Potential for Geothermal Energy at Boston College

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Abstract

This paper provides a synthesis of research on geothermal energy and provides the introductory research necessary for its possible implementation on Boston College's main campus. Heating and cooling building spaces contributes to considerable greenhouse gas emissions throughout the state of Massachusetts, and colleges have a unique ability to combat the emissions of their students and staff by choosing to infuse its energy portfolio with renewable sources. Included is an introduction to Boston College's current heating source as well as geothermal heating and cooling systems (or "geothermal HVACs," "ground-source heat pumps," and "GHPs"). Geothermal energy in the Northeast United States is explored through extensive literature review and case studies of other college campuses in the Boston area as well as from personal accounts from industry professionals.

The study finds that geothermal is in fact a viable in the Boston area and for various reasons an attractive endeavor undertaken by many other institutions which have reported favorable benefits. There are a number of factors that make the environment in Massachusetts able to harness geothermal energy and topographic conditions at Boston College that make it efficient to drill for ground-source heat. This paper also posits that there is a lot to gain from geothermal energy particularly as a college campus and that, as a Jesuit institution, implementing ground-source heat pumps aligns with Boston College's stated mission. This paper concludes with a call to action for the administrators to reconsider implementing geothermal as a heating and cooling source as well as several financial recommendations as to how to proceed with such an endeavor.

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Introduction

Space and water heating contributes to 27% of Massachusetts's greenhouse gas emissions (MassCEC). Boston College relies upon both oil and natural gas to heat and cool its campus's buildings. This project reviews the literature regarding the feasibility of implementing a geothermal heating and cooling system in Massachusetts to determine feasibility on Boston College's campus. I aimed to address the following research questions:

1. What are the advantages and challenges of geothermal systems in comparison with conventional HVAC systems?
2. Can geothermal energy be used in Massachusetts?
3. Should geothermal energy be used on a college campus?
4. Is Boston College well-suited for geothermal heating and cooling?

Although this is not a financial analysis, BC's adherence to a five-year payback policy is recognized, and potential financial incentives, recommendations for a future financial analysis, and funding structures are also included. "Turning the tide on global warming may be the most far-reaching challenge of our time, but it also is an extraordinary opportunity to create more efficient, resilient and sustainable colleges and universities—and to inspire students to make a commitment to climate action in their lives and careers" (Cross, Eagan, & Tolmé, 2011, p 7).

Background on Energy and Topography at Boston College

At Boston College, the Central Heating Plant (Figure 1) provides 3 million square feet of steam to 22 buildings on campus using oil and natural gas by operating three high-pressure steam boilers. The Boiler Room Foreman maintains the operation of the plant, supervising five operators working three shifts, 24 hours per day, 365 days per year. The dual-fuel capacity allows for flexibility of mechanical operations and better internal fuel cost management in the competitive fuel supply market (Boston College). As a school, the university consumes about 80,000,000 kWh per year and spend approximately $12.5 Million for electricity (personal communication, John MacDonald).

Figure 1: BC's Central Heating Plant houses one boiler field-erected in 1967 rated to produce 35,000 pounds of steam per hour and two boilers from 1979 rated to produce 50,000 pounds of steam per hour.

How Geothermal Systems Work

The ground temperature below the ground's frost line is relatively constant throughout the United States regardless of the season. In Boston, the average annual ground temperature a mere six feet below the surface remains a consistent 50°-55° Fahrenheit: cooler than the summer air and warmer than the winter air. Deeper into the ground, high grade geothermal can be accessed relatively consistently throughout the entire country (Figures 2 and 3). The subsurface of the earth is a heat sink in the summer and a heat source in the winter; this energy comes in large part from the sun as well as the center of the earth. A geothermal heat pump transfers heat from one location to another using a solution that circulates through loops of pipe in the ground and absorbs the Earth's heat which is then brought to the surface and transferred to a heat pump. The heat pump then warms or cools the air through ducts. The length of pipe needed is a function of system size, climate, soil/rock thermal characteristics and loop type. Geothermal HVAC are complex mechanisms that incorporate design aspects to complement the specifications of an area's topography, lithology, and soil conductivity among other variables (See Appendix A). Certain geothermal HVAC variations that may prove to be more advantageous depending on the area's conditions.

