Collaboration for Aquaponics Sustainable Energy

A Low Carbon Emitting Energy Source for Urban Aquaponics Systems

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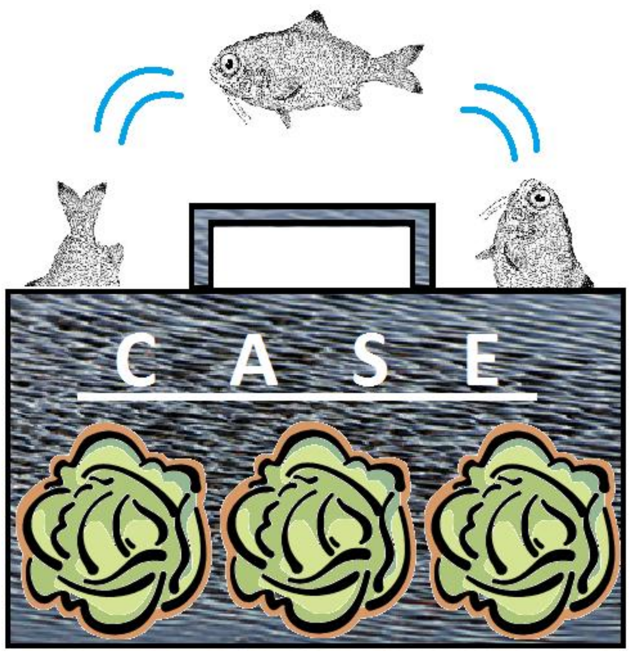
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1 EXECUTIVE SUMMARY

Cogeneration is when one fuel source satisfies two different power requirements. In this design, natural gas will satisfy both heat and power requirements for an aquaponics system. Thermal heat will be used to maintain fish tank temperatures at approximately 80°F year round. The engine will provide shaft power to run the recirculation and aeration pumps. The benefit of using cogeneration for this application when properly sized for the thermal load is an overall efficiency between 65%-80% while the electricity from a coal-fired power plant will have an efficiency of 30%-35%. This leads to greenhouse gas emission (GHG) benefits as well as lower operating expenses that will be quantified for the designed system in the next report. The design is expected to operate at a carbon dioxide emission rate of less than 610 grams of CO_2 per kWh of electricity which is what Milwaukee emits at its power plants.

Aquaponics is a sustainable farming practice that merges plant growth with raising fish. These systems are cyclic in nature where fish effluent provides nourishment to plant life while the plant life converts toxic fish waste to clean water that returns to the fish tank. Background is given to advantages of aquaponics over more traditional methods of farming as well as primary types of aquaponics systems. Important design parameters used in this proposal are hydraulic loading rate, hydraulic retention time, fish tank size, grow bed area and water flow rates. These parameters were then used to estimate the electrical power requirements for the pumping and aerating the fish water. A 3785 L media filled aquaponics system was estimated to have a power requirement of 0.273 kW and a heating requirement of 0.755 kW. A refined model for system sizing will ensue next quarter, but the initial results point to a match of power and thermal demand to thermal and power supply assuming the engine is 30%-35% efficient.

Organic waste streams associated with aquaponics systems make biogas capture and use as a fuel to generate power a viable option eco-conscious choice. Therefore biogas will be considered in this design but the specifics of anaerobic digester design and implementation will not be covered. Attention will be given to the environmental and economic impacts of running the system on a biogas fuel. The engine will be designed to run on natural gas because of its low carbon dioxide and hydrocarbon emission in comparison with 2-stroke engines ran on gasoline. Natural gas is also a readily available fuel source making the design more applicable to a wider audience.

Initial feasibility studies show that a natural gas CHP system could have a payback system of 6 years while a biogas ran system will have a payback period of 5 years. These values are preliminary and are likely to decrease as the design becomes clearer. The payback period is strongly dependent on the power provided and the initial costs of the system which will both be refined as the project continues. The most optimistic case of a solar thermal system had a payback period of 9 years not including installation costs.

The outcomes of this senior design project is to develop a combined heat and power engine set configured to meet the energy demands of aquaponic systems at different scales. Additionally, the design process will be detailed in a report to guide CHP design and improve energy efficiency for different size aquaponics systems. Software will be developed to complement the detailed design report and could be used for parametric study.

2 PROJECT STATEMENT

CASE's aim is to power an aquaponics system through the conversion of rejected biomass into heat, electricity and compressed air. The designed system will reduce the carbon footprint of green urban farming and lower operating expenses. The concept of using biogas in conjunction with combined heat and power (CHP) technologies is chosen to provide aeration for fish tanks, water pumping, and hot water for a recirculating aquaponics system found in urban farming operations. The final design will be the result of a collaborative effort between relevant industry partners.

3 BACKGROUND

Aquaponics is a new and emerging practice. Although there are functioning systems in existence, the fact that aquaponics is so new has left the optimization of the operation overlooked. Additionally, the new move towards green energy makes an engineered energy solution all the more vital. Through this analysis, a best practices manual will be developed and help make aquaponics an efficient and more sustainable process. The best practices manual will have the function of determining an efficient way to power varying sizes of aquaponics operations and provide an engineered approach towards making the system cost effective and environmentally responsible. Although the best practices manual will be the main outcome, additionally a prototype will be designed and constructed to be used as a demonstration project for Growing Power, an urban aquaponics operation located in Milwaukee, Wisconsin. The demonstration project will be used to show interested tourists and potential aquaponic farmers not only how to build a system, but how to efficiently power it.

3.1 URBAN AQUAPONICS

The term aquaponics refers to "the cultivation of fish and plants together in a constructed, re-circulating ecosystem utilizing natural bacterial cycles to convert fish wastes to plant nutrients" [1]. The idea of aquaponics can be deemed somewhat revolutionary, due to the fact that it is less than fifty years old and still not very well researched or known. This simple, yet brilliant, idea is constantly evolving and motivating others towards conservation and sustainable programs.

The early beginnings of aquaponics began in the 1970's with a couple from the New Alchemy Institute, a research center located near Cape Cod, Massachusetts. This couple formulated the idea that through combining fish tanks with vegetable plants, nourishment would be gained by converting ammonia from fish waste into nitrogen for plant fertilizer. This nitrogen is critical to plant growth. Aquaponics saw larger growth during the 1980's, when college professors and colleges began bringing this idea to the forefront of the conversation on hydroponics, which is the growing of plants in nitrogen rich water with no soil. The alternative, aquaponics, has proven to be more efficient than its predecessor hydroponics. Aquaponics truly began to take off when Will Allen began experimenting with a piece of land on the outer edges of Milwaukee. His successful experiments proved the potential of aquaponics and sustainable agriculture in transforming the surrounding urban community. With his success, he was able to found Growing Power, which is a beacon of hope for the surrounding community [2].

Today, aquaponics is gaining popularity with achievements like Will Allen and Growing Power. The publicity will help show the promise and efficiency of the aquaponics system not only in urban settings, but rural as well. With the success of Growing Power, many other startups have arisen showing that the success of Growing Power can be duplicated. For example, another urban farming and aquaculture operation is Sweetwater Organics also based in Milwaukee. As interest continues to rise, the funding and economic feasibility of aquaponics will increase.

Aquaponics takes into account the advantages of both hydroponics and aquaculture, while minimizing the disadvantages of each system. The comparison can be seen in Table I.

TABLE I: COMPARISON OF VARIOUS FORMS OF FOOD PRODUCTION (ADAPTED FROM [3])

	Advantages	Disadvantages
Organic Farming	- Presumed as a healthier method of growing food than commercial farming and thus has become popularized - Uses organic wastes as fertilizers. - Uses natural pest control. - Tends to produce better tasting and at times more nutritional crops.	- Requires more land than conventional farming. - Often higher costs to grow and certify crops. - Agribusiness is quickly replacing small-scale organic operations.
Inorganic Hydroponics	- High volumes of food are produced in a small space. - Has potential for year-round production if controlled.	- Highly dependent on costly manufactured/mined fertilizers.
Recirculating Aquaculture	- High biomass of fish produced in a small space.	- High rate of failure due to small margin for error. - Large waste stream produced.
Aquaponics	- All of the advantages of the other methods and additionally: - Reuse of fish waste as nutrients for plants. - Fish don't carry the pathogens (e.g. E. coli and Salmonella) found in warm-blooded animals. - Imitates a natural cycle and is the most sustainable of the four methods. - Consistent fish biomass in the fish tanks lets plants grow and thrive.	- Operator must have knowledge of both fish and plants production. - Major fluctuations in fish stocks in the tank can disrupt plant growth.

The use of aquaponics takes into consideration the disadvantages of both hydroponics and aquaculture. The disadvantages were being highly dependent on costly fertilizers and large waste stream produced for hydroponics and aquaculture, respectively. The fish waste, which is harmful to the fish if not re-circulated and filtered, is used by the plants as the fertilizer substitute. As the water from the tank funnels over the plants and the roots, the roots filter out the toxics and are used as nutrients before they enter the watershed. This represents a continuous closed-loop system [4].

There is no single model for the aquaponics design. However, several designs standout above the rest and are determined by the components it uses and whether or not it employs a media for the plant roots. The four most common types of aquaponics systems are media filled, flood and drain, nutrient film technique, and floating raft systems [4].

Media filled systems are important because they use a media in which plant roots are grown. This brings down the bottom line for the cost of the project. Fish waste is collected in the media and is processed by the bacteria present in within it. This is why the need for a biofilter and separate settling tank can possibly be avoided. If the media is not present, the biofilter and separate settling tank are needed so that the water can be cleaned and deemed habitable by the fish occupying the tank [4].

The next system is known as the flood and drain system. The flood and drain system is known for its simplicity, reliability, and user-friendliness. Plant roots are soaked in a concentrated nutrient solution until the solution has been drained. This procedure can be repeated several times a day to supply the plants with the necessary nutrients. This system does not require a medium for the roots, but a media can be used [4].

Nutrient film technique relies on the plant roots being exposed to a thin sheet of nutrient water, which runs through a pipe. This technique relies on the need for the water to reach the bottom layer of the roots. The remaining layer of the roots is portioned off to allow for a sufficient oxygen supply. In this system, the biofilter becomes critical as there is no media for bacteria to be sustained [4].

The last common system is the floating raft system. In this system, the plants are grown on lightweight rafts, most commonly used is Styrofoam. The plants are suspended by nets and roots allowed to extend into the water. With this system, the water beneath the rafts is much greater than any of the previously discussed methods. Since that is the case, the nutrients tend to become less concentrated and therefore higher feeding rates for the fish are needed. The water still needs to be circulated and a biofilter possibly used [4].

3.2 DIGESTER

Biogas is a type of natural gas that is produced by decomposing once living matter (biomass) into primarily methane. The volume of biogas released during decomposition is largely dependent on the type of biomass used, the time of season the crop was harvested as well as lipid and carbohydrate content. Biogas can be produced using many different biomass sources including municipal organic wastes, crop residue, manure and others. Table II shows an approximate energy content per ton of dry matter for several waste streams. This can be used to characterize the potential methane production for urban farming and determine if certain waste streams can provide the fuel required to heat, aerate and pump fish tanks.

TABLE II: BIOGAS YIELD FROM DIFFERENT RAW MATERIALS (ADAPTED FROM [5])

Raw Material	Estimated dry matter content (%)	Biogas yield (GJ/dry tonne)		
		Best estimate	Low value	High Value
Manure-cow	8	6.2	5	8.5
Manure-pig	8	7	5.6	8.5
Grease separator sludge	4	22	20	27
Ley crops	23	10.6	5.3	13
Municipal organic waste	30	12.4	10	14
Slaughterhouse waste	17	9.4		
Tops and leaves of sugar beets	19	10.6	7.8	14
Straw	82	7.1	5.3	8.5

Anaerobic digestion is a method of decomposing biomass using microorganisms in the absence of oxygen. The methane byproduct is collected and can be refined to compressed natural gas (CNG) for transportation or electricity and heat generation. Biofuel is 40-70% methane by volume, 30-60% carbon dioxide, and 1-5% of other gases including hydrogen sulfide and hydrogen [6]. Biogas must be treated for humidity and hydrogen sulfide before used in an internal combustion engine. A schematic overview of an anaerobic digester is shown in Figure 1.

A major drawback is that current digester technology is suited for large scale biofuel production and has high investment costs. Nevertheless, the environmental benefits and long term financial be rewards can outweigh the initial investment costs.

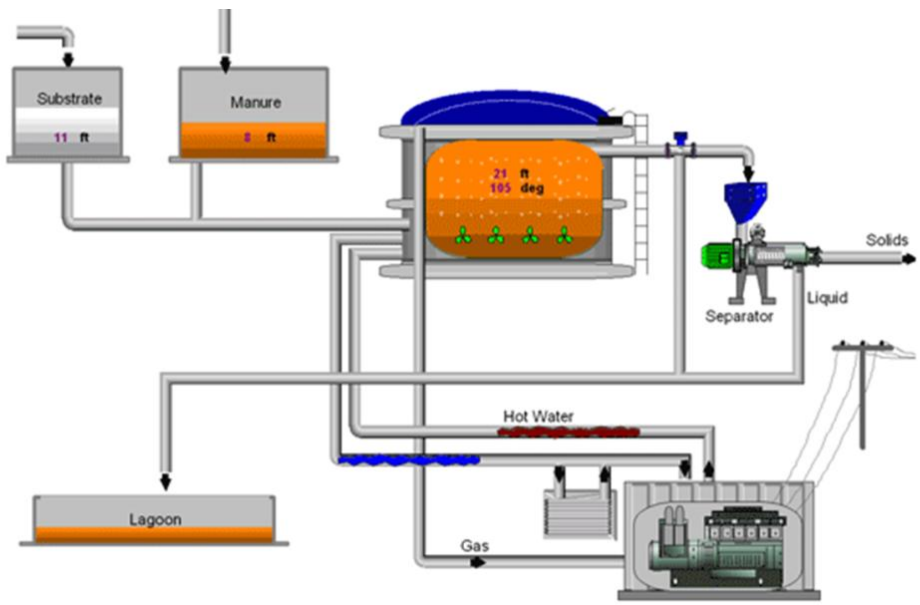


FIGURE 1: SCHEMATIC OF AN ANAEROBIC DIGESTER WITH COMBINED HEAT AND POWER (ADAPTED FROM [7])

Urban farming can stand to benefit from utilizing biogas in a CHP system because of the readily available organic waste used in composting. Urban farmers, like Growing Power in Milwaukee, have municipal organic wastes donated from breweries and area grocers to compost into high quality soil. In addition to biogas production anaerobic digestion can produce high quality fertilizer as well as compostable solids.

3.3 BIOGAS IN URBAN FARMING

Large quantities of organic waste, which are a typical byproduct of any aquaculture or agriculture operation, yield a great potential for the production of biogas. Biogas, which is primarily composed of methane (CH_4) and carbon dioxide (CO_2), is a naturally occurring byproduct of decomposition of organic matter. However, the control and capture of methane has recently gained attention for two primary reasons: (i) atmospheric methane has a significant global warming potential relative to CO_2 [8] and (ii) the energy potential of biogas makes it an excellent candidate as a substitute for natural gas. Urban aquaculture or agriculture operations may have livestock manure, industrial food waste, and other non-consumable plant matter which must be dealt with in a respectable way which is in compliance with the zoning of the area. Through the use of an anaerobic digester, the decomposition of these contaminates can be performed in a way which will minimize any impact on the surrounding community, while allowing for the collection of biogases and nutrient rich digestate.

In the design of the combined heat and power system for urban aquaculture operations, the design of an anaerobic digester will be beyond the scope of this project. However, attention will be paid into the economic and environmental benefit of the incorporation of such a system, along with the processing necessary to make biogas feasible with CHP systems.

Considerations of the design will include, but are not limited to: refinement of biogas, impact of sulfur based compounds on engine performance, and expected biogas production for various organic waste compositions. A feasibility study will be performed utilizing the CHP system at Milwaukee School of Engineering where the performance of the system will be investigated under various biogas mixtures. The results will be used to characterize the operation performance of a CHP system operation system relative to natural gas operation.

To perform this feasibility study all necessary equipment is available in the Advanced Energies Technology Laboratory at Milwaukee School of Engineering with exception to the biofuel and minor hardware necessary for it to be integrated.

3.4 Combined Heat and Power Cogeneration

The current electrical infrastructure which utilizes large, centralized power plants is inefficient due to high transmission and distribution losses in addition to high conversion losses [9].The result is that approximately one third of the energy contained in the fuel is converted to electricity made available for use, while the remaining two thirds is lost as heat [10]. It is possible to capture this 'waste' thermal energy and use it for a practical purpose. This is considered combined heat and power, CHP.

