



**STEAM TURBINE ELECTRIC GENERATOR**

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# Project title: STEG

## Component 1: Research

### Element A: Identification and Justification

#### Problem Statement: (ACT 2.0)

Almost all energy production is done with steam generators, since heat is the most common energy source, yet steam generators are only 33-48% efficient in transferring the heat energy to electricity, whereas a hydroelectric generator will have a 80% or higher efficiency, and wind turbines get about 50%. Using energy sources other than heat, higher electricity generation rates can be obtained, suggesting that turbines are not the issue. A new way of translating heat into motion needs to be found in order to increase the efficiency of electric generation.

#### Becoming an expert: (ACT 2.5)

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##### Associations, Organizations, and Societies:

GE (General Electric) - <https://www.ge.com/power>

EGSA (Electrical generating systems association) - [EGSA.org](http://EGSA.org)

Electric power research institute - <https://www.epri.com/>

NERC(North American Electric Reliability Corporation)<https://www.nerc.com/Pages/default.aspx>

NEEP (Northeast Energy Efficiency Partnership) - <https://neep.org/about>

Duke Energy <https://www.duke-energy.com/our-company/environment>

Exelon <https://www.exeloncorp.com/company/about-exelon>

energy and resources group <https://erg.berkeley.edu/>

Consumers energy - <https://www.consumersenergy.com/> - [education@consumersenergy.com](mailto:education@consumersenergy.com)

Duke energy carolinas - <https://www.duke-energy.com> -

Public service elec and gas [www.pseg.com](http://www.pseg.com)

DTE energy - <https://www.newlook.dteenergy.com/>

Dominion Energy <https://www.dominionenergy.com/> - [customercare@dominionenergy.com](mailto:customercare@dominionenergy.com)

Georgia Power - <https://www.georgiapower.com/> -  
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 Eric Prescott - [eprescott@epri.com](mailto:eprescott@epri.com)

## Conducting market research: (ACT 4.4)

Questions:

1. What do you need to know to design and develop a solution to your chosen problem?  
We need to know the specific mechanisms within turbine generators.
2. What is the need or want in your problem statement that is causing a problem?  
Heat in electric turbines does not convert to motion efficiently.
3. What customers will be interested or served by a solution to the problem?  
Electricity providers will be interested as well as companies that produce their own electricity
4. Is the assumed target market correct, smaller, larger?  
The target market is larger because electricity providers are large corporations.
5. Do products exist that already serve as a solution?  
Yes, all existing methods of generating electricity via heat are solutions to the problem, we are trying to create a more efficient method of making electricity
6. What competitors affect your solution options?  
Our solution is affected by our potential customers, who are presumably also working to improve their efficiency. Additionally, there are other companies and teams working to increase efficiency.
7. What solution characteristics and features are most important?  
Rate of electric generation, economic impact of solution components, and cost of components
8. How much would people pay for a solution?  
People would pay less than 7 cents per kilowatt hour of electric generation, as that is the lowest cost of power generation. A small generator can produce about 2 kilowatts of electricity for under \$500. People would pay less than that price - around \$200 - \$300, for a generator that could produce electricity at the same rate more cheaply.
9. Is the problem definition adequate or is the problem broader or narrower than the original problem statement indicates?



The problem definition is adequate. The problem is the release of energy, putting it to waste.

Designing the Market Research Plan:

Informational interviews:

Interview with experts - to learn about different facets of the problem - talk about types of turbines and generators - talk about different ideas and bounce different solutions around.

To do - email experts after we confirm a mentor

Surveys:

Targeted at home owning adults. Over the internet. To discern the relevance of a solution to the general public.

1. Have you noticed increasing electricity bills in the last 5-10 years?
2. If you said no to the above - Have you [or your family] made a concerted effort to reduce electricity usage
3. If you said yes to the above - have you [or your family] noticed an increased usage of electricity

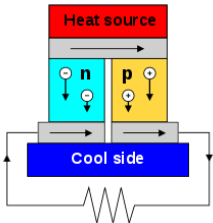
Focus groups:

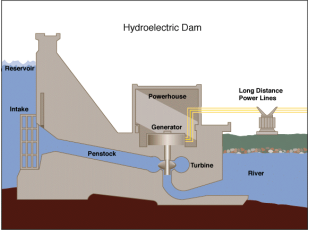
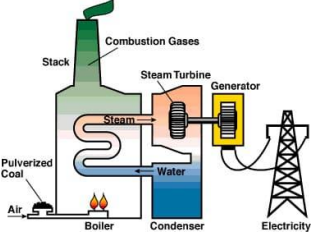
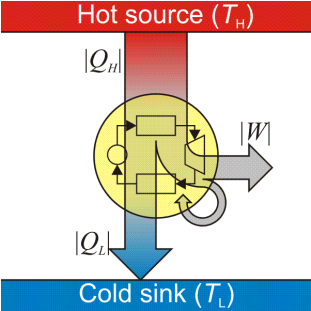
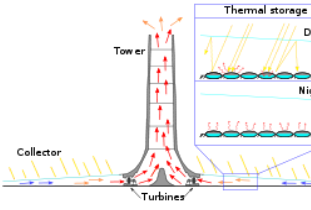
To be held after a working prototype has been developed to some degree. Associations and societies will be invited - to review our solution and its overall relevance.

## Knowledge of the Marketplace (Act 4.1)

Existing Similar Products:

The following table is used to research different types of possible solutions. Listing their pros and cons, it allows us to easily see what works in a design and what doesn't. It also requires us to research market users, giving us cost constraints based on the target consumer.

| Solution   | Pros   | Cons   | Market users   |
|--|--|--|--|
| <a href="#">Seebeck Generator</a><br> | <ul style="list-style-type: none"> <li>-Doesn't require moving parts</li> <li>-Uses changes in temperature</li> <li>-Solid state device</li> <li>-Clean</li> </ul> | <ul style="list-style-type: none"> <li>-Maximum efficiency is only 8.45%</li> <li>-Costs more for each watt</li> <li>-Requires high level engineering</li> </ul> | <p>Age: n/a<br/> Income: &gt;\$50M per year<br/> Location: Power Plants<br/> Education Level: B.S. or higher<br/> While a few small generators may be used privately, most are purchased commercially.</p> |
| <a href="#">Hydro turbine</a>  | <ul style="list-style-type: none"> <li>-Current largest source of renewable energy for US</li> </ul>   | <ul style="list-style-type: none"> <li>-Requires dams and takes up large space</li> </ul>  | <p>Age: n/a<br/> Income: &gt;\$200M per year<br/> Location: Close to a reservoir of water. Up on mountains.</p>  |

|   |   |  |   |
|---|---|--|---|
|  <p>Hydroelectric Dam</p>              | <p>-Up to 90% energy conversion</p> <p>-40% the cost of fossil fuel</p>   | <p>-Affects ecosystems in bodies of water</p> <p>-High initial cost</p> <p>-Emits CO<sub>2</sub> and methane</p>                           | <p>Education Level: B.S. or higher</p> <p>This one requires a little more investment in money and time. Only larger corporations will probably be able to buy it.</p>   |
| <p><u>Steam Turbine Generator</u></p>  | <p>- Operating speed is fast</p> <p>- High heating efficiency</p> <p>- high pressure of gas (because water)</p>   | <p>- high overnight cost</p> <p>- Less responsive to changes in power demand</p>   | <p>Age: n/a</p> <p>Income: &gt;\$50M per year</p> <p>Location: Power Plants</p> <p>Education Level: B.S. or higher</p> <p>Almost every power company uses this form of generator. Used for nuclear, fossil fuel, geothermal, etc..</p>                    |
| <p><u>Chemical heat engine</u></p>   | <p>-Uses changes in temperature</p> <p>-High heating efficiency</p> <p>-Uses abundant resources</p> <p>-</p>  | <p>-Requires large area</p> <p>-Large chemical consumption</p> <p>- Requires different fields of expertise</p> <p>-High operating cost</p> | <p>Age: n/a</p> <p>Income: &gt;\$100M per year</p> <p>Location: Power Plants</p> <p>Education Level: Experienced in power industry</p> <p>Cost can depend since it's a specific component of a generator. Any power company can probably afford it.</p>   |
| <p><u>Power updraft tower</u></p>    | <p>-24/7 automation</p> <p>-no resource costs</p> <p>-more efficient at higher latitudes</p> <p>-1 km tower estimated produce of 100MW and costs about 3.5 cents per MW</p> | <p>-air absorbs less energy than water</p> <p>-can produce small amounts of CO<sub>2</sub></p> <p>-depends on sunlight</p>                 | <p>Age: n/a</p> <p>Income: &gt;\$50M per year</p> <p>Location: Higher latitudes and sunny areas</p> <p>Education Level: n/a</p> <p>This one can use any heat source. As it takes a lot of space, only governments or large corporations would buy it.</p> |

|  |   |   |   |
|--|---|---|---|
| <a href="#">Patent for turbine blades in the shape of an airfoil</a> | -Airfoil shape is more efficient at converting steam's pressure into rotational energy  | -airfoil shapes are harder to manufacture than other shapes | Age: n/a<br>Income: >\$100M per year<br>Location: Low pressure Steam Turbines<br>Education Level: B.S. or higher<br>This component of an electric generator will only be implemented by the manufacturers and developers of electric generators |
| <a href="#">Patent for coil of electric generator</a>                | - improved efficiency of rotation to EMF<br>- reverses negative effects of deceleration | -very complex   | Age: n/a<br>Income: >\$100M per year<br>Location: electric generators<br>Education Level: B.S. or higher<br>This component of an electric generator will only be implemented by the manufacturers and developers of electric generators         |

The figure below describes the different users and buyers for STEG. They range from car companies to air conditioning to power companies. It also states the regions of these companies.

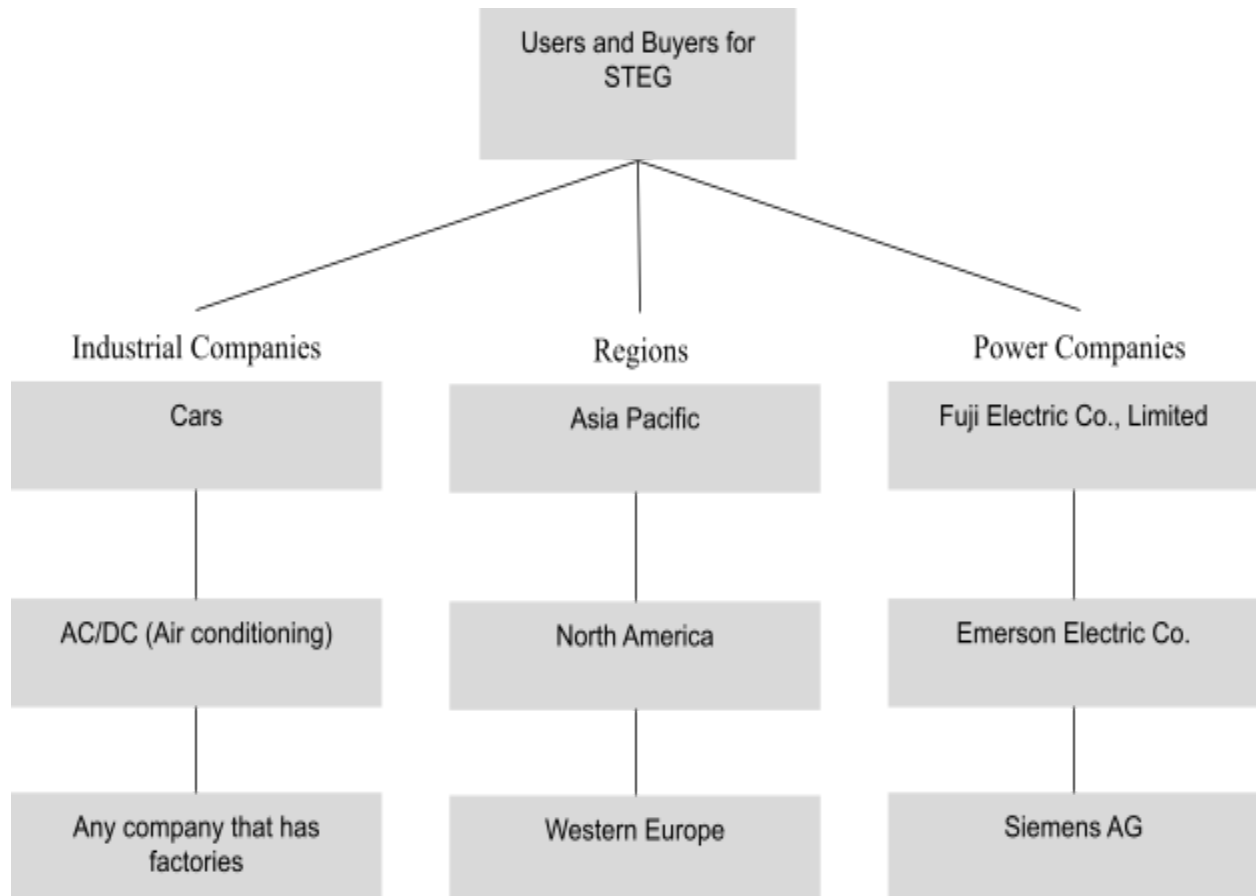


Figure 1: users and buyers for project STEG

### Evaluating Competition:

1. Who are our major competitors?
  - a. All steam turbine manufacturers and designers currently in business
2. On what basis do you compete?
  - a. We are trying to design a steam generator or a system within the generator that improves water efficiency
3. How do you compare?
  - a. We will measure the water use per unit of electricity created
4. Who are potential future competitors?
  - a. New power generation companies and steam turbine manufacturers
5. What are the barriers to entry for new competitors
  - a. Industrial scale steam turbines are very big, expensive and hot. Often, the turbine itself will exceed 15 meters in length and the steam, when it enters the high pressure blades, will be between 350 and 500 degrees celsius.

### Justification:

Our market is quite large as there are thousands of power companies around the world. Due to lack of resources and money, our team plans to create a small model prototype of our idea to propose to the market, dealing with a specific aspect of the problem, the heat to turbine energy conversion . It may be advisable to target smaller companies to increase our chances in selling our product.

## Element B: Documentation and Analysis of Prior Solution Attempts

### Prior Solution Attempts (ACT 1.0)

Adam, Jack, Yamato, Oisin

The prior solution matrix is used to index past solutions, ranking them on a number of factors. This is important because it not only gives us specific ideas for our design, but also lets us know what has already been done and what to avoid.

| Similar Solution Matrix   |   |  |  | Specifications                 |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|---|---|--|--|--------------------------------|---|---|---|---|---|---|---|---|--|--|--|--|--|--|--|--|
|   |   |  |  | 1 turbine usage (0-1)          |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | heat transfer efficiency (0-5) |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 3 innovative design (0-5)      |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | resource consumption (0-5)     |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 5 emissions (0-5)              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 6 potential cost (0-5)         |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 7 feasibility (0-5)            |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 8 specific appeal (0-5)        |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | general appeal of idea (0-5)   |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 10                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 11                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 12                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 13                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 14                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 15                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
| Sources   | Solutions & Designs   |  |  |                                |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | Self contained heat exchanger for electric generation   |  |  | 0                              | 5 | 5 | 5 | 5 | 0 | 1 | 3 | 5 |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | Power tower - system and method of using air flow generated by geothermal heat  |  |  | 1                              | 5 | 5 | 5 | 5 | 1 | 1 | 3 | 5 |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | Wind turbine generator including air-cooled heat exchanger  |  |  | 1                              | 4 | 5 | 5 | 5 | 2 | 0 | 3 | 3 |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | Gas turbine heat recovery steam generator and method of operation   |  |  | 1                              | 4 | 5 | 5 | 4 | 3 | 4 | 4 | 4 |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | System for generation of electricity by utilization of heat exchange between liquefied natural gas and intermediate heat medium |  |  | 1                              | 3 | 4 | 3 | 4 | 2 | 2 | 2 | 2 |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | Electricity generation device with several heat pumps in series   |  |  | 1                              | 4 | 3 | 4 | 5 | 3 | 4 | 4 | 4 |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | System for generating electricity using a chemical heat engine and piezoelectric material                                       |  |  | 0                              | 5 | 5 | 5 | 5 | 3 | 2 | 2 | 4 |  |  |  |  |  |  |  |  |
| <a href="http://patft.uspto.gov/r">http://patft.uspto.gov/r</a> | Passive heat extraction and electricity generation  |  |  | 0                              | 5 | 5 | 2 | 2 | 3 | 1 | 3 | 4 |  |  |  |  |  |  |  |  |
| Experts   |   |  |  | 1 Nikola Latic                 |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 2                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 3                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 4                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 5                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 6                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 7                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 8                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 9                              |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 10                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 11                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 12                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 13                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 14                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 15                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 16                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |
|   |   |  |  | 17                             |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |

Figure 2: design matrix ( appendix : 3 )

This design matrix showed us a number of things in terms of solutions. Firstly, there are many more turbine-less solutions out there than we had initially presumed. However, these solutions appear to be very costly, hard to implement, and don't seem to be more efficient than turbine generators. There are a few non-steam-powered turbine users using heat as an energy source. These tell us that it is possible to use mediums other than water, and are pointing us toward looking at different possible mediums.

## Element C: Presentation and Justification of Solution Requirements

### Design Specifications (ACT 1.1)

**Customer Needs** - The customers want efficient ways to generate electricity. Efficient meaning lower cost and higher output of electricity.

**Performance** - The product must be able to produce electricity via the use of heat in a manner such that the overall heat energy loss per unit of electricity produced is less than the current steam turbines in use.

**Target Cost** - Around 2 million per unit

**Size and Weight** - The restrictions of size and weight are that the new steam turbine must not be too much larger than the current models, thus allowing our turbines to fit inside power generation facilities with minimal modification to the current equipment layout. Alternatively, if our product improves the efficiency of a subsystem within the turbine, it must be able to fit inside the turbine with little to no change to the existing parts within.

