Increasing Energy Efficiency on Massachusetts Dairy Farms

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ABSTRACT

This report, prepared for Representative Anne Gobi, investigates methods to improve energy efficiency on Massachusetts dairy farms. We included a discussion on available technologies that, if implemented, would reduce the amount of electricity used by dairy farmers. Also, this report investigates the feasibility of implementing renewable energy sources, such as wind turbines, solar panels, and solar hot water heaters. For our sample of five farms, we recommended the technologies that would be best suited for their individual farms. Also, included is a method for other dairy farmers to calculate their potential energy savings.

EXECUTIVE SUMMARY

The dairy farms in Massachusetts are an important part of the state's economy and agricultural industry. They also provide the state with valuable open space, which helps preserve the environment and protects the rustic feel of rural communities. Due to recent economic events and many other factors, the number of dairy farms has decreased from 812 in 1982 to only 187 in 2007 (Massachusetts Dairy Farm Revitalization Task Force, 2007). The main causes for this dramatic decrease are the rising cost of fuel, feed, and electricity, as well as historically low prices for milk. Due to those circumstances, our project focused on reducing the amount of energy used on dairy farms to decrease their cost of production. Through working with Representative Anne Gobi and the dairy farmers in her district, we were able to determine which available technologies would be most beneficial for reducing energy consumption on dairy farms throughout the state.

Our project had three main objectives. The first objective was to determine how farmers were using electricity on their farms and what, if any, energy efficient technologies farmers currently had installed. Our second objective was to educate and advise dairy farmers on what technologies would be most beneficial in helping them reducing their electricity bills. Our final goal was to educate farmers on available rebate and grant programs that would reduce the cost of purchasing and installing those energy efficient technologies.

Prior to our arrival in Boston, we researched the different methods of reducing energy cost. Our research first focused on implementing renewable energy sources and discussed the feasibility of installing wind turbines, solar water heaters, methane digesters, photovoltaic cells, and bio-fuels. It was during this research that our group

discovered that our targeted population would not greatly benefit from implementing renewable energy sources. This was primarily due to the fact that their locations were not suitable for wind turbines. Methane digesters were not a worthy investment because of transportation costs for co-ops, cold winter temperatures, and small herd sizes. Photovoltaic cells were not a wise investment because of their heavy weight, large size, and high costs compared to their output. Bio-fuels were unreasonable because of high upkeep costs and negative global impacts on the environment and world food supply. Based on this preliminary research, we decided that most farms would benefit more by improving their energy efficiency. The three technologies that we focused on were pre-coolers, heat recovery tanks, and variable frequency drives. However, we found one farm that would benefit from solar water heaters.

In order to determine how farms were using electricity, our group met with five farmers in the fifth Worcester district. During each visit, we recorded data, such as horsepower and efficiency, of all the pumps in the farmer's refrigeration and milking systems. That helped us determine a baseline for the amount of electricity each farm consumed. Using that information, we were then able to perform a cost-benefit analysis for each of the three technologies. Finally, based on the calculations we developed for each of the five farms, we were able to create a general program that all farmers could use to estimate their total energy savings by implementing a pre-cooler, heat recovery tank, or variable frequency drive.

While visiting each of the five farms, we encountered a wide variety of situations. There were farmers that had not implemented any form of energy-saving device, as well as farmers that had most of the recommended technologies and were investigating alternative energy sources to further reduce their energy consumption. We also discovered that four out of the five farms had a pre-cooler installed, three out of the five had a heat recovery tank installed, and none of them had a variable frequency drive. It was also interesting to discover that one farm was considering implementing a solar water heater and another was investigating two wind 15 kW wind turbines for his farm.

One of the farms did not have one of the three recommended technologies. Based on our findings, that farm would see the greatest energy savings by installing a heat recovery tank, followed by a pre-cooler, and the least beneficial technology would be the variable frequency drive. For the other four farmers, we found that three of them would benefit from the installation of a variable frequency drive, with an annual energy savings between $525 and $862. The farmer who would not benefit from a variable frequency drive had a small herd size and was only milking his cows 2 hours a day, which greatly reduces the practicality of installing such a device.

For the five farmers that we visited, we recommended that four of them install a variable frequency drive. Also, for the farmer that had none of the three technologies installed we recommended that he first install a heat recovery tank because this will save him the most energy. We recommended that he install a pre-cooler and a variable frequency drive when he needed to replace his pump. Finally, for the farm considering implementing solar hot water heaters, we recommended an array size of 200 square feet and gave him a list of potential contacts that will aid in the installation and setup of his solar hot water heater.

For Massachusetts farmers in general, we advise that if they do not have a pre-cooler or heat recovery tank installed they should greatly consider it. Those were the two technologies that we found to have the most impact in reducing farms' energy consumption. Also, we recommend that if a farm is considering implementing alternative energy sources, they should first pursue energy efficiency. Alternative energy sources will have the greatest impact if the farm is operating as efficiently as possible. Finally, it is more cost effective to improve energy efficiency than it is to just install an alternative energy source. For any new project, we advise farmers to investigate utility, state, and federal incentive programs.

AUTHORSHIP

Andrew Sides, Kurt Schebel, Joe Wilkos, and Andrew McCarthy wrote this paper. At least one other author reviewed all sections and then the group read through the entire paper for continuity.

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CHAPTER ONE: INTRODUCTION

Farms are an important part of the national and state economies. They provide the consumer with fresh produce and goods. Besides the obvious advantage of local produce, farms also embody the rural character of towns that some people seek when deciding on a location to live. Finally, farms remain an important part in preserving our environment. If it was not for the undeveloped farmland, contractors would develop the land for many different uses.

The economic events within the last five years and the need for more land to house growing populations, are forcing farms, especially smaller family owned farms, to close. In particular, farms near urban centers are finding it more difficult to remain viable while avoiding the pressures of urban expansion. In the United States, the process of urban expansion is creating two problems. First, it is forcing farms to move away from major cities. Second, it is causing a shift in the locations of production. The highest rates of population growth in the United States are occurring in California, Texas, and Florida, causing an increase in demand for local produce in the south. So, while those states are experiencing large population growth, the population in the Midwestern states is remaining fairly constant and farmers are finding it harder to compete with the larger farms for the southern states.

In Massachusetts, one of the areas most affected by those economic pressures has been the dairy farms. In the past twenty-five years the number of dairy farms on Massachusetts has declined from 812 in 1982 to only 180 in 2007, and in just the last five years the number of farms has decreased by 200 (Census of Agriculture, 2002; Massachusetts Dairy Farm Revitalization Task Force, 2007). One reason for this decrease is the recently low price of milk and high cost of production. While this affects only the dairy industry, there are other factors that the entire farming community is also dealing with, including the increasing cost of energy, taxes, and health care (Census of Agriculture, 2002).

In 2006, the price of milk was at a twenty-five year low. Due to this, dairy farms were experiencing economic hardship caused by the large difference between the cost of milk and the cost of production. In order to help protect the dairy farms, the government of Massachusetts provided $3.6 million dollars in emergency relief and established the Dairy Farm Revitalization Task Force (see Glossary) (Historical Highlights: 2002 and Earlier Census Years, 2002). The primary goal of the Task Force was to recommend long-term solutions that would keep the dairy industry in Massachusetts viable. Among the recommendations by the Task Force was the idea to place alternative energy sources (see Glossary) on farms as a way to increase income or decrease energy expenses.

The state deemed it necessary to preserve Massachusetts dairy farms for multiple reasons. The first and most evident reason, according to Rep. Anne Gobi, (January 25, 2008) is in order for the municipalities to preserve their "rustic" feel. She also emphasized the value of open space, which is more desirable as a colonial farm than as a shopping plaza. As Daniel Smith stated (January 29, 2008), it has been considered that the less milk comes from local farms, the more spoiled it becomes. He also stated that if local farms were to disappear, shelf price of milk in Massachusetts would rise because the consumer would pay truck drivers instead of local farmers for semi-spoiled milk. Buying local milk supports the local economy, generating $500 million worth of dairy products, $50 million in sales, and an additional $120 to $150 million in peripheral economic activity (Massachusetts Dairy Farm Revitalization Task Force, 2007).

In order to help protect the viability of Massachusetts' diary farms, this project focused on means of improving energy efficiency. Our specific objectives were to determine the current energy usage on dairy farms, advise the dairy farmers on what energy efficient technologies would be most beneficial and educate them on available grants and loans. The methodologies our group followed included Geographic Information Systems (GIS) analysis, energy assessments, and cost-benefit analysis.

CHAPTER TWO: BACKGROUND

The goal of this project was to increase dairy farmers' energy efficiency in order to protect the viability of the remaining Massachusetts diary farms. The information presented in this background chapter discusses trends in the dairy industry of the United States and Massachusetts. Also, included in this chapter are the State of Massachusetts' actions to protect the dairy industry. In respect to increasing energy efficiency, this chapter discusses the implementation of solar and wind technologies, as well as the feasibility of implementing methane digesters and bio-fuels. Finally, we discuss available technologies for reducing a farmers' consumption of electricity, such as pre-coolers, heat recovery tanks, and variable frequency drives.

TRENDS IN THE UNITED STATES DAIRY INDUSTRY

One of the largest decreases in the dairy farm industry occurred during the twenty five year span of 1955 to 1979. According to Crowley and Niedermeier (1981), the number of dairy farms decreased from about 5 million, in 1955, to about 352 thousand in 1979. During this same period, the total number of dairy cows also decreased from over 21 million to about 10 million. Crowley and Niedermeier (1981) further state that the largest reason for the dramatic decrease is due in large part to advances in feed (see Glossary), selection of cows, and an improvement in dairy farm management. Due to those aforementioned changes, farmers were able to increase the average production of milk per cow to 5600 kilograms, an increase from 2600 kilograms in 1955. Another cause for this production increase is due to the introduction of mechanization in the dairy industry. As a result of those changes, farmers were able to increase their efficiency and increase their herd size. This reduced the need for smaller farms (Crowley & Niedermeier, 1981).

The number of dairy farms continues to decrease. Since 1979, the number of dairy farms in the United States has decreased by 74 percent, and by 2002, only 92,000 dairy farms remained (Historical Highlights, 2002). As stated by Cross (2001), one of the largest contributors to this decline is the increase in herd size. In fact, from 1992 to 2002 the number of dairy farms that had more than 1000 cows increased by 120 percent, from 564 to 1256 (Milk Cow Herd Size, 2002; Milk Cow Herd Size, 1992). Not only was there an increase in larger herds, but the distribution of cows by farm size shifted. So while the number of farms with a herd size of 1000 has approximately doubled, the total number of cows owned by these farms has more than quadrupled (Milk Cow Herd Size, 2002; Milk Cow Herd Size, 1992). But while the number of dairy farms has decreased dramatically, the total number of cows has remained relatively constant. In 1974, there were roughly 10.5 million dairy cows in the United States, and that number has only decreased by a little over a million in 30 years (Historical Highlights, 2002). This further shows that a large contributor to the decrease in dairy farms is the increase in efficiency allowing for larger farms.

A growing trend in the United States dairy industry is a shift in production. Cross (2001) states that in the 1920's, Wisconsin became the largest producer of milk and surpassed New York for the largest number of dairy cows. Wisconsin maintained its dominance for approximately seventy years, until 1993, when California gained the lead in dairy production. Also, in 1998, Wisconsin finally lost the lead in dairy herd size, once again to California. Cross (2001) further explains that the reason for this shift as being two fold. First, he explains that due to established minimum milk support prices, based on the distance from Eau Claire, Wisconsin, producers in southern states were averaging payments of about $2.00 per hundredweight more than those in Wisconsin. Also, while the population of Midwestern states has remained fairly constant, states such as California, Texas, and Florida have experienced rapid growth, increasing demand on local dairy farmers.

The northeastern United States reflects a microcosm of what is happening in the rest of the country. The Census of Agriculture (2002) shows that the Northeast is experiencing the same overall trends, such as the number of dairy farms decreasing while the number of larger dairy farms increases. Also, there is the same shift in production, with New York now being the largest producer. In fact, the number of dairy farms with a herd size larger than 1000 in New York has increased from 6 to 40, from 1992 to 2002 (Census of Agriculture, 2002). While there are some regional contributions to problems in the dairy industry, such as weather and production costs, the overall trends in the Northeast diary industry remains the same as the rest of the United States.

TRENDS IN THE MASSACHUSETTS DAIRY FARM INDUSTRY

Trouble has arisen in Massachusetts as well. According to the Revitalization Task Force (2007), a number of factors are negatively affecting Massachusetts dairy farming, including rising cost of feed, electricity and fuel, increasing property values, a disinterested generation, processor gouging, and foreign competition. As shown in Figure 1, Massachusetts has gone from having 829 farms to 189 farms, from 1980 to 2007 (Massachusetts Association of Dairy Farmers, 2007).

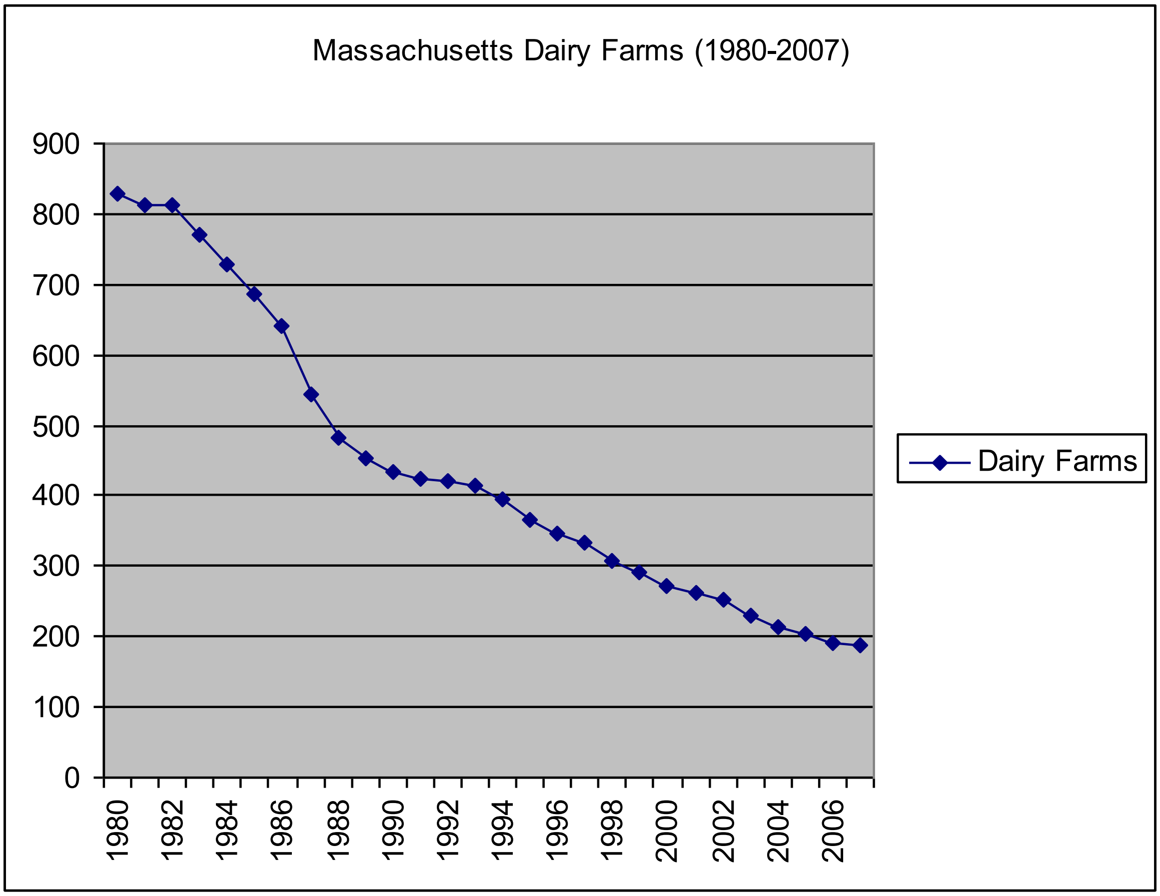

Figure 1: A Tally of Massachusetts Dairy Farms, 1980-2007 (University of Massachusetts: Amherst, 2007)

The first issue striking Massachusetts dairy farmers is the rising cost of feed. A number of factors have caused the price of feed to increase. Feed, like any supply used by any business, is cheaper if it is more popular because it becomes more readily available. However, Anne Gobi (January 25, 2008) states that as the number of dairy farms decreased, the cost of feed delivery increased, because it was no longer profitable for feed companies to make small deliveries. Likewise, according to the University of Massachusetts Amherst (2004), as farms of all types started to disappear from Massachusetts, dairy feed had to come from further and further away, driving up the cost.

Additionally, fuel and electricty costs have increased, making certain the operation of some machinery cost-prohibitive. For some farms, the expense of running everything from tractors to milk-pumping machines, virtual essentials, has driven the farm out of business. For farmers, the largest expenses have been gasoline and petroleum products (Massachusetts Association of Dairy Farmers, 2007). Figure 2 is a price paid index that displays the percentage increase of farm expenses relative to 1977. This figure shows that all costs have risen. In particular, fuel costs have jumped significantly higher in recent years, increasing close to 500 percent by 2005. Worse yet, fuel costs have been sporatic and unpredictable, leading to unnecessary or underestimated compensation.

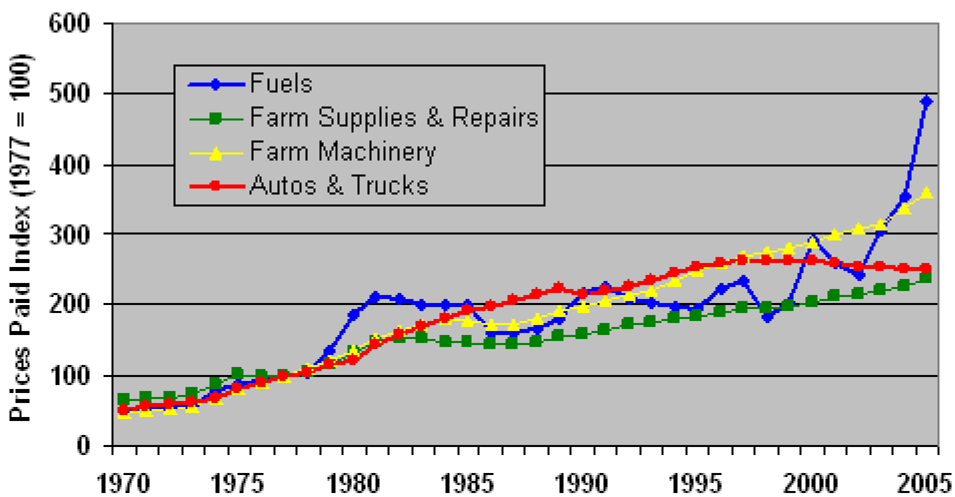

Figure 2: Increases in Fuel and Machinery Costs, 1970-2005 (University of Massachusetts: Amherst, 2004)

Additional the rising cost of electricity has been a large factor for the recent high cost of production. As shown in Figure 3, the cost of electricity in Massachusetts has increased by 40 percent in the last seven year.

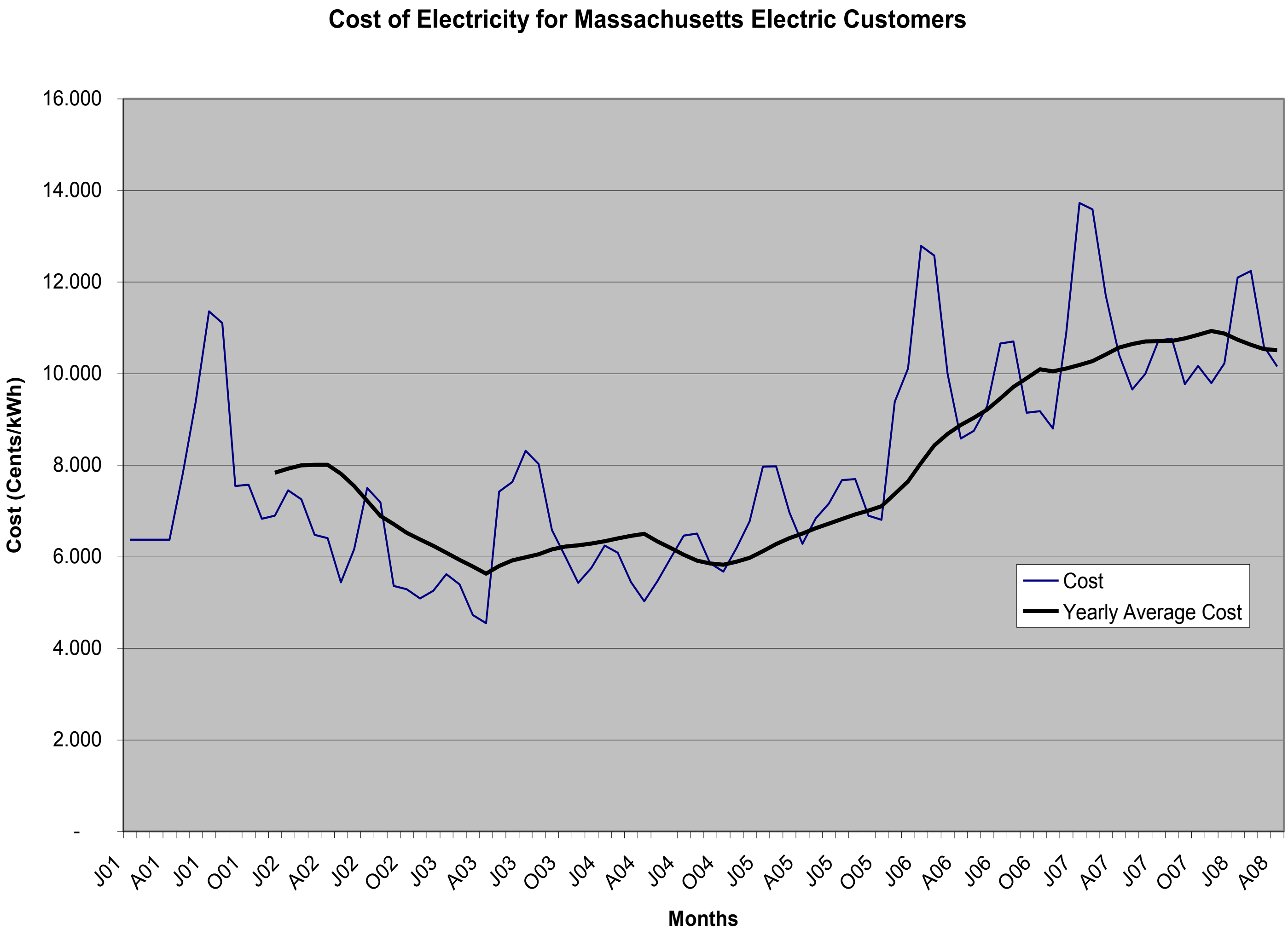

Figure 3: Electricity Costs for Massachusetts Electric Customers (Department of Public Utilities, 2008)

Massachusetts is now facing a phenomenon that has been shown to be disasterous in Connecticut and Rhode Island. In recent years, property values have increased due to a larger demand from the housing market, causing a decrease in supply and and increase in demand (S. Kulik, personal communication, January 29, 2008). Thus, taxes on a farm are higher than on a residential home. So, the farm is more monetarily valuable if sold to be used for commercial or residential land than if it is to be used for production. Figure 4 illustrates how much higher Massachusetts' land value is than its neighbors, with the notable exception of Connecticut and Rhode Island, whose farms are suffering as well. This higher value of land has propagated the effect of selling farms for land value.

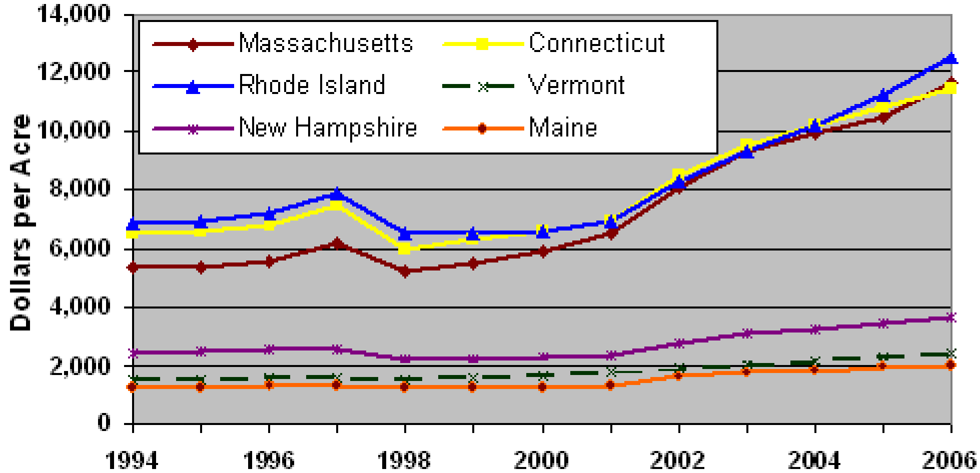

Figure 4: Real Estate Values by State (University of Massachusetts: Amherst, 2004)

Figure 5 shows a breakdown of farm operators by age. It is important to note that there are more farm operators over retirement age than there are farmers under the age of 45. This shows a shift of generational control over farming, and more specifically, a newer generation that is less interested in farming. Disinterest or perceived hopelessness lead to the selling of many farms in Massachusetts.