CHP is difficult to implement effectively with centralized power plants because these plants are generally located far from where the electricity is ultimately used. Certain power plants, such as the Valley Power Plant in Milwaukee, are located where combined heat and power is practical. The Valley Power Plant is a coal based power plant adjacent to downtown Milwaukee that provides both electricity and steam [11]. The Valley Power Plant is located where the thermal energy can be utilized, but most often this is not the case. Although CHP can be done at centralized power plants, it is not common.

Distributed power generation is where the electricity is generated at the site where it is to be used. The efficiency of these systems in electricity generation is generally lower than the efficiencies achievable by large power plants, but transmission and distribution losses are minimal for the distributed power generation systems [12]. A great advantage of distributed power generation systems is the ability to implement combined heat and power. The 'waste' heat normally associated with electricity generation can be used more easily than with a centralized power plant. Distributed combined heat and power is capable of achieving high overall efficiencies which can lead to cost savings when compared to purchasing electricity and energy for heating separately. The increase in overall efficiency also leads to lower emissions of CO_2 [9].

The general idea that includes combined heat and power (CHP) is cogeneration. Cogeneration is the use of a single fuel source to achieve multiple forms of useful energy [13]. This often includes thermal, mechanical, and electrical energy. The useful forms of energy obtained using a CHP system are electrical and thermal power [13]. CHP is most often implemented using a reciprocating internal combustion rather than other technologies such as fuel cells and gas turbines. This is mostly due to the versatility of reciprocating internal combustion engines and their low cost made possible by high production volumes.

A reciprocating internal combustion engine – generator with combined heat and power is comprised of five core components. The first is the prime mover, or in this case, the engine. The second is the generator which is often synchronous to allow for net metering with the local electric utility. The third, fourth, and fifth are the heat recovery system, heat rejection system, and electrical connection system [14].

CHP systems are generally identified by the prime mover. In general, diesel and natural gas engines are common and economical. Diesel engines are known for high efficiencies and are capable of operating with a large range in fuel quality which can include bio-diesel or algae-based diesel. Diesel engines have relatively high emissions of NO_X and particulates, but natural gas spark ignition engines have superior emission profiles [14]. Natural gas generators are the most common for CHP applications and routinely achieve overall efficiencies between 65-80% when combining electrical and thermal power output [14]. Natural gas engines are also capable of using different fuel qualities to allow for the use of field gas, pipeline quality gas, or biogas [14]. It should be noted that using alternative fuel sources requires careful consideration due to compositional differences and contaminants.

CHP systems are normally sized based on the thermal load required. This allows the generator to run near fully loaded where it is most efficient. If there is excess electrical capacity, it can often be sold back to the local electric utility.

Aquaponics and CHP are a natural fit. Pumps and compressors must be run, and the tank must be heated. There are both thermal and electric load requirements which could be met with CHP system. This can be used to reduce operating costs and CO_2 emissions. Another approach would be to use a cogeneration system to obtain only mechanical and thermal power. The mechanical power would be used to drive pumps and compressors while thermal energy would be used to heat the tank. It may also be possible to use the waste stream of an aquaponics system to create biogas by anaerobic digestion to power a natural gas, reciprocating internal combustion engine for cogeneration.

4 Specifications

This section presents the design specifications and considerations for an aquaponics system. These specifications and considerations include general design goals, constraints, environmental impact, budget, risks, testing, and maintenance.

4.1 Design Goals and Constraints

The overall project goals are:

- To develop a thermal model of an aquaponics system
- To determine the electrical and/or mechanical needs of an aquaponics system
- To develop an economic model for a combined heat and power (CHP) system
- To determine the environmental benefit of incorporating a CHP system
- To determine the necessary refinements to enable running a CHP system on biofuel
- To develop a best practices manual based on thermal, electrical and/or mechanical needs
- To construct a demonstration prototype for Growing Power based on best practices manual
- To create a program which allows users to calculate a best practice approach

In order to develop a best practices guide for an aquaponics energy system, goals and constraints must be set in order to focus the effort. The goals and constraints for both the aquaponics system and the energy system are outlined in this section.

Aquaponics:

- Maintain fish tank temperature between 55°f-85°F
- Greenhouse environment between 45-60% relative humidity and 55-85°F
- Consider both natural and artificial lighting for best practices simulation
- Fish tank size constraint 1,000-10,000 gallons
- Aquaponics system located in a greenhouse or indoor factory space

Power Production:

- Less than 610 g/kWh CO_2 emissions (current Milwaukee emission statistic)
- Meet environmental standards for noise and ventilation
- Provide power to aerate, heat, and pump tank water
- Lowest cost or least environmental impact
- Minimize initial expense
- Minimize payback time
- Operating on natural gas and/or biogas (if feasible)
- Continuous operation with expectation of maintenance shut-downs
- Backup fish aeration and pump system

4.2 Environmental Impact

As previously mentioned one of the design parameters for the CHP system requires a decrease in emissions green house gasses, the primary of which will be carbon dioxide. The emission of green house gasses from the designed system per unit energy will be compared against those released to produce the same ratio of energy from conventional electrical and thermal energy generation sources independently. A method of determining the resulting net emissions resulting from independent generation is presented in the following equation.

$$\Upsilon_{net} = \Upsilon_{electricity} + r_{thermal}\Upsilon_{thermal} \tag{4.6.1}$$

Where $\Upsilon_{electricity}$ and $\Upsilon_{thermal}$ are the direct emissions associated with the production of electrical and thermal power independently per kWh, and Υ_{net} is the net emissions associated with the production of the energy. Finally, $r_{thermal}$ is the ratio of thermal output to electrical output, which will hereafter be referred to as the power ratio. The CHP system designed must achieve a CO_2 emissions level less than net emissions found using the previous equation. If the demand for onsite electrical consumption is less than the power provided by the system, and energy to grid technology is utilized by the aquaponics operation, the returned electricity will be discounted from the net emissions of the CHP unit at a rate equivalent to what is emitted by the utility.

To understand the emissions of unit energy of electricity it becomes necessary to quantify the carbon emissions per unit energy based on the energy profile of the local utility. The energy profile for Wisconsin Energy Corporation is compared against the national average in Table III.

TABLE III: ENERGY PROFILE

Energy Source	We Energies [15]	US Standard [16]
Renewable	3.4	10.6
Biomass	0.8	1.4
Hydroelectric	1	6.9
Solar	0	0
Wind	1.6	1.9
Geothermal	0	0.4
Coal	53.9	44.45
Natural Gas	11	23.31
Nuclear	27.7	20.22
Oil	0	0.99
Other	4	0.57
Total	100	100

For this analysis, the CO_2 emissions per unit energy will be considered over the life time generation. Sources that have emissions associated with construction and demolition will included include these emissions along with the direct emissions of the technology. As a result, renewable sources, which include hydroelectric, solar, and wind, result in minor CO_2 emissions per unit energy produced. For comparison on a similar basis, the CO_2 emissions associated with the manufacture of the CHP system will need to be estimated. This will require a more detailed design before an exact value can be obtained. The CO_2 emissions are shown in Table IV.

TABLE IV: CO_2 EMISSIONS BASED ON FUEL AND SOURCE [17]

Source	Configuration/Fuel	Estimate gCO_2e/kWh
Wind	Onshore	9
Hydroelectric	Run-off-river	10
biomass	Forest wood	22
Solar PV	Polycrystalline silicone	32
Geothermal	Hot dry rock	38
Nuclear	Various reactor types	66
Natural Gas	Various combined cycle turbines	443
Heavy Oil	Various generator and turbine types	778
Coal	Various generator and turbine types with scrubbing	960

Applying the previous emissions to the energy profile Wisconsin Energy Corporation and the US standard yields estimated emissions per kWh of electricity produced for both Milwaukee and the national average. These results are presented in Table V.

TABLE V: CO_2 EMISSIONS FOR ELECTRICITY PRODUCTION ([15] AND [16])

Profile	Estimate gCO_2e/kWh
Milwaukee	610
National Average	555

Typically, thermal energy for aquaponics operations is generated through natural fired gas water heaters. Therefore, quantifying emissions associated with the production of thermal energy will be based on typical efficiencies for natural gas water heaters sized for residential use. Assuming complete combustion and lower heating values, the ideal system yields a CO_2 production rate of 197.8 gCO_2e/kWh per kWh of thermal energy. To obtain CO_2 emissions for real systems, the previous emission rate can be divided by the rated thermal efficiency of the system. Thermal efficiencies in the range of water heaters and their resulting emissions are presented in Table VI.

TABLE VI: NATURAL GAS WATER HEATER EMISSIONS AND EFFICIENCY [18]

Efficiency	Estimate gCO_2e/kWh
0.60[1]	330
0.75	263
0.86[2]	230

1. Conventional Gas Storage
2. Condensing Gas Storage

A mid-range efficiency of 0.75 percent was selected for this preliminary analysis. For the best practices manual, an exact annual fuel utilization efficiency (AFUE) will be approximated once a full thermodynamic model is developed and a more detailed understanding of the thermal load profile is obtained.

In the next phase of this project a more developed emissions model will be created based on the thermal load of the system, power ratio of the system, and onsite consumption of electrical energy. Additionally, a study will be conducted into what extent the use of biogas can be discounted from the net CO_2 emissions of the system. This study will take into account the global warming potential of the captured methane relative to CO_2 in addition to overall CO_2 emitted by the process.

4.3 Federal and State Incentives for CHP Systems

In order to minimize the payback period of proposed design, the system will be designed for compliance with existing standards for federal and state green energy incentives. Incentive programs were found and have been taken into account for the design criterion. It should be noted that not all operations are eligible for every incentive programs since many are designed for corporate and nonprofit organizations only. The federal government sponsors several programs which are available to applicants around the country in addition to programs which are sponsored by the states for which their respective residents are eligible. Of the discovered incentive programs, only one federal program was found. Several state programs exist in Wisconsin through the Focus On Energy Program all of which have since expired (see [19] and [20]). It was noticed that the requirements for the federal incentives are very similar to the expired state programs. Therefore, through meeting the requirements for the federal program the system will likely be eligible for any state incentives upon their reenactment.

4.3.1 Energy Improvement and Extensions Act

The Energy Improvement and Extensions Act enacted in 2008 established a corporate tax credit program for the development and installation of CHP systems. This program provides federal incentives for CHP systems up to 50 MW. In 2009 the act was again further expanded under The American Recovery and Reinvestment Act of 2009. This federal incentive program is available for any CHP system installed prior to January 1, 2017 and meets the stated criteria [21]:

- Installed system must not exceed 50 MW
- Must obtain a minimum of 60 percent minimum efficiency.
- Systems operating on 90 percent or more biomass based fuels are exempt from the previous limitation.
- At minimum 20 percent of the useful energy must be utilized for heating and 20 percent electrical needs.

Systems which met the previous criteria are eligible for up to 10 percent tax credit based on investment costs for the installation year. In order to minimize the payback period of the project the previous criteria will be incorporated into the design constraints of the system.

4.4 BUDGET

The project budget includes labor, materials, and overhead costs. The labor in the project includes all time required to create a best practices guide and to create the representative CHP system. The labor costs are given in Table VII.

TABLE VII: PROJECTED LABOR COSTS

Labor Resources	Hours	Hourly Rate	Subtotal	Source
Team Members	2700	$16	$43,200	Donation
Advisor	90	$75	$6,750	Donation
Professional Expertise	40	$50	$2,000	Donation

The material costs given in Table VIII are estimates for building a representative aquaponics system.

TABLE VIII: PROJECTED MATERIAL COSTS

Materials	Qty	Cost	Subtotal
1.2 kW Portable Generator	1	$300	$300
Heat Exchangers	2	$600	$1,200
Lumber	1	$250	$250
Fish Grade PVC Tank Liner	1	$585	$585
Air Pump	1	$100	$100
Water Pump	1	$289	$289
Battery	1	$85	$85
Hardware	1	$300	$300

The estimated overhead costs are given in Table IX.

Table IX: Projected Overhead Costs

Overhead Costs	Percent of Materials	Subtotal	Source
Building Space	10%	$3,420	Donation
Test Lab	10%	$3,420	Donation

The budget totals are given in Table X.

TABLE X: PROJECTED BUDGET TOTALS

Subgroup Totals	
Labor	$51,950
Materials	$2,509
Overhead Costs	$6,839.80
Grand Total	**$61,299**
Donation	**$55,370**
Adjusted Total	**$5,929**

4.5 MAINTENANCE

It is understood that a regular maintenance schedule must be followed to ensure a reliable and long-lasting power system. This maintenance includes regular inspections of critical parts as well as replacement when needed. The engine used must undergo regular replacement of the oil, oil filter, and spark plug. The system wil be designed in a way that allows for easy maintenance without endangering the plant and fish life.

4.6 RISK ANALYSIS

The proposed system must be analyzed for risks imposed on the aquaponics system, energy system, plant life, fish life, and persons working with or near the system. These risks include, but are not limited to, the following.

- Carbon monoxide poisoning
- Noise hazards
- Vibration hazards
- Burn and fire hazards
- Hazards to fish and plant life in the event of component failure
- Fuel leakage
- Oil spill

MSDS sheets for chemicals used are appended to this report. These include ethylene glycol, propylene glycol, and natural gas.

4.7 TESTING

The system must be tested prior to adding plant or fish life to the system. Ideally, the system would be tested in the environment where it will ultimately be used. This testing must be done to prove system safety and functionality.

5 MODELING

While completing the thermal and power analysis it was decided to construct the model for an above ground, cuboid shaped tank. This is based on the stand-alone tank design used by Growing Power and constructed during their training courses. This design provides easy scalability in addition to easy integration into re-purposed industrial buildings with an existing foundation.

5.1 THERMAL LOAD

To better understand the thermal demands of an aquaponics operation a thermal model is currently being developed to quantify the energy losses to the surrounding environment. To perform this analysis an excel worksheet was created which allows users to input system parameters which include, but is not limited to: tank geometries, insulation parameters, ambient conditions, and fluid properties.

Several sources of heat transfer were identified, of which three were determined to be of importance while developing the thermal model. They include: conduction into the ground, evaporation and convection. As a result of foliage located above the water surface which prevents direct solar irradiance from reaching the water surface, it was determined radiation heat transfer from the sun could be neglected. Additionally, only a small temperature difference exists between system and surroundings, thus radiative heat transfer out of the system would be insignificant and was thus ignored.

A diagram of the modeled system with the considered methods of heat transfer is presented in Figure 2.

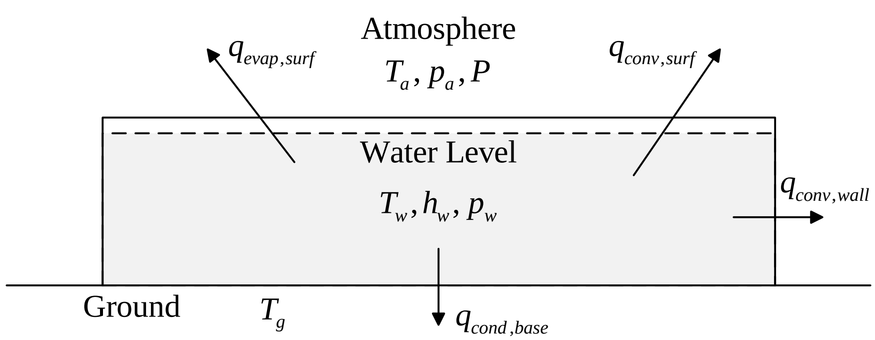


FIGURE 2: TANK HEAT TRANSFER DIAGRAM

The following subsections will detail the development of the model for each form of heat transfer presented in the previous figure.

5.1.1 WALL HEAT TRANSFER

To analyze losses through convection from the sides of the tank a free convection model was chosen as opposed to a forced convection. The indoor environment of greenhouses and re-purposed industrial buildings eliminate the presence of wind, thus making a free convection model more representative. The convective heat loss coefficient is present in the Nusselt number, which is function of the Grashoff and Prantdl numbers for the modeled system. The following derivation has been adapted from Heat Transfer by F.A. Holland et. al [22].

For a vertical plate with uniform wall temperature, no horizontal flow, and upward flow of the natural convection the following relations can be used to link the previous mentioned quantities:

$$N_{NU} = 0.13\left(N_{GR}N_{PR}\right)^{1/3} \tag{5.1.1}$$

When $\left(N_{NU}N_{PR}\right) = 10^9$ to 10^{12} and:

$$N_{NU} = 0.59\left(N_{GR}N_{PR}\right)^{1/4} \tag{5.1.2}$$

When $\left(N_{NU}N_{PR}\right) = 10^4$ to 10^9.