**Aesthetics** - There are no preferences for the way it looks.

**Materials** - All materials used must be able to withstand the temperatures and pressures within the steam turbine chamber. This means that they must withstand at least 600 degrees celsius. If any of our materials are used in the turbine blades itself they must survive the high rpm the shaft reaches.

**Safety and Legal Issues** - Some safety issues could be from burns from touching hot casings. Also if someone deliberately removed the casing and entered the engine, they could receive injuries or death. Legal issues that could arise would be from designs being too close to patented turbines. Also if the turbine malfunctioned and caused fires or explosions.

**Ergonomics** - The turbine must be more efficient with its use of water, by circulating it better throughout the system. The turbine design must also be easier to navigate than current models, making it easy to maintain, easy to clean, and easy to attach several turbines to each other.

**Operating Environment** - The product would be made less effective by vibration and excess particles. It should be placed and not touched or moved while in use.

**Global Environment** - The product could contain dangerous substances. These would have to be disposed of carefully, cooling them and containing them in filtered containers.

**Service Life** - Around 25 years

**Product Life** - 25 years

**Durability and Maintenance** - Yes, it will need maintenance during service life. The turbine will need the most maintenance. This would be about every 6 months. These service maintenance checks would not require any special tools. If something is found broken or needs to be changed all components can be found at hardware stores and online stores.

Additional Criteria :

**List of criteria from most important to least important:**

Performance, target cost, materials, consumer needs, safety and legal issues, durability and maintenance, global environment, service life, product life, operating environment, size restraints, ergonomics, aesthetics

### **Design Constraints:**

Several months, ~\$200,

### **Survey:**

**Name of Product:** Heat Transfer Mechanism for Turbine Generator

**Designer:** STEG

**Target Consumer:** power distributor

**Design Specifications organized according to priority:** performance and cost

### Survey Results: Justification of the problem & Design Specification

- The two surveys below are designed to help provide evidence and justification to this project as well as help give us some solution ideas from the consumer.

Homeowners survey (appendix : 4)

- Have you noticed increased electricity bills in the past 5-10 years?
- If you said yes to the above, have you noticed an increase in electricity usage?
- How many kilowatt hours do you consume per month?
- What is your electric bill per month?
- Do you have at home electric generation?

The survey was sent out to adults who pay an electric bill. 7 have responded.

Survey results can be found at appendix : 6

The results from this survey serve to reinforce the justification for our project. Respondents from a wide range of locations reported having increased electric bills. Furthermore, around 40% said that they haven't noticed their usage of electricity increasing. While this response isn't 100% trustworthy, it suggests that, in some places, electric costs are increasing on their own. The other 60% are part of an increasing demand for electricity. This majority tells us that they need more and more electricity as the years go on, prompting more electric generation. Perhaps this is the reason why costs are going up - providers are forced to generate electricity at more hours of the day, at less opportune rates, and from more costly sources rather than renewable sources.

In any case, the fact that electric bills are increasing is worrying. It justifies that electricity generation is a growing market. These costs may continue rising and electricity prices may eventually become unaffordable and electric companies will no longer be able to sell a significant amount of their product. The remainder of the questions serve to give our team a little insight into the condition of the current market. This data (how much they pay and how much they use) can be used later in our project when we are creating our final design.

Design Specification survey ( appendix : 5 )

- Where is your company located?
- How does your company generate electricity?
- What is a technological advancement(s) that your company made within the power industry?
- Do you believe that the energy conversion methods that we currently have are the most efficient they can be?

The survey was sent out to around 20 electric providers. Zero have responded.

## Mentor Information

- Eric Prescott, project director of the Electric Power Research Institute: [eprescott@epri.com](mailto:eprescott@epri.com):  
Planned to have Virtual meetings once every two weeks. After the first meeting we have not met due to changes in our project.  
[Eric Prescott feedback](#)
- Daniel M. Kammen, professor of engineering at Berkeley, Chair of Berkeley energy and resource group: [kammen@berkeley.edu](mailto:kammen@berkeley.edu),  
Virtual meeting once every two weeks - have not met due to developments in our project  
[Daniel Kammen feedback](#)

## Component 2: Design

### Element D Solution Idea Brainstorming

The below charts and tables are brainstorming methods for grouping and generating possible solutions to research.

#### **Mind map method**



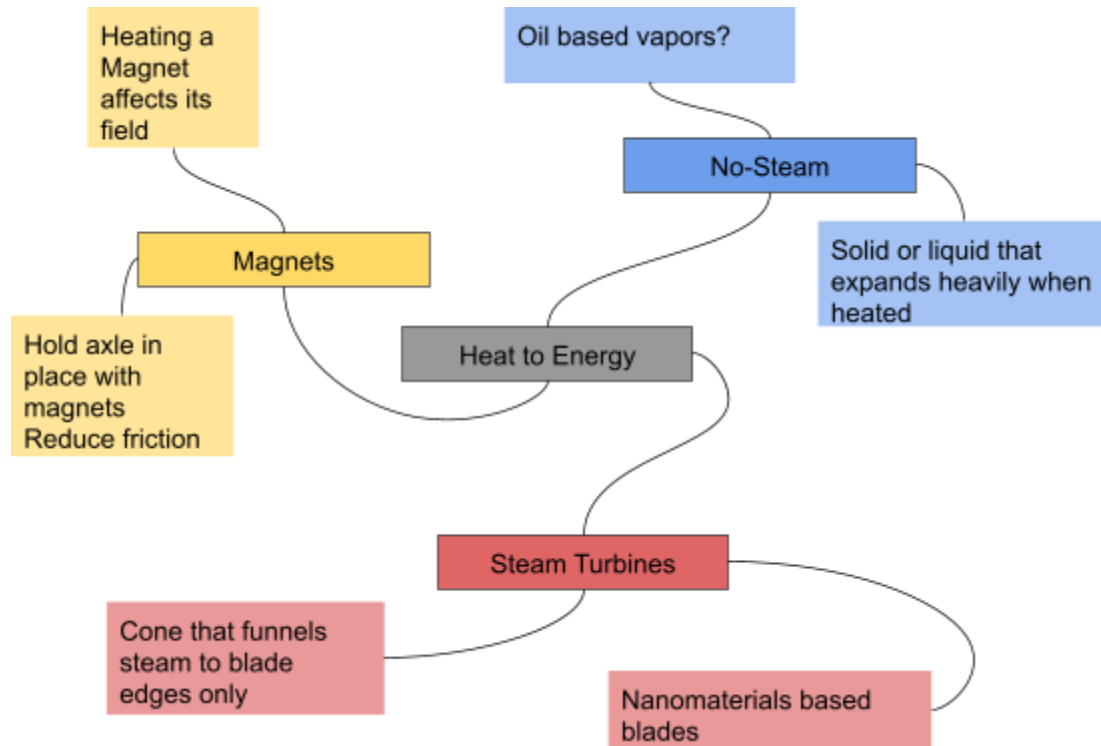


Figure 3: mind map brainstorming 1

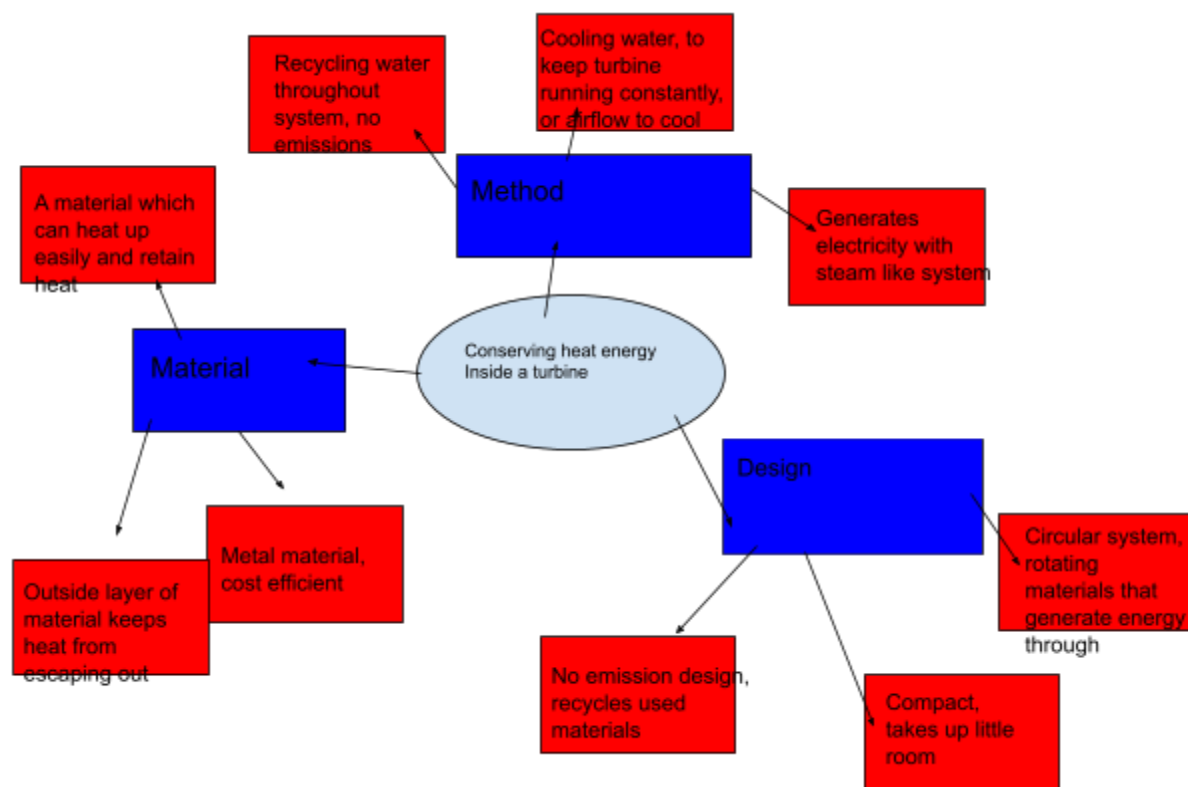
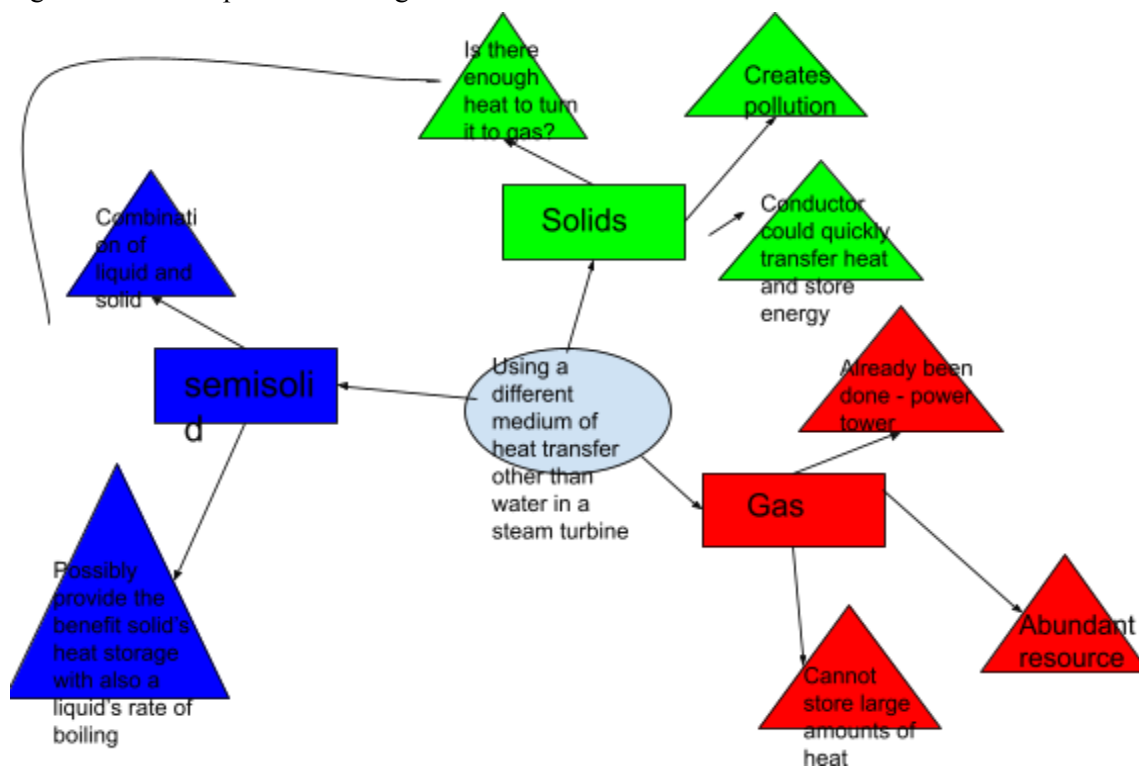


Figure 4: mind map brainstorming 2

Figure 5: mind map brainstorming 3  
SCAMPPER METHOD

|   |                  |  |
|---|------------------|--|
| S | Substitute       | Use sound energy instead? Can be done by using a transducer. Environment will matter.<br><a href="#">Research Paper</a>  |
| C | Combine          | Only uses kinetic energy at the moment to power the generator. We can utilize some of the heat energy that escapes in the process of converting to kinetic. (We can maybe use seebeck generators).<br><br>Also use hydro-turbines. The steam generators use water anyways. |
| A | Adapt            | N/A  |
| M | Magnify          | Use larger blades. Wind turbines are optimized by their large blades. Takes up a lot of space, but is good for efficiency.   |
| M | Modify           | Make it weigh less and reduce friction as much as possible. Use different materials and better motors. We can also modify the shape and number of the blades.  |
| P | Put into new use | n/a  |
| E | Eliminate        | Completely delete the turbine, and simply use the heat produced. Or delete the water and turbine and use the heat source.  |
| R | Rearrange        | N/A  |
| R | Reverse          | Start from kinetic energy? Or electricity?<br><br>Harvesting lightning energy:<br><a href="https://en.wikipedia.org/wiki/Harvesting_lightning_energy">https://en.wikipedia.org/wiki/Harvesting_lightning_energy</a>  |

Figure 6: scampper brainstorming method table

#### Additional Ideas

Turbine structure. More circular blades that catch more steam per turn. Already being used but could change materials to make turbines lighter and also stronger. Use gas instead of water. Idea doesn't work because it doesn't have a good recycling product.

Viewing all of these ideas, we first compounded ideas that were similar between group members. Then we eliminated ideas that were outside of our problem statement ( ideas that involve changing the turbine or removing the turbine ). Finally, we chose, of the remaining ideas, to research replacing water with some sort of a solid. It seemed the most logical and doable of the possibilities.

## Initial Concept Design

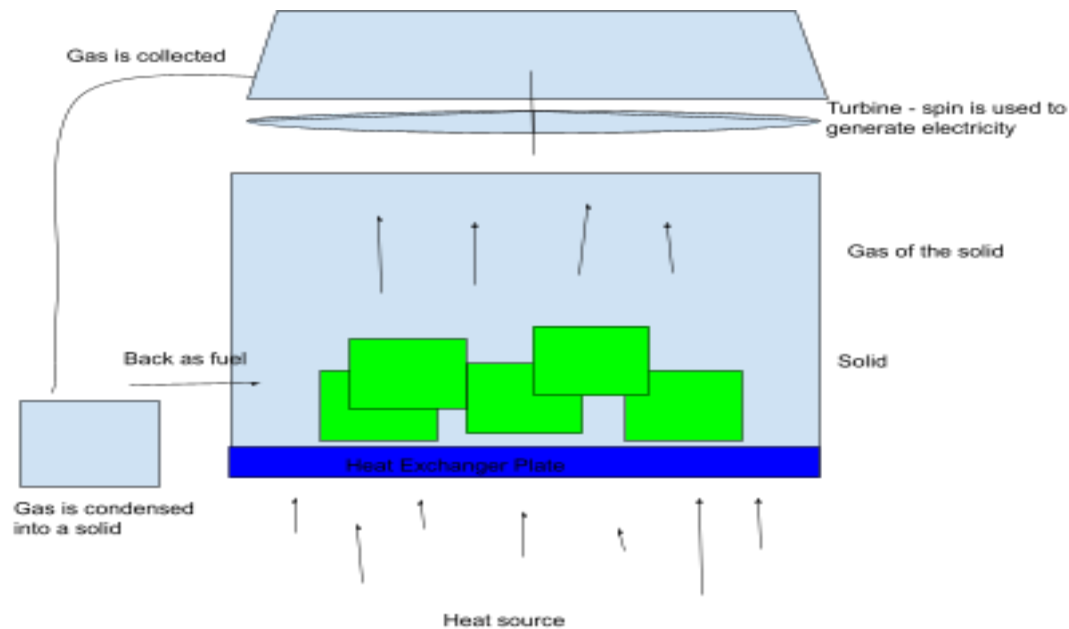


Figure 7: initial concept design - solid boiling chamber

This design is based upon the notion that water is a good storer of heat energy, therefore it is used widely. We know that in order to change phase between solid and liquid, additional energy must be absorbed. Therefore, our idea is to substitute the boiling of water with the boiling of some solid substance (solid at room temperature). We think that by having this additional change of phase, this solid will absorb more energy than water would and therefore provide more energy to the turbine. The rest of the design would be almost identical to a steam generator. It would funnel the boiled material into the turbine and then collect that gas and condense it into liquid. In our design, the liquid would then be further condensed into a solid. This would be done by placing the gas in a closed area which is then placed in a cold area - such as the ground at night.

## Initial Peer Feedback for the Initial Design Concept

After presenting our initial idea to our classmates, we received the following responses.