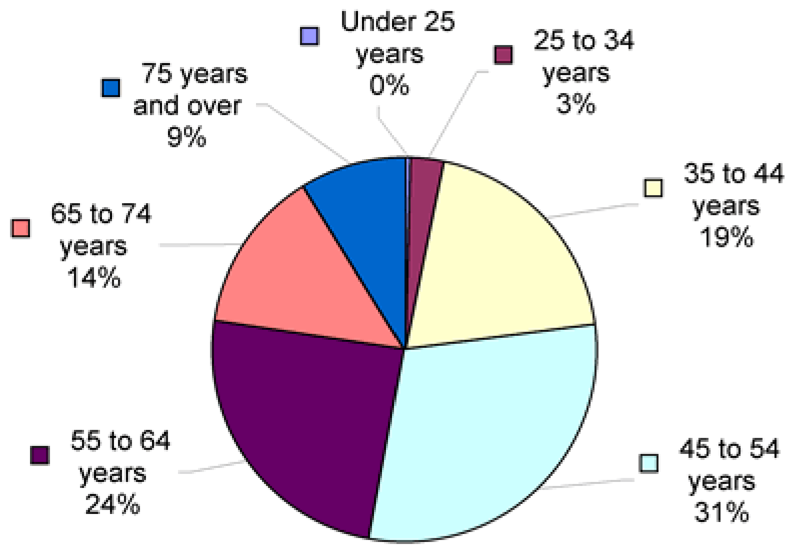

Figure 5: Percent of Farm Operators by Age (University of Massachusetts: Amherst, 2004

According to Daniel Smith (January 29, 2008), the largest cause for the disappearance of Massachusetts dairy farms is the increase in foreign competition. Figure 6 shows Massachusetts' slow decrease in milk output, while the American southwest booms in milk production by as much as 800 percent, since 1970 (United States Department of Agriculture, 2008). The southwest ships its excess milk to its neighbors, forcing neighboring regions to ship their milk elsewhere for a better market. This creates a rippling effect throughout the country resulting in foreign suppliers inundating Massachusetts. The result for Massachusetts is a decrease in the market value of local milk and an inability to sell to foreign markets (D. Bosely, personal communication, January 29, 2008).

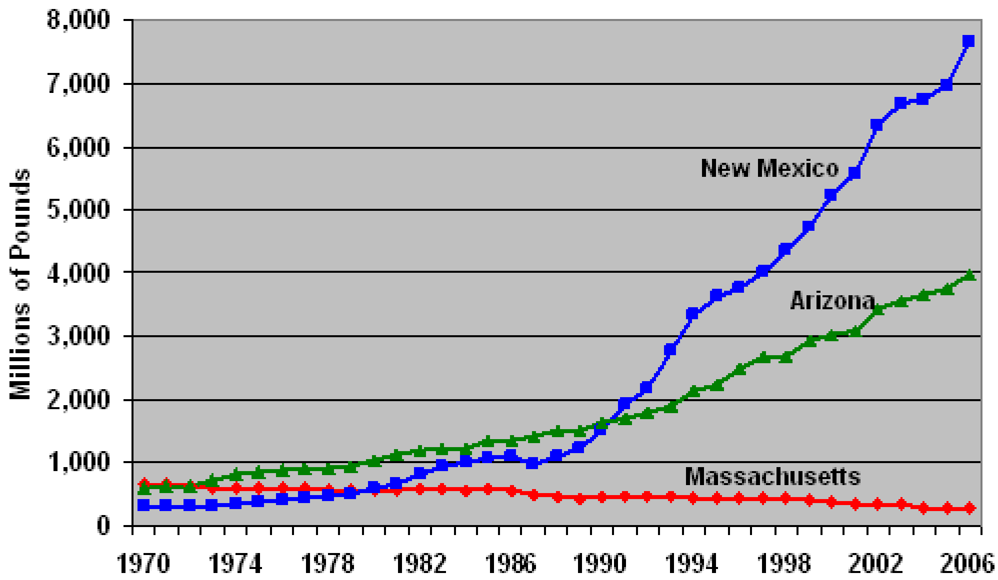

Figure 6: Massachusetts Production Stagnation by comparison to Growing States (A New Snapshot of Massachusetts Agriculture, 2004)

MASSACHUSETTS LEGISLATIVE RESPONSE

While the Massachusetts dairy industry has been declining for several years now, the state legislature only recently pursued aid and resolutions to this problem. In 2006, several conditions combined to severely threaten the acceleration of the loss of Massachusetts dairy farms (Massachusetts Dairy Farm Revitilization Task Force, 2007). Throughout the United States there was a steep drop in milk prices, harsh and unfavorable weather conditions, and a substantial increase in milk production costs. These conditions sparked various legislative efforts in Massachusetts designed to address these problems, including proposals for fee and subsidiary programs, revenue insurance programs, and emergency relief.

A main concern was the high price differential between the farm price of milk and the retail price of milk. According to Figure 7, the difference in these two prices was at its highest in 2007.

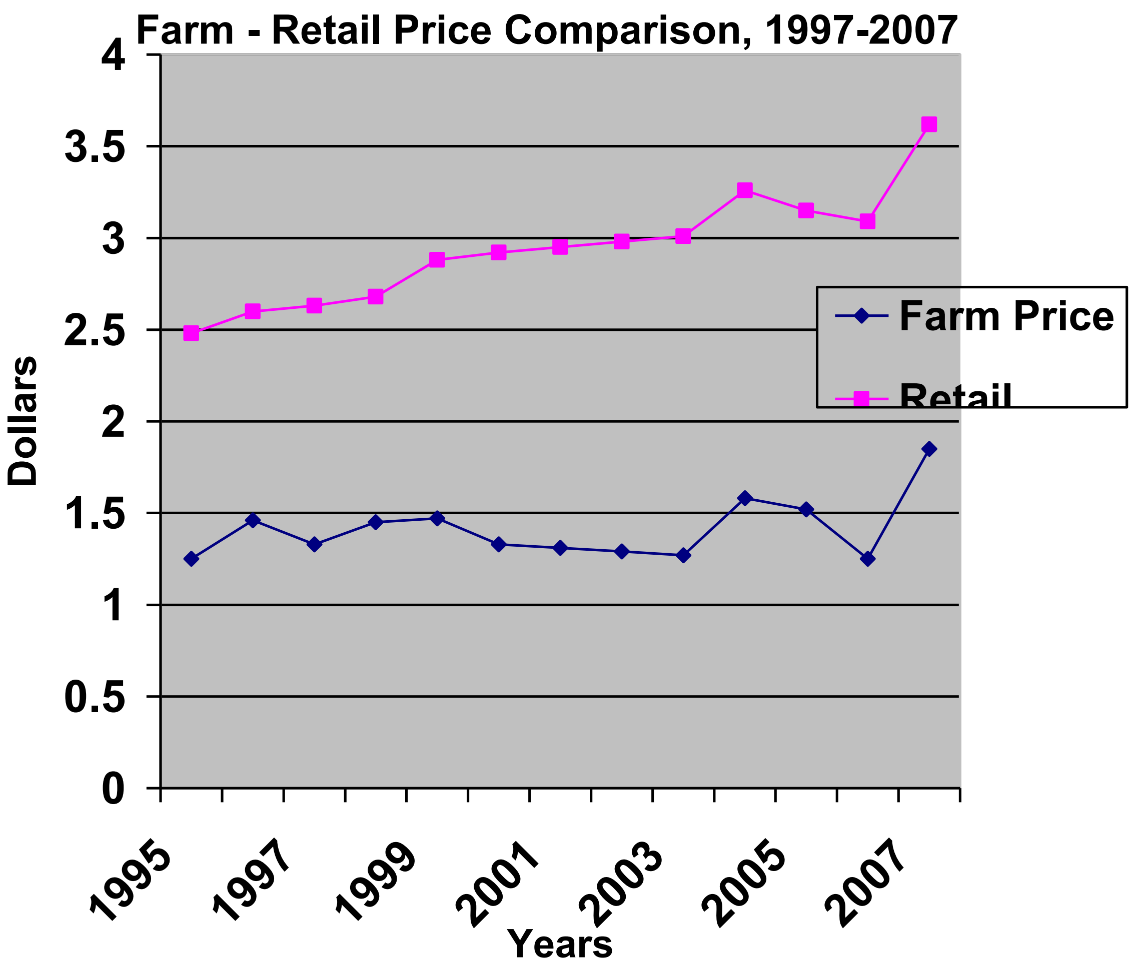

Figure 7: Comparison of Farm Price vs. Retail Price (Smith, 2008)

According to Vermont State Senator Daniel Smith (January 29, 2008), farmers lose a significant amount of money to the distributors and retailers. This is due to the large difference in farm price and retail price of milk. Estimated at $31,500 per farm, the difference totals $1.26 million dollars across New England and New York alone. This money cycles through the economy but is not arriving back at the farms, where, based on the problems presented in the introduction section, farmers need it.

In the spring of 2007, Scott J. Soares, the Commissioner of the Massachusetts Department of Agricultural Resources, declared a crisis in the dairy industry in response to a petition for the relief from the industry and ensuing hearings (Soares, 2007). Those crisis conditions lead to Massachusetts legislative action, which provided $3.6 million in emergency relief for dairy farmers to aid them for the aftermath of the 2006 year. The emergency relief, found in Chapter 42 of the Acts of 2007 (Massachusetts Legislature, 2007), was also accompanied with the establishment of the Revitalization Task Force.

The task force is presided over by Scott J. Soares and has a total of seventeen members: seven various members of the Massachusetts state government executive branch; six legislators, three dairy farmers; and a representative of milk processors. Our group will be citing the work of the Revitalization Task Force several times in our report and it is important to understand their purpose, which is to examine solutions to the Massachusetts dairy farm industry's problem (Massachusetts Dairy Farm Revitalization Task Force, 2007).

SOLAR AND WIND ENERGY

The Task Force has suggested the implementation of alternative energy as a source of income on farms. The principle sources of alternative energy that we will focus on are windmills and solar panels.

Windmills are a source of energy that have been in use on farms around the world for hundreds of years. However, in their traditional form, windmills pump water and tend to be much smaller than wind turbines. Wind turbines take up very little land and make nearly no impact on a farmers land.

One potential wind energy solution for farmers is smaller wind turbines, which produce about one to 10-kW. Those wind turbines are a more practical application for farmers as they are more affordable and versatile in their placement than large-scale wind turbines. A typical small wind turbine can range from $3,000 to $35,000 installed depending on the output, application, and size of the tower (U.S. Department of Energy, 2003). While a wind turbine with a lower output provides a lower initial investment, they tend to cost more overall as it takes longer to payback the overall cost.

Farms are suitable locations for wind turbines due to their open space. Wind turbine manufactures and the U.S. Department of Energy (2003) recommend that the placement of small wind turbines be on at least one acre of land, which is significantly less than what farmers typically own. Also, wind turbines are required to be 30 feet above any obstacle within 300 feet of the turbine. Farmers can place wind turbines far away from obstacles because they possess large open fields. This will reduce the height of the tower required thus reducing the cost. While wind energy is a viable solution for dairy farmers, the practicality is dependent on average wind speeds experienced at the individual farms. As shown in Figure 8, wind speeds vary considerably through the state of Massachusetts, with some of best wind conditions being in the western part of the state and on Cape Cod.

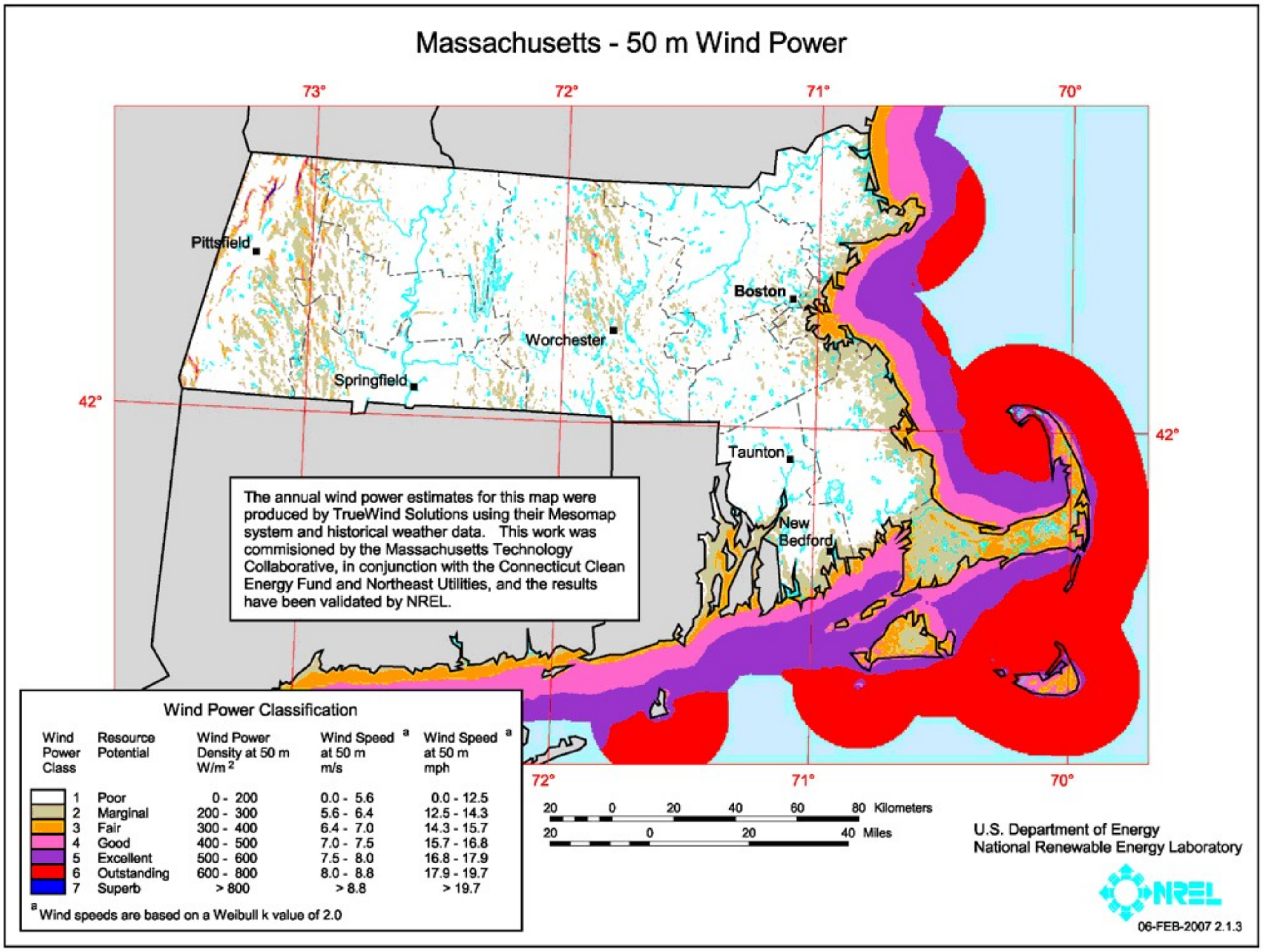

Figure 8: Massachusetts Wind Power at 50 meters (Massachusetts Wind, 2007)

Solar panels are another alternative energy source that the Massachusetts legislature is investigating for use on farms. A Massachusetts-based solar panel outputs approximately 1 kW per 100 square feet of open space based upon data collected by the National Renewable Energy Laboratory (2007) and the Massachusetts Technology Collaborative (2008). This data assumes trees, chimneys, or other obstructions do not shadow the open space during any portion of the day. Thus, in order to produce 1 MW of energy, photovoltaic cells would require 100,000 square feet, or a 316 ft square, of unobstructed land or rooftop. Designers only expect even a large system like that to make 1000 MWh of energy over the course of a year. Since a perfectly efficient system would produce 8760 MWh in a year, solar panels are only about eleven percent efficient (G. Palano, personal communication, March 28, 2008). Solar panels also have the disadvantage of high costs. Solar panels carry an installation cost of approximately nine dollars per Watt (Massachusetts Technology Collaborative 2007). Because of the cost and size of solar panels, a mega-Watt sized array would be incompatible with the required grazing land or small rooftops of an average farm. Also, in some counties there is a municipal power grid that does not offer buyback on power and thus does not support on-grid solar panels.

However, solar panels do present advantages to some consumers. Users can place them in nearly any environment, assuming there is a site that receives unobstructed daylight between the hours 9 AM and 3 PM. This scenario is ideally suited for a farmer who has a large tree-line on the north side of his pasture and cannot receive enough wind to make a wind turbine worthwhile (Massachusetts Technology Collaborative 2007). Solar panels can also collect energy in two different ways: photovoltaic cells produce electricity or solar water heaters (see Glossary) warm water through the collection of sunlight. Use of a solar water heater is advantageous for a farmer who has hot-water pipes running throughout the farm for heating. While not all farms have that infrastructure, farms already configured for wood or biomass heating are well suited. Certain natural gas companies, such as Keyspan in central Massachusetts, offer rebates up to $3.50 per Therm (see Glossary) for customers who install solar water heaters. Like photovoltaic cells, solar water heaters are virtually restricted to certain zones of Massachusetts by the bounds of those energy companies. Overall, they are very well suited for any farmer who is attempting to reduce or eliminate power costs.

IMPLEMENTATION OF SOLAR AND WIND TECHNOLOGIES

According to the Massachusetts Association of Dairy Farmers (2007), the biggest expense to farmers in Massachusetts is energy. The Revitalization Task Force proposed three different agreements to mitigate this. The first possibility is that the Massachusetts state government would provide photovoltaic cells (see Glossary) or windmills for the dairy farms in order to alleviate the cost of energy. The second possibility is for a large tax cut to go to farmers who install alternative energy. The final possibility is for the Massachusetts state government to encourage a co-reliant relationship between farmers and the energy companies for rental of the land. In all cases, there are a series of issues that must be resolved. Examples of these, mentioned in the pervious section, include, but are not limited to, cost versus benefit, rights to land, total amount of payment, and loss of "rustic feel" (A.Gobi, personal communication, January 25, 2008).

Implementation of alternative energy has a number of problems that it has faced and has yet to surmount. The most obvious issue with alternative energy is the initial investment cost. While the investment will pay itself back, the initial cost is beyond the means of the average person, making it impractical for widespread use. To counter this in Massachusetts, the government has set up grant funding available to all citizens, through the Massachusetts Technology Collaborative, that subsidizes the initial cost of photovoltaic cells and wind energy. Additionally, the federal government, through the

Department of Agriculture, has created the 9006 program, which funds up to 50 percent of an alternative energy project's cost. Also, the construction of alternative energy needs to face issues concerning legal placement rules. When building a tower, such as that of a windmill, there are height restrictions laid down by the Federal Aviation Administration based on distance from a runway. Also, simple zoning rules typically apply to most construction projects, but do not generally apply to farms in the interest that they can support their operation freely. The downside of this is that a farmer can not build alternative energy sources larger than his needs or encounter zoning issues. Additionally, many towns do not have zoning laws concerning alternative energy and would require local government action before any construction could start.

The first method of alternative energy implementation would be for the state to provide windmills or photovoltaic cells for a number of benefits to the farmer and the state. The first and most obvious benefit would be to provide the farmers with a source of energy to run their farms and a source of income by selling the energy to the power grid (Massachusetts Dairy Farm Revitalization Task Force, 2007). The second benefit would be a step in the direction towards Massachusetts' goal of 25 percent dependence on alternative energy sources by 2020 in accordance with the Green Communities Act (see Glossary) (2007). The final major benefit would be to make the farms among the first to be independent of the fluctuations and inevitable rises in oil prices (Massachusetts Dairy Farm Revitalization Task Force, 2007). This is an advantage for Massachusetts because it is a permanent and sustainable solution.

The second method of alternative energy implementation would be to have the state provide monetary incentive to farmers if they choose to install alternative energy sources on their farms. As stated by the Massachusetts Dairy Farm Revitalization Task Force (2007), this proposal would provide many of the same benefits as the first method, but would cost less to the state and ultimately the people of Massachusetts. The drawback to this would be more reluctance to move towards alternative energy due to initial investment. Currently, Massachusetts provides tax incentives for people adopting solar or wind energy (see Glossary) (The Green Communitites Act of 2007, 2007). However, according to the Revitalization Task Force proposal, the state would have to provide much more incentive to farmers to make this plan.

The third method would be for the state to foster a relationship between farmers and the power company in order to formulate a contract amongst themselves. That type of third-party agreement would entail a power company erecting windmills or solar panels in such a way as to not disturb the dairy farms. In exchange, the farmers would receive payment for use of their land. This plan provides the advantage of costing nearly nothing to the state and benefits all parties. The U.S. Government Accountability Office (2004) and the British Wind Energy Association (2005) conducted independent studies illustrating examples of that. In their examples, wind farm land owners annually receive two to five thousand dollars per turbine, leaving 99 percent of the landmass viable. The difficulties with this plan would be to both devise a strategy to make windmills or solar panels non-obtrusive and to settle the legal issues involved with rental of the land.

BIO-FUELS

The Massachusetts Dairy Farm Revitalization Task Force has made a number of recommendations to both decrease expenditures and increase income for Massachusetts

Dairy Farms. Among the most controversial is the use of bio-fuels (see Glossary). When viewing bio-fuels, it is necessary to analyze the three main possible products: ethanol, biogas and Rape Methyl Ester (RME). It is difficult to compare these fuels because there are an array of positives and negatives for each. Separating each of the fuels into different divisions will help break down the process of which fuel is necessarily the best for the given set of circumstances (see Appendix B).

While bio-fuels are a promising new technology, there are many critics who feel that using bio-fuels will eventually cause more harm than good. According to professor Tad Patzek (2005), bio-fuels are the worst solution for alternative energy with the highest energy cost with the least benefit. He claims that farmers have to observe the entire picture by stating that there is more energy used in the production of those fuels than the energy contained within it.

Because farmers make bio-fuels from food sources, such as corn, in addition to a demand for green energy, there has been a food shortage and inflation in food costs around the world. Farmers are planting corn in lieu of vegetables and other crops in order to profit from high corn prices due to its demand to create ethanol. Often times, the use of bio-fuels will cause more harm than good and is the worst means of alternative energy (Global Forest Coalition et al. 2006). Because of those issues, our group did not consider bio-fuels as a viable source of income in Massachusetts.

METHANE DIGESTERS

Methane digesters (see Glossary) are wastewater and solid treatment technology designed to process animal waste under anaerobic (see Glossary) conditions to yield methane gas and reduce the volume of solids and treated liquids. Anaerobic methane digesters have the potential for mitigating environmental pollution and creating a marketable energy product at the same time (Massachusetts Dairy Farm Revitilization Task Force, 2007). For more information on methane digesters, see Appendix C.

According to Riggle (1997), methane digesters are best suited for bigger farms that produce large amounts of manure. In fact, the AgSTAR Handbook (2004) illustrates that using digesters for electricity production is only effective on farms with more than 500 cows. This is because there is not enough waste produced to keep the digester at operating capacity. The feasibility of using digesters in Massachusetts is drawn into question, as the average heard size on dairy farms is 67, with only one farm having more than 500 cows (Census of Agriculture, 2002).

Smaller farms too can benefit from that technology by participating in a cooperative. A cooperative consists of trucks transporting manure from farms to a methane digestion plant. Those plants would serve several farms in a particular area depending upon manure transportation. According to Gerald Palano (2008), the small number of cows and dairy farms in Massachusetts in addition to the high prices in transportation costs make cooperatives have a long return-on-investment. Farmers participating in cooperatives will have to wait up to 10-15 years before receiving a profit on their initial investment in the cooperative.

Massachusetts farmers could consider using small-scale methane digesters that produce heat for cooking in their households. Farmers in Costa Rica have used these smaller digesters before to supply energy for their homes. According to Gerald Palano (2008), Massachusetts dairy farms do not have to proper piping for natural gases, like methane, to heat their homes. Hence, for farmers to implement those small-scale digesters, they would need to construct expensive piping throughout their farms.

For those reasons stated, our group decided not to include implementing methane digesters on dairy farms in our project. These digesters have been very helpful in areas such as Texas, Costa Rica, and Minnesota, but the current status of Massachusetts dairy farms does not support the state-wide implementation of similar digesters.

SOLAR WATER HEATERS

Solar water heaters take in sunlight and heat up water that a pump pipes into a home for use. Solar water heating is a technology that has existed for centuries. Today, engineers have solar water heating has been refined and optimized through the application of convective and radial heat transfer studies. According to Gerald Palano (April 11, 2008), those projects can be anything from a do-it-yourself project to a highly advanced vacuum tube system tailored to fit the consumer's needs. Often, solar hot water can fulfill sixty to eighty percent of the consumer's energy needs (SunRay Solar, 2007).