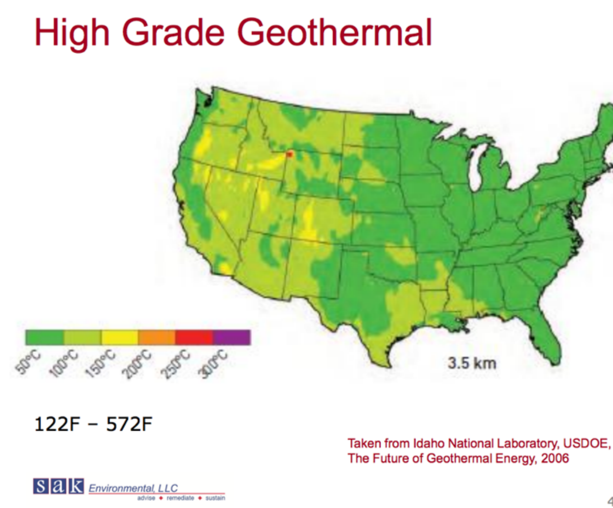

Figure 2: Heat map at 3.5 km depth throughout the United States

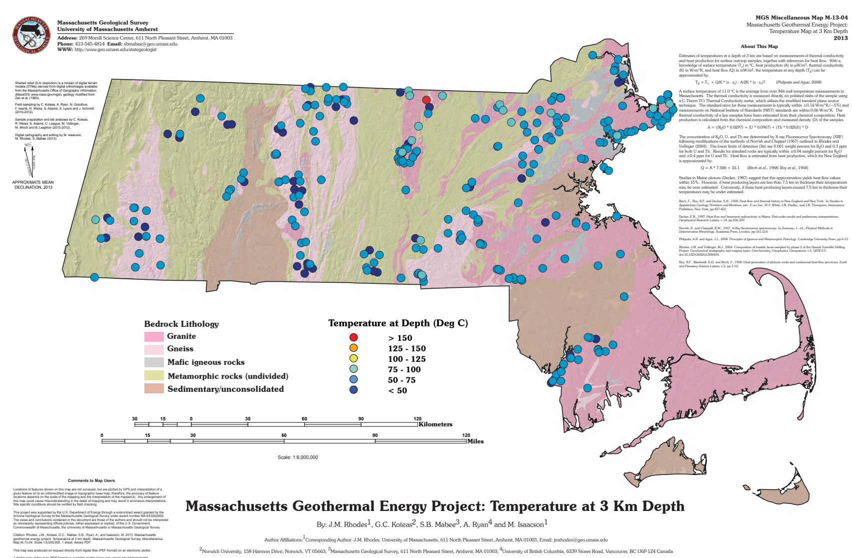

Figure 3: Temperature of various locations in Massachusetts at 3 km depth demonstrates consistency throughout the state

Closed-loop Systems

In a closed-loop system, the same solution is recirculated within sealed pipes or tubes. Where space allows, the loop piping can be buried horizontally in trenches ranging from 3 to 8 feet deep and 100 to 400 feet long; these horizontal systems are commonly placed under parking lots. Where space is limited, the sealed loop piping can be inserted in small holes ranging from 100 to thousands of feet deep that are installed using a drilling rig. This vertical placement is commonly a more expensive approach because of the excavation expense (Figure 4). The number of holes and depth varies depending on many factors including soil and rock condition.

Closed loops that can additionally integrate nearby water sources like ponds and aquifers are very economical because water is more conductive than soil (Lloyd 2011, p 53). The primary advantage is that underground issues are simplified by the fact that the system does not directly interface with the underground environment in any significant way. The primary disadvantage of this approach is that it offers the least amount of thermal exchange per given length of well bore as compared to other geothermal systems (Haley & Aldrich, 2008).

Open-loop Systems

Water is not recirculated in an open-loop system, but pumped back into the source. Like a that of a closed-loop, an open-loop system can be horizontally or vertically oriented, but it must be used where groundwater is of adequate quantity and quality. Freshwater is continuously pumped through the heat pump where heat is extracted or expelled with the water discarded to a secondary well or pond (Figure 4). Open-loop geothermal systems can be the least expensive method in many circumstances; they are the simplest to install and use ground water from an aquifer or pond which is piped directly into the building’s pressure tank and then to the heat pump. Once water is cycled through the geothermal system, it is returned to the aquifer by discharging it through a properly sized drain field, a pond, river, lake or well. A water filter is required to keep out contaminants and must be cleaned regularly (Lloyd 2011, p 51). The clear majority of US installations are closed-loop and employ a high-density polyethylene pipe buried in the earth circulating water with propylene glycol antifreeze additive. Open-loop is less expensive to install but viability is dependent on geology, aquifer yield and a suitable location to dump groundwater (Tucker, 2009, p. 19).

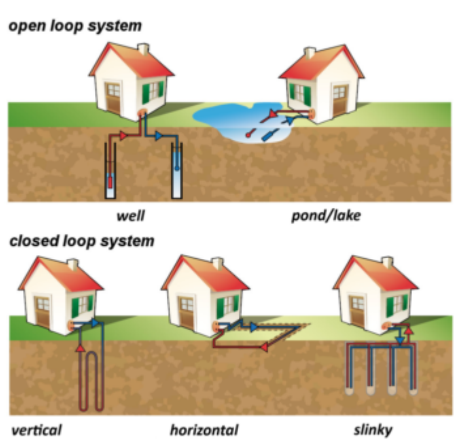

Figure 4: Different orientations of geothermal wells (Ingram's Water and Air Equipment)

Geothermal Energy in the US

Geothermal heat pumps can be used just about anywhere in the US because all areas have nearly constant shallow ground temperatures, although systems in different locations will varying degrees of efficiency and cost savings (Energy.gov). The EPA has estimated that the US could reduce its dependence on foreign oil by 21.5 million barrels of crude oil each year for every one million homes using geothermal energy and reduce greenhouse gases by eliminating 5.8 million metric tons of CO_2 emissions annually (Lloyd 2011, p 101). Electricity from renewables is projected to continue to increase with geothermal making up a mere 4% renewable electricity generation (Figure 5).

