Solar-Geothermal Hybrid Systems: A Possible Solution to UMass Amherst's Massive Heat Problem

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1. Executive Summary

Carbon dioxide has been connected to events such as global warming, coral bleaching and many other things that are currently posing a threat to our planet. One of the largest contributors to our carbon emissions is the Central Heating Plant, producing 85,000 metric tons of CO2 per year. Our team decided to investigate an alternate, renewable and eco-friendly way to mitigate the emissions produced by the plant. Following the example set by Ball State University (BSU), we found that implementing a geothermal system would decrease carbon emissions from the CHP by 72%. However, the immense size of the system would have to be increased relative to that of BSU's in order to meet the heating demands of our campus. As BSU's system is already one million ft^2, increasing the size is unrealistic as UMass does not have large amounts of free space. Our team has decided to look at an innovative and alternative way to implement a geothermal system at UMass that will overcome this problem. Our proposal is to expand the BSU system design by combining it with a photovoltaic solar field, so that together the system as a whole can produce the necessary heat required by the facilities on campus. In addition, this new system will be able to provide cooling during warmer months, and is capable of producing electricity with litle reliance on an outside source. The total cost of this system is estimated to be $100 million, with annual savings of $2 million for the total amount of CO2 mitigated. This is a small price to pay for securing a brighter and better future.

2. Introduction

It is only after the last breath of air can be taken, only after the last bee flaps its wings, only after the last plant sways in the wind, only after the last glacier has melted and the last fish has taken its final swim, that we will realize we should have done more. Scientists around the world cannot seem to agree on the numbers, however there is a consensus on one thing and that is that the human race is in imminent danger. Events such as global warming, coral bleaching, and pollution threaten the very foundation of our planet. Current levels of carbon dioxide in our atmosphere have been linked to these events and it is evident that something must be done. As a result, many states and institutions have made it one of their priorities to find different ways to reduce their carbon emissions. Our Chancellor Subbaswamy has challenged us to achieve net zero carbon emissions by the year 2030 [1]. One of the largest contributors to the university's carbon emissions is the Central Heating Plant, which produces 85,000 metric tons of carbon dioxide a year. What can we do to mitigate these high levels of carbon dioxide being released into our environment? In this paper we will investigate the possibility of replacing the current plant with an alternative green and renewable system. Research in the fields of thermodynamics and mechanical engineering are both incorporated into our findings and contribute to our overall solution.

3. Problem Statement

At the University of Massachusetts Amherst, Chancellor Subbaswammy has created a goal for the campus to reach net-zero carbon emissions by the year 2030 in order to help reduce the harmful effects of climate change. One of the main problems that the university faces when attempting to achieve this goal is how to provide heat to an entire campus throughout the year, especially during the cold winters, in a “carbon-free” way. Currently, UMass is heated using the newly developed Central Heating Plant (CHP) on campus that provides heat to the entire campus. A possible alternative to heating the campus is developing a geothermal energy system that uses the thermal energy from the earth to heat water or other liquids that then provides the needed heat. A geothermal energy system has shown to work on other campuses in reducing carbon emissions, such as Ball State University (BSU) who were able to reduce their carbon emissions by 30% in about 5 years [2]. A similar system has the potential to limit the need for the CHP. However, in western Massachusetts, there may not be enough geothermal resources in the ground for a system like this to be efficient in heating water. Due to this, a stand-alone geothermal energy system, with the same size as BSU, may not be enough to provide the needed heat to the entire campus.

The way that UMass Amherst currently provides heat to its buildings certainly has many flaws. The CHP operates by burning fossil fuels to heat up water into steam, which is then sent through more than 25 miles of pipes around campus which then transfers heat into the buildings [3]. The main problem with this is that, because it burns fossil fuels, it produces about 185 million pounds of carbon emissions per year [4]. Due to this, in order for UMass to reach carbon neutrality, there will have to be a major change in how heat is provided to campus so that the need for the CHP is reduced. One idea that may provide a solution is the use of carbon-capturing technology that captures CO2 as it leaves the plant and processes it in a way that does not harm the environment [5]. Although this technology provides a simple and effective method, carbon capture technology is indicated to only capture 90% of carbon emissions. Therefore, the CHP would still be releasing 10% of its emissions, or 18.5 million lbs of carbon, into the atmosphere [5]. Instead of trying to capture a majority of carbon emissions, a solar-geothermal hybrid system is more beneficial as it may be able to provide similar functions as the CHP with a massive reduction in carbon emissions.

The most important aspect of the development of an effective geothermal energy system is the sufficient amount of geothermal resources available in the ground. However, geothermal resources are scarce at UMass Amherst, or more precisely, the Massachusetts region in general. Figure 1 illustrates the amount of geothermal resources within the U.S. region. From the visual, it can be seen that Massachusetts has a relatively low amount of geothermal resources available when compared to the rest of the country. For example, at a distance of three km below the earth’s surface, the temperature in Amherst is 86 °C whereas in Reno, NV the temperature is 156 °C [6]. Then, looking at the thermodynamic equation $Q = m*C*\Delta T$, where Q = heat, m = mass, C = specific heat, and ΔT = temperature difference – we can see that a larger temperature difference, ΔT, results in a greater amount of heat energy available from geothermal sources in

Nevada than Massachusetts. Due to this, it may be challenging to generate the required heat energy to distribute throughout the UMass campus.