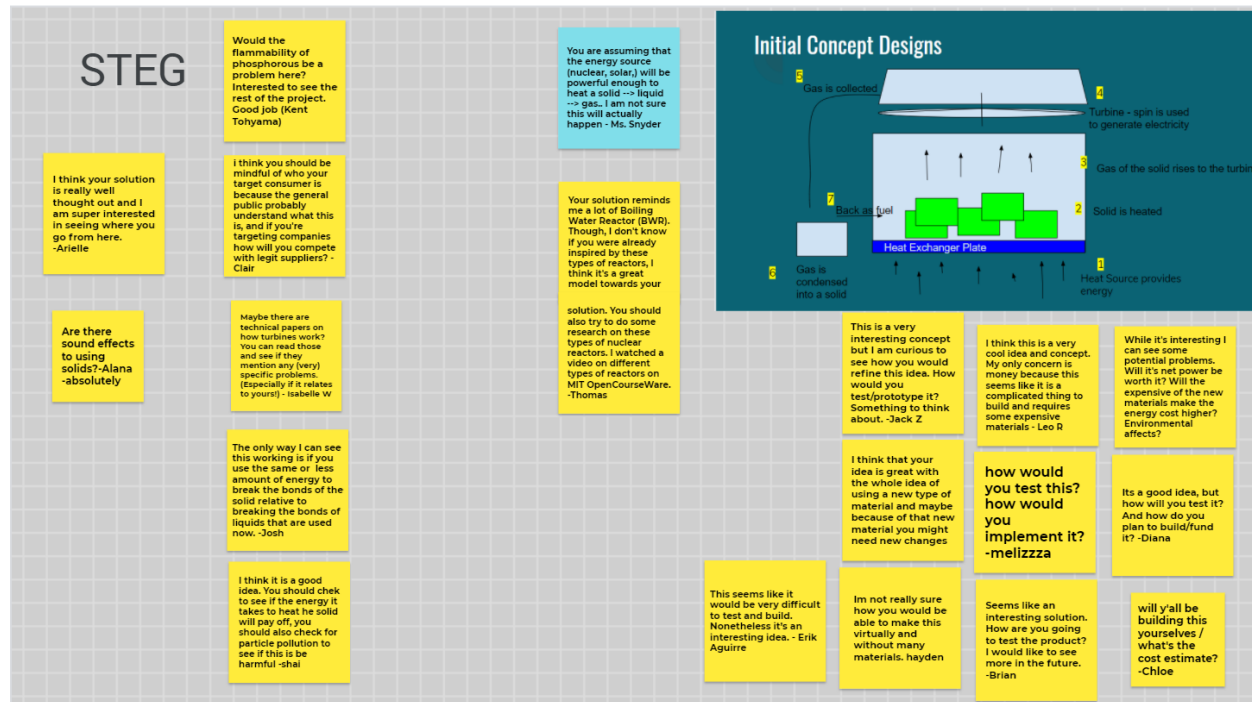


Figure 8: peer review to initial design ideas - appendix : 1b

### Summary of responses:

There were two main concerns: Doability and whether the energy it takes to boil the solid will be worth it.

We will *not* be creating the actual generator, and most likely be creating a CAD model or a miniature physical model of the generator component. In order to prove that it works, we will also calculate, and possibly simulate the component. As for energy, we are not concerned about how much we will have to use, as most generators have renewable energy sources, or just abundant ones like fossil fuels. Additionally, we will be looking for solids with a low-melting point so typical fossil fuel plants will be able to heat it.

### Initial Concept Research Notes:

After heat transfer calculations, we have discovered that boiling a solid material would be less efficient than boiling water.

It appears that it does not matter how much energy a material absorbs, only the rate at which it absorbs energy

We have developed an equation for the rate of heat transfer that tells us that the lower the boiling point of the substance, the more efficient it is at transferring heat to it.

See energy transfer research ( appendix : 8 )

## Revised Design Concept:

- After reviewing our initial concept design, we have conceived a completely new design. Feedback from our mentor, Eric Prescott, advises us to research specific methods of generating electricity. According to him, we should focus on the start up speed of how quickly a design can go from off to 100% generation. He acknowledged that efficiency is generally important, but this factor of speed is more important to electric providers as it allows them to quickly adjust to changing electrical demand. An additional benefit of finding new ways to adjust to changing energy demand is reducing fossil fuel consumption. Currently, when power production needs to be increased, it will be fossil fuel plants that will increase production as it is easy to burn more gas or coal. Renewable plants cannot be controlled in this way as of yet, so if a way were to be designed and implemented, the use of it could take the place of these fossil fuel plants. Also we learned from the feedback of our mentor that there are different ways to transfer steam in a steam turbine. We did not know there were multiple ways to transfer steam before.

[Cycle research](#) see appendix : 9

After researching different types of electric plants that incorporate a steam powered turbine generator, we have chosen to create a design specifically for Flash Steam Geothermal Plants. In order to control the power generation of such plants, we need to control how much water is flashed. Therefore, we need to control the flow of water down the injection well.

Possible ways to do this are:

- 1 Have a valve to control how much water can go down the injection well
- 2 Have multiple injection wells(would require possibly larger production well)
- 3 Primary loop where water is heated - secondary loop can be placed in contact with primary loop to increase heat energy: heat exchange with water source?
- 4 Using a solid to store excess energy (bad for lifespan of geothermal source) - to be used in tandem with #1

[Geothermal Research](#) see appendix 10

This document contains all the research done in order to determine how best to adjust flow to the injection well.

|      | 1                            | 2           | 3           | 4  |
|------|------------------------------|-------------|-------------|--|
| Pros | Allows water to be decreased | More water  | Not sure    | Store excess energy decently well. Use of storage versus higher demand might not average out |
| cons | Cannot increase              | Costs a lot | Costs a lot | Sucks out energy   |

|  |              |  |  |        |
|--|--------------|--|--|--------|
|  | water amount |  |  | source |
|--|--------------|--|--|--------|

Figure 9: table of the pros and cons of different general ideas dealing with geothermal wells

Solution:

After debating the pros and cons of our ideas in addition to researching the injection wells of geothermal power plants, we have come up with the following idea.

Funnel type device to allow increased surface area that water can flow down. At the top of this funnel will be a water control that will open and close circularly. The control will be powered by a motor.

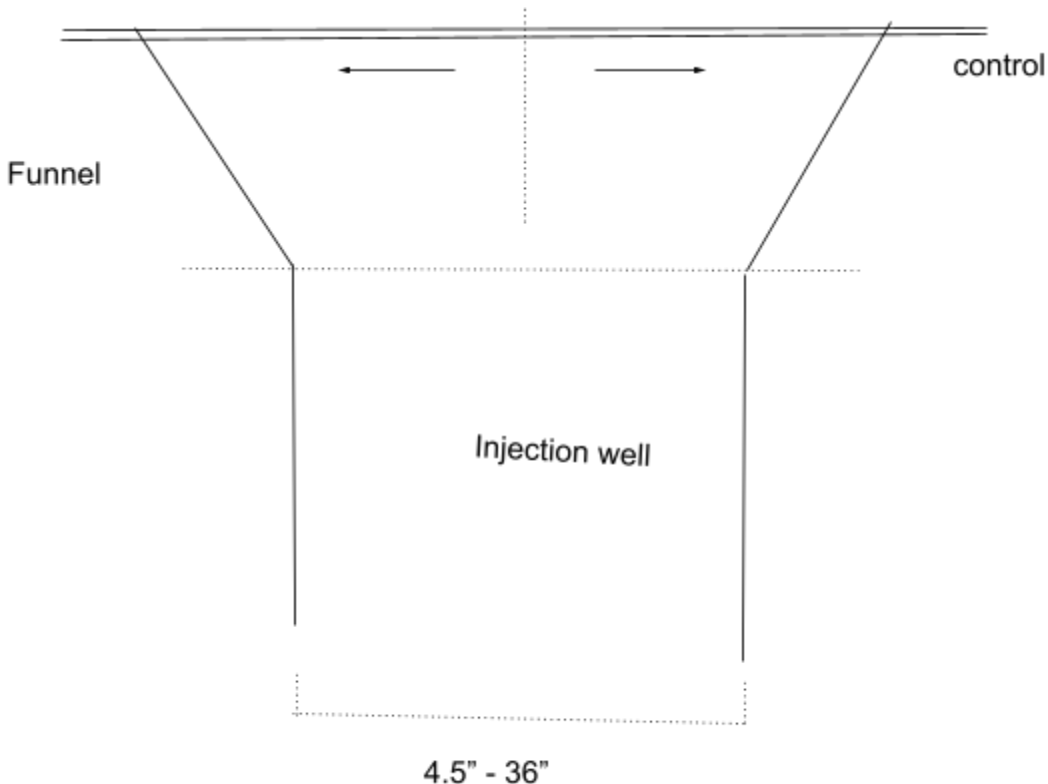


Figure 10: initial solution idea sketch

In order to determine the angle and height of the Funnel, we need to research the amount of water flow that will have an impact on the performance of the plant as well as the cost of material used (most likely steel). We also need to take into consideration the severe pressures the control valve may face when completely closed. Because the system will be under high stresses and will be made of steel and other strong materials, each product will be specifically designed to each injection well (there is no one size fits all solution). We will also need to develop some type of key that matches power production to the percent that the control is open so that an operator could easily know when to open or close the control and how much. Ideally, we would create a program that could take input requested power and adjust the control automatically.

Finally, we also have to design the mechanism for the control. It needs to be designed without external openings or else the minerals in the water will fill and jam those mechanisms.

## Updated solution

After beginning the design process for this solution, we learned some fluid dynamic laws. It turns out that volume flow rate, the amount of water flow per time is equal to  $AV$ . Bernoulli's law states that  $A_1V_1 = A_2V_2$ . This means that changing the size of the pipe would not change volume flow rate. Therefore, our funnel solution to increase the possible amount of water flow was invalid. We did learn; however, that increasing pressure increases velocity. Because water is almost completely incompressible, applying pressure to the water would only force it to reduce volume a negligible amount, while velocity would be greatly increased by the pressure gain. Therefore, the volume flow rate would be increased.

From this, we have developed our final solution. It is a cylindrical device that will be able to close and open. It will act as piping down the injection well. When production needs to be increased and more water must be used, the device will attempt to close. The water will resist constriction as it is a liquid with high density, and will instead gain pressure. This component will have two parts - the compression unit which the water will run through and the exterior shell which will support and contain the compression unit.

There will be a second component to the design. The control valve. It will allow us to control the amount of water flowing through the system ( from maximum allowed by pipe size and lower ). This way, we will be able to decrease the amount of power production.

This two fold design will be able to increase and decrease the production of a geothermal flash plant at will.

## Prototype Design Documentation (ACT 3.3)

### *Annotated Sketches*



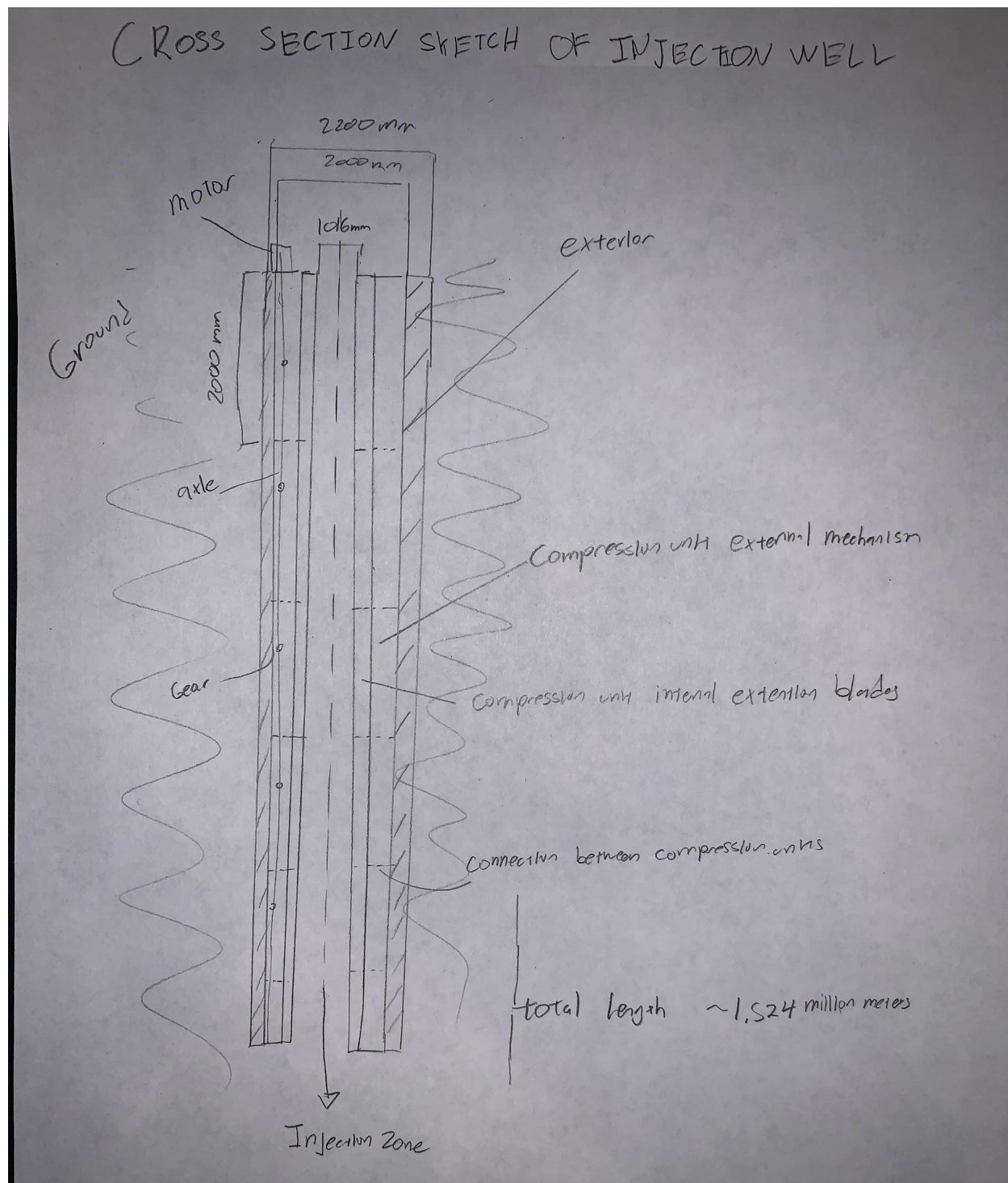


Figure 11: Cross sectional sketch of solution version 2

The above cross sectional sketch depicts the injection well changes. There are multiple cylindrical layers: The interior (where the water will flow through - where the center dashed line is), the compression unit

interior(the walls - very short width, have solid horizontal lines), the compression unit exterior(the mechanism - have dashed horizontal lines), the exterior(will connect to the compression unit - have slashes), and the ground outside(wavy lines).

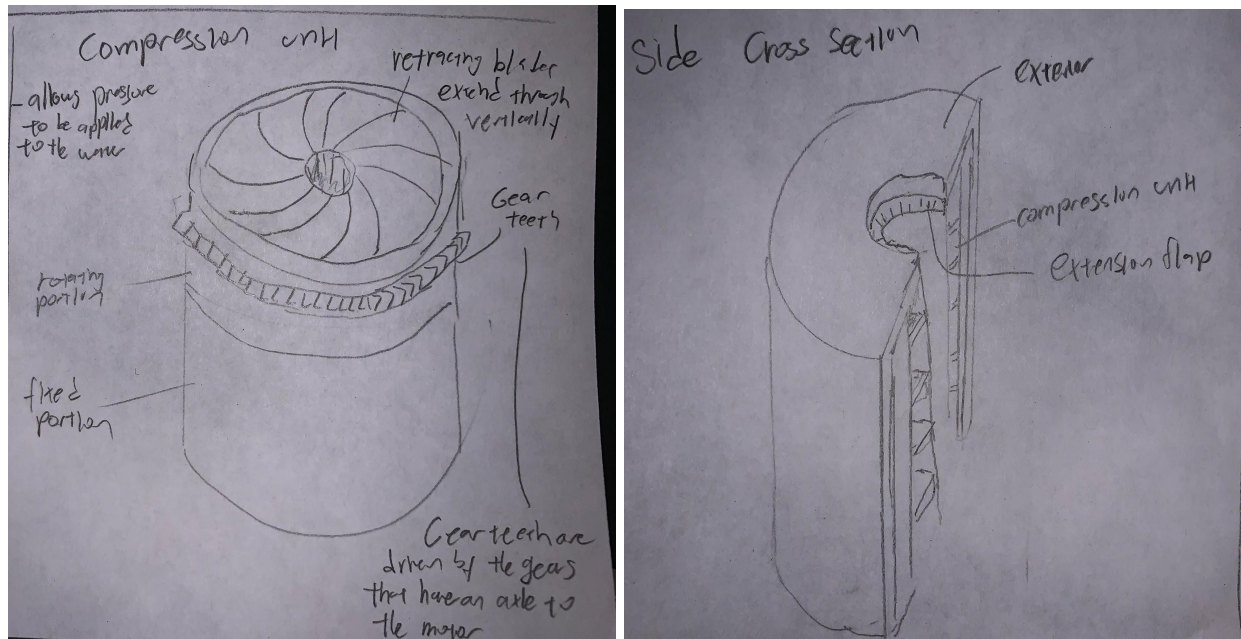


Figure 12 ( left ) : compression unit sketch. Figure 13 ( right ) : cross sectional view of compression unit

The two sketches above depict the individual compression units. These will be able to open and close along its interior in order to provide increases in pressure. This is implemented through an Iris Mechanism. By rotating a top plate, blades will be forced to move. With enough of these blades, this linear motion actually creates an almost circular shape, growing more circular as it closes.

The unit features an extension flap (only the first compression unit will have this) in order to direct the water flow from the top opening into the slightly changing interior diameter (while the diameter is not supposed to change due to water's incompressibility, we must prepare for the event that we do compress it or when the water pushes the blades outward).

The design also includes gear teeth along the rotating portion. A gear can then turn the top plate and therefore apply more or less pressure. This allows an axle to power these gears, controlling the gears from the surface (as many units will be underground).

In the first sketch shown, there are many compression units stacked on top of each other. This to reduce the pressure and stress on each part as well as to increase the feasibility of installation.

