons/year) / Number of cows * (year/days) * (lbs/ton) = Organic Substrate Utilized by
Digester Type (lbs/cow/day)                    */
/*Unit:        lbs/cow/day                     */
if AD_Cows > 0 then OS_cow_added = Organic_Substrate_Added / AD_Cows * lbs_ton / day_yr;
Label OS_cow_added = "Organic Substrate Utilized by Digester Type (lbs/cow/day)";
/*Food Waste as a Percent of Total Influent by State (%)                                                                    */
/*Formula:  Annual Organic Substrate Utilized by Digester Type (tons/year) / [Annual Organic Substrate Utilized by Digester Type (tons/year) + Manure
Production by cows with manure directed to each digester type (tons/year)] = Food Waste as a Percent of Total Influent by State (%)         */
/*Unit:        %                                                                                                          */
IF (Organic_Substrate_Added + Tot_Manure_Prod) > 0 then FW_Pct_Tot = Organic_Substrate_Added / (Organic_Substrate_Added +
Tot_Manure_Prod );
                                       else FW_Pct_Tot = 0;
Label FW_Pct_Tot ="ood Waste as a Percent of Total Influent by Region (%)";
/*Food Waste N (Nitrogen) Content               %= lbs N/lbs food waste                          */
/*Food Waste P (Phosphorus) Content             %= lbs P/lbs food waste              */
/*Food Waste K (Potassium) Content              %= lbs K/lbs food waste              */
/*VS Content of Food Waste                                     lbs VS/lb food waste*/
/*Methane Conversion Factor for Food Waste % as a decimal*/
/*VS_Content_Food_Waste       = Manure * 1.25;*/
/*Food_Waste_N_Content        = 0.02 ;*/
/*Food_Waste_P_Content        = 0.02 ;*/
/*Food_Waste_K_Content        = 0.02 ;*/
/*Methane_Conversion_Factor_FW = 0;*/
/* ----------------------------------- PRODUCTION ----------------------------------- */
/* BioGas_Ouput Biogas output/lb V.S.          ft3 biogas/lb              5.75                                        DMI defined */
/*BioGas_Parm = 5.75; */
/*Increase in Biogas Production per Percent of Food Waste included in influent */
/* ft3 biogas */
/*OS_Gas_Factor = 2.7;*/
```

```
/*Biogas Production Manure Only (ft3 biogas/cow/day)      */
/*Formula:  (V.S. lbs/cow/day) * (ft3 biogas/ Lb. VS) = (ft3 biogas/cow/day)*/
/*Unit:        ft3 biogas/cow/day*/
Bio_Gas_Day = VS_Dairy_Cow * BioGas_Parm;
/*Biogas Production Manure and Co-substrate (ft3 biogas/cow/day)                                                    */
/*Formula:  Biogas Production Manure Only (ft3 biogas/cow/day) + [Increase in biogas production per % increase in food waste * % food waste utilized by state * biogas production manure only (ft3 biogas/cow/day)] = Biogas Production with Codigestion for each digester type (ft3 biogas /cow /day)*/
/*Unit:        ft3 biogas/cow/day                                                                                              */
Bio_Gas_Cogen_Day = Bio_Gas_Day * ( 1 + FW_Pct_Tot * OS_Gas_Factor);

/*Annual Biogas Produced (ft3 biogas/year)     */
/*Formula:  Biogas Production Manure and Co-substrate (ft3 biogas/cow/day) * Number of cows * days/year = Annual Biogas Produced (ft3 biogas/year)*/
/*Unit:        ft3 biogas/year*/
Bio_Gas_Annual = Bio_Gas_Cogen_Day * AD_Cows * day_yr;

/*Methane Content of biogas- Manure Only      ft3 methane/ft3 biogas*/
/*Bio_Gas_Methane_Parm = 0.58;*/

/*Adjusted Methane Production (ft3 methane/cow/day)      */
/*Formula:  Biogas Production with Codigestion (ft3 biogas /cow/day) * Methane content of biogas (%) = Adjusted Total Methane Production (ft3 methane /cow /day) */
/*Unit:        ft3 biogas/cow/day*/
Bio_Gas_Methane = Bio_Gas_Cogen_Day * Bio_Gas_Methane_Parm;

/*Annual Adjusted Methane Produced (ft3 methane/year)  */
/*Formula:  Adjusted Methane Production (ft3 methane/cow/day) * Number of cows * days/year = Annual Adjusted Methane Produced (ft3 methane/year)*/
/*Unit:        ft3 methane/year*/
Methane_Prod_Adj_Annual = Bio_Gas_Methane * AD_Cows * day_yr;

/*Energy potential of methane        btu/ft3 methane*/
/*Energy_Pot_Methane = 923;*/

/*Annual Adjusted Methane Produced (ft3 methane/year)  */
/*Formula:  Adjusted Methane Production (ft3 methane/cow/day) * Number of cows * days/year = Annual Adjusted Methane Produced (ft3 methane/year)*/
/*Unit:        ft3 methane/year*/
Methane_BTU = Bio_Gas_Methane * Energy_Pot_Methane;

/*Annual BTUs of Energy (BTUs/year)            */
/*Formula:  BTUs of Energy Produced (BTUs/cow/day) * Number of cows * days/year = Annual BTUs of Energy (BTUs/year)*/
/*Unit:        BTUs/year*/
Energy_Annual_BTU = Methane_BTU * AD_Cows *day_yr;

/* BTUs per MMBTU */
/*BTU_MMBTU = 1000000; */

/*Annual MMBTUs of Energy (MMBTUs/year)  */
/*Formula:  Annual BTUs of Energy (BTUs/year) * MMBTU/BTUs = Annual MMBTUs of Energy (MMBTUs/year)*/
/*Unit:        MMBTUs/year*/
Energy_Annual_MMBTU = Energy_Annual_BTU / BTU_MMBTU;
```

```
/*Energy to electricity conversion   btu/kwh       3,413 */
/*BTU_electricity_conv = 3413; */

/*Electricity Produced with 100% Conversion (kWh/cow/day)            */
/*Formula:  Total BTUs of Energy Production (btu/ cow/ day) * Energy to electricity conversion (kwh/btu) = Potential Electricity production (kwh/ cow/ day)*/
/*Unit:        kWh/cow/day*/
Electricity_Prod_Full = Methane_BTU / BTU_electricity_conv ;

/*Thermal efficiency  factor: CH4 - kWh          % as a decimal          0.35*/
/*Thermal_efficiency_factor = 0.35;*/
/*Capacity factor (uptime)             % as a decimal          0.9*/
/*Capacity_factor  = 0.9;*/
/*Parasitic load - Digester system   % as a decimal          0.1*/
/*Parasitic_load_Elec  = 0.1;*/


/*Adjusted Electricity Production (kWh/cow/day)             */
/*Formula:  Maximum Potential Electricity production (kwh/ cow/ day) * Electricity Generation Efficiency Factor (%) * Electricity Capacity Uptime Factor (%) * [1 - (Parasitic Load Factor)] (%) = Adjusted Potential Electricity Production (kwh/ cow/ day)*/
/*Unit:        kWh/cow/day*/
Electricity_Prod_Adj = Electricity_Prod_Full * Thermal_Efficiency_Factor * Capacity_Factor * (1 - Electric_Gen_Parasitic_Load);

/*Annual Electricity Production (kWh/year)       */
/*Formula:  Adjusted Electricity Production (kWh/cow/day) * Number of cows * days/year = Annual Electricity Production (kWh/year)*/
/*Unit:        kWh/year*/
Electricity_Prod_kW_yr = Electricity_Prod_Adj * AD_Cows * day_yr ;

/*Parasitic load - To Run Digester  % as a decimal*/
/*Parasitic load - Gas Clean-up Facility          % as a decimal*/
/*BTU per cf               BTU/cf*/
/*Parasitic_load_NG_Digester  = 0.3;*/
/*Parasitic_load_NG_Cleanup   = 0.15;*/
/*BTU_FT3                  = 1025;*/

/*Adjusted Pipeline-Quality Biomethane (CH4) Production (MMBTUs/cow/day)
                                                                              */
/*Formula:  Total BTUs of energy production (BTUs/ cow/day) * [1 - parasitic load factor to operate digester (%)] * [1 - parastic load factor for biomethane cleanup facility (%)] * BTU to MMBTU Conversion Factor (1mmbtu / 1,000,000 btu) = Potential Pipeline Quality Biomethane Production (mmbtu/cow/day)
              */
/*Unit:        MMBTUs/cow/day
              */
Natural_Gas_Prod = Methane_BTU * (1 - NG_Parasitic_Load) * (1 - NG_Parasitic_Load) / BTU_MMBTU ;

/*Annual Biomethane Production (MMBTUs/year)            */
/*Formula:  Adjusted Pipeline-Quality Biomethane (CH4) Production (MMBTUs/cow/day) * Number of cows * days/year = Annual Biomethane Production (MMBTUs/year)*/
/*Unit:        MMBTUs/year*/
Natural_Gas_Prod_MMBTU = Natural_Gas_Prod * AD_Cows * day_yr;

/*BTUs per Diesel Gallon Equivalent              BTUs/DGE  128,700 */
/*BTU_DGE = 128700; */
```

```
/*CNG (DGEs/cow/day)                */
/*Formula:  Total BTUs of energy production (BTUs/ cow/day) * [1 - parasitic load factor to operate digester (%)] * [1 - parasitic load factor for biomethane cleanup facility (%)]  / diesel gallon equivalent conversion factor (128,700btu/gallon) = Potential CNG Production (diesel gallon equivalents/cow /day)*/
/*Unit:        DGEs/cow/day*/
CNG_Prod = Methane_BTU * (1 - NG_Parasitic_Load) * (1 - NG_Parasitic_Load) / BTU_DGE;