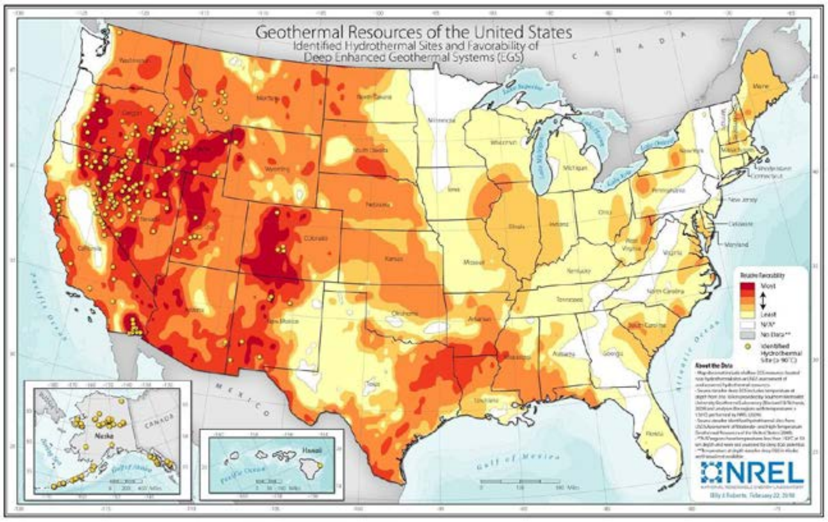

Figure 1. Geothermal resources are shown across the U.S. region, where darker and redder areas indicate higher amounts of geothermal resources [6]

An example of a geothermal energy system comes from BSU, a smaller university located in eastern Indiana. They constructed a geothermal energy system over a four-year period that now provides heat to their entire campus. With this new system, they eliminated the need for a coal-fired power plant on their campus that was the previous source of heat. All of this reduced the campus's carbon emissions by 30% in only 5 years [2]. Although the area that BSU is located has a similar amount of geothermal resource availability according to the map in Figure 1, the UMass campus is nearly twice the size of BSU, in terms of square footage, and would therefore require a larger plant to provide the necessary heat [2]. As seen in calculation 1 (Appendix, pg 18), the current size of the geothermal plant at BSU is about one million ft^2. Simply increasing the size of this plant in order to fit the demands for UMass is not a viable solution as UMass does not currently have many open areas larger than one million ft^2 [7].Creating additional space could lead to the deforestation of surrounding areas, which is not an ideal solution as this would require removing a large number of plants responsible for capturing carbon naturally. Therefore, a stand-alone geothermal energy system would not be the best solution for UMass Amherst, because it likely would not provide sufficient energy for such a large campus.

Finding a sufficient way to provide heat to the UMass Amherst campus in an environmentally friendly manner is a major problem when trying to reach carbon neutrality. The development of a stand-alone geothermal energy system provides a possible solution, but this approach suffers from the limitations described above. We still believe that BSU provides a critical example of how a geothermal energy system can be implemented and reduce a substantial amount of carbon emissions while providing a significant amount of heat for campus.

Driven by this belief, we have conducted research into a hybrid geothermal system that uses a solar field addition, providing more energy to heat UMass's ever-growing community.

4. Solution & Technology

As discussed in the geothermal energy problem statement, one of the most pressing issues in UMass Amherst's effort to reach carbon neutrality is how to properly provide heat to the entirety of campus in a "carbon-free" way. Looking into a stand-alone geothermal energy system in which water is heated or cooled, depending on the season, using the constant underground temperatures provides an attractive solution. However, with a campus as large as UMass and its plan to add several more buildings in the upcoming years [7], a stand-alone system will unlikely be able to produce enough heat energy for the entire campus, as discussed in the problem statement above. From this problem comes an even more attractive solution – the development of hybrid systems that uses energy from the sun as an additional source to improve the harvesting efficiency (energy/area) of a geothermal system. Such a hybrid system can use solar panels to further heat the working fluid to a higher temperature so that it reduces the need for deep wells and higher underground temperatures. The solar panels can either be thermal solar panels, which heat the water directly, or photovoltaic (PV) solar panels, which produce electricity that then can power a water heater and/or power any other electrical device that may be needed. The combined technology of geothermal and solar energy shows promising solutions to heating UMass' campus in a way that is clean and renewable.

As previously mentioned in the problem statement, the BSU geothermal system showed favorable heat energy production given the limited geothermal resources in Indiana. UMass Amherst could implement a similar system as the geothermal resources are also relatively scarce in Massachusetts (see Fig. 1). This comparison comes from the fact that Indiana and Massachusetts share the same average ground temperature 500 meters below the earth's surface of around 25-50 degrees Celsius [4]. The BSU system contains wells at a depth of about 150 meters that reach a constant ground temperature of 57 ^{o}F, as seen by the green line in Figure 2 [2]. From this figure, it can be seen that the system was successful in adding and removing thermal energy in the colder and warmer months, respectively. Based on calculation 2 (Appendix pg. 18), the BSU system can produce 335 billion BTU/year of heat [2]. However, UMass Amherst is about twice the size of the BSU campus, in terms of square footage, and requires 421 billion BTU/year of heat (see calculation 3, Appendix pg. 18) [4]. An obvious solution to accommodate for the difference in heat load requirements between UMass and BSU is to implement a larger geothermal system. This raises several questions about how geothermal systems scale in size with respect to energy output, cost, and land-use efficiency. Although these questions are important our team chose to focus on a more innovative solution to solve the size discrepancy. We decided to study the implementation of a solar-geothermal hybrid system to simultaneously capture energy from both the ground and the sun.

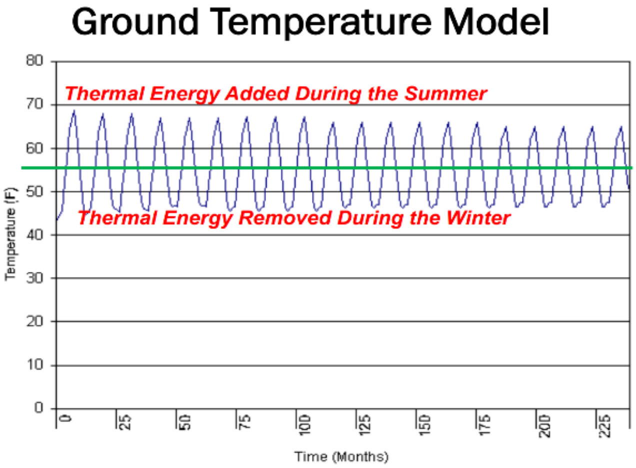

Figure 2. Provides the ground temperature model within Ball State University. [2]