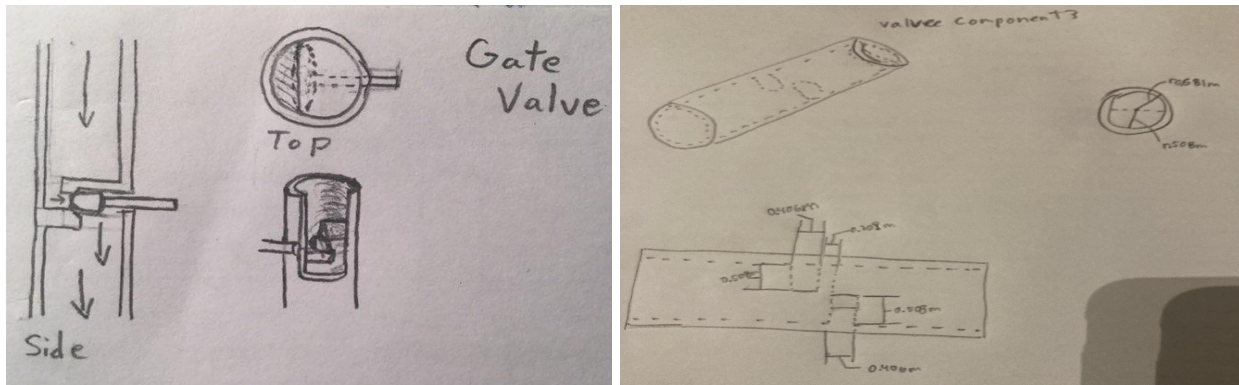


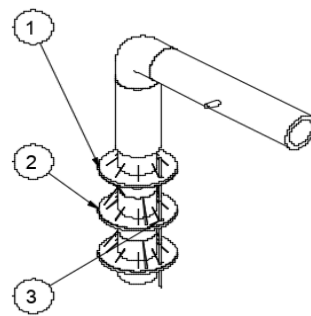
Figure 14 ( left ) gate valve sketches. Figure 15 ( right ): additional gate valve sketches

These last two drawings are the valve control mechanism. This would be placed on top of the injection well and would flow directly into it. The type of valve used is a gate valve. This valve can reduce the amount of water flow from a maximum by pushing a stopper farther into a slot.

### *CAD Models, Drawings, and Sketches*

\*parts from parts lists can be referenced in the complete drawing files after this section

### *Assembly*



| 3    | 3   | Resized complete iris |
|------|-----|-----------------------|
| 2    | 2   | Injection exterior    |
| 1    | 1   | Valve 1               |
| Item | Qty | Part Number           |

Figure 16 (left): assembly CAD. Figure 17 (right): assembly sketch

Above is the complete assembly of all parts of the design. Note that while there are three exteriors attached, a working model would have several hundred.

## Compression unit

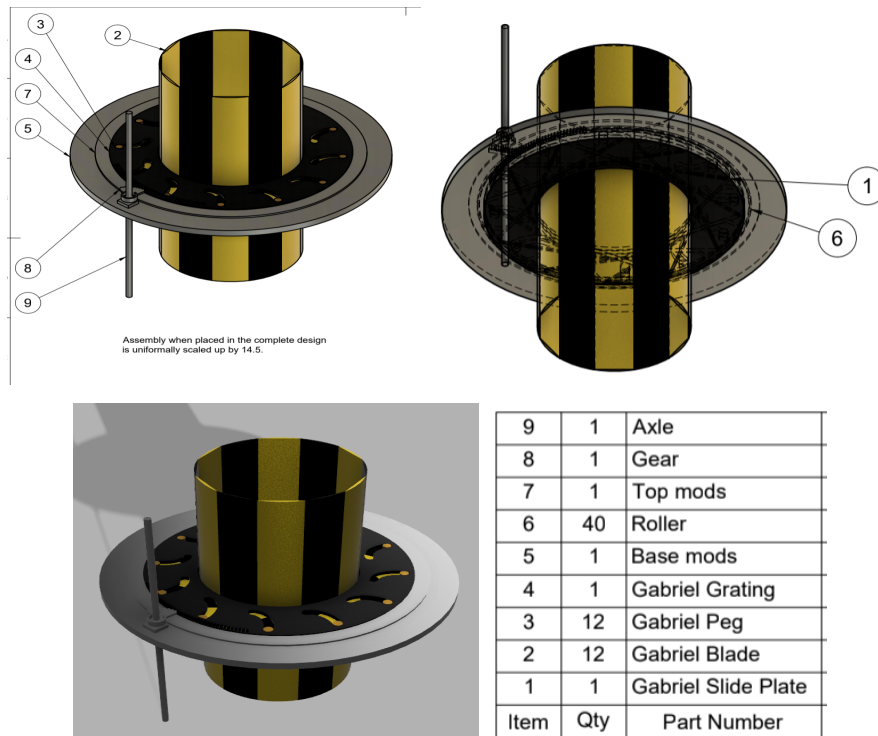


Figure 18 (top left): Compression unit assembly sketch. Figure 19 (top right): Compression unit assembly sketch view 2. Figure 20 (bottom left): Compression unit assembly. Figure 21 (bottom right): compression unit assembly parts list

These images above show the modeled and drawn compression unit. There were many changes made from the initial sketch design. First of all, the shape. The initial unit was a cylinder. Now it has more of a top shape. After creating the design, we realized that the exterior mechanism of the iris took up much more space than we had initially thought.

There is also a change in volume. In the initial design, the mechanism of the iris was going to fill the entire height that the blades would be, making a cylinder. We changed the design for a thinner mechanism to save material. This left long extrusions from the blades to fill the space where more mechanism would have been. The pure iris mechanism can be seen here.



You can see two layers of plates(grey), blades in the middle (of alternating black and gold), and pegs (gold).

How the mechanism works is that, when the top plate rotates, it shoves the pegs along with it in the peanut shaped slots. These pegs are attached to the blades. The movement of them pushes the plates along linear grooves.

Because there are so many blades, this creates a rotational motion in from the top view

\*note - Top Plate = Slide plate

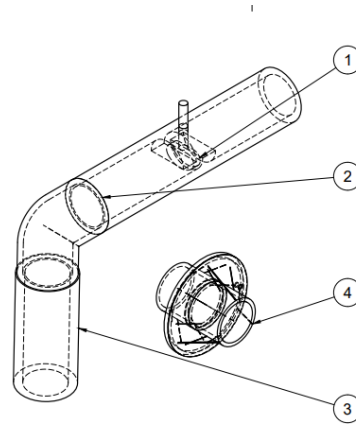
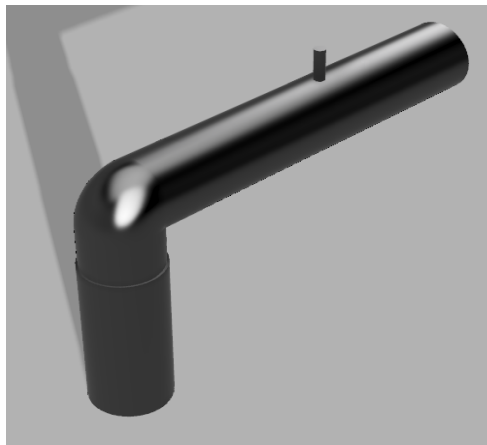
Figure 22: Iris device birds eye view

There are also additions (which we called modifications) to the basic iris design. These were all based around the implementation of rotational motion. If we were to rotate the top plate as is, it would not only have friction against the blades, but also damage them. To fix this, we created rollers that the top plate could sit on. These rollers needed a top and bottom surface to roll on. The Base Mods is an attachment that connects to the base/grating plate. This had a deep track for the rollers. The Top Mods were attached to the midpoint of the Top plate. These have a shallow track that the rollers will make contact with. The rollers will support and suspend the Top Plate slightly.

The last addition was a hole that allowed an axle to run through the modification plates. In order for a gear to touch the Top Plate gear teeth, it would have to be close to it, preventing unnecessary size and bulk. A hole through the mod plates allows the gears to be close to the rotating portion without needing a separate placement.



## Gate Assembly



| 4          | 1   | Injection exterior | Steel    |
|------------|-----|--------------------|----------|
| 3          | 1   | Component3         | Steel    |
| 2          | 1   | Component2         | Steel    |
| 1          | 1   | Stopper            | Steel    |
| Item       | Qty | Part Number        | Material |
| Parts List |     |                    |          |

Figure 23 (top left): gate assembly Cad model. Figure 24 (top right): Gate assembly sketch. Figure 25 (middle): Gate assembly parts list

The Gate valve we modeled is almost identical to the one we designed. The only difference is that we added a corner pipe and vertical pipe in order for the pipe to connect to the injection well.

\*note - component 2 = gate valve pipe. component 3 = corner and extension pipe.

## Exterior shell

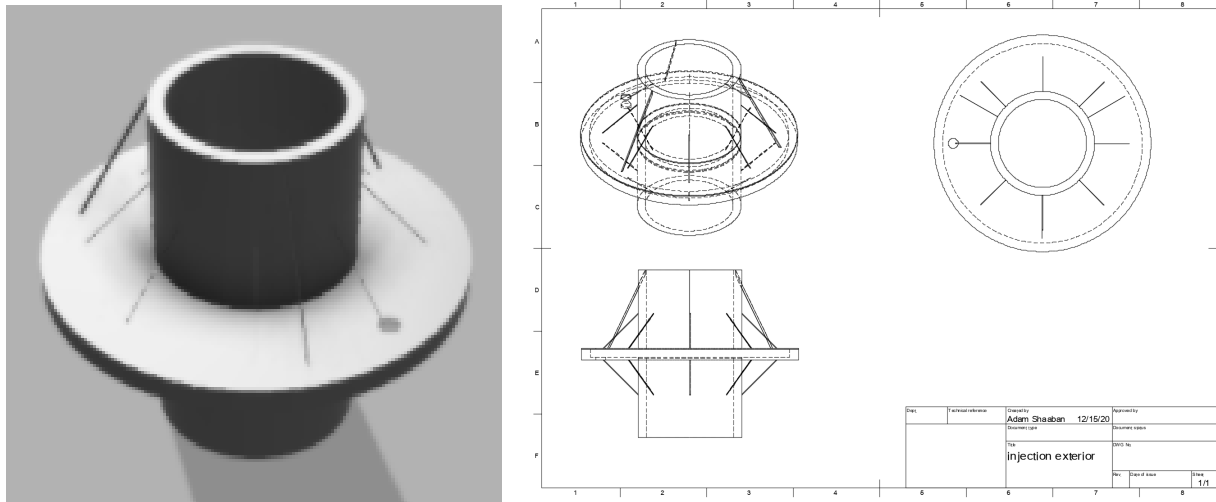


Figure 26 (left): exterior cad model. Figure 27 (right): exterior component sketch.

The fourth major component is the exterior. Notice that it looks quite different from the initial design (a cylinder). This is because the mechanism of the iris took much more space than we had thought it would (modifications and actual iris mechanism combined). Rather than increase the size of the exterior, we realized that a more fitted shape would be more efficient. This reduces the materials use, weight, and cost of the potential larger cylinder. It also more efficiently uses the space available (with a cylinder, most of it would be empty) and provides better support for each individual compression unit, allowing them a fitted space to sit.

On both the upper and lower half, we included support beams. These would help the extruded portion stay upright. There is also a small hole in the extrusion. This is where the long axle would run through.

Annotated drawings ( components used in larger assemblies above in order of appearance )