In the previous equations, the Nusselt number is:

$$N_u = hL/k \tag{5.1.3}$$

The Grashof number is:

$$N_{GR} = g\beta\rho^2 L^3 \Delta T / \mu^2 \tag{5.1.4}$$

And the Prandtl number is:

$$N_{PR} = C_p \mu / k \tag{5.1.5}$$

Where the meanings of the symbols in the previous equations have the meanings given in Table XI.

TABLE XI: DEFINITIONS OF SYMBOLS PRESENT IN SIDE CONVECTION THERMAL MODEL

Property	Units	Description
h	Btu/(h ft^2 F)	film heat transfer coefficient
L	ft	height of vertical surface
k	Btu/([h ft^2 (F/ft)]	thermal conductivity of fluid
g	ft/h^2	gravitational acceleration
β	F^{-1}	coefficient of cubic thermal expansion
ρ	lb/ft^3	density of fluid
ΔT	F	temperature difference between outside surface and atmosphere
μ	lb/(h ft)	dynamic viscosity of fluid
C_p	Btu/(lb F)	specific heat of air

A diagram showing the cross section of the tank walls is presented in Figure 3.

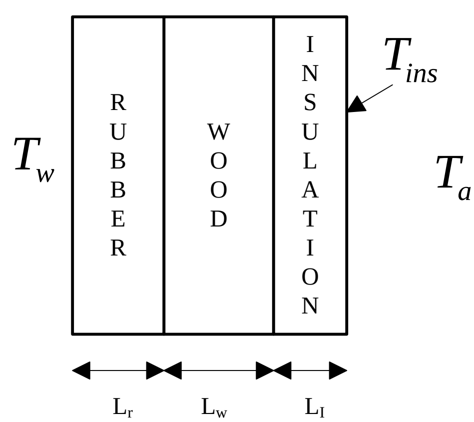


FIGURE 3: CROSS SECTION OF TANK WALL

The ΔT In the previous equations is the temperature difference between the outside surface of the tank, T_{ins}, and the atmospheric temperature, T_a, at a distance which is not influenced by the tank. The temperature at the surface is dependent on the heat flux through the tank, which depends on the film heat transfer coefficient which is a function of the surface temperature. As a result, it is necessary to involve an iterative technique to determine the surface temperature and heat flux through the walls. This process can be performed through solving the following equations:

$$q_{conv,wall} = \frac{T_w - T_a}{R_{Total}} \tag{5.1.6}$$

Where q is the heat flux from the tank and R_{Total} is the resulting thermal resistance determined through the following equation:

$$R_{total} = \frac{1}{A}\left[\left(\sum_{i=1}^{n}\frac{L_i}{k_i}\right) + \frac{1}{h}\right] \tag{5.1.7}$$

And:

$$T_{ins} = A\left(\sum_{i=a}^{n}\frac{L_i}{k_i}\right) q_{conv,wall} \tag{5.1.8}$$

For the iteration method, an initial guess of T_{ins} is made by the user, and the resulting convective heat transfer is determined through equation (5.1.6). An internal iterative solve in excel compares the resulting T_{ins} obtained through equation (5.1.8) to the initial and iterates to converge on a solution based on the difference.

5.1.2 Convection

Evaporation and convective losses from the top surface of the aquaponics tank are based on models developed by R.V. Dunkle and I.S. Bowen. Dunkle performed extensive researched into the modeling of solar distillation ponds and has developed a model for evaporation heat transfer. The environmental conditions of these ponds are very similar to those of aquaponics tanks, thus the theory was adopted for this analysis. Durke concluded that the evaporation heat transfer can be approximated by the following equation [23]:

$$q_e = 0.0254\left[\left(T_w - T_a\right) + \left(\frac{p_w - p_a}{39 - p_a}\right)\left(T_a + 460\right)\right]^{1/3}\left(p_w - p_a\right)h_w \tag{5.1.9}$$

Where:

$$p_a = \phi p_{sat@T_a} \tag{5.1.10}$$

The definitions of each constant are presented in Table XII.

TABLE XII: CONVECTION AND EVAPORATIVE CONSTANTS DEFINED ([24] AND [25])

Term	Units	Definition
q_e	BTU/(hr-ft^2)	Evaporative losses (BTU/hr-ft^2)
T_w	°F	Water temperature (°F)
T_a	°F	Ambient temperature (°F)
p_w	psi	Saturation pressure at the water temperature
p_a	psi	Partial pressure of the water in the atmosphere
$p_{sat@T_a}$	psi	Saturation pressure at atmospheric temperature
P	psi	Barometric pressure of dry air
ϕ		Relative humidity
h_w	BTU/lbm	Heat of vaporization of water (BTU/lbm)

Additionally, I.S. Bowmen has shown that the energy losses of evaporation from a surface of a body of water are related to the convection losses through the following formula [26]:

$$\frac{q_c}{q_e} = 0.004943\left(\frac{T_w - T_a}{p_w - p_a}\right)\frac{P}{14.7} \quad (5.1.11)$$

Where q_c is the convective (BTU/hr-ft^2) and P is the barometric pressure in (psi).

5.1.3 Conduction

A simple conduction model was assumed for the heat transfer between the bottom of the aquaponics tank and the ground. For the development of this model it was assumed the ground was a semi-infinite body of constant temperature. The resulting heat transfer becomes:

$$q_{cond,base} = \frac{\left(T_w - T_g\right)}{R_{base}} \quad (5.1.12)$$

Where R_b is the combined thermal resistance of the bottom of the tank determined by:

$$R_{base} = \frac{1}{A}\left[\sum_{i=1}^{n}\frac{L_i}{k_i}\right] \quad (5.1.13)$$

For this model it is assumed that no additional insulation other then the wood and rubber tank liner is present as a result of the structural requirements of supporting the tank weight.

5.1.4 Results

The previously derived model was applied to an estimated load which is representative of typical conditions in a greenhouse environment. The assumed environmental and tank parameters are presented in Table XIII and the resulting thermal losses are shown in Table XIV.

TABLE XIII: ENVIRONMENTAL AN TANK PARAMETERS

	Property	Value	Units
Tank	Tank Width	4	ft
	Tank Height	4	ft
	Tank Length	8	ft
	Water Temperature	80	°F
	Additional Insulation	None	
Environment	Atmospheric Temperature	60	°F
	Atmospheric Pressure	14.7	psia
	Relative Humidity	0.50	

TABLE XIV: ESTIMATED THERMAL LOSSES OF REPRESENTATIVE TANK

Method	Value (Btu/hr)
$q_{evap,surf}$	956
$q_{conv,surf}$	247
$q_{conv,wall}$	857
$q_{cond,base}$	516
Total	2576

The values presented in the previous table are approximate values based on a single environmental condition for the tank. During the second phase of this project, a load profile will be developed where representative environmental parameters will be obtained for various times throughout the year. From this profile, a more representative load model will be developed.

5.2 Mechanical Load

Mechanical power requirements of an aquaponics system are primarily the power to pump and aerate the water. An Excel spreadsheet where a user can specify fish tank (rearing tank) volume and a few other design parameters and an estimate of mechanical power is calculated. An electrical requirement may be required for artificial lighting in unused manufacturing space that is common to urban aquaponics, but will not be considered in the design proposal.

5.2.1 Large Scale Raft Aquaponics Sizing

A raft aquaponics system developed by James Rakocy and the University of the Virgin Islands (UVI) will be used to better understand power requirements such as pump work, and tank aeration for larger systems. The power requirements and major dimensions of the UVI system are given in Table XV. The rearing tank volume is replaced 1.37 times per hour. The net energy consumption for continuously running blower and water pumps is 53.68 kWh. It is assumed that the UVI system was run from electrical energy and no thermal energy requirements due to the Caribbean climate.

TABLE XV: PHYSICAL DIMENSIONS OF THE UVI RAFT AQUAPONICS SYSTEM [23]

Parameter	English Unit	Metric Unit
Rearing Tanks	8,240 gallons	31,200 Liters
Total Water	29,375 gallons	110,000 Liters
Total Growing Area	2304 sq. ft.	214 sq. meters
Flow Rate	100 GPM	380 Liter/Min
Water Pump	0.5 Hp	0.37 kW
Blower (Plants and Tanks)	2.5 Hp	1.85 kW
Daily Energy Consumption	53 kWh	53 kWh

5.2.2 Medium Scale Recirculating Aquaponics Sizing

A smaller 3785 Liter recirculating aquaponics system will now be analyzed for mechanical energy inputs. This size of system would be commonly employed in backyard applications. A key feature of this type of aquaponics is waste water filtration through inexpensive biofilter material such as coconut husk, gravel, sand and other porous media that is a part of the growing bed.

The growing bed area can be calculated using the flow rate and hydraulic loading ratio (HLR). The fish tank volume will be replaced 1.37 times every hour in accordance with the UVI raft system described previously. The rearing tank is specified by the farmer, in this case 3785 Liters. Therefore, the desired flow rate is 5.185 m^3/hr. The hydraulic loading ratio is a ratio of influent waste stream to area of the grow bed. The HLR is meant to be a measure of nutrient consumption by the growing bed. According to a study, an optimal HLR was found to be 1.28 m/day [28]. The surface area of the grow bed is calculated from equation (5.2.1) and found to be 97.28m^2.

$$A_{GrowBed} = \frac{FlowRate}{HLR} = \frac{5.185\, m^3/hr}{0.0533\, m/hr} = 97.28m^2 \quad (5.2.1)$$

The hydraulic retention time (HRT) is a measure of the time the biofilter and plants have to clear the fish waste from water flowing through the grow bed. The depth of water is calculated using the HRT with equation (5.2.2). According to a study, the ideal HRT is 0.575 hours, so this value is used for further calculation [29]. Growing Power uses a coconut husk biofilter material because it is relatively cheap and lightweight. The porosity (Φ) of the material was found to be 47% [30].

$$WaterDepth = \frac{HRT(Q_w)}{\theta(A_{GrowBed})} = \frac{(0.575\,hr)(5.185\, m^3/hr)}{0.47(97.28\,m^2)} = 0.065\,m \quad (5.2.2)$$

A schematic of the aquaponics system under analysis is given in Figure 4. The pump will supply fish effluent to the top grow bed and gravity will drain back to the fish tank. There are a variety of other configurations possible, but this can be used as a reasonable approximation for pump power requirements.

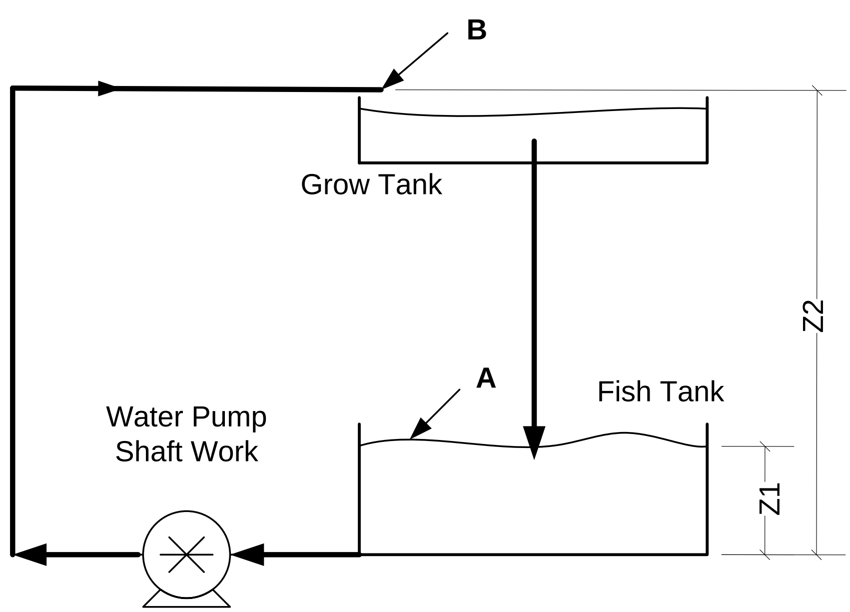


FIGURE 4: AQUAPONICS PLUMBING SCHEMATIC

A modified Bernoulli equation can be written between points A and B and is shown in equation (5.2.3). It is assumed constant 1" diameter cross section and smooth plastic tubing is used. The pressure at A and B are both at atmospheric. The simplified is shown in equation (5.2.4).

$$\frac{P_A}{\rho g}+\frac{v_A^2}{2g}+z_1+h_{Pump}=\frac{P_B}{\rho g}+\frac{v_B^2}{2g}+z_2+K_L\frac{v_B^2}{2g} \quad (5.2.3)$$

$$P_A=P_B=0$$

$$v_A=0$$

$$h_{Pump}=\frac{v_B^2}{2g}(1+K_L)+(z_2-z_1) \quad (5.2.4)$$

In order to calculate the loss coefficient, "K_L", the flow in the pipe must be determined either turbulent or laminar flow. The Reynold's number, "R_e", is a dimensionless parameter used to determine this and is calculated in equation (5.2.5) where dynamic viscosity "μ", density "ρ" are material properties specific to water and "d" is the pipe diameter used. The second parameter needed to find the dynamic friction factor is the relative roughness which is the roughness of the pipe per diameter. A Moody chart was used to reference the friction factor and was found to be 0.022 [31].

$$R_e=\frac{\rho v_B d}{\mu}=\frac{\left(1000\,{}^{kg}\!/_{m^3}\right)\left(2.84\,{}^{m}\!/_{s}\right)\left(0.0254\,m\right)}{0.000894\,{}^{kg}\!/_{m-s}}=80800 \quad (5.2.5)$$

$$R_e>4000\ \therefore\ \text{Turbulent Flow}$$

The equivalent pipe length method of determining friction loss in pipe flow is akin to replacing the elbow in a pipe with a straight length of pipe that would yield the same frictional losses. The equation used to calculate the effective loss coefficient for two elbows is equation (5.2.6) which uses an equivalent length to diameter ratio of 30 for each elbow. It was estimated that 4.5 meters of piping and two elbows were used in the system shown in Figure 4.

$$K_L=(number\ of\ elbows)(f)\left(\frac{PipeLength}{Diameter}\right)=2(0.022)(30)=1.32 \quad (5.2.6)$$

Table XVI shows the applicable loss coefficients and the corresponding equivalent length per diameter. The total loss coefficient is 6.72. The pipe entrance was assumed to be a sharp-edged inlet and the exit was assumed to be an inward projecting pipe.

TABLE XVI: CALCULATING THE EFFECTIVE LOSS COEFFICIENT USING THE EQUIVALENT PIPE LENGTH [32]

	Quantity	Equivalent Length [L/D]	Loss Coefficient K_L
Elbow:	2	30	1.32
Pipe Friction:	N/A	177	3.90
Entrance Loss:	N/A	N/A	0.5
Exit Loss:	N/A	N/A	1
	Effective Loss Coefficient:		6.72

An elevation difference between Z_1 and Z_2 was chosen to be 2 meters. This is slightly taller than the typical elevation difference seen at Growing Power. Solving for the pressure head added by the pump "h_{pump}" from equation (Bernoulli) the pump must add 5.179 meters of H_2O. The mechanical pump work is then found from equation (5.2.7). An estimated 65% conversion efficiency "η" was used.

$$\dot{W}_{mech,actual} = \frac{\rho g h_{Pump} Q}{\eta} = \frac{\left(1000 \,{}^{kg}\!/\!{}_{m^3}\right)\left(9.81 \,{}^{m}\!/\!{}_{s^2}\right)\left(5.18m\right)\left(0.00144 \,{}^{m^3}\!/\!{}_{s}\right)}{0.65} = 112.6W \quad (5.2.7)$$

5.2.3 Medium Scale Aeration Power Requirements

Aerating the water is another power requirement of the proposed aquaponics system. When the water falls from the grow tank back into the fish tank, the water is aerated. However, it is suggested that additional aeration systems are used to ensure the health of fish and plant life. The maximum stocking density of Tilapia when algal blooms are present is 0.06 kg/L of tank volume [33]. The tank under consideration could support approximately 227 kg of Tilapia. Studies have shown that traditional aeration systems can provide dissolved oxygen at a rate of 0.455 kg O_2/kWh. Tilapia will experience faster growth rates at oxygen concentrations greater than 0.298 gram O_2/kg fish/hr. The 227 kg of fish in the tank, in order to promote fast fish growth, must have at least 67.7 grams O_2/hr. The resulting power requirement for aeration is 0.149 kW. [33]

5.2.4 Key Results

The total system power requirement for a 3785 liter is 0.273 kW. These pumps can be expected to run continuously and therefore have a daily energy consumption of 6.6 kWh. The UVI system had an aquaculture tank approximately 10 times the size of the small modular system used for the analysis. The UVI system had a factor of 8 times the daily energy requirement. Next quarter, the effect of scale on aquaponics systems will be fully understood, but at the moment it appears that there is an energy advantage to be gained with greater scale.

