Milwaukee School of Engineering
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# Residential Distributed Energy Generation System

# Proposal

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# Executive Summary

For the purpose of generating electricity and thermal energy to meet the electrical, heating, cooling and hot water demands of a standard home in Milwaukee, Wisconsin, in the We Energies distribution area, it was recommended to implement an internal combustion engine generator set fueled by natural gas that runs on a thermal load following strategy.

Four overall designs were considered consisting of the internal combustion engine, fuel cell, wind, and solar powered systems. Each system was designed independent of the others. A MATLAB program was generated to compare all of the systems versus the conventional means of electrical and thermal energy production. The internal rate of return (IRR) was also calculated for each system to determine the economic feasibility.

With the program outputs and the IRR were then used to select the most cost effective system. Each system was analyzed, considered and compared to the other systems based on initial cost, operating cost, incentives (i.e. tax credits, government loans, etc), fuel cost, reliability, size, aesthetics, emissions, ease of maintenance, buy back benefits, and IRR.

The natural gas fueled internal combustion engine proved the most economically feasible with a payback period of 1.7 years and minimized environmental impacts by reducing overall carbon dioxide emissions.  By using natural gas as fuel, other adverse pollutants are reduced, and the system takes advantage of the existing natural gas infrastructure.

**Table of Contents**

# I. Introduction

## *Problem Statement*

The objective is to design a distributed energy system for a single family residence located in the We Energies service area. The system must meet the energy requirements of the house while minimizing cost and environmental impacts.

The energy systems considered were fuel cell, internal combustion engine, wind power generator, and solar photovoltaic. While the fuel cell and the internal combustion engine systems also produce thermal energy that can be utilized for the residential house, the wind power generator and solar photovoltaic systems have to be supplemented with home heating sources.

The potential systems were considered based on their potential to generate electricity, heat (both space and water heating), total system cost, operating cost (including cost of fuel and maintenance), and carbon dioxide emissions.

Using information provided by Lawrence Berkley National Laboratory's (LBNL) Home Energy Saver it was calculated that the average house in the Milwaukee, Wisconsin area uses approximately 7,187 kWh of electricity per year and a total of 2,126 therms for home and water heating producing 18.8 tons of $CO_2$ per year.[1] The average home size was also calculated to be 2000 square feet and 2 stories.[2] Based on the heating and cooling degree days for Milwaukee, WI, the energy consumption was determined on a per month basis. These values were required on a per month basis for input to a MATLAB generated load estimating program.

The standard house in Milwaukee, Wisconsin obtains electricity from the electrical grid. A coal fired power plant supplies the majority of the electricity to the grid.[3] The standard house heating system uses a central natural gas furnace while the cooling system uses central air conditioning. The hot water system also uses natural gas as fuel.[1]

## *Specifications*

The final system needed to meet the majority of the household electrical needs. The system also needed to meet the household space and water heating requirements. In conjunction with the electrical and heating outputs, the system had to reduce the environmental impacts of conventional electrical and thermal energy generation (i.e. $CO_2$ emissions). The marketability, and therefore the cost reduction and aesthetics of the final system were also considered.

## *Background*

In order to limit the number of systems to be considered to a number that could feasibly be analyzed, the distributed power systems were researched, designed, and analyzed on a single type basis. Systems containing only solar, wind, fuel cells, and internal combustion engines with standard practice redundancy were considered. It was concluded that an initial patent search was not necessary for this project as the ideas electrical generation, and combined heat and power systems are common knowledge among the scientific community; therefore, these ideas are not available for patent. A literature search was conducted to assess current projects currently in use and production. A list of companies was found; they include organizations such as Marathon Engine Systems, Plug Power, British Gas, and the Gas Technology Institute. Marathon Engine Systems, in East Troy, Wisconsin, was visited to gain more intimate knowledge of the production and use of micro combined heat and power (CHP) systems.

The U.S. Department of Energy (DOE), in association with U.S Energy Information Administration (EIA) statistics on energy consumption were key sources of information. The LBNL's Home Energy Saver calculated the domestic electricity, heating, cooling and hot water needs based on the DOE-2 building simulation program version 2.1E.[4] These needs were then inputted into a MATLAB program along with each systems calculated output. The program compared each system versus the standard residential system on a per month basis and calculated the economic feasibility of each system. Based on the program outputs, the final system was determined.

# Systems Considered

The following sections describe the single systems. Each system was designed independent of the other systems and the data from the analysis was used in the MATLAB program to determine each systems economic feasibility and carbon footprint.

## *Internal Combustion Engine*

There are many internal combustion (IC) engines for different fuel types on the market with a 5 kilowatt (kW) capacity. These engines usually operate lawnmowers, generators and pumps. Almost all of these engines are air cooled to reduce cost. In order to design an effective cogeneration system to capture the heat and produce the power, the engine needs to be water cooled. This allowed the engine coolant to be used to help meet the heating needs of the house.

Gasoline engines have many options on the market including many that are used as generators. However, these engines are not intended for long life continuous use applications and are an air cooled design. This made these engines a poor choice for a prime power system that must be reliable with minimal down time. Gasoline engines can also use renewable fuels such as ethanol to reduce $CO_2$ emissions.

Diesel engines have many options in the market as well. Diesel engines are built to withstand the higher compression ratio which yields a longer engine life compared to gasoline engines. Many of the diesel engines in this size are air cooled to reduce cost, but increasing the size opens new options including the Yanmar 2TNV70-ASA. This is a 2 cylinder 10.2 kW variable speed engine. This engine is oversized for the application;

however, it has performance characteristics that allowed steady fuel consumption at half of the peak power.[5] The performance curve can be found in *Appendix V*. Running an engine at lower power than it has been designed to run at induces more losses. Fortunately, cogeneration has the capability to capture these losses in the form of heat. A bonus to running at lower speed is less wear on the engine prolonging the engine's life. Wolter Power Systems, a local distributer, quoted this engine at $2,400.[6] The Yanmar can also use biodiesel to reduce $CO_2$ emissions. In the code of the MATLAB model, the 100% biodiesel was used to reduce $CO_2$ emissions.

Natural gas/liquid propane (NG/LP) fueled engines offer a viable option for stationary power generation, yet most water cooled are 10 kW or higher. One particular engine made by Marathon Engine systems is a 5 kW water cooled engine. The engine life is over 40,000 hours with maintenance intervals of 4,000 hours or every 6 months of continuous use.[7] Marathon quoted the price of their engine at $2,000 with $75 of maintenance every 4,000 hours. The Marathon engine can be produced to run on either natural gas or liquid propane. This engine could be altered to burn biogas or hydrogen; however, there is currently not a distribution infrastructure to support these types of fuel.

## *Fuel Cell*

Fuel cells are a flexible source of power. They can use many different fuels to produce the hydrogen that is needed for them. They also offer the option for grid independence as well as for the potential for cogeneration with the waste heat. Fuel cells have many benefits but are hindered by the high initial cost.