An example of a solar-geothermal hybrid system can be found in Fallon, Nevada and it is known as the Stillwater Triple Hybrid Power Plant. Studying such examples provide best practices that give benchmark information on the efficiencies that can be obtained by combining renewable energy technologies. The plant recently underwent renovations that transformed a stand-alone geothermal energy system to a solar-geothermal hybrid system, where thermal solar panels are used to heat water to increase the efficiency of the plant, in terms of energy per footprint area. Figure 3 illustrates the design for the power plant, where water is used when circulating the wells (referencing the blue line) [8]. The heat from the water is then transferred to the working fluid, which in this case is impure isobutane. Due to its lower boiling point (10.8 °F at 760 mm Hg) and being known as an excellent refrigerant, the impure isobutane is easily converted to gas which spins turbines as it expands (referencing the green line in figure 2) [9, 10]. Demineralized water, a less corrosive fluid compared to distilled water, is used as the heat transfer fluid in the solar portion of the system (referencing the orange line). After the demineralized water goes through the solar field to be heated, it then goes through the solar heat exchanger to further heat the geothermal water that comes out of the ground. After heat transfer, the water is returned into the earth while the isobutane is cooled and condensed back into a liquid for another cycle. The study found that the solar field transfers 41.5 GWh/year to the water and then to the isobutane [8]. From this, it was found that the addition of the solar field raises the temperature of the working fluid (isobutane) by 5-10 ^{o}F. Based on calculation 4 (Appendix pg. 20), the actual calculated temperature difference is about 8 ^{o}F, but since this will fluctuate due to solar availability and slightly changing heat capacity, we assume the enhanced heating stays in the range of 5-10 ^{o}F. (The reason why the heat capacity will change is due to the fact that it is a function of both temperature and fluid density. Since fluid is being converted from liquid to gas with an increase in temperature, the heat capacity does not remain constant throughout the process). With this addition, the Stillwater plant increased electricity production from 160.7 GWh/year to 170.9 GWh/year, or by about 6% [8]. Although this plant is used to produce electricity and not heat, it still provides an example of the use of a hybrid system and how it increases the production of renewable energy. Thus, the hybrid system was successful in increasing the maximum temperature of the working fluid, which is our target for UMass.

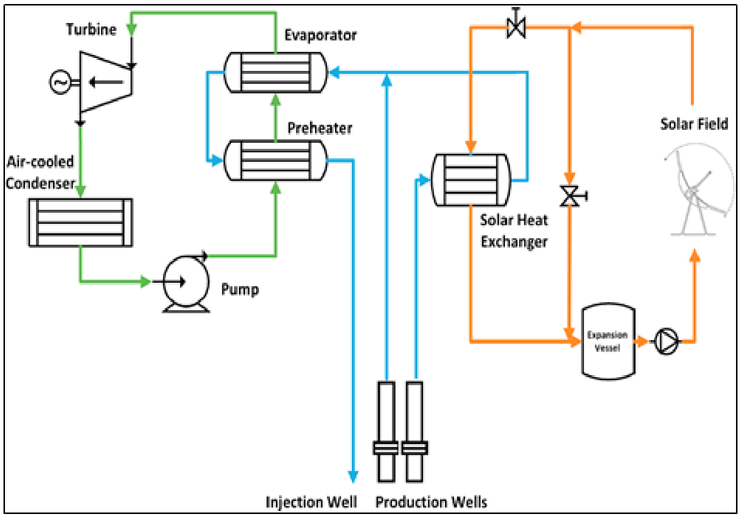

Figure 3. The diagram of the Stillwater power plant design that shows the addition of the solar fields [8]

When considering a solar-geothermal hybrid system, the selection of solar panels is critical. There are two main categories of solar energy: photovoltaic (PV) which is used to generate electrical energy, and thermal which is used to generate heat energy [11]. A PV solar panel consists of many photovoltaic cells, which are semiconductors usually made of silicon. These cells have a positive and negative side, and when the photons, or light particles, from the sun hit these cells, electrons are knocked off from one side and become free. The free electrons are then attracted to the other side of the cell which creates a potential, or voltage, and the flow of the free electrons generates a current which is used for electrical work [12]. PV panels have efficiencies in converting sunlight to electricity of 15% - 20% with some very expensive technologies approaching 50% in recent years [13]. However, these panels with higher efficiencies are still being researched and not available for commercial use. In contrast, solar thermal panels convert the infrared (IR) light from the sun into heat energy that is stored and transferred in a fluid, usually water. A series of reflectors, or mirrors, focuses the IR light into a receiver with the fluid circulating inside. The heat that is harvested can be used as heat energy directly, or used to produce electricity indirectly [14]. Thermal panels have efficiencies ranging from 70% - 90% in converting infrared light from the sun to heat energy [11, 13, 15]. The average PV solar panel is 5.4 x 3.25 ft^2 which produces 320 W, yielding an energy density of 196 W/m^2, whereas thermal panels have an energy density of 114 W/m^2 (see calculation 5, Appendix pg. 20) [16, 17]. As the price of PV solar panels is \$1.00 – \$1.50 per Watt in Massachusetts, this results in a cost of about \$196 – \$294 per m^2 [17, 18]. In 2008, the cost of thermal solar panels was 20% of PV panels per meter squared, meaning that during this time the cost of a solar thermal installation would be 20% that of a similarly sized solar PV installation [11]. However, the cost of PV solar panels has been decreasing over time, and since electricity is a more versatile form of energy than is heat, a solar PV–geothermal hybrid system would be more beneficial to UMass [14].

With a stand-alone geothermal system being able to increase water temperature by about 50 degrees Fahrenheit, the addition of solar fields providing an extra 5-10 degrees Fahrenheit, and the steady decline in the price of PV solar panels, a solar-geothermal hybrid system provides a reasonable solution to the problem of providing heat to the UMass campus. The next step is to design an implementation plan for a hybrid system at UMass Amherst.

5. Implementation Plan at UMass Amherst

As discussed in previous sections, in regards to UMass Amherst's massive heating problem, utilizing new technologies in geothermal energy provides the most promising solutions. It was found that the development of a stand-alone system, similar to the size of BSU, that uses geothermal energy alone to provide heat would be ineffective for the area and therefore needs to be expanded upon to construct a feasible solution. From this comes the conclusion that UMass Amherst should develop a solar-geothermal hybrid system that will provide a significant amount of heat throughout the winters and even provide air conditioning during the warmer months. It was decided that the system should utilize photovoltaic (PV) solar panels as they are cheaper and the use of electricity is more versatile than heat energy. The last question then becomes, how can an idea like this actually be put into action? UMass Amherst can use researched examples of similar systems as a blueprint for the cost, size, and energy production, and compare it to the needs of their campus. All of this can be used to develop a plan for a hybrid system on the campus that helps sustain the heat needs of UMass year-round in a "carbon-free" way.