6 Potential Designs

The design will use a natural gas engine to provide for the total energy needs of an aquaponics system. This includes mechanical, thermal, and potentially electrical loads. The natural gas engine will be fitted with an exhaust gas heat exchanger to recover thermal energy and use it to heat the water in an aquaponics system.

The engine may be either liquid cooled or air cooled, but it must run on biogas, natural gas, or a blend of the two. This allows for the use of a biogas fuel source which can come from on-site anaerobic digestion of farm waste. If biogas is not available at the project start or becomes unavailable, the engine can still be run using natural gas from the utility. In general, the selection of natural gas engines is limited; however, gasoline engines can be modified to run on natural gas.

The pumps, compressors, and alternators required for the aquaponics system can be driven from the engine shaft power through a gearbox or pulley system. Alternatively, electric pumps and compressors could be used, and the engine could be used to turn an alternator only.

Two options were identified for method of transferring heat from the CHP system to the aquaponics system. The identified methods are:

- Method 1: The tank water would serve as the heat transfer medium between the CHP system and the tank.
- Method 2: A secondary heat transfer fluid in a closed loop serving as a heat transfer medium.

Method 1 would likely yield higher heat transfer effectiveness since less heat exchangers would be necessary in the circuit. This method, however, poses contamination issues where suspended matter in the fluid would passes through the heat exchangers on the CHP system and can potentially obstruct flow the system. Therefore, method 2 was selected.

The selection of the heat transfer fluid in the closed loop is of high importance in the design of the system. In the event of a leakage, the fluid within the loop could be released into the tank and eventually into a food supply. As a result, it is necessary to select a heat transfer fluid that is neither dangerous to humans or the aquaculture. Potential fluids that meet this criterion include water and propylene glycol or a mixture of the two.

During the next phase of this project, a study will be performed utilizing the CHP system in the Advanced Energies Technology Laboratory at the Milwaukee School of Engineering to determine the effectiveness of each heat transfer fluid. There is evidence that the lower specific heat of propylene glycol, relative to water, may yield higher heat transfer efficiency. Since temperature difference is the driving force of heat transfer, a lower specific heat would result in greater temperature gains in the transfer fluid. This study will be performed by studying the existing CHP systems performance while operating with pure water as a coolant and a mixed coolant. It should be noted that if this investigation yields results that suggest water will perform better, propylene glycol will be added to the mixture at a ratio to insure that freezing will not occur and that the system is protected.

Water also must be pumped from the tank to the plants above. This can be incorporated into the heating loop through the heat exchanger, or an independent pump can be used. An alternative approach would be to use an airlift pump.

Compressed air for aeration can be obtained with an electric or belt driven compressor. This compressed air could also be used in an air lift pump.

The tank temperature can be regulated in several ways depending on the heating method used. This includes turning on and off the pump that circulates water through the exhaust gas heat exchanger, bypassing the heat exchanger, or regulating the flow rate through the heat exchanger.

A schematic of a potential design is shown in Figure 5.

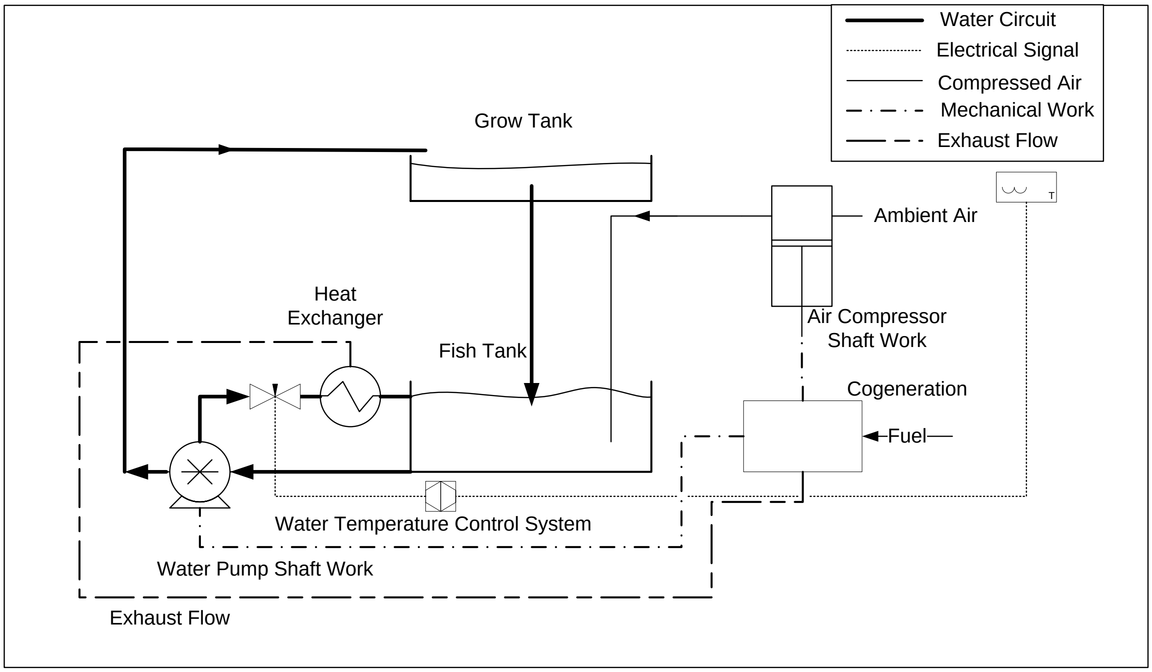


FIGURE 5: SCHEMATIC OF POTENTIAL SYSTEM

7 FEASIBILITY

Initial feasibility shows that using a combined heat and power energy system for aquaponics is feasible with a payback period just over five years. The project utilizes proven technology and is technically feasible. The details are given in the remainder of this section.

7.1 MONETARY FEASIBILITY

In order to determine how effective a system is and to properly choose a system, it is important to create an economic model. This model is a culmination of the data that represents the critical variables of a data set. In this case, the economic model was used to show the variance in cost per kilowatt-hour and payback time. In this model, the system's payback periods were calculated using both natural gas and biofuel.

To start the model, a few inputs are needed in order to calculate values such as the yearly savings and yearly energy costs. The needed inputs are shown in Table XVII. The daily thermal needs were determined using the thermal modeled previously discussed. The daily electric needs of the system were again modeled for size of the tank and needs of the mechanical systems. The utility charge for gas and electricity were gathered from the We Energies site for the average household. The cost for biofuel was taken from a renewable energies website and used as an example if the generation was powered by biofuel. The cost per kilowatt for the system is varying due to different materials could be available at different times and installation costs could vary. The size of the system is relative to the need for the mechanical systems. The maintenance cost was a generalized value that would cover needs such as oil changes, part repair, or part replacement. The thermal efficiency represented the heat that would be able to be saved for the purpose of heating the tank.

TABLE XVII: INPUT VARIABLES FOR ECONOMIC MODEL 00[36]

Variable	Value
Daily Thermal Needs (kWh)	18.12
Daily Electric Needs (kWh)	6.55
Utility Charge for Gas ($/kWh)	$0.0298
Utility Charge for Electricity ($/kWh)	$0.129873
Cost for Biofuel ($/kWh)	$0.023885
Cost per kW for System ($/kW)	Varies ($1500)
Size of System (kW)	1
Maintenance Cost per Year (dollars)	$250.00
Thermal Efficiency (%)	85

Taking these variables and running them through the Excel calculator with calculations in the appendix resulted in the yearly gas need, yearly electrical need, heat produced yearly, and cost of the system. These results can be seen in Table XVIII.

TABLE XVIII: CALCULATED VALUES

Parameter	Value
Yearly Gas Need (kWh)	7780.9
Yearly Electrical Need (kWh)	2390.75
Heat Produced Yearly (kWh)	6613.8
Yearly Gas Cost (dollars)	$185.85
Yearly Electrical Cost (dollars)	$0.00
Yearly Maintenance (dollars)	$250.00
Yearly Savings (dollars)	$289.02
Cost of System (dollars)	$1500.00
Payback (years)	5.2

This economic model takes into account several assumptions which include running the system 24 hours a day and the system will not be shut down for maintenance. Additionally, the daily thermal and electric need is an average taking into account daily temperature changes which vary with climate region. The tank size was simulated at 1,000 gallons for both the electrical and thermal models.

Figure 6 shows the cost of the system versus the payback cost for both running the system off biofuel and natural gas. The equations for the lines are also provided on the graph to illustrate the linearity of each cost. The yearly savings for using biofuel as the main fuel source was approximately $298.02 per year, while the yearly savings for using natural gas $242.99 per year. The more expensive the cost per kilowatt of the system, longer the payback and the greater the margins for using biofuel are.

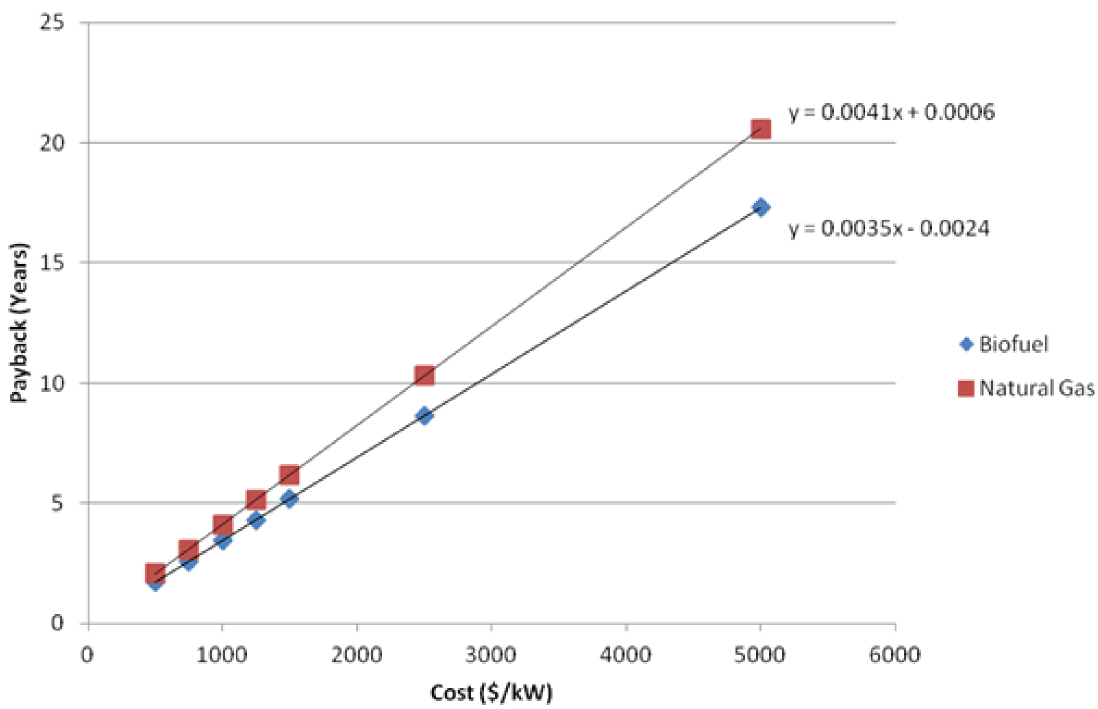


FIGURE 6: PAYBACK TIME OF COGENERATION SYSTEMS WITH SYSTEM COST

A common target for cost was used to compare the system equally and the cost per kilowatt of $1,500 was used. Using this as the main cost comparator and all other variables the same, the payback time for the biofuel fueled system was 5.2 years. The payback for the natural gas fueled system was 6.2 years. Using payback purely as the method of choosing the fuel, the fuel that would be selected would be biofuel. The payback period is a half a year faster for the biofuel, which would be a reasonable choice for choosing biofuel as the main fuel source.

7.2 Technical Feasibility

Aquaponics systems have been around for half a century. As time passes, technology improves, and the cost of operation decreases. This project does not need any under-developed or cost inhibitive pieces of equipment. Equipment such as motors, pumps, and generators are all readily available in the required sizes. The necessary maintenance is not overly burdensome and could be done by a properly trained individual.

8 Alternative Design Option

An alternative design that could be used to deliver the thermal loads for the aquaponics system is a solar thermal system. A solar thermal system would have a large initial cost but the benefit would be the fact that there is no fuel cost since the system uses the sun’s energy to create hot water. The benefit to using the solar thermal system would be that depending on the size of the aquaponics system, the fish tank can act as the storage tank as well as having no fuel cost or harmful emissions associated with the energy generated by the system. However, an additional storage tank would still be needed in scenarios in which the fish tank was at maximum temperature. This additional storage tank would prevent energy from being wasted in this scenario where the tanks cannot be used for thermal storage. Swimming pools have been heated in a similar fashion with notable success and can be used as a good approximation for a system to be installed on an aquaponics system. An example of a solar thermal system for a pool can be seen in Figure 7.

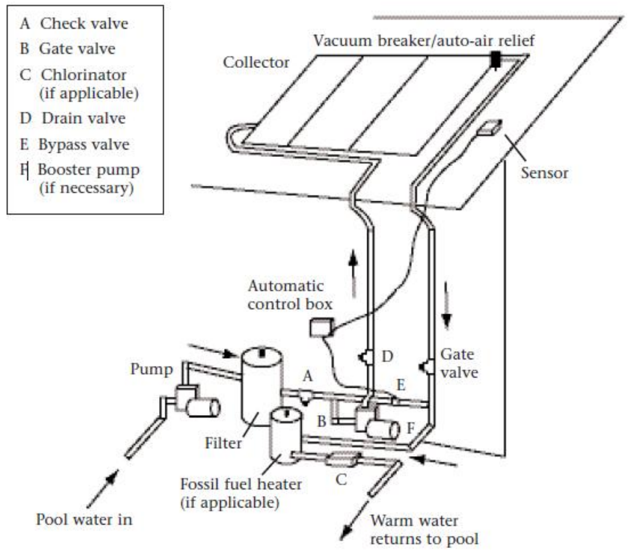


FIGURE 7: SOLAR POOL HEATING SYSTEM (ADAPTED FROM [37])

The biggest concern when using a solar thermal system would be the economic feasibility. A cost analysis was performed using twenty eight different prepackaged solar thermal systems from Caleffi. System costs ranged from $12,000 – $25,000 excluding installation costs. Using a simple payback method as seen in equation (8.0.1), the payback time was calculated.

$$\text{Years} = \frac{\text{System Cost}}{(\$/\text{kWh})(\text{kWh/day})(\text{days/year})} \tag{8.0.1}$$

With the results from equation (8.0.1) it was found that the payback times ranged from 13 – 26 years when replacing electric resistance heaters. The payback time for replacing natural gas water heaters with 80% efficiency ranged from 32 – 67 years. The shorter payback times were for the larger systems in which an output of at least 30 kWh/day was reached. An additional payback was calculated when a 30% federal tax credit was factored in as seen in equation (8.0.2). The federal tax credit was found to be one of the only incentives for the state of Wisconsin outside of loans [38].

$$\text{Years} = \frac{\text{System Cost - 0.3 SystemCost}}{(\$/\text{kWh})(\text{kWh/day})(\text{days/year})} \tag{8.0.2}$$

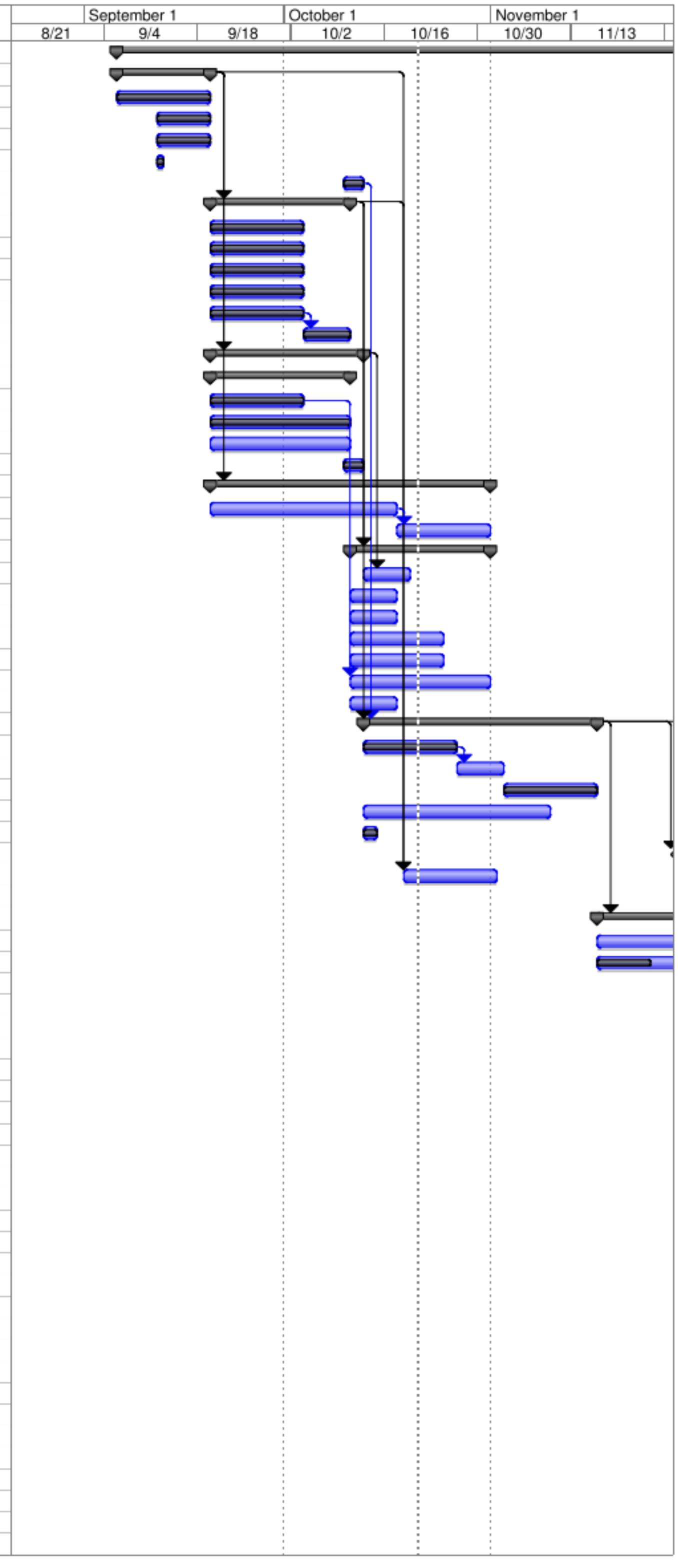
With the results from equation (8.0.2) it was found that the payback times ranged from 22 – 47 years for natural gas hot water heating and 9 – 18 years for electrical hot water heating. For smaller tanks, it was found that electric restive heaters are typically used since the thermal demands of the tank are less then what is typical for natural gas heaters. Additional time would need to be added for installation costs in both scenarios. Furthermore, assumptions were made when doing this analysis. The first assumption is that the given Caleffi values for kWh/day are accurate for everyday throughout a calendar year. The second assumption is that the price per kWh to be saved is $0.11/kWh for electricity and $0.02729/kWh for natural gas.

