3.1 Design Context

3.1.1 Broader Context

Describe the broader context in which your design problem is situated. List relevant considerations related to your project in each of the following areas:

Area	Description	Examples
Public health, safety, and welfare	The public health and safety will be increased due to the decrease in fossil fuels consumption.	Reducing exposure to pollutants and a reduction in operations and maintenance.
Global, cultural, and social	Our project reflects the values of the city and Ames and of the University. Both groups are working to reduce their dependence on fossil fuels.	Convincing the university to implement this technology would need a strongly backed proposal.
Environmental	The project is intended to reduce the negative environmental impacts of the university's power plant.	Decreases energy generated using non-renewable sources.
Economic	Helping the school reduce oil and gas purchases. Helps power plant reduce steam output across campus.	Buy renewables off MISO and store heat for steam. This allows us to decrease the amount of steam that the powerplant has to generate and also saves us money from oil and gas purchases.

3.1.2 User Needs

List each of your user groups. For each user group, list a needs statement in the form of:

- Iowa State University
  - The “thermal battery” will be used to reduce Iowa State’s dependence on fossil fuels by using renewable energy to store heat for later use. In other words, the battery will be “charged” with heat in the summer when the heating demand is low and it will be released in winter when demand is high.
- The students, faculty, and visitors at Iowa State University
  - This group relies on the current heating system in place at Iowa State University. They need a way to have heating at all times, no matter the circumstances. Our design will revolve around the idea of a secure heating source under all conditions.
- Ames Electrical Power Plant Faculty
  - This group needs a way to connect to and control the input, output, and interior conditions of the system. They will be maintaining and operating the system, so we will need to conform to their design requests as well.

3.1.3 Prior Work/Solutions

Include relevant background/literature review for the project:

We are working with Polar Night Energy, who primarily works in Finland. They are building their first two systems for public use in Kankaanpää and Tampere. These are finnish cities. These require less power than the system our school needs, but these projects show that they work, are sustainable, and cost effective.

https://polarnightenergy.fi/references

3.1.4 Technical Complexity

Provide evidence that your project is of sufficient technical complexity. Use the following metric or argue for one of your own. Justify your statements

1. The design consists of multiple components/subsystems that each utilize distinct scientific, mathematical, or engineering principles.

Engineering & Mathematical Principles involved:

- Economic calculations on capital and ongoing costs.
- Power plant engineering
  - embedding PNE into the current system.
  - Space and heating load estimation.
- Emission reductions/environmental impact of the system

2. The problem scope contains multiple challenging requirements that match or exceed current solutions or industry standards.

Solution complexity and challenges:

This system would be one of the first in use. It would provide a new outlet for renewable energy, and energy conservation. The implementation of this project would also be a model for heating large communities with low carbon emissions.

3.2 Design Exploration

3.2.1 Design Decisions

List key design decisions (at least three) that you have made or will need to make in relation to your proposed solution. These can include, but are not limited to, materials, subsystems, physical components, sensors/chips/devices, physical layout, features, etc.

1. Where the system will be located on campus or near campus.
2. How large the system will be.
3. How much energy our system provides the university.

3.2.2 Ideation

For one design decision, describe how you ideated or identified potential options (e.g., lotus blossom technique). List at least five options that you considered.

Design Decision	**Observation**	**Ideation**
ISU heating load	Our original design revolved around implementing our system at the ISU Power Plant.	This design had multiple options. First, we had hoped our system would have the potential to produce 100% of the university's steam. This design turned out to be very large and expensive. So, we further split that idea into 75%, 50%, and daily steam production.
Location	We then went on our power plant tour, and this led us to design a system further downstream in the district heating system.	As our PNE system can produce steam at 90 PSIG, we can connect our system where the campus uses 90 PSIG steam to increase efficiency. This system will also reduce the pressure drop that occurs far from the source, the Ames Electric Power Plant.
Costs	The university needs a way to decrease their fuels costs while continuing to provide steam for the university	The installed PNE will be powered by renewable energy to be purchased at low prices during off-peak hours. The cost of purchasing renewables is cheaper than buying coal and gas through the addition of renewable energy credit.
Size	ISU Power Plant planned to eliminate all coal generators in 4 years time leaving a huge empty space at the power plant.	The first plan to place PNE at the power plant replacing the current coal boilers. However, the director suggested a location at the parking lot on the west side of the campus. The size of the storage can occupy the suggested location which includes the decision to place the storage either above ground or underground.
Hooking into the steam lines on the other side of campus from the power plant.	The pressure in the steam pipes currently drops off as you get farther from the power plant.	Our PNE system would be able to reduce that pressure drop by providing an influx of steam in a different location. This would allow the whole district heat system to run more efficiently.

