Alternative Energy Generation at School A

Enhancing the Renewable Energy Portfolio of a Rural School District for Sustainability and Educational Opportunities

Project Description

School District A, located in a rural town in north central USA, serves a student population of approximately 300 students, grades 4K through 12th, all within a single facility (School A). School A is passionate about renewable energy and through a collaboration involving its Physics students and local renewable energy companies installed a 36-solar panel array on the school's rooftop in 2013. These panels currently generate about 4.5% of the school's energy need.

School A has requested engineering services to design a new, expanded renewable energy system on school property based on solar, wind, geothermal, or an integration of systems. The renewable energy system must make economic sense for the district to invest in with a goal of meeting 25% of the school's energy needs. The school would like for this project to also provide learning opportunities for high school students, who will participate in an introductory engineering course, as well as the surrounding community. The district has set a target of seven years projected payback for the project.

School A property line

Design Options

For the preliminary design phase of the project, the student team developed three alternatives for a renewable energy system at School A based on the three renewable energy sources identified in the request for services. Design I consisted of installing a 990-solar panel array system on the school's rooftop; this option was not chosen, as the school already had a solar array installed and it did not diversify School A's portfolio. Design II consisted of installing a 100 kW wind turbine on the northwest portion of the school property; this option was not chosen because it produced less energy than other options and because of potential social impacts on the community, such as view disruption. Design III, the recommended option, consisted of pairing a 990-solar panel array system on the school's rooftop with a 92-ton vertical geothermal system in the field west of the school. This option helped to significantly reduce energy costs and diversify School A's renewable energy portfolio.

Methodology

The student design team addressed multiple engineering analyses for the three alternatives considered: structural, environmental, construction, hydraulic, and geotechnical. Using these analyses, the three alternatives were compared in a decision matrix to suggest a final design for the renewable energy system.

Criteria Considered		Weight (%)	Design I Rating (1-3)	Design I Score	Design II Rating (1-3)	Design II Score	Design III Rating (1-3)	Design III Score
Environmental Analysis	Energy Production	10	2	0.20	1	0.10	3	0.30
	CO2 Avoidance	10	2	0.20	1	0.10	3	0.30
	System Lifetime	10	2	0.20	1	0.10	3	0.30
Safety Analysis	Construction & Use	25	2	0.50	1	0.25	3	0.75
Construction Analysis	Ease of Construction	10	3	0.30	1	0.10	2	0.20
Economic Analysis	Annual O&M Costs	5	3	0.15	1	0.05	2	0.10
	Initial Project Costs	5	3	0.15	2	0.10	1	0.05
	Payback Period	10	3	0.30	1	0.10	2	0.20
Societal Analysis	Visual Obstruction	5	1.5	0.08	1	0.05	1.5	0.08
	Disruption	5	3	0.15	2	0.10	1	0.05
	Education	5	2	0.10	2	0.10	2	0.10
Total		100	Score	2.33	Score	1.15	Score	2.43

Decision matrix for design options with Option III scoring the highest

Design Constraints

Several design constraints for the project were considered:

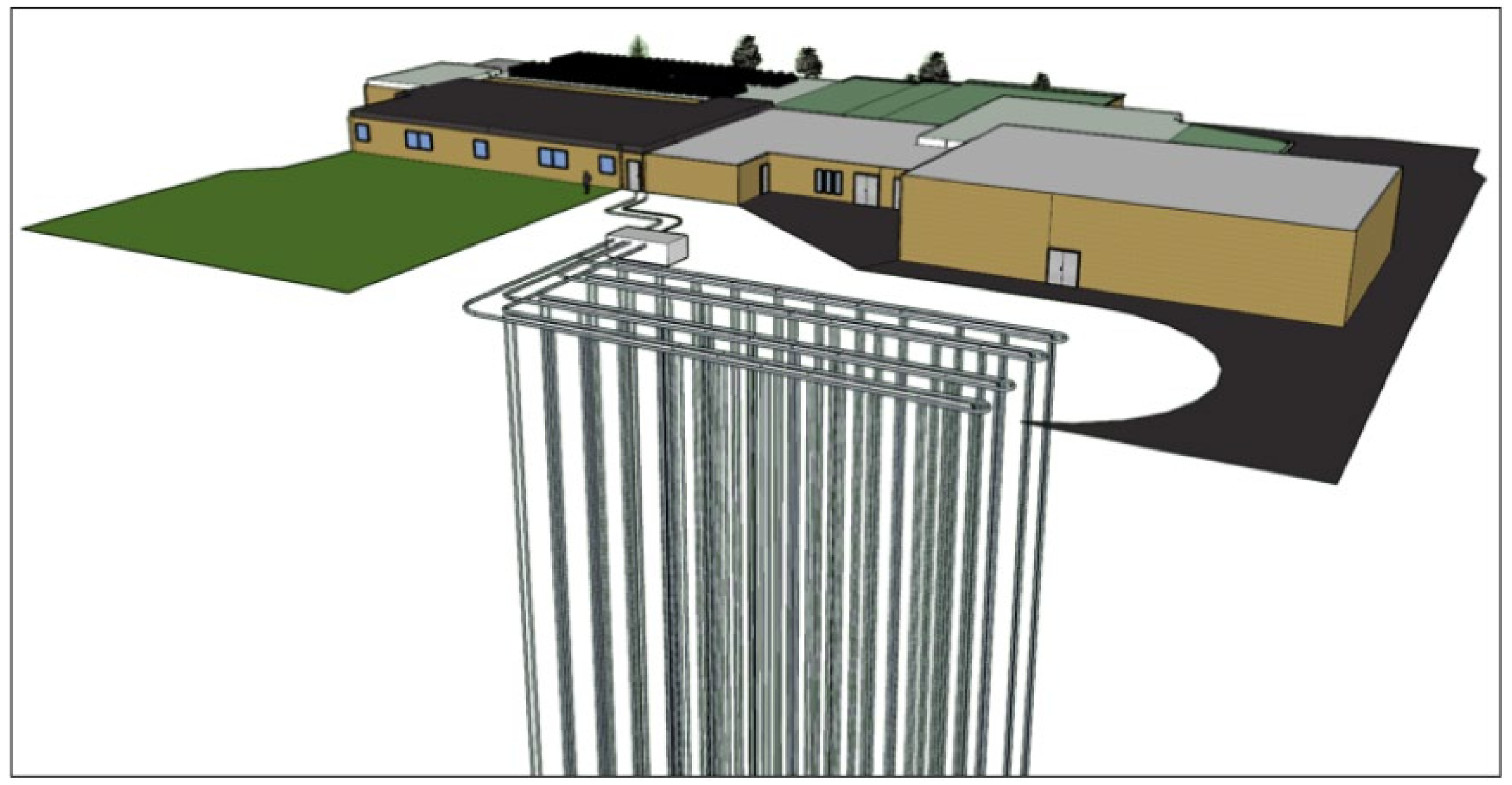
Economic: Economic viability of the final design depended on staying within a fixed budget for implementation and meeting the seven year target for return on investment.

Environmental: The team assessed the potential burden on the environment and emissions associated with the stages of both the solar array's life-cycle and the geothermal system's life-cycle, which were assumed to be 30 years and 50 years, respectively.

Social: Social, political, and ethical concerns were considered with respect to public acceptance of the renewable energy system.

Health and Safety: In addition to worker safety, there was a need to develop a final design that was isolated from school children who may be near the system.