/*Annual CNG (DGEs/year)          */
/*Formula:  CNG (DGEs/cow/day) * Number of cows * days/year = Annual CNG (DGEs/year)*/
/*Unit:        DGEs/year*/
CNG_Prod_MMBTU = CNG_Prod * AD_Cows * day_yr;

/*Nitrogen volatilization % as a decimal          0*/
/*Phosphorus Volatilization          % as a decimal*/
/*Potassium Volatilization           % as a decimal*/
/*Nitrogen_volatilization                = 0;*/
/*Phosphorus_volatilization          = 0;*/
/*Potassium_volatilization           = 0;*/

/*Nitrogen (TKN) in liquid filtrate    % as a decimal          0.823*/
/*Phosphorus in liquid filtrate        % as a decimal          0.622*/
/*Nitrogen_in_Filtrate    = 0.823;*/
/*Phosphorus_in_Filtrate             = 0.622;*/
/*Potassium_in_Filtrate= 0.00;*/

/*N (Nitrogen) potential with codigestion (lbs N/cow/day)    */
/*Formula:  N excretion rate (Pounds N/ cow/ day) * (1 - % N volatilization) * (% of N that goes to the liquid filtrate) + Food Waste Weight (lbs food waste added/ cow/ day) * (N as % of food waste) = N potential (lbs N/cow/day)*/
/*Unit:        lbs N/cow/day*/
N_Prod_Codigest = (N_Excreted_Dairy_Cow * (1 - N_volatilization) * N_in_Filtrate); * + (OS_cow_added * Food_Waste_N_Content ) ;

/*Recovery Rate for N  % as a decimal                    0            0.4          0.4*/
/*Recovery Rate for P  % as a decimal                    0            0.8          0.8*/
/*Recovery Rate for K  % as a decimal                    0            0            0*/
/*If DigesterType = "Lagoon"       then do; N_Recovery_Rate = 0.00; P_Recovery_Rate = 0.00; K_Recovery_Rate = 0.00; end;*/
/*If DigesterType = "Plug_Flow"    then do; N_Recovery_Rate = 0.40; P_Recovery_Rate = 0.80; K_Recovery_Rate = 0.00; end;*/
/*If DigesterType = "Complete_Mix" then do; N_Recovery_Rate = 0.40; P_Recovery_Rate = 0.80; K_Recovery_Rate = 0.00; end;*/

/*N (Nitrogen) recovered (lbs N/cow/day)        */
/*Formula:  N potential with codigestion (lbs N/ cow/ day) * N recovery rate (%) = N recovered (lbs N/ cow/ day)*/
/*Unit:        lbs N/cow/day*/
N_Recovered = N_Prod_Codigest * N_Recovery_Rate;

/*Annual N (Nitrogen) recovered (lbs N/year)    */
/*Formula:  N (Nitrogen) recovered (lbs N/cow/day) * Number of cows * days/year = Annual N (Nitrogen) recovered (lbs N/year)*/
/*Unit:        lbs N/year*/
N_Recovered_yr = N_Recovered * day_yr;

/*Manure Phosphorus content (lbs)              lbs/cow/day              0.17*/
/*Manure Phosphorus content          % as a decimal          0.001*/
/*Manure_P_Content = 0.17;*/
/*Manure_P_Percent = 0.001;*/
```

```
/*P (Phosphorus) potential with codigestion (lbs P/cow/day)               */
/*Formula:  Manure weight (Pounds manure/ cow/ day) * (P as % of total manure) * (% of P that goes to the liquid filtrate) + Food Waste Weight (lbs
food waste added/ cow/ day) * (P as % of food waste) = P potential (lbs P/cow/day)*/
/*Unit:        lbs P/cow/day*/
P_Prod_Codigest = (Manure_P_Content * (1 - P_Volatization) * P_in_Filtrate); * + (OS_cow_added * Food_Waste_P_Content ) ;

/*P (Phosphorus) recovered (lbs P/cow/day)    */
/*Formula:  P potential with codigestion (lbs P/ cow/ day) * P recovery rate (%) = P recovered (lbs P/ cow/ day)*/
/*Unit:        lbs P/cow/day*/
P_Recovered = P_Prod_Codigest * P_Recovery_Rate;

/*Annual P (Phosphorus) recovered (lbs P/year)              */
/*Formula:  P (Phosphorus) recovered (lbs P/cow/day) * Number of cows * days/year = Annual P (Phosphorus) recovered (lbs P/year)*/
/*Unit:        lbs P/year*/
P_Recovered_yr = P_Recovered * day_yr;

/*Manure Potassium content (lbs)  lbs/cow/day               0.23*/
/*Manure Potassium content         % as a decimal           0.0015*/
/*Manure_K_Content = 0.23;*/
/*Manure_K_Percent = 0.0015;*/

/*K (Potassium) potential with codigestion (lbs K/cow/day) */
/*Formula:  Manure weight (Pounds manure/ cow/ day) * (K as % of total manure) * (% of K that goes to the liquid filtrate) + Food Waste Weight (lbs
food waste added/ cow/ day) * (K as % of food waste) = K potential (lbs K/cow/day)*/
/*Unit:        lbs K/cow/day*/
/*K_Prod_Codigest = (Manure_K_Content * (1 - Potassium_volatilization) * Potassium_in_Filtrate); * + (OS_cow_added * Food_Waste_P_Content ) ;*/

/*K (Potassium) recovered (lbs K/cow/day)      */
/*Formula:  K potential with codigestion (lbs K/ cow/ day) * K recovery rate (%) = K recovered (lbs K/ cow/ day)*/
/*Unit:        lbs K/cow/day*/
/*K_Recovered = K_Prod_Codigest * K_Recovery_Rate;*/

/*Annual P (Phosphorus) recovered (lbs P/year)              */
/*Formula:  P (Phosphorus) recovered (lbs P/cow/day) * Number of cows * days/year = Annual P (Phosphorus) recovered (lbs P/year)*/
/*Unit:        lbs P/year*/
/*K_Recovered_yr = K_Recovered * day_yr;*/

/* Nutrient Enriched Fiber */

/*Nutrient Enriched Fiber Recovered              yd3/cow/day                              0              9              7*/
/*If DigesterType = "Lagoon"       then do; Fiber_Recovery_Rate = 0.00; end;*/
/*If DigesterType = "Plug_Flow"    then do; Fiber_Recovery_Rate = 9.00; end;*/
/*If DigesterType = "Complete_Mix" then do; Fiber_Recovery_Rate = 7.00; end;*/

/*Nutrient Enriched Fiber Production (yd3 fiber /cow/day)   */
/*Formula:  yd3 fiber /cow/year / Days/year = yd3 fiber/cow/day*/
/*Unit:        yd3 fiber/cow/day*/
Fiber_Production = Fiber_Recovery_Rate / day_yr;

/*Annual Nutrient Enriched Fiber (yd3/year)      */
/*Formula:  Nutrient Enriched Fiber Production (yd3 fiber /cow/day) * Number of cows * days/year = Annual Nutrient Enriched Fiber (yd3/year)*/
/*Unit:        yd3/year*/
Fiber_Production_yr = Fiber_Recovery_Rate * AD_Cows; * day_yr;
```

```
/* Greenhouse Gas Offset Credits */

/*GHG Carbon Offset Credits                    */
/*Equivalent reductions in CO2 emisions per ton CH4     tons C02 reductio/ton CH4        21*/
/*Maximum methane producing capacity of dairy manure  ft3 methane/lb VS       3.84*/
/*Density of methane at 25 degrees Celcius,    lb/ft3        0.041*/
/*Maximum methane producing capacity of food waste     ft3 methane/lb VS       ??*/
/*Equ_red_CO2_emision             = 21;*/
/*Max_methane_prod_cap_manure             = 3.84;*/
/*Density_methane =    0.041;*/
/*Max_methane_prod_cap_FW      = 1;          */

/*GHG Offset Credits (lbs carbon offset credits/cow/day)    */
/*Formula:  lbs of Carbon Equivalent Offsets =  21  * (Proportion Manure x ( VS x TAM/1000 x MCF x B0 x 0.041 lbs.ft3) +(1-Proportion Manure) x ( (
VS x TAM/1000 x MCF x B1 x 0.041 lbs.ft3)*/
/*Unit:       Potential lbs carbon offset credits/cow/day*/
GHG_Offset_Credits = Equ_red_CO2_emision*( ( (1-FW_Pct_Tot)  * VS_Dairy_Cow       * Max_methane_prod_cap_manure *
Methane_Conversion_Factor * Density_methane)
                                + (FW_Pct_Tot     * VS_Content_Food_Waste * Max_methane_prod_cap_FW     * Methane_Food_Waste_Factor *
Density_methane)  );

/*Annual GHG Offset Credits (lbs carbon equivalents/year)              */
/*Formula:  GHG Offset Credits (lbs carbon offset credits/cow/day) * Number of cows * days/year = Annual GHG Offset Credits (lbs carbon
equivalents/year)*/
/*Unit:       lbs carbon equivalents/year*/
GHG_Offset_Credits_yr = GHG_Offset_Credits * AD_Cows * day_yr;

/*GHG Offset Credits (MT carbon equivalents/year)         */
/*Formula:  */
/*Unit:       MT carbon equivalents/year*/
GHG_Offset_Credits_yr = GHG_Offset_Credits_yr / lbs_mtonne;


/*Renewable Energy Credit          REC/kWh   0.001*/
/*RECs per MWh        REC/MWh  1.000*/
/*Renewable_Energy_Credit         = 0.001;*/
/*RECs_MWh             = 1.000;*/