3.2.3 Decision-Making and Trade-Off

Demonstrate the process you used to identify the pros and cons or trade-offs between each of your ideated options.

Our first option was to design our system to meet 100% of the University's heating demands. This system would be located at the Ames Power Plant, and connect to the current district heating system. We decided as a group that meeting 100% of the University's demands was semi-impractical as the size of the system would need to be very large, and in turn expensive. We decided to take into consideration the thoughts of the university and ask the director of the power plant what his thoughts are. This collaboration allowed us to get insight into where the ideal location would be for our system. Weighing the pros and cons of these initial designs, we concluded that a smaller system downstream would be best for the University and our group.

3.3 Proposed Design

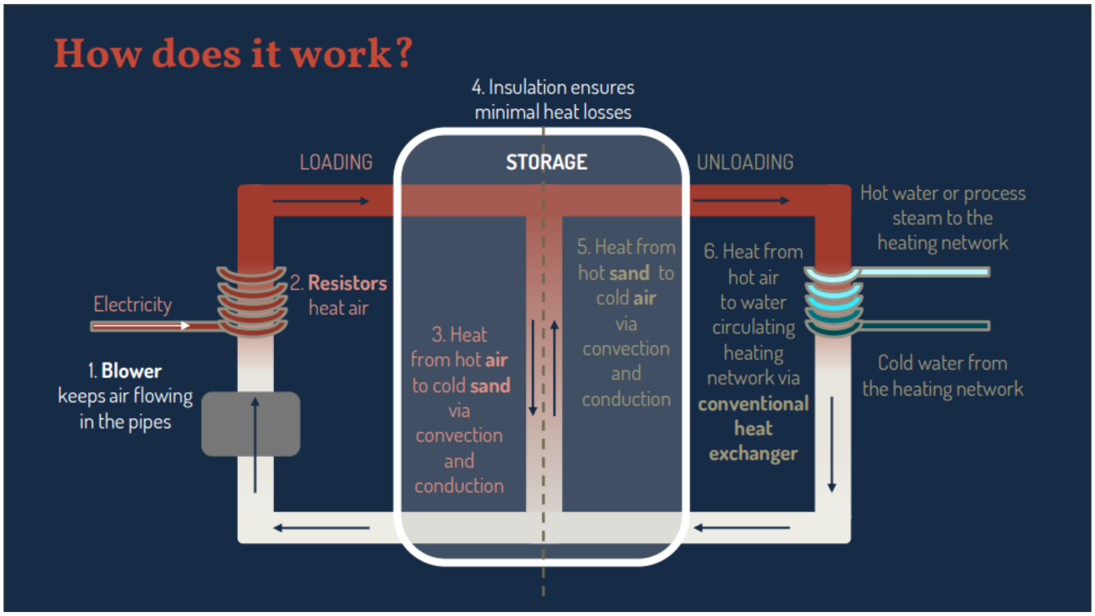
Discuss what you have done so far – what have you tried/implemented/tested?

Currently, we have collected the heating energy use data from 2020-21. This will give us a baseline for the size we would like to design our system around. We have also gone as a group and received a tour of the power plant that supplies ISU with heating, cooling, and electricity. During this tour we asked our guide, Mark Kruse, what the best location may be for a system such as ours. This led us to designing our system downstream and not located within the power plant itself. While these are not directly tests on a system, we are incorporating decision making and trying to find the most effective solution to the problem at hand.

3.3.1 Design Visual and Description

Include a visual depiction of your current design. Describe your current design, referencing the visual. This design description should be in sufficient detail that another team of engineers can look through it and implement it.