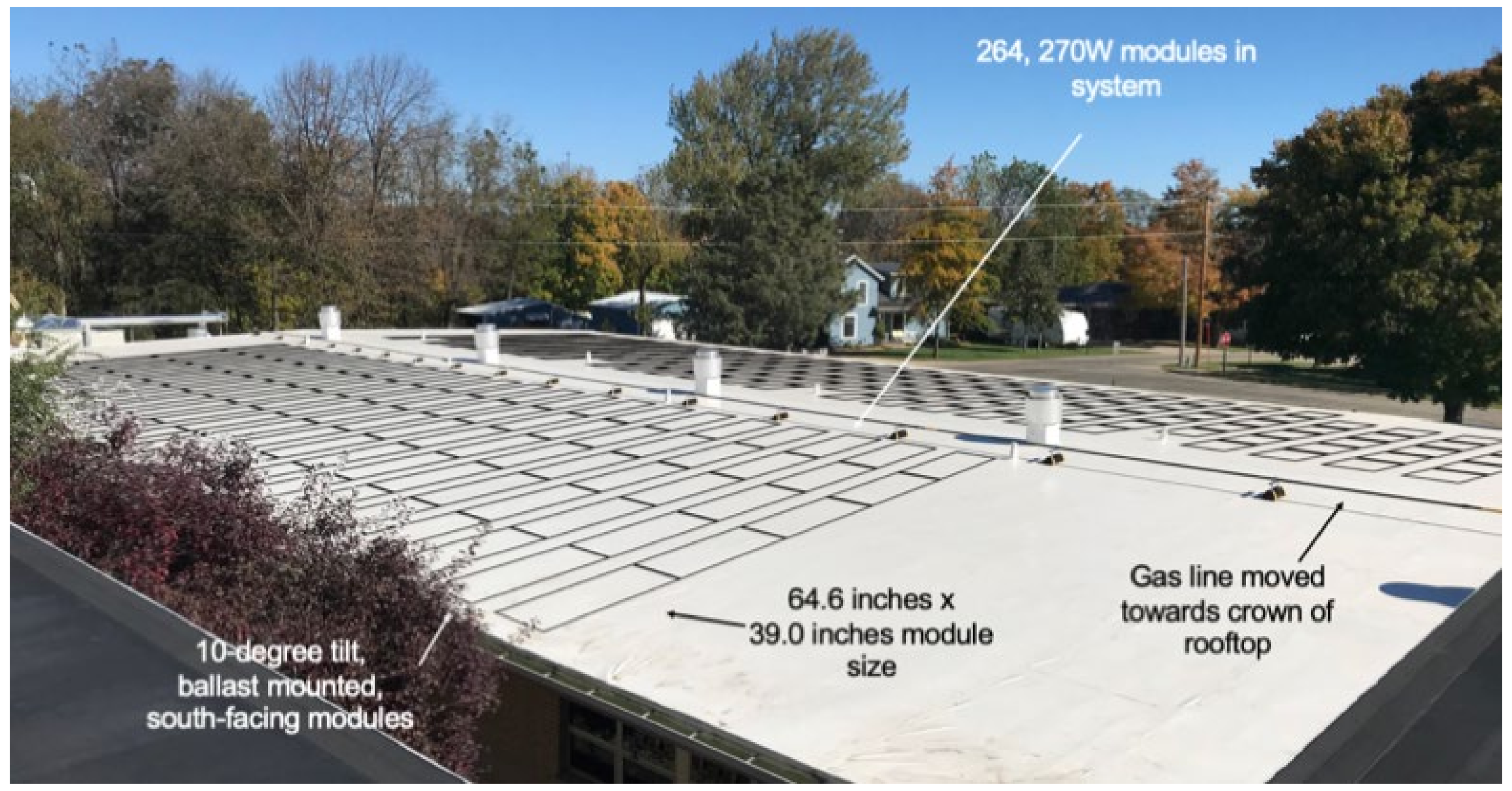
Constructability: Considerations related to earthwork required for the geothermal field and structural integrity of the 1956 rooftop that will support the mounted solar panels.



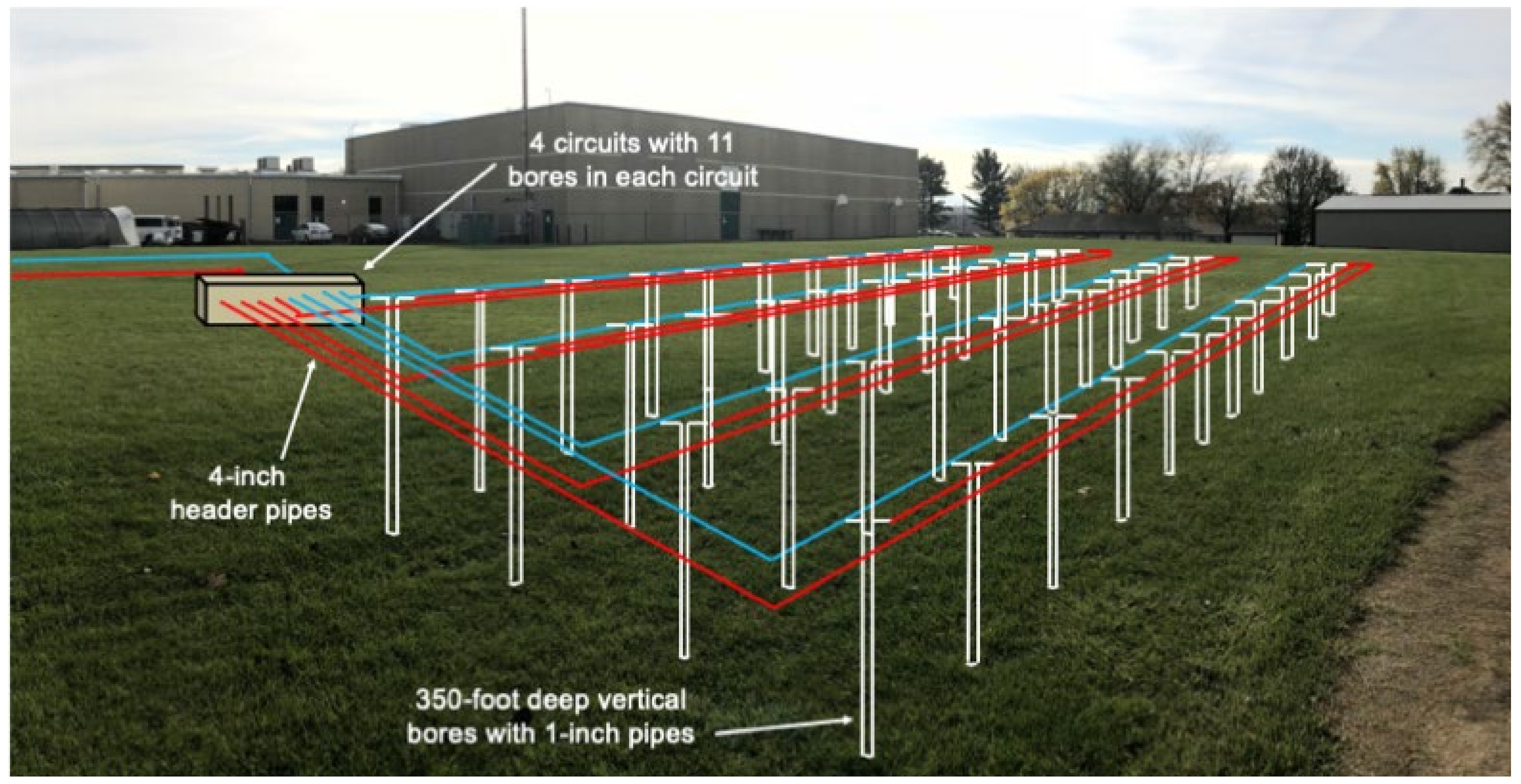
Rendering of renewable energy system at School A, facing northeast (including solar and geothermal system components)