Fuel sources such as natural gas and liquid propane can be used in the production of hydrogen for the cell. Other options include renewable energy sources for hydrogen production such as wind and solar power. These renewable sources would be used to power an electrolysis process to break hydrogen off of oxygen in water. If a low cost or no cost source of electricity is used to make hydrogen, the system can become cost effective. Fuel cells allow for storage of energy, which makes it dispensable; this allows for the option of grid independence.

The fuel cell systems operate with few moving parts which yield a quiet power source. By harnessing waste heat, the energy utilization factor of a fuel cell system can be up to 70%.[8] A low value without using waste heat would be near to 40%.[9] A fuel cell system can create energy and store it continuously so that peak demands can be met without interference; weather related outages would be minimized. A 5 to 7 kW system that can power a 2000 sq ft home is roughly the size of a freezer chest.[8] Most of the wear and tear can be predicted and remedied before critical failure. The few moving parts of the system are a benefit as it reduces unforeseen problems. The initial cost of the system may be eased by government funding as long as size requirements are met.

Both the initial cost and the cost of operation are above that of standard power sources that are currently being used.[8] A Ballard representative quoted a 1 kW PEM fuel cell stack designed for residential use that is currently being used in Japan as being near

$10,000. Fuel Cells are plagued with difficult installation, partly due to commercial unavailability. Although there are many companies that are planning to make a residential unit available in the next few years, there are no residential systems that are available at present. It is required to keep fuel cells running at a minimum load so that they will maintain the needed operating temperature. This can sometimes mean that the fuel cell is being run at a load that is higher than is needed just to maintain optimal running conditions. Although unplanned maintenance may be low, expected failures can become expensive and are dependent on the fuel source. A Department of Defense study found that a fuel source of natural gas needed the most component replacement.[10] Data for a long term life cycle of a fuel cell system is not currently available. Units are not currently commercially available for residential applications, so projected base costs and operational costs vary slightly.

The Department of Defense study also outlined life expectancy for fuel cells. A large fuel cell stack averaged around 2485 hours of operation. A smaller cartridge system averaged around 190 hours of operation but cartridges could be replaced with no tools and without disrupting the energy flow. [9] A different site noted that in a residential system that the cells would have to be completely replaced within 5 years, even with proper component maintenance. [8]

In order to perform the economic feasibility study an initial cost of a fuel cell system was needed. As stated before, there are no current residential systems that are commercially available, so this figure was not readily available. After speaking with a representative of Ballard Power Systems Incorporated, maker of a residential fuel cell in Japan, it was determined that the company hopes to release a similar unit in the United States in the near future. For this reason it was decided to use the cost of the Japanese residential fuel cell as the initial cost for this model. The federal government allows for some tax incentives which consist of 30% of the initial cost, but cannot exceed $500 per .5 kilowatt.[11] For the calculations a 3 kilowatt system was selected as being adequate to meet the energy needs of the house. This would give an initial cost of $30,000. This could then be discounted at the maximum rate of $500 per .5 kilowatt, which would bring the initial cost to $27,000.

## *Wind*

The wind power density throughout the nation is divided into seven classes with class 1 having the lowest power density and class 7 having the highest. The majority of southeastern Wisconsin has a wind power class of 2[12] which is the lowest recommended class for onsite wind electricity generation.[13] The average monthly wind speed of southeastern Wisconsin is low to moderate ranging from 9.2 to 12.8 miles per hour (4.1 to 5.7 m/s).[14] The cost of a small wind system ranges from $1,000 to $5,000 per kW.[15] It is recommended that the wind generator be placed on a tower that is at least 30 feet above anything within 300 feet to avoid turbulence.[13] Maintenance costs are around $50 per year, and the production of electricity by wind generators produces no adverse emissions.[15]

Two different wind generator systems were considered: the 10 kW Bergey Excel and the 3 kW Whisper H175. The installed systems would cost $35,000 for the 10 kW and $15,000 for the 3 kW.[15] Using the small wind spreadsheet model from the U.S. Department of Energy,[16] the power output per month was determined and is displayed in *Table 1*. By inputting the average monthly wind speed into the model, the power output on a yearly basis was determined. In order to put the power back into a monthly basis, the yearly power was divided by 12 months. This was completed for each of the average monthly wind speeds for Milwaukee, Wisconsin to compare to the other energy systems.

Assumptions:
Total installed costs of $35,000 for the 10 kW and $15,000 for the 3 kW
Rotator hub height of 79 feet
Availability of 98%
Performance derating of 10%
Monthly power output is the yearly power divided by 12 months

**Table 1: Wind Power Output Per Month**

| Month | Milwaukee, WI Avg. Wind Speed (mph) | 10 kW Bergey Power Output (kWh/month) | 3 kW Whisper Power Output (kWh/month) |
|---|---|---|---|
| January | 11.86 | 1,559 | 594 |
| February | 9.62 | 956 | 363 |
| March | 11.19 | 1,379 | 523 |
| April | 12.53 | 1,734 | 665 |
| May | 11.41 | 1,439 | 547 |
| June | 11.41 | 1,439 | 547 |
| July | 9.40 | 898 | 341 |
| August | 9.17 | 841 | 320 |
| September | 10.07 | 1,075 | 407 |
| October | 12.75 | 1,790 | 688 |
| November | 11.86 | 1,559 | 594 |
| December | 11.41 | 1,439 | 547 |
| **Total** | | **16,110** | **6,136** |

## *Solar PV & Solar Water Heating*

This section discusses the benefits and strategies employed for running a home on Solar Power. Solar radiation can be harvested to create electrical energy with the aide of solar photovoltaic (PV) cells. Solar radiation can also be converted into thermal energy to be used for heating needs.

The home solar panels were designed with the strategy of generating enough electricity to supply 100% of the electrical needs, and 65% of the hot water needs.[17] Solar powered cooling is not a viable option as a solar cooling system can be shown to cost upwards of $6,000 per ton of cooling and not sized for residential purposes.[17] The electrical strategy is to generate electricity and sell it back to the utility (We Energies). This will take advantage of We Energies solar buyback program. The utility company purchases 100% of the solar PV electricity generated at the rate of $0.225 per kilowatt hour through the program.[18] The home will then take electricity from the grid and the user, as part of the "Energy for Tomorrow" program, will use renewable energy in return at a premium ($0.137 per kilowatt hour). The house's PV cells will be sized to meet the needs of the home on a year basis so the net usage compared with the output will be essentially zero.

The solar panels were sized using the LBNL Home Energy Saver data, wholesalesolar.com's (a solar panel retailer) Solar Panel Sizing formula, and data obtained from the DOE on solar radiation in the Milwaukee area. The per month radiation (in $W/m^2$) was used to determine how large of a system, and how many panels must be used to obtain the required amount of energy.