/*Renewable Energy Credits (RECs/cow/day)  */
/*Formula:  Adjusted Potential Electricity production (kwh/ cow/ day) * (REC per kWh) = Renewable Energy Certificate Generation (RECs/ cow/ day)*/
/*Unit:       RECs/cow/day*/
Renewable_Energy_Credits =  Electricity_Prod_Adj * Renewable_Energy_Credit;

/*Annual RECs (RECs/year)         */
/*Formula:  Renewable Energy Credits (RECs/cow/day) * Number of cows * days/year = Annual RECs (RECs/year)*/
/*Unit:       RECs/year*/
Annual_RECs = Renewable_Energy_Credits * AD_Cows * day_yr;


/*Renewable Fuel Conversion Factor           BTUs/Gallon              77,000 */
/*RINs per Renewable Fuel Equivalent Gallon RIN/RFEG  1 */
```

```
/*Renewable_Fuel_Conv_Factor    = 77000;*/
/*RINs_RFEG                  = 1.000;*/

/*Renewable Identification Number Production (RINs/cow/day)          */
/*Formula:  CNG production (diesel gallon equivalents/cow/day) * diesel gallon equivalent conversion factor (128,700btu/gallon) / renewable fuel equivalent gallon conversion factor (77,000 btu/gallon) * RIN conversion factor (1 RIN / renewable fuel equivalent gallon) = RINs/cow/day*/
/*Unit:       RINs/cow/day*/
Renewable_ID_Num_Prod = CNG_Prod * BTU_DGE / Renewable_Fuel_Conv_Factor * RINs_RFEG;

/*Annual RINs (RINs/year)            */
/*Formula:  Renewable Identification Number Production (RINs/cow/day) * Number of cows * days/year = Annual RINs (RINs/year)*/
/*Unit:       RINs/year*/
Annual_RINs = Renewable_ID_Num_Prod * AD_Cows * day_yr;

                    Label Scenario = "Name of the overall scenario";
    Label Regions = "Name of the Region which can be any geographic boundary";
    Label Economic_Scenario = "Set of economic parameters used for the calculation";
    Label Capital_Cost_Centers = "Set of Cost Center Names and Percent";
    Label Dairy_Farm_Scenario = "Name of a Set of Dairy Components";
    Label Dairy_Type = "Type of Dairy";
    Label Bedding_Type = "Type of Bedding";
    Label Backend_Treatment = "Name of Treatment of Digester Output";
    Label Digester_Type = "Name of the type of anaerobic digester";
    Label Region_Input_Set = "Regional Input Data Set Name";
    Label Region_Cow_Scenario = "Cow Parameters by Region";
    Label Cows = "A set of Cow Parameters";
    Label Organic_Substrate = "A Type of Organic Substrate";
    Label AD_Percent = "Percent of the digester type of all anaerobic digesters within the region";
    Label Census_2000 = "Regional Population from 2000 Census - # people";
    Label Census_2010 = "Regional Population from 2010 Census - # people";
    Label Top_10_Dairy_State = "Indicator that Region is one of the top ten dairy states";
    Label Number_of_Animals = "Number of Diary Cows in Region";
    Label Number_Farm_with_Digesters = "Number of Farms with Digesters in Region";
    Label VS_Dairy_Cow = "Volitile Solids of Dairy Cow Manure (V.S. lbs/cow/day)";
    Label VS_Dairy_Heifer = "Volitile Solids of Dairy Heifer Manure (V.S. lbs/cow/day)";
    Label N_Excreted_Dairy_Cow = "";
    Label N_Excreted_Dairy_Heifer = "";
    Label Total_VS = "";
    Label N_Excreted_per_Cow = "";
    Label Methane_Conversion_Factor = "";
    Label Methane_Production = "";
    Label Tipping_Fees = "";
    Label Pipeline_Biomethane_Price = "";
    Label CNG_Price = "";
    Label Diesel_Price = "";
    Label Electricity_Price = "Electricity Price $/kWhr EIA, Average Retail Electricity Price paid by Industrial Customers" ;
    Label Recovered_Nitrogen_N_Price = "";
    Label Recovered_Phosphorus_Price = "";
    Label Recovered_Potassium_K_Price = "";
    Label NEFP_Covered_Lagoon = "Nutrient Enriched Fiberc Price for Covered Lagoon $/yd3 of fiber";
    Label NEFP_Plug_Flow = "Nutrient Enriched Fiberc Price for Plug_Flow $/yd3 of fiber";
    Label NEFP_Complete_Mix = "Nutrient Enriched Fiberc Price for Complete_Mix $/yd3 of fiber";
    Label GHG_Offset_Credit_Price = "";
```

```
Label REC_Price = "";
Label RIN_Price = "";
Label DPM_Nutrient_Removal = "";
Label DPM_Nutrient_Recovery = "";
Label DPM_Sand = "";
Label DPM_DryLot = "";
Label Collectable_Manure = "";
Label Gas_Production_Modifier = "";
Label Electric_Gen_Parasitic_Load = "";
Label Capacity_Factor = "";
Label Thermal_Efficiency_Factor = "";
Label Max_Substrate_Capacity = "Max_Substrate_Capacity";
Label N_Recovery_Rate = "";
Label P_Recovery_Rate = "";
Label K_Recovery_Rate = "";
Label Capital_Cost_Per_Cow = "";
Label NG_Parasitic_Load = "";
Label NG_Cleanup_Parasitic_Load = "";
Label Fiber_Recovery_Rate = "";
Label N_Volatilization = "";
Label P_Volatization = "";
Label N_in_Filtrate = "";
Label P_in_Filtrate = "";
Label K_in_Filtrate = "";
Label Pct_Preconstruction_Permitting = "";
Label Pct_System = "";
Label Pct_Site_Infrastructure = "";
Label Pct_Integration = "";
Label Pct_Utilities = "";
Label Pct_Administration = "";
Label Pct_Financing = "";
Label Pct_Contingency = "";
Label Electric_Gen_Capital_Cost_Parame = "";
Label RNG_Cap_Cost_Parameter = "";
Label CNG_Cap_Cost_Parameter = "";
Label Operation_Cost_Parameter = "";
Label Equity = "Equity percent (%)";
Label Debt = "Debt percent (%)";
Label Grants = "Funds contributed from grants ($)";
Label Third_Party_Funds = "Funds contributed from third party investors ($)";
Label OPEX_Inflation = "Operational Expenditure (OPEX) inflation (%/yr)";
Label Electricity_Inflation = "Inflation of electricty price (%/yr)";
Label Natural_Gas_Inflation = "Inflation of natural gas price (%/yr)";
Label Diesel_Inflation = "Inflation of diesel price (%/yr)" ;
Label CNG_Inflation = "Inflation of CNG price %/yr";
Label Tax_Rate = "Tax rate percent (%)";
Label Carbon_Credit_Inflation = "Inflation of carbon credit price per year (%/yr)";
Label NG_Spot_Price = "Compressed Natual Gas spot price ($/GGE)";
Label CNG_Spot_Price = "Spot price of natual gas ($/MCF)";
Label Loan_APR = "";
Label Diesel_Price = "General nonregional diesel price $/GGE)";
Label Inflation_Env_Credits = "Inflation of environmental credit price (%/yr)";
Label Inflation_Diesel = "Inflation of diesel price (%/yr)";
```

```
Label Inflation_Other = "Inflation of all other prices (%/yr)";
Label Planning_Horizon = "";
Label Cow_Cost_Yr = "Average cost to support a single cow per year ($/yr)";
Label Cow_Electric_Potential = "Electricity production potential in Mega Watt Hours (MWh) /cow/yr";
Label Cow_Natural_Gas_Potential =
 "Renewable Natural Gas production in Million Cubic Feet (MCF) per cow per year without parasitic reduction";
Label NG_Parasitic_Reduction = "Parasitic reduction for clean natural gas (%)";
Label CNG_Potential =
 "Potential production of Compressed Natual Gas (CNG) Methane Gasoline Gallon Equivalent (GGE) / Million Cubic Feet (MCF)";
Label CNG_Parasitic_Load = "CNG parasitic load expressed as a %";
Label Animal_Unit =
 "Weight of a standard animal (lb/animal). An animal unit (AU) is a standardized measure of animals used for various agricultural purposes. A 1,000-pound beef cow is the standard measure of an animal unit.";
Label AU_VS_Excretion_Rate = "Animal Unit Volital Solid Excretion Rate (lb/AU/day)";
Label Animal_Mass = "Average dairy cow mass (lb/cow)";
Label VS_Excretion_Rate = "Average Dairy Cow Volital Solid Excretion Rate ((lb/cow/day)";
Label Manure_Excretion_Rate = "Average Dairy Cow Manure Extraction Rate (lb/cow/day)";
Label Manure_P_Content = "";
Label Manure_P_Percent = "";
Label Manure_K_Content = "";
Label Manure_K_Percent = "";
Label Substrate_Gas_Factor = "";
Label Biogas_Parameter = "";
Label VS_Content_Food_Waste = "";
Label N_Content_of_Food_Waste = "";
Label P_Content_of_Food_Waste = "";
Label K_Content_of_Food_Waste = "";
Label Methane_Food_Waste_Factor = "";
Label Renewable_Fuel_Conv_Factor = "BTU / gal";
Label RINs_RFEG = "RIN / RFEG (Renewable Fuel Fuel Equivalent)";
Label day_yr = "day / yr";
Label ft3_m3 = "ft3 / m3";
Label mtonne_ton = "metric tonne / ton";
Label kg_lb = "kg / lb";
Label yd3_ft3 = "yd3 / ft3";
Label lbs_ton = "lb / ton";
Label lbs_mtonne = "lb / metric tonne";
Label BTU_MMBTU = "BTUs per MMBTU";
Label BTU_electricity_conv = "Energy to electricity conversion - btu/kwh";
Label Bio_Gas_Methane_Parm = "Methane Content of biogas- Manure Only -- ft3 methane/ft3 biogas";
Label Energy_Pot_Methane = "Energy potential of methane -- btu/ft3 methane";
Label BTU_FT3 = "BTU / ft3";
Label BTU_DGE = "BTUs per Diesel Gallon Equivalent - BTU / DGE";
Label Max_methane_prod_cap_FW = "Maximum methane producing capacity of food waste - ft3 methane / lb VS";
Label Renewable_Energy_Credit = "Renewable Energy Credit  -- REC/kWh";
Label RECs_MWh = "RECs / MWh";
Label Equ_red_CO2_emision = "Equivalent reductions in CO2 emisions per ton CH4 - tons C02 reductio/ton CH4";
Label Max_methane_prod_cap_manure = "Maximum methane producing capacity of dairy manure - ft3 methane/lb VS";
Label Density_methane = "Density of methane at 25 degrees Celcius, lb/ft3";
Label BioGas_Parm = "BioGas_Ouput Biogas output/lb V.S.      ft3 biogas/lb";
Label OS_Gas_Factor = "Increase in Biogas Production per Percent of Food Waste included in influent";
Label AD_Cows = "Number of Cows in the Region";
Label Tot_Manure_Prod = "";
```