Outcomes and Conclusions

The project team recommended a final design for the renewable energy system that integrates a 75-ton geothermal energy system – which includes 44, 350-foot vertical wells – with a 71 kWdc expandable photovoltaic solar array system – which includes 264 south-facing ballasted solar panel modules. This design would offset School A's energy costs by 40% by producing 98,000 kWh and reducing the school's consumption of natural gas by 28,000 CCF annually.



Solar component of final design, facing northeast



Geothermal system component of final design, facing southeast

Knowledge and Skills Gained

The students applied their engineering curriculum to a real-world problem. They used their knowledge of civil engineering to evaluate alternatives, considered risks and benefits, and created a viable final design, while meeting the time and budget constraints of their client and internal organization. Their interaction with mentors, members of the school district, and other engineering professionals taught them valuable communication skills, and gave them insights into questions about ethics, professional responsibilities, and the logistics of taking a design project to completion.

Alternative Energy Generation at School A

School District A, located in a rural town in central USA, serves a student population of approximately 300 students, grades 4K through 12th, all within a single facility (School A). School A is passionate about renewable energy and through a collaboration involving its Physics students and local renewable energy companies installed a 36-solar panel array on the school's rooftop in 2013. These panels currently generate about 4.5% of the school's energy need. School A has requested engineering services to design a new, expanded renewable energy system on school property based on solar, wind, geothermal, or an integration of systems. The goals of the renewable energy system are to help subsidize energy costs by meeting 25% of the school's energy needs and provide educational opportunities for its students.

In collaboration with P.E.'s and two School A project leaders, a team of five undergraduate civil and environmental engineering students worked to evaluate the costs and output of the solar, wind, and/or geothermal deployment and their associated budget ranges, cost/benefit analysis, and lifetime sustainability in order to recommend a final design that met the school's goals for energy output, environmental sustainability, and education opportunities.

The students developed three design alternatives, preparing a concept design for each by applying engineering analyses for the three alternatives with structural, environmental, construction, hydraulic, and geotechnical engineering considerations. Then, having achieved an understanding of the primary design constraints of the project, they prepared an evaluation matrix in which weighted decision criteria were applied to each concept design. Based on input from their collaborators, including the School A renewable energy system project leaders, the team made a recommendation to proceed with a final design that integrates geothermal and photovoltaic solar components. This design was shown to diversify School A's renewable energy portfolio while reducing annual energy costs by 40%.