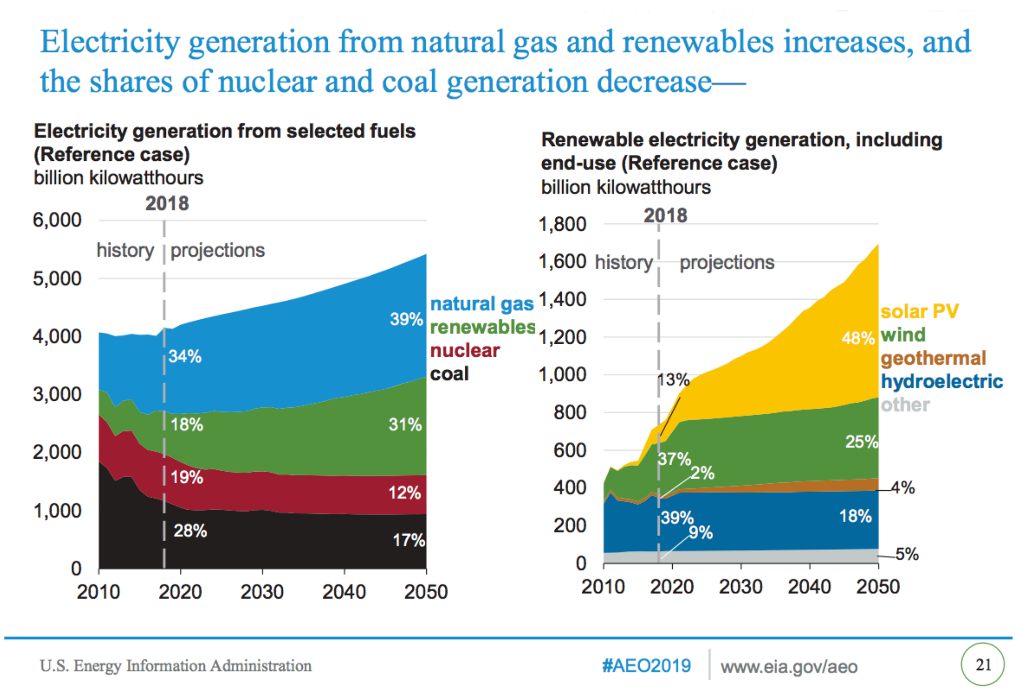

Figure 5: Electricity generation projections from the US Energy Information Administration

Methods

Learning about Renewable Energy, Geothermal Energy, and Boston College

The methods used in this research report chiefly consist of literature reviews and interviews. To begin, it was vital to have a foundational knowledge of the energy landscape in the United States. I referenced “The Annual Energy Outlook 2019 With Projections to 2050” from the US Energy Information Administration, as its primary sources on electricity generation were important in my understanding of the current state of renewable energy as well as trends.

The book <u>The Smart Guide to Geothermal</u> and many government resources available online were integral in my knowledge of how geothermal systems operated, their variations, the installation process, and the benefits, challenges, and misconceptions of ground-source systems.

With this knowledge, I contacted John MacDonald, head of Boston College's Energy Department, who I interviewed regarding energy usage at the school as well as BC's topography. Throughout the project, I also communicated with Bruce Dixon, the head of the Sustainability Department at Boston College, to discuss BC's progress in implementing geothermal and to attain an initial study on BC's geology to initially explore geothermal energy as a heating and cooling source.

I relied on the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy for infographics and geothermal maps. Focusing my search further, The Massachusetts Geothermal Data Project was invaluable in supplementing my knowledge about the state's geothermal activity.

Investigation of Feasibility Through Case Studies

I then researched case studies of higher education institutions integrating geothermal technologies onto their campuses, paying attention to those in the Boston area which have undergone geothermal HVAC projects for campus infrastructure. I chose to highlight specifically schools in Boston so that I could eliminate variables like weather, soil and bedrock thermal conductivity, and lithology where other city-schools in the Northeastern US would differ. The National Wildlife Federations "Going Underground on Campus" guide to geothermal energy on college campuses highlighted case studies of 79 American universities that have employed geothermal technologies. This compilation was important for aggregate data collection and observations about geothermal campuses as a specific subset. One of the most pertinent pieces of literature was provided to me the sustainability coordinator at Harvard; a "Lessons Learned" analysis was created in 2007 reflecting upon the geothermal projects for eight buildings on its Cambridge campus. Along with the benefits Harvard has gained from the projects, this document provides a thoughtful and candid account of the missteps of these projects and has given me more realistic expectations of the difficulties to anticipate. It includes recommendations like optimal well conditions and instructions for best maintenance practices. To further round out my case study review, I collaborated with BC librarian Enid Karr. She guided me towards reports, articles, and case studies from colleges in the Northeast which had implemented geothermal.

Geothermal Interviews and Consultations

This feasibility study involved expanding on literature review by conducting conversations with professionals in the geothermal energy field to attain real accounts from alternative perspectives. I made dozens of cold calls and sent tens of emails to geothermal companies in the Northeastern US. Eventually, I interviewed George Whiting from Whiting Geothermal LLC. who studied geothermal technology in Sweden. I spoke to Ed Malloy, engineer and founder of New England Renewable Energy Systems which was eventually bought by a larger competitor after completing the financial analyses and installations of approximately 150 GHPs. I communicated with Ron Peterson from Atlantic Well Drilling while he was onsite.

While I had gained a theoretical background from an expansive literature review, dialoging with people in the geothermal industry presented me with more practical expectations of what a geothermal project at Boston College could entail. One of the most influential of my interviews was with the senior project manager from Compass Project Management who is currently working on Boston University's new, carbon-free Data Sciences Center.

The last of my interviews was with Jacqueline Guyol, the Program Administrator of Clean Heating & Cooling at the Massachusetts Clean Energy Center. Given that BC would not be eligible for tax incentives as a non-profit, she directed my attention to various financing options available to Boston College to finance clean energy projects.

Results

Research Question 1: What are the advantages and challenges of geothermal systems in comparison with conventional HVAC systems?

According to the Environmental Protection Agency, geothermal ground-source heat pump systems are one of the most energy efficient, environmentally clean, and cost-effective space conditioning systems available (Lloyd 2011, p 15), (Tables 2 and 3). Geothermal heat pumps do not create air polluting greenhouse gas emissions, instead using the earth's heat energy as a renewable resource. These technologies can be used to offset carbon dioxide equivalent greenhouse gas emissions associated with on-campus fossil fuel combustion.

Ground-source heating generates favorable returns on clean energy investments. While BC's duel-fuel capacity boilers buffer against energy prices in either the oil or natural gas market, geothermal energy provides a complete hedge against uncertain future supplies of finite fossil fuels, volatile market prices (See Appendix C), and mandated emissions limits (Cross et al., 2011, p 7).

A GHP lasts about 25 years, double that of a boiler or furnace and AC system (Lloyd 2011, p 72). Not only does it require significantly less maintenance than the Boston College Central Heating Plant, but it is also safer to operate, because there are no oil filters or nozzles to clean, open flames, carbon monoxide, oil storage tanks, sludge, or combustion byproducts like particulates. Noticeably enhanced comfort has been commonly reported from patrons of buildings with geothermal heating and cooling because of the consistent humidity and temperature levels throughout the space. Other aesthetic benefits include the lack of chimney and no noise pollution.

