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Proposal Title: Underground Thermal Energy Storage for a Sustainable Future

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200 word (maximum) summary of the proposal or video:

One major opportunity for energy innovation is presented in President Robert Barchi's recently approved Strategic Plan, which calls for the construction of six new academic buildings and three new residential buildings totaling over 1.3 million ft^2 in the next decade. It is of pivotal importance that they are designed with energy conservation in mind, which allows for a promising proposal utilizing Borehole Thermal Energy Storage (BTES) technology.
BTES systems involve storing thermal energy several hundred feet underground, to provide heating in the winter and cooling in the summer.

Using a similar case study at The Richard Stockton College in New Jersey, the authors of this proposal estimate that this solution can generate upwards of $1.44 million and reduce carbon emissions by over 15.1 million pounds annually, which is the equivalent of taking 2,000 cars off the road each year. With an estimated payback time of only 8 years, BTES can be financed in a very short period of time relative to the lifespan of the buildings. Funding the initial investment would not be an issue given that Rutgers is already spending over $250 million to finance the construction of the buildings, in addition to the $750 million Building Our Future Bond Act. The university would only need to raise an additional 4.5% in funds, which can be easily achieved through a combination of borrowing, utilities rebates, grants, or existing funds.

Introduction

Adoptability is a pivotal consideration in the construction of any successful energy conservation scheme. Proposals requiring drastic alterations in existing roads and facilities, for instance, often spawn too many complications to be considered implementable. On the other side of the token, identifying opportunities for energy sustainability that avoid large-scale infrastructural changes is a task of appreciable difficulty. Fortunately, both these concerns can be alleviated by aiming to modify existing construction *plans* as opposed to existing *infrastructure*. The subject of this proposal thus capitalizes on the immense scope of construction efforts Rutgers will carry out over the next ten years. In particular, the development of six new academic buildings and three new residential buildings spanning all three campuses of Camden, Newark, and New Brunswick is anticipated to be a promising target [1]. While not explicitly mentioned in President Barchi's recently approved "Strategic Plan," it is of extreme importance that these buildings—to be used perhaps by the next hundred years of Rutgers students—are constructed to be as eco-friendly and energy-efficient as possible. In other words, the blueprints for these nine new facilities must be modified as to minimize the future carbon footprint and maximize future financial savings before any development begins. Luckily, the master plan for these architectural projects will not be completed until Fall 2014, and a window of opportunity for energy innovation is therefore presented [1].

In order to produce a sustainable change in terms of future energy conservation for these buildings, the authors of this paper have established a set of criteria that the proposed solution should follow. The technology should 1.) solve an energy conservation issue that current buildings at Rutgers fail to address, 2.) have a strong energy storage component, which is typically the bottleneck in renewable energy schemes, and 3.) implement harmoniously with existing construction plans. Underground Thermal Energy Storage (UTES), the subject of this proposal, is the ideal solution given this set of criteria. UTES is a form of energy storage technology in which heat is collected and stored underground for a period of several months. It is particularly effective for large-scale seasonal storage of thermal energy from hot summer months for space heating during cold winter months, while also operating in reverse to replace air conditioning during the summer months. Several types of storage mediums for UTES technologies exist, including geological strata and aquifers. However, due to the higher maintenance costs and limited applicability of the latter, this report will only be discussing the implementation of the former, known as Borehole Thermal Energy Storage (BTES) technology.

BTES involves drilling and trenching to create boreholes, several hundred feet in depth, which can be installed in a wide range of geological strata that can range from sand to crystalline hard rock. The boreholes are lined with polyethylene piping a few inches in diameter, which are connected by a U-shaped piece at the bottom of the borehole. These pipes are then filled with water or glycol to act as thermal conductors to transfer heat between the surrounding soil and back to the buildings. There are several advantages to BTES technology over traditional renewable energy schemes, such as photovoltaics and hydroelectricity. For one, the "storage" aspect of this technology is highly efficient. At depths of over ten meters below ground level, temperature is very weakly influenced by local variations in above-ground climate, and thermal energy can be stored over very long periods of time with minimal loss. In a period of a month, heat is only transferred approximately one meter through the soil [2]. For instance, the BTES operating at The Richard Stockton College of New Jersey had an operating heat loss of only 2% over a six-month period [3]. A secondary benefit is that the "thermal earth battery" technology used in BTES systems has life expectancies in excess of 100 years, an over five-times increase in sustainability over technologies warrantied by solar manufactures [4]. Finally, when taking into consideration that the efficiency and specific construction costs of this type of renewable energy system increases with size, and that this technology is an effective use of resources as it does not appear above ground, the BTES solution is an ideal addition to Rutgers' large-scale Strategic Plan initiatives. By constructing BTES systems under the area of land expected to house the nine new buildings prior to their development, Rutgers can expect substantial reductions in terms of its carbon footprint and energy consumption, translating to hefty financial savings.