Solar water heaters can be of two types, closed loop and open loop. In an open loop system, the water that heats up in the solar collector is the very same water used throughout the house for heating, showering, and cleaning. In a closed loop system, the water that warms in the solar collector heats the water used throughout the house, while the water in the solar collector continuously loops through the collector. Open loop systems are less expensive than closed loop systems and are in widespread use in tropic and desert areas, such as Israel. However, in colder climates where freezing is possible, a closed loop system is required in order that the solar collectors contain anti-freeze.

A typical solar water heater in North America consists of a collector, a storage tank, a circulation pump, and a temperature-activated servomechanism. Figure 9 shows a completed solar water heater system by AET Solar. In addition to the primary components, there are additional valves located throughout the system to cope with the high thermal stresses involved with moving hot water and the winter's cold temperatures. Water flows in two loops, the closed loop and the open loop. The open loop, labeled by the "Cold Water In" and "Hot Water Out" pipes, represents the intake of water into the house and water moving to the showers and sinks. The closed loop is a solvent of water and anti-corrosion compound or anti freeze that constantly circles through the solar collectors and a coil of tubing inside the tank. In the coiled tube inside the tank, the heat from the closed loop transfers into the water of the open loop in the hot water tank and warms the water entering the house's plumbing.

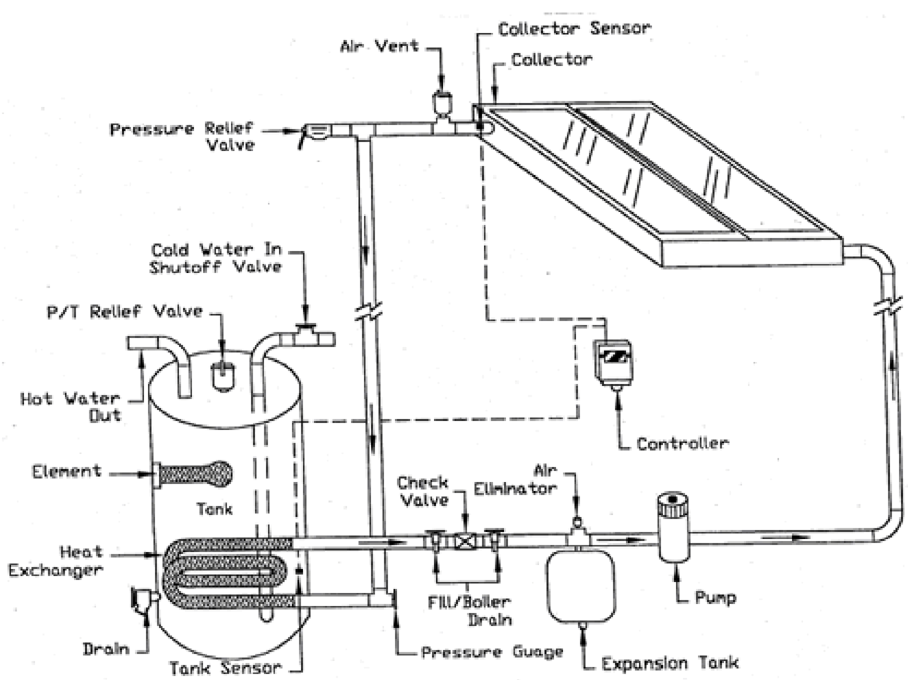

Figure 9: A Complete Solar Water Heater System (AET Solar, 2004)

Designers tailor a solar hot water system to the needs of the customer. The design is dependent on their budget, current plumbing, solar radiation, mounting surface, and the amount of time the customer is willing to devote to installation. The most high performance solar collectors, known as vacuum tube collectors, are immune to freezing in the winter (Department of Energy, 2007). Figure 10 shows the cross section of a vacuum tube collector and its mountings.

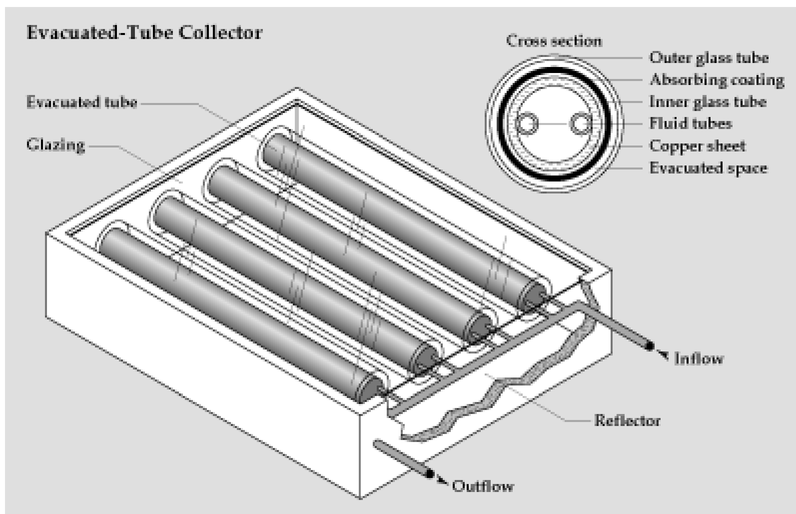

Figure 10: A Vacuum Tube Solar Collector (Department of Energy, 2007)

The most common solar collectors are flat-plate collectors due to their mildly cheap prices. They consist of a black metallic plate with water piping (either copper or polymer) running throughout. Varying companies have differing schemes on how the water travels throughout the plate or how the pipe attaches to the plate. Despite these differences, there is an overall design for flat-plate collectors, shown in Figure 11.

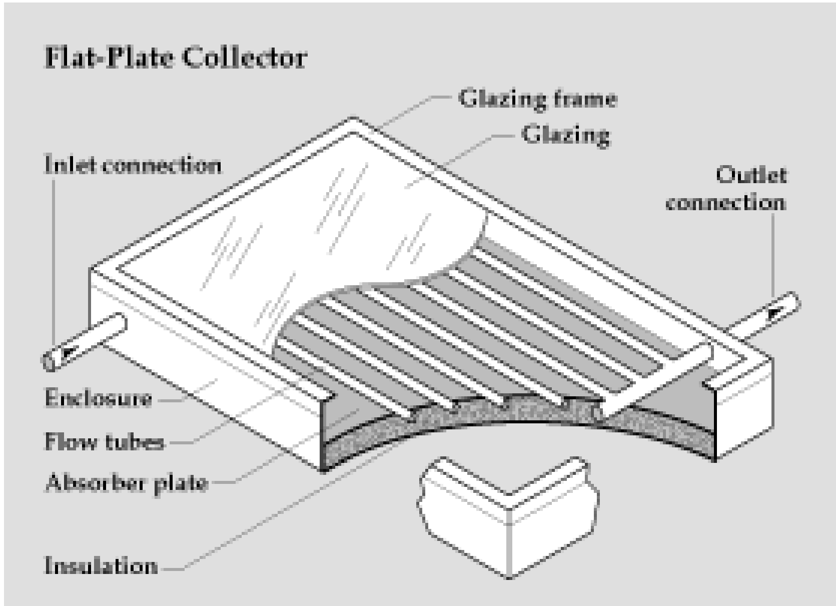

Figure 11: A Flat Plate Solar Collector (Department of Energy, 2007)

Finally, there are also do-it-yourself solar collectors commonly called formed plastic collectors. Those are common in third world countries, hobbyists, and people merely striving to lower their heating bill. While many other collectors can cost between $3000 and $6000 for a complete system, a formed plastic collector can cost as low as $200 (Provey, 2006). However, those plastic collectors have three main disadvantages. First, they can take several days to install and are strictly do-it-yourself, as opposed to contracted out (Canivan, 2002). Second, they do not absorb as much sunlight when not pointed at the sun as commercial solar water heaters, making them have a lower output over time. Finally, the user must empty them every winter before freezing temperatures come, or they become irreparably damaged. Figure 12 shows John Canivan holding one of his formed plastic collectors.

Figure 12: A Formed Plastic Collector (Canivan, 2002)

In order to properly size a solar water heater for an application, a manufacturer often has to give their recommendation. However, as a rule-of-thumb, 20 ft^2 of solar panel is necessary for the first two members of a family, and an additional 12 ft^2 is necessary for each additional person for a family in New England (Solar Rating and Certification Corporation, 2001). Along with collectors, the design must include a tank to hold the hot water. According to SunRay Solar, a solar tank tends to be about twice the size of a gas- or electric-heated tank for the same application. They continue on to state that 1 ft^2 of solar collector needs 1.5 to 2 gallons of tank capacity in order to both keep the tank warm and keep the collectors from overheating.

ENERGY EFFICIENT TECHNOLOGIES FOR DAIRY FARMS

Another method for reducing the cost of energy on farms was to install energy-efficient equipment. A few of the most practical and feasible applications for reducing the amount of energy used on a farm are described in the following sections. While this section focuses primarily on dairy farm equipment, other options include using high efficiency lighting fixtures, high volume low speed fans, high efficiency motors and improving insulation on existing structures.

Pre-Coolers

One method of reducing energy consumption on a farm was to install a pre-cooler. As shown in Figure 13, a pre-cooler is a counter-flow heat exchanger (see Glossary) that uses cold water to reduce the temperature of the milk prior to refrigeration. As the milk enters the pre-cooler at the body temperature of a cow, a pump forces it through a series of small tubes. Those tubes are surrounded by cold water, usually from the farmer's well, flowing in the opposite direction of the milk. When the milk exits, the pre-cooler has reduced the temperature of the milk ninety-five degrees Fahrenheit to approximately sixty degrees Fahrenheit (G. Palano, personal communication, March 28, 2008). The discharge water from that system exits at approximately seventy degrees Fahrenheit. Farmers can then use that water as drinking water for the cows or any other job around the farm where warm water is used.

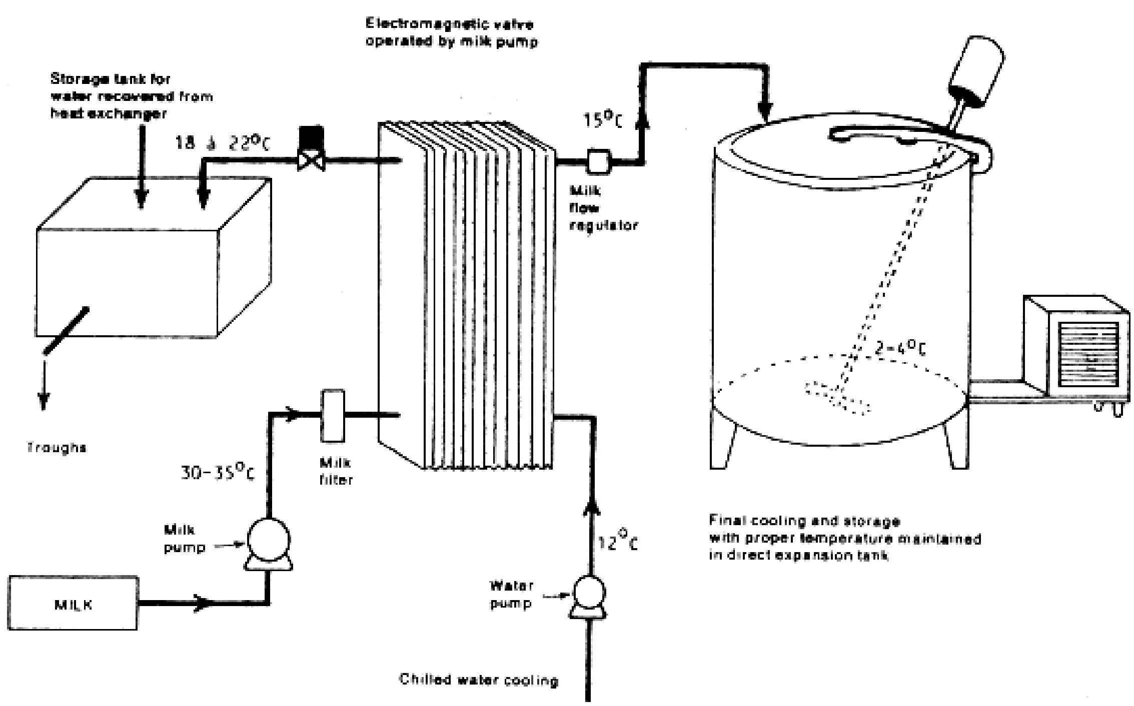

Figure 13: Pre-Cooler Diagram (J.C. Belloin, 1988)

By reducing the initial temperature of the milk, farmers will be able to reduce the amount of energy used in their refrigeration process. The use of a pre-cooler may be able to reduce the amount of energy used in the refrigeration process by as much as forty percent. Also, a pre-cooler is relatively inexpensive compared to other farm equipment, with units costing on average $3,000. Palano (2008) states that one final advantage to installing a pre-cooler in Massachusetts is that some electric companies will provide as much as a forty percent rebate for the cost of installation.

Refrigeration Heat Recovery

Similar to the pre-cooler process in regards to heat transfer is a refrigeration heat recovery system. Traditionally, refrigeration systems discharge their exhaust gasses, which can reach as high as two-hundred degrees Fahrenheit, into the atmosphere. In order to reduce the amount of energy to heat the water used in sterilization, a refrigeration heat recovery system utilizes those exhaust gases to heat a large water tank. As shown in Figure 14, a pump transfers the exhaust gasses to a pipe that runs through a large water tank. Through that process the temperature of the water in the tank increases to about 115 degrees Fahrenheit.

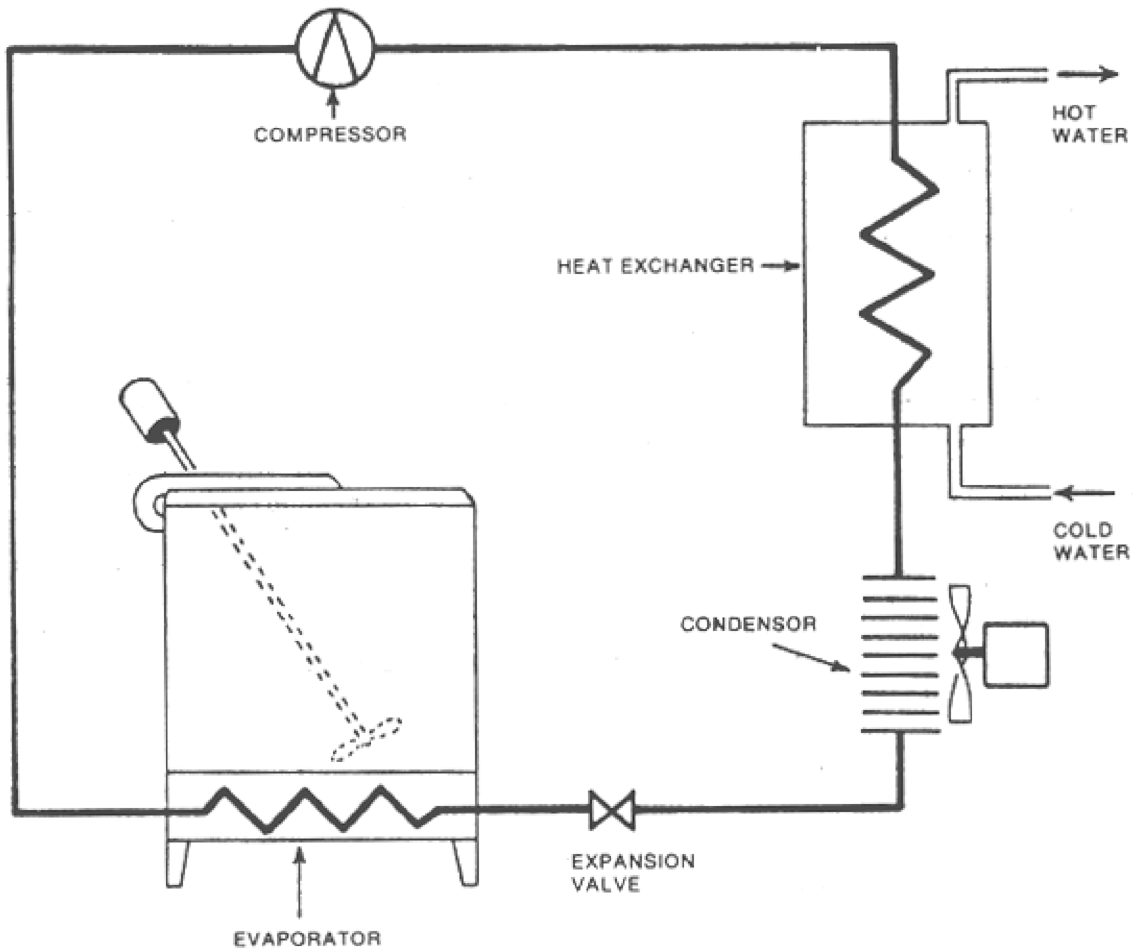

Figure 14: Diagram of a Refrigeration Heat Recovery System (J.C. Bellion, 1988)

As stated by Sanford (n.d.), it is generally more expensive to heat up water than it is to cool down milk. So, one of the biggest contributors to improving efficiency on farms could be a heat recovery system. Similar to pre-coolers, electric companies in

Massachusetts will also provide an equal rebate for the installation of a refrigeration heat recovery system.

Vacuum Systems

It was necessary to examine the farmer's vacuum pump, because those pumps can be a high energy consumer on the dairy farm. As shown in Figure 15, a variable speed vacuum pump adjusts vacuum pressure so that it does not use more suction pressure than is needed. There is no loss in milk production, since the variable speed drive slows the motor down to maintain a set point instead of constantly running at the same rate. This will decrease the motor speed, creating a more energy efficient process.

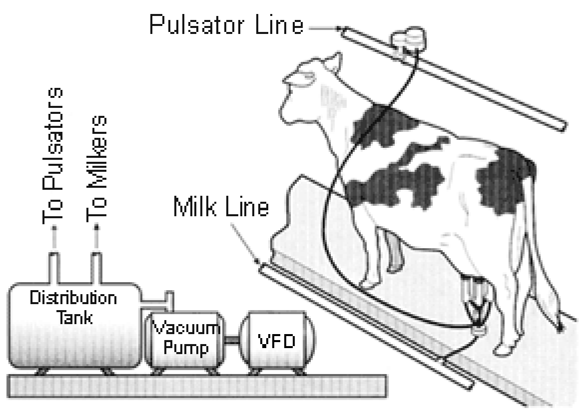

Figure 15: Diagram of a Variable Speed Drive (Wisconsin Public Service Corporation, n.d.)

OUTDOOR WOOD FURNACES

Many farmers have turned to outdoor wood furnaces in an attempt to save money on their electric and heating bills. Outdoor wood furnaces look like a small utility shed, as shown in Figure 16.

Figure 16: Diagram of an Outdoor Wood Furnace (Central Boiler, 2008)

Those furnaces use a slow-burning fire to heat water that travels to and from the desired building. The system is essentially a wood furnace surrounded by hundreds of gallons of water, depending upon the size. The water circulates in a closed system, which the customer can regulate through automatic controls. Insulated underground pipes connect the furnace to the building and, as a result, manufacturers can place the furnace up to 500 feet away from the desired structure (Central Boiler, 2008). The pipes attach to a heat exchanger or circulator, which conveys the energy into the house's heating system.

Outdoor wood furnaces can heat homes, barns, garages, pools, hot tubs, and whatever other structure the pipes can attach to. Figure 17 shows a wood furnace attaching to a house.

Figure 17: Operational Diagram of a Wood Furnace (Central Boiler, 2008)

There are a variety of sizes and manufacturers of outdoor wood furnaces. In order to calculate which size they need, users must take into account ceiling heights, windows, additional square footage of basements and upstairs, insulation, building age, geographic location, heating systems, number of buildings, installation, and the distance from the furnace to the heated buildings. Manufacturers use either a BTU (see Glossary) rating or square footage capabilities. Because BTU's in wood vary, square footage is the most accurate measure and manufacturers always recommend an over-sized furnace.

Outdoor wood furnaces are a common way for farmers to heat their homes and barns. According to the Massachusetts Committee on Environment, Natural Resources, and Agriculture (2007), outdoor wood furnaces offer a safe way to heat homes because they remove the threats of chimney fires, carbon monoxide build up, and oxygen depletion associated with indoor heating appliances. An outdoor wood furnace provides 100 percent thermostatically controlled heat for multiple buildings and the ability to heat domestic hot water. According to James Talvy (April 10, 2008), wood is an abundant resource on farms due to the process of field fertilization. Farmers constantly have to cut down the trees surrounding their fields because these trees feed off the fertilizer and grow exponentially as a result.

Wood is a renewable fuel that is carbon neutral. According to the Massachusetts Committee on Environment, Natural Resources, and Agriculture (2007), outdoor wood furnace emissions are very similar to other wood heating appliances. However, outdoor furnaces can be very problematic and controversial. Wood furnaces require a large amount of wood and muscle power to run. Additionally, farmers need to be monitoring the furnace constantly to ensure it is running correctly. Also, there are environmental concerns as well. Outdoor furnaces create large amount of smoke that can be harmful to neighbors at low altitudes. There are many rules and regulations owners must follow when operating their outdoor furnace. According to James Talvy (April 10, 2008), West Brookfield does not allow him to operate his furnace in the summer months due to the high smoke emissions. Figure 18 shows smoke coming from a wood furnace.

Figure 18: Outdoor Wood Furnace (Washington State Department of Ecology, 2008)

CO2 emissions are also another concern with wood furnaces. However, Smith, Heath, and Jenkins (2002) state that burning wood biomass creates just as much CO2 emissions as letting the wood rot. Obviously, burning the wood speeds up the process of CO2 emissions greatly, but the farmers are constantly cutting down trees on the edges of their farms and wood boilers are effective way to convert that wood into useful energy.

CHAPTER THREE: METHODOLOGY

The overall goal of this project was to improve energy efficiency on Massachusetts dairy farms. Our specific objectives were to determine the current energy usage on dairy farms, advise the dairy farmers on what energy efficient technologies would be most beneficial and educate them on available grants and loans. The methodologies our group followed included Geographic Information Systems (GIS) analysis, energy assessments, and cost-benefit analysis.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

A geographic information system (see Glossary) is any system for capturing, storing, analyzing, and managing data that is spatially referenced to Earth. GIS permits users to create interactive searches, analyze spatial information, edit data and maps, and present the results of such operations. Using GIS allowed our group to analyze important information relative to each participating farm concerning the implementation of solar and wind power.

In order to assist the farmer in the planning stages of constructing a wind mill or solar panel, our group had to become educated in the amount of wind and sunlight each farm receives annually. Our group used the Massachusetts GIS system, also known as Oliver, to which we had access to through the Massachusetts government website. Massachusetts GIS provided us with wind maps, topographic maps, and spatial views of the farms. All of those allowed us to determine the best locations for building a solar panel or wind turbine. GIS gave us annual wind averages for wind speeds at thirty, fifty, seventy, and one hundred meters. Depending upon the height of the proposed windmill, we told the farmer how much power he could expect from the windmill.

Before our group met with each farm for ourselves, we needed to gain an understanding of the farm's landscape and surrounding area. Along with supplying important topographic data for each farm, GIS also provided us with constraint data pertaining to the farm and its vicinity. For example, GIS can identify flood zones, marsh areas, conservation lands, environmentally protected areas, structures, and other obstacles that prohibit constructing windmills and solar panels. Before traveling to each farm, our group made sure we used GIS to obtain a good understanding of each farm's constraints.

ENERGY ASSESSMENTS

While visiting the farms, our group used an energy assessment methodology. The purpose for our group conducting an energy assessment was to determine whether the farmers could save money by implementing energy-efficient devices and systems. Switching simple utilities, such as light bulbs, could save the farmers a significant amount of money; our group determined the exact amount in our findings and analysis.

According to the Section 9006 Program (2008), all energy efficiency improvement projects with total eligible project costs of $50,000 or less must provide an energy assessment (see Appendix D). All energy efficient projects costing more than $50,000 must provide an energy audit (see Appendix D). Our group used energy assessments because the farms we visited were not considering projects of $50,000 or more due to their size.

Our group's energy assessments included a situation report (see Appendix D) and a report on potential improvements (see Appendix D). The purpose of an energy assessment was to include adequate and appropriate evidence of energy savings expected when the farmer operates the proposed system. The situation reports provided an assessment of current energy costs and efficiency by analyzing energy bills and briefly surveying the target building, machinery, or system. Our group created potential improvements reports to estimate the overall costs and expected annual energy and cost savings from the proposed improvements.

To obtain an idea of how much energy the farm was using, our group acquired the farmer's electric bills for all fuels and utilities. Those electric bills allowed us to conduct an energy assessment for each farm. To accurately conduct an energy assessment, we took pictures of the name plates on all equipment and utilities. Our group would determine whether it was economically beneficial to upgrade the farm's current equipment and utilities in our energy assessment analysis.