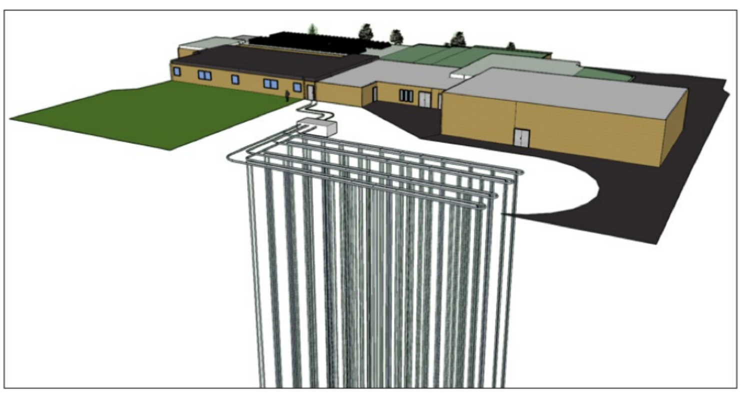


Figure 1: Rendering of renewable energy system at School A, facing northeast (including solar and geothermal system components)

As noted, several design constraints for the project were considered. Economic viability of the final design depended on staying within a fixed budget for implementation and meeting a target of 7 years projected payback. As a sustainability project, the team assessed the potential burden on the environment and emissions associated with the stages of both the solar array's life-cycle and the geothermal system's life-cycle, which were assumed to be 30 years and 50 years, respectively. Social, political, and ethical concerns were considered with respect to public acceptance of the renewable energy system. In addition to worker safety, there was an important need to develop a final design that was isolated from school children who may been near the system. Finally, constructability considerations related to earthwork required for the geothermal field and structural integrity of the 1956 rooftop that will support the mounted solar panels.

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School A has requested engineering services to design a new, expanded renewable energy system on school property consisting of solar, wind, geothermal energy, or a mix of these energy sources. The renewable energy system must make economic sense for the district to invest in with a goal of meeting 25% of the school's energy needs. The school would like for the project to also provide learning opportunities for high school students, who will participate in an introductory engineering course, as well as the surrounding community.

Figure 1. School A property line.

The district will explore public-private partnerships for possible sources of funding for the project with a target of 7 years projected payback. Towards that end, School District A challenged a team of civil and environmental engineering undergraduate students (the student team) to evaluate the costs and output of the solar, wind, and/or geothermal deployment and their associated budget ranges, cost/benefit analysis, and lifetime sustainability in order to recommend a final design that meets the School's goals for energy output, environmental sustainability, and educational opportunities.

With the project goals established, the student team began collaborating with faculty members, professional engineers, mentors, and project leaders from the school. The design included application of engineering principles in structural, environmental, construction, hydrologic, and geotechnical engineering. The student team prepared and submitted: a proposal (as though they were competing for the project); a formal preliminary design report describing the three concept designs; a listing of pertinent regulatory standards and professional codes; a geotechnical report; contract documents (construction contract, technical specification, construction plans); regular project management reports; regular peer evaluation reports; opinions of cost; and project schedules. Their work included three formal presentations of their design proposals.

The student team developed three concept designs for the School A renewable energy system: Design I consisted of installing a 990-solar panel array system on the school's rooftop; this option was not chosen, as the school already had a solar array installed and it did not diversify School A's portfolio. Design II consisted of installing a 100 kW wind turbine on the northwest portion of the school property; this option was not chosen because it produced less energy than other options and because of potential social impacts on the community, such as view disruption. Design Ill, the recommended option, consisted of pairing a 990-solar panel array system on the school's rooftop with a 92-ton vertical geothermal system in the field west of the school. This option helped to significantly reduce energy costs and diversify School A's renewable energy portfolio.

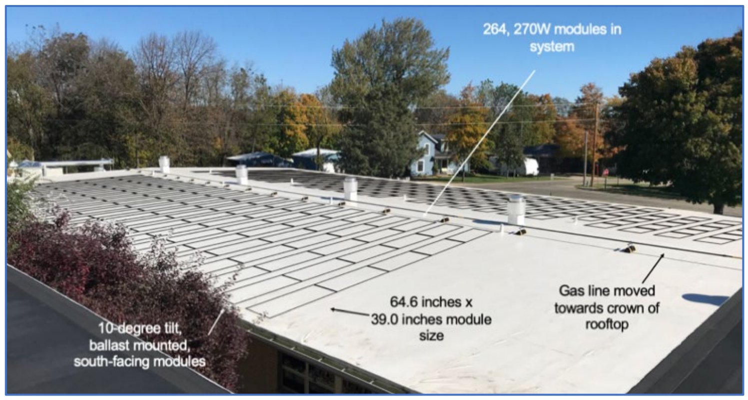

Figure 2. Solar component of the final design, facing northeast.

The student team then developed an Evaluation Matrix to compare the three alternative designs based on environmental, safety, construction, economic, and societal considerations. The student team ultimately recommended a final design that integrates a 75-ton geothermal energy system – which includes 44, 350-foot vertical wells – with a 71 kWdc expandable photovoltaic solar array system – which includes 264 south-facing ballasted solar panel modules. This design would offset School A's energy costs by 40% by producing 98,000 kWh and reducing the school's consumption of natural gas by 28,000 CCF annually.