The scope of the project the payback time is too long for solar thermal systems to be considered. Additionally, the only systems that have considerable payback times are the larger systems which make the scalable process dependent on the size of the solar thermal system and not on the size of the aquaponics system. Despite the long payback time, solar thermal systems have been previously incorporated in aquaponics systems including those used at Growing Power, but this project goal is to explore combined heat and power systems which have been proven to be beneficial conceptually. The proposed design path uses a CHP system alone to validate the conceptual benefit.

9 SCHEDULE

GANTT Chart

ID	Indicators	Task Name
1		**Project Proposal**
2	✓	**Establish Project and Project Group**
3	✓	Define Problem Statement
4	✓	Write project charter
5	✓	Determine file storage method
6	✓	Create weekly update template
7	✓	Submit Gantt Chart
8	✓	**Conduct Literature search**
9	✓	Research chp systems
10	✓	Research cost associated with chp installation
11	✓	Research biogas
12	✓	Research anaerobic digestion
13	✓	Research patents
14	✓	Review literature found
15		**Identify potential industry Partners**
16		**Meet with Potential Industry Partners**
17	✓	Meet with SweetWater or GrowingPower
18	✓	Meet with Pieper Power
19		Meet with Marathon Engines
20	✓	Memorandum of understanding
21		**Fund project**
22		Identify sources of funding
23		Apply for funding
24		**Preliminary Design**
25		Establish stakeholder expectations
26		Select environment for simulated aquaponics system
27		Select simulated aquaponics system
28		Biogas chp feasibility study
29		Establish load profile
30		Create Economic Model
31		Determine source of biomass
32		**Write Proposal**
33	✓	Create outline
34		Show why use chp only
35	✓	Write Background Section
36		Write Specifications Section
37	✓	Decide on project length
38		Submit Proposal
39		Green energy summit abstract
40		Asme abstract submission
41		**Design**
42		Develop electric model
43		Develop themal model
44		Size digester
45		Size chp system
46		Develop thermal energy storage device
47		Design Prototypes
48		MSDS and Environmental Concerns
49		Create presentation powerpoint
50		**Write best practices guide**
51		Create thermal model software
52		Create economic model software
53		Perform environmental impact study
54		Optimize operation method
55		Submit Design Report
56		Winter Presentation
57		Green energy summit paper
58		Green energy summit paper submission
59		**Prototype and Testing**
60		Find biogas provider
61		Establish fuel delivery method
62		Instrument engine
63		Test biogas in MSOE chp system
64		Optimize engine operation
65		Implement system
66		Asme Paper
67		Asme Paper submission
68		Write final paper
69		Create presentation poster
70		Spring presentation



ID		Task Name
1		**Project Proposal**
2	✓	**Establish Project and Project Group**
3	✓	Define Problem Statement
4	✓	Write project charter
5	✓	Determine file storage method
6	✓	Create weekly update template
7	✓	Submit Gantt Chart
8	✓	**Conduct Literature search**
9	✓	Research chp systems
10	✓	Research cost associated with chp installation
11	✓	Research biogas
12	✓	Research anaerobic digestion
13	✓	Research patents
14	✓	Review literature found
15		**Identify potential industry Partners**
16		**Meet with Potential Industry Partners**
17	✓	Meet with SweetWater or GrowingPower
18	✓	Meet with Pieper Power
19		Meet with Marathon Engines
20	✓	Memorandum of understanding
21		**Fund project**
22		Identify sources of funding
23		Apply for funding
24		**Preliminary Design**
25		Establish stakeholder expectations
26		Select environment for simulated aquaponics system
27		Select simulated aquaponics system
28		Biogas chp feasibility study
29		Establish load profile
30		Create Economic Model
31		Determine source of biomass
32		**Write Proposal**
33	✓	Create outline
34		Show why use chp only
35	✓	Write Background Section
36		Write Specifications Section
37	✓	Decide on project length
38		Submit Proposal
39		Green energy summit abstract
40		Asme abstract submission
41		**Design**
42		Develop electric model
43		Develop thermal model
44		Size digester
45		Size chp system
46		Develop thermal energy storage device
47		Design Prototypes
48		MSDS and Environmental Concerns
49		Create presentation powerpoint
50		**Write best practices guide**
51		Create thermal model software
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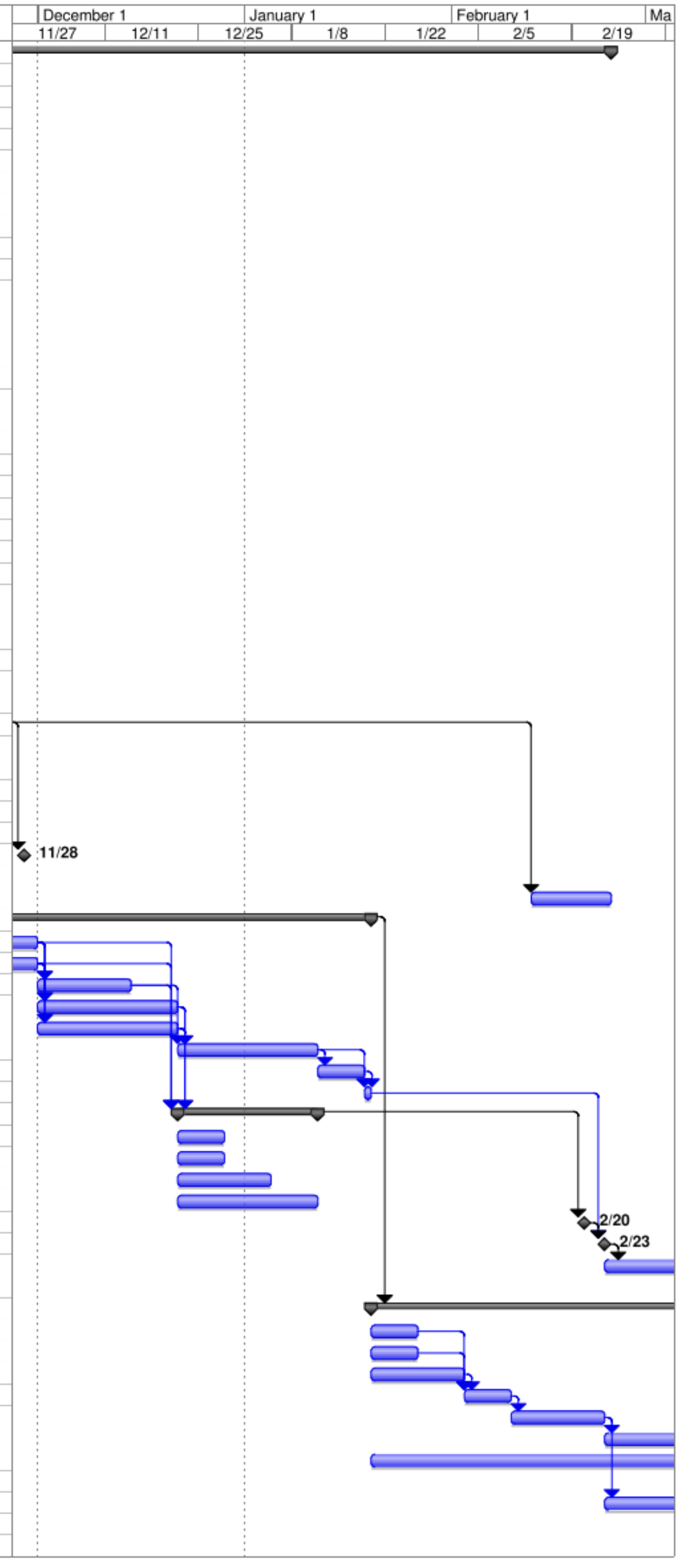

ID		Task Name	rch 1 3/4 3/18 · April 1 4/1 4/15 · May 1 4/29 5/13 · June 1 5/27
1		**Project Proposal**	
2	✓	**Establish Project and Project Group**	
3	✓	Define Problem Statement	
4	✓	Write project charter	
5	✓	Determine file storage method	
6	✓	Create weekly update template	
7	✓	Submit Gantt Chart	
8	✓	**Conduct Literature search**	
9	✓	Research chp systems	
10	✓	Research cost associated with chp installation	
11	✓	Research biogas	
12	✓	Research anaerobic digestion	
13	✓	Research patents	
14	✓	Review literature found	
15		**Identify potential industry Partners**	
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17	✓	Meet with SweetWater or GrowingPower	
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21		**Fund project**	
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28		Biogas chp feasibility study	
29		Establish load profile	
30		Create Economic Model	
31		Determine source of biomass	
32		**Write Proposal**	
33	✓	Create outline	
34		Show why use chp only	
35	✓	Write Background Section	
36		Write Specifications Section	
37	✓	Decide on project length	
38		Submit Proposal	
39		Green energy summit abstract	
40		Asme abstract submission	
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42		Develop electric model	
43		Develop themal model	
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65		Implement system	
66		Asme Paper	
67		Asme Paper submission	5/4
68		Write final paper	
69		Create presentation poster	
70		Spring presentation	5/25

10 Deliverables

The design team will develop an energy supply system for an aquaponics operation through the conversion of biogas into heat, electricity and compressed air. The designed system will reduce the carbon footprint of "green" urban farming and will lower operating expenses. This design will include the development of best practice guidelines that could be used to develop new and improved aquaponics systems. Additionally, a demonstration sized combined heat and power unit will be constructed and fitted to an aquaponics system at the Growing Power site.

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APPENDIX A: TEAM MEMBER RESUMES

Christopher J. Chapman

Present Address	**Permanent Address**
1948 North Second Street	28664 East River Road
Milwaukee, WI 53212	Perrysburg, OH 43551
(715) 213-9785	chapmancj@msoe.edu

Objective A full-time entry-level position to show my technical expertise and experience, where I can utilize my skills and knowledge in the mechanical engineering field.

Qualifications *SolidWorks, PowerPoint, Excel, Matlab, Publisher, Access, C++*. Self-motivated worker with team-oriented experience. Project leader. Travel Experience. Customer service experience.

Education **Milwaukee School of Engineering**; B.A. expected May 2012
Major: Mechanical Engineering. Dean's List, all semesters. 3.4 GPA.

Coursework-Completed	*Coursework-Enrolled*
Heat Transfer	Thermodynamic Applications
Materials Science	Finite Elements
Fluid Mechanics	Control Systems
Mechanics of Materials	Senior Design

Experience

Engineering Intern — **Engineering Department, Midwest Generation.** Waukegan, IL
Interned with a 690 MW coal-fired power plant that is a merchant power producer. Assisted in tasks such as unit inspection, pipe modeling, and part classification. May 2011 - September 2011.

Research Assistant — **Institutional Research, MSOE.** Milwaukee, WI
Assisted the Director of Institutional Reporting in collecting data about the university, and compiled it into over 20 national surveys per year. September 2008 - present.

Ride Operator — **Park Operations, Toledo Zoo.** Toledo, OH
Served as a ride operator and host for zoo-oriented rides such as the train and carousels. Promoted the safety and well-being of animals and 5,000 daily visitors. June 2010 - August 2010.

Achievements MSOE Ultimate Frisbee Captain. Eagle Scout, attained over 50 merit badges. National Honor Society. Chess Club President.

Activities Following and playing sports, chess, reading, computer games. Nominated for Outstanding Peer Mentor.

1041 Knapp St. Apt. 417
Apt. 417
Milwaukee WI, 53202

BRANDON JACKSON
US Citizen

Cell: (608) 669 2305
Email: jacksonb@msoe.edu

EDUCATION

Milwaukee School of Engineering — Milwaukee, WI
Bachelor of Science, Mechanical Engineering — Graduation May 2012
Overall G.P.A.: 3.85/4.0

CORE COMPETENCIES

Programming Languages	Applications	Related Course Work
MATLAB	SolidWorks	Numerical Analysis
SIMULINK	AutoCAD	System Dynamics
C++	LabView	Thermodynamics
	Microsoft Office	Heat Transfer
		Design of Machinery
		Mechanics of Materials

PROFESSIONAL EXPERIENCE

HUSCO International — Waukesha, WI — Summer 2011
Test and Analysis Engineer (Intern)
Worked in the Corporate Development Engineering Department which is responsible for new product development and hydraulic valve performance analysis for HUSCO.
Key responsibilities include:

- Assembling, testing, and calibrating inductive current sensing circuits compatible with a controller-area networks.
- Designing and installation of the sensor network on the skid-steer loader which included pressure transducers, flow meters, position sensors, and current probes.
- Testing vehicle performance and compiling final performance report.

Peer Tutor — Milwaukee, WI — 2008 - Present
MSOE
Assisted individual students in improving academic achievement by meeting on a regular basis to clarify learning problems and work on study skills. Other duties included: reviewing class material, discussing solutions to problems and test preparation.
Key responsibilities include:

Serving as a role-model for professional student behavior.
Having exceptional communications skills to properly communicate with students.

Research Associate — Huntsville, AL — Summer 2010
NASA Propulsion Academy
Worked as a member of a research team responsible for identifying the causes of pressure oscillations in the solid rocket boosters incorporated into the planned Ares launch vehicles. Schlieren imagery was used to visualize pressure vortices which were then correlated with pressure measurements. Findings were presented to NASA personnel and at the Wisconsin Space Conference.
Key responsibilities included:

Designing a lab-scale cold-flow test chamber simulate a solid rocket booster.
Creating a MATLAB program to analyze resulting pressure oscillations.

Wisconsin Space Grant Consortium — Winter - Spring 2010
Collegiate Rocket Design Competition
Two year participant in the WSGC annual rocket competition.
Key responsibilities included:

Team lead (Second year) where I was responsible for scheduling meetings and serving as a liaison with the state space grant.
Creating a MATLAB numerical simulation program to select design variables and predict performance.