COST-BENEFIT ANALYSIS

A large contributing factor for any decision to implement alternative energy is an analysis of the cost versus the benefit of such investment. The following section will discuss our methods for determining the return on investment time (ROI, see Glossary) through the calculation of initial cost and state-provided rebates.

Our first step in the cost-benefit analysis was to find a way to describe accurately the initial cost of wind turbines and solar panels. We did this by researching manufacturers and installers of those technologies and by investigating historical alternative energy projects. While solar energy costs remain constant throughout Massachusetts, the initial cost for wind energy increases if the selected site does not have nominal wind conditions (see Glossary). To predict for that cost increase, we collected data on the price of less-than-ideal wind turbines. From this data, we constructed costcurves showing price versus output of solar and wind energy and analyzed whether wind or solar would be best suited for the farm's energy needs. In cases where both wind and solar were reasonable options, we predicted the cost after rebate to determine the best option.

The next step was to research the rebate and incentive programs available to those who install solar panels or wind turbines. Our main sources for that information were through the Database of State Incentives for Renewables and Efficiency (www.dsireuse.org) and the Massachusetts Technology Collaborative (http://masstech.org). Those websites provide a list of available programs that grant financial reimbursement for projects dealing with renewable energy sources. For example, there are rebates provided for the feasibility studies (see Glossary) of wind and solar projects as well as to offset the cost of the actual product.

Finally, we determined the ROI by using equation 1.

Equation 1: Return on Investment Time for Energy Sources

$$ROI = \frac{Cost}{Output * 24 * 365.25 * .10}$$

"Cost" is the initial price, in dollars, of the selected energy source with all of the rebates factored in. "Output" represents the expected power output by the device in kW. One multiplies "Output" by 24 to convert it from the power measurement of kW to the energy measurement of kWh. One multiplies this number by 365.25 to determine the expected number of kWh produced per year. Then, one multiplies this number by .10 to convert kWh/year into dollars/year, as energy is generally $.10/kWh. ROI will be output in number of years.

To further verify that our cost-benefit analysis was accurate, we modeled the payback period using the Net Present Value (See Appendix H). By performing this analysis we determined that our calculations were indeed correct and we continued to use the ROI equation for our analysis.

INFORMATIONAL CD FOR FARMERS

To reach out and help other Massachusetts dairy farmers, other than the ones we visited individually, we created CD's with an Excel spreadsheet and a set of instructions. This spreadsheet calculates energy savings per month, monthly and annual cost savings, return on investment period, and carbon savings per year. To see this Excel spreadsheet see Appendix E.

The read-me file starts off with an introduction introducing Anne Gobi then us as a project team. After the introduction, there are brief explanations on the various means of energy efficiency, then an explanation describing how and what to put into the input parts of the Excel spreadsheet. Prices for these energy efficiency products are briefly described with different prices for different size motors that the farmers might encounter. It was also necessary to let the farmers know about grants, rebates, and loans available to them. A description on the Database of State Incentives for Renewables and Efficiency (DSIRE) is also in the read-me, with the website link to get to DSIRE. A reference to our final paper is included in the end, describing how the paper gets more involved. To see this instructional file see Appendix F.

CHAPTER FOUR: FINDINGS AND ANALYSIS

The various farms we visited were diverse in their characteristics. Some were traditional family-owned for generations, while others were owned by a trust and others still were bought in the last twenty years. They had varying size operations, different technologies installed, different budgets, and different objectives. We took all of their situations into account and prepared an Excel spreadsheet that would calculate how much savings they would receive by employing new technology.

We based the analysis that we made around experimental and empirical data collected from the Wisconsin Public Service (Wisconsin Public Service, 2008) and manufacturer's expectations (Mueller Corporation, 2006). By typing in a farm's data, we would instantly have an expression of how the farm benefited, which could in turn, be inserted into a mail-merged Word document seen in Appendix G.

For a plate cooler, there was a linear relationship between total quantity of milk and energy savings (Wisconsin Public Service, 2008). We derived the total amount of milk from the number of cows multiplied by the number of milking sessions per day. Then, we used a linear regression that related total milk to energy savings based on empirical data and determined the relation coefficient to be 1.7628 kWh/(cow-milkings per day). Equation 2 describes this calculation.

Equation 2: Calculation of Monthly Energy Saved for a Plate Cooler

$$Energy = 1.7628 * Cows * Milkings$$

For variable frequency drives, the correlation was not nearly as simple. We based our equation to describe savings upon three variables: the number of milking stations in a farmer's parlor, the horsepower of the pump, and the number of hours the pump operates. If the ratio of milking units to pump horsepower, multiplied by.2 is less than .24, we considered the pump to be grossly oversized for its application, and for the purposes of calculation, is considered .35 (Wisconsin Public Service Corporation, n.d.). We have shown this calculation, called speed ratio, in Equation 3.

Equation 3: Calculation of Speed Ratio

$$SpeedRatio = .2 * \frac{Units}{HP} \text{ or } .35$$

We then used this speed ratio to calculate Equation 4. Several of the variables are determined empirically (Wisconsin Public Service Corporation, n.d.), but .746 represents the conversion rate between horsepower and kWh, .05 is the amount of inefficiency inherent in the motor, and 365.25 is the number of days per year.

Equation 4: Calculation of Monthly Energy Saved for a Variable Frequency Drive

$$Energy = HP * .746 - (.05 * HP * 10 * SpeedRatio + 1.7729) * 365.25 * Hours$$

According to the Mueller Corporation (2006), to determine the savings on a heat recovery tank, we needed to know the number of pounds of milk produced by the farm per day and the change in temperature the milk went through by the work of the compressor. According to David Hanson (April 9, 2008), a cow produces about eight gallons of milk per day. We obtained the number of gallons of milk by multiplying the number of cows by eight. Then we multiplied by eight again, representing how many pounds a single gallon of milk weighs (Goff, D., 1988.). Then, to determine the temperature change of the milk, we asked farmers what the temperature of the milk was leaving the plate cooler and at what temperature they stored the milk. If farmers did not know those temperatures, we substituted typical values that plate coolers output and common storage temperatures. In the case of Farmer A, who did not own a plate cooler, we used the temperature of a healthy cow, which is 101.5 degrees Fahrenheit (Macdonald, 1984). We described this determination in Equation 5. We used the constants 365.25 and 12 to convert this daily energy savings calculator to a monthly energy savings calculator. The constant 64 represents the number of pounds of milk per cow. The constant .6 represents the efficiency of the heat recovery tank, and 3414 converts BTUs to kWh.

Equation 5: Calculation of Monthly Energy Saved for a Heat Recovery Tank

$$Energy = \frac{Cows*64*(InputTemp - StorageTemp)*.6*365.25}{3414*12}$$

A side benefit of a heat recovery tank is that it makes hot water. We included a calculator that determined the number of gallons the tank increased by 100 degrees Fahrenheit daily. This calculation is similar to the amount of energy saved equation, but divides by 830, which is the conversion factor for number of BTUs recovered per gallon. We showed this in Equation 6.

Equation 6: Calculation of Daily Number of Gallons Raised by 100°F

$$HotWater = \frac{Cows*64*(InputTemp - StorageTemp)*.6}{830}$$

We expressed all calculations of monthly cost savings by multiplying the amount of energy savings per month by the cost of energy. We showed this expression in Equation 7.

Equation 7: Calculation of Monthly Savings

$$MonthlySavings = Cost*Energy$$

To calculate annual savings, we multiplied monthly savings by twelve. We showed this in Equation 8.

Equation 8: Calculation of Annual Savings

$$AnnualSavings = 12*Cost*Energy$$

To calculate return on investment (ROI), we divided the initial cost by the annual savings. We have shown this in Equation 9.

Equation 9: Calculation of Return on Investment for Efficiency Measures

$$ROI = \frac{InitialCost}{12*Cost*Energy}$$

To calculate the amount of carbon saved, we used the national average amount of carbon emitted per kWh, 1.35 lbs/kWh, as published by the Department of Energy

(2008). We then took the energy saved per month, labeled here as "Energy," multiplied it by 12 to make it annual savings output, then divided by 2000 to convert from lbs to tons. We expressed this relationship in Equation 10.

Equation 10: Calculation of Carbon Savings in tons/year

$$CarbonSavings = \frac{Energy * 1.35 * 12}{2000}$$

FARM A

Farm A is located in Hardwick, Massachusetts. The farm contained no means of alternative energy nor energy efficiency apparatus previously mentioned in the paper. Table 1 provides a list of inputs recorded and analyzed from our dairy farm visits and farm research.

Table 1: Farm A's Input Data

Farm A	
Cost of Energy ($/kWh)	.13450
Number of Cows Milked	100
Number of Milkings per day	2
Number of milking stations	12
Horsepower of Vacuum Pump	5
Hours per day Vacuum Pump operates	8
Input Temperature (F)	101.5
Tank Temperature (F)	35
Cost of Pre-cooler ($)	2400
Cost of Variable Frequency Drive ($)	2000
Cost of Heat Recovery Tank ($)	4200

From the data inputs provided in Table 1 and the Excel program created, described in the methodology, the following tables show the benefit of installing a pre-cooler, variable frequency drive, and a heat recovery tank.

Table 2: Farm A Pre-Cooler Output Data

Pre-cooler	
Energy Savings Per Month (kWh)	353
Monthly Cost Savings ($)	47.42
Annual Cost Savings ($)	569.03
Return on Investment (years)	4.2
Carbon Savings/year (tons)	2.9

Table 3: Variable Frequency Drive Output Data

Variable Frequency Drive	
Energy Savings Per Month (kWh)	184.2
Monthly Cost Savings ($)	24.8
Annual Cost Savings ($)	297.3
Return on Investment (years)	6.7
Carbon Savings/year (tons)	1.5

Table 4: Heat Recovery Tank Output Data

Heat Recovery Tank	
Energy Savings Per Month (kWh)	2276.7
Gallons of water raised 100F (daily)	308
Monthly Cost Savings ($)	306.2
Annual Cost Savings ($)	3674.5
Return on Investment (years)	1.1
Carbon Savings/year (tons)	4.2

By using the information taken from the farms and entering it into the Excel energy analysis tables, our group was able to determine the total amount of energy saved per month in kWh. As shown in Table 5, Farm A would save approximately 352kWh, 184kWh, and 856kWh for the installation of a pre-cooler, variable frequency drive, and a heat recovery tank, respectively. By summing this data and subtracting it from the Farm A energy bill, our group devised a potential new monthly energy bill.

Table 5: Farm A's Monthly Energy Usage and Potential Savings in kWh

kWh	Pre-cooler	Variable Frequency Drive	Heat Recovery Tank	Total	Old bill	New Bill
January2007	352.58333	184	856	1392.583	6800	5407.417
February2007	352.58333	184	856	1392.583	6560	5167.417
March2007	352.58333	184	856	1392.583	6800	5407.417
April2007	352.58333	184	856	1392.583	5440	4047.417
May2007	352.58333	184	856	1392.583	5360	3967.417
June 2007	352.58333	184	856	1392.583	4880	3487.417
July2007	352.58333	184	856	1392.583	4800	3407.417
August 2007	352.58333	184	856	1392.583	5120	3727.417
September2007	352.58333	184	856	1392.583	4960	3567.417
October2007	352.58333	184	856	1392.583	4960	3567.417
November2007	352.58333	184	856	1392.583	4880	3487.417
December2007	352.58333	184	856	1392.583	6400	5007.417
January2008	352.58333	184	856	1392.583	8000	6607.417
February2008	352.58333	184	856	1392.583	6560	5167.417
March2008	352.58333	184	856	1392.583	6400	5007.417
April2008	352.58333	184	856	1392.583	6560	5167.417

Figure 19 illustrates the difference between Farm A's current monthly energy usage, in kWh, and the potential energy savings after installing a pre-cooler, variable frequency drive, and heat recovery tank.

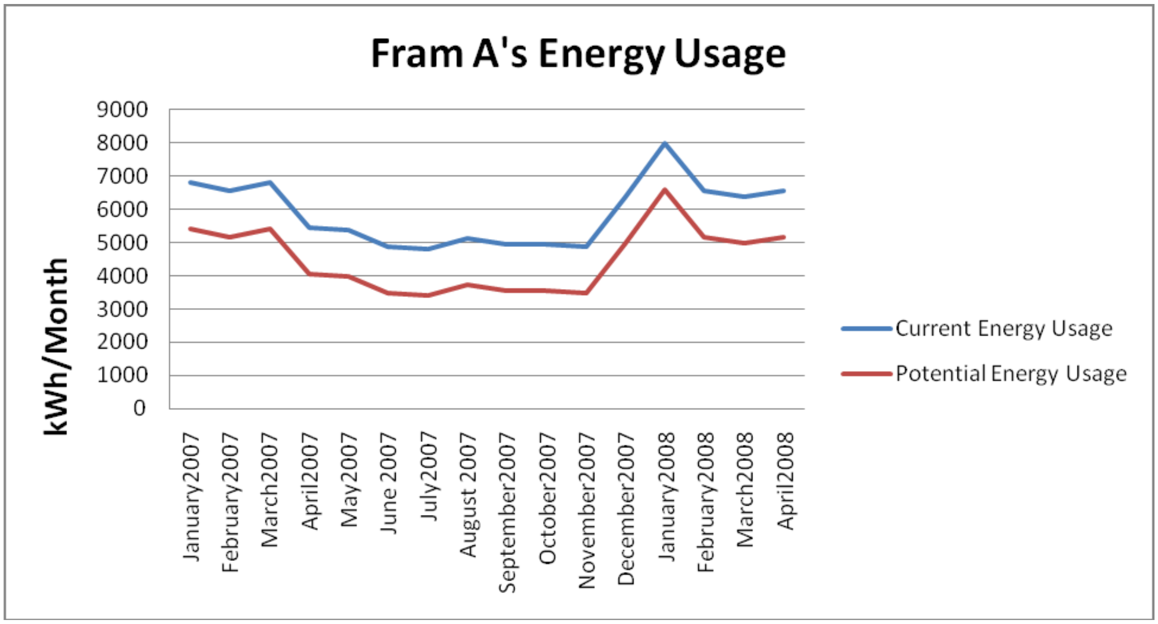

Figure 19: Energy Usage on the Farm A

Figure 20 is a breakdown of the monthly energy savings on Farm A for each device.

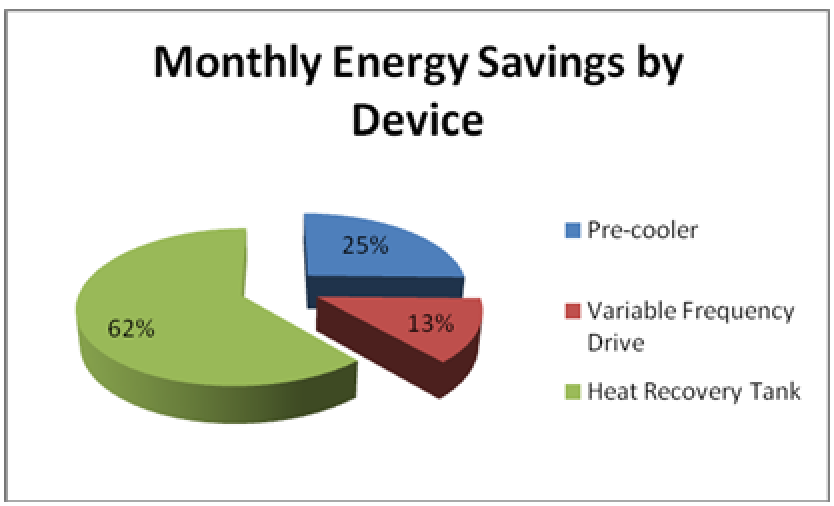

Figure 20: Farm A's Monthly Energy Savings by Device

The heat recovery tank makes up 62 percent of the savings and would be the ideal device for Farm A. The pre-cooler would save 25 percent of the monthly bill and the heat recovery tank would save the remaining 13 percent.

FARM B

Farm B is located in North Brookfield, Massachusetts. The farm contained no means of alternative energy, but had a pre-cooler and a heat recovery system installed. Table 6 provides a list of inputs recorded and analyzed from our dairy farm visits and farm research.

Table 6: Farm B's Input Data

Farm B	
Cost of Energy ($/kWh)	.13450
Number of Cows Milked	40
Number of Milkings per day	2
Number of milking stations	8
Horsepower of Vacuum Pump	7.5
Hours per day Vacuum Pump operates	7
Input Temperature (F)	59
Tank Temperature (F)	35
Cost of Pre-cooler ($)	2400
Cost of Variable Frequency Drive ($)	4700
Cost of Heat Recovery Tank ($)	4200

From the data inputs provided in Table 6 and the Excel program created, described in the introduction to this chapter, the following tables show the benefit of installing variable frequency drive and the amount of energy they are saving by having a pre-cooler and a heat recovery tank installed.

Table 7: Farm B's Pre-Cooler Output Data

Pre-cooler	
Energy Savings Per Month (kWh)	141
Monthly Cost Savings ($)	18.97
Annual Cost Savings ($)	227.61
Return on Investment (years)	10.5
Carbon Savings/year (tons)	1.1

Table 8: Farm B's Variable frequency Drive Output Data

Variable Frequency Drive	
Energy Savings Per Month (kWh)	534.3
Monthly Cost Savings ($)	71.9
Annual Cost Savings ($)	862.4
Return on Investment (years)	5.4
Carbon Savings/year (tons)	4.3

Table 9: Farm B's Heat Recovery Tank Output Data

Heat Recovery Tank	
Energy Savings Per Month (kWh)	328.7
Gallons of water raised 100F (daily)	44
Monthly Cost Savings ($)	44.2
Annual Cost Savings ($)	530.5
Return on Investment (years)	7.9
Carbon Savings/year (tons)	0.6

By using the information taken from the farms and entering it into our Excel energy analysis tables, our group was able to determine the total amount of energy saved per month in kWh. As shown in Table 10, Farm B would save approximately 141kWh, 531kWh, and 534kWh for the installation of a pre-cooler, variable frequency drive, and a heat recovery tank, respectively. By summing this data and subtracting it from the Farm B energy bill, our group devised a potential new monthly energy bill.

Table 10: Farm B's Monthly Energy Usage and Potential Savings in kWh

kWh	Pre-cooler	Variable Frequency Drive	Heat Recovery Tank	Total Savings	Old Bill	Potential Bill
December2006	141	531	534	534	3163	2629
January2007	141	531	534	534	4372	3838
February2007	141	531	534	534	4092	3558
March2007	141	531	534	534	4568	4034
April2007	141	531	534	534	3707	3173
May2007	141	531	534	534	3072	2538
June 2007	141	531	534	534	2836	2302
July2007	141	531	534	534	2625	2091
August 2007	141	531	534	534	2792	2258
September2007	141	531	534	534	2717	2183
October2007	141	531	534	534	2560	2026
November2007	141	531	534	534	2674	2140
December2007	141	531	534	534	3477	2943

Figure 21 illustrates the difference between Farm B's current energy usage and the potential energy usage after installing a pre-cooler, variable frequency drive, and heat recovery tank.

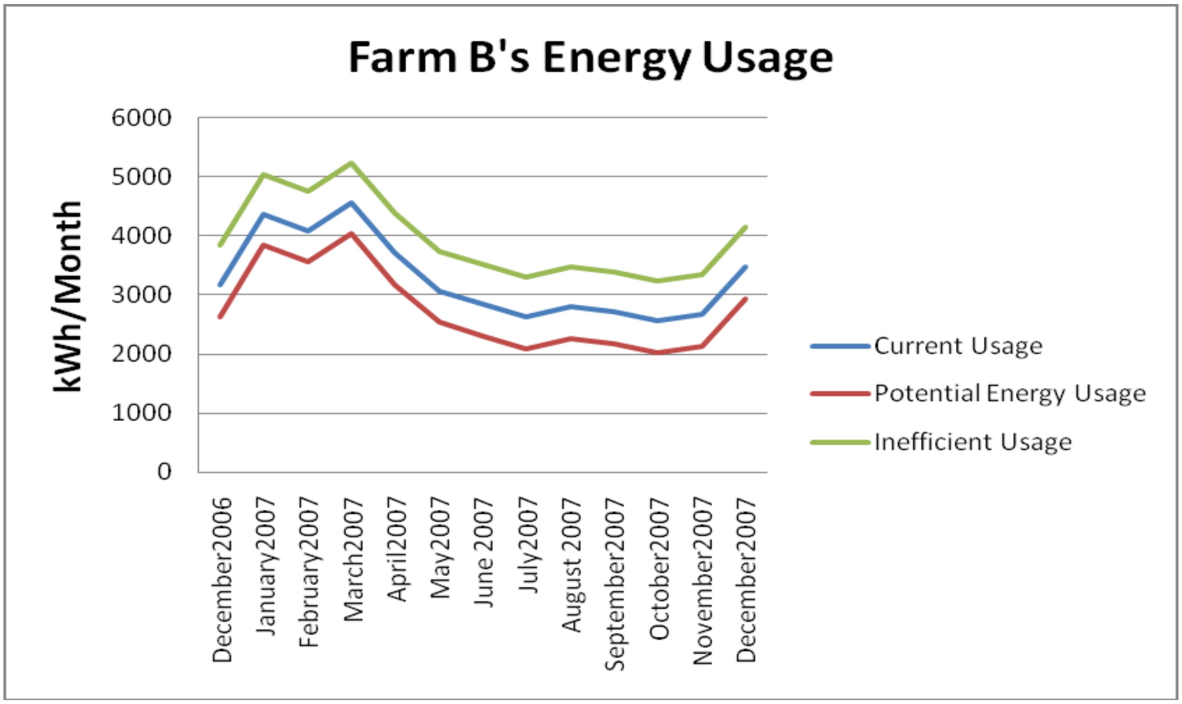

Figure 21: Energy Usage on Farm B

Figure 22 is a breakdown of the monthly energy savings on Farm B for each device.

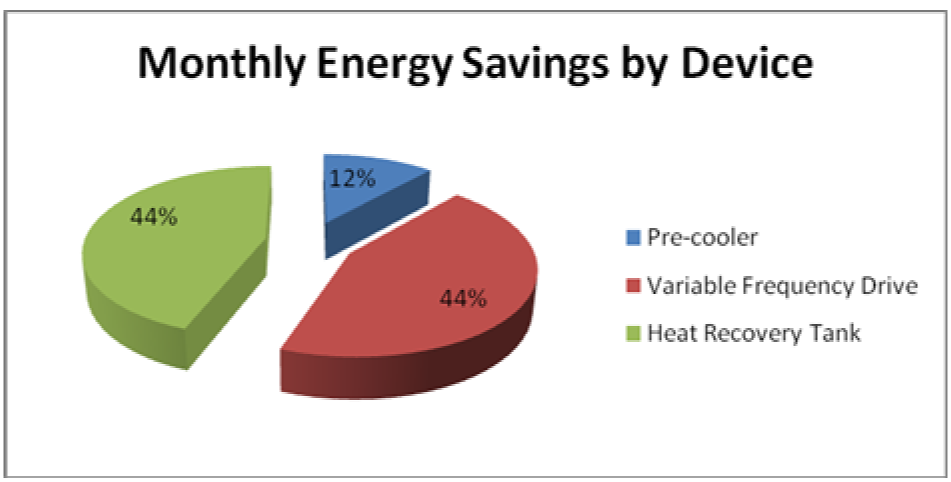

Figure 22: Farm B's Monthly Energy Savings by Device

Both the heat recovery tank and the variable frequency drive take up 44 percent of the monthly energy savings and would be the ideal device for Farm B. A new pre-cooler on Farm B would make up the remaining 12 percent of the energy savings.

FARM C

Farm C is located in Hardwick, Massachusetts. The farm contained no means of alternative energy, but had a pre-cooler and a heat recovery system installed. Table 11 provides a list of inputs recorded and analyzed from our dairy farm visits and farm research.

Table 11: Farm C's Input Data

Farm C	
Cost of Energy ($/kWh)	.13450
Number of Cows Milked	38
Number of Milkings per day	2
Number of milking stations	12
Horsepower of Vacuum Pump	5
Hours per day Vacuum Pump operates	2
Input Temperature (F)	59
Tank Temperature (F)	35
Cost of Pre-cooler ($)	2400
Cost of Variable Frequency Drive ($)	2000
Cost of Heat Recovery Tank ($)	4200

From the data inputs provided in Table 11 and the Excel program created, described in the methodology, the following tables show the benefit of installing variable frequency drive and the amount of energy they are saving by having a pre-cooler and a heat recovery tank installed.