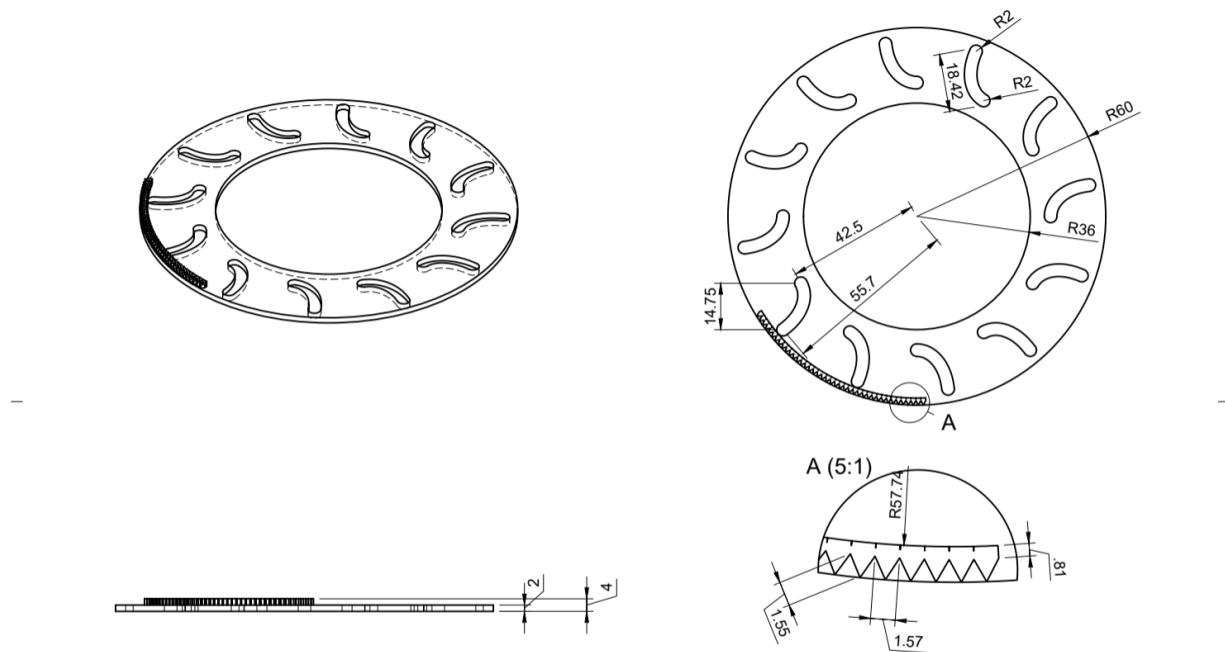


Figure 28: Top Plate | Slide plate sketch

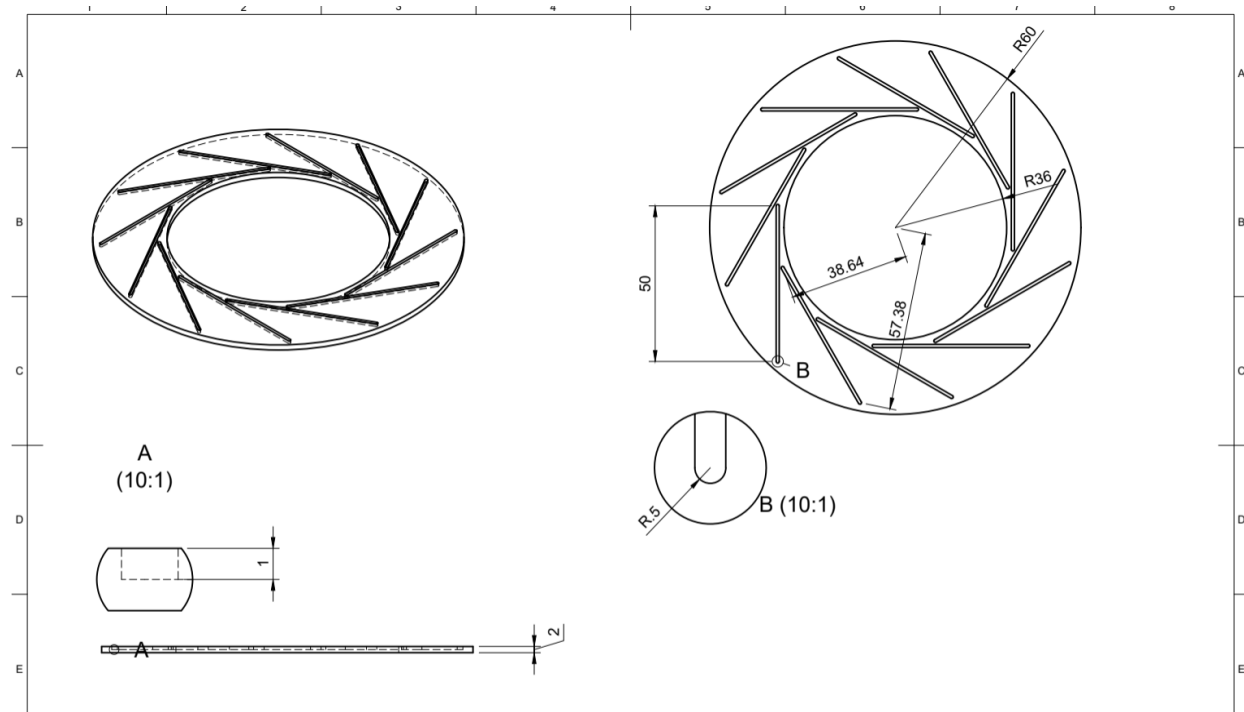


Figure 29: Bottom Plate | Grating sketch



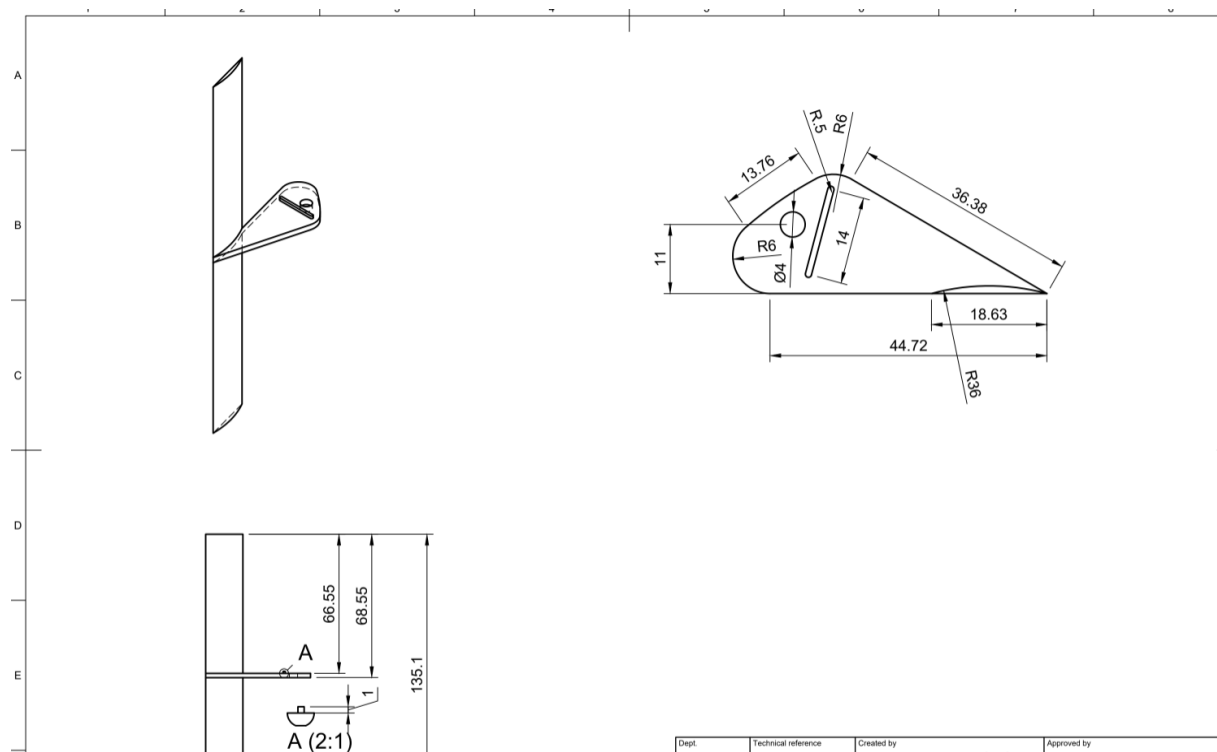


Figure 30: Blade sketch

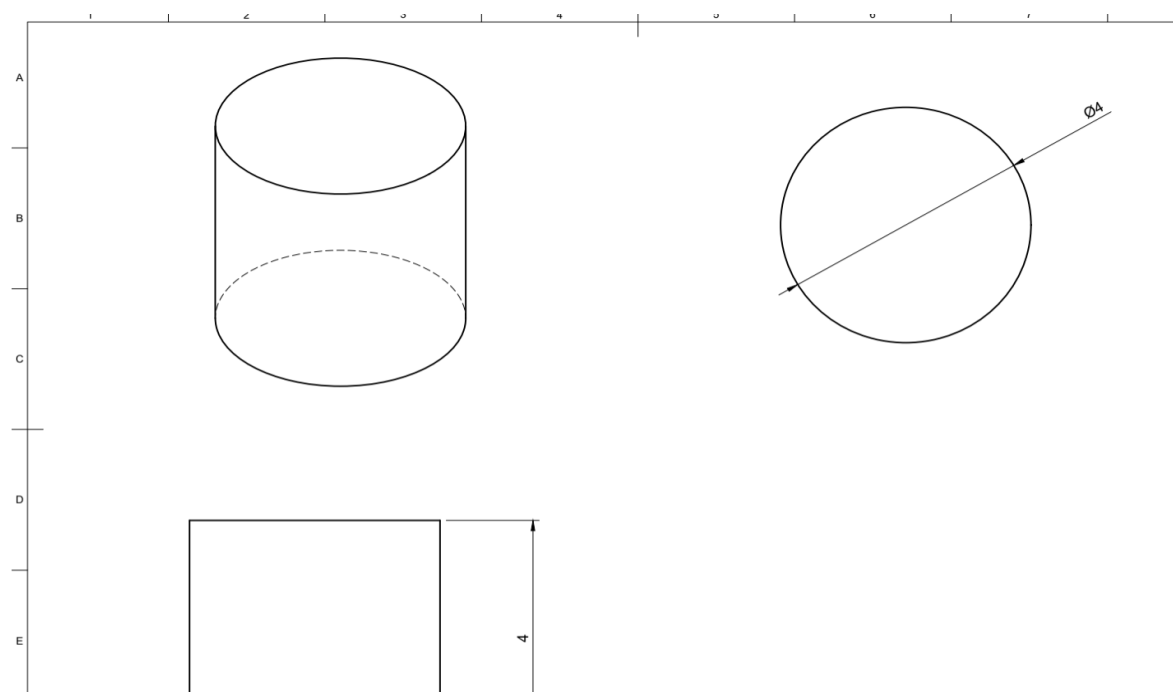


Figure 31: Peg sketch

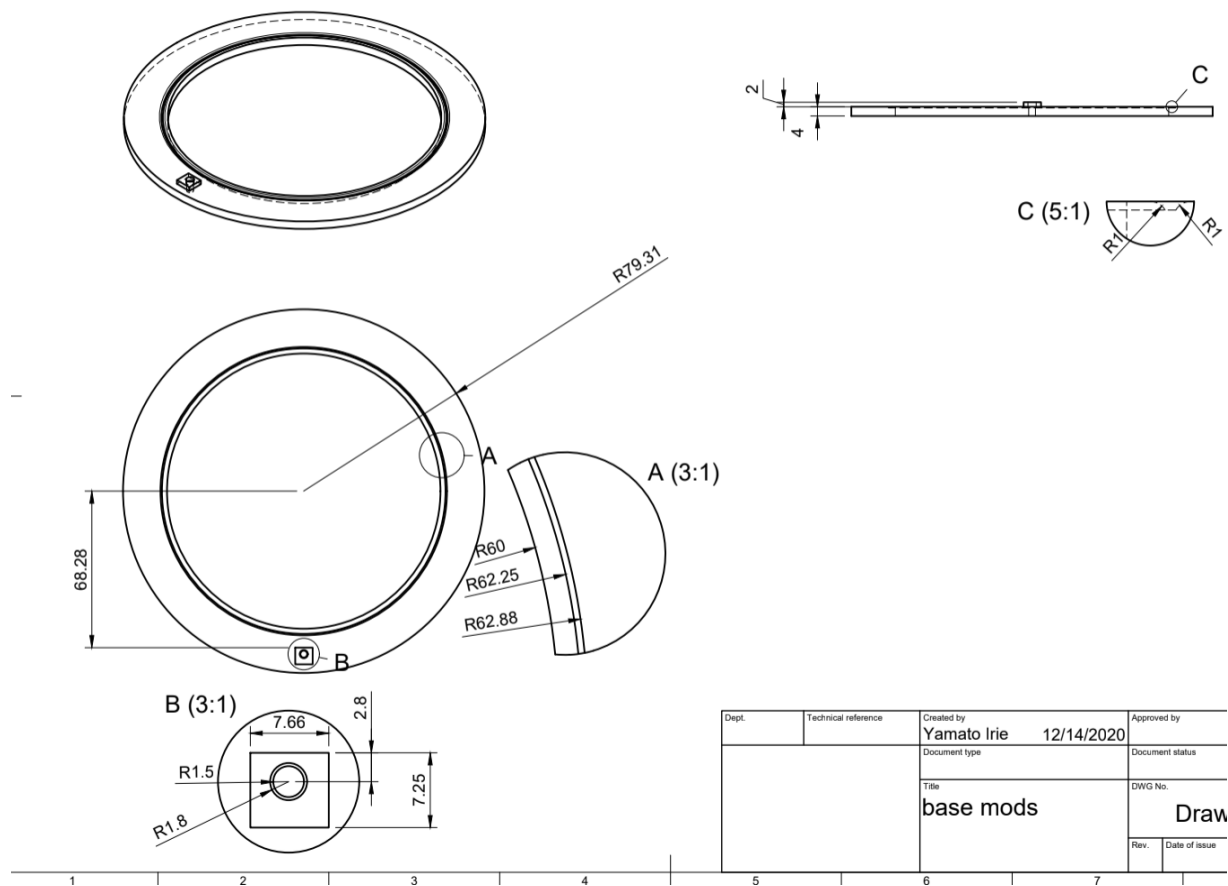


Figure 32: Base Modifications sketch

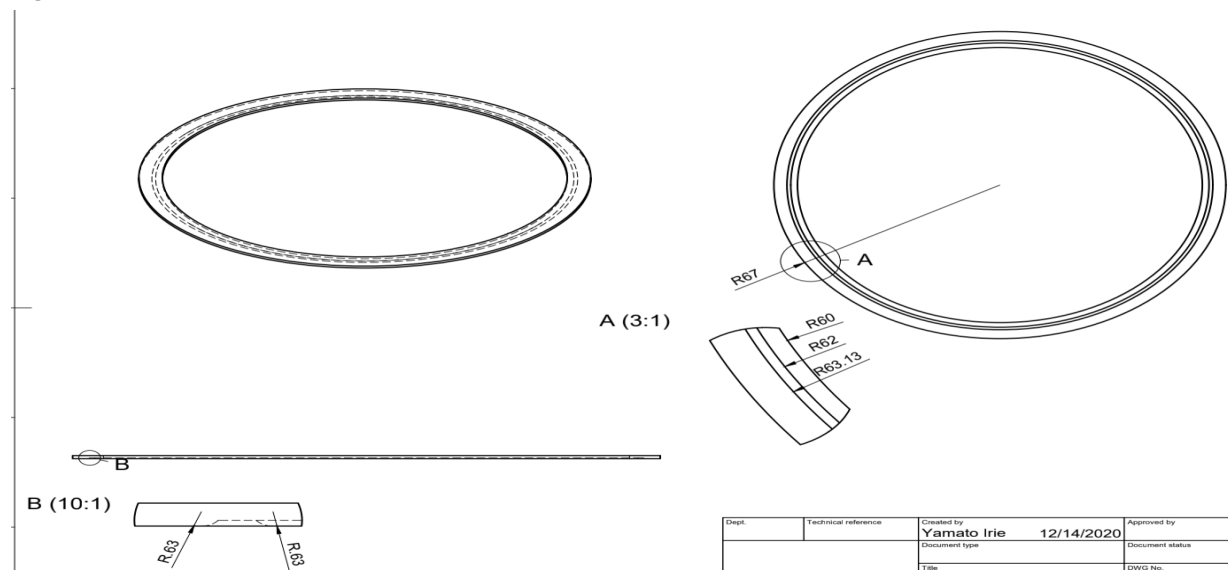


Figure 33: Top Modifications sketch

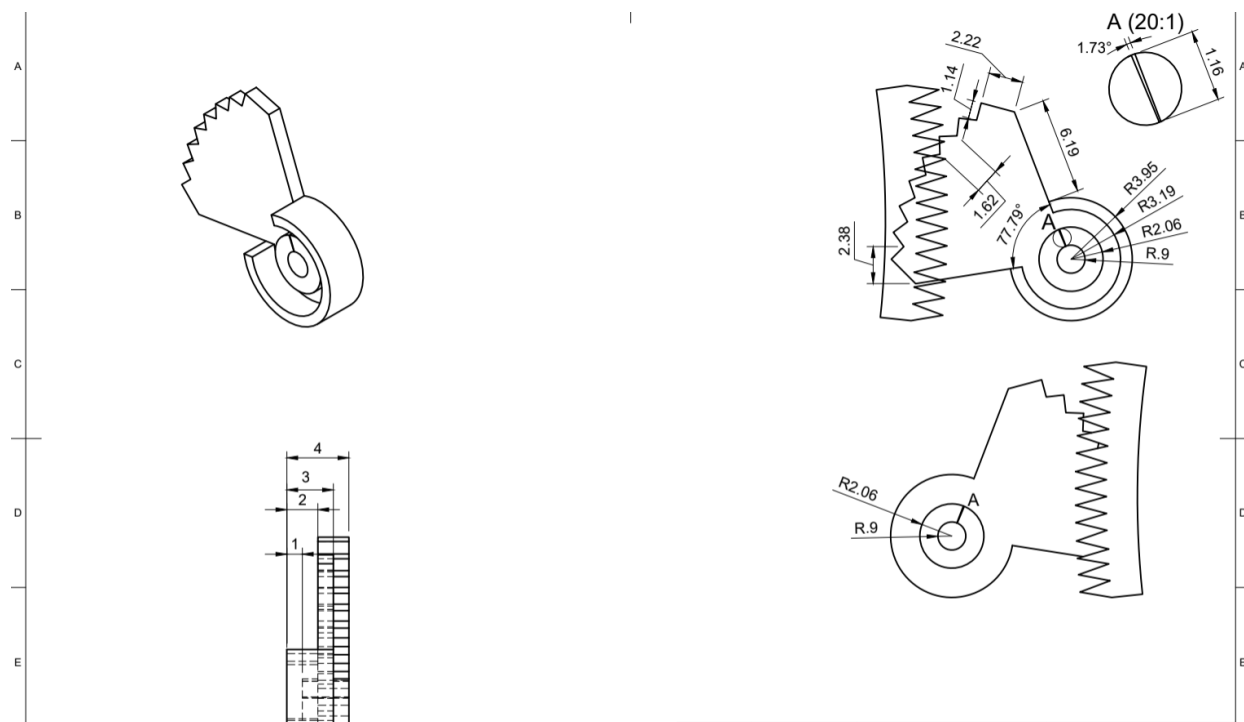


Figure 34: Gear sketch

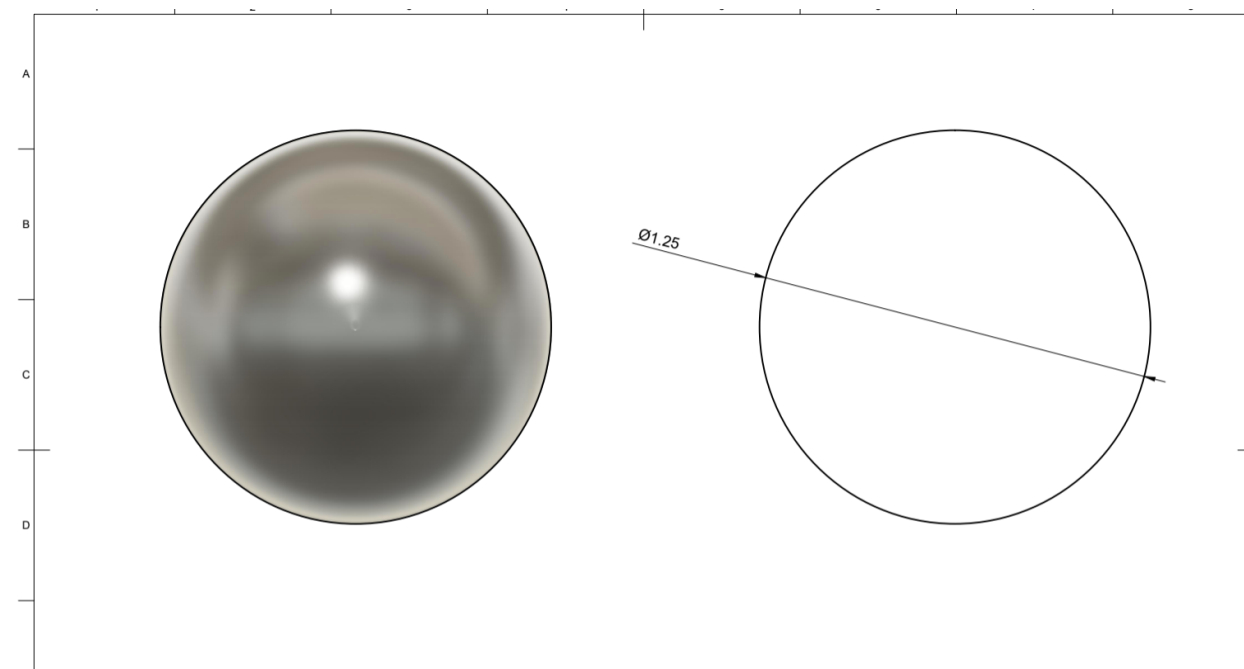


Figure 35: Roller sketch

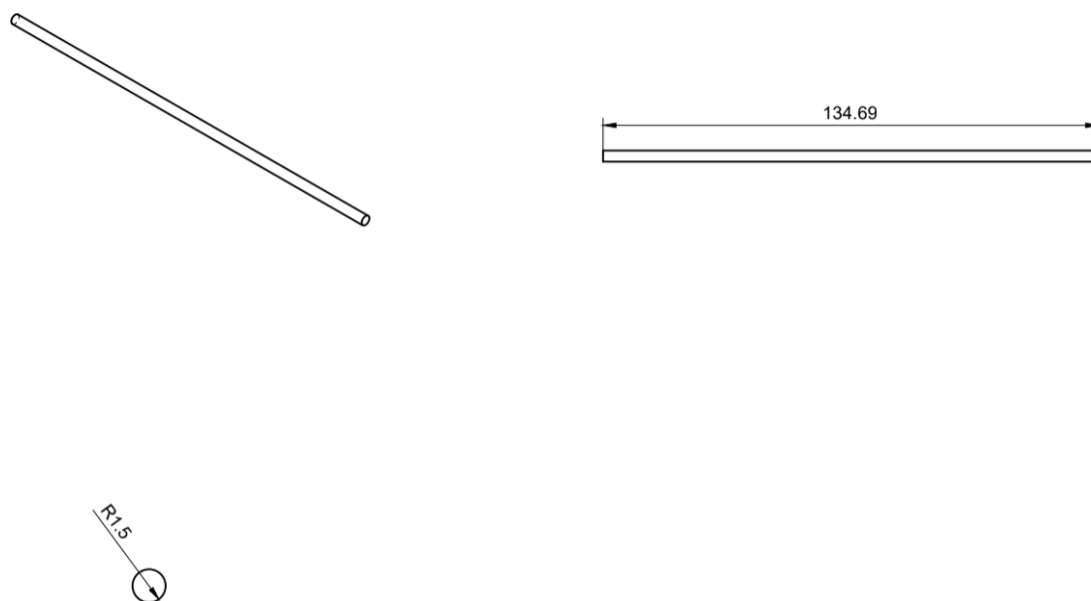


Figure 36: Axle sketch

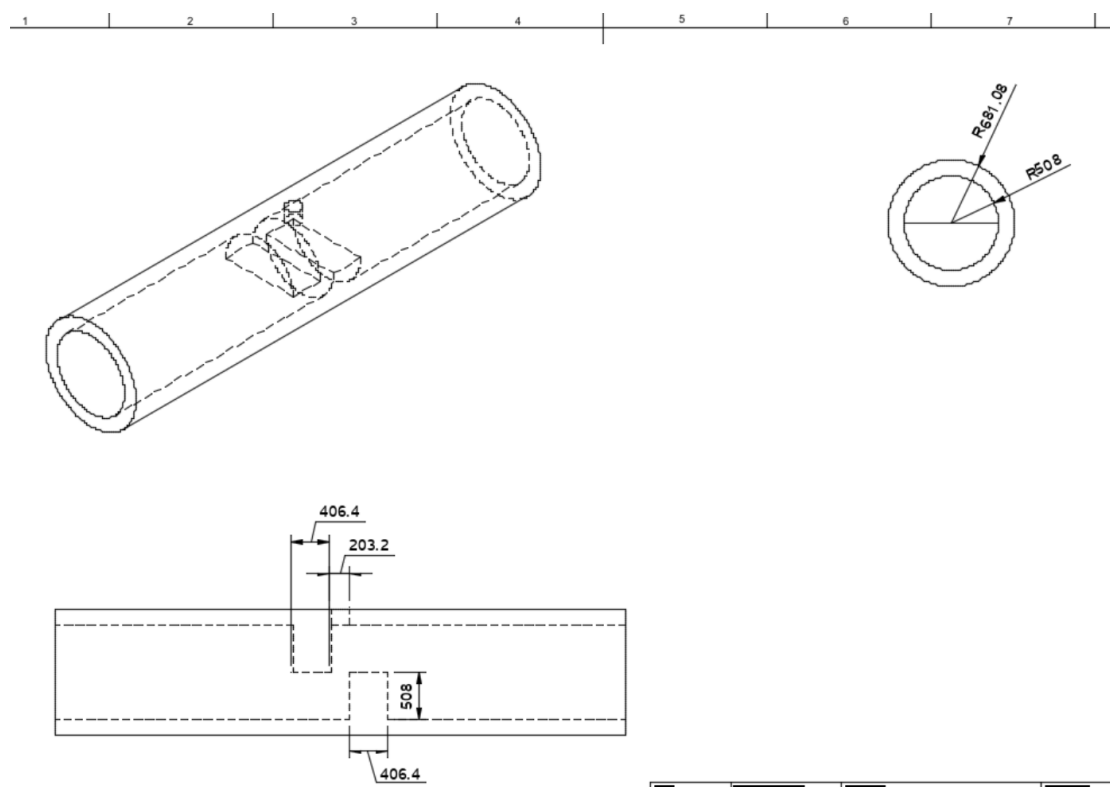


Figure 37: Gate piece / component 1 sketch

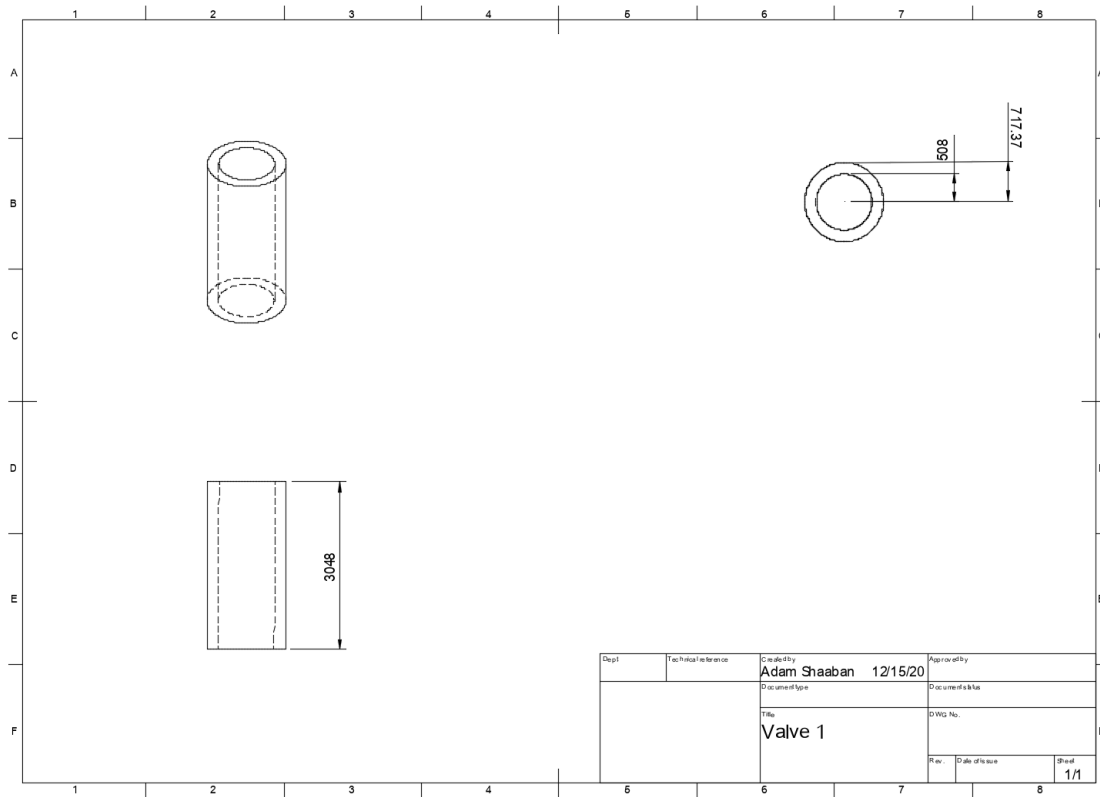


Figure 38: Pipe / component 2 sketch

## Project Improvement

- Function.**  
 The operation of the product is quite simple. It is almost automatic/mechanical.
- Ergonomics.**  
 The product is user friendly and only requires a small amount of operation. The ease of use can be improved by implementing a computer program to operate the product.
- Safety.**  
 The product may be dangerous because it will have to withstand high stress and pressure of large amounts of water. The compression mechanisms face high pressures from the water flow. If one were to burst or even malfunction, the entire system would get out of alignment and water would flow into the exterior, possibly ruining the compression device.
- Cost.**  
 While it is a capital concern to remain as cheap as possible, the primary concern in function and safety. Strong and expensive materials must be used. The amount of materials used can be

optimized to reduce cost, as well as specific chosen material for each component and even using multiple materials on a single component.

- *Standardization.*

There are some parts (screws and gears) that are standardized and universal. Most of the components of this design though, are custom pieces that will vary depending on the geothermal plant in question.

- *Quality Control.*

Some components will be very difficult to manufacture. The compression unit has many moving parts that must all function precisely. As of now, we do not know a way to simplify the design.

- *Ease of Maintenance.*

The product will be nearly impossible to perform maintenance on, as it is going to sit well beneath the earth. The need for maintenance can be reduced by ensuring quality parts as well as strong and well designed components. The installation must also be carefully done so that there is no interference to the device. The costs will result in almost zero as the design must not require it (increasing initial costs)

- *Durability.*

The life of the product is not yet determined as it will require complex calculations of the stress on objects and so forth. A general estimate for the desired life is 30 years. Because all of the compression units are identical, they will all wear out around similar times.

- *Environment.*

The manufacturing process is not extremely harmful. It will require the refinement and smelting of steel as well as rubbers. The materials are recyclable. In addition, the resource demand is not very high. The greatest component is steel, which is completely recyclable.

### *Cost Estimate*

This is the cost estimate for constructing the design. The size (diameter and depth) are both dependent on the given circumstance of Geothermal Energy. The dimensions that have been used here are on the upper end of what could be demanded ( a geothermal well could go from 36" diameter to 4" and could have a depth of greater than 5000ft. The Manufacturing costs and Labor costs estimates are extremely rough. In practice, these would likely be combined by the manufacturing company/agent who is contracted to construct it.

| Materials Cost Estimate |        |  |                      |                     |
|-------------------------|--------|--|----------------------|---------------------|
| Part                    | Weight | Material (cost of steel is .677usd/kg) | Number of components | Price per component |
| Iris mechanism          | 2457kg | Steel ( + small                        | ~781                 | \$1508.598          |

|   |   |                    |                  |                 |
|---|---|--------------------|------------------|-----------------|
|   |   | amounts of rubber) |                  |                 |
| Exterior Shell  | 6307kg  | steel              | ~781             | \$3872.498      |
| Valve Pipe  | 62600kg   | steel              | 1                | \$42,380        |
| Total cost of materials   |   |                    |                  | \$4.25 million  |
| Manufacturing costs estimate  |   |                    |                  |                 |
| Type of machinery necessary to construct  | Steel Pipe Making Machine                         | Shaping machine    | Slotting machine | Milling machine |
| Cost to obtain machinery  | <u>\$60,000</u>                                   | +20,000            | <u>\$43,000</u>  | <u>\$60,000</u> |
| Cost of space required at 10,000 square feet  | <u>\$763200</u>                                   |                    |                  |                 |
| Total Manufacturing Costs Estimate  |   |                    |                  | \$1.01 million  |
| Labor cost estimate   |   |                    |                  |                 |
| Time to construct   | One year  |                    |                  |                 |
| Cost per worker   | \$16/hour   |                    |                  |                 |
| Hours worked per worker   | 2600 (52 weeks/year x 5 days/week x 10 hours/day) |                    |                  |                 |
| Number of workers   | 50  |                    |                  |                 |
| Total labor cost  |   |                    |                  | 2.08 million    |
| Total production cost estimate  |   |                    |                  | 7.34 million    |
| Note: the total cost for an entire Geothermal plant is \$170 million. This design should add a small portion of this 7.34 million to the cost (both require a steel pipe). The Geothermal cost includes the digging and excavating cost and building materials of the plant itself while our cost estimate does not |   |                    |                  |                 |

Figure 39: Cost estimate table

## Element E: Applications of STEM Principles and Practices

### Scientific and Engineering Principles to Investigate

- Bernolli's Principle - This principle states that the sum of all energy in a streamline must be the same at all points in that streamline. Kinetic energy, potential energy, and internal energy are altogether constant. We need to know how these energies are related to understand how the flow rate, related to kinetic energy, can be increased.
- Volume Flow Rate - Volume flow rate is a term describing how much liquid passes through an area at a given time. It is modeled by the equation  $Q = VA$  where  $Q$  is flow rate,  $V$  is velocity of fluid, and  $A$  is the cross sectional area that the liquid passes through. This term tells us what factors go into increasing the amount of water passing through our system.
- Enthalpy - the internal energy of a system. In order to increase the rate at which water can flow, we need to understand what determines its velocity. Enthalpy is conserved unless heat or work are added or removed from the system. Pressure times volume is one term of internal energy.
- Compressibility - the measure of how easy it is to restrict the volume of a gas or liquid. Water is considered highly incompressible because a large increase in force results in a tiny decrease in volume. The incompressibility of water allows us to apply force without reducing the area, thereby increasing the pressure (pressure is Force over Area)