BENJAMIN J. STEFFES

2523 N. OAKLAND AVE APT 203
MILWAUKEE, WI 53211
(414) 979-9474
STEFFESB@MSOE.EDU

EDUCATION

Milwaukee School of Engineering — **Graduation: May 2012**
Degree: Bachelor — **GPA** 3.88/4.00
Major: Mechanical Engineering

Fox Valley Technical College — **Graduation: June 2007**
Degree: Pilot Certification — **GPA:** 3.78/4.00
Major: Aeronautics-Pilot Training

EXPERIENCE

Standards Designer Intern — *March 2011 through Present*
Generac Power Systems - Waukesha, WI

- Develop standards for engineering design, materials, workmanship, and testing
- Create solid model and drawing templates
- Created software to standardize hardware selection
- Serve as a Windchill PDM administrator

Engineering Intern — *September 2009 through April 2011*
Brass Light Gallery - Milwaukee, WI

- Developed new product for commercial and residential lighting
- Modified existing product designs for new applications
- Created solid models of products and parts

Mechanical Engineering Summer Intern — *June 2010 through August 2010*
Emteq - New Berlin, WI

- Designed components for aircraft lighting in multi-disciplinary teams
- Built product prototypes
- Designed and built test fixtures
- Conducted thermoplastic testing and research

Injection Molder Operator — *June 2009 through May 2010*
MSOE Rapid Prototyping - Milwaukee, WI

- Produced ABS models of amino acid side chains
- Used mechanical skills to repair and maintain equipment

Pilot — *2007 through November 2008*
Mesaba Airlines - Eagan, Minnesota

- Acted as First Officer on the CRJ-200

SKILLS/TOOLS

Three Dimensional Modeling (SolidWorks and Pro/ENGINEER)
Numerical Simulation (MATLAB and Microsoft Excel)
Finite Element Analysis (ANSYS)
Microsoft Office Applications (Word, PowerPoint, Excel, and Visio)
Certified Pilot and Flight Instructor

Nate Weber

1854 N Cambridge Ave
Milwaukee, WI 53202

(815)883-4064
webern@msoe.edu

Permanent Address: Pontiac, IL

Education:
Currently Attending: Milwaukee School of Engineering
1025 N. Broadway
Milwaukee, WI 53202
Bachelor of Science in Mechanical Engineering
GPA: 3.48
Graduation: May 2012

Honors and Organizations:
Residential Housing Association
Intramural Football, Basketball, Softball
Peer Mentor Program
Dean's List & High Honors List
Skate Club

Relevant Coursework:
Automated Controls
Thermodynamics
Heat Transfer
Mechanics of Materials
Advanced Energy Topics
Design of Machinery
SolidWorks
Thermodynamics

Software
SolidWorks
MATLAB
AutoCad
C++

Work Experience:

Sept. 09/10/11 - May 10/11/Present — Admission Ambassador — MSOE Enrollment Office, Milwaukee, WI

- Reach out and relate to prospective students through phone calls or on a tour of MSOE
- Pointing out positive aspects about MSOE on the phone or on a tour of MSOE
- Provide support and ensure employees are staying on task

May 10/11 - Aug. 10/11 — Field Agent — Cathodic Protection Management, Milwaukee, WI

- Follow mapping and written directions to established test point locations
- Measure voltage readings off 35,000 residential and commercial test points
- Use voltage readings to determine if pipelines are protected

June 09 - Aug. 09 — Highway Department — Livingston County Highway, Pontiac, IL

- Enforce quantity control and assisting construction management on roadways
- Put identification numbers on bridges over Livingston County
- Placement, setup and organization of traffic counters

June 07/08 - Aug. 07/08 — Maintenance Crew — Pontiac Grade School, Pontiac, IL

- Room cleaning (removal and put back of furniture, wax removal, application of wax)
- Outside maintenance (power wash building, water plants, weed whacking, leaf blowing)
- Removal of carpet and glue

daniel.a.neumann@msoe.edu
(715) 218-5238

DANIEL A. NEUMANN

2126B Delaware Avenue
Grafton, WI 53024

OBJECTIVE **MECHANICAL ENGINEER**

Secure a full-time position with a Professional Engineering firm where I can apply my academic knowledge in practical, client-focused applications and develop professionally into a leader.

EDUCATION

2006-Present **MILWAUKEE SCHOOL OF ENGINEERING** Milwaukee, WI

B.S. in Mechanical Engineering Graduating February 2012

Cumulative GPA: 3.77

- Elective coursework in advanced energy topics, aerodynamics, lasers and applications, Finite Elements Analysis using ANSYS software.
- Professional societies involved with are Tau Beta Pi Honor Society, American Society of Mechanical Engineers (ASME) and Society of Automotive Engineers (SAE).
- Senior design project entails the use of a micro combined heat and power generator ran on biofuel to satisfy thermal and electrical requirements of an urban aquaponics system.
- Participated on a 10 person design team sponsored by the Wisconsin Space Grant Consortium to construct an imaging device to measure sulfur dioxide particles with respect to altitude.

EMPLOYMENT

12/09-7/10 **SOUTHEASTERN WISCONSIN ENERGY TECHNOLOGY RESEARCH CENTER** Milwaukee, WI

Undergraduate Researcher

- Contributed gearbox research to a multi-disciplinary and multi-institutional effort to dynamically model a wind turbine drivetrain using Simulink and Matlab.
- Calculated stiffness parameters for a 750 kW utility scale wind turbine 3 stage gearbox.
- Participated in bi-weekly conference calls to the National Renewable Energies Lab.
- Presented research at the 2010 Renewable Energy Summit in Milwaukee, WI.

12/08-11/09 **MSOE RAPID PROTOTYPING - RESEARCH** Milwaukee, WI

Undergraduate Research Assistant

- Researched a proprietary investment casting technique to produce fine resolution small parts.
- Prepared 5 sections of metal prototypes for viewing under microscope.
- Modeled prototypes using Magics RP, Solidworks, SolidCast, and LabView software.

7/02-3/06 **GREENHECK FAN CORPORATION** Schofield, WI

Mechanical Drafter

- Established 3 training manuals to standardize test procedures used in unit assembly.
- Redesigned parts using AutoCad for new manufacturing technology and Lean principles.
- Consulted with engineers, salesmen, manufacturing employees, senior drafters, and others.

PUBLIC SERVICE

8/03-Present **WISCONSIN ARMY NATIONAL GUARD** Madison, WI

- Conceptualized and performed helicopter structural damage repairs in accordance with Technical Manuals and engineering standards.
- Managed maintenance tasks for a civilian contract maintenance team as well as an army mechanic team for 10 UH-60M helicopters.
- Deployed as a part of a 15,000 member NATO/Multi-national Peace Enforcement Team in Kosovo as well as in support of Operation Iraqi Freedom.

APPENDIX B: TEAM CHARTER

PROJECT TEAM CHARTER

CASE SENIOR DESIGN TEAM
(2011-2012)

Milwaukee School of Engineering
Mechanical Engineering Department

Advisor: Dr. Christopher Damm

1.0 Project Team Objectives

The Collaboration for Aquaponics Sustainable Energy (CASE) design team promises to provide a respectful environment for team members to develop academically and professionally in the various tasks involved in the development of a sustainable energy system for urban agriculture and aquaculture.

2.0 Core Values

The following will be held as the core values for the project team:

Respect	Honesty	Flexibility
Shared Learning	Diligence	Communication
Professionalism	Punctuality	

3.0 Team Norms

3.1 Each project team member will be responsible for his individual project roles and responsibilities.
3.2 Upon the assignment of any task, a tentative completion date will be assigned.
3.3 The project team will interact as needed through email, telephone, text messaging, internet chat, in-person, or any other forms of social media to respond to necessary tasks. An effort should be made to document all conversations regarding the project.
3.4 Team members are expected to respond to requests in a timely manner, within one business day, unless the nature of the request requires a more expedition response.
3.5 If a team member is going to be away for an extended period of time the other team members should be notified in advance, except in the event of an emergency.
3.6 All team members shall be on time for scheduled meetings. If a team member is unable to make a scheduled meeting time they shall notify the team in advance of said meeting.
3.7 All electronic files will be stored on the network drive for the project. It is the responsibility of the individual to save local copies of their own work.
3.8 Team members shall be confronted by the group for violation of any of these policies. Excessive violations of these policies are grounds for reflection in the peer review grading process.

4.0 Meeting Times

The following times have been approved for group meeting times for the Fall trimester. Additional meetings will be added throughout the project and it is the requirement of each member to attend said meetings if their presence is requested:

Day	Time	Location
Monday	11:00 – 12:00	SG-40
Tuesday	09:00 – 10:00	SG-40
Thursday	09:00 – 10:00	S-341
Friday	09:00 – 10:00	SG-40

At the start of the Winter and Spring trimesters, additional meetings plans will be decided upon as a group within the first week of the start of the term.

5.0 Weekly Reports

Each team member is responsible for completing a weekly report of their contribution and time commitment for each week. These reports shall be submitted to Dr. Damm on a weekly basis along with being made available to the remaining team members. Weekly reports will be turned in compliance with a predetermined template.

6.0 CASE Team Members

The team members for CASE team include:

Neumann, Daniel A.
Chapman, Christopher J.
Jackson, Brandon A.
Weber, Nathaniel G.
Steffes, Benjamin J. (Team Lead)

The roll of the team lead is limited to the following:

- General Scheduling
- Liaison for communications between the team, Dr. Damm, and initial contact with Industry partners
- Limited decision making in the event that a decision cannot be made by the team democratically.

The position of team lead will be voted on by the team as a whole. The team lead will serve for the entire duration of the project unless deemed incompetent. In this event,

Acknowledged and Agreed to by the CASE Team:

Neumann, Daniel A. Date

Chapman, Christopher J. Date

Jackson, Brandon A. Date

Weber, Nathaniel G. Date

Steffes, Benjamin Date

Dr. Christopher Damm (Project Advisor) Date

APPENDIX C: MEMORANDUM OF UNDERSTANDING – GROWING POWER

MEMORANDUM OF UNDERSTANDING

BETWEEN

MSOE "CASE" SENIOR DESIGN TEAM

AND

GROWING POWER

This MEMORANDUM OF UNDERSTANDING is hereby made and entered into by and between the GROWING POWER and The Milwaukee School of Engineering Collaboration for Aquaponics Sustainable Energy Senior Design Team, hereinafter referred to as CASE.

A. PURPOSE:
The purpose of this MOU is to continue to develop and expand a framework of cooperation between Growing Power and CASE to develop a mutually beneficial project.

B. CASE SHALL:
Design an energy supply system for an aquaponics operation through the conversion of biomass into heat, electricity and compressed air. The designed system will reduce the carbon footprint of "green" urban farming, and will lower operating expenses. The concept of using biogas in conjunction with combined heat and power (CHP) technologies is chosen to provide aeration for fish tanks, water pumping, and hot water for a recirculating aquaponics system found in urban farming operations. CASE shall develop best practices design guidelines that could be used to develop new and improved aquaponic systems. Additionally, a demonstration sized micro-combined heat and power unit will be constructed and fitted to an aquaponics system at the Growing Power site.

C. Growing Power SHALL:
Set aside a necessary plot of greenhouse space for which a prototyped model can be built, assembled and tested. Access to operation during agreed on hours as well as any necessary information will be provided.

D. IT IS MUTUALLY UNDERSTOOD AND AGREED BY AND BETWEEN THE PARTIES THAT:

1. <u>MODIFICATION</u>. Modifications to this agreement shall be made by mutual consent of the parties, by the issuance of a written modification, signed and dated by authorized officials, prior to any changes being performed.

2. <u>PARTICIPATION IN SIMILAR ACTIVITIES</u>. This agreement in no way restricts CASE or Growing Power from participating in similar activities with other public or private agencies, organizations, and individuals.

3. <u>TERMINATION</u>. Either party, upon thirty (30) days written notice, may terminate the agreement in whole, or in part, at any time before the date of expiration.

4. PRINCIPAL CONTACTS. The principal contacts for this instrument are:

   Growing Power:
   Technical: Authorized Official:

   CASE
   Technical:
   Dr. Chris Damm (414) 277-7543 damm@msoe.edu
   Ben Steffes
   Chris Chapman
   Nate Weber
   Dan Neumann
   Brandon Jackson

5. NON-FUND OBLIGATING DOCUMENT. This agreement is neither a fiscal nor a funds obligation document. Any endeavor or transfer of anything of value involving reimbursement or contribution of funds between the parties to this agreement will be handled in accordance with applicable laws, regulations, and procedures. Such endeavors will be outlined in separate agreements that shall be made in writing by representatives of the parties and shall be independently authorized by appropriate statutory authority. This agreement does not provide such authority. Each party shall be fiscally responsible for their own portion work performed under the MOU.

6. COMMENCEMENT/EXPIRATION DATE. This agreement is executed as of the date of last signature and is effective through 6/01/2012 at which time it will expire unless extended.

7. LIABILITIES. It is understood that neither party to this Memorandum of Understanding is the agent of the other and neither is liable for the wrongful acts or negligence of the other. Each party shall be responsible for its negligent acts or omissions and those of its officers, employees, agents or students, howsoever caused, to the extent allowed by their respective state laws.

8. THE PARTIES ACKNOWLEDGE THAT THE WORK SET FORTH IN ARTICLES B AND C IS EXPERIMENTAL IN NATURE AND NEITHER PARTY MAKES A WARRANTY OF ANY KIND, EXPRESSED OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

IN WITNESS WHEREOF, the parties hereto have executed this agreement as of the last written date below.

FOR GROWING POWER:

Date: ____________________ ____

Name and Title:

FOR THE MILWAUKEE SCHOOL OF ENGINEERING DESIGN TEAM:

Date:____________________ ____

APPENDIX D: MATERIAL SAFETY DATA SHEETS

Material data safety sheets for chemicals which will likely be used are given after this page.

SECTION 1: IDENTIFICATION

MSDS ID: MSDSP149

PRODUCT NAME: PRESTONE ANTIFREEZE/COOLANT
Product Number: AF777
Formula Number: YA721, YA718, YA718B

MANUFACTURER: Prestone Products Corporation
39 Old Ridgebury Road
Danbury, CT 06810-5109

INFORMATION PHONE NUMBER: (203) 731-3686

EMERGENCY PHONE NUMBER: CHEMTREC 1-800-424-9300
483-7161 in the District of Columbia

MSDS DATE OF PREPARATION/REVISION: 10/18/99

SECTION 2: PRODUCT COMPONENTS

HAZARDOUS COMPONENTS	CAS#	PERCENT	EXPOSURE LIMITS
Ethylene Glycol (aerosol)	107-21-1	80-96	None Established-OSHA PEL 100 mg/m3 Ceiling ACGIH TLV
Diethylene Glycol	111-46-6	0-8	None Established OSHA PEL, ACGIH TLV

Non-Hazardous Ingredients >1%
Water 7732-18-5

SECTION 3: HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Eye and upper respiratory irritant. May cause nausea, vomiting, headache, drowsiness, blurred vision, convulsions, coma or death if ingested or inhaled. Prolonged or repeated skin contact may cause dermatitis or skin sensitization.

POTENTIAL HEALTH EFFECTS:

INHALATION: May cause irritation of the nose and throat with headache, particularly from mists. High vapor concentrations caused, for example, by heating the material in an enclosed and poorly ventilated workplace, may produce nausea, vomiting, headache, dizziness and irregular eye movements.

SKIN CONTACT: No evidence of adverse effects from available information.

EYE CONTACT: Liquid, vapors or mist may cause discomfort in the eye with persistent conjunctivitis, seen as slight excess redness or conjunctiva. Serious corneal injury is not anticipated.

INGESTION: Following ingestion, a bitter taste may be noted. May cause abdominal discomfort or pain, nausea, vomiting, dizziness, drowsiness, malaise, blurring of vision, irritability, back pain, decrease in urine output, kidney failure, and central nervous system effects, including irregular eye movements, convulsions and coma. Cardiac failure and pulmonary edema may develop. Severe kidney damage which may be fatal may follow the swallowing of ethylene glycol. A few reports have been published describing the development of weakness of the facial muscles, diminishing hearing, and difficulty with swallowing, during the late stages of severe poisoning.

CHRONIC EFFECTS: Prolonged or repeated inhalation exposure may produce signs of central nervous system involvement, particularly dizziness and jerking eye movements. Prolonged or repeated skin contact may cause skin sensitization and an associated dermatitis in some individuals. Ethylene glycol has been found to cause birth defects in laboratory animals. The significance of this finding to humans has not been determined. See section 11 for additional information.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: The available toxicological information and a knowledge of the physical and chemical properties of the material suggest that overexposure in unlikely to aggravate existing medical conditions.

CARCINOGEN: None of the components of these products is listed as a carcinogen or suspected carcinogen by IARC, NTP or OSHA.

SECTION 4: FIRST AID MEASURES

INHALATION: Remove the victim to fresh air. If breathing has stopped administer artificial respiration. If breathing is difficult, have medical personnel administer oxygen. Get medical attention.

SKIN CONTACT: Remove contaminated clothing. Immediately wash contacted area thoroughly with soap and water. If irritation persists, get medical attention.

EYE CONTACT: Immediately flush eyes with large amounts of water for 15 minutes. Get medical attention if irritation persists.