One potential idea for the implementation of a hybrid system at UMass is to avoid building a whole new plant, but instead, to modify the Central Heating Plant (CHP) in a way that uses these ideas to reduce the amount of fossil fuels it needs to burn. As discussed in the Solution & Technology Section, the CHP currently provides all the heat required for campus; however, the CHP produces about 185 million pounds of carbon emissions per year, due to the fact that it burns fossil fuels [4]. The CHP was just built in 2009 and it's not ideal to get rid of a newly developed, $133 million plant [3]. Therefore, there is a possibility of modifying the current system with a solar-geothermal addition to reduce the use of fossil fuels. The potential plan would be to add geothermal wells below, or near, the CHP which would be used to further heat the water. Then, PV solar panels could be added on the roof of the CHP to provide electricity for the pumps and possibly a heater. However, it would require more work to modify such a big plant and still have it not be carbon neutral than to scrap the plant and start over with a new system. In addition, all the data needed – plant blueprints and operational specification data – to assess this plan are not currently available to our team. Due to this, a possibly better idea for UMass is to build an entirely new solar-geothermal system that eliminates any need to retrofit the CHP.

A stand-alone hybrid system, separate from the CHP, would allow UMass to significantly reduce its emissions while continuing to produce large amounts of energy. Currently, UMass produces about 1.073 trillion BTU of heat energy per year, which is carried to campus in the form of steam [4]. A hybrid system would produce hot and cold water through the use of a PV solar geothermal hybrid system, reducing the need for mass amounts of steam and ultimately lowering the campus's heat load to 421 billion BTU/yr. The 25 plus miles of steam pipes underneath UMass could most likely be converted into hot water pipes, as shown by previous examples [19]. The geothermal portion of this hybrid system should use the BSU's geothermal system as a blueprint. As stated in the problem statement, the size of BSU's geothermal system is roughly one million square feet, and this system produces 335 billion BTU/year, providing sufficient energy to heat their entire campus. The system eliminated the need for a coal-fired power plant on their campus [2]. UMass could implement a similar system that could produce the same amount of energy. Therefore, with UMass hydronic heat load being 421 billion BTU/yr, the geothermal portion would account for about 80% of the heat energy needed per year. As discussed below, the implementation of a solar field addition will be used to make up for a large portion of the unaccounted heat load.

We recommend placing a solar PV field directly over the geothermal system, fulfilling the hybrid aspect of our idea. A solar field with the same square footage of the BSU geothermal system would produce about 14 MW (47.8 million BTU/hr) of power at a cost ranging from $14.4 – $21.5 million (see calculation 6, Appendix pg. 21) [17]. As seen in calculation 7 (Appendix pg. 22), the electricity that the PV solar panels generate will be used to power the water pumps, which require about 8 MW of power [20]. That will leave about 6 MW that can be used to help heat the water. Due to the fact that the sun is not always available for electricity generation, it was estimated that the solar field will produce a total of 140 billion BTU/yr (see calculation 6, Appendix pg. 21). Of this total, 80 billion BTU will be used to power the pumps and 60 billion BTU will be used to generate thermal energy to heat the water. This additional heat energy available will increase the percent of UMass' heat load that this system can produce to 93%. For the warmer months of the year in which heat is not as much of a necessity, the electricity generated that is set aside for heat can potentially be used to power a unit to help cool water or even be used throughout campus for everyday life. This is why using PV panels instead of thermal panels proves beneficial, as the versatility of electricity can serve many different purposes throughout the year.

When looking at the logistics of constructing an actual system, it is important to understand how much it will cost and how much carbon will be mitigated for every dollar spent. Assuming similar geothermal cost as BSU ($83 million), then adding the maximum size 14 MW solar field, would result in a final cost of around $100 million [2]. Although this seems like a high price, as seen in calculation 8 (Appendix pg. 22), the cost of carbon mitigated is $38 per metric ton of CO2. This carbon mitigation cost was calculated assuming that the new system would last for 30 years. It was also estimated that the yearly operational costs would be about

$.98 million per year but that UMass would potentially save around $2 million every year based on how much BSU was able to save [2].

The implementation of this hybrid system was considered in three possible locations, as shown in Figure 4. At first, the area northwest of campus, labeled A in the figure, seemed to be the most ideal spot, as it would not affect campus life. However, after further research, it was found that this area is a protected wetland and therefore cannot be used for this system [21, 22]. The next best option, and the one we are proposing, is the recreational fields, labeled as B in the figure, due to the proximity to the CHP. These fields could be moved to the area behind McGuirk Stadium, shown by the white box in the figure, so that campus life and recreation could still occur. The other viable, but unlikely, option is purchasing Hadley farmland across route 116. It is unlikely because this would force families out of their homes causing a big uproar in the town. With all of the options at hand, we are proposing that the hybrid system replaces the recreational fields, as the fields themselves can be moved to a new location with little repercussions, unlike wetlands and families.