Table 12: Farm Cs Pre-cooler Output Data

Pre-cooler	
Energy Savings Per Month (kWh)	134
Monthly Cost Savings ($)	18.02
Annual Cost Savings ($)	216.23
Return on Investment (years)	11.1
Carbon Savings/year (tons)	1.1

Table 13: Farm C's Variable Frequency Drive Output Data

Variable Frequency Drive	
Energy Savings Per Month (kWh)	46.1
Monthly Cost Savings ($)	6.2
Annual Cost Savings ($)	74.3
Return on Investment (years)	26.9
Carbon Savings/year (tons)	0.4

Table 14: Farm C's Heat Recovery Tank Output Data

Heat Recovery Tank	
Energy Savings Per Month (kWh)	312.2
Gallons of water raised 100F (daily)	42
Monthly Cost Savings ($)	42.0
Annual Cost Savings ($)	503.9
Return on Investment (years)	8.3
Carbon Savings/year (tons)	0.6

By using the information taken from the farms and entering it into our Excel energy analysis tables, our group was able to determine the total amount of energy saved per month in kWh. As shown in Table 15, Farm C would save approximately 134kWh, 46kWh, and 312kWh for the installation of a pre-cooler, variable frequency drive, and a heat recovery tank, respectively. By summing this data and subtracting it from the Farm C energy bill, our group devised a potential new monthly energy bill.

Table 15: Farm C's Monthly Energy Usage and Potential Savings in kWh

kWh	Pre-cooler	Variable Frequency Drive	Heat Recovery Tank	total	Old Bill	Potential Bill
April2007	134	46	312	46	5800	5754
May2007	134	46	312	46	4360	4314
June 2007	134	46	312	46	5960	5914
July2007	134	46	312	46	4800	4754
August 2007	134	46	312	46	4520	4474
September2007	134	46	312	46	4046	4000
October2007	134	46	312	46	4480	4434
November2007	134	46	312	46	4400	4354
December2007	134	46	312	46	4680	4634
January2008	134	46	312	46	6320	6274
February2008	134	46	312	46	4280	4234
March2008	134	46	312	46	4446	4400
April2008	134	46	312	46	4640	4594

Figure 23 illustrates the difference between Farmer C's current energy usage and the potential energy usage after installing a pre-cooler, variable frequency drive, and heat recovery tank.

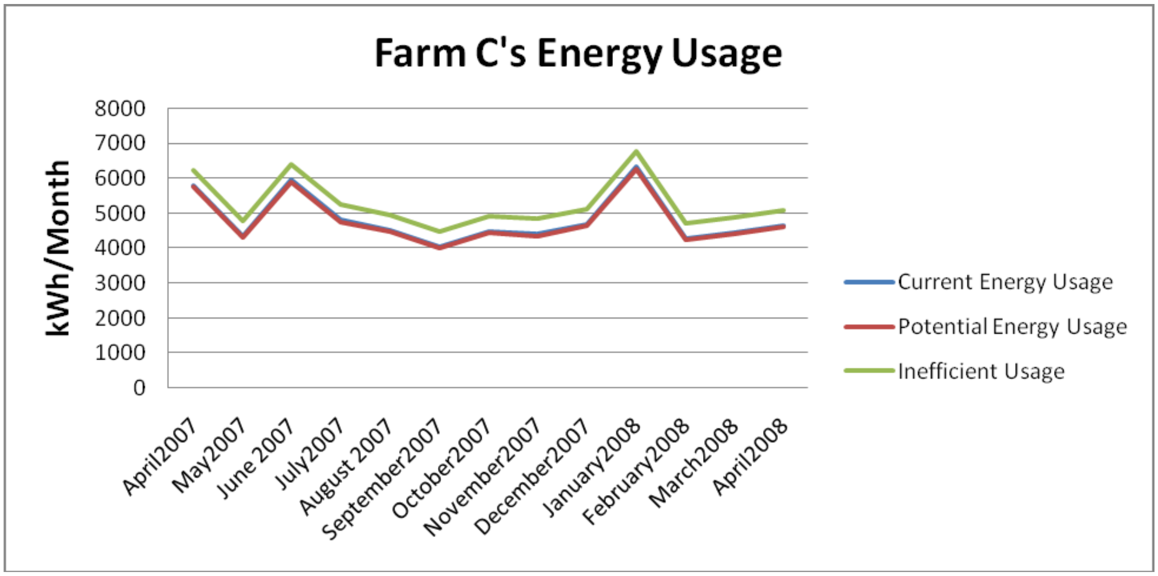

Figure 23: Energy Usage on Farm C

Figure 24 is a breakdown of the monthly energy savings on Farm C for each device.

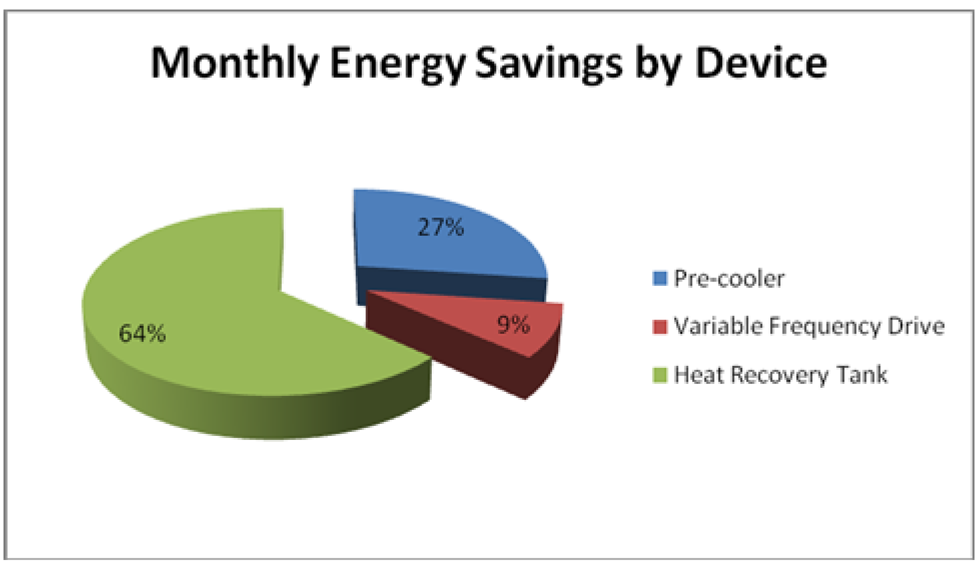

Figure 24: Farm C's Monthly Energy Savings by Device

The heat recovery tank would save the most energy on Farm C, taking up 64 percent of the monthly energy savings. A new pre-cooler on Farm C would save 27 percent and a variable frequency drive would only save 9 percent of the total savings.

FARM D

Farm D is a 1,000 acre farm located in Barre, Massachusetts. Farmer D has approximately 100 cows, which he milks twice daily. The milk process takes an estimated seven hours a day to complete. The farm is equipped with a milk pre-cooler, but not a heat recovery tank or a variable frequency drive. Table 16 provides a list of inputs recorded and analyzed from our dairy farm visits and farm research.

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Table 16: Farm D's Input Data

Farm D	
Cost of Energy ($/kWh)	.13450
Number of Cows Milked	100
Number of Milkings per day	2
Number of milking stations	8
Horsepower of Vacuum Pump	5.5
Hours per day Vacuum Pump operates	7
Input Temperature (F)	59
Tank Temperature (F)	35
Cost of Pre-cooler ($)	2400
Cost of Variable Frequency Drive ($)	2100
Cost of Heat Recovery Tank ($)	4200

From the data inputs provided in Table 16 and the Excel program created, described in the methodology, the following tables show the benefit of installing a pre-cooler, variable frequency drive, and a heat recovery tank.

Table 17: Farm D's Pre-Cooler Output Data

Pre-cooler	
Energy Savings Per Month (kWh)	353
Monthly Cost Savings ($)	47.42
Annual Cost Savings ($)	569.03
Return on Investment (years)	4.2
Carbon Savings/year (tons)	2.9

Table 18: Farm D's Variable Frequency Drive Output Data

Variable Frequency Drive	
Energy Savings Per Month (kWh)	325.8
Monthly Cost Savings ($)	43.8
Annual Cost Savings ($)	525.8
Return on Investment (years)	4.0
Carbon Savings/year (tons)	2.6

Table 19: Farm D's Heat Recovery Tank Output Data

Heat Recovery Tank	
Energy Savings Per Month (kWh)	821.7
Gallons of water raised 100F (daily)	111
Monthly Cost Savings ($)	110.5
Annual Cost Savings ($)	1326.1
Return on Investment (years)	3.2
Carbon Savings/year (tons)	1.5

The return on investments in years for pre-coolers, variable frequency drives, and heat recovery tanks are 4.2, 4.0, and 3.2 years respectively for Farm D. While these numbers are all estimations, the return on investment time is very short, considering most of this equipment lasts approximately twenty years. Farm D already has a pre-cooler and could consider installing a variable frequency drive and a heat recovery tank based upon those numbers.

Farm D is currently in the process of planning the construction of two, 15kW Proven (see Glossary) windmills. One windmill site would be in close proximity to the farm, the other near the farm store and would cost approximately $90,000 and $75,000, respectively. Listed below are the project specifications for one of the turbines.

Project 1

1. One, 15kWProven Energy Wind Generator, white in color
2. One, 15m (49ft) monopole tower of marine grade steel , silver in color
3. Two, concrete foundation structures for tower base plate(1) and winch anchor(1)
4. Underground conduit duct back to barn (approximately 800 feet)
5. Balance of systems to include AC/DC disconnects, controller, inverters, a production grade meter, and necessary miscellaneous electrical components
6. All applicable writing and submittals necessary to secure MTC SRI rebate
7. All necessary permits required of local inspectional services department
8. All necessary permits required to commission and net meter with National Grid

Farm D and Proven are investigating several rebates, grants, incentives, and discounts from state and government programs. Those programs could pay up to 50 percent of the total cost of the two windmills. The average annual wind speed for this area is approximately 11 mph. The cut wind speed for the Proven turbines 5.6 mph. The ideal output for those turbines is 27 mph.

Nexamp (see Glossary) used AWS TrueWind's Maps (see Glossary) and a calculator tool developed by The Cadmus Group (see Glossary) to determine their estimated numbers of annual kWh. Nexamp estimated that Farm D windmill could produce 27,200kWh and the Stephens Farm Store could produce 16,800kWh of electricity on an annual basis. According to the owner (April 10, 2008), those numbers represent 46 percent and 44 percent of all electricity used by the Stephens Farm and Store, respectively. These values indicate electricity saving of approximately $4,000 and $2,000 for the farm and store, respectively.

By using the information taken from the farms and entering it into our Excel energy analysis tables, our group was able to determine total amount of energy saved per month in kWh. As shown in Table 20, the Farm D would save approximately 353kWh, 326kWh, and 822kWh for the installation of a pre-cooler, variable frequency drive, and a heat recovery tank, respectively. By summing this data and subtracting it from the Farm D energy bill, our group devised a potential new monthly energy bill.

Table 20: Farm D's Monthly Energy Usage and Potential Savings in kWh

kWh	Pre-cooler	Variable Frequency Drive	Heat Recovery Tank	Total Energy Saved	Old Bill	Potential Bill
March2007	353	326	822	1148	5670	4522
April2007	353	326	822	1148	5023	3875
May2007	353	326	822	1148	4731	3583
June 2007	353	326	822	1148	4440	3292
July2007	353	326	822	1148	4212	3064
August 2007	353	326	822	1148	4614	3466
September2007	353	326	822	1148	4810	3662
October2007	353	326	822	1148	4418	3270
November2007	353	326	822	1148	4227	3079
December2007	353	326	822	1148	5405	4257
January2008	353	326	822	1148	5575	4427
February2008	353	326	822	1148	6041	4893

Figure 25 illustrates the difference between Farm D's current energy usage and the potential energy usage after installing a pre-cooler, variable frequency drive, and heat recovery tank.

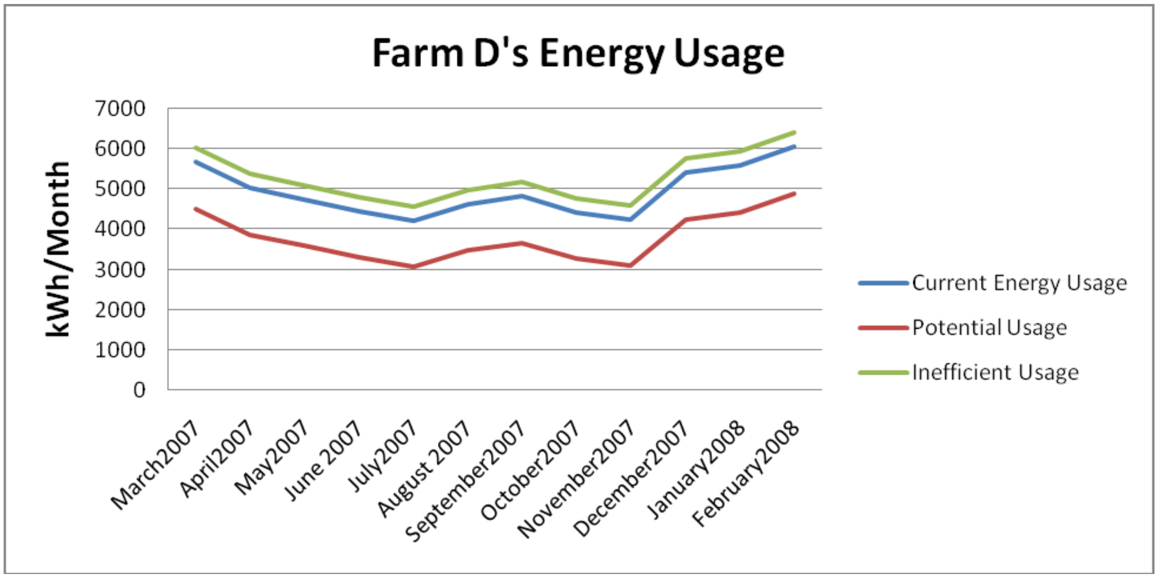

Figure 25: Energy Usage on Farm D

Figure 26 is a breakdown of the monthly energy savings on Farm D for each device.

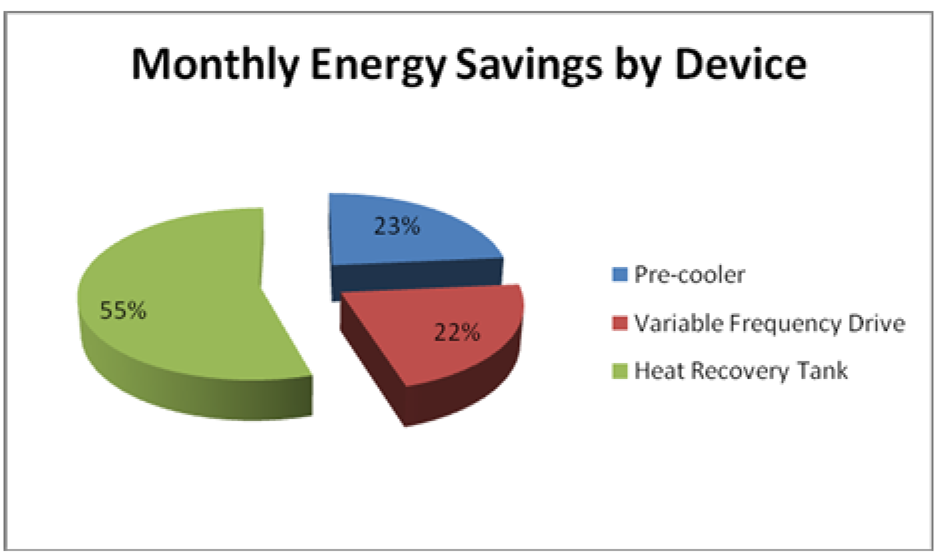

Figure 26: Farm D's Monthly Energy Savings by Device

The heat recovery tank would save the most energy on Farm D, taking up 55 percent of the monthly energy savings. A new pre-cooler on Farm D would save 23 percent and a variable frequency drive would save 22 percent of the total savings.

FARM E

Farm E is a 60 acre farm in West Brookfield, Massachusetts on North Main Street. Farmer E operates the farm alone, and milks forty Holstein cattle twice a day. The farm had both a 114 gallon heat recovery tank and a 27-plate pre-cooler. However, he did not own a variable frequency drive. Table 21 provides a list of inputs recorded and analyzed from our dairy farm visits and farm research. In the case of the cost of the pre-cooler and heat recovery tank, these inputs were written as the historical cost of the respective technologies and inflation-adjusted.

Table 21: Farmer E's Input Data

Farm E	
Cost of Energy ($/kWh)	.13450
Number of Cows Milked	40
Number of Milkings per day	2
Number of milking stations	8
Horsepower of Vacuum Pump	7.5
Hours per day Vacuum Pump operates	5
Input Temperature (F)	59
Tank Temperature (F)	35
Cost of Pre-cooler ($)	2400
Cost of Variable Frequency Drive ($)	4700
Cost of Heat Recovery Tank ($)	4200

From the data inputs provided in Table 21 and the Excel program created, described in the introduction to this chapter, the following tables show the benefit received from installing a pre-cooler and a heat recovery tank as well as the potential savings received by a variable frequency drive.

Table 22: Farmer E's Pre-Cooler Output Data

Pre-cooler	
Energy Savings Per Month (kWh)	141
Monthly Cost Savings ($)	18.97
Annual Cost Savings ($)	227.61
Return on Investment (years)	22.9
Carbon Savings/year (tons)	1.1

Table 23: Farmer E's Variable Frequency Drive Output Data

Variable Frequency Drive	
Energy Savings Per Month (kWh)	381.7
Monthly Cost Savings ($)	51.3
Annual Cost Savings ($)	616.0
Return on Investment (years)	7.6
Carbon Savings/year (tons)	3.1

Table 24: Farmer E's Heat Recovery Tank Output Data

Heat Recovery Tank	
Energy Savings Per Month (kWh)	328.7
Gallons of water raised 100F (daily)	65
Monthly Cost Savings ($)	44.2
Annual Cost Savings ($)	530.5
Return on Investment (years)	7.9
Carbon Savings/year (tons)	0.6

While the two technologies that he has installed have provided him with extreme dividends, he could still benefit from a variable frequency drive. His farm uses a relatively small parlor and a high horsepower pump, which makes it beneficial to buy a variable frequency drive. However, due to the fact that he milks his cows for such a short period of time and has a small herd, he cannot expect his benefits to offset his initial cost for nearly eight years.

By using the information taken from the farms and entering it into our Excel energy analysis tables, our group was able to determine the total amount of energy saved per month in kWh. As shown in Table 25, the Farm E would save approximately 141 kWh, 382 kWh, and 329 kWh for the installation of a pre-cooler, variable frequency drive, and a heat recovery tank, respectively. By summing this data and subtracting it from the Farm E energy bill, our group devised a potential new monthly energy bill.

Table 25: Farmer E's Monthly Energy Usage and Potential Savings in kWh

kWh	Pre-cooler	Variable Frequency Drive	Heat Recovery Tank	Total	Old Bill	Potential Bill
December2006	141	382	329	382	3163	2781
January2007	141	382	329	382	4372	3990
February2007	141	382	329	382	4092	3710
March2007	141	382	329	382	4568	4186
April2007	141	382	329	382	3707	3325
May2007	141	382	329	382	3072	2690
June 2007	141	382	329	382	2836	2454
July2007	141	382	329	382	2625	2243
August 2007	141	382	329	382	2792	2410
September2007	141	382	329	382	2717	2335
October2007	141	382	329	382	2560	2178
November2007	141	382	329	382	2674	2292
December2007	141	382	329	382	3477	3095

Figure 27 illustrates the difference between the Farm E current energy usage and the potential energy usage after installing a pre-cooler, variable frequency drive, and heat recovery tank.

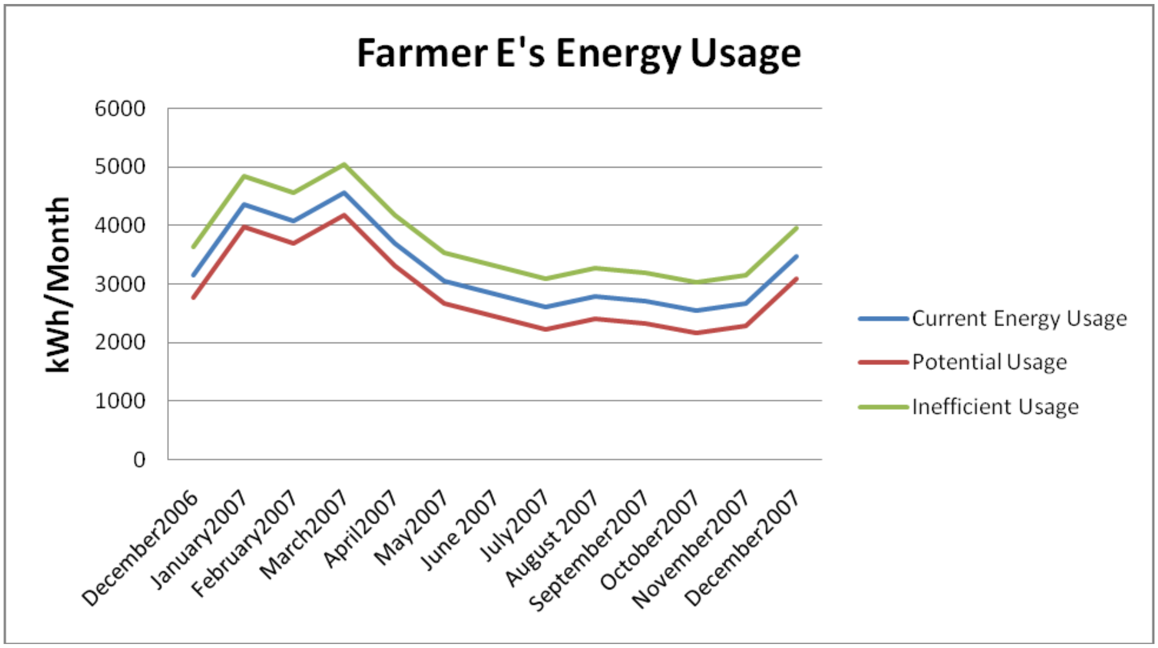

Figure 27: Energy Usage on Farm E

Figure 28 is a breakdown of the monthly energy savings on Farm E for each device.

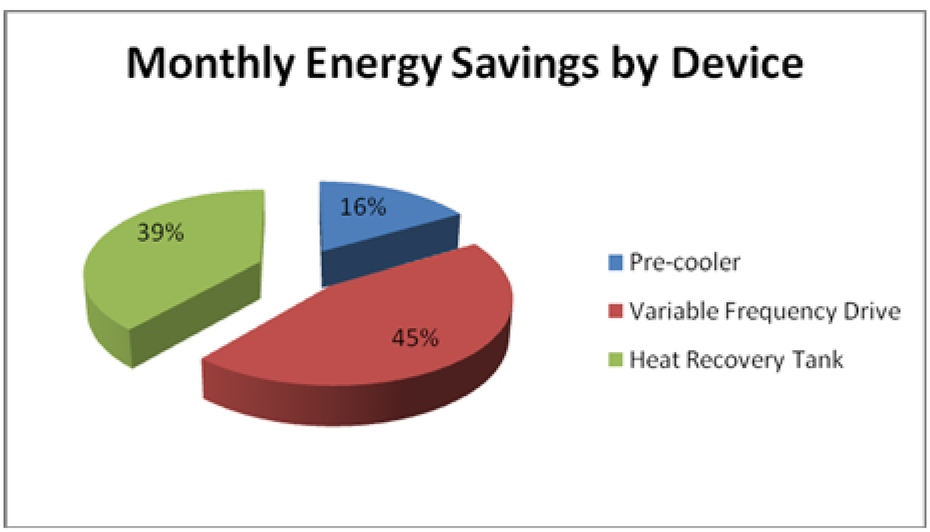

Figure 28: Farm E's Monthly Energy Savings by Device

A new variable frequency drive would save the most energy on Farm E, taking up 45 percent of the monthly energy savings. A new pre-cooler on Farm E would save only 16 percent and a heat recovery tank takes up 39 percent of the total savings.

Farmer E has installed a 300-gallon Empyre-brand wood boiler on his property to make his farm and house heat independent of fuel prices. According to the owner, (April 10, 2008) the wood burner operates by burning tree limbs that he removes from the edges of his grazing land each spring. He also stated that the wood that he collects will last him an entire year. However, during the summer, the town bans the use of his wood stove because of the amount of smoke it outputs. To adjust for this, he has to run his oil furnace in his house and propane furnace in his barn during the summer. He asked us if we could help him design an alternative energy solution to his water-heating issues.

We investigated several different power sources for his farm, including wind and methane digesters. Given that he would only need this system between April and September; we concluded that a solar water heater system was most appropriate for his needs. A solar water heater system was ideal for his situation for a number of reasons. First, a solar water heater faces damage if operated during the winter, but since he did not need the system during the winter, he could drain it and not have to worry about it. Second, he will be operating the solar collectors during the most irradiant time of the year, boosting his expected performance by approximately 1/3. Finally, he already had an easily accessible water-storage tank in the form of the 300-gallon jacket surrounding his wood boiler. This wood boiler is atop an open south-facing rise, giving a clear view of the sun for most of the day.