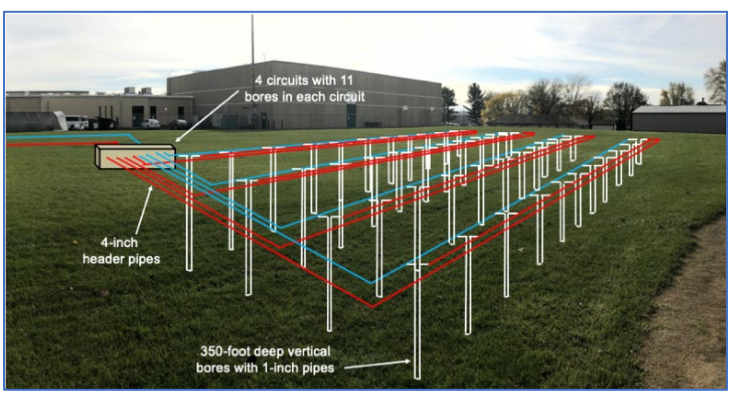

Figure 3. Geothermal system component of final design, facing southeast.

Collaboration of Faculty, Students and Licensed Professional Engineers

Were licensed professional engineers (P.E.s) involved?

Two of the professors for the class are currently licensed P.E.'s and provided design supervision, lessons-learned experiences, critique and oversight for presentations and reports, and advice for client relationships and public meetings. In addition, overall instruction for the course was provided weekly by a P.E. Two student team presentations (at the preliminary and final design stages) were made to a panel of judges from the local P.E. community, thereby widening the students' exposure to other professionals and affording opportunities for additional critique of their work.

How did the students, faculty, and P.E.s interact?

The weekly contact between the P.E. professors and students allowed the students to benefit from the P.E.'s many years of experience. At the same time, the judges and faculty expected the student team to retain responsibility for its own performance to the pre-established goals for time management, presentations, design components, deliverables, and schedules. Both judges and faculty made themselves available for phone or email discussions as necessary and provided review of the student deliverables.

What did the students learn through the collaboration that would not have been learned in the classroom?

<u>Communication and Collaboration as Components of Design</u>: Collaboration between engineers, stakeholders, regulatory agencies, and the public is difficult if not impossible to teach in the classroom. In this project, the student team spoke directly to the project leaders in School A, learning to listen and balance the needs and requirements of various entities. The project constraints and needs then became critical elements of three concept designs.

<u>Multiple Right Answers</u>: Most classroom activities and problems are designed to promote an understanding of the theory by having a single "correct" answer. In this project, having achieved an understanding of the engineering, economic, environmental, and public constraints, the students prepared an evaluation matrix (Figure 4) in which weighted decision criteria were applied to three concept designs, all of which can be considered "right answers". The team made a recommendation to proceed with Design III, the most expensive option to implement but one that satisfied the reduction in energy costs and carbon footprint over the system lifetime while diversifying School A's renewable energy portfolio.

Criteria Considered		Weight (%)	Design I		Design II		Design III	
			Rating (1-3)	Score	Rating (1-3)	Score	Rating (1-3)	Score
Environmental Analysis	Energy Production	10	2	0.20	1	0.10	3	0.30
	CO2 Avoidance	10	2	0.20	1	0.10	3	0.30
	System Lifetime	10	2	0.20	1	0.10	3	0.30
Safety Analysis	Construction & Use	25	2	0.50	1	0.25	3	0.75
Construction Analysis	Ease of Construction	10	3	0.30	1	0.10	2	0.20
Economic Analysis	Annual O&M Costs	5	3	0.15	1	0.05	2	0.10
	Initial Project Costs	5	3	0.15	2	0.10	1	0.05
	Payback Period	10	3	0.30	1	0.10	2	0.20
Societal Analysis	Visual Obstruction	5	1.5	0.08	1	0.05	1.5	0.08
	Disruption	5	3	0.15	2	0.10	1	0.05
	Education	5	2	0.10	2	0.10	2	0.10
Total		100	Score	2.33	Score	1.15	Score	2.43

Figure 4. Evaluation Matrix - a higher score indicates a more desirable outcome.

Application/Integration of Multiple Disciplines: In this project, it was necessary for the student team to combine their individual skills for successful performance of the work, yet complete tasks in several disciplines of civil and environmental engineering. To do this, they identified the skill sets of each team member, assigned themselves tasks accordingly, and sought outside advice from mentors, faculty and other students in areas where needs remained.