```
        Label FW_parm = "";
        Label Food_Waste = "Food Waste Available in Region - tons/yr";
        Label Pct_Waste_Manure = "";
        Label Pot_Org_Sub_Need = "";
        Label Region_Pot_Org_Sub_Need = "";
Format
FW_Avail_Pct          PERCENT6.2
OS_Cow_Added          COMMA20.2
Max_Substrate_Capacity  PERCENT6.2
Region_Pot_Org_Sub_Need COMMA20.2
Organic_Substrate_Added COMMA20.2
FW_Pct_Tot            PERCENT6.2
Bio_Gas_Day           COMMA20.2
Bio_Gas_Cogen_Day      COMMA20.2
Bio_Gas_Annual         COMMA20.2
Bio_Gas_Methane        COMMA20.2
Methane_Prod_Adj_Annual COMMA20.2
Methane_BTU           COMMA20.2
Energy_Annual_BTU      COMMA20.2
Energy_Annual_MMBTU     COMMA20.2
Electricity_Prod_Full   COMMA20.2
Electricity_Prod_Adj    COMMA20.2
Electricity_Prod_kW_yr  COMMA20.2
Natural_Gas_Prod        COMMA20.3
Natural_Gas_Prod_MMBTU   COMMA20.3
CNG_Prod              COMMA20.3
CNG_Prod_MMBTU         COMMA20.2
N_Prod_Codigest        COMMA20.2
N_Recovery_Rate        COMMA20.2
N_Recovered           COMMA20.2
GHG_Offset_Credits      COMMA20.2
GHG_Offset_Credits_yr   COMMA20.2
GHG_Offset_Credits_yr   COMMA20.2
Renewable_Energy_Credits COMMA20.4
Annual_RECS           COMMA20.2
Renewable_ID_Num_Prod   COMMA20.2
Annual_RINs           COMMA20.
;
run;
Proc Sort;
By Scenario Regions Digester_Type;
run;
```

Co-Product Valuation Code

```
DATA  Dairy.Valuation;
  SET Dairy.Production;

  /*Organic Substrate Value ($/cow/day)  */
  /*Formula:  Organic Substrate Utilized by Digester Type (lbs/cow/day) * (1/tons per pound) * Tipping Fees( $/Ton organic waste received) = Organic Substrate Value ($/cow/day)*/
  /*Unit:  $/cow/day*/
  Organic_Substrate_Value = OS_cow_added * (1/lbs_ton) * Tipping_Fees;
  Format Organic_Substrate_Value DOLLAR20.2;

  /*Organic Substrate Value ($/year)  */
  /*Formula:  Organic Substrate Value ($/cow/day) * Number of cows * days/year = Organic Substrate Value ($/year)*/
  /*Unit:  $/year*/
  /*Organic_Substrate_Value_Annual = =C818*Calculate!C$40*NatlAssum!$C$9;*/
  Organic_Substrate_Value_Annual = Organic_Substrate_Value * AD_Cows * day_yr;
  Format Organic_Substrate_Value_Annual DOLLAR20.;

  /*Adjusted Electricity Value ($/cow/day)  */
  /*Formula:  Adjusted Electricity Production (kWh/cow/day) * $/kWh = Adjusted Electricity Value ($/cow/day)*/
  /*Unit:  $/cow/day*/
  /*Adj_Electricity_Value=C351*PriceAssum!$D11*/
  Adj_Electricity_Value = Electricity_Prod_Adj * Electricity_Price;
  Format Adj_Electricity_Value DOLLAR20.2;

  /*Annual Electricity Value ($/year)  */
  /*Formula:  Adjusted Electricity Value ($/cow/day) * Number of cows * days/year = Annual Electricity Value ($/year)*/
  /*Unit:  $/year*/
  Adj_Electricity_Value_Annual = Adj_Electricity_Value * AD_Cows * day_yr;
  Format Adj_Electricity_Value_Annual DOLLAR20.;

  /*Adjusted Pipeline-Quality Biomethane (CH4) Value ($/cow/day)  */
  /*Formula:  Adjusted Pipeline-Quality Biomethane (CH4) Production (MMBTUs/cow/day) * $/MMBTU = Adjusted Pipeline-Quality Biomethane (CH4) Value ($/cow/day)*/
  /*Unit:  $/cow/day*/
  /*Adjusted_NG_Value=C389*PriceAssum!$E11*/
  Adjusted_NG_Value = Natural_Gas_Prod * Pipeline_Biomethane_Price;
  Format Adjusted_NG_Value DOLLAR20.;

  /*Annual Pipeline-Quality Biomethane Value ($/year)  */
  /*Formula:  Adjusted Pipeline-Quality Biomethane (CH4) Value ($/cow/day) * Number of cows * days/year = Annual Pipeline-Quality Biomethane Value ($/year)*/
  /*Unit:  $/year*/
  /*Annual_NG_Value */
  Adj_NG_Value_Annual_Annual = Adjusted_NG_Value * AD_Cows * day_yr;
  Format Adj_NG_Value_Annual_Annual DOLLAR20.;

  /*CNG ($/cow/day)  */
  /*Formula:  CNG (DGEs/cow/day) * $/DGE = CNG ($/cow/day)*/
  /*Unit:  $/cow/day*/
  /*CNG_Value=C428*PriceAssum!$F11*/
  CNG_Value = CNG_Prod * CNG_Price;
```

```
Format CNG_Value DOLLAR20.;

/*Annual CNG Value ($/year)  */
/*Formula:  CNG ($/cow/day) * Number of cows * days/year = Annual CNG Value ($/year)*/
/*Unit:  $/year*/
/*CNG_Value_Annual=C935*C$40*NatlAssum!$C$9*/
CNG_Value_Annual = CNG_Value * AD_Cows * day_yr;
Format CNG_Value_Annual DOLLAR20.;

/*N (Nitrogen) Recovered Value ($/cow/day)  */
/*Formula:  N (Nitrogen) recovered (lbs N/cow/day) * tons/lb * $/ton N = N (Nitrogen) Recovered Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*N_Recovered_Value=C484*(1/NatlAssum!$C$10)*PriceAssum!$G11*/
N_Recovered_Value = N_Recovered * (1 / lbs_ton) * Recovered_Nitrogen_N_Price;
Format N_Recovered_Value DOLLAR20.2;

/*Annual N (Nitrogen) Recovered Value ($/year)  */
/*Formula:  N (Nitrogen) Recovered Value ($/cow/day) * Number of cows * days/year = Annual N (Nitrogen) Recovered Value ($/year)*/
/*Unit:  $/year*/
/*N_Recovered_Value_Annual=C974*C$40*NatlAssum!$C$9*/
N_Recovered_Value_Annual = N_Recovered_Value * AD_Cows * day_yr;
Format N_Recovered_Value_Annual DOLLAR20.;

/*P (Phosphorus) Recovered Value ($/cow/day)  */
/*Formula:  P (Phosphorus) recovered (lbs P/cow/day) * tons/lb * $/ton P = P (Phosphorus) Recovered Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*P_Recovered_Value=C537*(1/NatlAssum!$C$10)*PriceAssum!$H11*/
P_Recovered_Value = P_Recovered * (1 / lbs_ton) * Recovered_Phosphorus_Price;
Format P_Recovered_Value DOLLAR20.2;

/*Annual P (Phosphorus) Recovered Value ($/year)  */
/*Formula:  P (Phosphorus) Recovered Value ($/cow/day) * Number of cows * days/year = Annual P (Phosphorus) Recovered Value ($/year)*/
/*Unit:  $/year*/
/*P_Recovered_Value_Annual=C1010*C$40*NatlAssum!$C$9*/
P_Recovered_Value_Annual = P_Recovered_Value * AD_Cows * day_yr;
Format P_Recovered_Value_Annual DOLLAR20.;

/*K (Potassium) Recovered Value ($/cow/day)  */
/*Formula:  K (Potassium) recovered (lbs K/cow/day) * tons/lb * $/ton P = K (Potassium) Recovered Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*K_Recoved_Value=C592*(1/NatlAssum!$C$10)*PriceAssum!$G11*/
/*K_Recoved_Value = K_Recovered * (1 / lbs_ton) * Recovered_Potassium_K_Price;*/
/*Format K_Recoved_Value DOLLAR20.2;*/