Cost Analysis

In order to analyze the cost and saving projections for a potential BTES project, it would be valuable to consider other successful examples of BTES implementation. One prime example is the large-scale BTES system operating at The Richard Stockton College of New Jersey. The Geothermal Project design featured 400 boreholes with heat exchange wells, each 425 feet deep, all of which were installed in a parking lot spanning 3.5 acres [5]. The BTES system was financed by a grant provided the New Jersey Departments of Environmental Protection and Higher Education and a utilities rebate from the Atlantic City Electric Company, totaling a combined $5.1 million [5]. This information is useful as it can be extrapolated to the scale of Rutgers University to glean overall cost estimates.

First, it is necessary to calculate the total amount of land that will be used by Rutgers for this BTES project. This was done by first obtaining the gross square-footage for each of the nine new buildings. Because only the area on the base of the building needs to be considered for UTES projects, the gross area values, which represent the total areas with all floors considered, were divided by the number of floors in each building. However, this information was not readily available, and so the number of floors for each building was estimated using the artist renditions of each building appearing in the Strategic Plan booklet. All these estimations and calculations appear in Table 1 below, and it was concluded that approximately 212,620 square-feet of land will be used for this project.

Table I - Total project area calculations for nine new buildings [1]

	Gross Square-Footage	Floors	Square Footage of Building Base
Chemistry Building	145,000	7	20,714
Academic Building	200,000	6	33,334
William Levine Hall	57,000	4	14,250
Nursing & Science Building	100,000	5	20,000
Life Sciences Center	93,000	6	15,500
Engineering Building	112,500	4	28,125
Honors College	170,000	5	34,000
College Ave Apartments	240,000	7	34,286
Washington Street	211,000	17	12,412
Total	1,328,500		212,620

To estimate the validity of this square-foot estimation, we approximated the size of the ground under the Library of Science and Medicine building using a Google Maps view of Busch campus [6]. Using the scale on the map, the dimensions of the building were found to be 35 by 45 meters, or roughly 17,000 square-feet. Nine buildings of this size would take up 153,000 square-feet of land. Our estimate of 212,620 square-feet means that the average size of the nine new buildings is slightly larger than the size of the Library of Science and Medicine building, which seems very reasonable.

Finally, for the purposes of simplicity, it was assumed that Rutgers will utilize boreholes of the same depth and spacing relative to each other. Thus, a simple proportionality calculation can be used: that is, if it cost Richard Stockton College $5.1 million to install boreholes in 152,460 square-feet of land, it would cost Rutgers University $7.1 million to install boreholes in 212,620 square-feet of land. Factoring in inflation, as the Geothermal Project was implemented in 1994, the cost of the proposed project becomes $11.3 million [7]. This cost projection, however, can be considered a very conservative estimate for several reasons. First, since the BTES system at The Richard Stockton College of New Jersey was constructed roughly twenty years ago, at a time when geothermal heat storage technology was considered relatively novel, it is reasonable to assume that the inflation-adjusted construction costs have decreased since then. Secondly, as suggested in the introduction, the cost of implementing a BTES project in existing infrastructure (such as a parking lot) rather than prior to the construction of buildings is much higher. Finally, it is generally recognized for such projects that specific construction costs decrease with increasing size of the project.

Savings Analysis

To calculate the payback time of this project, the project is scaled towards matching the efficiency of The Richard Stockton College of New Jersey's BTES system. In the cited example, 70% of natural gas consumption was saved by the addition of the BTES system [5]. Back calculating to find out how much energy their BTES system is producing per year, the authors calculated the average heating consumption in a laboratory/college education building to be 115 kWh/ft^2/year [8,9]. Using an 80% efficiency for thermal energy conversion from natural gas, and then multiplying by the area of space heated, 480,000 ft^2, this report calculates a total heat consumption of 69 MWh/Year [10]. To confirm the accuracy of this number, 70% of this value (70% natural gas saved) is converted to Btu and multiplied by the price of natural gas in 1994 (approximately $2.50/1,000,000 Btu [11]) to obtain savings of $411,999. This is extremely close to the measured savings of $400,000 [12]. The energy produced per year at The Richard Stockton College of New Jersey is now divided by 3.5 acres of boreholes to find the power produced per area [5]. Scaling to the size of the proposed 4.88 acre project at Rutgers, an energy production of 96,205,714.29 KWh/year is achieved. This is approximately 15.1 million pounds of CO_2 emissions per year, which is equivalent to roughly the emissions from 2,000 cars per year [13, 14]. Multiplying by the cost of natural gas today, $4.40, the savings per year amounts to $1,444,317.15 [11]. However, with the expected rise of natural gas prices, potential savings will also rise proportionally to the price of gas. Given a proposed $11.3 million for this project, the payback period is estimated to be approximately 8 years. If costs are driven down by our conservative estimates, the projected payback time could potentially become less than 5 or 6 years.