- Following the diagram below, the steps are as follows.
  - 1. A blower, one of the only moving parts in this system, keeps air moving through the system.
  - 2. Renewable energy purchased from the grid is applied to resistors in order to heat the air going into the storage container.
  - 3. Heat is transferred from the air to the sand by convection and conduction.
  - 4. The insulated storage reduces heat loss which is pivotal in that it allows us to store the heat for longer periods of time.
  - 5. The same way the heat is stored it is extracted from the hot sand to the air.
  - 6. The heat in the air is then transferred to water by a heat exchanger. In our case, we want it to be used to make 90 PSI steam to heat the campus.
  - Lastly, the steam is pumped into the existing steam system to meet campus needs.

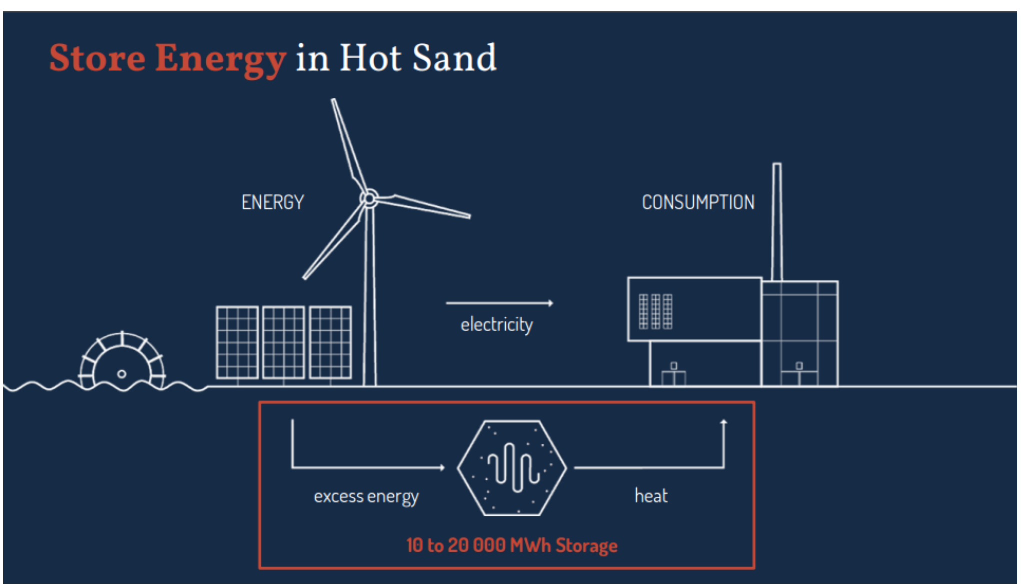


3.3.2 Functionality

Describe how your design is intended to operate in its user and/or real-world context. This description can be supplemented by a visual, such as a timeline, storyboard, or sketch.

How well does the current design satisfy functional and non-functional requirements?

- Polar Night Energy's system uses electricity to heat sand in an insulated enclosure. This heat can then be extracted to generate steam which can be used for heating or power. In Iowa State University's case the idea is to purchase renewable energy from the grid at night and in the summer when energy demand is low, store that energy as heat in the "thermal battery", and expel that heat energy during the day and in the winter when demand is high.
- Polar Night Energy's design fulfills all functional and non-functional requirements.



3.3.3 Areas of Concern and Development

What are your immediate plans for developing the solution to address those concerns? What questions do you have for clients, TAs, and faculty advisers?

There are two points of possible concern. The first is whether or not we can get the cost to be a net positive after reducing our gas and coal costs. The second would be whether or not the university will be willing to implement it should we find that the system is economical. The immediate plan is to find the sweet spot where we can maximize the reduction in fuel costs with a minimum investment cost. This would make the university more likely to build the system. We have already gathered a ton of information from PNE, ISU, MISO, and our adviser. The next step is to consolidate that information into a strong argument.

NOTE: The following sections will be included in your final design document but do not need to be completed for the current assignment. They are included for your reference. If you have ideas for these sections, they can also be discussed with your TA and/or faculty adviser.

3.4 Technology Considerations

Highlight the strengths, weaknesses, and trade-offs made in technology available.

Discuss possible solutions and design alternatives

3.5 Design Analysis

– Did your proposed design from 3.3 work? Why or why not?

– What are your observations, thoughts, and ideas to modify or iterate over the design?

3.6 Design Plan

Describe a design plan with respect to use-cases within the context of requirements, modules in your design (dependency/concurrency of modules through a module diagram, interfaces, architectural overview), module constraints tied to requirements.