/*Annual K (Potassium) Recovered Value ($/year)  */
/*Formula:  K (Potassium) Recovered Value ($/cow/day) * Number of cows * days/year = Annual K (Potassium) Recovered Value ($/year)*/
/*Unit:  $/year*/
/*Annual_K_Recovered_Value=C1047*C$40*NatlAssum!$C$9*/
/*Annual_K_Recovered_Value = K_Recoved_Value * AD_Cows * day_yr;*/
/*Format Annual_K_Recovered_Value DOLLAR20.;*/

/* Note: Need to input these differently */
If Digester_Type = "Lagoon"        then Fiber_Price = NEFP_Covered_Lagoon;
```

```
If Digester_Type = "Plug_Flow"      then Fiber_Price = NEFP_Plug_Flow;
If Digester_Type = "Complete_Mix"   then Fiber_Price = NEFP_Complete_Mix;
Drop NEFP_Covered_Lagoon NEFP_Plug_Flow NEFP_Complete_Mix;
Format Fiber_Price DOLLAR20.2;

/*Nutrient Enriched Fiber Value ($/cow/day)  */
/*Formula:  Nutrient Enriched Fiber Production (yd3 fiber /cow/day) * $/yd3 of fiber = Nutrient Enriched Fiber Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*Nutr_Enrich_Fiber_Value  =C631*PriceAssum!$J11*/
Nutr_Enrich_Fiber_Value  = Fiber_Production * Fiber_Price;
Format Nutr_Enrich_Fiber_Value DOLLAR20.2;

/*Annual Nutrient Enriched Fiber Value ($/year)  */
/*Formula:  Nutrient Enriched Fiber Value ($/cow/day) * Number of cows * days/year = Annual Nutrient Enriched Fiber Value ($/year)*/
/*Unit:  $/year*/
Nutr_Enrich_Fiber_Value_Annual = Nutr_Enrich_Fiber_Value * AD_Cows * day_yr;
Format Nutr_Enrich_Fiber_Value_Annual DOLLAR20.;

/*GHG Offset Credits Value ($/cow/day)  */
/*Formula:  GHG Offset Credits (lbs carbon offset credits/cow/day) * $/ lb carbon credit offset = GHG Offset Credits Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*GHG_Offset_Credit_Value=C670/NatlAssum!$C$11*PriceAssum!$M11*/
GHG_Offset_Credit_Value = GHG_Offset_Credits / lbs_mtonne * GHG_Offset_Credit_Price;
Format GHG_Offset_Credit_Value DOLLAR20.2;

/*Annual GHG Offset Credits Value ($/year)  */
/*Formula:  GHG Offset Credits Value ($/cow/day) * Number of cows * days/year = Annual GHG Offset Credits Value ($/year)*/
/*Unit:  $/year*/
/*Annual_GHG_Offset_Credit_Value=C1125*C$40*NatlAssum!$C$9*/
Annual_GHG_Offset_Credit_Value = GHG_Offset_Credit_Value * AD_Cows * day_yr;
Format Annual_GHG_Offset_Credit_Value DOLLAR20.;

/*Renewable Energy Credits Value ($/cow/day)  */
/*Formula:  Renewable Energy Credits (RECs/cow/day) * $/MWh = Renewable Energy Credits Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*REC_Value=C726*PriceAssum!$N11*/
REC_Value = Renewable_Energy_Credits * REC_Price;
Format REC_Value DOLLAR20.2;

/*Annual RECs Value ($/year)  */
/*Formula:  Renewable Energy Credits Value ($/cow/day) * Number of cows * days/year = Annual RECs Value ($/year)*/
/*Unit:  $/year*/
/*REC_Value_Annual=C1164*C$40*NatlAssum!$C$9*/
REC_Value_Annual = REC_Value * AD_Cows * day_yr;
Format REC_Value_Annual DOLLAR20.;

/*Renewable Identification Number Value ($/cow/day)  */
/*Formula:  Renewable Identification Number Production (RINs/cow/day) * $/RIN = Renewable Identification Number Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*RIN_Value=C765*PriceAssum!$O11*/
RIN_Value = Renewable_ID_Num_Prod * RIN_Price;
Format RIN_Value DOLLAR20.2;
```

```
/*Annual RINs Value (RINs/year)  */
/*Formula:  Renewable Identification Number Value ($/cow/day) * Number of cows * days/year = Annual RINs Value (RINs/year)*/
/*Unit:  $/year*/
/*RIN_Value_Annual */
/*RIN_Value_Annual=C1203*C$40*NatlAssum!$C$9*/
RIN_Value_Annual = RIN_Value * AD_Cows * day_yr;
Format RIN_Value_Annual DOLLAR20.;

/*Value of Electricity and RECs ($/cow/day)  */
/*Formula:  Adjusted Electricity Value ($/cow/day) + Renewable Energy Credits Value ($/cow/day) = Value of Electricity and RECs ($/cow/day)*/
/*Unit:  $/cow/day*/
/*Value_Elec_And_RECs=C857+C1164*/
Value_Elec_And_RECs = Adj_Electricity_Value + REC_Value;
Format Value_Elec_And_RECs DOLLAR20.2;

/*Value of Electricity and RECs ($/year)  */
/*Formula:  Value of Electricity and RECs ($/cow/day) * Number of cows * days/year = Value of Electricity and RECs ($/year)*/
/*Unit:  $/year*/
/*Value_Elec_And_RECs_Annual=C1250*C$40*NatlAssum!$C$9*/
Value_Elec_And_RECs_Annual =Value_Elec_And_RECs * AD_Cows * day_yr;
Format Value_Elec_And_RECs_Annual DOLLAR20.;

/*Value of Pipeline Natural Gas ($/cow/day)  */
/*Formula:  Adjusted Pipeline-Quality Biomethane (CH4) Value ($/cow/day)*/
/*Unit:  $/cow/day*/
/*Value_NG_Adjusted=C896*/
Value_NG_Adjusted = Adjusted_NG_Value;
Format Value_NG_Adjusted DOLLAR20.2;

/*Value of Pipeline Natural Gas ($/year)  */
/*Formula:  Value of Pipeline Natural Gas ($/cow/day) * Number of cows * days/year = Value of Pipeline Natural Gas ($/year)*/
/*Unit:  $/year*/
/*Value_NG_Adj_Annual=C1287*C$40*NatlAssum!$C$9*/
Value_NG_Adj_Annual = Value_NG_Adjusted * AD_Cows * day_yr;
Format Value_NG_Adj_Annual DOLLAR20.;

/*Value of CNG and RINs ($/cow/day)  */
/*Formula:  CNG ($/cow/day) + Renewable Identification Number Value ($/cow/day) = Value of CNG and RINs ($/cow/day)*/
/*Unit:  $/cow/day*/
/*Value_CNG_And_RIN=C935+C1203*/
Value_CNG_And_RIN = CNG_VAlue + RIN_Value;
Format Value_CNG_And_RIN DOLLAR20.2;

/*Value of CNG and RINs ($/year)  */
/*Formula:  Value of CNG and RINs ($/cow/day) * Number of cows * days/year = Value of CNG and RINs ($/year)*/
/*Unit:  $/year*/
/*Value_CNG_And_RIN_Annual=C1324*C$40*NatlAssum!$C$9*/
Value_CNG_And_RIN_Annual = Value_CNG_And_RIN * AD_Cows * day_yr;
Format Value_CNG_And_RIN_Annual DOLLAR20.;

/*Max Value of Electricity + RECs, Pipeline Biomethane, and CNG + RINs ($/cow/day)  */
/*Formula:  Maximum of (Electricity + RECs Value, Pipeline Biomethane Value, and CNG + RINs Value) */
/*Unit:  $/cow/day*/
```

```
 /*Max_Value_Sum=MAX(C1250,C1287,C1324)*/
 Max_Value_Sum  = MAX(Value_Elec_And_RECs,Value_NG_Adjusted,Value_CNG_And_RIN);
 Format Max_Value_Sum DOLLAR20.2;

 /*Max Value of Electricity + RECs, Pipeline Biomethane, and CNG + RINs ($/year)  */
 /*Formula:  Max Value of Electricity + RECs, Pipeline Biomethane, and CNG + RINs ($/cow/day) * Number of cows * days/year = Max Value of
Electricity + RECs, Pipeline Biomethane, and CNG + RINs ($/year)*/
 /*Unit:  $/year*/
 /*Max_Value_Sum_Annual=MAX(C1267,C1304,C1341)*/
 Max_Value_Sum_Annual = MAX(Value_Elec_And_RECs_Annual,Value_NG_Adj_Annual,Value_CNG_And_RIN_Annual);
 Format Max_Value_Sum_Annual DOLLAR20.;

 /*Max Value of Primary Products with Co-Products ($/cow/day)  */
 /*Formula:  */
 /*Unit:  $/cow/day*/
 /*Max_Value_Prod_And_CoProd=IF(C1361=C1250,$A$1244,IF(C1361=C1287,$A$1281,IF(C1361=C1324,$A$1318,"error")))*/
      If Max_Value_Sum = Value_Elec_And_RECs        then Max_Value_Prod_And_CoProd = "Electricity + RECs Value";
 Else  If Max_Value_Sum = Value_NG_Adjusted         then Max_Value_Prod_And_CoProd = "Pipeline Biomethane Value";
 Else  If Max_Value_Sum = Value_CNG_And_RIN         then Max_Value_Prod_And_CoProd = "CNG + RINs Value";
 Else                                               Max_Value_Prod_And_CoProd = "Error";
 Format Max_Value_Prod_And_CoProd $255.;

 /*Annual Max Value of Primary Products ($/year)  */
 /*Formula:  */
 /*Unit:  $/year*/