The first step of the process was to determine how large of a solar collector Farm E would need. Farmer E stated that he had a 150 gallon boiler and it was not providing enough hot water for his house and his barn (April 10, 2008), so he upgraded to a 300 gallon boiler, which suited his needs. This gave us a baseline idea of how much energy he used for heating. The fact that he had one forty-gallon propane-fired tank and one sixty-gallon oil-fired tank to heat his barn and house, respectively, reinforced this calculation. By calculating that he needs two times as many square feet of collector area as he does heating tank volume (in gallons), we figured that he would need at least 200 square feet of collector area. However, with the minimum of 200 square feet, his 300 gallon tank would be sluggish to heat up after the night's heating has taxed it. For example, early morning hours would see his heat system at its coldest and with a smaller array; the tank may not reheat for some time. That could be catastrophic for early morning utter-cleaning before milking. However, he cannot construct an enormous array with a 300 gallon tank because the heater would heat the tank up to the point that the solder in the array would melt, and in essence, destroy itself. Thus, according to manufacturer's warnings and a Popular Mechanics study (Provey, 2006), he should not exceed 300 ft^2 of solar water collector. Since manufacturers generally sell solar collectors in 24 ft^2, 32ft^2, or 40 ft^2 panels, five 40 ft^2 panels could fulfill his need with room to expand later.

The next issue to confront was to analyze how Farmer E would mount those collectors. Fortunately, his site had an unobstructed view of the horizon and is not near any structures, making it suitable for a ground mount system. Some companies, such as AET Solar, sell mounting brackets. Other companies give instructions on how to build a mounting bracket out of aluminum or wood. We also determined that for use on Farm E, the panels should be facing higher than the traditional longitudinal angle. Table 26 shows the amount of solar radiation, kWh/m^2 per day, that a measuring station at Worcester airport recorded, some 13 miles to the east of Farm E. The measuring station tilted the measuring panel at an angle equal to its latitudinal location, 42.27 degrees, and fixed it pointing south. Table 27 shows a similar measurement, except the measuring station tilted the panel to face 15 degrees higher, or an angle with level ground of 27.27 degrees. Both panels recorded data over the course of 360 months from 1961 to 1990.

Table 26: Amount of Solar Radiation at-Latitude at Worcester Airport (kWh/m2 per day)

	Low	Average	High
January	2.7	3.4	4.1
February	3.1	4.2	5.6
March	3.5	4.8	5.7
April	4.1	5.0	5.9
May	4.3	5.2	6.2
June	4.5	5.4	6.2
July	4.8	5.5	6.1
August	4.6	5.3	6.2
September	4.2	5.0	5.7
October	3.6	4.3	5.3
November	2.2	3.0	3.6
December	2.0	2.8	3.5

Table 27: Amount of Solar Radiation at Latitude minus 15 degrees at Worcester Airport (kWh/m2 per day)

	Low	Average	High
January	2.4	3.0	3.5
February	2.9	3.8	5.0
March	3.5	4.6	5.3
April	4.2	5.1	6.0
May	4.6	5.5	6.6
June	4.9	5.8	6.8
July	5.2	5.9	6.6
August	4.8	5.6	6.4
September	4.2	4.9	5.7
October	3.5	4.0	4.9
November	2.0	2.8	3.2
December	1.8	2.4	3.0

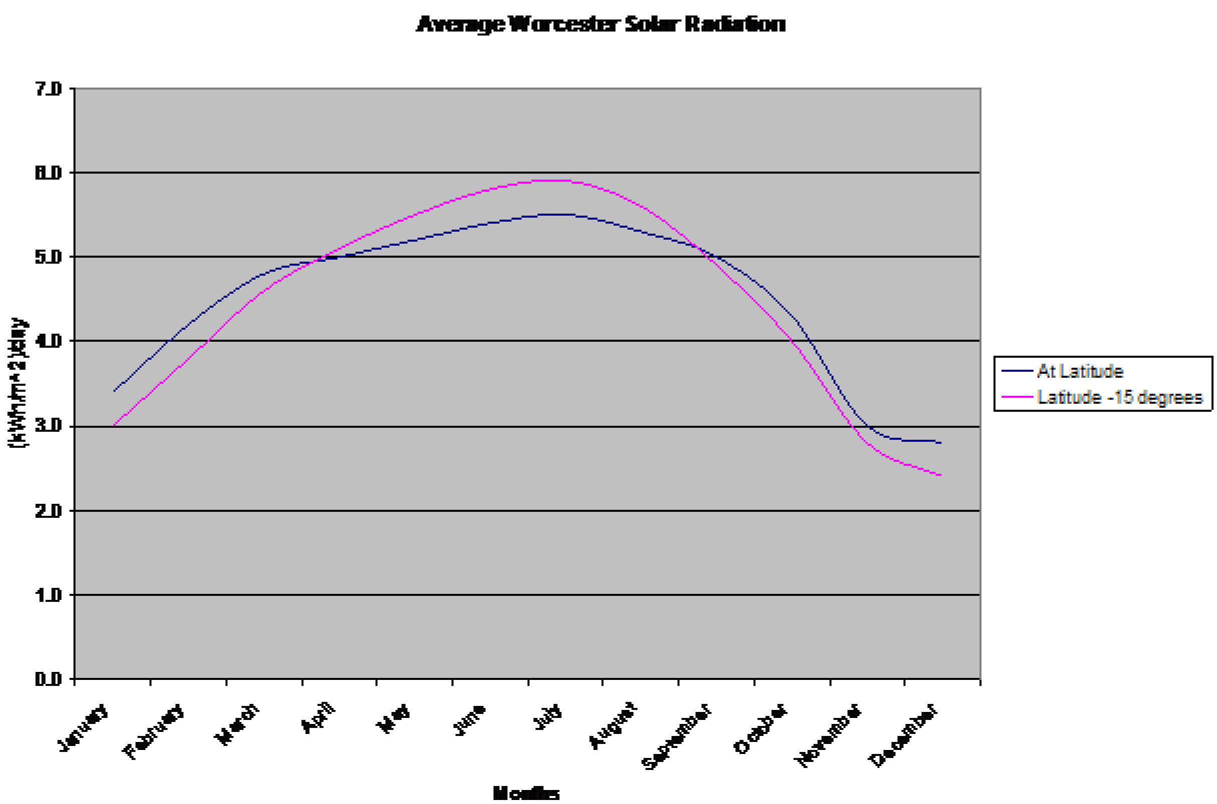

Figure 29: Solar Radiation in Worcester, MA with fixed south-facing flat collectors

As Figure 29 shows, a higher-pointing solar collector performs better in the summer months and worse in the winter months. However, given that Farmer E will only use those panels in the summer, it is more advantageous for his panels to point upwards. Installers should perform further study to determine just how high a solar panel should point to optimize radiation input.

The final challenge was to adapt the solar collector to the hot water tank on the wood boiler. Figure 30 shows the back of the wood boiler as it is now. It has one closed loop that travels to the house (right) and one closed loop that travels to the barn (left), and carries heat to the respective 80 gallon and 60 gallon water tanks. That proved to be useful in designing a piping scheme to attach solar hot water.

Figure 30: Pipe Attachments on Farmer E's Wood Boiler

CHAPTER FIVE: CONCLUSIONS

In this section we discuss our recommendations on what previously discussed technologies will be most beneficial to each of the five farms we visited. Additionally, based on the data we have collected we will discuss the benefits that other farms in Massachusetts can experience by implementing those technologies. Finally, we will discuss our recommendations for the use of alternative energy on dairy farms. A final note for this section; we calculated all costs at retail price and did not factor in the available grants and rebates, so the actual time these farmers will see a return on investment will be less.

FARM A

Farm A is the only farm that we visited that did not have any of the three technologies that we investigated installed. So, our recommendation for his farm is that he installs a pre-cooler, a heat recovery tank, and a variable frequency drive. If Farm A installs a pre-cooler it will be saving on average 353 kWh per month, with an annual savings of $569 dollars on its electricity bill. The return on investment for the pre-cooler is 4.2 years. If Farm A installs a heat recovery tank the energy savings are even more dramatic. It will be saving 2277 kWh per month with an annual cost savings of $3674. The return on investment for the installation of a heat recovery tank will be 1.1 years. So, we recommend that Farmer A first implement a heat recovery tank before installing the other two technologies. Finally, if Farmer A were to install a variable frequency drive, he would see a monthly savings of 184 kWh. This translates into an annual savings of $297 with a return on investment of 6.7 years. So, if Farmer A is planning on replacing their pump within the next seven years, he should wait to replace his pump; if not, he should replace his pump as soon as possible.

FARM B

Having the majority of energy efficient equipment that we investigated, we recommend that Farm B install a variable frequency drive for his vacuum pump. The return on investment for this technology will be 5.4 years. So, if Farmer B is planning on replacing his vacuum within that time period, we recommend that he wait until then to implement a variable frequency drive. Otherwise, we recommend that he add that technology as soon as possible.

FARM C

The Robison's farm has recently downsized its herd, so their farm is set up to milk one hundred cows but is only milking thirty eight. With this decrease in herd size, Farm C is able to reduce the amount of time it milks per day. Since the vacuum pump is only running for two hours a day, the practicality of installing a variable frequency drive decreases. The return on investment for such an installation will be 26.9 years, making a variable frequency drive impractical for Farm C. Also, Farm C currently has a pre-cooler and a heat recovery tank, so there is nothing further that we can recommend for Farm C.

FARM D

Farm D is unique in its use of heat exhausted from his refrigeration compressors. During the winter months Farmer D uses that heat to warm one of his barns. So, his decision of whether he wants to continue to heat his barn during the winter months or reduce his electrical usage determines the feasibility of installing a heat recovery tank. If Farmer D decides to install a heat recovery tank, he will be saving $110 per month with a return on investment of 8.3 years. Another option for Farm D is only using the heat recovery tank during the warmer months of the year when he does not have to heat his barn. Since he uses that heat for approximately six month of the year, the return on investment will increase to sixteen years, but it will reduce his energy bill during the months were there is the greatest demand for electricity. As shown in Figure 3, it is during the summer months that the cost of electricity is at its highest, so this is an option that Farm D should consider.

The other technology that we recommend Farm D implement is a variable frequency drive. The return on investment for the installation of such a drive will be four years. We also recommend that Farmer D install this technology as soon as possible, unless they plan on replacing their vacuum pump within the next four years.

FARM E

Farmer E was one of the farmers who considered implementing an alternative energy source on his farm. For his previously described project, we recommend that he install 5 flat plate solar collectors each measuring 40 square feet. In order to connect those panels to his water storage tank, he will also need to purchase additional lengths of similar pipe in the collectors. While choosing what panels to select for his project, we recommend that Farmer E verify that the panels have received an OG300 rating by the Solar Rating Certification Corporation. This will guarantee that he is receiving high quality solar collectors and that the panels meet their appropriate specifications. Finally, we recommend that Farmer E speaks with a representative from the Solar Energy Industries Association to help him determine the optimal location on his property to install his solar collectors.

Farmer E will also benefit from the installation of a variable frequency drive if he needs to replace his vacuum pump within the next seven years. With a variable frequency drive installed, Farmer E will save 382 kWh per month and save $616.02 on his electricity bill per year. The return on investment will 7.6 years. Since it is a relatively long investment period, implementing a variable frequency drive will only be beneficial if Farmer E's pump fails and needs replacement.

RECOMMENDATIONS

MASSACHUSETTS DAIRY FARMERS

Based on the data we have collected, we have found that the two most beneficial technologies that dairy farmers can implement to reduce their energy bill are pre-coolers and heat recovery tanks. We recommend that any dairy farmer in the state of Massachusetts who does not have those technologies installed do so. However, each dairy farm is unique and farmers must consider their individual farm's return on investments before implementing those technologies. While we have shown that pre-coolers and heat recovery tanks have a relatively low return on investment, we did not factor in the many rebate programs available to dramatically reduce the cost for those technologies. In many cases a farmer will be able to receive a rebate of about seventy-five percent for the cost of the product. So, for many of the farmers this will reduce the return on investment period to under one year.

IMPLEMENTING ALTERNATIVE ENERGY SOURCES ON MASSACHUSETTS DAIRY FARMS

Given the diversity of Massachusetts dairy farmers, it is very difficult to recommend the implementation of alternative energy sources for those farmers. One recommendation that we can provide is that farmers pursue energy efficiency before they consider implementing any form of alternative energy. As seen in our sample of five farms, the two that are considering implementing alternative energy sources already had their farms running as efficiently as they could. So, for alternative energy sources to have the greatest impact in reducing energy costs, farmers should first pursue energy efficiency.

SOCIETAL IMPACT

The findings that we have collected in this project will help the dairy farmers of the 5th Worcester District. However, the collection of data, methods of calculation, and energy-saving techniques hold true for any dairy farm that has vaguely similar specifications.

There were a variety of factors that made many Massachusetts dairy farms disappear. Those factors have been rampant in Connecticut, Rhode Island, and Pennsylvania for years. That has happened due to the countless farms that suffer from the same situation as Massachusetts' farms, including the prohibitive energy costs. If the remaining farms have not implemented the recommended technologies, their profit margins are likely slim or counter-productive. By installing the efficiency measures, their profits may return and make themselves viable once more.

Those farms that still hold a large profit margin may not have upgraded their process yet, but rising energy costs will inevitably affect their operation. States such as Vermont, Maine, and New York have had similar issues as Massachusetts in the past and are likely to have them again, at which point the topics of our research will help them.

Throughout the United States and onto other global dairy farms, energy prices are rising. While their profit margins remain solid and their farms remain on the upswing, unavoidable global circumstances will, in time, force farms to evolve. When it becomes necessary for even the largest farms to upgrade their technology to save on energy bills, those findings will be useful in determining which investment is best suited for them.

If any dairy farm on the globe is struggling under the burden of energy costs, it can benefit from our research. Even if it has more than 500 cattle, exists in an area that does not have freezing temperatures, and has access to abundant wind or hydrological energy, energy efficiency measures can alleviate energy bills for smaller investment costs. Our project will also help farmers decide which of the efficiency measures will save them the most energy for their dollar.

APPENDIX A: STRUCTURE OF THE MASSACHUSETTS STATE GOVERNMENT

Representative Anne Gobi, who serves on the Massachusetts House of Representatives, representing the Fifth Worcester District, sponsors our project. This district includes towns in Worcester and Hampshire counties including Barre, Brookfield, Hardwick, New Braintree, North Brookfield, Petersham, Phillipston, Templeton, Ware, West Brookfield, and precincts 2 and 3 of the town of Spencer. Representative Gobi has been in the House of Representatives since 2001, and prior to her election into the House she served on the Spencer Democratic Town Committee. Along with representing these towns, Representative Gobi serves on several House Committees; these include the House Committee on Ways and Means, the Joint Committee on Environmental, Natural Recourses and Agriculture, and the Joint Committee on Public Health (http://www.mass.gov).

ORGANIZATION OF THE MASSACHUSETTS STATE GOVERNMENT

Like the Government of the United States, three branches: Executive, Legislative and Judicial divide the Massachusetts State Government, as shown in Figure 19. Ratified in 1780, the Massachusetts Constitution is the oldest in the world that is still in use (http://www.sec.state.ma.us). The Governor heads the executive branch. It is the Governor's duties to prepare the annual budget, accept or veto bills, and nominate judicial officers among other responsibilities. There are seven trial court departments in the judicial branch. The highest court in the State is the Supreme Court, which consists of a Chief Justice and six Associate Judges (http://www.mass.gov). It is the Supreme

Courts responsibility to advise the Governor and Legislature regarding the law of Massachusetts.

The Senate and the House of Representatives are the two houses of the Legislative Branch or the General Court. The General Court consists of forty Senators and one hundred and sixty Representatives (http://www.sec.state.ma.us). Each branch appoints its own leader, the Senate elects a President and the House elects a Speaker. It is the responsibility of these leaders to appoint majority leaders and select chairs and members of joint committees. Joint committees consist of six senators and fifteen representatives, with a chair from each branch (http://www.sec.state.ma.us).

LAWMAKING IN MASSACHUSETTS

To pass a law in the State of Massachusetts a petition with the accompanying bill or other like motion a person must file with the House or Senate Clerk's office (www.mass.gov). Next, an appropriate joint committee, such as the ones that Representative Gobi is a member of, receives the bill. It is the responsibility of these committees to schedule public hearings for each bill. This allows for citizens, other legislators and lobbyists to voice their views on the bill. The joint committee then reviews the public's testimony and discusses the merits of the bill. Finally, the committee will offer a recommendation to the House or Senate to pass the bill, not pass the bill or change the bill (www.mass.gov).

Then, if a bill has a favorable report, legislation gives it a first reading. In the Senate, the Committee of Ethics and Rules receives the bill after the first reading; in the House of Representatives, the Committee on Steering, Policy and Scheduling receives the bill after the first reading. Following the first reading, there is a second reading where the bill is open for debate on motions or amendments (www.mass.gov). After all debates are over, a vote takes place. If the bill receives a majority vote is given a third reading and referred to the Committee on Bills in the Third Reading. This committee exams the legality, constitutionality, and ensures that is does not duplicate or contradict an existing law. Following the third reading the branch votes on whether the bill becomes a final draft (ww.mass.gov).

If the bill receives a favorable vote after the third reading, it must go through three readings in the other branch. If the bill passes through these three reading it goes to the Legislative Engrossing Division. However, if the legislature adds an amendment during this process it returns to the previous branch for another vote of approval (www.mass.gov). The final step, for a bill to pass, is a final vote of approval by both houses; the House takes a vote followed by a Senate vote. The governor receives the bill if both the House and the Senate approve. The governor may sign the bill into law, allow the bill to become law by not signing it within ten days while the legislature is in session, veto it, or return it to the legislature with recommendations.

JOINT COMMITTEE ON ENVIROMENTAL, NATURAL RESOURCES AND AGRICULTURE

All bills pertaining to natural resources, the environment, and agriculture in Massachusetts go to the Joint Committee on Environmental, Natural Resources and Agriculture. Some of the matters that the committee handles include the control of hunting, fishing and conservation. The committee also deals with all matters pertaining to the environment such as, air, water and noise pollution, and all matters regarding solid waste disposal and sewerage. Finally this committee handles all matters pertaining to the agricultural industry of Massachusetts and any problems regarding farms (www.mass.gov).

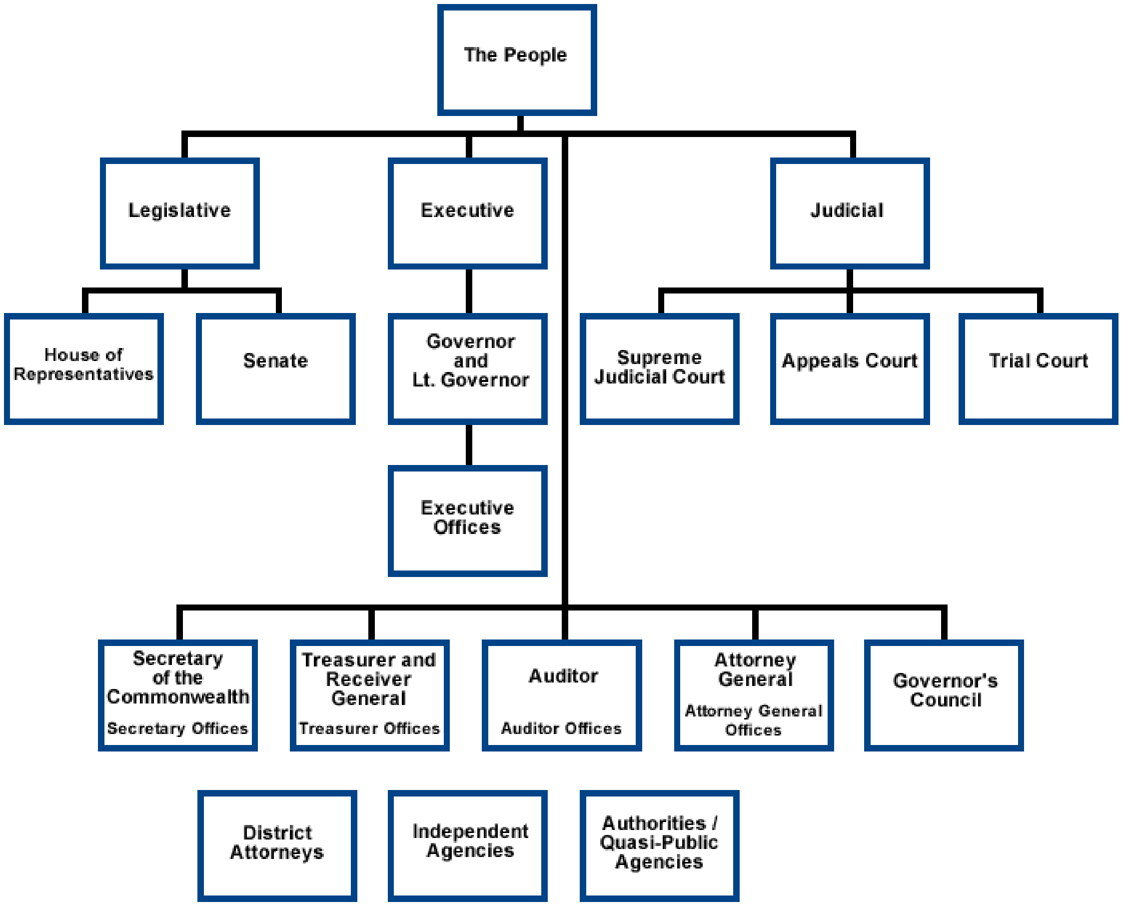

Figure 19: Organizational Chart of the Massachusetts State Government (www.mass.gov)

APPENDIX B: BIO-FUELS

In order to run a farm entirely based on reproduced fuel, Frederiksson et al. (2006) concluded that RME is worst suited for a place like Massachusetts because it takes up an average of 9.3 percent of the land to produce. Ethanol is moderately better, consuming 5.9 percent of land, while biogas is the most viable option, taking up only 3.8 percent. The type of fuel harvested is dependent on the value of the farmer's land.

According to Anne Gobi (January 25, 2008), many companies are trying to buy out farms for the land, so they can build a more profitable structure such as a mall. However, the productive output of the land significantly increases to a competitive rate if farmers use it to create bio-fuels. In order to understand the arguments for and against bio-fuels, it is important to understand their potential output. Likewise, it is important to understand just how much energy bio-fuels use in their production. Naturally, when a farm is more efficient, it will be more profitable in the end. Table 28 shows the overall energy produced for each of the fuels in The United States and illustrates how much energy actually went into this process in gigajoules (see Glossary). The cultivation figures included energy for cultivation and harvest of the area needed to produce raw materials for the amount of fuel produced. Effects of transport to the farm in drying of the crop were also included as part of cultivation. Biogas produced the most energy, but required the most energy to create. Biogas is more suitable for its ratio of output-to-input is greater than ethanol. As far as the best ratio, RME definitely ranks higher than both Ethanol and Biogas.

Table 28: A Comparison of Bio-fuels by Production and Use (GJ) (Fredriksson et al., 2006)

	Cultivation	Fuel prod.	Total (allocated)	Total (not allocated)	Energy in fuel produced
RME					
Fuel	123	0	123	264	1983
Electricity	6	93	99	204	
Heat	37	2	39	83	
Total	166	95	261	551	
Ethanol					
Fuel	127	0	127	143	1697
Electricity	12	87	99	105	
Heat	73	300	373	402	
Total	214	387	599	650	
Biogas					
Fuel	52	0	52	61	2676
Electricity	0	384	384	452	
Heat	0	142	142	167	
Total	52	526	578	680	

The alternatives to bio-fuels, such as diesel, have a much larger environmental impact. Table 29 shows a synopsis of each fuel's impact on the environment and compares each fuel's contribution to global warming, acidification (see Glossary), and eutrophication (see Glossary). RME is a well-ranked fuel in regards to global warming, but scores the worst in regards to acidification and eutrophication. Overall, the environmental impact of these three alternative fuels will be an improvement over current energy solutions used on farms (Fredriksson et al., 2006).

Table 29: Potential Atmospheric Impact of Various Fuels (Fredriksson et al., 2006)

	RME	Ethanol	Biogas	Diesel
Global warming potential (kg CO_2-equivalents)				
Cultivation	22	1057	150	–
Fuel production	447	6534	30,593	14,718
Soil emissions	43,288	40,621	28,087	–
Fuel utilisation	0	14,878	8107	142,984
Total	43,757	63,090	66,937	157,702
Acidification potential (kg SO_2-equivalents)				
Cultivation	87	58	12	–
Fuel production	2	53	5	141
Soil emissions	159	193	154	–
Fuel utilisation	1398	707	688	1110
Total	1646	1011	859	1251
Eutrophication potential (kg O_2-equivalents)				
Cultivation	751	494	112	–
Fuel production	10	200	20	893
Soil emissions	38,167	43,483	14,154	–
Fuel utilisation	12,155	6151	5981	9649
Total	51,083	50,328	20,267	10,542

Figure 20 shows the overall process of how ethanol is produced and made from recycled food waste and manure. Additionally, it is clearly shown how all processes of ethanol production are interrelated as well as the lack of waste produced. This is very important when we want to consider the long term effects that creating energy has on our enviroment. Ultimately, Massachusetts aims to maintain sustainable development and a rural atmosphere. These examples fit very well into those guidelines.