INGESTION: Seek immediate medical attention. Immediately call local poison control center or go to an emergency department. Never give anything by mouth to or induce vomiting in an unconscious or drowsy person.

NOTES TO PHYSICIAN: The principal toxic effects of ethylene glycol, when swallowed, are kidney damage and metabolic acidosis. The combination of metabolic acidosis, an osmol gap and oxalate crystals in the urine is evidence of ethylene glycol poisoning.

Pulmonary edema with hypoxemia has been described in a number of patients following poisoning with ethylene glycol. Respiratory support with mechanical ventilation may be required.

There may be cranial nerve involvement in the late stages of toxicity from swallowed ethylene glycol. In particular, effects have been reported involving the seventh, eighth, and ninth cranial nerves, presenting with bilateral facial paralysis, diminished hearing and dysphagia.

Ethanol is antidotal and its early administration may block the formation of nephrotoxic metabolites of ethylene glycol in the liver. The objective is to rapidly achieve and maintain a blood ethanol level of approximately 100 mg/dl by giving a loading dose of ethanol followed by a maintenance dose. Intravenous administration of ethanol is the preferred route. Ethanol blood levels should be checked frequently. Hemodialysis may be required.

4-Methylpyrazole (Antizole(R) or Fomepizole), a potent inhibitor of alcohol dehydrogenase, has been used therapeutically to decrease the metabolic consequences of ethylene glycol poisoning. Additional therapeutic modalities which may decrease the adverse consequences of ethylene glycol metabolism are the administration of both thiamine and pyridoxine. As there are complicated and serious overdoses, we recommend you consult with the toxicologists at your poison control center. This antidote is now approved by the F.D.A. and in many cases has replaced ethanol in the treatment of ethylene glycol poisoning.

SECTION 5: FIRE AND EXPLOSION DATA

FLASH POINT: 242 F (117 C) TOC
220 F (104 C) PMCC

AUTOIGNITION TEMPERATURE: Not determined

FLAMMABILITY LIMITS: LEL: 3.2% UEL: 15.3%

EXTINGUISHING MEDIA: For large fires, use alcohol type or all-purpose foams. For small fires, use water spray, carbon dioxide or dry chemical.

SPECIAL FIRE FIGHTING PROCEDURES: Do not spray pool fires directly. Cool fire exposed containers with water. Firefighters should wear positive pressure self-contained breathing apparatus and full protective clothing for fires in areas where chemicals are used or stored.

UNUSUAL FIRE HAZARDS: A solid stream of water or foam directed into hot, burning liquid can cause frothing.

HAZARDOUS COMBUSTION PRODUCTS: Burning may produce carbon monoxide and carbon dioxide.

SECTION 6: ACCIDENTAL RELEASE MEASURES

Wear appropriate protective clothing and equipment (See Section 8). Collect with absorbent material and place in appropriate, labeled container for disposal or, if permitted flush spill area with water.

SECTION 7: HANDLING AND STORAGE

DANGER: Harmful or Fatal if Swallowed

Do not drink antifreeze or solution.
Avoid eye and prolonged or repeated skin contact.
Avoid breathing vapors or mists.
Wash exposed skin thoroughly with soap and water after use.
Do not store in opened or unlabeled containers.

Keep container away from open flames and excessive heat.
Do not reuse empty containers unless properly cleaned.

Empty containers retain product residue and may be dangerous. Do not cut, weld, drill, etc. containers, even empty.

Sudden release of hot organic chemical vapors or mists from process equipment operating at elevated temperature and pressure, or sudden ingress of air into vacuum equipment, may result in ignitions without any obvious ignition sources. Published "autoignition" or "ignition" temperatures cannot be treated as safe operating temperatures in chemical processes without analysis of the actual process conditions. Use of this product in elevated temperature applications should be thoroughly evaluated to assure safe operating conditions.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION: Use general ventilation or local exhaust as required to maintain exposures below the occupational exposure limits.

RESPIRATORY PROTECTION: For operations where the TLV is exceeded a NIOSH approved respirator with organic vapor cartridges and dust/mist prefilters or supplied air respirator is recommended. Equipment selection depends on contaminant type and concentration. Select and use in accordance with 29 CFR 1910.134 and good industrial hygiene practice. For firefighting, use self-contained breathing apparatus.

GLOVES: Chemical resistant gloves such as neoprene or PVC where contact is possible

EYE PROTECTION: Splash-proof goggles.

OTHER PROTECTIVE EQUIPMENT/CLOTHING: Appropriate protective clothing as needed to minimize skin contact. Suitable washing and eye flushing facilities should be available in the work area. Contaminated clothing should be removed and laundered before re-use.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE AND ODOR: Yellow liquid with a mild odor.

pH: Not determined	SPECIFIC GRAVITY: 1.12
BOILING POINT (F): 334 F	VAPOR PRESSURE: Less than 0.1
FREEZING POINT (F): -8 F	VAPOR DENSITY: 2.1
SOLUBILITY IN WATER: 100%	EVAPORATION RATE: Less than 1
PERCENT VOLATILE: None	VISCOSITY: Not determine

SECTION 10: STABILITY AND REACTIVITY

STABILITY: Stable
CONDITIONS TO AVOID: None known.
INCOMPATIBILITY: Normally unreactive, however, avoid strong bases at high temperatures, strong acids, strong oxidizing agents, and materials reactive with hydroxyl compounds.
DECOMPOSITION PRODUCTS: Carbon monoxide, carbon dioxide.
HAZARDOUS POLYMERIZATION: Will not occur
CONDITIONS TO AVOID: None known.

SECTION 11: TOXICOLOGICAL INFORMATION

ACUTE TOXICITY VALUES:

Ethylene Glycol: LD50 Oral Rat: 4700 mg/kg
LD50 Skin Rabbit: 9530 mg/kg

Diethylene Glycol: LD50 Oral Rat: 12,565 mg/kg
LD50 Skin Rabbit: 11,890 mg/kg

SIGNIFICANT LABORATORY DATA WITH POSSIBLE RELEVANCE TO HUMAN HEALTH:
Ethylene glycol has been shown to produce dose-related teratogenic effects in rats and mice when given by gavage or in drinking water at high concentrations or doses. Also, in a preliminary study to assess the effects of exposure of pregnant rats and mice to aerosols at concentrations 150, 1,000 and 2,500 mg/m3 for 6 hours a day throughout the period of organogenesis, teratogenic effects were produced at the highest concentrations, but only in mice. The conditions of these latter experiments did not allow a conclusion as to whether the developmental toxicity was mediated by inhalation of aerosol, percutaneous absorption of ethylene glycol from contaminated skin, or swallowing of ethylene glycol as a result of grooming the wetted coat. In a further study, comparing effects from high aerosol concentration by whole-body or nose-only exposure, it was shown that nose-only exposure

resulted in maternal toxicity (1,000 and 2,500 mg/m3) and developmental toxicity in with minimal evidence of teratogenicity (2,500 mg/m3). The no-effects concentration (based on maternal toxicity) was 500 mg/m3. In a further study in mice, no teratogenic effects could be produced when ethylene glycol was applied to the skin of pregnant mice over the period of organogenesis. The above observations suggest that ethylene glycol is to be regarded as an animal teratogen; there is currently no available information to suggest that ethylene glycol caused birth defects in humans. Cutaneous application of ethylene glycol is ineffective in producing developmental toxicity; exposure to high aerosol concentration is only minimally effective in producing developmental toxicity; the major route for producing developmental toxicity is perorally.

Two chronic feeding studies, using rats and mice, have not produced any evidence that ethylene glycol causes dose-related increases in tumor incidence or a different pattern of tumors compared with untreated controls. The absence of carcinogenic potential for ethylene glycol has been supported by numerous invitro genotoxicity studies showing that it does not produce mutagenic or clastogenic effects.

This products contains less than 0.5% tolytriazole which has demonstrates mutagenic activity in a bacterial test system. A correlation has been established between mutagenic activity and carcinogenic activity for many chemicals. Tolytriazole has not been identified as a carcinogen or probable carcinogen by NTP, IARC or OSHA.

SECTION 12: ECOLOGICAL INFORMATION

Ethylene Glycol: LC50 Goldfish: 5,000 mg/L/24 hr. at 20 C static conditions.

Toxicity threshold (cell multiplication inhibition test):
Bacterial (Pseudomonas putida): 10,000 mg/l
Protozoa (Entosiphon sulcatum and Uronema parduczi Chatton-Lwoff): >10,000 mg/l
Algae (Microcystis aeruginosa): 2,000 mg/l
Green algae (Scenedesmus quandricauda): >10,000 mg/l

SECTION 13: DISPOSAL INFORMATION

Dispose of product in accordance with all local, state/provincial and federal regulations.

SECTION 14: TRANSPORT INFORMATION

U.S. DOT HAZARD CLASSIFICATION

PROPER SHIPPING NAME: None
UN NUMBER: None
LABELS REQUIRED: None

DOT MARINE POLLUTANTS: This product does not contains Marine Pollutants as defined in 49 CFR 171.8.

IMDG CODE SHIPPING CLASSIFICATION

DESCRIPTION: Not Regulated

Note: IF A BULK SHIPMENT IS INVOLVED, THE FOLLOWING INFORMATION APPLIES:

U.S. DOT HAZARD CLASSIFICATION

PROPER SHIPPING NAME: Environmentally hazardous substance, liquid, N.O.S. (Ethylene glycol)
UN NUMBER: UN3082
LABELS REQUIRED: Class 9, UN3082

SECTION 15: REGULATORY INFORMATION

EPA SARA 311/312 HAZARD CLASSIFICATION: Acute health, chronic health

EPA SARA 313: This Product Contains the Following Chemicals Subject to Annual Release Reporting Requirements Under SARA Title III, Section 313 (40 CFR 372):

Ethylene Glycol 107-21-1 80-96%

PROTECTION OF STRATOSPHERIC OZONE: This product is not known to contain or to have been manufactured with ozone depleting substances as defined in 40 CFR Part 82, Appendix A to Subpart A.

CERCLA SECTION 103: Spills of this product over the RQ (reportable quantity) must be reported to the National Response Center. The RQ for this product, based on the RQ for Ethylene Glycol (96% maximum) of 5,000 lbs, is 5,208 lbs. Many states have more stringent release reporting requirements. Report spills required under federal, state and local regulations.

CALIFORNIA PROPOSITION 65 - This product may contain the following substances known to the State of California to cause Cancer and/or Reproductive Harm: 1,4-Dioxane (trace amount).

EPA TSCA INVENTORY: All of the components of this material are listed on the Toxic Substances Control Act (TSCA) Chemical Substances Inventory.

CANADIAN ENVIRONMENTAL PROTECTION ACT: All of the ingredients are listed on the Canadian Domestic Substances List.

CANADIAN WHMIS CLASSIFICATION: Class D - Division 2 - Subdivision B - (A toxic material causing other chronic effects)

EUROPEAN INVENTORY OF EXISTING COMMERCIAL CHEMICAL SUBSTANCES (EINECS): All of the ingredients are listed on the EINECS inventory.

AUSTRALIA: All of the ingredients of this product are listed on the Australian Inventory of Chemical Substances.

SECTION 16: OTHER INFORMATION

NFPA RATING (NFPA 704) - FIRE: 1
HEALTH: 2
REACTIVITY: 0

REVISION SUMMARY: Section 4: Notes to Physican
Section 9: Specific Gravity
Section 16: Contact Name and Address

This MSDS is directed to professional users and bulk handlers of the product. Consumer products are labeled in accordance with Federal Hazardous Substances Act regulations.

While Prestone Products Corporation believes that the data contained herein are factual and the opinions expressed are those of qualified experts regarding the results of tests conducted, the data are not to be taken as a warranty or representation for which Prestone Products Corporation assumes legal responsibility. They are offered for your consideration, investigation and verification. Any use of these data and information must be determined by the user to be in accordance with applicable federal, state and local laws and regulations.

If more information is needed, please contact: Stan Prusakowski
Prestone Products Corporation
55 Federal Road
Danbury, CT 06810
(203)830-7865

MATERIAL SAFETY DATA SHEET
Propylene Glycol

SECTION 1: IDENTIFICATION

Company Name:	QUALICHEM TECHNOLOGIES
Address:	885 Woodstock Rd Roswell, GA 30075
Phone No.	(800) 658-7716
Fax No.	(877) 209-1556
Emergency Phone No.	CHEM-TEL 800-255-3924
Date Prepared:	5/21/97
Date Revised:	10/11/05

SECTION 2: INGREDIENTS

Hazardous Ingredients

MATERIAL	CAS NO.	%	TLV
NONE			

Non-Hazardous Ingredients

1-2 PROPANEDIOL		99.9	NONE ESTAB.
WATER		BAL.	NONE ESTAB.

SECTION 3: HEALTH HAZARDS

Ingestion:	IF MORE THAN SEVERAL MOUTHFULS ARE INGESTED, ABDOMINAL DISCOMFORT, NAUSEA AND DIARRHEA MAY OCCUR.
Inhalation:	NOT A LIKELY ROUTE OF EXPOSURE. INHALATION OF MIST MAY BE IRRITATING TO RESPIRATORY TRACT, HEADACHE, NAUSEA AND DROWSINESS.
Skin Contact:	NOT AN IRRITANT. PROLONGED CONTACT CAN RESULT IN DEFATTING.
Eye Contact:	CAUSES MILD IRRITATION.
Other Information:	OTHER THAN ACUTE EFFECTS LISTED ABOVE, NO LONG TERM EFFECTS KNOWN.

SECTION 4: FIRST AID

Ingestion:	DRINK SEVERAL GLASSES OF WATER TO DILUTE. NO NOT INDUCE VOMITING UNLESS DIRECTED TO DO SO BY MEDICAL PERSONNEL. NEVER GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON. GET MEDICAL ATTENTION.
Inhalation:	REMOVE VICTIM TO FRESH AIR. GET MEDICAL ATTENTION IF SYMPTOMS PERSIST.
Skin Contact:	WASH WITH PLAIN WATER OR SOAP AND WATER.
Eye Contact:	IMMEDIATELY FLUSH WITH CLEAR WATER FOR 15 MINUTES AND GET MEDICAL ATTENTION IF IRRITATION PERSISTS.
Notes to Physician:	NO ANTIDOTES KNOWN. TREAT SYMPTOMS SUPPORTIVELY.

SECTION 5: FIRE AND EXPLOSION HAZARD DATA

Flash Point/Method:	NONE
Lower Limit in Air:	N.A.
Upper Limit in Air:	N.A.
Extinguishing Media:	WATER OR ANY MEDIA SUITABLE FOR THE SURROUNDING FIRE.
Procedures:	FIREFIGHTERS SHOULD WEAR NORMAL PROTECTIVE EQUIPMENT. SELF-CONTAINED BREATHING APPARATUS SHOULD BE USED IN CONFINED AREAS.
Unusual Hazards:	NONE
Combustion Products:	IF WATER IS EVAPORATED, OXIDES OF CARBON AND NITROGEN MAY BE PRODUCED.

SECTION 6: ACCIDENTAL RELEASE MEASURES

Personal Precautions:	THE WEARING OF SAFETY GLASSES AS A MINIMUM IS RECOMMENDED.
Environmental Precautions:	THIS PRODUCT HAS A LOW HAZARD POTENTIAL IF RELEASED INTO THE ENVIRONMENT ACCIDENTLY.
Procedures for Clean Up:	SMALL SPILLS MAY BE FLUSHED WITH COPIOUS QUANTITIES OF WATER, PREFERABLY TO A SANITARY SEWER. LARGER SPILLS MAY BE DIKED TO MINIMIZE RUN-OFF. LIQUID MAY BE ABSORBED IN SAWDUST OR ANY AVAILABLE ABSORBANT AND SWEEPINGS DISPOSED OF IN A LANDFILL. OBEY ALL FEDERAL, STATE OR LOCAL REGULATIONS.
Prohibited Materials:	NONE

SECTION 7: HANDLING AND STORAGE

Handling:	NORMAL INDUSTRIAL HANDLING PRACTICES.
Storage:	KEEP OUT OF REACH OF CHILDREN. STORE IN A COOL, DRY PLACE. KEEP CONTAINERS TIGHTLY CLOSED WHEN NOT IN USE.