/*Max_Value_Prod_And_CoProd_Annual=IF(C1378=0,0,IF(C1378=C1267,$A$1244,IF(C1378=C1304,$A$1281,IF(C1378=C1341,$A$1318,"error"))))*/
       If Max_Value_Sum_Annual=Value_Elec_And_RECs_Annual then Max_Value_Prod_And_CoProd_Annual="Electricity + RECs Value";
 Else    If Max_Value_Sum_Annual=Value_NG_Adj_Annual        then Max_Value_Prod_And_CoProd_Annual="Pipeline Biomethane Value";
 Else    If Max_Value_Sum_Annual=Value_CNG_And_RIN_Annual   then Max_Value_Prod_And_CoProd_Annual="CNG + RINs Value";
 Else                                                         Max_Value_Prod_And_CoProd_Annual="Error";
 Format Max_Value_Prod_And_CoProd_Annual $155.;

 /*Max Value of Primary Products and Co-Products ($/cow/day)                          */
 /*Formula:  (Max Value of Electricity + RECs, Pipeline Biomethane, and CNG + RINs ($/cow/day)), Organic Substrate Value ($/cow/day) + N
(Nitrogen) Recovered Value ($/cow/day) + P (Phosphorus) Recovered Value ($/cow/day) + K (Potassium) Recovered Value ($/cow/day) + Nutrient
Enriched Fiber Value ($/cow/day) + GHG Offset Credits Value ($/cow/day) = Max Value of Primary Products and Co-Products ($/cow/day)
*/
 /*Unit:  $/cow/day                      */
 /*Tot_Value_Prod_And_CoProd=C1361+C818+C974+C1010+C1047+C1086+C1125*/
 Tot_Value_Prod_And_CoProd =
SUM(Max_Value_Sum,Organic_Substrate_Value,N_Recovered_Value,P_Recovered_Value,Nutr_Enrich_Fiber_Value,GHG_Offset_Credit_Value); /* +
K_Recovered_Value */
 Format Tot_Value_Prod_And_CoProd DOLLAR20.2;

 /*Annual Max Value of Primary Products and Co-Products ($/year)  */
 /*Formula:  Max Value of Primary Products and Co-Products ($/cow/day) * Number of cows * days/year = Annual Max Value of Primary Products and
Co-Products ($/year)*/
 /*Unit:  $/year*/
 /*Tot_Value_Prod_And_CoProd_Annual=C1433*C$40:C$50*NatlAssum!$C$9*/
 Tot_Value_Prod_And_CoProd_Annual =  Tot_Value_Prod_And_CoProd * AD_Cows * day_yr;
 Format Tot_Value_Prod_And_CoProd_Annual DOLLAR20.;
```

```
RUN;

PROC SORT;
  BY Scenario Regions Digester_Type;
RUN;
```

Digester Capital Cost Code

```
Data Dairy.MS_Results;
Set  Dairy.Valuation;

/* These are Capital Cost parmeters in the DMI model */
/* Units $/cow for each digester type                    */
/*If DigesterType = "Complete_Mix"      Then Cap_Cost_Per_Cow = 895;*/
/*If DigesterType = "Lagoon"            Then Cap_Cost_Per_Cow = 600;*/
/*If DigesterType = "Plug_Flow"         Then Cap_Cost_Per_Cow = 825;*/
/*Format Cap_Cost_Per_Cow DOLLAR20.;*/
/**/
/* Digester Capital Cost Modifiers - DPM = Digester Price Modifier */
/* See DMIModel.xls FWC Projections C16:f19                     */
/* Units % */
/*BeddingType     = "Sand";*/
/*If BeddingType  = "Manure Solids"      Then DPM_Sand = 0.00;  /* type = 1 */*/
/*If BeddingType  = "Sand"               Then DPM_Sand = 0.25;  /* type = 2 */ */
/*If BeddingType  = "Other Organics"     Then DPM_Sand = 0.00;  /* type = 3 */*/
/**/
/*Backend_Trt     = "Nutrient Recovery";*/
/*If Backend_Trt  = "Screened Only"      Then Do; */
/*  DPM_Nutrient_Removal = 0.00; */
/*  DPM_Nutrient_Recover = 0.00; */
/*  End;  /* type = 1 */*/
/*If Backend_Trt  = "Nutrient Removal"  Then Do; */
/*  DPM_Nutrient_Removal = 0.15; */
/*  DPM_Nutrient_Recover = 0.00; */
/*   End;  /* type = 2 */*/
/*If Backend_Trt  = "Nutrient Recovery" Then Do; */
/*   DPM_Nutrient_Removal = 0.00; */
/*   DPM_Nutrient_Recover = 0.25; */
/*   End;  /* type = 3 */*/
/**/
/*DairyType       = "Dry Lot";*/
/*If DairyType    = "Freestall"         Then DPM_DryLot  =  0.00;  /* type = 1 */*/
/*If DairyType    = "Dry Lot"           Then DPM_DryLot  = -0.33;  /* type = 2 */

DPM_TOT                          = 1 + SUM(DPM_Sand,DPM_Nutrient_Removal,DPM_Nutrient_Recovery,DPM_DryLot);

Format DPM_Sand            Percent6.2;
Format DPM_Nutrient_Removal Percent6.2;
Format DPM_Nutrient_Recovery Percent6.2;
Format DPM_DryLot          Percent6.2;
Format DPM_Tot             Percent6.2;

/* Capital Cost for the particular digester */
/* Units $ */
Capital_Cost = AD_COWS * Capital_Cost_Per_Cow;
Format Capital_Cost DOLLAR20.;

/* Capital Costs assign to construction component */
/* PCP = Pre-construction permitting */
```

```
CapCost_PCP = Capital_Cost * Pct_PreConstruction_Permitting;
/* SYS = Pre-construction permitting */
CapCost_SYS = Capital_Cost * Pct_System;
/* SIT = Pre-construction permitting */
CapCost_SIT = Capital_Cost * Pct_Site_Infrastructure;
/* INT = Pre-construction permitting */
CapCost_INT = Capital_Cost * Pct_Integration;
/* UTL = Pre-construction permitting */
CapCost_UTL = Capital_Cost * Pct_Utilities;
/* ADM = Pre-construction permitting */
CapCost_ADM = Capital_Cost * Pct_Administration;
/* FIN = Pre-construction permitting */
CapCost_FIN = Capital_Cost * Pct_Financing;
/* CON = Pre-construction permitting */
CapCost_CON = Capital_Cost * Pct_Contingency;
/* Total costs */
CapCost_TOT = SUM(CapCost_PCP,CapCost_SYS,CapCost_SIT,CapCost_INT,CapCost_UTL,CapCost_ADM,CapCost_FIN,CapCost_CON);

Format
CapCost_PCP DOLLAR20.
CapCost_SYS DOLLAR20.
CapCost_SIT DOLLAR20.
CapCost_INT DOLLAR20.
CapCost_UTL DOLLAR20.
CapCost_ADM DOLLAR20.
CapCost_FIN DOLLAR20.
CapCost_CON DOLLAR20.
CapCost_TOT DOLLAR20.
;
/* Capital Cost adjusted for the particular digester */
/* Units $ */
Capital_Cost_Adj = Capital_Cost * DPM_TOT;
Format Capital_Cost_Adj DOLLAR20.;

/* Capital Costs assign to construction component using adjusted costs */
/* PCP = Pre-construction permitting */
CapCost_PCP_Adj = Capital_Cost_Adj * Pct_PreConstruction_Permitting;
/* SYS = Pre-construction permitting */
CapCost_SYS_Adj = Capital_Cost_Adj * Pct_System;
/* SIT = Pre-construction permitting */
CapCost_SIT_Adj = Capital_Cost_Adj * Pct_Site_Infrastructure;
/* INT = Pre-construction permitting */
CapCost_INT_Adj = Capital_Cost_Adj * Pct_Integration;
/* UTL = Pre-construction permitting */
CapCost_UTL_Adj = Capital_Cost_Adj * Pct_Utilities;
/* ADM = Pre-construction permitting */
CapCost_ADM_Adj = Capital_Cost_Adj * Pct_Administration;
/* FIN = Pre-construction permitting */
CapCost_FIN_Adj = Capital_Cost_Adj * Pct_Financing;
/* CON = Pre-construction permitting */
CapCost_CON_Adj = Capital_Cost_Adj * Pct_Contingency;
/* Total costs */
```

```
CapCost_TOT_Adj =
SUM(CapCost_PCP_Adj,CapCost_SYS_Adj,CapCost_SIT_Adj,CapCost_INT_Adj,CapCost_UTL_Adj,CapCost_ADM_Adj,CapCost_FIN_Adj,CapCost_
CON_Adj);
Format
CapCost_PCP_Adj DOLLAR20.
CapCost_SYS_Adj DOLLAR20.
CapCost_SIT_Adj DOLLAR20.
CapCost_INT_Adj DOLLAR20.
CapCost_UTL_Adj DOLLAR20.
CapCost_ADM_Adj DOLLAR20.
CapCost_FIN_Adj DOLLAR20.
CapCost_CON_Adj DOLLAR20.
CapCost_TOT_Adj DOLLAR20.
;

/* ------------------------ START Electrical Capital Costs ---------------------- */

/* Electrical Generation Capital Cost Parameter, Cost per kWhr producted   */
/* Units $/kWh */
Elec_Gen_CapCost_Parm = 0.21;
Format Elec_Gen_CapCost_Parm DOLLAR20.2;
/* Capital Cost to generate Electricity */
/* Units $  */
Elec_Gen_Cap_Cost = Electricity_Prod_kW_yr * Elec_Gen_CapCost_Parm;
Format Elec_Gen_Cap_Cost DOLLAR20.2;

/* SalePct is on the Digester Decision Tool page, I think it means how much you want to sell as opposed to reues */
/*Electrical_SalePct    = 1.0;*/