The panel chosen was the Kyocera 200W module (KC 200GT model). Using Kyocera PV Calculator the total electrical system cost was calculated, with tax benefits, such as a $1.00 per kWh/year or $1.50 per kWh/year reward, grant money (We Energies will pay for up to 25% of the total installed cost) and an average value of $8 per Watt, to be $22,000.[19] The system requires a 4 kW solar array at 28.2 $m^2$.

**Table 2: System Costs with Incentives**

| 4kW PV system | | | |
|---|---|---|---|
| Panels | Incentive | Tax | Total |
| $ 32,000.00 | $ 8,000.00 | $ 2,000.00 | $22,000.00 |

Solar water heaters are designed to supply 50-85% of the house's hot water needs.[17] It was assumed that the systems hot water heater will supply 65% of the hot water needs from solar and the rest of the heating will be through the conventional Natural Gas heating. The overall reduction in natural gas fueled water heating proves an economic and environmental benefit. The owner of the solar water heater will only need to burn 35% of the fuel that a conventional natural gas fueled water heater would. Burning less fuel will lead to lower emissions from the house.

*Figure 1* shows the typical layout of a solar powered water heating system. The thermal energy provided from the sun raises the temperature of the liquid (typically an antifreeze or refrigerant solution). The heated solution flows to a shell and tube heat exchanger where the thermal energy of the solution in the pipes flows to the lower temperature water. The water, once heated is pumped to the hot water tank for holding and further heating by natural gas flame.

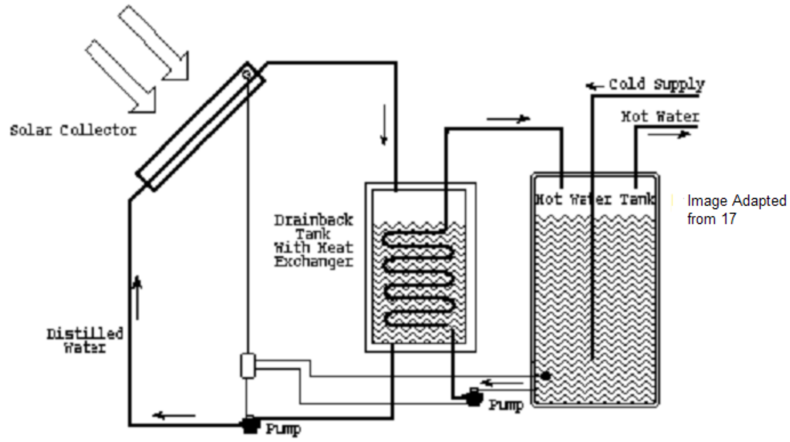


**Figure 1: A Typical Solar Power Water Heater Process Design**
*(Adapted from GreenBuilder.com)*

The cooling to the house will be provided by a standard high efficiency central air conditioning unit. A solar powered cooling unit is not feasible for residential applications, based on the size of the systems and the cost to implement a cooling system.

Solar heating can be achieved through radiant heating. Solar collectors can transfer thermal energy to a solution just as in solar water heating or solar cooling. This fluid can then flow through a heat exchanger and increase the temperature of the surrounding air, or the fluid can flow through the floor and raise the temperature of the floor. The floor then increases the temperature of the air and is more likely to hold the heat throughout the night when the sun will be unable to heat the solution.

A backup system will be required as sizing the solar heater to meet the peak load would prove to make the system far too large and would be unnecessary for the majority of the heating days.

Assumptions associated with Solar Design
-Solar water heaters provide 50-80% of hot water needs[17]. Assumed 65% of needs year as it is the median value of this range
-Water heating cost is 35% of the yearly value; this value was calculated from the total therms used for a typical home for water heating needs
-Cooling is assumed to be using Central AC
-Heating system not sized to meet full heating load; 65% assumed, taken from total therms used.
-The thermal output from the PV cell is either dispersed to the environment or used in the solar water heating or space heating.
-Family size of 3 people[20]
-20-30 gallons of hot water per person per day
-Space exists for enough panels to fulfill needs

# II. Feasibility Study

## *Economic Analysis*

### We Energies Rates and Fuel Prices

We Energies, the local utility company in Milwaukee, Wisconsin, provides electrical and natural gas services. They offer multiple rates for each energy source depending upon the customer's needs. For electrical service a customer has several options. Residential rates are either a flat rate or variable rates throughout the day according the peak hours. Business rates only have the peak and off peak hourly rates. Both residential and business customers can choose the "Energy for Tomorrow" option for a small premium to receive all of its power from renewable sources.[21] The current electrical rate for residential We Energy customers is $0.0999 per kilowatt hour (kWh).[22] The business rates vary by the kilowatt hour usage. The natural gas rates vary between residential and business use as well. The business rates vary on size and application. The residential rate is adjusted each month to match the market value of natural gas. In this feasibility study the price for October of 2007 was used at an adjusted rate of $1.12 per therm.[23]

We Energies also has buyback programs for customer power generation. For solar power, We Energies will purchase the power back at $0.225 per kilowatt hour.[24] The remaining renewable energy generating sources are paid the customers rate for electricity. This includes wind, fuel cells, landfill gas, hydroelectric, and biofuels. For non renewable generation We Energies uses a different system. We Energies records the kWh produced and once the value of this energy reaches $25 using the customers electrical rate We Energies will write a check. The kWh that are left over at the end of the month that do not add up to the $25 amount are transferred over to the following month.[25] This essentially becomes a full net metering program when looked at over a period of several months.

The national average fuel prices of biodiesel, liquid propane, and ethanol were found in the July 2007 release of the "Clean Cities Alternative Fuel Price Report." The national average fuel price was used because the fuel prices are continuously changing making it difficult to quantify a regional average. *Table 3* has the fuels and prices per gallon and therm.[26]

**Table 3: National Average Fuel Prices**

| Fuel | Nationwide Average Price for Fuel | Units of Measurement | Price per therm ($10^5$ BTU) |
|---|---|---|---|
| Gasoline (Regular) | $3.03 | per gallon | $2.25 |
| Diesel | $2.96 | per gallon | $2.30 |
| NG* | $2.09 | per GGE | $1.82 |
| Ethanol (E85) | $2.63 | per gallon | $3.22 |
| Propane | $2.58 | per gallon | $3.09 |
| Biodiesel (B20) | $2.96 | per gallon | $2.34 |
| Biodiesel (B2-B5) | $2.84 | per gallon | $2.21 |

| | | | |
|---|---|---|---|
| Biodiesel (B99-B100) | $3.27 | per gallon | $2.79 |

** Number used from We Energies*

## Description of Code

The economic model of the system was created in MATLAB. The goal of the MATLAB program was to compare different system options to the standard conventional systems of the house. First the user selects a system to compare to the standard grid connection. The system selection menu is shown in step A in *Figure 2*. The Fuel Cell and IC Engine options require that a fuel and energy strategy be chosen. The Wind system also has the option to choose between two different sizes. The last button on the system select menu allows the user the option to input a custom fuel or electricity price. This is shown in step B.