Table 1: (Lloyd 2011, p 22)

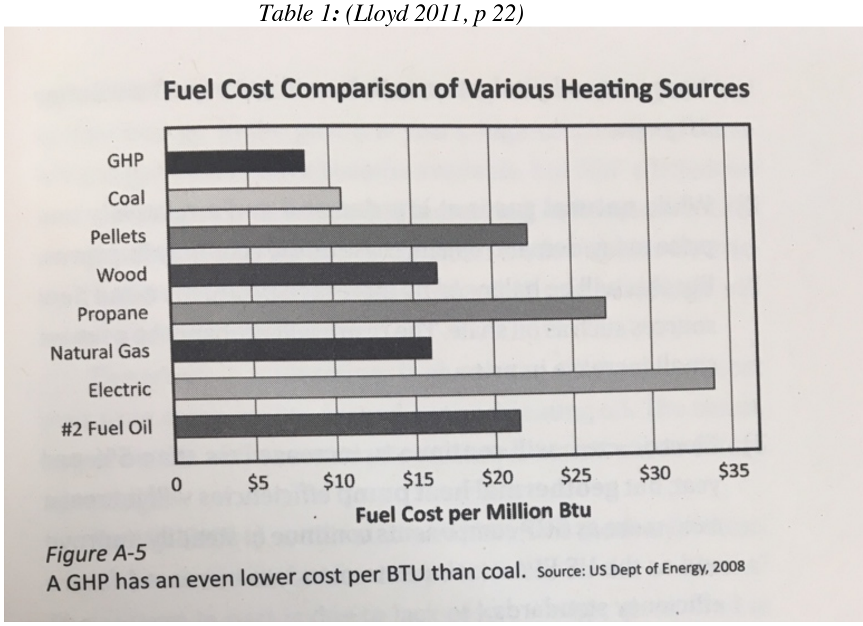

Table 2: (Lloyd 2011, p 23)

Heating Cost Comparison Data

Fuel Type	Fuel Unit	Fuel Price per Unit	Btu per Unit	Fuel Price per Million Btu	Efficiency	Fuel Cost per Million Btu
GHP	kWh	$0.116	3,412	$33.90	400%	$8.48
Coal	Ton	$200.00	25,000,000	$8.00	75%	$10.67
Pellets	Ton	$250.00	16,500,000	$15.15	68%	$22.28
Wood	Cord	$200.00	22,000,000	$9.09	55%	$16.53
Propane	Gallon	$1.93	91,333	$21.16	78%	$27.13
Natural Gas	Therm*	$1.25	100,000	$12.50	78%	$16.03
Electric Baseboard	kWh	$0.116	3,412	$33.90	100%	$33.90
#2 Fuel Oil	Gallon	$2.33	138,690	$16.80	78%	$21.54

*Therm = 100,000 Btu

Figure A-4
A GHP (geothermal heat pump) has the lowest cost per BTU of any other heat source. Source: US Dept of Energy, 2008

With so many variations that are so heavily dependent upon the environment in which they are installed and financial incentives where eligibility differs, there is no clear cut answer as to what a payback period would resemble; geothermal heating and cooling pumps can range from 2-40+ years. Closed-loop geothermal installations cost more than a fuel burner plus full AC because of drilling and excavation costs; however, open-loop heat sources can often cost less than a fossil-fuel system plus full AC. Installation is complex and requires high level professionals. Ed Malloy reports that it "takes a village" to install ground-source heating because numerous areas of expertise must collaborate on a holistic approach to execution (Ed Malloy, personal communication).

While costs are saved on fuel, there may be an increase in electricity use depending on pipe configuration (Lloyd 2011, p 73). Geothermal systems operate with electricity and the heat from the ground, but if the heat pump doesn't provide enough heat, it will be supplemented with additional electricity which can be exorbitant. Although the electrical energy is needed to power the technology itself can be the product of fossil fuel combustion, the upstream leveraging reduction on CO_2 equivalent greenhouse gas emissions remains significant. In fact, because of the high coefficients of performance in the physics of heat pump energy transfer, geothermal heat pumps produce multiple units of heating and cooling thermal energy for every purchased kilowatt-hour (kWh) of electrical power (Cross et al., 2011, p 8).

Research Question 2: Can geothermal energy be used in Massachusetts?

According to a 2006 study by the National Renewable Energy Laboratory (NREL), geothermal energy is utilized in all 50 states, and there are enough untapped geothermal resources in the nation alone to provide a 30,000-year energy supply at our current domestic rate of demand (Cross et al, 2011, p 11). As mentioned, the heat energy a few feet below the surface in Massachusetts remains at a generally consistent 50°-55° throughout the year, and the further pipes extend beneath the surface, the more inconsequential ambient temperatures become. As a result, geothermal energy is accessed across the state (Figure 6).