- Torque - In our design, we are planning on converting rotational motion into increased pressure. We need to have an understanding of Torque, the rotational force, in order to determine the amount required to provide that pressure.
- Rankine cycle - The Rankine cycle models the work done through a Steam Generator. It goes, Pump (pushes the water through), Steam Generator(heats water), Turbine(converts steam power to electricity), Condenser(returns steam to water). In order to increase the thermal efficiency of work done, the average temperature must be increased. This can be done at any of the four points. Our prototype attempts to do this by increasing the pressure between the pump and the Steam Generator (geothermal well).

### Validation of Investigation and Concepts: Mentor Feedback

#### **Mentor Approval:**



“Approved. Remember, the energy cannot be created or destroyed, just transferred from kinetic to potential, or vice versa, in a more efficient way.” Eric Prescott, Director of the Electric Power Research Institute

## Equipment and Technology

In order to build our prototype, we are going to need a 3D printer to create some of our parts, Robotec to control the motors for rotation of our device, drills to build a wooden frame, gorilla glue to secure our parts together, and plumbers tape to help seal pipes together.

### **Building instructions:**

- Small pieces of the rubber sheet will be cut out and placed on the ends of the stopper and the blade.
- Blade/peg pieces will be placed into grating/bot mods/shell. Wd40 will be applied to the sliding joints
- Rollers will be placed in the Bot Mods
- Slide plate/top mod piece will be placed on top of the grating piece and sit on the rollers.
- Wooden frame will be placed and build holding up the outer rim of the shell
- Gear piece will be placed through the axle and gorilla glue will be applied to the connection
- axle/gear piece will be placed through the appropriate hole. bearing will be fixed on the bottom of the shell.
- The top part of the shell will be placed on the bottom half with the axle through it. It will be fixed with gorilla glue where the two halves meet
- Bearing will be placed under the shell on the axle.
- Bearing will be placed above the shell on the axle
- Gate valve piece will be attached to two short pieces of pvc pipe with duct tape and gorilla glue
- Gate valve pvc end will be fixed into an elbow pvc piece
- Second end elbow will be fixed into a straight pvc piece.
- Last pvc piece will be fixed into the shell opening. Plumbers tape will be used to tighten the connection.
- Wooden frame will be adjusted to hold up all components and support the pipes as well as having a stand for the motor at the top of the axle.
- Stopper placed in
- Motor placed and affixed to the axle

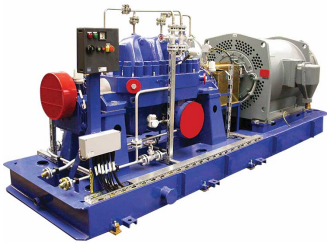
## Element F: Consideration of Design Viability


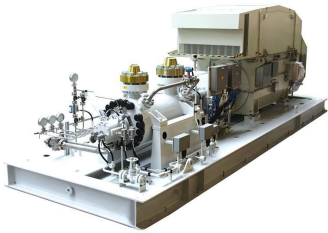
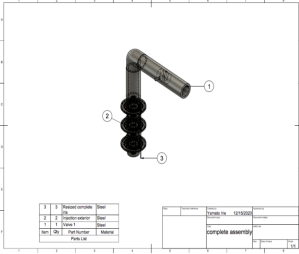
### Introduction:

To compare our pump design to competitor and commercial options, a chart showing pricing for manufacture and consumer price, as well as a section of pros and cons will be provided. This will show the value of our product and how it compares to these competitors.

It should be noted that all commercial prices are an estimate due to the fact that large components such as these are not sold on the open market.

### Market Analysis

| Products<br>Include picture and link  | Manufacturer<br>Price       | Consumer<br>Price     | Pros & Cons   |
|---|-----------------------------|-----------------------|---|
| Competitor 1: <a href="#">Ruhrpumpen</a><br>SM multistage axially split pump<br> | Estimate<br><u>\$40,600</u> | Estimate<br>+\$50,000 | Pros <ul style="list-style-type: none"> <li>- Max flow rate of 2000m<sup>3</sup>/hour</li> <li>- Easy to maintain</li> <li>- Durable materials</li> </ul> Cons <ul style="list-style-type: none"> <li>- Cost is high</li> <li>- Only withstands pressures of 276 bar</li> </ul> |
| Competitor 2: <a href="#">Ruhrpumpen</a><br>GP multistage radially split pump   | Estimate<br><u>\$40,600</u> | Estimate<br>+\$50,000 | Pros <ul style="list-style-type: none"> <li>- Max flow rate of up to 900m<sup>3</sup>/hour</li> <li>- Withstands up to 400 bar pressure</li> </ul> Cons <ul style="list-style-type: none"> <li>- Lower pump rate</li> <li>- cost</li> </ul>                                     |

|  |   |                               |  |
|--|---|-------------------------------|--|
|   |   |                               |  |
| <p>Competitor 3: <a href="#">Ruhrpumpen</a><br/>A Line Multistage radially split pump</p>  | <p>Estimate<br/><u>\$40,600</u></p>   | <p>Estimate<br/>+\$50,000</p> | <p>Pros</p> <ul style="list-style-type: none"> <li>- Max flow rate of up to 1400m<sup>3</sup>/hour</li> <li>- Withstands up to 450bar pressure</li> <li>- Withstands up to 450 celsius</li> </ul> <p>Cons</p> <ul style="list-style-type: none"> <li>- cost</li> </ul>   |
| <p>Our Product:</p>   | <p>Estimate<br/>\$1,000<br/>Cost does not include additional piping, similar to a commercial pump</p> | <p>\$7,000</p>                | <p>Pros:</p> <ul style="list-style-type: none"> <li>- cost</li> <li>- Smaller diameter</li> <li>- Can work in series (\$1,000 per)</li> </ul> <p>Cons:</p> <ul style="list-style-type: none"> <li>- Decreased efficiency ( at this point, incomparably lower to our small scale model )</li> <li>- Lower Temperature and pressure threshold</li> </ul> |

## Summary

On the table above is listed information for three of the best geothermal production companies. There is also a pros and cons list of all the companies. Below them is our model for increasing pressure in pipes to increase water velocity. Our manufacturing and consumer pricing is also listed, but is not a direct comparison since our model is used in large scale plants. In the geothermal industry, mostly between bearing type pumps are used to increase the energy of the working fluid (where the turbine is connected

to). Our design, a positive displacement pump, can be implemented because it can be placed in series. This means that our design, if adjusted in material usage to withstand high pressures and temperatures, can be implemented in different numbers of series. Essentially, this would allow a consumer who has a lower max flow rate demand than the competitive models for boiler feed to purchase a small number of our pumps, not wasting the max flow rate of the available models and the accompanying cost.

All three of the competitor models come from the same company, Ruhrpumpen. While Ruhrpumpen does not have a monopoly over the pump industry, pumps of similar type across different companies would be almost identical. We have researched different pump types across the same company instead to collect a wider range of information on the types of pumps used.

Of the three pumps, the A Line seems to be the best option. It has better statistics at the figures we are looking for than the other two models. However, the GP is said to be *the* Boiler Feed Water Pump. While we aren't looking to take their design of using hydraulics, we can learn from them. Both designs incorporate many structure and durability focus choices such as O-rings, screw caps, double mechanical seals, and API 610 materials ( cast iron, carbon steel, ni resist, duplex, super duplex, bronze and [others](#) ). These materials specifications are of high interest to us as we have been unsure what materials to use besides types of steels. We will research these materials further to determine which to use for which parts of the iris-displacement pump. One final change we can make after doing this research is to increase the diameter of the pump. While the water pipes will remain the same, they will flow into a larger area than now. The competitors all have much larger diameters and widths than the actual exit pipe sizes (2-4 inches).