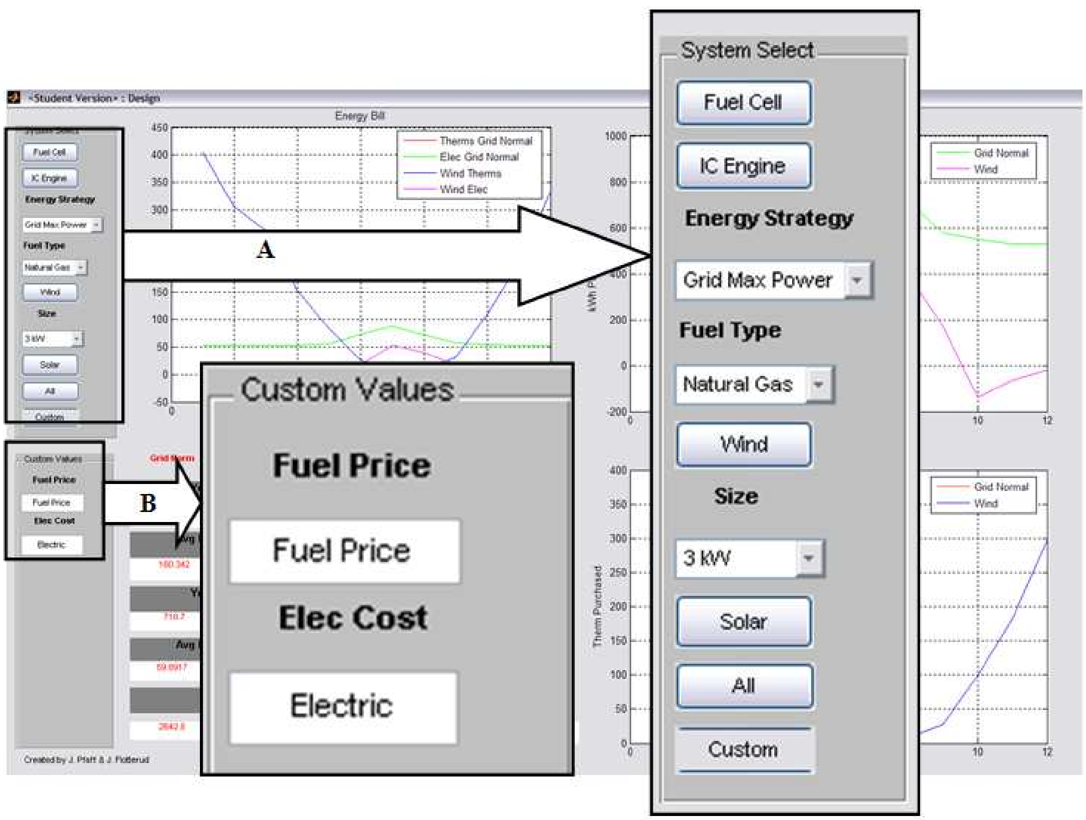


**Figure 2: System Select and Custom Options Menu**

Once all the system options are selected the program creates three graphs. The three graphs are shown in *Figure 3*. The graph labeled as C is the comparison of the energy bills of the normal grid connected and the system broken into an electric bill and heating bill. The graph shown as D in the same figure is the graph of the kilowatt hours purchased from the electric company. This is again a comparison of the selected system and a normal grid connected residence. If the selected system shows a negative kilowatt hours purchased this would denote a credit to the house. The last graph on this figure is labeled as E and is the therms of natural gas purchased from the utility company. The natural gas is used to heat the house, so this graph will show if there is any heating benefit gained from the selected system.

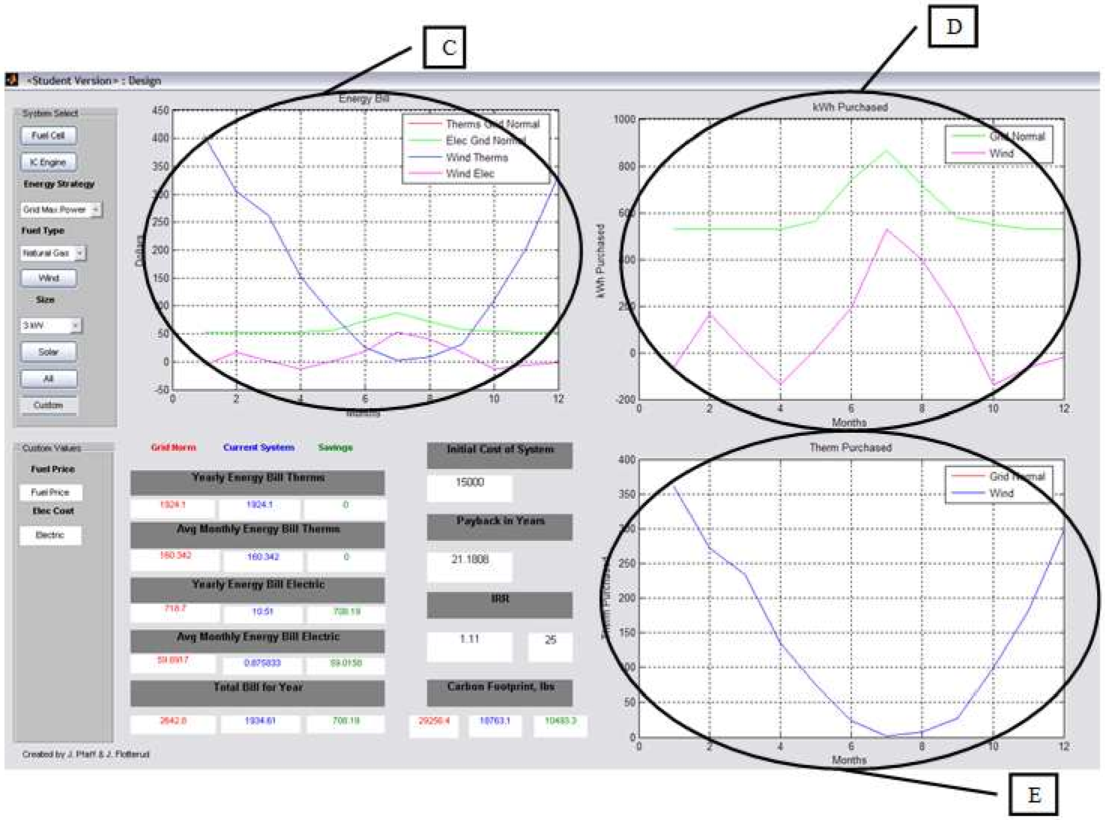


**Figure 3: The Three Graphs Created by the Program**

The total energy bill was calculated for the selected system as well as the normal grid connected house. The yearly bill is the sum of the monthly energy bills over the course of a year. The average monthly bill is the yearly bill divided over the twelve months in a year. This is shown in greater detail in step F in *Figure 4.*

For each system a simple payback was determined based on the yearly savings on the overall energy bill. The overall energy bill is the combined total of the kilowatt hours and the therms purchased which would be comprised of both the electrical and heating needs of the house. The internal rate of return (IRR) was determined for all systems that provide a yearly savings on total energy bills when compared to the standard. The IRR was found over the projected life of the specific system and took into account the initial cost, yearly energy bill savings and the projected maintenance costs. The value of which comes from setting the net present value (NPV) to zero and iterating to find a solution. This is shown in step G in *Figure 5*. Under the IRR the projected life of the system is also shown and was used as the time frame over which the IRR was calculated.