/* Capital Costs apportioned to various construction components */
/* PCP = Pre-construction permitting */
Elec_Gen_Cap_Cost_PCP = Elec_Gen_Cap_Cost * Pct_PreConstruction_Permitting;
/* SYS = Pre-construction permitting */
Elec_Gen_Cap_Cost_SYS = Elec_Gen_Cap_Cost * Pct_System;
/* SIT = Pre-construction permitting */
Elec_Gen_Cap_Cost_SIT = Elec_Gen_Cap_Cost * Pct_Site_Infrastructure;
/* INT = Pre-construction permitting */
Elec_Gen_Cap_Cost_INT = Elec_Gen_Cap_Cost * Pct_Integration;
/* UTL = Pre-construction permitting */
Elec_Gen_Cap_Cost_UTL = Elec_Gen_Cap_Cost * Pct_Utilities;
/* ADM = Pre-construction permitting */
Elec_Gen_Cap_Cost_ADM = Elec_Gen_Cap_Cost * Pct_Administration;
/* FIN = Pre-construction permitting */
Elec_Gen_Cap_Cost_FIN = Elec_Gen_Cap_Cost * Pct_Financing;
/* CON = Pre-construction permitting */
Elec_Gen_Cap_Cost_CON = Elec_Gen_Cap_Cost * Pct_Contingency;
/* Total costs */
Elec_Gen_Cap_Cost_TOT =
SUM(Elec_Gen_Cap_Cost_PCP,Elec_Gen_Cap_Cost_SYS,Elec_Gen_Cap_Cost_SIT,Elec_Gen_Cap_Cost_INT,Elec_Gen_Cap_Cost_UTL,Elec_Gen_
Cap_Cost_ADM,Elec_Gen_Cap_Cost_FIN,Elec_Gen_Cap_Cost_CON);

Elec_Total_Capital_Cost = Elec_Gen_Cap_Cost_TOT + Capital_Cost_Adj - Grants ;
```

```
Elec_Gen_EQUITY        = Elec_Total_Capital_Cost * EQUITY;
Elec_Gen_DEBT          = Elec_Total_Capital_Cost * DEBT;
Elec_Gen_APR           = FINANCE('PMT',Loan_APR,Planning_Horizon,Elec_Gen_DEBT);

Format
Elec_Gen_Cap_Cost_PCP DOLLAR20.
Elec_Gen_Cap_Cost_SYS DOLLAR20.
Elec_Gen_Cap_Cost_SIT DOLLAR20.
Elec_Gen_Cap_Cost_INT DOLLAR20.
Elec_Gen_Cap_Cost_UTL DOLLAR20.
Elec_Gen_Cap_Cost_ADM DOLLAR20.
Elec_Gen_Cap_Cost_FIN DOLLAR20.
Elec_Gen_Cap_Cost_CON DOLLAR20.
Elec_Gen_Cap_Cost_TOT DOLLAR20.
Elec_Total_Capital_Cost DOLLAR20.
Elec_Gen_APR         DOLLAR20.
Elec_Gen_EQUITY      DOLLAR20.
Elec_Gen_DEBT        DOLLAR20.
;
/* ------------------------- END   Electrical Capital Costs ---------------------- */

/* ------------------------- START Natural Gas Capital Costs ---------------------- */
/* Renewable Natual Gas Generation Capital Cost Parameter, Cost per ??? producted   */
/* Units $/??? */
RNG_Gen_CapCost_Parm = 33.65;
Format RNG_Gen_CapCost_Parm DOLLAR20.2;

/* Capital Cost to generate renewable natural gas */
/* Units $  */

RNG_Gen_Cap_Cost = Natural_Gas_Prod_MMBTU * RNG_Gen_CapCost_Parm;
Format RNG_Gen_Cap_Cost DOLLAR20.2;

/* SalePct is on the Digester Decision Tool page, I think it means how much you want to sell as opposed to reues */
/*Electrical_SalePct    = 1.0;*/


/* Capital Costs apportioned to various construction components */
/* PCP = Pre-construction permitting */
RNG_Gen_Cap_Cost_PCP = RNG_Gen_Cap_Cost * Pct_PreConstruction_Permitting;
/* SYS = Pre-construction permitting */
RNG_Gen_Cap_Cost_SYS = RNG_Gen_Cap_Cost * Pct_System;
/* SIT = Pre-construction permitting */
RNG_Gen_Cap_Cost_SIT = RNG_Gen_Cap_Cost * Pct_Site_Infrastructure;
/* INT = Pre-construction permitting */
RNG_Gen_Cap_Cost_INT = RNG_Gen_Cap_Cost * Pct_Integration;
/* UTL = Pre-construction permitting */
RNG_Gen_Cap_Cost_UTL = RNG_Gen_Cap_Cost * Pct_Utilities;
/* ADM = Pre-construction permitting */
RNG_Gen_Cap_Cost_ADM = RNG_Gen_Cap_Cost * Pct_Administration;
/* FIN = Pre-construction permitting */
RNG_Gen_Cap_Cost_FIN = RNG_Gen_Cap_Cost * Pct_Financing;
/* CON = Pre-construction permitting */
```

```
RNG_Gen_Cap_Cost_CON = RNG_Gen_Cap_Cost * Pct_Contingency;
/* Total costs */
RNG_Gen_Cap_Cost_TOT =
SUM(RNG_Gen_Cap_Cost_PCP,RNG_Gen_Cap_Cost_SYS,RNG_Gen_Cap_Cost_SIT,RNG_Gen_Cap_Cost_INT,RNG_Gen_Cap_Cost_UTL,RNG_G
en_Cap_Cost_ADM,RNG_Gen_Cap_Cost_FIN,RNG_Gen_Cap_Cost_CON);

RNG_Total_Capital_Cost = RNG_Gen_Cap_Cost_TOT + Capital_Cost_Adj - Grants ;
RNG_Gen_EQUITY       = RNG_Total_Capital_Cost * EQUITY;
RNG_Gen_DEBT         = RNG_Total_Capital_Cost * DEBT;
RNG_Gen_APR          = FINANCE('PMT',Loan_APR,Planning_Horizon,RNG_Gen_DEBT);

Format
RNG_Gen_Cap_Cost_PCP DOLLAR20.
RNG_Gen_Cap_Cost_SYS DOLLAR20.
RNG_Gen_Cap_Cost_SIT DOLLAR20.
RNG_Gen_Cap_Cost_INT DOLLAR20.
RNG_Gen_Cap_Cost_UTL DOLLAR20.
RNG_Gen_Cap_Cost_ADM DOLLAR20.
RNG_Gen_Cap_Cost_FIN DOLLAR20.
RNG_Gen_Cap_Cost_CON DOLLAR20.
RNG_Gen_Cap_Cost_TOT DOLLAR20.
RNG_Total_Capital_Cost DOLLAR20.
RNG_Gen_APR        DOLLAR20.
RNG_Gen_EQUITY      DOLLAR20.
RNG_Gen_DEBT        DOLLAR20.
;
/* ------------------------ END   Natural Gas Capital Costs ---------------------- */

/* ------------------------ START CNG Capital Costs ---------------------- */
/* CNG Generation Capital Cost Parameter, Cost per ??? productd   */
/* Units $/??? */
CNG_Gen_CapCost_Parm = 60.79;
Format CNG_Gen_CapCost_Parm DOLLAR20.2;

/* Capital Cost to generate Electricity */
/* Units $  */
CNG_Gen_Cap_Cost = CNG_Prod_MMBTU * CNG_Gen_CapCost_Parm;
Format CNG_Gen_Cap_Cost DOLLAR20.;

/* SalePct is on the Digester Decision Tool page, I think it means how much you want to sell as opposed to reues */
/*Electrical_SalePct    = 1.0;*/


/* Capital Costs apportioned to various construction components */
/* PCP = Pre-construction permitting */
CNG_Gen_Cap_Cost_PCP = CNG_Gen_Cap_Cost * Pct_PreConstruction_Permitting;
/* SYS = Pre-construction permitting */
CNG_Gen_Cap_Cost_SYS = CNG_Gen_Cap_Cost * Pct_System;
/* SIT = Pre-construction permitting */
CNG_Gen_Cap_Cost_SIT = CNG_Gen_Cap_Cost * Pct_Site_Infrastructure;
/* INT = Pre-construction permitting */
CNG_Gen_Cap_Cost_INT = CNG_Gen_Cap_Cost * Pct_Integration;
/* UTL = Pre-construction permitting */
```

```
CNG_Gen_Cap_Cost_UTL = CNG_Gen_Cap_Cost * Pct_Utilities;
/* ADM = Pre-construction permitting */
CNG_Gen_Cap_Cost_ADM = CNG_Gen_Cap_Cost * Pct_Administration;
/* FIN = Pre-construction permitting */
CNG_Gen_Cap_Cost_FIN = CNG_Gen_Cap_Cost * Pct_Financing;
/* CON = Pre-construction permitting */
CNG_Gen_Cap_Cost_CON = CNG_Gen_Cap_Cost * Pct_Contingency;
/* Total costs */
CNG_Gen_Cap_Cost_TOT =
SUM(CNG_Gen_Cap_Cost_PCP,CNG_Gen_Cap_Cost_SYS,CNG_Gen_Cap_Cost_SIT,CNG_Gen_Cap_Cost_INT,CNG_Gen_Cap_Cost_UTL,CNG_G
en_Cap_Cost_ADM,CNG_Gen_Cap_Cost_FIN,CNG_Gen_Cap_Cost_CON);