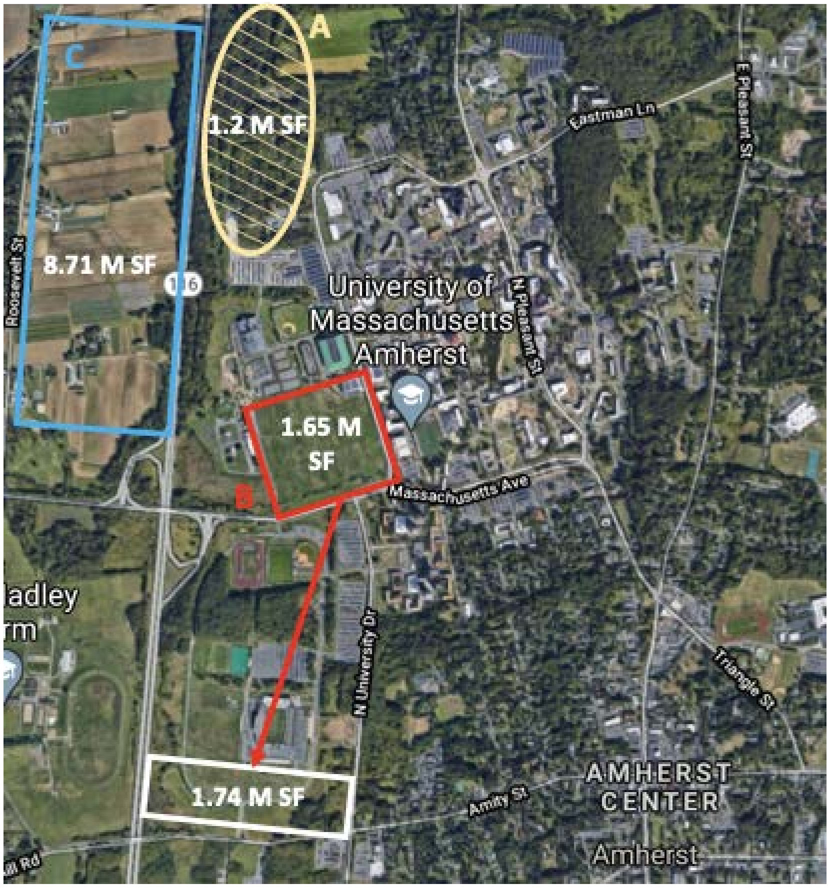

Figure 4. Possible locations of solar-geothermal hybrid system at UMass Amherst. **A.** Wetland northwest of campus (unviable), **B.** Recreation fields (most viable) where the arrow demonstrates a possible relocation for the fields, **C.** Hadley Farmland (unlikely).

In terms of our goal to reach net-zero carbon emissions, a geothermal system has the potential of leading us to a path in which the university could overcome the challenge presented before us. However, due to the challenges of an ever-expanding campus, and constraints in both the environment and available space, it is evident that a standalone geothermal system is not enough. To solve this a solar-geothermal system could be implemented onto our campus. Modifying the CHP to fit these accommodations may prove to be a difficult task due to the fact that we do not currently possess the information to approach this scenario, and the logistics of modifying such a plant may prove to be difficult. As a result, from our research on the model incorporated at BSU, building a hybrid system, which incorporates solar PV and geothermal energy, separate from the CHP may be a better alternative. This new implementation would cover 93% of the heating demands of the university, provide aid to cooling buildings during the warmer months, and mitigate carbon emissions that will ultimately help UMass reach their 2030 carbon neutrality goal.

6. Project Pros and Cons

When looking at the implementation of any new structure on campus whether it be a new energy source infrastructure, housing towers, or even just an academic building, it is important to understand the pros and cons of its development. In this case, the construction of a solar-geothermal hybrid energy system on the UMass Amherst campus will have to be analyzed to determine if the pros heavily outweigh the cons and that its implementation is logical. This analysis can be done based on four categories: environmental effects, energy magnitude, economical considerations, and social equity. In each of these categories we present information on both sides of the spectrum and overall give a strong argument for whether or not to proceed with this project. Based on the research that will be discussed, it can be concluded that an implementation of a solar-geothermal hybrid system is logical at UMass Amherst as the pros massively outweigh the cons.

Environmental Pros & Cons

One of the main reasons for attempting to reduce carbon emissions is that carbon dioxide has substantial negative effects on the environment, such as air pollution, that effectively lead to climate change. [23]. In the year of 2019 the central heating plant produced 70% of all the energy used at UMass [1]. The steam plant also provides 100% of the steam that is needed for heating and cooling buildings across campus [24]. However, as mentioned in the Problem Statement, producing 1.405 trillion BTU/yr of energy releases about 185 million lbs (85,000 Metric Tons) of carbon dioxide into the atmosphere per year [4, 25]. Studies have shown that a geothermal energy system has the potential to lower this amount substantially. According to the Idaho National Engineering and Environmental Laboratory, geothermal power plants produce 60 pounds of carbon dioxide per MWh [26]. This means that a 1 kWh geothermal system produces 0.06 lbs of carbon dioxide [26]. Based on this calculation, a geothermal system that produces the same amount of energy as the CHP would only produce around 6 million lbs of carbon emissions [26]. However, the proposed geothermal system at UMass would produce a smaller amount of heat energy than the CHP which will lower that number even further. In fact, as seen in calculation 7, it is estimated that the new hybrid system can reduce carbon emissions from the CHP by 72%. Furthermore, in a closed loop system, gases removed from wells are injected back into the earth, so there are almost no gas emissions into the atmosphere [27]. Another key fact to notice is that geothermal plants produce no solid waste. At most some geothermal fluids require solid byproducts to be handled. However, these byproducts can often contain valuable minerals that can be recovered and recycled for other uses [28]. Given these environmental factors, implementing a geothermal-hybrid system would provide some positive effects to the UMass community as a whole.

As we know the CHP already has over 25 miles of pipes running through campus which provide the heating and cooling demands for residential areas and various buildings. Instead of building a whole new system and replacing all the pipes, there may be a way to maintain the current pipe infrastructure at UMass by just using the CHP steam pipes for hot water [19]. This would save us a large amount of resources, space, and environmental damage caused by construction throughout all of campus. However, this approach would increase construction time as once the geothermal system is constructed, it would require a phased approach to connect every building to the new system. This means that both the CHP and the hybrid system would be needed to continue to run until the phased approach was complete. Whether it is more effective to just construct a new piping system or try to salvage the existing one is currently unknown to our team and it would have to be investigated further in the future.

The actual plant development gives rise to one drawback of this system, which is that the construction of the main plant requires a large quantity of space. After observing a map of UMass, the northwest side area of campus that is mostly covered by trees and grass, can be potentially used to build this plant. We must take into account that building such a massive system in this space can cause damage to the ecosystems that surround the area. It could also bring harmful effects to the wildlife that inhabit those areas as well. This is why we have decided that a better area for implementation is the large UMass recreational fields. Another con is that, although the gases that are not released into the atmosphere, the gases returned to the earth include sulfur dioxide and silica [28]. Research has shown that large amounts of carbon dioxide causes injury to plants when it is absorbed faster than they are detoxified [29]. In addition we must consider that the system requires large amounts of water, and this water will have to be taken from somewhere and can have negative effects depending on where it is acquired. However, these negative environmental facts are overshadowed by the reduction in carbon emissions that this system can create.