Learn to Identify the Uncertainties: Engineering projects have uncertainties, and awareness of the uncertainties informs the designers and user of related risks. Many classroom activities present the student with data and/or a set of assumptions upon which analyses are to be based. In this project, students were challenged to identify areas where they did not have or find pertinent information, or where certain information was not knowable prior to performing analyses. They correctly identified several items (geotechnical conditions, current-day quality of existing materials, site plans prepared by others, etc.) as items that should be noted and considered.

Protection of Public Health, Safety, and/or Welfare of the Public

The student team was challenged to evaluate the three design alternatives based on environmental, safety, and societal considerations. Constructability and economic viability were also considered. Economic viability of the final design depended on staying within a fixed budget for implementation and meeting a target of seven years projected payback. As a sustainability project, the team assessed the potential burden on the environment and emissions associated with the stages of both the solar array's life-cycle and the geothermal system's life-cycle, which were assumed to be 30 years and 50 years, respectively. Social, political, and ethical concerns were considered with respect to public acceptance of the renewable energy system. In addition to worker safety, there was an important need to develop a final design that was isolated from school children who may be near the system. Finally, constructability considerations related to earthwork required for the geothermal field and structural integrity of the 1956 rooftop that will support the mounted solar panels. The selected design scored highest with respect to environmental and safety considerations and very well with respect to societal considerations.

Environmental Engineering. As noted, the student team assessed the potential burden on the environment and emissions associated with the stages of both the solar array's life-cycle and the geothermal system's life-cycle. A cradle to grave assessment was completed and the amount of energy required for the whole life cycle of the solar system and geothermal system were found to be approximately 280,000 MJ and 110,000 MJ, respectively. The student team also found that this design would reduce the school's emissions by approximately 8,200 tons of CO2 annually.

Multidiscipline and/or Allied Profession Participation

During this project, the work by the student team included structural, geotechnical, environmental, hydraulic, and construction engineering, drafting, estimating, scheduling, client and community interaction, review of regulatory requirements and professional standards, and preparation of written reports and construction documents. The five civil and environmental engineering students logged approximately 1,200 hours of design work, including team meetings and meetings with mentors and faculty.

Examples of the multidisciplinary engineering analysis performed by the student team follow:

Structural Engineering. The structure that will support the solar array was built in 1956, a time when structures were built to support a snow load of 30 pounds per square foot (psf). Current codes only require 20 psf for snow load. Therefore, the solar panels can weigh up to 10 psf, but the proposed system would only add approximately 5.2 psf of load. The structural analysis of the roof-mounted array also accounted for loading due to wind. The proposed solar array will be installed using a ballast mounting technique, which is ideal because it eliminates rooftop penetration. A schematic of a typical ballast system is shown in Figure 5.

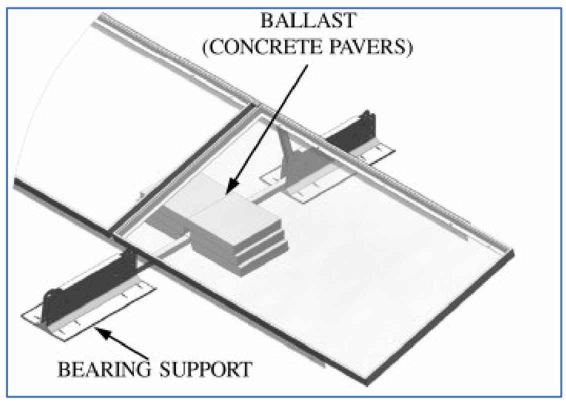

Figure 5. Illustration of ballast mounting technique.

Construction Engineering. The site staging and sequence of construction was established for the proposed design. The vertical well geothermal system will be installed in the field west of the school, which is easily accessible. The staging areas for both systems and the geothermal access route is shown in Figure 6.

Figure 6. Construction sites and staging areas.

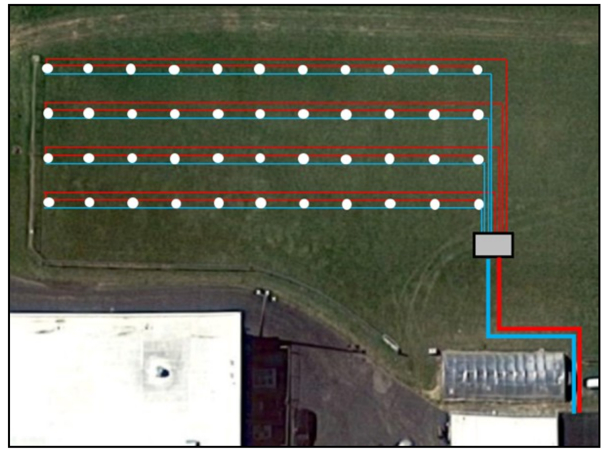
Figure 7. Aerial view of geothermal well system.