## Distribution

Our product is not one we could sell on the open market nor could we manufacture it on our own. Our plan is to contact existing manufacturers and pump designers who, after receiving our pitch and demonstration, could take the model further. In this case, they would either keep us as a partner or buy the design off of us and continue to patent it themselves. Examples of a Pump manufacturer and distributor are: Flowserve Corporation, Sulzer Corporation, General Pump, and of course Ruhrpumpen. We would also consider partnering and handing off our design to a smaller research group such as EPRI, the institute of our mentor Eric Prescott.

We would not want to consider a patent because there are plenty of details that need to be reworked and changed before a commercial design is complete - yes the model is there and we have planned a small scale model that tests the concept, however a full sized and industrial pump requires many more details that we are continually learning and some that we will likely never uncover.

## Component 3: Prototype and Test

### Element G: Construction of a Testable Prototype

#### ACT 1.0: Prototype Planning and Documentation

##### Bill of Materials

| Item  | QTY    | Description                             | Vendor                 | Cost    | Notes   |
|---|--------|---|------------------------|---------|---|
| PETG  | 9000 g | Main material for CAD components        | <a href="#">Amazon</a> | \$57.99 | Parts will be printed on a personal 3D printer. This assumes 100% infill (max cost) |
| ^ The following parts will be printed on Gabriel's 3D printer. <ul style="list-style-type: none"> <li>- Stopper</li> <li>- Butterfly valve piece</li> <li>- Gear</li> <li>- Upper half of shell body</li> <li>- slide plate and lower half of shell body</li> <li>- peg and blade</li> <li>- grating</li> </ul> |        |   |                        |         |   |
| screws  | 10+    | Will be used to connect the wood frame. | Amazon                 | <\$5    | (Likely to have at home. If not, cost as shown on left)                             |

|                             |            |   |                            |   |  |
|-----------------------------|------------|---|----------------------------|---|--|
| 2x4 wood                    | 1          | Wood frame  | <a href="#">Home depot</a> | \$4.45                                      | Will be cut into smaller pieces using a saw (or another tool). |
| Thin rubber sheet           | 1          | Transparent and heat resistant                        | <a href="#">Amazon</a>     | \$14.59                                     | Attached to iris blades in order to increase friction.         |
| Axle                        | 1          | Vex component<br>Axle to attach to gear and spin iris | None                       | No cost                                     | (from snyder vex parts)  |
| PVC 45 degree two way elbow | 5 / 1 pack | PVC pipe  | <a href="#">Home depot</a> | \$2.55 per unit<br>\$10.19 per package      |  |
| Pvc straight pieces         | 5          | PVC pipe  | <a href="#">Home depot</a> | \$2.73 per feet<br>\$13.63 per 5 ft package | Same as above  |
| Vex Button                  | 1          | Vex component   |                            |   | Smash Vex parts  |

|                 |   |                                       |                        |         |                         |
|-----------------|---|---------------------------------------|------------------------|---------|-------------------------|
| Vex motherboard | 1 | Vex component                         |                        |         | Smash Vex parts         |
| Motor           | 1 | Vex component                         |                        |         | (from snyder vex parts) |
| Bearing         | 6 | Vex component                         |                        |         | (from snyder vex parts) |
| Wd40            | 1 | Multi-Use Lubricant Smart Straw Spray | <a href="#">Amazon</a> | \$15.61 | online                  |
| Gorilla glue    | 1 | Used to glue all components           | <a href="#">Amazon</a> | \$7.99  | online                  |
| Plumbers tape   | 1 | Tightens connection between PVC       | <a href="#">Amazon</a> | \$2.38  | online                  |

## Tools and Equipment

| Item       | Exists in Lab (Y/N) | Source if not in Lab | Outside Source Notes      |
|------------|---------------------|----------------------|---------------------------|
| 3D Printer | N                   |                      | Gabriel owns a 3D printer |

|                 |   |                |                                    |
|-----------------|---|----------------|------------------------------------|
| Drill           | N |                | Household Item                     |
| Robot C program | Y |                | school                             |
| Fusion 360      | N | Home Computer  | We all have Fusion 360 free trials |
| Motor saw       | N | Household Item |                                    |

### Needed Knowledge

---

| Item              | Need Outside Assistance (Y/N) | Source                             |
|-------------------|-------------------------------|------------------------------------|
| Fusion 360        | N                             | All members know how to use Fusion |
| Using 3D printer  | N                             | Gabriel                            |
| Assembly of parts | N                             | none                               |
| Vex Robotics      | N                             | Some members may know              |

### Reflection

In order to build our design at a small scale, we will have to implement a number of revisions.



We have changed our metal material to PLA to allow us to 3D print custom parts. This requires us to consider degrading due to PLA parts moving against each other as well as the water tight capabilities of it. Because the PLA will not create perfectly smooth and flat surfaces, pieces such as the blade and the grating will not create a watertight seal. To combat this, we are planning to use the pvc pipes to create additional pressure between pieces such as these.

Long pipe sections will be replaced with PVC as it is much cheaper as well as designed to carry water. This includes the upper and lower connections to the Shell as well as connections to the valve.

The valve has been redesigned as a butterfly valve for greater effect as well as a reduction in necessary volume to print.

The diameters of the shell, blade, grating, slide plate all must be increased in order to match the 2" and 2.375" diameter of the inside and outside of our PVC piping. The interior diameter of the shell has also been opened further, as to let the outer part of the PVC through rather than let the inner part sit on it.

The shell has been removed completely. The PVC pieces will hold the assembly in place, securing the bottom plate with gorilla glue. (1)

To accommodate the Vex parts that we will be using in order to create rotation, we are changing the size of axle holes in the shell and gear.

We have eliminated the use of mod plates and rollers as we are using the pressure between components to create a watertight seal. Rollers would reduce from that pressure.(2)

The blades are now slanted faces, angling outwards in order to shove water through the device.(3)

Additionally, we have redesigned many parts to be in the same CAD file so that they will be 3D printed together. This will make for a stronger connection between non moving parts. This is a lot easier than using gorilla glue to connect parts.

The final designs can be found in the appendix

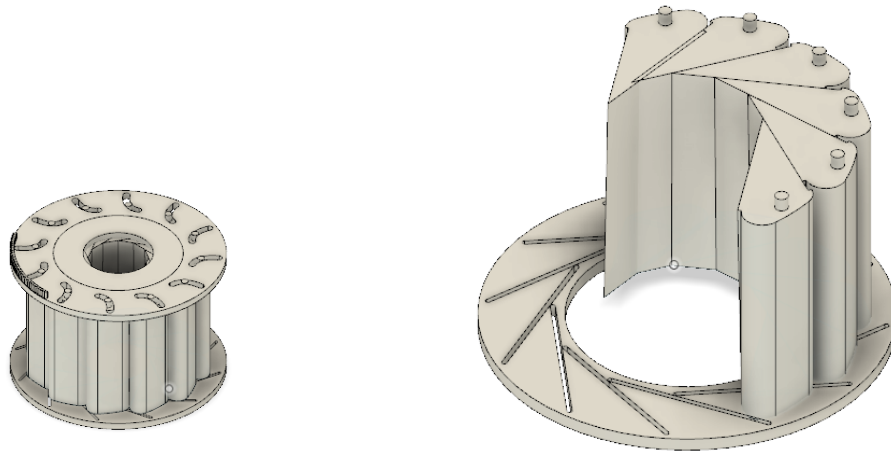


Figure 40 (left): edited compression unit assembly. Figure 41 (right): cross section of edited compression unit

The above photos depict the changes made labeled 1, 2, and 3.

## Element H: Prototype Testing and Data Collection Plan

### Test Criteria

**Performance:** we want to know if the design can perform as a pump, returning water in a loop to its initial high or head, and if it works better than existing pumps.

**Durability and Maintenance:** we want to know how long the design can run at a time, how often it needs to be repaired, and what repairs need to be made.

What do we need to know/test in our design? What type of testing is it?

Can the pump push water in a cycle? - qualitative

What rate does water move around the loop? - quantitative

Is there water leakage in blades? - qualitative

What is the period and rotation of the motor and gear in a successful cycle? - Quantitative

Can the gear withstand 1 min of running? - qualitative

Can a motor provide enough torque? - qualitative

The table below shows the specific criteria and parts, what information is needed to find if a part has met that criteria, the type of testing that it is, and the degree of accuracy that can produce the result.

| part                 | Criteria/what   | Description of data needed   | Quantitative or qualitative | Degree of accuracy           | Link Source |
|----------------------|---|--|-----------------------------|------------------------------|-------------|
| Gear                 | Gear must be strong enough to rotate without breaking                               | Visually seeing if the gear has not broken   | Qualitative                 |                              |             |
| Motor                | What rotation and period of the motor is necessary to create a cycle.               | Degree of rotation and rotations per minute.   | Quantitative                | 5 degrees.<br>2 seconds      |             |
| Pump                 | What speed does the water travel around the cycle                                   | How many rotations per minute the water makes through the cycle                      | Quantitative                | .125<br>Rotations per minute |             |
| Pump                 | Can the water run for one minute straight   | Visually seeing continuous flow  | Qualitative                 |                              |             |
| Pump                 | If cannot run a cycle, what is the change in water level it creates                 | Difference of water level in farthest pipe from pump activated to no pump activated. | Quantitative                | 1 cm                         |             |
| Blade and gate piece | Must be able to contain water without leaking at pipe joints, blade joints, or gate | Visual check   | Qualitative                 |                              |             |

Figure 42: criteria of testing table

### Test Procedure Summary

Our team has devised the following tests to measure the effectiveness of our solution. In the text below we explain what tests we will be performing, what information we will get from them, safety considerations, and general procedures. More specific and detailed procedures and data collection will be provided on the following table.

#### Pre Construction Tests:

While constructing our prototype, we will be testing the functionality of individual parts.

This means testing:

- The rotational ability of our motors and the rpm

- The watertight capabilities of the pipe on the grating

- The ability of the butterfly valve to rotate

These tests will allow us to determine the functionality of specific components of our solution so that we can make fixes before constructing the entire device.

#### Post Construction Tests:

Initial conditions: Prototype is completed. Power is provided to the motors. The motors are activated. Water is placed in the container. The butterfly valve is opened.

The types of tests we will be doing will be on the Performance and the Durability of our model.

Performance tests: To determine how effectively the iris mechanism can pump water. The pump's effectiveness at pumping water is the measure of how it can add energy to the system. The first benchmark is whether or not it can pump water in a cycle ( pass fail ). The second is the speed at which water travels around the cycle ( data collection ). The rate that the competitor models can pump upwards of 2,000 meters cubed per hour. If our small scaled and lower strength model can pump at 1/20th of that rate, the model will be considered a success. This is because we first know that our model is designed to pump at lower rates. Secondly, we know that we already can improve our pump through a variety of ways found in the previous elements. Finally, the power and torque that can be applied to this model and from our motor will be significantly lower than a full scale model.

Our procedure to test these will be to place a small rubber ball in with the water to visually measure the motion of the water.

**Durability tests:** To determine the cost effectiveness of our design. How quickly parts degrade is an important factor in assessing both what parts need to be reinforced and redesigned. For an effective solution, all parts would perform as intended for a long duration of use, at least 10 years, 90% of the day.

Our procedure to test the durability will be to run at a much higher rate than intended.

### Safety considerations

As our device deals with water and electronics, we need to be extremely careful. In the case of water leakage, little to severe, we must prevent the water from making contact with our motors, wires, and motherboard. To do so, we will surround the electrical connections in plastic wrap, ensuring that the wires are not touched by water spillage.

### Additional Materials Required

In order to perform these tests, we will need plastic wrap and tape, a rubber ball, a camera to record and check visual data, and masses of different weights.

### Testing procedures

| Test           | Procedure & Safety Considerations  | <u>Data Collection and benchmarks</u> - appendix 16   |
|----------------|--|---|
| Motor strength | Position the motor, axle, and gear so that the gear is the closest to the ground and the motor is held up by vex carriages.<br>Place mass next to the gear so that rotating the gear would push the mass. Start with a mass of 500g and increase by 500g increments<br>Motor is powered by robot c program. At varying levels of power (start at 80 and increase by 10 until hitting max power), place the masses of varying weight. Increase power until mass can be moved, then increase mass and repeat the process starting at the last successful power.<br>Tests should be done in the center of a large table so that no masses fall off. | Data will be measured on a table of two variables: mass and motor power.<br>This data can be used to measure the torque that the motor can provide.   |
| Motor RPM      | Same set up as the motor strength test except tape the highest successful mass to the gear. Load program that changes speed direction. At a constant rate. Start this change at once every 2.5 seconds ( 5 second activation ). If it successfully pulls the mass, reduce by .5 seconds. Repeat until failure.   | Data will be collected on a table of rotations per second and success. The highest successful RPM tells us what the max rate we can run our pumps at. |
| Cycle          | Pour 1 L of water in the top container. Place one small rubber ball in the container.<br>Power pumps at maximum power, activating every 5 seconds.   | Data will be recorded as well as marked in a table with success and period.   |

|               |  |   |
|---------------|--|---|
|               | <p>Open the butterfly valve.</p> <p>Record on phone.</p> <p>Decrease the period by 1 second and repeat until at 1 second.</p> <p>If the rubber ball fails to make it back to the reservoir at 1 second period, continue to the next test.</p>  |   |
| Water flow    | <p>If the cycle test passes, repeat it at the successful pump rate and record the time it takes for the ball to pass through. Record it for three cycles.</p> <p>If the cycle test fails, reposition the pipes so that they do not flow in a cycle. Instead, the last pipe sends water into a second reservoir. Mark what height on the second reservoir is 1 L. Pour 1 L of water into the first reservoir with the butterfly closed. Record on phone and set up a timer. Hit start on the timer at the same time as opening the butterfly valve. Hit stop timer when the second reservoir reaches the 1 L mark. Repeat with the motors on at activating every 5 seconds, repeating trials reducing per second until getting to 1 second.</p> | <p>For if the cycle test passes, data will be recorded on a phone. The speed of the water in ml/second can be found by taking the rotations per second of the ball, multiplying by the mm length, and converting to mL.</p> <p>For if the cycle test does not pass, record data in a table with times for without motors and with motors at each time interval.</p> |
| Durability    | <p>If the cycle test passes, set up initial conditions. Close butterfly valve. Pour in 1 L of water. Turn on motors to the highest successful rpm. Run for 10 cycles. Check for breaks or fractures on the gear, blades, or shell. If none, run again for 15 cycles. Continue at increments of 5 until a break is found ( or the system goes out of place )</p>  | <p>Data will be recorded with photos and on a table that lists which parts did not break and which parts broke for each set of cycles.</p>  |
| Water leakage | <p>Simultaneously as each of the previous tests, check for water leaks in between blades and grating and slide plate as well between the plates and the pvc pipes.</p>   | <p>Data will be recorded visually and with photos.</p>  |

Mentor Check-in Feedback Regarding Testing Criteria and Testing Procedures:

N/A

## Element I: Testing Data Collection and Analysis

### Prototype Complete Design Solution

Diagram of Model including physical supports and logistics

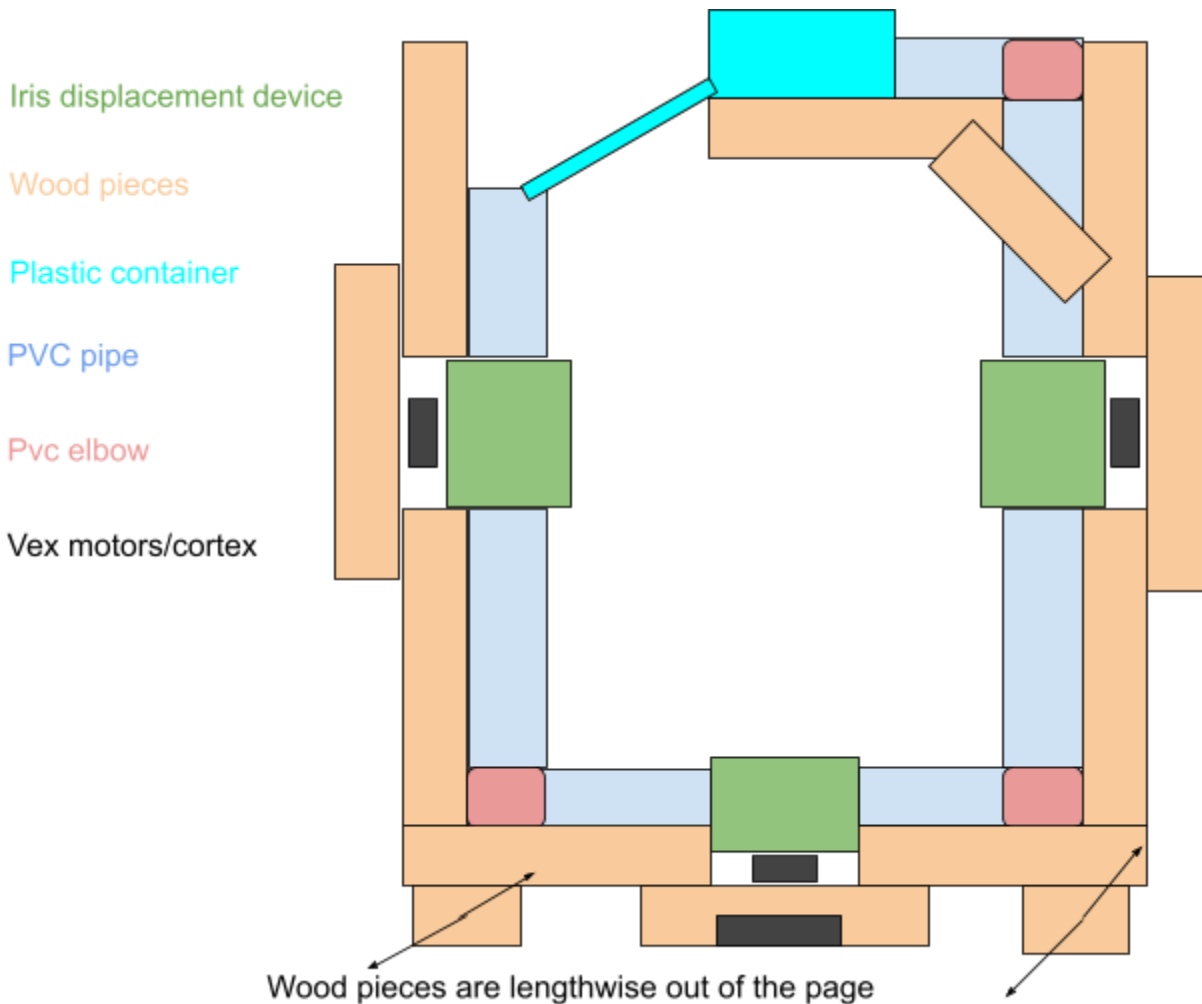


Figure 43: model diagram

The diagram depicts the plan for the pumps, the water loop, the support frame, and the electronic components.