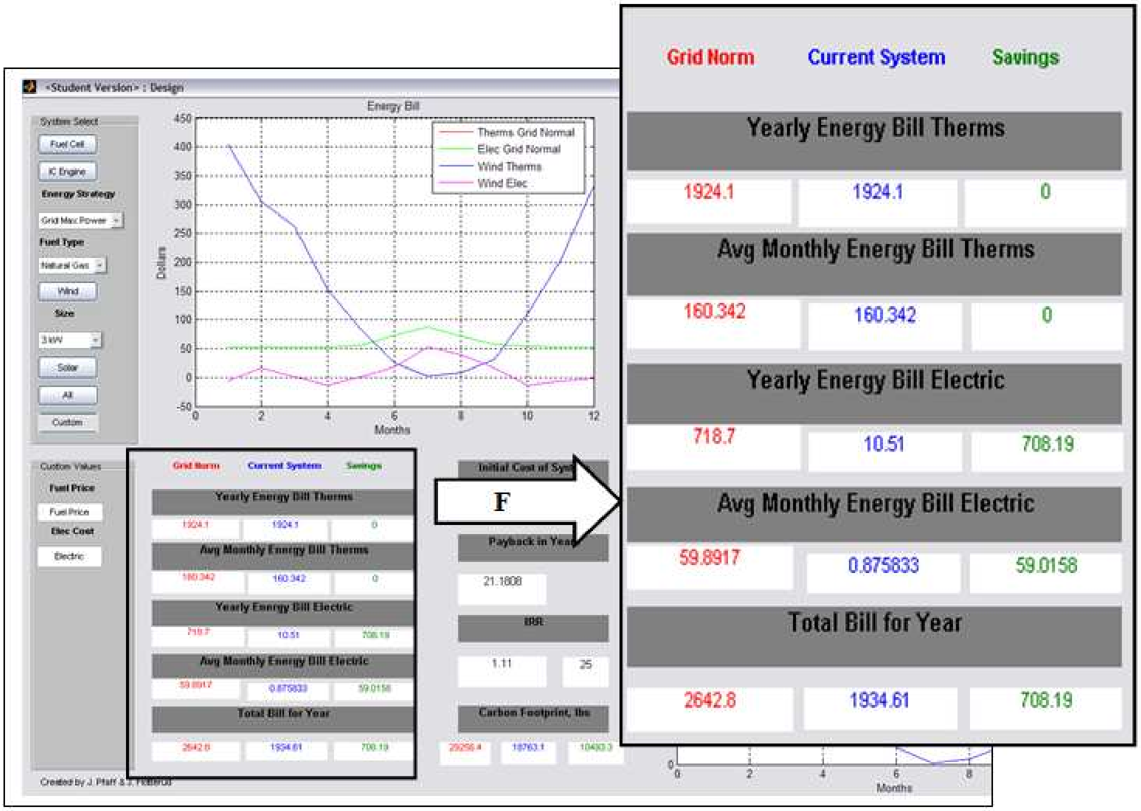


**Figure 4: Calculated Energy Bills**

## Simple Payback

$$T_{PB} = {}^{I_O}\!/_{C_t}$$

$T_{PB}$ = Time of Payback

$C_t$ = Cash Flow

$I_O$ = Initial Cost

## Internal Rate of Return

$$NPV = 0 = I_O + \sum_{t=1}^{N} \frac{C_t}{(1+IRR)^t}$$

$C_t$ = Cash Flow

$I_O$ = Initial Cost

$N$ = Life of system in years

$IRR$ = Internal rate of return

$NPV$ = Net present value

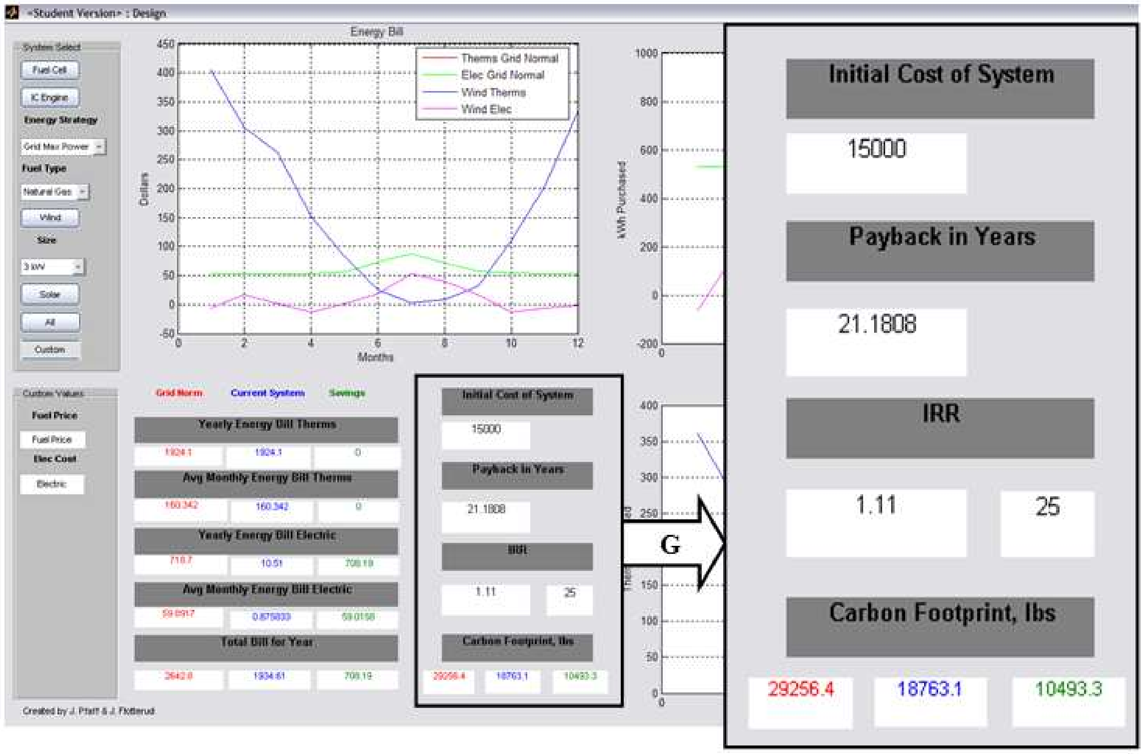


**Figure 5: Calculated Outputs of Program**

The carbon footprint, the amount of carbon dioxide produced, of the different systems was determined, as well as the carbon footprint of the normal conventional system. The amount of carbon dioxide produced from one therm of natural gas was found, as well as that of one kilowatt of electricity produced by We energies, which is mostly produced from coal. The carbon dioxide content from each fuel option for the IC engine and the fuel cell was also found. This is also shown in step G in *Figure 5*, with the first column being the grid normal, then the selected system and the last column is the difference between the two. In the actual program these values are color coordinated whenever they appear.