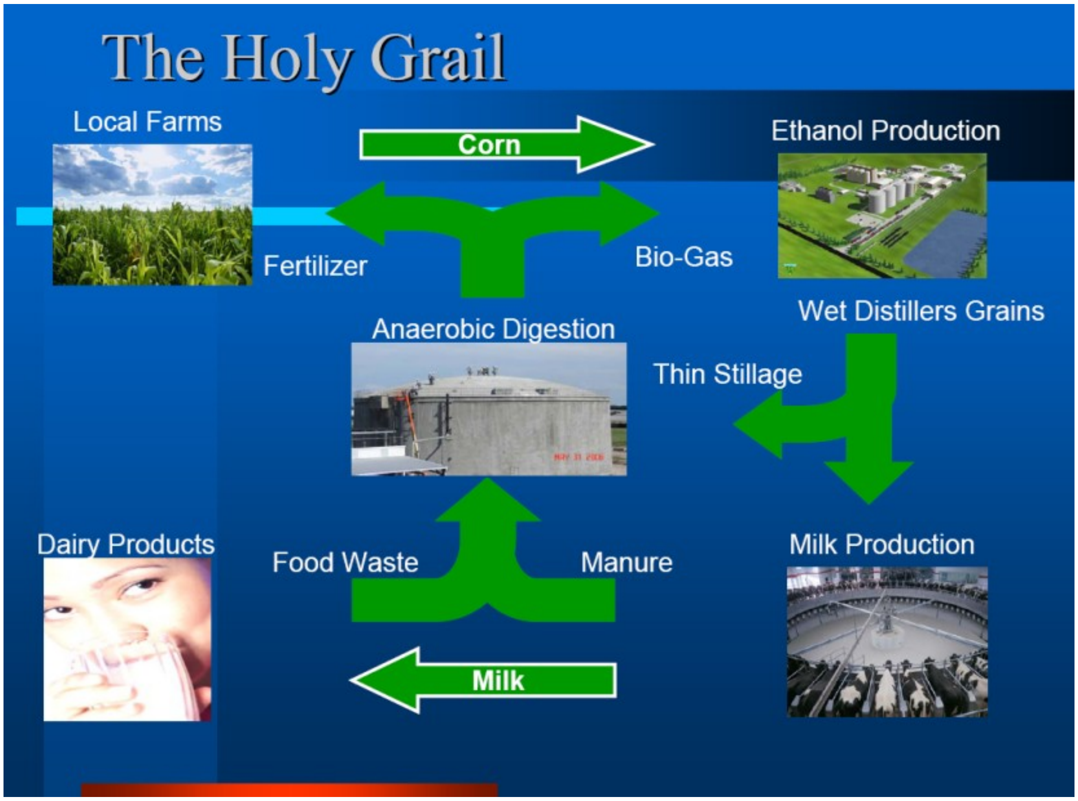

Figure 20: Process of Creating Ethanol (Stephenson, 2007)

APPENDIX C: METHANE DIGESTERS

Methane digesters (see Glossary) are wastewater and solid treatment technology designed to process animal waste under anaerobic (see Glossary) conditions to yield methane gas and reduce the volume of solids and treated liquids. Anaerobic methane digesters have the potential for mitigating environmental pollution and creating a marketable energy product at the same time (Massachusetts Dairy Farm Revitilization Task Force, 2007). As shown in Figure 21 below, farmers sell and use methane to generate electricity on the farm. The solid matter left behind creates valuable soil and fertilizer, and the digester purifies and reclaims remaining liquid or turns it into a liquid fertilizer.

Figure 21: Dairy Waste to Resources (Hagevoort, 2007)

In 1970, the use of anaerobic digesters was an increasing phenomenon. The rising oil prices created an interest in alternative energy sources. One of the sources that showed the most potential was the use of methane created by livestock manure (Riggle, 1997; AgSTAR Handbook, 2004). The greatest appeal for this technology was with farmers. Riggle (1997) explains that by using anaerobic digesters, farmers could potentially generate their own energy needs and sell any surplus back to the grid. So with the help of federal funding, approximately 140 anaerobic digesters were constructed. The federal government constructed about half of these digesters on farms and built the others at universities for research and demonstration purposes. Riggle (1997) also states that while these programs were showing progress, the reduction in oil prices and the decrease in price of energy purchased from renewable sources caused a large decrease in the use of farm based anaerobic digesters.

According to Riggle (1997), methane digesters are best suited for bigger farms that produce large amounts of manure with little to no bedding (see Glossary) added. In fact, the AgSTAR Handbook (2004) illustrates that using digesters for electricity production is only effective on farms with more than 500 cows. This is because there is not enough waste produced to keep the digester at operating capacity. The feasibility of using digesters in Massachusetts is drawn into question, as the average heard size on dairy farms is 67, with only one farm having more than 500 cows (Census of Agriculture, 2002). However, smaller farms too can benefit from this technology by participating in a cooperative, rather than paying for energy from the grid.

One example of a working cooperative is Oregon's Methane Energy and Agricultural Development (MEAD) (see Glossary) Biogas Methane facility in the Port of

Tillamook Bay. Initially MEAD had plans to build one central facility to handle the waste from the entire county, but it was determined that building smaller, locally centralized facilities would be more beneficial. By building smaller, local facilities, the Port of Tillamook Bay was able to decrease the initial investment to farmers, reduce the length of transportation, and allow for alternative locations in case of a flood or other emergency (Bio-Gas Methane Facility, 2005). One reason the MEAD project was successful is because this cooperative was a joint venture between public and private organizations; various government organizations and the Tillamook County Creamery Association divided the cost (Riggle, 1997).

An alternative to large scale digesters is smaller polyethylene digesters built into the ground. However, those do not work in the cold weather of Massachusetts. Another alternative to harvesting electricity from a methane digester is to collect the methane for heating. However, that is not cost-effective if the farm does not already have infrastructure otherwise used for natural gas.

One of the advantages of digester technology is that it could potentially reduce the amount of pathogens in dairy wastes and could significantly reduce the amount of methane gas in the air. It is estimated that if California digested its 65 billion pounds of manure produced every year, the output would be extremely fertile farm soils as well as more than two-hundred megawatts of power (Dairies: Methane Digesters, n.d.). Despite the clear benefits of providing clean energy, Riggle (1997) states that farmers have been reluctant to pursue the anaerobic process because of its high investment in money and management. Unfortunately, there are no available rebate options for such technologies in Massachusetts.

Bio-power stations (see Glossary) can handle either waste in solid or liquid form. According to the AgSTAR Handbook (2004), this is necessary because animal manure has different characteristics and farmers use various methods of manure collection. The solid and liquid residues are separate and go through very similar processes and eventually produce electricity and heat. The Massachusetts Dairy Farm Revitilization Task Force (2007) states that bio-power stations have several benefits: they reduce the mass of solids and the odor associated with the waste products, they produce clean effluent for recycle irrigation, they reduce pathogens associated with waste, they generate energy, and they concentrate the nutrients in a solid product for storage and export.

There are many concerns about using methane digesters on dairy farms besides the expensive costs. The digesters require that the manure retain water. The wet transportation necessary to preserve the manure is very expensive and requires specialized methods. It is vital that the manure does not lose moisture during the transportation process and those couriers easily transport water to the digesters. Furthermore, as stated by Representative Anne Gobi (2008), farmers have been reluctant to seek outside help and adapt new technologies that could improve their business and profit. Another concern presented by Kaparaju & Rintala (2006), is that operators only recover part of the methane potential from post-storage tank materials.

Methane Digesters are a realistic solution to farmers' monetary problems considering that Cowpot's Farm in Colebrook, Connecticut is currently operating several digesters. Colebrook, Connecticut is less than ten miles from the Massachusetts border; therefore, any problems created by the New England climate are a non-issue to farmers considering using large methane digesters. Farmer's interested in learning more about the financing and the costs of implementing a methane digester should consider the size of their farm, the number of animal units (AU, see Glossary) they own, and the type of digester they are interested in. The following chart taken from AgSTAR program of the Environmental Protection Agency (EPA) displays the type of methane digester, its effectiveness, and its cost of use per AU.

Table 30: Environmental Protection Agency (2002)

Options	Odor Control	Greenhouse Gas Reduction	Water Quality Protection	Cost Range ($ per 1,000lbs/live weight)*
Covered Lagoon Digesters with Open Storage Ponds	E	H	G	150-200
Heated Digesters (i.e., complete mix and plug flow) with open storage tanks	E	H	G	200-400
Aerated Lagoons with Open Storage Ponds	G-E	H	F-G	200-450
Separate Treatment Lagoons and Storage Ponds (2-cell systems)	F-G	L	G	200-400
Combined Treatment Lagoons and Storage Ponds	P-G	L	F-G	200-400
Storage Ponds and Tanks	P-F	M-H	P-F	50-500
Key: P=poor, F=fair, G=good, E=excellent, L=low, M=medium, H=high				
*Aerated lagoon energy requirements add an additional $35-50 per 1000 lbs/year				

According to Table 30, digesters typically cost around 400 dollars/ 1,000 pounds of animal weight. A cow typically weighs between 600-900 pounds with the largest cattle reaching weights of 1800 pounds (Beef Cattle Production Information, n.d.). Depending upon how many cows a farmer owns, he could estimate the total cost and size of the digester he would need. A farmer can order based upon their requirements because digesters come in a variety of sizes.

An important case study farmers can consider when contemplating methane digesters is the case of the Haubenschild Family Farm near Princeton, Minnesota. The

Haubenschild Family Farm installed a digester that linked manure handling and electricity generation equipment at their 800-cow farm in 1999. While the AgSTAR chart only considers investment requirements for the digester, the Haubenschild Family Farm economic analysis considers the investment requirements for the digester, financing, labor requirements, repairs and maintenance for the equipment involved, electricity sales and avoided purchases, LP gas avoided purchased, and other benefits observed by the farm operator.

According to Lazarus and Rudstrom (n.d.), the Haubenschild digester cost $355,000, without labor costs, or $444/cow, in 1999. Equipment costs have significantly risen over the last nine years, according to the USDA's index of prices paid by the farmers (2007). A similar project today could cost close to $550 dollars per cow, for parts alone, because of this increase. With labor costs, the price per cow for farms could reach as high as $1000. The State of Minnesota also provides a six-year $150,000 zero-interest loan. Massachusetts does not provide similar assistance, but the federal government has a small selection of loans that farmers can investigate.

APPENDIX D: ENERGY ASSESSMENT AND AUDIT GUIDLINES

Additional Information & Guidance
Energy Assessments and Energy Audits for the Section 9006 Program

Energy assessments

All energy efficiency improvement projects with total eligible project costs of $50,000 or less must provide an energy assessment. The energy assessment must include adequate and appropriate evidence of energy savings expected when the proposed system is operated as designed. This assessment should be conducted by an experienced energy assessor, certified energy manager or professional engineer from an independent firm or the local utility.

The energy assessment must cover the following:

<u>Situation report</u>
Provide an assessment of current energy cost and efficiency by analyzing energy bills and briefly surveying the target building, machinery, or system.

<u>Potential improvements</u>
Identify and provide a savings and cost analysis of low-cost/no-cost measures. Estimate the overall costs and expected annual energy and cost savings from these improvements.

Energy audits

An energy audit must be conducted for all energy efficiency improvement projects with total eligible project costs greater than $50,000. An energy audit is a written report by an independent, qualified party that focuses on potential capital-intensive projects and involves detailed gathering of field data and engineering analysis. The audit provides detailed project costs and savings information with a high level of confidence sufficient for major capital investment decisions. Typically, Certified Energy Managers and Professional Engineers qualify as independent qualified parties; *however the vendor and the applicant do not qualify.* An energy audit may also be performed by the local utility. The methodology of the energy audit must meet professional and industry standards.

The energy audit must cover the following:

<u>Situation report</u>
Provide a narrative description of the facility or process, its energy system(s) and usage, and activity profile. Also include price per unit of energy (electricity, natural gas, propane, fuel oil, renewable energy, etc.,) paid by the customer on the date of the audit. Any energy conversion should be based on use rather than source.

<u>Potential improvements</u>
List specific information on all potential energy-saving opportunities and their costs.

Disclaimer: This technical requirements worksheet is applicable only for projects eligible under the Section 9006 Simplified Application Process (total eligible project costs $200,000 or less). This worksheet is provided by the National Renewable Energy Laboratory (NREL) to assist applicants in meeting technical requirements contained in Appendix A of 7 CFR Part 4280. This worksheet is meant for guidance purposes only, and is not considered a requirement of the program. The above rule is the final authority for application requirements.

Technical analysis

Discuss the interactions among the potential improvements and other energy systems.

- Estimate the annual energy and cost savings expected from each improvement identified in the energy audit.
- Calculate all direct and indirect costs of each improvement.
- Rank potential improvement measures by cost-effectiveness.

Potential improvement description

Provide a narrative summary of the potential improvement(s) and its ability to provide needed benefits, including a discussion of nonenergy benefits.

- Provide preliminary specifications for critical components.
- Provide preliminary drawings of project layout, including any related structural changes.
- Document baseline data compared to projected consumption, together with any explanatory notes. When appropriate, show before-and-after data in terms of consumption per unit of production, time or area. Include at least 1 year's bills for those energy sources/fuel types affected by this project. Also submit utility rate schedules, if appropriate.
- Identify significant changes in future related operations and maintenance costs.
- Describe explicitly how outcomes will be measured.

APPENDIX E: COST CALCULATOR EXCEL SPREADSHEET

INPUT	
Cost of Energy ($/kWh)	.13450
Number of Cows Milked	40
Number of Milkings per day	2
Number of milking stations	8
Horsepower of Vacuum Pump	7.5
Hours per day Vacuum Pump operates	7
Input Temperature (F)	59
Tank Temperature (F)	35
Cost of Pre-cooler ($)	2500
Cost of Variable Frequency Drive ($)	4750
Cost of Heat Recovery Tank ($)	4300

INPUT	(yellow)
OUTPUT	(green)

OUTPUT	
Pre-cooler	
Energy Savings Per Month (kWh)	141
Monthly Cost Savings ($)	18.97
Annual Cost Savings ($)	227.61
Return on Investment (years)	10.5
Carbon Savings/year (tons)	1.1
Variable Frequency Drives	
Energy Savings Per Month (kWh)	534
Monthly Cost Savings ($)	71.87
Annual Cost Savings ($)	862.42
Return on Investment (years)	5.5
Carbon Savings/year (tons)	4.3281189
Heat Recovery Tank	
Energy Savings Per Month (kWh)	329
Gallons of water raised 100F (daily)	44
Monthly Cost Savings ($)	44.20
Annual Cost Savings ($)	530.46
Return on Investment (years)	8.1
Carbon Savings/year (tons)	0.599595181

APPENDIX F: INFORMATIONAL CD INSTRUCTIONS

Increasing Energy Efficiency on Massachusetts Dairy Farms

This was a project completed by a group of students from Worcester Polytechnic Institute, which included Kurt Schebel, Andrew Sides, Joseph Wilkos, and Andrew McCarthy. Representative Anne Gobi sponsored this project. The purpose of this project was to advise and assist Massachusetts dairy farmers on ways to improve energy efficiency. Our project also consisted of determining what investment is best suited for farmers and educating them on available loans and grants.

The three means of improving energy efficiency that we considered were pre-coolers, variable frequency drives, and heat recovery tanks. This CD includes a spreadsheet for calculating energy savings per month, monthly and annual cost savings, return on investment period, and carbon savings per year. To calculate these, input the corresponding values in the yellow highlighted input section, as shown bellow, on the Excel spreadsheet.

INPUT	
Cost of Energy ($/kWh)	.13450
Number of Cows Milked	40
Number of Milkings per day	2
Number of milking stations	8
Horsepower of Vacuum Pump	7.5
Hours per day Vacuum Pump operates	7
Input Temperature (F)	59
Tank Temperature (F)	35
Cost of Pre-cooler ($)	2500
Cost of Variable Frequency Drive ($)	4750
Cost of Heat Recovery Tank ($)	4300

Input temperature is the temperature of the milk when it enters the refrigeration tank coming from either the cow or the pre-cooler. The tank temperature is the temperature you store your milk at.

A typical price for a plate cooler can range from $1600 to $10,000, depending on how much milk you are cooling at any time, i.e. the size of your parlor. A typical price for a variable frequency drive is about $2000 for a 5 HP pump attachment or about $4700 for 7.5 HP pump attachment. A typical price for a heat recovery tank is between $2900 and $5000, depending on the amount of hot water needed, the temperature of the milk entering the tank, the temperature you cool it to, and the size of your milk tank. The typical prices for a 40-100 milking-cow farm are the default settings on the Excel sheet. All prices are calculated before labor or rebates. Your plumber or electric motor serviceman can give a specific estimate. This was designed to provide dairy farmers with a general background on some energy efficiency products and give them an idea of what these products have to offer.

All costs here are calculated before any rebates or incentives. Database of State Incentives for Renewables and Efficiency (DSIRE) will give you a list of eligible grant and rebate programs available to your specific area. The database can be located at DSIREUSA.org. Typically your electric company will provide incentives for efficiency measures.

A more detailed description of this project will be available at WPI's Gordon Library's online catalog. Gordon's library web address is http://www.wpi.edu/Academics/Library/.

APPENDIX G: SAMPLE LETTER TO FARMERS

Dear Mr. «Farm_Name»,

We would like to thank you for participating in our study of Massachusetts dairy farms. It has helped further our education as well as provided a model for other farmers similar to you to follow. The following is an analysis of how your farm would benefit or is benefiting from certain efficiency measures. In order for these calculations to be correct, please verify that the following information about your farm is correct.

Cost of electricity per kWh: $«Cost_of_Energy_kWh»
Number of cows milking: «Number_of_Cows_Milked»
Number of milking sessions per day: «Number_of_Milkings_per_day»
Number of milking units: «Number_of_milking_units»
Horsepower of vacuum pump: «Horsepower_of_Vacuum_Pump» HP
Hours per day vacuum pump is operating: «Hours_per_day_Vacuum_Pump_operates» hours
Temperature of milk leaving cow or plate cooler: «Input_Temperature_F» ºF
Temperature maintained in milk tank: «Tank_Temperature_F» ºF

PLATE COOLER
Initial Cost: $«Cost_of_Precooler_»
Energy savings per month: «Energy_Savings_Per_Month_kWh» kWh
Monthly cost savings: $«Monthly_Cost_Savings_»
Annual cost savings: $«Annual_Cost_Savings_»
Estimated payback: «Return_on_Investment_years» years
Tons of carbon-dioxide saved per year: «Carbon_Savingsyear_tons» tons

VARIABLE FREQUENCY DRIVE
Initial Cost: $«Cost_of_Variable_Frequency_Drive_»
Energy savings per month: «Energy_Savings_Per_Month_kWh1» kWh
Monthly cost savings: $«Monthly_Cost_Savings_1»
Annual cost savings: $«Annual_Cost_Savings_1»
Estimated payback: «Return_on_Investment_years1» years
Tons of carbon-dioxide saved per year: «Carbon_Savingsyear_tons1» tons

HEAT RECOVERY TANK
Initial Cost: $«Cost_of_Heat_Recovery_Tank_»
Energy savings per month: «Energy_Savings_Per_Month_kWh2» kWh
Gallons of water raised 100 ºF: «Gallons_of_water_raised_100F_daily» gallons
Monthly cost savings: $«Monthly_Cost_Savings_2»
Annual cost savings: $«Annual_Cost_Savings_2»
Estimated payback: «Return_on_Investment_years2» years
Tons of carbon-dioxide saved per year: «Carbon_Savingsyear_tons2» ton

APPENDIX H: ECONOMIC ANALYSIS USING NET PRESENT VALUE

To verify our calculations for the return on investment period and to more accurately predict that period for long-term investments, we used the Net Present Value (NPV) equation. NPV is a method used to determine the overall cost benefit of a project over its given lifespan. To determine the NPV we used Equation 11. For our analysis, we used the current prime interest rate as our discount rate, which was equal to approximately 3 percent.

Equation 11: Net Present Value

$$\mathrm{NPV} = -C_0 + \sum_{t=1}^{N} \frac{C_t}{(1+r)^t}$$

Where:

C_0 – Initial investment (cost of product) at $t = 0$
N - Total time of the project (expected life of product)
C_t - Net cash flow at time t.
r - Discount rate
t - Time of the cash flow

Based on our analysis using Equation 11, we were able to determine the payback period as well as the net savings for the life of the product. Since the payback period for many of the farms was within five years, the NPV equation verified that our ROI estimates were reasonably accurate.

INDIVIDUAL FARMS

The following figures 22 through 24 illustrate the NPV for the installation of a pre-cooler, heat recovery tank, and a variable frequency drive on the Farm A.