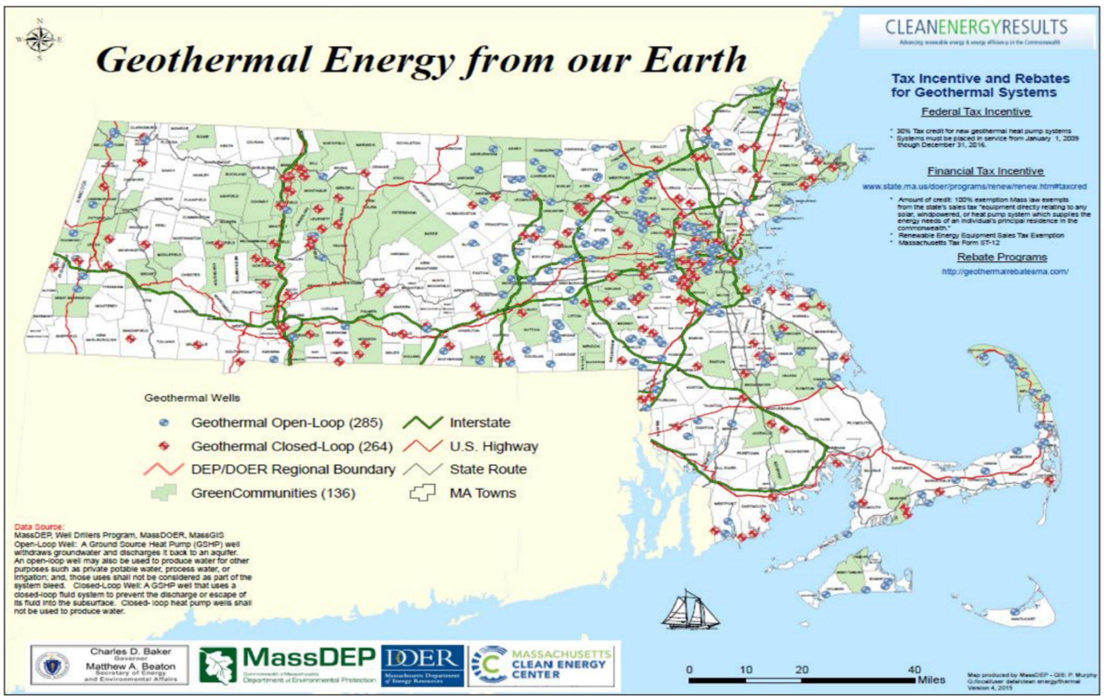

Figure 6: Shows the 549 open- and closed-loop geothermal energy wells in the State of Massachusetts, all notably concentrated near the city of Boston (MassCEC)

Case Study: Trinity Church Boston, MA

In 2001, a geothermal energy system was installed in Trinity Church in Copley Square. Six wells, each 1,500 feet deep, were drilled within feet of the structure. Thirteen heat pumps totaling 130 tons of capacity were installed, to result in an estimate savings total $67,000 per year. (Lloyd 2011, p 151).

Research Question 3: Should geothermal energy be used on a college campus?

The US Department of Energy reported that over 500 schools in the US have installed geothermal heating and cooling systems (Lloyd 2011, p 149). College campuses are uniquely suited to lead the way in geothermal technology implementation because they have many structures and considerable acreage under single control. Colleges also have staff who know, in depth, the performance characteristics of individual buildings and the campus as an integrated whole. As a result, colleges have the ability to undertake geothermal projects that are multi-building and multi-scale to have a considerable impact.

The 4,350 U.S. colleges & universities as of 2009 have 19.6 million students and 240,000 buildings with 5 billion square feet of floor space and a cumulative economic purchasing power of multi-billions of dollars. These institutions spend between $15 and 18 billion in new construction and renovation each year and $20 billion for facilities maintenance, operations and utilities. "Perhaps more important is the fact that today's college and university students will become leaders in most areas of the U.S. economy in the years to come. What they see modeled and emphasized during their college years will have an impact on their understanding of sustainability and climate change, and on their future decisions about energy use" (Cross et al., 2011, p 14).

Geothermal projects can create new research and service-learning opportunities, encourage interdisciplinary collaboration among faculty, prepare students for sustainability and climate leadership in all careers and professions, appeal to current and prospective students, parents and donors, and foster a campus-wide ethic of environmental stewardship. The scalable nature of geothermal technology is that they can be used to diversify an existing energy portfolio or eventually be integrated into the campus as a whole. Of the various renewable energy sources available to colleges and universities such as solar, wind, biomass, micro-hydro and geothermal, geothermal energy offers the most dependably-constant and low-impact supply (Cross et al., 2011, p 11).

Boston University

Boston University retrofitted its first geothermal building with six 1,500 foot deep wells to warm and cool the 95,000 square foot space at 882 through 888 Commonwealth Ave in the mid 2000's. This building is considered one of the most historic on Commonwealth Avenue in

Brookline. The university pursued geothermal over other renewable sources because of its reliability and projected a payback period between seven to nine years (Waltz).

Currently, BU is finishing a different program to determine an estimate for the conductivity of 31 1,500 foot closed-loop geothermal wells for its new Data Sciences Center. The goal for the high rise is to be a carbon free home to house data science, computer science, and math departments. One of the additional benefits realized have been that geothermal heating and cooling equipment is so much smaller than that of a conventional system, so the university could reduce the building's total footprint necessary for this storage. Senior Project Manager Chris Kenney said he couldn't identify many non-financial disincentives to implementing, as it is out of sight and virtually maintenance free (Chris Kenney, personal communication).

Harvard University

Geothermal heat pump projects have been installed for eight Harvard University buildings (Figure 12). Harvard has used a combination of open- and closed-loop wells for both retrofitted and new buildings which contain classrooms, labs, administrative offices, and student residences. Harvard chose open-loop wells partly because of limited space.

For the retrofits, the GHP systems added summertime air conditioning to buildings that previously lacked central cooling. Open-loop systems have cut an estimated 20-50% in energy costs over conventional HVAC, and the building systems are outperforming energy efficiency expectations. Harvard has since achieved Gold and Platinum LEED certification for a number of its buildings. The university reports the systems are reliable, long-lasting and produce comfortable heat. In addition, they are reportedly well-suited to the university's urban location particularly in summer because of their reduced noise.

The Office of Sustainability's Assistant Director, Nathan Gauthier, reports that a single 1,500 foot well cost around $80,000, about $50 per foot. With a payback of over 40 years, they were not installed for their cost-effectiveness but for their various other benefits. Performance of the open-loop wells has diminished somewhat over time due to the tendency of the aquifers to heat up in summer, providing less cooling capacity and reducing system efficiency. The open-loop systems are also prone to corrosion due to brackish groundwater, plus minerals in the water clog filters requiring added maintenance (Cross et al., 2011, p 29).