The carbon footprint for the normal conventional system was calculated from We Energies emission rate for their energy mix and the emission rate of natural gas for heating purposes. The energy mix and emission rates for We Energies from the EPA were used for this study. *Figure 6* and *Figure 7* were adapted from data on the EPA's website.[27]

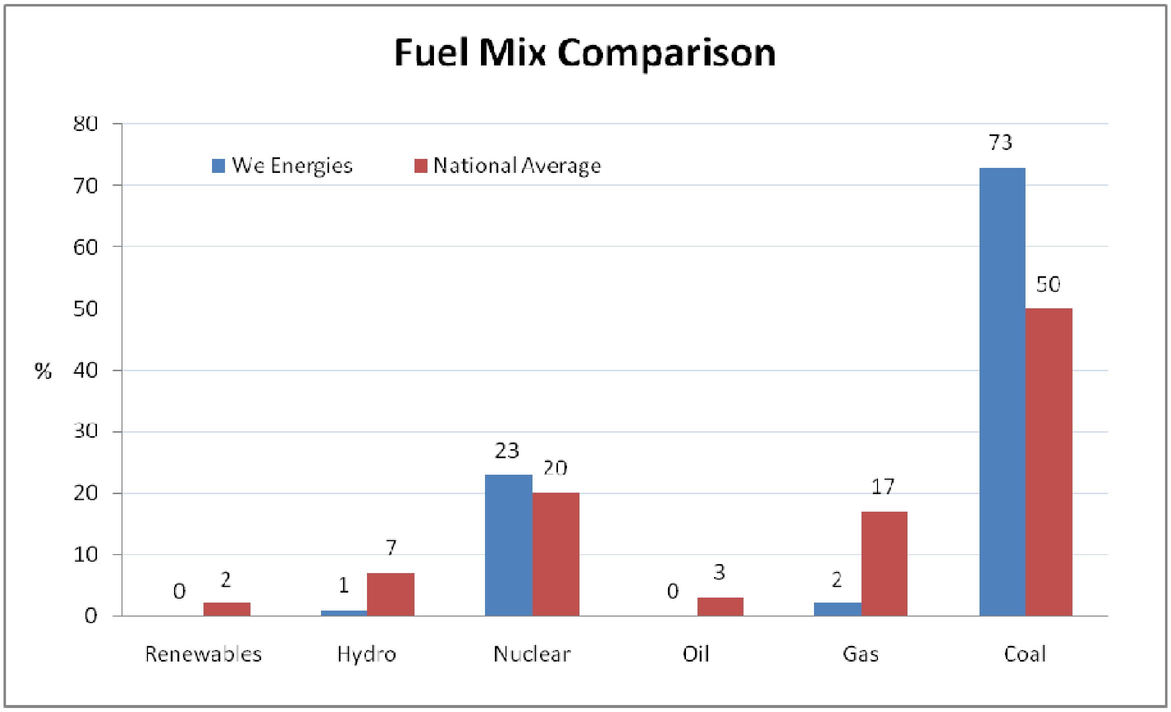


**Figure 6: Fuel Mix Comparisons**

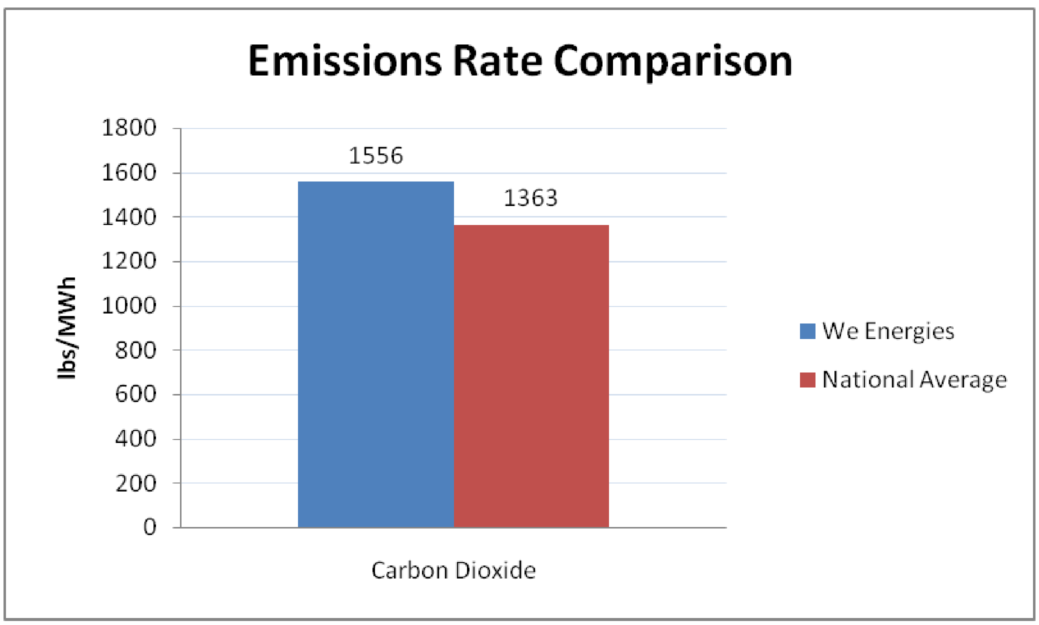


**Figure 7: Emissions Rate Comparison**

The amount of carbon dioxide produced from one therm of natural gas, gasoline, diesel, biodiesel, and propane were found as different options of fuel for the IC engine. Biodiesel emits 78.45% less $CO_2$ than regular diesel.[28] This is used to find biodiesels emission factor.