Energy Pros & Cons

From the energy point of view, the implementation of the solar-geothermal hybrid energy system will need to produce a substantial amount of heat energy to provide the majority of the heat load on campus. As stated in previous sections, the CHP generates a total annual steam amount of 1.2 billion pounds. From this steam, the amount of heat energy provided per year is 1.073 trillion BTU [4]. Instead of a steam-based system, the solar-geothermal hybrid will utilize hot water to heat up UMass Amherst. Hot-water systems have been shown to be more effective as variables such as water temperature and flow can be easily controlled. Steam-heated buildings also have an issue with uneven heating as maintenance staff has to overheat buildings to provide adequate heat to others [30]. Based on calculation 3 (Appendix pg. 18), it was shown that the geothermal-hybrid system which incorporates hot-water systems would save around 631 billion BTU/yr. Thus, a hot-water system can eliminate problems with maintenance and uneven heating and reduce the needed heat load of UMass to about 421 billion BTU/yr.

Although the solar-geothermal hybrid energy system yields many benefits, one drawback is that the hybrid system will not produce a substantial amount of electricity that can be used for everyday campus life. Compared to the CHP, which produces 335 billion BTU of electricity for campus use, the hybrid system will be able to produce a total amount of electricity of 140 billion BTU/yr (from the 14 MW solar field) [1]. Although this is still a decent amount of electricity, most of that is used daily to power the pumps and provide extra water heating and cooling. In fact, it is estimated that about 80 billion BTU/yr of that electricity will be used to power the pumps and then most of the rest will be used for other heating and cooling needs, leaving only a small amount for campus use (see calculation 6, Appendix pg_). This is one of the problems with attempting to eliminate the need for the CHP, as electrical energy will need to be either purchased from an outside source or produced through some other method elsewhere on campus.

Economics Pros & Cons

As calculated in the implementation section, it was estimated that the total cost of a solar/geothermal hybrid system will be about $100 million. This number represents the upfront cost of the plant and does not account for yearly maintenance. It is estimated that the operating costs of a geothermal plant is $.01 per kWh and since it’s estimated that the geothermal portion of this plant will produce 98 million kWh/yr (335 billion BTU/yr) , that yields an estimated operating cost of about $980,000 per year [4, 31]. However, it is important to analyze the dollar amount for every metric ton of CO2 emissions this system will reduce. To do this, we have to assume that the system will be good for 30 years. This means that the upfront cost will be spread out over this 30 year period and yearly operations will sum to $30 million over 30 years, giving a total price of $130 million for the whole 30 year period. From calculation 8 (Appendix pg. 22), it is estimated that this new system will mitigate about 61,000 metric tons of CO2 produced by the CHP every year. Using these numbers we get that the carbon mitigation cost of this system is about $70 per metric ton of CO2. This may seem a little high, however, if we take into account that BSU saved about $2 million dollars annually, and UMass might save a similar amount due to energy savings, that reduces that 30 year cost by $60 million [2]. Now we see a 30 cost of only $100 million which reduces the carbon mitigation cost to around $38 per metric ton of CO2. This number is very promising as the Department of Energy (DOE) has set an expectation value for new renewable energy systems to have a carbon mitigation cost of $40 per metric ton of CO2 which is very close to our estimated value for this system [32]. The only problem with spending all of this money is that the CHP was just developed in 2009 and cost $133 million to construct [3]. Due to this, it is not economically sound to eliminate such an expensive plant that still has a long life left. However, with the amount of carbon emissions this hybrid system will mitigate, it is worth it to spend the money on this new system in order to reach the 2030 carbon neutrality goal.

Social Equity Pros & Cons

Implementing a large solar geothermal hybrid system near the UMass campus raises the concern of social equity. Through the construction period and lifetime of this facility, it should not disrupt campus life, UMass master plan for buildings, and social policy of the surrounding towns. In an ideal world, a facility this large would not disrupt any of the previously listed items. However, there will be people that do not agree with this facility and/or zoning legislature that poses roadblocks. Like every situation, the pros must outweigh the cons. This facility would reduce the amount of carbon emissions from the CHP by 72%, as stated above, aiding not only the UMass 2030 carbon-zero goal, but also the Massachusetts 2050 80% carbon reduction goal (as UMass is the lead emitter in the state).

The proposed land, current recreational fields, is adjacent to the CHP and is large enough to support a BSU sized geothermal system as previously mentioned in the implementation section. However, this poses the issue of disrupting campus life. As seen in figure 4 of the implementation section, the recreational fields could be moved behind McGuirk stadium and what is now known as “the bubble”. This new space is larger than the current recreational fields, and the number of potential fields that could be built in this new area depends on the geometrical size and orientation of each respective field. Construction of these new fields must occur before construction of the hybrid system to ensure that campus life is not disrupted. Although these new fields would be farther away from campus, in order to reach the 2030 goal, numerous sacrifices will have to be made. With the approval of this hybrid system, this facility would provide numerous construction jobs on campus. As UMass moves more towards clean renewable energy, the CHP would slowly be relieved of being the main provider of campus energy, resulting in a significant decrease in carbon emissions.

From all the data and research that has been presented, it can be concluded that a solar-geothermal hybrid system is logical to implement on the UMass Amherst campus. The pros heavily outweigh the cons as the system has the proper energy magnitude, is environmentally friendly, matches the DOE’s carbon mitigation cost, and is socially acceptable. The system has the potential to be a major contributor to UMass carbon mitigation as they fight towards net-zero carbon emissions by 2030.