CNG_Total_Capital_Cost = CNG_Gen_Cap_Cost_TOT + Capital_Cost_Adj - Grants ;
CNG_Gen_EQUITY        = CNG_Total_Capital_Cost * EQUITY;
CNG_Gen_DEBT          = CNG_Total_Capital_Cost * DEBT;
CNG_Gen_APR           = FINANCE('PMT',Loan_APR,Planning_Horizon,CNG_Gen_DEBT);

Format
CNG_Gen_Cap_Cost_PCP DOLLAR20.
CNG_Gen_Cap_Cost_SYS DOLLAR20.
CNG_Gen_Cap_Cost_SIT DOLLAR20.
CNG_Gen_Cap_Cost_INT DOLLAR20.
CNG_Gen_Cap_Cost_UTL DOLLAR20.
CNG_Gen_Cap_Cost_ADM DOLLAR20.
CNG_Gen_Cap_Cost_FIN DOLLAR20.
CNG_Gen_Cap_Cost_CON DOLLAR20.
CNG_Gen_Cap_Cost_TOT DOLLAR20.
CNG_Total_Capital_Cost DOLLAR20.
CNG_Gen_APR         DOLLAR20.
CNG_Gen_EQUITY      DOLLAR20.
CNG_Gen_DEBT        DOLLAR20.
;
/* ------------------------- END   CNG Capital Costs ---------------------- */
```

Digester Balance Sheet Code

```
Data Ele_IS;
Set Dairy.MS_Results;
 Do Year = 1 to Planning_Horizon;
   Rev_Electric = Annual_Electricity_Value;
   Rev_Tipping  = Organic_Substrate_Value_yr;
   Rev_RNG      = Adj_NG_Value_Annual;
     Rev_CNG      = Annual_CNG_Value;
   Rev_N        = Annual_N_Recovered_Value;
     Rev_P        = Annual_P_Recovered_Value;
   Rev_NEFiber  = Annual_Nutr_Enrich_Fiber_Value;
   Rev_GHG      = Annual_GHG_Offset_Credit_Value;
     Rev_REC      = Annual_REC_Value;
     Rev_RIN      = Annual_RIN_Value;

   Exp_OM_Ele   =(Electricity_Prod_kW_yr*Operation_Cost_Parameter)+(0.025*Elec_Total_Capital_Cost);
   Exp_OM_RNG   =(Natural_Gas_Prod_MMBTU*Operation_Cost_Parameter)+(0.025*RNG_Total_Capital_Cost);
     Exp_OM_CNG   =(CNG_Prod_MMBTU       *Operation_Cost_Parameter)+(0.025*CNG_Total_Capital_Cost);

     Exp_Util_Ele = Elec_Gen_Cap_Cost_UTL;
   Exp_Util_RNG = RNG_Gen_Cap_Cost_UTL;
   Exp_Util_CNG = CNG_Gen_Cap_Cost_UTL;

   Depreciation_Pct = 0.30;

   Exp_Depr_Ele = (Elec_Total_Capital_Cost * (1 - Depreciation_Pct)) / Planning_Horizon;
   Exp_Depr_RNG = (RNG_Total_Capital_Cost  * (1 - Depreciation_Pct)) / Planning_Horizon;
   Exp_Depr_CNG = (CNG_Total_Capital_Cost  * (1 - Depreciation_Pct)) / Planning_Horizon;

   Exp_Loan_Ele = Elec_Total_Capital_Cost * Loan_APR;
   Exp_Loan_RNG = RNG_Total_Capital_Cost  * Loan_APR;
   Exp_Loan_CNG = CNG_Total_Capital_Cost  * Loan_APR;

   OUTPUT;
 End;
 Format
 Rev_Electric       DOLLAR25.
 Rev_Tipping        DOLLAR25.
 Rev_RNG            DOLLAR25.
 Rev_CNG      DOLLAR25.
 Rev_N        DOLLAR25.
 Rev_P        DOLLAR25.
 Rev_NEFiber  DOLLAR25.
 Rev_GHG      DOLLAR25.
 Rev_REC      DOLLAR25.
 Rev_RIN      DOLLAR25.
  Exp_OM_Ele      DOLLAR25.
  Exp_OM_RNG      DOLLAR25.
  Exp_OM_CNG      DOLLAR25.
  Exp_Util_Ele      DOLLAR25.
  Exp_Util_RNG      DOLLAR25.
  Exp_Util_CNG      DOLLAR25.
```

```
  Depreciation_Pct      Percent6.2
 Exp_Depr_Ele      DOLLAR25.
 Exp_Depr_RNG      DOLLAR25.
 Exp_Depr_CNG      DOLLAR25.
 Exp_Loan_Ele      DOLLAR25.
 Exp_Loan_RNG      DOLLAR25.
 Exp_Loan_CNG      DOLLAR25.
 ;
 RENAME Nutr_Enrich_Fiber_Value = Nutrient_Enrich_Fiber_Value;
RUN;
Proc Sort ;
by Scenario Regions Digester_Type;
run;

Data Dairy.Income_Statement;
Set Ele_IS;
By Scenario Regions Digester_Type;
Format
Revenue_Electricity  DOLLAR20.
Revenue_Tipping         DOLLAR20.
Revenue_RNG                         DOLLAR20.
Revenue_CNG                         DOLLAR20.
Revenue_N                                       DOLLAR20.
Revenue_P                                       DOLLAR20.
Revenue_NEFiber       DOLLAR20.
Revenue_GHG                         DOLLAR20.
Revenue_REC                         DOLLAR20.
Revenue_RIN                         DOLLAR20.
Tot_Rev_Ele        DOLLAR20.
Tot_Rev_RNG        DOLLAR20.
Tot_Rev_CNG        DOLLAR20.
;
Revenue_Electricity =  Rev_Electric*((1+Electricity_Inflation)**year);
Revenue_Tipping        =            Rev_Tipping              *((1+Electricity_Inflation)**year);
Revenue_RNG                         =            Rev_RNG               *((1+Natural_Gas_Inflation)**year);
Revenue_CNG                         =  Rev_CNG                         *((1+  CNG_Inflation)**year);
Revenue_N                                       =            Rev_N                    *((1+Inflation_Other)**year);
Revenue_P                                       =  Rev_P               *((1+Inflation_Other)**year);
Revenue_NEFiber       =            Rev_NEFiber             *((1+Inflation_Other)**year);
Revenue_GHG                         =            Rev_GHG               *((1+Carbon_Credit_Inflation)**year);
Revenue_REC                         =  Rev_REC                         *((1+Inflation_Env_Credits)**year);
Revenue_RIN                         =  Rev_RIN                         *((1+Inflation_Env_Credits)**year);

Tot_Rev_Ele        =  Sum(Revenue_Electricity,Revenue_REC,Revenue_GHG,Revenue_NEFiber,Revenue_N,Revenue_P,Revenue_Tipping);
Tot_Rev_RNG        =  Sum(Revenue_RNG,      Revenue_RIN,Revenue_GHG,Revenue_NEFiber,Revenue_N,Revenue_P,Revenue_Tipping);
Tot_Rev_CNG        =  Sum(Revenue_CNG,      Revenue_RIN,Revenue_GHG,Revenue_NEFiber,Revenue_N,Revenue_P,Revenue_Tipping);

Expenses_OM_Ele    =  Exp_OM_Ele   *((1+Inflation_Other)**year);
Expenses_OM_RNG    =  Exp_OM_RNG   *((1+Inflation_Other)**year);
Expenses_OM_CNG    =  Exp_OM_CNG   *((1+Inflation_Other)**year);
Expenses_Util_Ele  =  Exp_Util_Ele *((1+Inflation_Other)**year);
Expenses_Util_RNG  =  Exp_Util_RNG *((1+Inflation_Other)**year);
Expenses_Util_CNG  =  Exp_Util_CNG *((1+Inflation_Other)**year);
```

```
Tot_Exp_Ele        =  Sum(Expenses_OM_Ele,Expenses_Util_Ele,Exp_Depr_Ele,Exp_Loan_Ele);
Tot_Exp_RNG        =  Sum(Expenses_OM_RNG,Expenses_Util_RNG,Exp_Depr_RNG,Exp_Loan_RNG);
Tot_Exp_CNG        =  Sum(Expenses_OM_CNG,Expenses_Util_CNG,Exp_Depr_CNG,Exp_Loan_CNG);

Net_Operating_Income_Ele =  Tot_Rev_Ele - Sum(Expenses_OM_Ele,Expenses_Util_Ele);
Net_Operating_Income_RNG =  Tot_Rev_RNG - Sum(Expenses_OM_RNG,Expenses_Util_RNG);
Net_Operating_Income_CNG =  Tot_Rev_CNG - Sum(Expenses_OM_CNG,Expenses_Util_CNG);

Earning_Before_Tax_Ele =  Tot_Rev_Ele - Tot_Exp_Ele;
Earning_Before_Tax_RNG =  Tot_Rev_RNG - Tot_Exp_RNG;
Earning_Before_Tax_CNG =  Tot_Rev_CNG - Tot_Exp_CNG;

Debt_Service_Coverage_Ele = Net_Operating_Income_Ele / -Elec_Gen_APR;
Debt_Service_Coverage_RNG = Net_Operating_Income_RNG / -RNG_Gen_APR;
Debt_Service_Coverage_CNG = Net_Operating_Income_CNG / -CNG_Gen_APR;
IRR_Parm_ELE = -Elec_Total_Capital_Cost;
IRR_Parm_RNG = -RNG_Total_Capital_Cost ;
IRR_Parm_CNG = -CNG_Total_Capital_Cost ;
```

[i]. http://www.merriam-webster.com/dictionary/optimization

[ii]. http://www.phoenix-int.com/

[iii]. The Planning Model is discussed in detail in appendix 1.7

[iv]. http://en.wikipedia.org/wiki/Genetic_algorithm