1 kWh in Wisconsin = 1.556 lbs of $CO_2$[29]

1 Therm of natural gas = 11.68 lbs of $CO_2$[30]

1 Therm of gasoline=15.52 lbs of $CO_2$[31]

1 Therm of diesel=16.09 lbs of $CO_2$[32]

1 Therm of biodiesel = 3.47 lbs of $CO_2$

1 Therm of Propane = 13.83 lbs of $CO_2$[32]

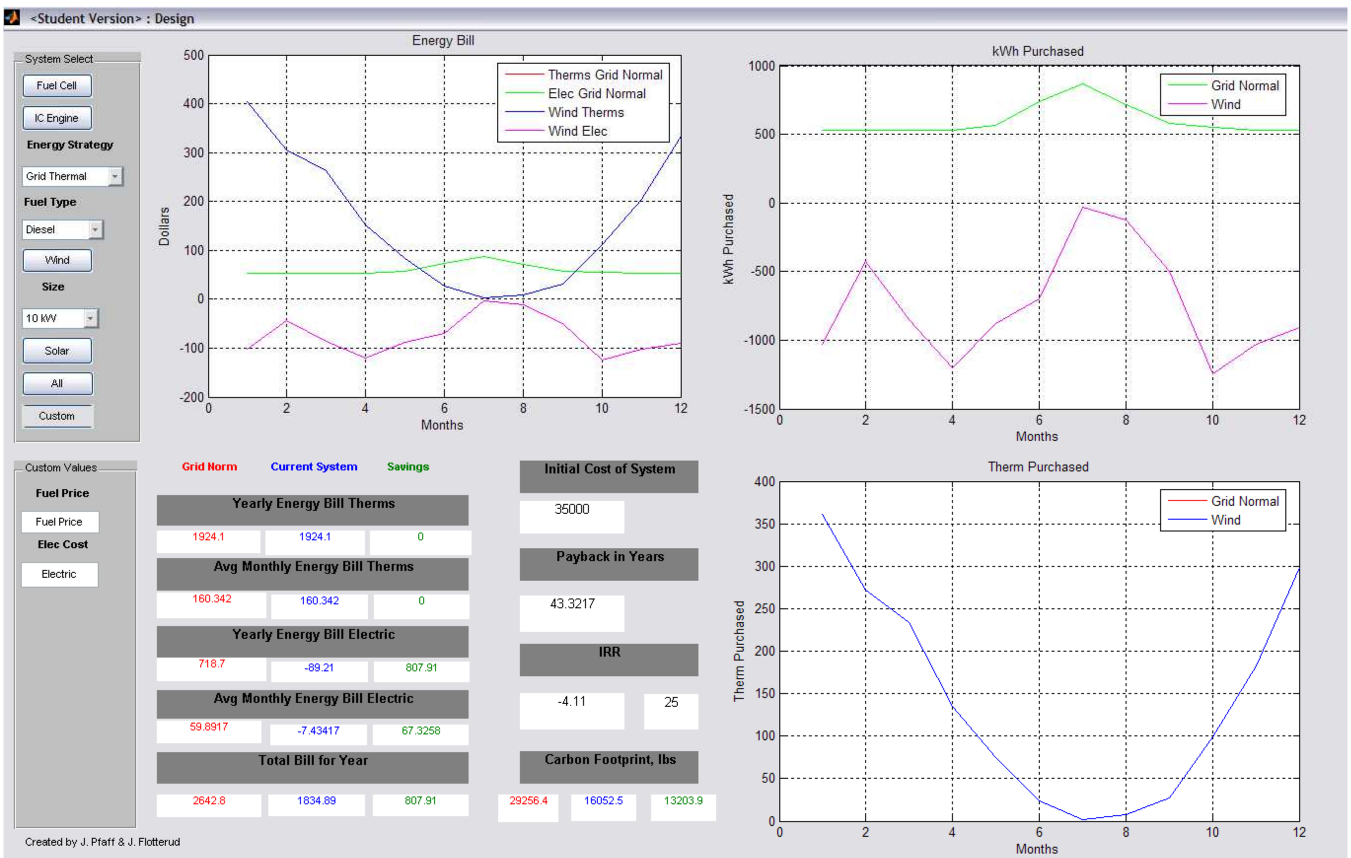


**Figure 8: Sample Screenshot of Economic MATLAB Model**

The output from the MATLAB model was compiled into one table and is shown in *Table 4*. Shown in this table are the calculated values for the IRR, the pounds of carbon per kilowatt-hour, and the simple payback period. If a system did not provide for a positive savings in energy bill when compared to the grid normal strategy it was noted as a loss for the payback, this is because the consumer would never see a financial benefit from this system. For this reason the IRR for these systems was not calculated.

**Table 4: Outputs from MATLAB Econimic Model**

| Fuel | System | Strategy | Payback Period | IRR | $CO_2$ lbs/kW |
|---|---|---|---|---|---|
| Natural Gas | Fuel Cell | | | | |
| | | Grid Thermal | 12.48 | -22.55 | 0.58674 |
| | | Grid Electric | loss | | 0.527318 |
| | | Grid Full Power | 10.48 | -18.14 | 0.780912 |
| | | No Grid | 524.63 | <-100 | 0.56934 |
| | IC Engine | | | | |
| | | Grid Thermal | 1.696 | 119.62 | 0.47826 |
| | | Grid Electric | 58.45 | <-100 | 0.525909 |
| | | Grid Full Power | loss | | 0.953894 |
| | | No Grid | 2.98 | 19.44 | 0.433194 |
| LP | Fuel Cell | | | | |
| | | Grid Thermal | loss | | 1.33482 |
| | | Grid Electric | loss | | 0.624384 |
| | | Grid Full Power | loss | | 3.62883 |
| | | No Grid | loss | | 0.674142 |
| | IC Engine | | | | |
| | | Grid Thermal | loss | | 0.606737 |
| | | Grid Electric | loss | | 0.622715 |
| | | Grid Full Power | loss | | 2.53764 |
| | | No Grid | loss | | 0.512934 |
| Gasoline | IC Engine | | | | |
| | | Grid Thermal | loss | | 0.614964 |
| | | Grid Electric | loss | | 0.69881 |
| | | Grid Full Power | loss | | 1.2675 |
| | | No Grid | loss | | 0.575614 |
| Diesel | IC Engine | | | | |
| | | Grid Thermal | loss | | 0.635149 |
| | | Grid Electric | loss | | 0.72434 |
| | | Grid Full Power | loss | | 1.31381 |
| | | No Grid | loss | | 0.596643 |
| BioDiesel | IC Engine | | | | |
| | | Grid Thermal | loss | | 0.185985 |
| | | Grid Electric | loss | | 0.156242 |
| | | Grid Full Power | loss | | 0.283391 |
| | | No Grid | loss | | 0.128697 |
| | Wind | | | | |
| | | 3 kw | 21.18 | 1.11 | 0.395313 |
| | | 10 kw | 43.32 | -4.11 | 0.284687 |
| | Solar | | | | |
| | | | 11.91 | 6.46 | 0.56175 |

As shown in *Table 2,* there were only four systems that had a positive IRR:  the IC engine on a thermal load strategy with natural gas, the IC engine on a no grid strategy with natural gas, wind, and solar.  The best economic option is the IC engine on a thermal load strategy with natural gas.  It has the best payback period that is about 1.70 years and a reasonable carbon footprint of 0.48 ($CO_2$ lbs/kWh).