Hydraulic Engineering. To appropriately size the geothermal system, an analysis of the system's flow rates was conducted acknowledging anticipated head losses. This allowed the student team to correctly size all pipes in the system and determine the most appropriate pump for the system flow. The total flow rate required for the 75-ton system is 225 gallons per minute (gpm). As illustrated in Figure 7, header pipes (HDPE DR-11, 4-inch diameter) will route water to and from the four circuits of 11 geothermal wells each. The header pipes merge in a vault located below the ground surface. From the vault, the heated water is routed into the school and to the mechanical room in the basement where heat pumps will be located. The recommended heat pump can accommodate a flow rate of 57 gpm, and a total of four heat pumps will be needed.

Geotechnical Engineering. The student team utilized three Wisconsin DNR well logs to estimate subsurface conditions at School A. These well logs – all located within 1,300 feet of School A – showed a clay layer overlaying a clay with sand and gravel layer overlaying a sandstone layer. Furthermore, the water table was observed at a depth between 25 and 30 feet. A complete geotechnical analysis is still necessary for a more thorough, accurate design.

Knowledge and Skills Gained

The students applied their engineering curriculum to a real-world problem. They used their knowledge of civil engineering to evaluate alternatives, considered risks and benefits, and created a viable final design, while managing themselves to meet the time and budget constraints of their client and internal organization.

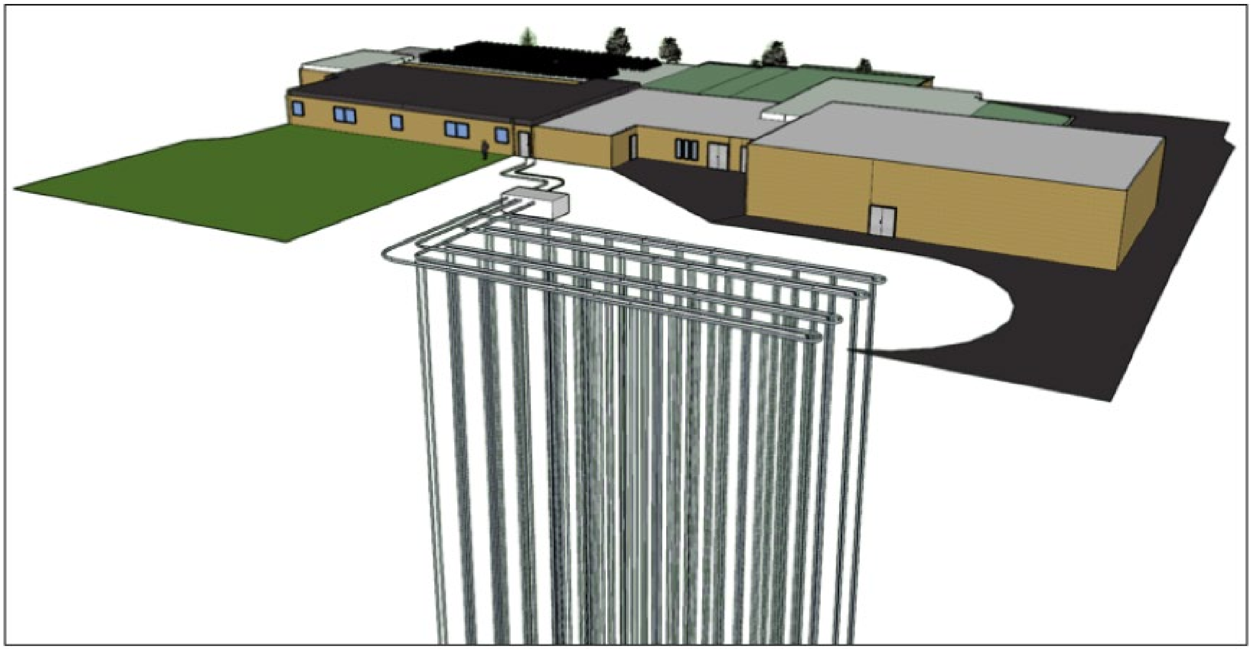

Figure 8. Rendering of the final design for the renewable energy system at School A, facing northeast (including solar and geothermal system components).

Their interaction with mentors and other members of the engineering profession taught them valuable communication skills, and gave them insights into questions about ethics, professional responsibilities, and the logistics of taking a design project to completion.