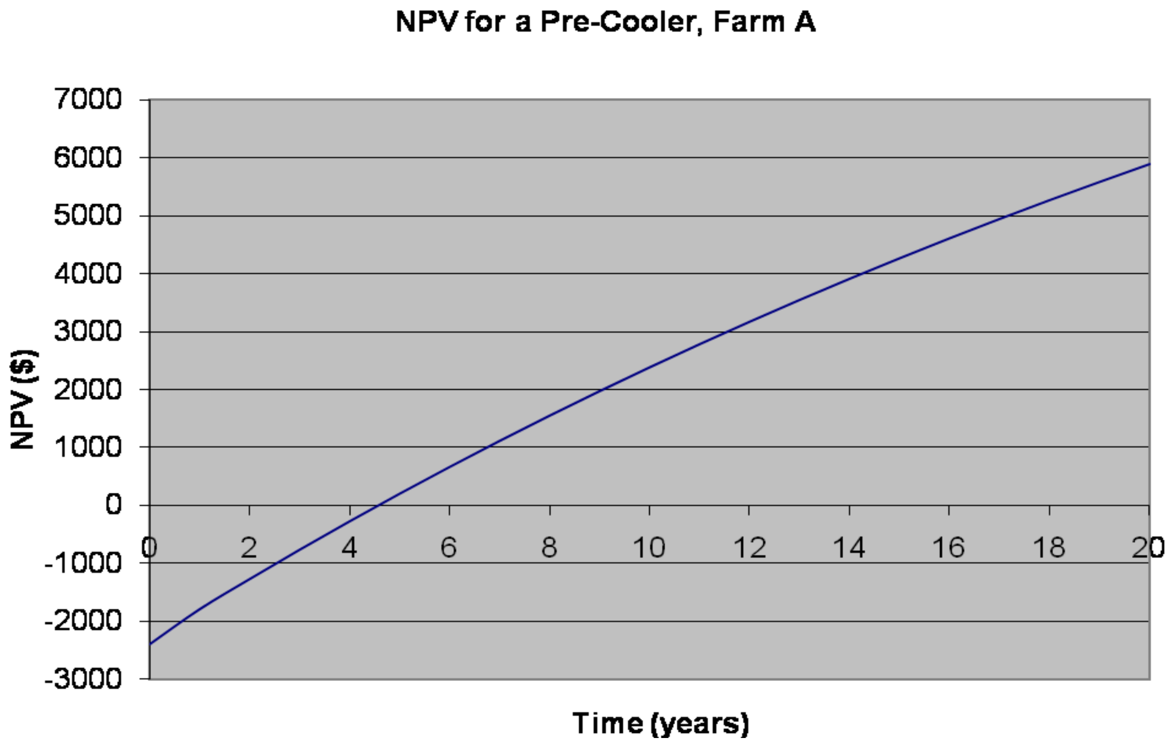

Figure 22: NPV for a Pre-cooler at 3% Prime Rate, Farm A

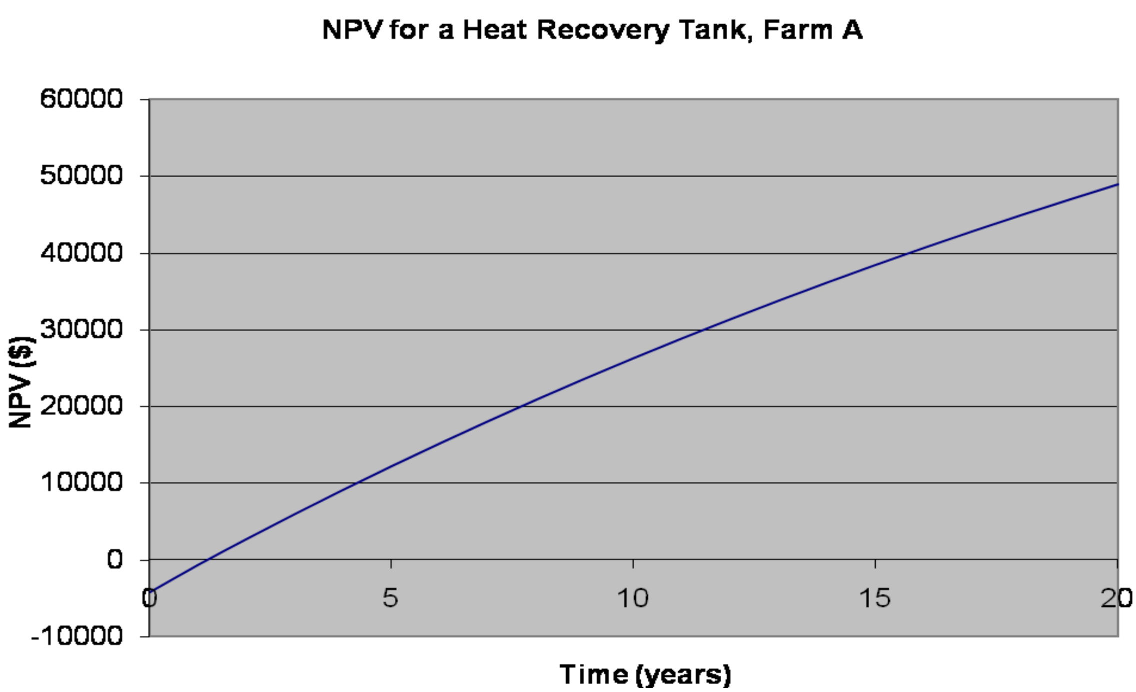

Figure 23: NPV for a Heat Recovery Tank at 3% Prime Rate, Farm A

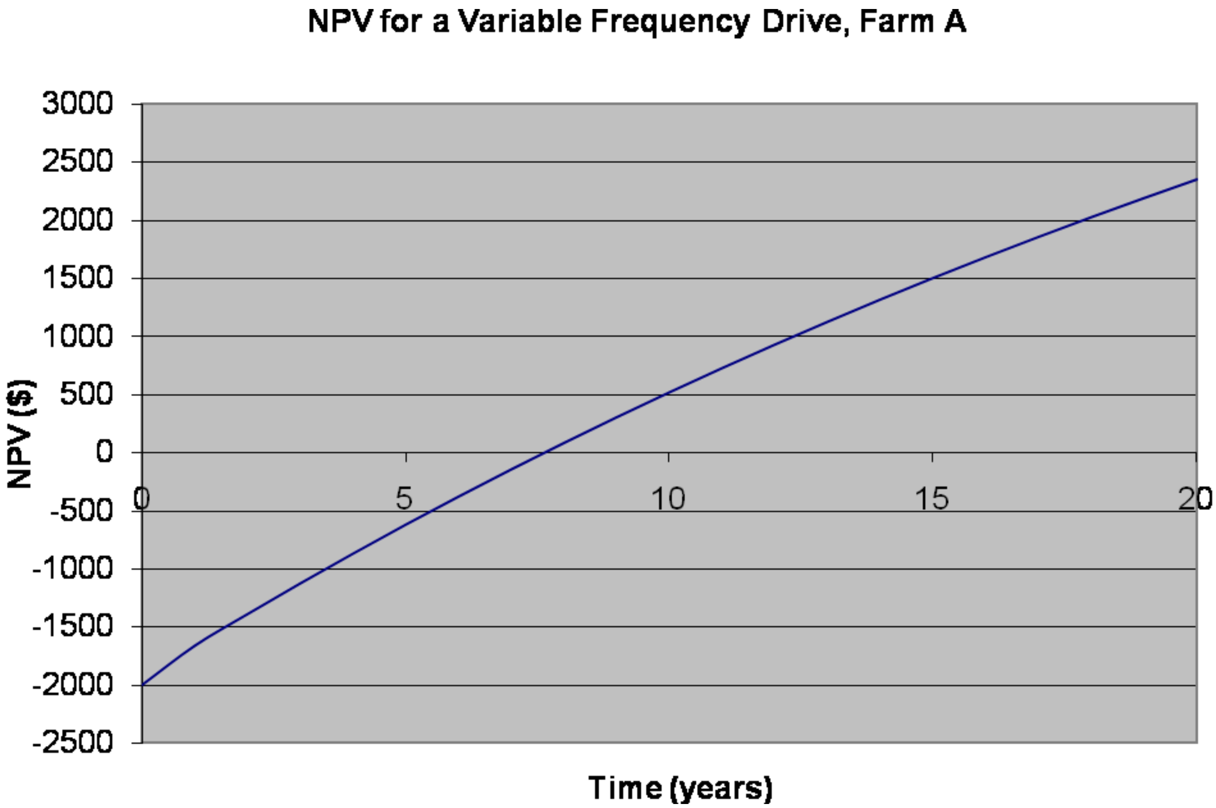

Figure 24: NPV for a Variable Frequency Drive at 3% Prime Rate, Farm A

As shown in Figure 22, a pre-cooler will have a payback period of 4.5 years on Farm A. This is slightly lower than the 4.8 years predicted by the ROI equation. Figure 23 predicts that the payback period for a heat recovery tank to be a little over one year, which is also what the ROI equation predicted. Finally, Figure 24 shows the payback period for a variable frequency drive to be 7.5 years, which is slightly greater than the 6.7 years predicted by the ROI equation.

Figure 25 shows the NPV for the installation of a variable frequency drive on Farm B.

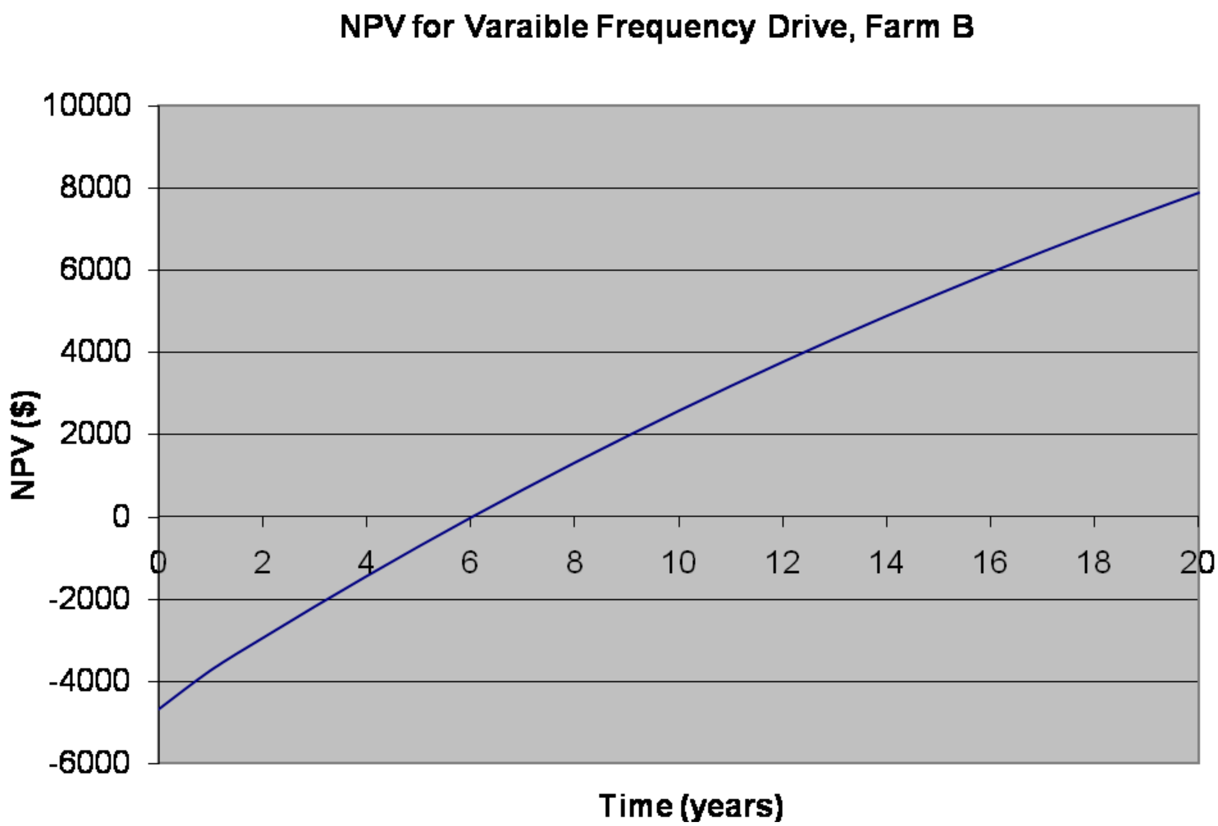

Figure 25: NPV for a Variable Frequency Drive at 3% Prime Rate, Farm B

As shown in Figure 25, the payback period for Farm B would be six years; this is slightly higher than the 5.4 years predicted using the ROI equation. Also, that is well within the twenty year life span of the variable frequency drive making it a reasonable investment for Farmer B.

Figure 26 shows the NPV for the installation of a variable frequency drive on Farm C.

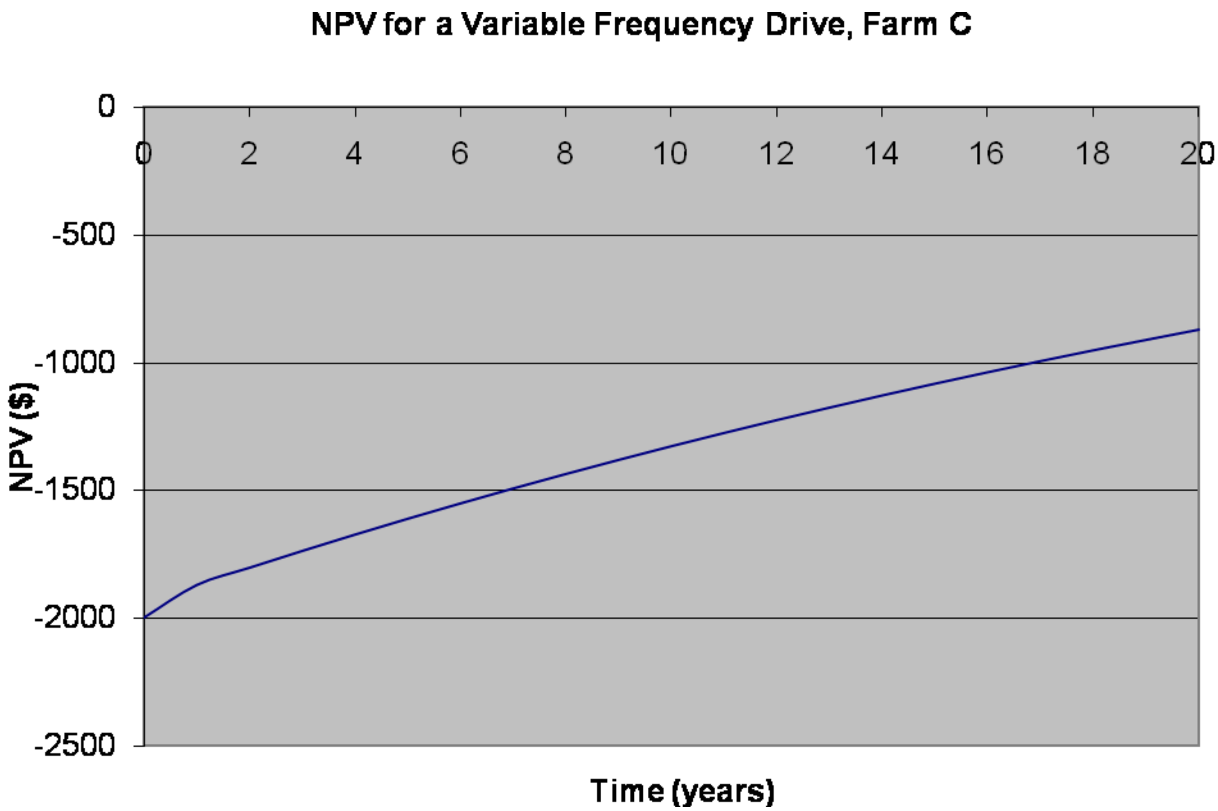

Figure 26: NPV for a Variable Frequency Drive at 3% Prime Rate, Farm C

As shown in Figure 26, a variable frequency drive will never receive a return on investment for its given lifespan. The ROI equation provided similar results. However, the calculated payback period is drastically different between the two. The ROI equation predicts a return on investment in 26.9 years, where the NPV equation predicts the payback to be in 56 years. Since these are both outside the expected life span of the drive, we can disregard this difference.

Figures 27 and 28 show the NPV for the installation of a variable frequency drive and a heat recovery tank on Farm D.

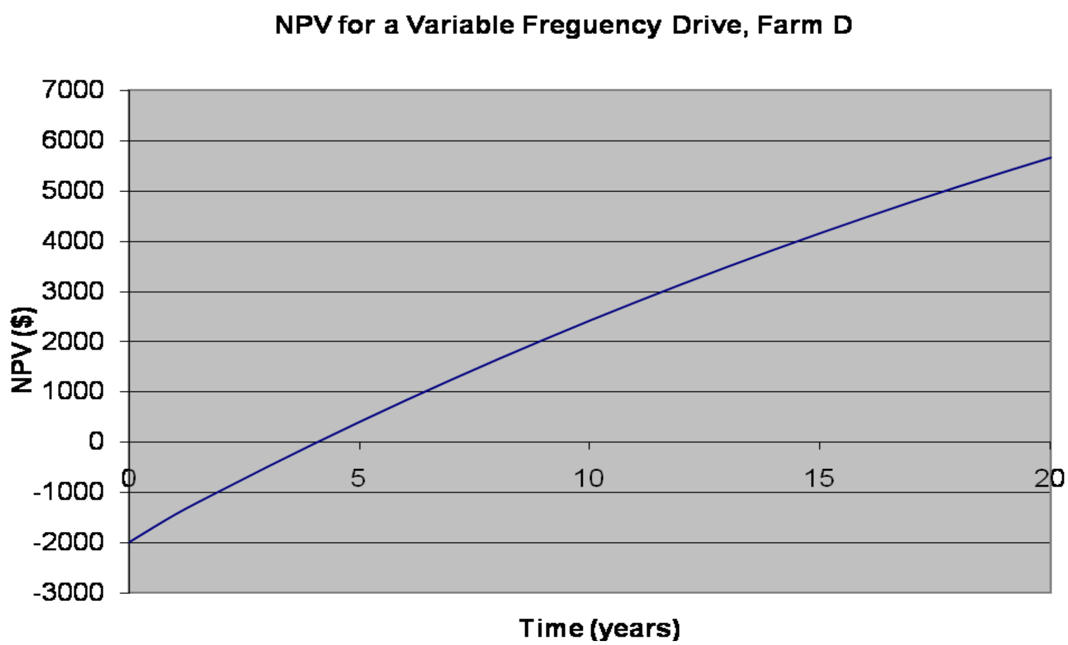

Figure 27: NPV for a Variable Frequency Drive at 3% Prime Rate, Farm D

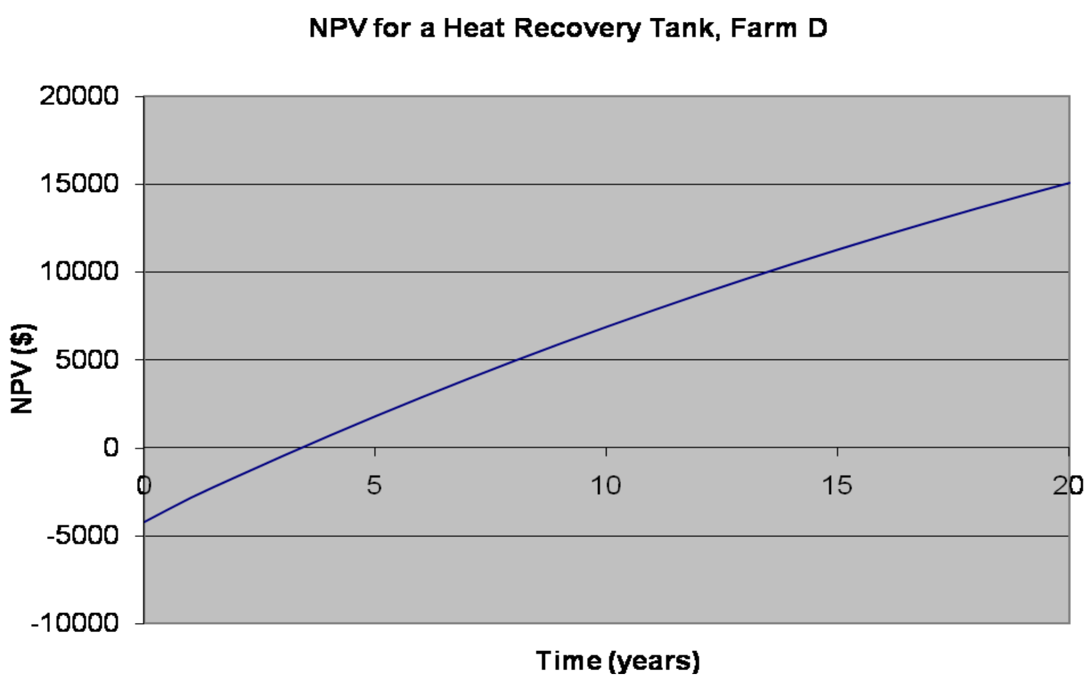

Figure 28: NPV for a Heat Recovery Tank at 3% Prime Rate, Farm D

As shown in Figures 27 and 28 the payback period will be 4.2 years for a variable frequency drive and 3.5 years for a heat recovery tank. This once again verifies that our ROI equations are appropriate for those relatively short term investments.

Figure 29 shows the NPV for the installation of a variable frequency drive on Farm C.

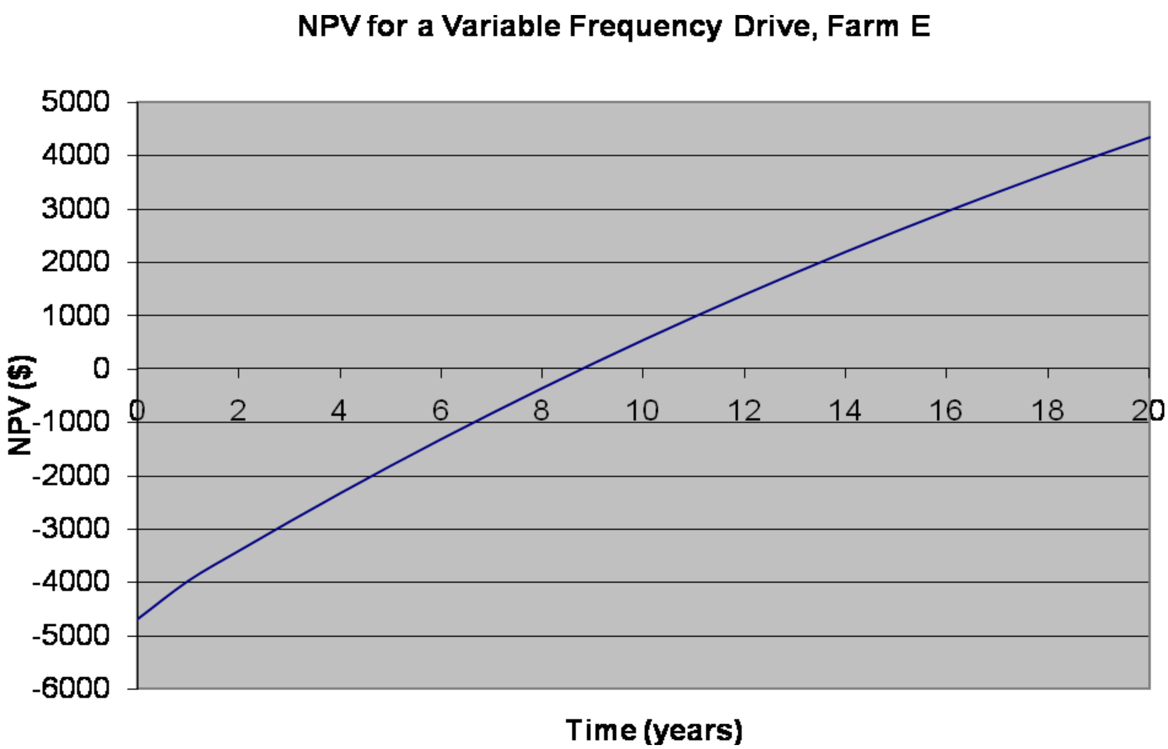

Figure 29: NPV for a Variable Frequency Drive at 3% Prime Rate, Farm E

The payback period for the installation of a variable frequency drive on Farm E will be 8.6 years, as shown in Figure 29. This is one year greater than what the ROI equation predicted.

We obtained similar results for the payback period using the both the ROI and NPV equations. The NPV equation was more conservative in its estimate and more accurately predicted the payback period for a return on investment greater than ten years.

But since the majority of the investments had a payback period of less than ten years, we feel that it is justified to use either equation.

APPENDIX I: GLOSSARY

Acidification – Creation of acid rain through sulfur dioxide pollution.

Alternative Energy – Energy that comes from an alternative source other than fossil fuels.

Anaerobic Digestion – Process in which microorganisms break down biodegradable material in the absence of oxygen animal waste under anaerobic conditions to yield methane gas and reduce the volume of solids and treated liquid.

Animal Unit (AU) – One mature cow of approximately one thousand pounds and a calf up to weaning, usually six months of age, or their equivalent.

AWS TrueWinds Map- Wind Map prepared by AWS TrueWind and sponsored by the Connecticut Clean Energy Fund, Northeast Utilities Systems, and the Massachusetts Technology Collaborative Renewable Energy Trust.

Bedding – A substance used to facilitate the collection of animal manure and used to comfort and insulate animals as they sleep. Typically hay, wood chips, saw dust, straw, or sand are used.

Bio-fuels – Considered a solid, liquid, or gas fuel derived from biomass.

Bio-power Stations – Biomass fuels those power plants.

BTU – British Thermal Unit. It is equivalent to 0.2931 watt-hours

The Cadmus Group- Cadmus' staff of consultants provides an array of research and analytical services in the U.S. and abroad to help government, non-profit, and corporate clients address critical challenges in the environmental and energy sectors.

Counter-Flow Heat Exchanger – A device in which fluids travel in opposite directions to aid in the process of heat transfer.

Cultivation - the planting, growing, and harvesting of crops or plants, or the preparation of land for the purpose of using them for bio-fuels.

Cut wind speed- The speed at which a wind turbine starts to run (the cut-in speed, usually at 3-5 m/s) and the speed at which a wind turbine is programmed to stop (the cut-out speed).

Dairy Farm Revitalization Task Force – The Task Force appointed by Scott J. Soares, the Commissioner of the Massachusetts Department of Agricultural Resources, to seek long and short term solutions to preserve and strengthen the dairy farm industry in Massachusetts. This task force reports causes of and solutions to the Massachusetts dairy farm crisis to the commissioner, Scott J. Soares, and the Massachusetts legislature.

Eutrophication – Excessive nutrients in a lake or other body of water, usually caused by runoff of nutrients (animal waste, fertilizers, sewage) from the land, which causes a dense growth of plant life.

Farmer's Feed – Farm animal's food blended from various raw materials targeted towards a specific animal.

Feasibility Study - An initial study performed to determine if a project is a valuable investment.

Gigajoules - The Joule is the SI unit of energy measuring heat, electricity and mechanical work. A Gigajoule is 10^9 Joules.

Green Communities Act – Meet at least 20 percent of the Commonwealth's electric load by the year 2020 through new, renewable generation.

Methane Digesters – Wastewater and solid treatment technology designed to process

MWh – A unit of energy commonly used in measurement of output of large power plants. It is 1000 kWh or a mega-Watt output over an hour.

Nexamp- Nexamp designs, finances, builds and operates projects that reduce energy consumption and carbon emissions for businesses, governments and homeowners.

Nominal Wind Conditions – The range of wind speeds at which a wind turbine functions at the manufacturers' specified output.

Oregon's Methane Energy and Agricultural Development (MEAD) – Provides a simple, cheap conversion of dairy farm waste to clean electrical power and marketable by-products.

Photovoltaic Cells – A panel that converts solar energy into electricity; also known as a solar panel.

Renewable Energy – Energy that effectively uses natural resources such as sunlight, wind, rain, tides and geothermal heat.

Servomechanism – Also known as a servo, it is a device that takes in an input modifies its behavior to move its input closer to a desired goal, producing a negative feedback loop. For example, a thermostat in a house is a servomechanism.

Solar Energy – Energy that comes directly from the sun. Essentially supports all life on Earth.

Solar Water Heater -- A solar cell that collects light and converts it to heat stored in water. They are commonly used to heat houses.

Therm – A unit of energy commonly used in measurement of spatial heating. It is equivalent to 29.3 kWh

Wind Energy – Energy formed by the conversion of wind into useful form, such as electricity, using wind turbines.

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