Harvard Well Inventory

	Wells	Depth (feet)	Designed to Bleed	Pump Depth (feet)	Pump Capacity (GPM)	VFDs*
Blackstone	2	1500	Yes	110	180	Yes
QRAC	2	1500	Yes	100	180	Yes
90 Mount Auburn	3	450 - 650	Yes	100	270	Yes
Radcliffe Gym	2	1500	Yes	100	160	Yes
2 Arrow St (condo).	3	1500	No			Yes
1 Francis Ave.	2	750, 850	Yes	100	160	Yes
Future Projects						
Byerly Hall	5	1500	No	100	410	Yes
Weld Hill (Closed Loop)	88	500	No	N/A	680	Yes

* Variable Frequency Drives allow a pump to run at partial capacity, reducing energy cost

Figure 7: Open-loop wells provide partial heating and cooling for seven of Harvard's structures. The university also recently completed its first closed-loop system with 88 boreholes of 500 feet deep for the 27,000 square-foot Weld Hill Building (Harvard Office of Sustainability).

Research Question 4: Is Boston College well-suited for geothermal heating and cooling?

Boston College considered implementing geothermal in 2008. A study was conducted to determine if the college should hire a design engineer to subsequently evaluate the cost of the project. Financial reasons and unstable contractor costs led to BC's administrators dismissal of the concept, so a financial feasibility analysis was never completed. At the time of the study, geothermal pricing from contractors was fluctuating which Bruce Dixon says "would not have been in the best interest of the College. Unfortunately, this concept was not reviewed for other future projects probably because our peer Colleges and Universities didn't find success in the concept." However, Bruce also says he "will be keeping an eye on the BU Geothermal project to determine price, length of the project cost overruns (if any) and reliability as well as the contractors involved in the project" (Bruce Dixon, personal communication). John MacDonald reported that to his recollection, the school didn't pursue the project because it was "easy enough to put in a chiller and put in a boiler that anyone could fix and maintain" without an intimate knowledge of geothermal wells. He said that there were more opportunities elsewhere that the administration felt would cause much less aggravation (John MacDonald, personal communication).

In terms of disruption to school functions, BU plans for the remaining 28 wells for its new building to be drilled with two drill rigs at a rate of one well per three weeks which includes installing the vertical piping system. The process will be beginning in the summer with completion anticipated in January.

Integration with BC's Topography

The 2008 Geothermal Study conducted by Haley & Aldrich, Inc. on behalf of the BC campus found thicker overburden deposits with deeper bedrock in the range of 35 to 75 feet confined to the Lower Campus in the area of the Modular Housing, Flynn Recreation Complex, and Alumni Stadium buildings. This is notable considering closed loop systems are particularly advantaged economically where there is thicker overburden because it allows for soil drilling as opposed to the premium on bedrock drilling. The report showed that on the Main Campus, depth to groundwater within the Lower Campus is commonly less than five feet deep as anticipated based upon the proximity to the Chestnut Hill Reservoir (Haley & Aldrich, Inc., 2008).

Although BC's campus adjoins the Chestnut Hill Reservoir, this is maintained as an emergency backup status for the city of Boston's water needs, so it will likely be unavailable to use for an open-loop system extraction or a closed loop pond system. In addition, open-loops at Harvard have struggled with maintaining pipe integrity because of the composition of the water, the sediments that can cause clogging, and the exposure to other weather elements.

Vertical wells can harness the conductivity of the water close to the surface of lower campus to increase the system's efficiency. Greater depth of the vertical system can capture greater heat when compared to a horizontal system. Senior Project Manager at Compass Project Management and leader of the construction of BU's Data Sciences Center, Chris Kelley, proposed that even without evaluation, closed-loop vertical systems would be his best guess as to what type of geothermal well might suit BC's topography (Chris Kelley, personal communication). To confirm this, a thermal conductivity test would be completed at BC.

This is consistent with my conversations with industry professionals from the Boston area; all agreed that closed-loop systems were more commonly implemented in the Northeast, as they have a longer life cycle and can withstand more without foreign particles being introduced due to water quality. Closed-loops were also recommended because they require much less maintenance than their counterparts. Ed Malloy Commissioned 100-150 high-end residential buildings in Massachusetts, most of which all of which he reports were vertical and approximated two-thirds of which were closed-loop.

Closed-loops can be paved over because of their sealed nature, lack of moving parts, and minimal maintenance necessary. The objective of space heating and cooling is to provide enough BTUs to keep up with heating loss or removing BTUs at the rate of heat gain, for this reason, it helps if there is good insulation in the building because it's always less expensive to save a BTU than make or remove one. (Ed Malloy, personal communication). In order to create the most efficient heating and cooling system, new structures or buildings that have good insulation should be considered for retrofitting over those without.

Financing Geothermal at BC

I am surprised to hear that Boston College uses a simple payback period for its capital budgeting projects. This method is designed to determine the number of years that it takes to recover the initial investment. While easy to understand, a payback period is widely regarded as an inherently flawed metric for capital budgeting because it doesn't take into account the time value of money. It also neglects cash flows received after the payback period which presents an issue for projects in which large cash flows may occur after the payback period has ended. There is also no indication of the project's profitability or return on investment**,** opportunity costs, financial discount factors, or inflation.

A return on investment "should be the metric used for evaluating any sustainability-related technology. Remarkably with [the payback] approach, the otherwise pessimistic impression of a fourteen- or even twenty-year 'payback' is better understood as a 7% or 5% return on investment respectively" (Cross et al., 2011, p 10). John Kelly, the Chief Operating Officer of Geothermal Exchange Organization claims that a payback is often a misleading metric for the benefits of ground-source heat pump systems and recommends a more sophisticated approach such as a "net present value over the estimated 50+ year projected life of the in-ground geothermal loop." He suggests that "Although the ground loop represents a significant portion of the initial cost of a GHP system, it lasts well beyond the projected service life of the above-ground heat pump equipment. That is, if the mechanical equipment is replaced after 25 years, it does not require the expense of replacing the ground loop." (Cross et al., 2011, p 18).