7. Conclusion

In conclusion, our team has conducted an investigation into the possible benefits of implementing a hybrid geothermal-solar PV plant at UMass. The evidence strongly indicates that developing such a geothermal/solar hybrid energy system on the UMass campus is the next step that UMass should take in order to accelerate towards the 2030 carbon neutrality goal. As UMass moves forward with their carbon mitigation plans, there is no question that a main problem that needs solving is the mass amounts of carbon emissions that come from the CHP every year to heat the UMass campus. Geothermal energy systems, such as BSU, have proven to be beneficial in providing sufficient heat to entire campuses while reducing both carbon emissions and heat load. Then, with the addition of a solar field, like at the Stillwater power plant, these systems can have increased energy production that makes them not only more efficient, but also self-sustainable. A facility at UMass that incorporates a geothermal system replicated after the one at BSU with the addition of a 14 MW solar field is heavily favorable as it is estimated from our calculations that the system has the potential to reduce the carbon emissions from the CHP by 72%. Although the estimated upfront cost of the system ($100 million) is high, as discussed above, the cost of carbon mitigation is around $38 per metric ton and CO2 mitigated. With this being lower than the DOE's recommended carbon mitigation cost of $40 per metric ton of CO2 mitigated, it proves that spending this money is worth the major reduction in carbon emissions. Although there are some cons, the fact that this system will provide 93% of UMass' required heat load, add additional cooling energy during warmer months, requiring minimal outside electricity to run and potentially give some generated electricity back to campus continues to overshadow these negatives. An implementation of a solar-geothermal hybrid system at UMass proves to be both feasible and logical. This new renewable energy technology will prove to be revolutionary in UMass's fight against climate change, setting an inspirational standard for other universities across the globe.

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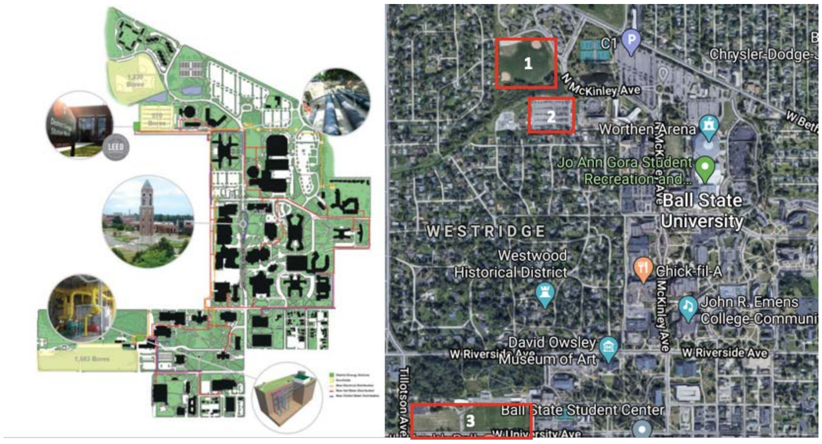
Appendix

Calculations

1. BSU geothermal system size



Referencing the image on the left from the BSU Geothermal Powerpoint slides, we found the location on Google Maps and were able to calculate the following areas [2]:

1. 312500 SF
2. 203500 SF
3. 417142 SF

Total area of BSU Geothermal = **933142 SF, or about 1 Million SF**

2. BSU heat generated

BSU steam used per year (coal plant) = 700 million lbs/year [2]

BSU coal plant heat energy generated = 700,000,000 lbs/year * 1194 BTU/lbs = 835 billion BTU/year

Energy Reduction of BSU = 500 billion BTU/year [2]

BSU geothermal heat energy generated = 835 billion - 500 billion = **335 billion BTU/year**

3. Energy Saved with moving from steam to hydronic heating.

To calculate saved energy with a geothermal system:

Using equation $Q = m*C*\Delta T$

To get m, looking at CHP data:

$m\_CHP = (898{,}910{,}280 \text{ lbs/yr}) * (0.45 \text{ Kg/lbs}) * (1 \text{ yr}/3.15*10^{7} \text{ s}) = 13.37 \text{ Kg/s}$ [3]

C_liq = heat capacity of water = 4,174 J/(Kg*K) [assuming constant]

C_st = heat capacity of steam = 2.01 J/(g*K) [assuming constant]

Heat of vaporization of water = Q_vap = 2,258 J/g

Assuming inlet temp of water for both systems = 68 F = 293.15 K

Assuming outlet temp of CHP (steam) = 250 F = 394.261

Assuming outlet temp of geothermal (water) = 150 F = 338.706 K

Energy for CHP

_______Q (CHP) = Q_liq + Q_vap + Q_st

Q_liq = (13.37 Kg/s)*(4,174 J/Kg*K)*(373 K - 293.15 K) = 4,456,139 W = 133 billion BTU/yr

Q_vap = (13370 g/s)*(2,258 J/g) = 30,189,460 W = 902 billion BTU/yr

Q_st = (13370 g/s)*(2.01 J/g*K)*(394.261-373) = 571,361 W = 17 billion BTU/yr

Q (CHP) = 133 billion + 902 billion + 17 billion = **1.052 trillion BTU/yr**

Energy for geothermal

To find the heat required to heat hot water, we need a new flow rate. To get this we will first find the increase in flow rate at BSU when switching from steam to hot water and then compare that increase to what would be needed at UMass.

BSU steam heat load = Q = 835 billion BTU/yr (from calculation 2)

To find flow rate, we need to consider the three different phases of heating water like with the CHP

Q = 835 billion BTU/yr = 28 million W = Q_liq + Q_vap + Q_st

Q = m*(4.174 J/g*K)*(79.85 K) + m*(2,258 J/g) + m*(2.01 J/g*K)*(21.261 K)

Now can solve for m to get :

m_st = 10.63 Kg / s

Now we need to solve for mass flow rate for the geothermal system at BSU which is an easier calculation

Q = 335 billion BTU/yr = 11.2 million W = m*(4,174 J/Kg*K)*(338.706 K - 293.15 K)

m_liq = 58.9 Kg/s

Now we can find a ratio of mass flow rates

Ratio = 58.9/10.63 = **5.541**

Now using this ratio we can calculate the flowrate needed at UMass for hot water m_liq = m_CHP * ratio = (13.37 Kg/s) * 5.541

m_liq = 74.1 Kg/s

Now we can solve for the heat required for hot water

Q = (74.1 Kg/s)*(4,174 J/Kg*K)*(338.706 K - 293.15 K)