Considerations and Suggestions

One very important consideration is how this project will be funded. In President Robert Barchi's "Strategic Plan", it was stated that the cost of construction for these nine buildings will be funded by the $750 million Building Our Future Bond Act [1]. However, there is an important consideration to make here. In the Capital Facilities Programs Solicitation document supplied by the State of New Jersey Office of the Secretary of Higher Education, the eligibility criteria for potential recipients for the Building Our Future Bond Act is outlined. A key criterion section 2.1.E. describes "a commitment [of the institution] to provide matching funds to support 25% of the Project" [15]. In other words, at least $250 million must by generated by Rutgers by intra-institutional sources or borrowings. As such, raising an additional $11.3 million only means raising at most another 4.5%. However, as not all the construction projects will commence at the same time, all this financing does not need to be immediately obtained. Given Rutgers' $3.6 billion annual budget, and the fact that the payback for the BTES systems is less than 5 years, this funding figure does not seem at all unreasonable [16]. These funds can be raised through a combination of utilities rebates and state grants, which is how The Richard Stockton College of New Jersey financed their projects [17]. However, because time is an issue, master plans for construction should be completed by the Fall of 2014, as it is preferable to use a small portion of Rutgers' existing funds to initially finance the first of the BTES systems. This will require approval from the Board of Governors.

Another consideration is how these new buildings are going to be modified to serve as vehicle to promote eco-awareness on campus. According to Dr. Manish Chhowalla, many Korean universities incorporate display monitors outside of buildings that detail exact energy and utilities expenditure statistics for the facilities [18]. The profound effect of such real-time visual feedback systems is well documented [19]. By subtly reminding students and professors that energy conservation is an important issue for the university in which they attend, energy conservation habits, such as lowering thermostat temperatures or turning off lights when leaving a room, are promoted to a noteworthy degree. The authors of this report would therefore like to integrate the necessary infrastructure for keeping relative energy usage metrics, such as electricity, heat, and water, into these nine new buildings before they are constructed. In addition, the feedback panels should also display information such as the number of cars' emissions the BTES system has offset or pounds of CO_2 removed from the atmosphere. By further demonstrating the value Rutgers places on environmentalism, students and faculty alike will be further incentivized to reduce their excessive energy consumption.

Finally, it is worth mentioning one unexpected benefit of this proposal on the environment. By effectively reducing the operating cost of the nine buildings, Rutgers will no longer have to take as large of a percentage out of research grants and funds. This results in larger allocations to such research thrusts as environmental engineering or sustainable energy, which may ultimately provide substantial long-run payoffs.

Timeline for Implementation

Step One: Drafting and approval (completed by December 2014)

A key initial step is to draft up a detailed proposal for the implementation of this technology. This is to be pitched to and accepted by the Board of Governors by December 3rd at the latest, the date of the last meeting in 2013. The proposal should highlight budgetary considerations and important engineering aspects such as geological surveys of the land and detailed drilling plans. Sources of funding for this project initially will likely be through university funds; this is because the grant writing and approval process may delay the start of the construction considerably. This is unfavorable because construction of some buildings is expected to begin very soon (estimated January 2015). However, for the construction projects that begin later, it would be advisable to apply for grants from the Department of Energy to fund these projects, minimizing overall out-of-pocket spending for the implementation of the BTES systems.

Step Two: Drilling for first set of buildings (completed by July 2015)

The estimated time required for this construction project will be calculated using University of Ontario Institute of Technology as a reference. In 2003, UOIT utilized three rigs, each drilling one 700-foot deep hole a day over a span of 100 days [5]. For the BTES system to be built in Rutgers University, there will be approximately 560 boreholes total. This figure was calculated by scaling up Richard Stockton College's 400-hole project to the size of available land at Rutgers University. If an assumption is made that half of the construction plans are expected to begin as soon as possible, that means 280 boreholes will need to be drilled prior to the construction of those buildings. Three rigs would be able to accomplish this in less than 100 days. Factoring in time for removal of surface soil from the well field area prior to drilling, as well as insertion of high density polyethylene pipes and backfilling the boreholes with clay slurry for sealing purposes after drilling, a conservative estimate for the total time-span of this first half of this project is six months. This means that for the first set of buildings expected to begin construction on January 2015, the BTES system will be completed by July of the same year.

Step Three: Construction of buildings (additional 3.5-10.5 years)

According to the Strategic Plan, construction for all the buildings is expected to be completed in 3-10 years, although no specific timeline for individual buildings was given. As mentioned in the second step, only 280 of the 560 total boreholes were drilled first so that construction for some buildings can begin immediately. Thus, somewhere along this 3-10 year timeframe, another 280 boreholes must be drilled, which will extend the construction plans by at most another six months. Construction will now additionally include the installation of solar heat collectors on the top of the roofs to maximize heat collection, and the aforementioned energy monitor displays to encourage eco-friendly habits on campus.

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