Each system in the MATLAB model was coded accordingly to accommodate the different energy buyback rates and the different power outputs of the systems.  The specific processes for each system are outlined below.

## Wind

Of the two different systems analyzed, the smaller 3 kW system has a lower initial cost, but does not meet the electrical needs of the house for every month, and the larger 10 kW system does not require the home to purchase any electrical energy from the utilities. Both systems have a full dependence on the utilities to supply the heating needs of the home.  Also, both of the systems are limited to a buyback rate of $0.10.

## Solar

The solar outputs were based off a 4 kW system.  Solar energy is a renewable energy and is therefore eligible for a premium sale price of $0.225 per kWh to We Energies.  For this reason all the electricity produced was sold to the utilities, and the energy needs of the house were purchased from the utilities.  This practice makes the system economically feasible but does create an issue with the carbon footprint that the house would create. The renewable energy that is made from the solar photovoltaic system does not create carbon emissions, however because all that energy is being sold to the utilities, that benefit is seen at different location.  As far as the actual house is concerned, the same amount of non-renewable energy is being purchased as in the standard home, so there is no reduction of carbon footprint seen at the house.

## IC Engine and Fuel Cell Strategies

The IC engine and the fuel cell function on different principles, but they were both operated using the same strategies.  Both systems used a fuel to produce electricity with heat as a byproduct.  However both systems had different efficiencies resulting in different results.  The IC engine had an electric efficiency of 26% electrical and 66% heat.  The fuel cell produced electricity at 40% and heat at 30%.  There were four strategies that were used to find the most advantageous method of running the system: thermal demand, electrical demand, full power, and running with no grid connection.  For all of the strategies both heat and electricity are produced and there must be a load or a way to dump the excess energy.  Dumping the energy also reduces the systems efficiency.

### Thermal Demand Strategy

The thermal demand strategy ran to match the heating needs of the house. The electricity produced was proportional to the heat produced; therefore, the electricity produced would not exactly match the needs of the house. The excess power would be sold back to the utility, or the needed power would be purchased from the utility. This allowed the system to always run at maximum efficiency.

### Electrical Demand Strategy

The electrical demand strategy ran the system to match the electrical demand of the house. Therefore, the heating needs were not exactly met. The heat that was produced would not meet the needs of the house or would exceed them. If the heating needs were not met, a backup heating system was required. If the heating needs were exceeded, the excess heat was dumped to the atmosphere through a radiator. Dumping the energy reduces the systems efficiency.

### Full Power Strategy

The full power strategy ran the system at its peak output. This produced the maximum amount of electricity that could be sold back to the utility as well as heat for the house. This method was efficient as long as all of the heat was being utilized by the house. If the heat was being released outside through a radiator, the efficiency was greatly reduced, making the system expensive to operate. Running the system at full power would increase engine wear.

### No Grid Strategy

The no grid strategy matched the electrical and heating needs exactly. The system created electricity and heat at a curtain ratio. This ratio does not match the ratio of heat and electricity the house needs. This strategy is used where there is not a grid connection therefore excess electricity could not be dumped onto the grid. Excess heat could still be dumped to the atmosphere. This strategy ran to match the electrical load and check to make sure it was matching the heat load. If it has excess heat it would dump it to the atmosphere through the radiator. If it needed more heat the system would produce more electricity producing more heat in the process. The excess electricity was then run through an electric heater to produce more heat. This was done until the heat and electrical loads are both met. This system worked efficiently as long as the heating needs were larger than the electrical load.

## III. Recommendation

It is recommended that the internal combustion engine using natural gas with the thermal demand strategy be used for the residential distributed energy generation. The system proved economically superior to the other systems, and by using natural gas, adverse emissions are reduced. Recalling the internal combustion engine with the thermal strategy, the energy generation is based on the residential heating needs. This strategy allows the system to run at maximum efficiency during these times of heating needs.

The internal combustion engine could easily be implemented into not only new houses but also existing residences as well. The national infrastructure can support such a system because it runs on natural gas. Creating onsite electricity and thermal energy improves the overall efficiency, and therefore, reduces the carbon dioxide emissions to 0.48 lbs/kWh. The payback period for the internal combustion engine with the thermal demand strategy is 1.70 years with an internal rate of return of 119%.

It is proposed to implement the system in the Advanced Energy Technologies Lab at the Milwaukee School of Engineering. The system could then be analyzed and compared to conventional methods of generating electricity and thermal energy.

# IV. Timeline

The timeline for the design project is outlined in *Table 5*. The table contains the duration of the project from the start date to the finish date and the resources allocated for the particular task. Resource allocation does not exceed 85% per person in case of any unforeseen circumstances that would require immediate attention. Due to the small size of the design group, tasks will be completed by all group members at different contribution levels. The contribution levels are denoted by the percentage next to each resource name. The remainder of the design project is divided into the two quarters as denoted by the blank row in *Table 5*. The Gantt chart for the design project is located in *Appendix III*.

**Table 5 Timeline for the Design Project**

| Task Name | Duration | Start | Finish | Resource Names |
|---|---|---|---|---|
| Acquire Funding/Material | 115 days | 11/28/07 | 05/05/08 | Matt[20%],Jenny[20%],John[20%],Mike[20%] |
| Determine Constraints | 6 days | 11/27/07 | 12/04/07 | Matt[50%],Jenny[50%],John[50%],Mike[50%] |
| Create Flow Diagram | 3 days | 12/04/07 | 12/06/07 | Matt[50%],Jenny[50%],John[50%],Mike[50%] |
| Design/Choose Components | 46 days | 12/06/07 | 02/07/08 | John[65%],Jenny[65%],Matt[50%],Mike[50%] |
| Model Entire System | 6 days | 02/07/08 | 02/14/08 | Matt[65%],Mike[65%],Jenny[60%],John[60%] |
| Prepare Presentation | 12 days | 02/07/08 | 02/22/08 | Matt[65%],Jenny[65%],John[65%],Mike[65%] |
| Present Presentation | 1 day | 02/22/08 | 02/22/08 | Matt,Mike,Jenny,John |
| | | | | |
| Design System Interface | 10 days | 03/03/08 | 03/14/08 | Matt[50%],Mike[50%],Jenny[30%],John[30%] |
| BuildComponents | 32 days | 03/03/08 | 04/15/08 | John[50%],Jenny[50%],Matt[30%],Mike[30%] |
| Assemble Components | 11 days | 04/16/08 | 04/30/08 | Matt[65%],Jenny[65%],John[65%],Mike[65%] |
| Run and Test System | 14 days | 05/01/08 | 05/20/08 | Matt[50%],Jenny[50%],John[50%],Mike[50%] |
| Prepare Final Presentation | 8 days | 05/13/08 | 05/22/08 | Matt[80%],Jenny[80%],John[80%],Mike[80%] |
| Present Final Presentation | 1 day | 05/23/08 | 05/23/08 | Mike,Matt,Jenny,John |

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