Apart from the aforementioned inherent financial benefits realized by implementing geothermal HVAC, BC is also eligible for a grant up to $250,000 through the MassCEC Grant program until December of 2020. The college would also be able to attain Alternative Energy

Credits through Massachusetts State Government after a sustainability evaluation of the finished building (MassCEC). The college is not restricted to paying its own resources, many residential, commercial, and university structures implement energy-saving systems with the help of various financing strategies. Below is a table adapted from (Cross et al., 2011, p 14) that indicates the ways in which universities have outsourced to fund geothermal projects in addition to investing campus resources.

Table 3: Financing Strategies for Geothermal Technologies (Cross et al., 20011, p 14)

College or university	**Sources in addition to capital budgets**
Ball State University (IN)	State appropriations and Federal stimulus grant
Drury University (MO)	Alumni gifts
Feather River College (CA)	Lease agreement, Private grants
Hamilton College (NY)	State grant
Lake Land College (IL)	Guaranteed energy savings contract and Federal grant
Northland College (WI)	Fundraising campaign
Richard Stockton (NJ)	Utility rebates, State grants
University of Illinois-Chicago	Independent foundation established by utility
University of Maine at Farmington	State bond issue, Alumni gifts

Geothermal as Jesuit Institution

In 2009, Fairfield University completed construction on an environmentally friendly home for the Jesuit community and a gathering place. Multiple architectural firms were screened in an attempt to find one that clearly embraced the Jesuit environmental goals for the building (Tucker, 2009, p. 17).

At Loyola University, the Institute of Environmental Sustainability posits that "sustainability is driven by our Jesuit tradition of social justice, our service to humanity, and our role as an institution of higher education. It is embodied in an educational experience for our students and activities that seek to meet the needs of the present generation without compromising the ability of future generations to meet their own needs." The school's "Jesuit tradition leads [it] to seek social justice and care for creation through local action that creates a global impact" (Loyola University Chicago, Institute of Environmental Sustainability).

Installing ground-source heating at BC also adheres to goals set out in BC's 2009 Institutional Master Plan which outlines The University's commitment to investigating "cogeneration using combined heat and power technology and economically feasible sources of on-site renewable energy such as geothermal" (BC Institutional Master Plan, 2009) as well as its mission as a Jesuit University.

Discussion and Recommendations

Throughout the course of this study, it has become clear that there are innumerable incentives to implement geothermal systems both in Massachusetts and particularly on college campuses. While I've found that there are an extensive amount of advantages and drawbacks of geothermal energy, the deciding factor about what galvanizes a college to pursue or cease the exploration of geothermal projects obviously differs among campuses based on which of those factors the college prioritizes.

Limitations of the Study

1. Inability to access updated financial and other energy-saving data from the case studies and do a more quantitative analysis as well as lack of insight on BC's financial capability to go forth with a geothermal project
2. Firsthand accounts from geothermal professionals were opinion-based and could have been flawed or misconstrued
3. Certain sources were published prior to 2015. Because the technology has changed, some figures need to be updated.

Recommendations

1. Due to the geographical characteristics of lower campus, I recommend that further feasibility studies surrounding the ability to implement vertical, closed-loop geothermal wells on lower campus in the mod parking lot move forward.
2. Buildings to be considered for retrofitting should either have high quality insulation or the project should be coupled with increasing the insulation of the structures like that of the Modular Housing.
3. An evaluation of the project be done from a holistic point of view as a collaborative effort between administration, students, and staff. All stakeholders should take a part in deciding if renewable energy is something that they want to see on campus. I recommend that a number of departments be incorporated on an interdisciplinary project to forge

partnership among Environmental Studies, Geology, Public Health and Nursing, and the Carroll School of Management among others.

4. Open dialogues should be held with Harvard, BU, MIT, and another colleges about lessons learned from their geothermal programs and how renewable energy projects could be encouraged and made feasible to other institutions.
5. Hire recommended professionals with campus geothermal experience to come to campus and do a more holistic evaluation.
6. I recommend that this study by used as an introduction for a more nuanced financial evaluation to be conducted to see if there are more appropriate ways in which Boston College should be evaluating such projects. A simple payback period is an inherently flawed metric because it does not incorporate metrics like opportunity costs or the time value of money, two essential concepts to consider when thinking about project investment. I would instead like to examine more comprehensive numbers like the return on investment or project net present value.
7. A revolving green fund for projects that align with BC's mission but have a longer payback be established and other financing opportunities like grants and fundraising campaigns should also be considered.

It is time to reevaluate the prospect of using geothermal as a source at Boston College. There are a number of success stories that are reason to believe that geothermal in Massachusetts can provide an invaluable resource to the college in innumerable ways. In addition, a number of geological factors specific to BC and precedents in nearby Boston make it clear that Boston College's topography and infrastructure have multiple aspects that could prove ideal for different GHPs. As a university, and particularly as a Jesuit institution, I feel it is Boston College's responsibility to make good on its commitment to the continued research and serious consideration of renewable energy implementation. I hope this study urges bold action and critical leadership today and throughout the next decades, when our actions will determine the fate of the climate for generations to come.