Q = 14,090,170 W = **421 billion BTU/yr**

Energy saved = 1.052 trillion BTU/yr - 421 billion BTU/yr

Energy saved = 631 billion BTU/yr

4. Stillwater temperature increase of isobutane

Additional energy able to be produced = 41.5 GWh/yr = 4734301.428 J/s [8]

Using equation $Q = m*C*\Delta T$

m = (586 kg/s) * (1000 g/kg) * (1 mol/51.82 g) = 11308 mol/s [8]

C = 95.21 J/(mol*K)

$\Delta T = Q/(m*C) = 4.40$ K

A difference in 4.40 K will result in a difference in Fahrenheit of 7.92 F

Increase in temperature = **7.92 degrees F**

5. PV vs. Solar Thermal Panels

______

______**Energy Densities**

PV panel size = 5.4 * 3.29 ft^2 = 17.55 ft^2 [17]

PV panel energy (for size above) = 320 W [17]

PV energy density = 320 W / 17.55 ft^2 = 18.23 W/ft^2 = **196.27 W/m^2**

Thermal Energy Density = 250 – 2500 ($kW\text{-}hr/m^2/year$) [16],

where equator and deserts/open spaces have an upper range of this value.

Assume 1000 ($kW\text{-}hr/m^2/year$) for Amherst, MA

Thermal Energy Density =

1000 ($kW\text{-}hr/m^2/year$) * 1 (year) / 365 (days) * 1 (day) / 24 (hours) = **114.16 W/m^2**

Cost

PV = $1.00 – $1.50 per Watt [18]

PV Cost/m^2 = \$1.00/Watt * 196.27 W/m^2 – \$1.50/Watt * 196.27 W/m^2

PV Cost/m^2 = **\$196.27 – \$294.40 per m^2**

6. Solar Field Cost & Energy Generation

Total area of BSU Geothermal = **933142 SF, or about 1 Million SF**

Dense Solar Field Power = 933142 (SF) / 65 (SF/KW) = 14356.03077 KW = **14.36 MW**
Non-Dense Solar Field Power = 933142 (SF) / 100 (SF/KW) = 9331.42 KW = **9.33 MW**

Cost Dense (optimal for maximum energy generation):
1 (\$/W) * 14.36 (MW) * 1E6 (W/MW) = **\$14,356,030.77**
1.5 (\$/W) * 14.36 (MW) * 1E6 (W/MW) = **\$21,534046.16**

\$14,356,030.77 – \$21,534046.16

Cost Non-Dense:
1 (\$/W) * 9.33 (MW) * 1E6 (W/MW) = **\$9,331,420**
1.5 (\$/W) * 9.33 (MW) * 1E6 (W/MW) = **\$13,997,130**

\$9,331,420 – \$13,997,130

Energy Generation:

Assume the system will run at 14 MW for 12 hours a day (daytime) on ⅔ of the days in the year. When the system is running, 8 MW will be used for the pumps while 6 MW will be used for heating. So, during the times when the field is not producing (night time, rainy/snowy days), electricity will need to be brought in from an outside source.

I. Electricity produced for pumps per year

7.972 MW = 27,201,599 BTU/hr (see calculation 7)

27,201,599 BTU/hr * 12 hrs/day * ⅔ * 365 days/year = **79.4 billion BTU/yr**

II. Heat produced per year

6.028 MW = 20,568,394 BTU/hr (see calculation 7)

20,472,852 BTU/hr * 12 hrs/day * ⅔ * 365 days/year = **60 billion BTU/yr**

III. Total Energy

Total Energy = 79.4 + 60 = **139.4 billion BTU/yr**

7. Electricity needed for pumps/chillers

Chiller: Carrier United Technologies – 19XR-B6GC65720RU7 [20]

Cooling capacity: 8792 kW (2500 Ton), Input power: 1402 kW = 1.402 MW [20]

Input power for 1000 ton = 591 KW [20]

Pumps that will be needed [2]

- (4) 2,500-ton heat recovery chillers 1402 KW = 1.402 MW*4 = 5.608 MW
- (4) 1,000-ton cooling towers = 591 KW = .591 MW*4 = 2.364 MW

Electricity needed = 5.608 MW + 2.364 MW = **7.972 MW = 27.2 million BTU/hr**

Electricity leftover = 14 - 7.972 = **6.028 MW = 20.5 million BTU/hr**

8. Total CO2 mitigated

Carbon generated from heat energy from the CHP
Source: [4]
Heat energy from CHP = 1.073 trillion BTU/yr
Total energy from CHP = 1.405 trillion BTU/yr
Percent of energy that comes from CHP that is heat = 76.4%
CO2 emitted per year by CHP = 120,000 metric tons * 70% = 85,000
CO2 emitted from production of heat energy = 85,000 * .764 = **65,940 metric tons**

Heat produced from geothermal system = 335 billion BTU/yr [2]
Heat produced from solar field = 60 billion BTU/yr (from above)
Total heat produced by system = **395 billion BTU/yr**

UMass hydronic heat load = 421 billion BTU/yr (from above)
% heat load that system can supply = (395 billion/421 billion) * 100 = **93%**

Total CO2 mitigated = 65,940*.93 **= 61,324 metric tons per year**

Percent mitigated from the CHP from heat = 93%

Percent mitigated from CHP = (61,324/85,000)*100 **= 72%**

Cost of carbon mitigation

______**Maintenance cost**

General cost = $.01 per KWh

Energy generated from geothermal = 335 billion BTU/yr = 98 million KWh/yr

Yearly operation cost = **$ .98 million**

Without annual savings

Cost of carbon mitigated = (total cost over 30 yr)/(total CO2 mitigated over 30 yr)

$/CO2 = (($100 million)+($0.98 million*30))/(61,324 metric tons*30)

Cost of carbon mitigated = **$70.3 per metric ton of CO2**

With annual savings

Cost of carbon mitigated = (total cost over 30 yr)/(total CO2 mitigated over 30 yr)

$/CO2 = ($100 million+30*($0.98 million)-30*($2 million))/(61,324 metric tons*30)

Cost of carbon mitigated = **$37.7 per metric ton of CO2**