SECTION 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

Precautionary Measures:	STANDARD INDUSTRIAL HANDLING PRECAUTIONS.
Engineering Controls:	NONE
Control Limits:	NONE.
Equipment for Personal Protection:	EYEWASH STATION AND SAFETY SHOWER IN AREA OF USE.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	CLEAR LIQUID
Odor:	CHARACTERISTIC
pH (undiluted):	<12
Specific Gravity:	1.05-1.07
Density:	8.88 lbs./gal.
Solubility in Water:	COMPLETE
Boiling Point:	212^{o}F
Percent Volatile:	<5 (WATER)
Vapor Pressure (mmHg):	N.D.
Vapor Density:	N.D.
Evaporation Rate:	(water=1): ~1

SECTION 10: STABILITY AND REACTIVITY

Stability:	STABLE
Conditions to Avoid:	NONE
Hazardous Polymerization:	STABLE
Conditions to Avoid:	NONE
Incompatibility:	MAY REACT WITH STRONG OXIDIZING AGENTS OR ACIDS.
Hazardous Decomposition Products:	IF WATER EVAPORATED, OXIDES OF CARBON COULD BE PRODUCED BY COMBUSTION.

SECTION 11: TOXICOLOGICAL INFORMATION

Material & Tests:	NONE DETERMINED. LOW ORDER OF TOXICITY EXPECTED.
Symptoms:	N.A.
Effects:	N.A.

MATERIAL SAFETY DATA SHEET
Propylene Glycol

SECTION 12: ECOLOGICAL INFORMATION

Possible Effects:	TOXIC EFFECTS MINIMAL .
Biodegradability:	ALL ORGANIC COMPONENTS ARE BIODEGRADABLE.
Persistence:	NOT PERSISTENT.
Aquatic Toxicity:	N.D.

SECTION 13: DISPOSAL CONSIDERATIONS

General Considerations:	THIS PRODUCT IS NOT A HAZARDOUS WASTE.
Procedures:	DISPOSAL BY USE PREFERRED BUT IF THIS NOT POSSIBLE, DILUTE WITH COPIOUS QUANTITIES OF WATER AND FLUSH TO WASTE, PREFERABLY TO A SANITARY SEWER. OBEY ALL FEDERAL, STATE OR LOCAL REGULATIONS.

SECTION 14: TRANSPORT INFORMATION

Shipping Name:	COMPOUNDS, WATER TREATMENT, N.O.S.
Primary Hazard Class:	NON-HAZARDOUS PER D.O.T. REGULATIONS
Secondary Hazard Class:	N.A.
Identification No.	N.A.
Packing Group:	N.A.
1996 NAERG No.	N.A.

SECTION 15: REGULATORY INFORMATION

Regulation	Material	RQ	Max. %
CERCLA (40 CFR302.4):	NONE		
SARA 302 (Sect. 355, Appendix A):	Material	TPQ	Max. %
	NONE		
SARA 311/312 :	Categories	Hazards	
	IMMEDIATE HEALTH	EYE IRRITANT	
SARA 313 (40 CFR 372.45):	Material		Max. %
	NONE		
CWA (40 CFR 401.15):	NONE		
RCRA (40 CFR 261):	NONE		
OSHA (29 CFR 1910.1200):	ALL COMPONENTS LISTED UNDER THIS STANDARD ARE SHOWN IN SECTION 2 OF THIS MSDS.		
TSCA	ALL INGREDIENTS IN THIS PRODUCT ARE LISTED IN THE TSCA INVENTORY.		

SPECIAL STATE REGULATIONS

STATE	INGREDIENT	%	REGULATORY DESIGNATION
NONE			

MATERIAL SAFETY DATA SHEET
Propylene Glycol

SECTION 16 OTHER INFORMATION

SUGGESTED HAZARD RATINGS

NFPA*	HAZARD	HMIS*
1	HEALTH (Blue)	1
1	FIRE (Red)	1
0	REACTIVITY (Yellow)	0
	PERSONAL PROTECTION	B
	SPECIAL HAZARDS	

*Notes: 0 = Insignificant; 1 = Slight; 2 = Moderate; 3 = High; 4 = Extreme

Prepared By: Environmental Manager

The data contained in this Material Safety Data Sheet has been prepared based upon an evaluation of the ingredients in the product, their concentration in the product and potential interactions. The information is offered in good faith and is believed to be accurate. It is furnished to the customer who is urged to study it carefully to become aware of hazards, if any, in the storage, handling, use and disposal of the product; and to insure his employees are properly informed and advised of all safety precautions required. The information is furnished for compliance with the "Occupational Safety and Health Act" of 1970, the "Hazards Communication Act" of 1983 as well as various other Federal, State and Local regulations. Use or dissemination of all or part of this information for any other purpose is prohibited by law.

**** MATERIAL SAFETY DATA SHEET ****

NATURAL GAS

CHES 1728

**** SECTION 1 - CHEMICAL PRODUCT AND COMPANY IDENTIFICATION ****

MSDS Name: NATURAL GAS

Product CAS:

Product Code:

Synonyms: MARSH GAS; METHANE; NATURAL GAS; SYNTHETIC NATURAL GAS

Company Identification:

Name: WISCONSIN GAS COMPANY

Address: P.O. BOX 544

Address:

City: MILWAUKEE **State:** WI **Zip:** 53201

For information, call:

Emergency Number: 800-261-5325

Emergency Agency:

Number:

MSDS Creation Date: 03/22/2000

Supersedes Date:

Miscellaneous:

PRODUCT NAME OR CODE: NATURAL GAS

NAME AND/OR OTHER IDENTIFICATION: NATURAL GAS

GENERAL INFORMATION: A MIXTURE OF LOW MOLECULAR WEIGHT HYDROCARBON GAS, FUEL GAS DELIVERED IN PIPELINES, USED FROM COMPRESSED GAS CYLINDERS. CONSIDERED A SIMPLE ASPHYXIANT.

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**** SECTION 2 - COMPOSITION, INFORMATION ON INGREDIENTS ****

Chemical Name	CAS	MIN	MAX
METHANE	74-82-8	90.2	90.2
ETHANE	74-84-0	7.02	7.02
PROPANE	74-98-6	1.0	1.0
ISOBUTANE	75-28-5	0	0
N-BUTANE	106-97-8	0	0
ISOPENTANE	78-78-4	0	0
N-PENTANE	109-66-0	0	0
NEOPENTANE	463-82-1	0	0
OTHER ALIPHATIC HYDROCARBONS	(none)	0	0

Miscellaneous:

INGREDIENT	TLV	PEL	CARCINOGEN
METHANE	---	---	NO
ETHANE	---	---	NO
PROPANE	1000	2500	NO

OTHER TRACE MATERIALS (LT 1% BY WEIGHT) MAY INCLUDE ISOBUTANE, N-BUTANE, ISOPENTANE, N-PENTANE, NEOPENTANE, OTHER ALIPHATIC HYDROCARBONS IN CONCENTRATIONS LT 100 PPM (BY VOLUME); ODORANT (MIXTURE OF MERCAPTAN AND ALKYL SULFIDE IN CONCENTRATIONS OF LT 50 PPM).

INGREDIENTS SUBJECT TO SARA TITLE III, SECTION 313: NONE

Lbs of VOC per Gallon Coating (minus water):

Coating Density (lbs/gal):

Solvent Density (lbs/gal):

Percent Solvent (volume):

Percent Solids (volume):

Percent Water (volume):

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**** SECTION 3 - HAZARDS IDENTIFICATION ****

NFPA: Health: 1 **Fire:** 4 **Reactivity:** 0 **Other:**

HMIS: Health: 1 **Fire:** 4 **Reactivity:** 0 **Special Protection:**

Miscellaneous:

HAZARD RATINGS (CERCLA):
TOXICITY: 1
IGNITABILITY/FLAMMABILITY: 4
REACTIVITY: 0
PERSISTENCE: 0

SEE SECTION 11 FOR TOXICOLOGY INFORMATION.

POTENTIAL HEALTH EFFECTS

Target Organs:

RESPIRATORY SYSTEM, LUNGS - SIMPLE ASPHYXIANT; SKIN AND EYES

ROUTES OF ENTRY: INHALATION, SKIN AND EYE CONTACT.

Eye:

MAY CAUSE IRRITATION OF EYES IN LARGE CONCENTRATIONS

SYMPTOMS OF ACUTE EXPOSURE: SEE MISCELLANEOUS.

Skin:

MAY CAUSE IRRITATION OF SKIN IN LARGE CONCENTRATIONS

SYMPTOMS OF ACUTE EXPOSURE: SEE MISCELLANEOUS.

Ingestion:

SYMPTOMS OF ACUTE EXPOSURE: SEE MISCELLANEOUS.

Inhalation:

SYMPTOMS OF ACUTE EXPOSURE: SEE MISCELLANEOUS.

Miscellaneous:

PRE-EXISTING CONDITION: SOME PULMONARY CONDITIONS.

SEE SECTION 11 FOR MUTAGENIC AND CARCINOGENIC DATA.

SYMPTOMS OF ACUTE EXPOSURE INCLUDE RESPIRATORY ARREST, UNCONSCIOUSNESS; MAY CAUSE NAUSEA, VOMITING, DIZZINESS, DROWSINESS, STUPOR, DISCOMFORT AND REDNESS TO SKIN AND EYES.

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**** SECTION 4 - FIRST AID MEASURES ****

Eye:

N/A

Skin:

N/A

Ingestion:

N/A

Inhalation:

REMOVE FROM EXCESSIVE EXPOSURE TO FRESH AIR IMMEDIATELY. IF BREATHING HAS STOPPED, PERFORM ARTIFICIAL RESPIRATION. KEEP INDIVIDUAL WARM AND AT REST.

Notes to Physician:

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**** SECTION 5 - FIRE FIGHTING MEASURES ****

Unusual Fire and Explosion Hazards:

RE-IGNITION OR EXPLOSION MAY OCCUR IF THE FLAME IS EXTINGUISHED WITHOUT STOPPING THE FLOW OF GAS AND/OR COOLING SURROUNDINGS AND ELIMINATING IGNITION SOURCES.

Special Fire Fighting Procedures:

WEAR SCBA AND FULL PROTECTIVE GEAR. DO NOT EXTINGUISH FLAMES WHILE GAS IS FLOWING. USE WATER SPRAY TO COOL SURROUNDINGS AND EXPOSURES.

Extinguishing Media:

CARBON DIOXIDE, DRY CHEMICAL, HALON

Flash Point:

-306 F

Flammable Limits:

Lower Limit:

(LFL): 4%

Upper Limit:

(UFL): 16%

AutoIgnition Temperature:

900 F - 1200 F

General Information:

THERMAL DECOMPOSITION PRODUCTS: CARBON MONOXIDE, CARBON DIOXIDE, SULFUR DIOXIDE, NITROGEN OXIDES.

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**** SECTION 6 - ACCIDENTAL RELEASE MEASURES ****

Disposal:

MATERIAL IS A GAS WHICH NATURALLY DISSIPATES.

Spills/Leaks:

EVACUATE AREA. PROVIDE OPTIMUM EXPLOSION-PROOF VENTILATION. SHUT OFF SUPPLY, REMOVE OR ELIMINATE IGNITION SOURCES. MINOR LEAKS CAN BE DETECTED WITH A SOAP SOLUTION APPLIED TO SUSPECTED LEAK POINTS. NEVER USE A FLAME TO DETECT LEAKS.

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**** SECTION 7 - HANDLING and STORAGE ****

Handling:

SEE "STORAGE" BELOW.

Storage:

NATURAL GAS IS CONTAINED AND DELIVERED IN PIPING AND EQUIPMENT DESIGNED FOR ELEVATED PRESSURES. USE EXPLOSION-PROOF CLASS I, GROUP D ELECTRICAL EQUIPMENT AND NON-SPARKING TOOLS.

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**** SECTION 8 - EXPOSURE CONTROLS, PERSONAL PROTECTION ****

Engineering Controls:

VENTILATION: USE EXPLOSION-PROOF, NON-SPARKING VENTILATION EQUIPMENT TO DILUTE NATURAL GAS.

Eyes:

NONE SPECIFIED.

Skin:

NONE SPECIFIED.

Clothing:

Respirators:

IN AREAS WHERE CONCENTRATIONS MAY EXCEED 10,000 PPM (1%), SUCH AS CONFINED SPACES, ENCLOSED AREAS, ADJACENT TO BLOWING NATURAL GAS, USE SELF-CONTAINED BREATHING APPARATUS (SCBA)

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**** SECTION 9 - PHYSICAL AND CHEMICAL PROPERTIES ****

Appearance/Odor:

COLORLESS FLAMMABLE GAS, ALMOST ODORLESS. ODORANTS ADDED AS A SAFETY PRECAUTION IMPART DISTINCTIVE SULFUR-LIKE ODOR.

pH:

Vapor Pressure: (@ 70 F): 760 MM HG

Vapor Density: (AIR=1): 0.6

Evaporation Rate:

Viscosity:

Boiling Point: -258 F

Freezing/Melting Point: -296 F

Decomposition Temperature:

Solubility: NEGLIGIBLE

Specific Gravity: .60

Molecular Formula:

Molecular Weight: 16

Miscellaneous:

SPECIFIC GRAVITY: 0.55 - 0.60 AT 30" HG AND 60 F.

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**** SECTION 10 - STABILITY AND REACTIVITY ****

Chemical Stability:

STABLE; AVOID CONTACT WITH FLAMES OR HEAT SOURCES. COMBINES READILY WITH AIR AND OTHER OXIDIZERS TO FORM A COMBUSTIBLE ATMOSPHERE.

Conditions to Avoid:

Incompatibilities with Other Materials:

OTHER OXIDIZERS INCLUDING CHLORINE, CHLORINE DIOXIDE, BROMINE PENTAFLUORIDE, OXYGEN, OXYGEN DIFLUORIDE, NITROGEN TRIFLUORIDE, FLUORINE MONOXIDE.

Hazardous Decomposition Products:

CARBON MONOXIDE, CARBON DIOXIDE, SULFUR DIOXIDE, NITROGEN OXIDES.

Hazardous Polymerization:

DOES NOT OCCUR.

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**** SECTION 11 - TOXICOLOGICAL INFORMATION ****

Toxicological Information:

MUTAGENIC DATA: NONE KNOWN.

CARCINOGENICITY: NO BY IARC, NTP, OSHA

TOXICOLOGY: PRACTICALLY NONTOXIC. SIMPLE ASPHYXIANT BY INHALATION - NATURAL GAS DISPLACES OXYGEN REQUIRED FOR RESPIRATION. MAY ALSO CAUSE CENTRAL NERVOUS SYSTEM DEPRESSION IN LARGE CONCENTRATIONS.

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**** SECTION 12 - ECOLOGICAL INFORMATION ****

Ecological Information:

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**** SECTION 13 - OTHER PRECAUTIONS ****

Other Precautions:

Work/Hygienic Practices:

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**** SECTION 14 - TRANSPORT INFORMATION ****

Transportation Information:

Label Information:

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**** SECTION 15 - REGULATORY INFORMATION ****

Regulatory Information:

29 CFR 1910 (OSHA GENERAL INDUSTRY):
SECTION .20 - ACCESS TO EMPLOYEE EXPOSURE AND MEDIAL RECORDS
SECTION .94 - VENTILATION
SECTION .132 - PERSONAL PROTECTIVE EQUIPMENT
SECTION .134 - RESPIRATORY PROTECTION
SECTION .151 - MEDICAL SERVICES AND FIRST AID

SECTION .1200 - HAZARD COMMUNICATION
SECTION .1450 - HAZARDOUS CHEMICALS IN LABORATORIES

49 CFR 172: REGULATED BY DOT (UN 1971, UN 1972); DOT HAZARD CLASS 2.0

STATE REGULATIONS: MASSACHUSETTS, PENNSYLVANIA, MINNESOTA, CALIFORNIA, NEW JERSEY RIGHT TO KNOW LISTS.

INTERNATIONAL REGULATIONS: AUSTRALIAN EXPOSURE STANDARDS - ASPHYXIANT AT LT 18% OXYGEN, EXPLOSION HAZARD; CANADA - BRITISH COLUMBIA AND ONTARIO TWAS - SIMPLE ASPHYXIANT; ISRAEL TWAS - SIMPLE ASPHYXIANT.

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**** SECTION 16 - ADDITIONAL INFORMATION ****

Additional Information:

MATERIAL SAFETY DATA SHEET
REVISION DATE: 3/22/00

SUPPLIER NAME AND ADDRESS:
WISCONSIN GAS COMPANY
626 EAST WISCONSIN AVENUE
MILWAUKEE, WISCONSIN 53202

THIS MSDS MEETS THE REQUIREMENTS OF OSHA 'HAZARD COMMUNICATION STANDARD' 29 CFR 1910.1200.

THE INFORMATION PRESENTED HEREIN HAS BEEN COMPILED FROM SOURCES CONSIDERED TO BE RELIABLE AND IS ACCURATE AND RELIABLE TO THE BEST OUR OUR KNOWLEDGE AND BELIEF, BUT IS NOT GUARANTEED TO BE SO.

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