References

Appendix

Appendix A: Massachusetts Geothermal Energy Project Data

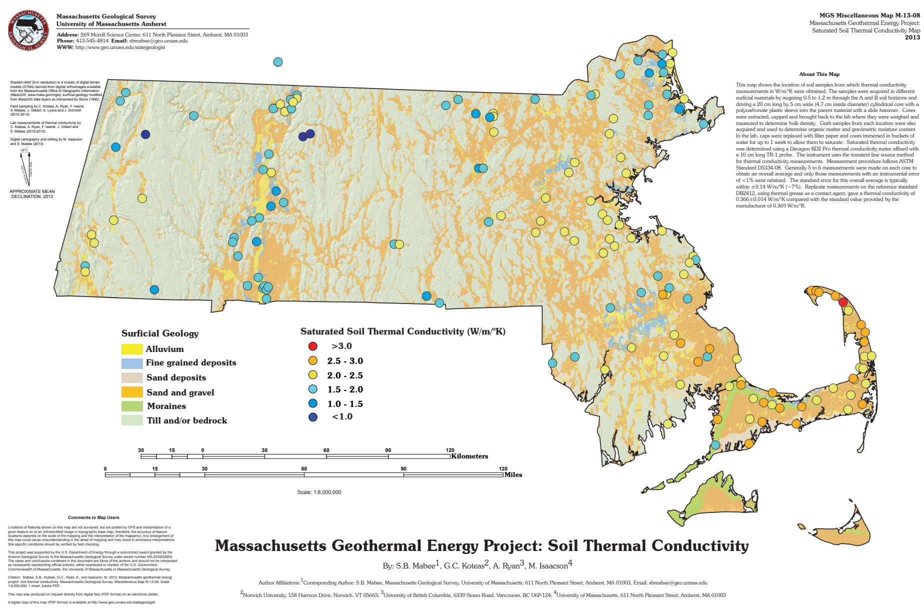

Figure 8: Massachusetts Soil Thermal Conductivity

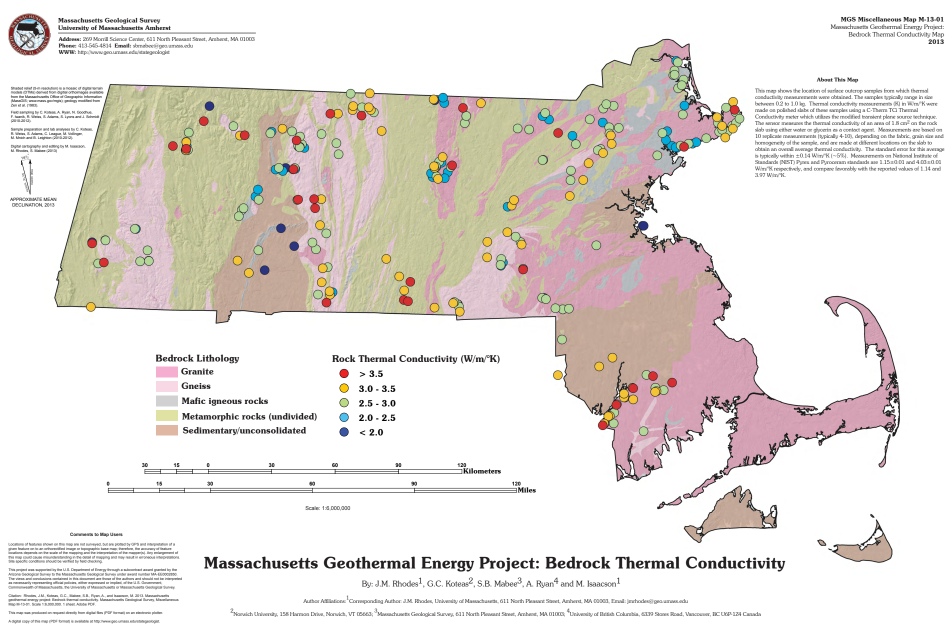

Figure 9: Massachusetts Bedrock Thermal Conductivity

Appendix B: Natural gas and oil price graphs indicate price volatility over the past 20 years

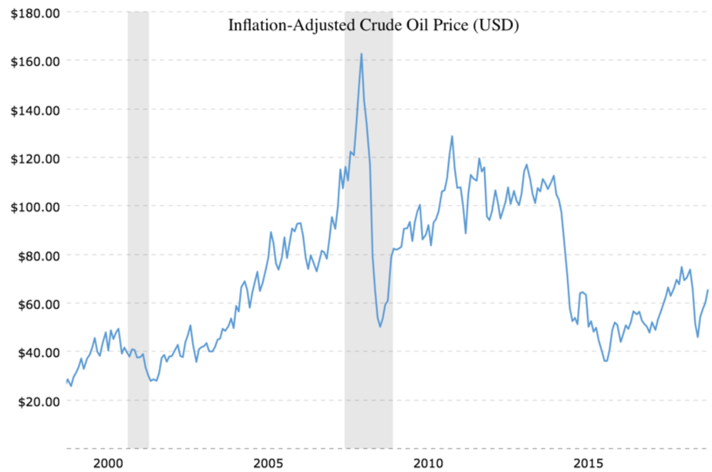

Figure 10: WTI crude oil prices adjusted for inflation using the headline CPI. The price of WTI crude oil as of April 22, 2019 is $65.58 per barrel (MacroTrends)

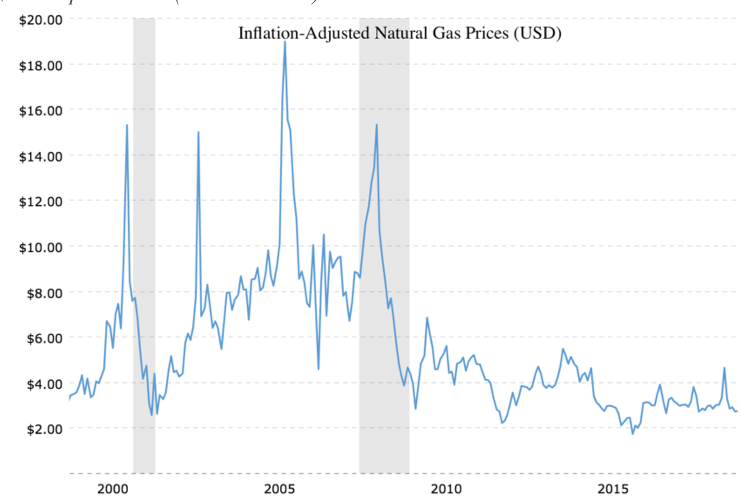

Figure 11: Inflation-adjusted Henry Hub natural gas prices in U.S. dollars. The current price of natural gas as of April 15, 2019 is $2.75 (MacroTrends)

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