Water will be held in the container and flow through the pipes clockwise. The Iris pumps will activate in series (1, 2, 3) to try to push the water back into the container. The reason for this sequential motion is to attempt to push the same set “block” of water through the entire loop at once, accelerating it each time it reaches the next point.



Figure 44 (top left): pvc pipes w/ tape. Figure 45(top right): uneven pvc sanded face. Figure 46 (bottom): measured wood piece.

The edges of pvc pipes must be sanded completely level in order to make watertight seals between each iris and the pipes. I used tape to make an even line ( shown in fig. 44) to sand down to using an electric sander.

Wood pieces are cut to length as shown in fig 46.



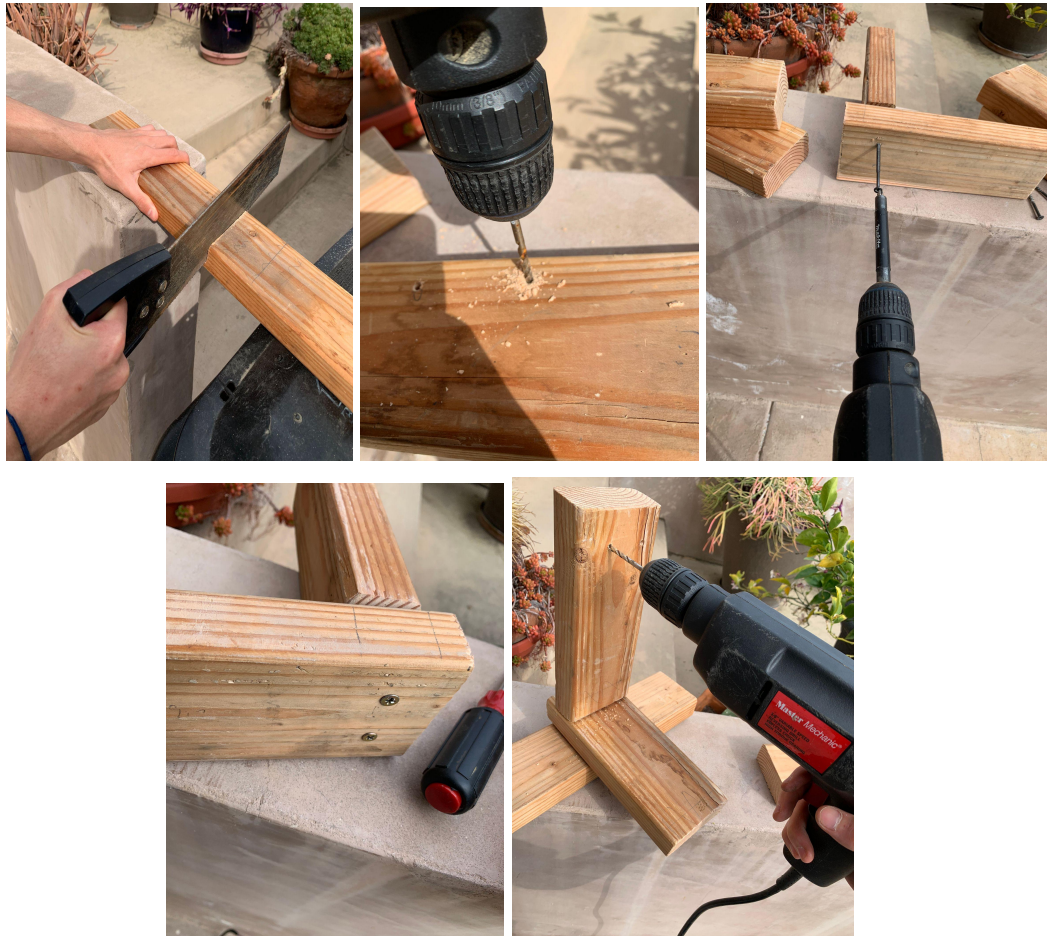


Figure 47 (Top left): Cutting wood. Figure 48 (Top Middle): Boring holes  $\frac{3}{4}$  through the wood. Figure 49 (Top Right): drilling screws in. Figure 50 (Bottom left): drilled screws. Figure 51 (bottom right): boring additional holes.

The above photos show the process employed to physically construct the wooden frame. These photos go sequentially left to right, top to bottom like a book. The wood was measured and sawn by hand (Fig 47). It was then sanded down to avoid splinters and make the edges flat for pieces that were going to stand on a surface. Then holes were bored for screws to fit in later as the screws were not strong enough to be drilled in straightaway (fig 48). Drilling screws into the second piece of wood required checking the quality of the connection (fig 50). Sometimes this would require boring a hole in the second piece. This process was repeated as more wood pieces were added on to the structure. The fourth and fifth photo all show the same size of wood pieces being fixed together. This structure is constructed twice as the base of the design is symmetrical.

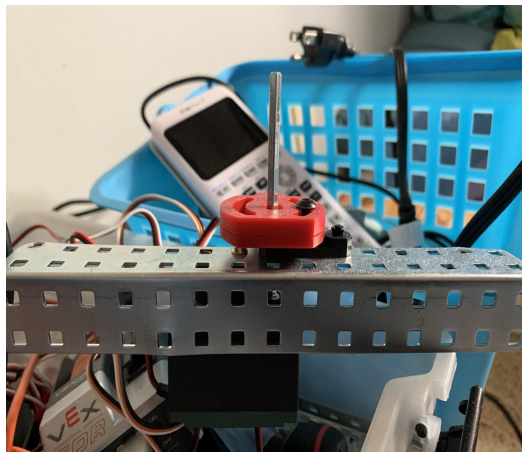


Figure 52: wooden frame progress

This is the total progress made with the piping and frame. It shows about half or more of the wood frame constructed. The base piece between the two sides is not drilled in yet. The reason for this and the reason that there has been no more construction vertically is because I need to be sure about the distance between the pipes and my placement of the structure before drilling. This measurement will come by placing the 3D printed assembly between the two pipes and on top of each vertically oriented pipe.

The metal pieces on each motor will be drilled into the wood. The current orientation of these pieces needs to be changed in order to fit against the wood so that the axle runs close with the pipes. This cannot be ascertained without the 3D assembly which will physically show where the axle needs to be.

### Building and Programming motors for Iris rotation



Motors (the bottom box with the green stripe) are attached to an potentiometer ( the red disk) to restrict their movement to about 40 degrees

This axle will drive the Iris Displacement devices and will be affixed to the wood by its metal holder.

Figure 53: motor / potentiometer connection

```

while (1==1){

    if (SensorValue[bumper] == 1 )//motor 1 sequence
    {
        wait(spacer);
        motor[motor1]= -motorspeed;//clockwise - - values
        untilPotentiometerGreaterThan(937, in1);
        motor[motor1]=(motorspeed);//counterclockwise - + values
        untilPotentiometerLessThan(200, in1);
        motor[motor1]= 0;

//        wait(waittime);

        motor[motor2]= -motorspeed;
        untilPotentiometerGreaterThan(937, in2);
        motor[motor2]=(motorspeed);
        untilPotentiometerLessThan(200, in2);
        motor[motor2]= 0;

//        wait(waittime);

        motor[motor3]= -motorspeed;
        untilPotentiometerGreaterThan(937, in3);
        motor[motor3]=(motorspeed);
        untilPotentiometerLessThan(200, in3);
        motor[motor3]= 0;

    }
}

```

Potentiometer values range from 0 to 4370 which equates to 230 degrees. 937 - 200, the bounds I used is 40 degrees.

While (1 == 1 ) is a looping function that tells the code to continuously rerun.

The code for the Robot C program is fairly simple. It tells the motors to rotate in one direction until the potentiometer reads a certain angle. Then, it tells the motor to turn the opposite direction until the potentiometer reaches the initial position.

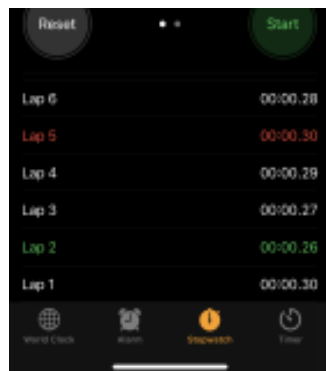
Figure 54: robot c code ( full code can be found at appendix - 18 )

“Spacer” is a variable that allows us to adjust the time it takes for each motor to activate to an even period ( 1 second, 2 second, 3 second )

“Motor value” is a variable measuring the rotating ability of the motor. Higher motor values correspond to faster rotations.

## Determining Spacer Values

In the photo of the code, motor values are denoted by a number. This is a value that ranges from 0 to 127 with 127 being the maximum power provided by the motor. These values are unrelated to the amount of time it takes the motors to spin an axle 40 degrees and hit the potentiometer bounds. The following steps were taken to correlate motor values with time between direction changes in order to determine spacer values.



For different motor values in increments of 10, each change in rotation (counterclockwise to clockwise) was timed with the lap function in the iPhone stopwatch app. For lower values, this was simple because the change in direction creates a sound change that is easily heard. However, at higher values as shown in the following table, it became increasingly difficult to measure the times.

Figure 55: stopwatch app

This data was recorded in a spreadsheet that can be found in the appendix ( appendix 15 )  
 Over 30 pieces of data are included for each motor value in determining the average time it takes to rotate 40 degrees. These values are in milliseconds.  
 Times reached down to .0014 seconds, meaning that the lap button had to be pressed with high accuracy and low response time. Due to this it was decided that the times for motor values 100 to 127 should be approximated by a curve that fits the previous data.

Regressions were created using different calculator regressions. The first is linear regression, the second is quadratic regression, the third is logarithmic, the fourth is exponential, and the last is vector quadratic. These were used to model the upper motor value data. The exponential regression function best fit the data and relationship between motor value and rotational speed. This analysis can be found in the appendix under number 17: regressions analysis.

The exponential function  $y = 6.277x^{-0.4333505}$ , where y is time and x is motor speed was then used to find spacer values. The exact process used as well as the spacer values found at different desired intervals can be found in the appendix, under 15: motor values to time

### 3D printing

## Evaluate Prototype

### **Successes:**

The prototype was successful in the woodworking stage and programming stage of construction. The woodworking stage created a solid physical foundation and allowed for variability in pipe lengths ( we were able to use the middle attaching pieces shown in the diagram of the model on pg 55 so that the pipes fixment to the foundation is not dependent on the end of a wood piece )  
 The programming stage produced a fully functioning program that can easily be tested and seen visually with integer periods.

### **Failures:**

The 3D printing / pump assemblage process failed. The process took longer than expected and had numerous failures caused by this and the design.

There were also issues with physical error. The pvc pipes were manually cut to the size we needed and were therefore not cut perfectly flat. These edges needed to be sanded until they were

as close to flat and level as possible. Any imperfections in flatness would create spaces between where a pipe face and the pump face meet, allowing water to pass through.

While the wood frame was well measured and matched the size specifications, some of the drilled connections were imperfect. In figure 52, this is shown, where the attached wood piece does not sit against its adjacent piece perfectly, leaving some space between them.

The process used to create integer periods of pumping was imperfect. Firstly, the data collection method used to find *spacer* was flawed. It relied on human reaction to click the lap button on the timer as well as to register each change in motor direction by ear. The model used to generate *spacer* values at higher motor values when it would be too difficult to measure by ear or hand was also imperfect. It does not perfectly match the inputted data. Additionally, it might not reflect the actual relationship behind motor values to rotational speed as the wrong regression may have been chosen.

- These issues reflect problems arising in the prototype construction, the quality of the building process, and the design of the prototype. None of the aforementioned issues were caused by the testing process or testing criteria as the testing stage was not reached.

### **Summary of Proposed Corrections:**

In order to solve the above failures, the following corrections can be implemented in the future.

To solve the design and 3D printing issues, we would order our pieces printed from a custom manufacturer.

To solve the issue of uneven pipe faces, we could order pvc pipes sized to our needs. PVC pipes also have labels that stick out of the pipe. These labels prevent the pipes from laying flush against the wood frame and should be sanded off. The imperfect screwed connections between wood pieces can easily be solved by boring holes all the way through each piece of wood before drilling in screws.

In order to make the measurement of *spacer* data more accurate, a high speed camera can be used. Time stamps can be related to the visual indication of a directional change in the rotation. This will allow not only for more accurate data to be taken, but for data to be taken at higher motor values - eliminating the need for a regression analysis.

An additional change of replacing motor/potentiometer combinations with motor servos. Vex Motor Servos have the ability to rotate certain amounts of time or degree. This would reduce the number of wires and help reduce size.

## **Element J: Documentation of External Evaluation**

Survey can be found in appendix

Based on our feedback in a survey, which was designed to explain our prototype to our peers and the general populace, most surveyed people believe our solution solves a necessary problem.



Half of our survey respondents asked meaningful questions about our design viability, giving us insight for possible issues. Overall, our design has been approved as a possible solution by over 76% of respondents. We have not yet heard back from our mentors. Feedback from classmates and survey takers has been key in our prototypes development, as our product design has shifted dramatically throughout the testing process. Although our design has changed, our initial problem statement still renders useful compared with our updated prototype.

Some notable responses include:

“It may be because there is just a virtual model available to see, but I feel like there might be some water leaking in between the blades. Additionally, this might not be too reliable as the small rails seem like they could get jammed as it weathers.”

“Not exactly criticism, but some questions that popped into my head:

1. What is the size of this part?
2. If this is a pump, is it designed to provide constant flow, and for how long?
3. Could this design be better utilized as a variable fluid flow restrictor, rather than a water displacement pump?”

“Your concept/invention helps to further geothermal energy making it easier and hopefully cheaper to make this renewable energy source a bigger player in the current energy market”

“Questions to consider - what are the logistics of scaling the models up or down for varying degrees of commercial or consumer viability? What kind of upkeep is required and are pieces easily replaceable/fixable?”

“this is just one part of a whole system. Would this part work in preexisting machines that are used for geothermal? would you be open to creating a whole system? does it only work for water? could it work for other fluids that geothermal technology may use?”

Mentor Response:

The problem is focused on economic advantages of an alternative pump design. The pump design must still be thoroughly evaluated to assure cycle functionality (pressure and flow rate for suction/pressurized recovery) and market competitive energy efficiency (working fluid energy conversion/actuation energy to operate the device). Also, when making cost arguments, one must address the installation, operation, and maintenance costs. The geothermal working fluid will impact corrosion assisted degradation modes.

## Element K: Reflection on the Design Process

Our prototype is a scaled down version of the actual iris pump system and is not representative of industrial production. However, mass production is likely not necessary. There exists only a small market for our product. It would only be applicable to geothermal plants that have not yet been constructed because the cost to insert our product into an already constructed and in the ground plant is much higher. Geothermal plants take many years to build and are only installed where there is an electrical demand for one. It is much more likely that, in the most successful case, the prototype would be sold to an existing construction and power company.

When we sell it commercially the product will be scaled up to the size of the power plant. Additionally there are differences between our physical prototype and virtual one. Pipes rotate in a rectangular cycle at the moment. This is to prove that our pump works, but for the full-scaled version, it will simply be placed in the geothermal pipes.

For the solution to be successful, more detail needs to be recorded and we will need to run other tests such as evaluation of efficiency at high temperatures and pressure. A simulation may be necessary to observe how the pumps will work under other conditions. We will also need to implement Api 90 materials that are not the PVC pipes that we used for the prototype.

## Appendix:

### 1) [Peer review](#)

This document includes different groups giving us feedback on our presentation/research document. It also includes our reflections about the feedback and what we plan to do next in our project.

### b) [Initial design feedback](#)

Peer feedback to the initial design idea

### 2) [Mentor Feedback](#)

This document includes all feedback from our mentor.

### 3) [Design matrix](#)

This document details research on similar solutions to our brainstormed ideas.

### 4) [homeowners survey](#)

This survey asks about electric usage and knowledge of electric demand and cost. It is targeted toward homeowners.

### 5) [design specifications survey](#)

This survey asks about design criteria an experienced consumer would want included in a steam turbine. It is targeted toward employees of electric companies and power companies.

6) [Homeowners survey results](#)

This document shows pie charts of the results of the survey

7) [Elevator Pitch](#)

This video is a quick summary of our problem statement, justification, and initial/final design.

8) [Energy transfer research](#)

This document details the research behind the revised initial idea on the boiling of a solid versus liquid substance to transfer energy from heat to motion.

9) [Cycles research](#)

This document includes research on the energy cycles of different power production methods in order to determine which one our group should focus on

10) [Geothermal research](#)

This document includes additional research on the workings of geothermal plant systems

11) [3D Parts](#)

These documents include files of different parts in our Assembly

12) [3D Assembly Photo](#)

This document includes our full 3D assembly part.

13) [3D Iris](#)

This video includes a 3D video of our assembly part working as it would in our project.

14) [prototype evaluation survey](#)

This survey asks for comments, concerns, and additional ideas for our prototype as well as a general survey of stakeholder's opinions of our prototype.

15) [Motor values to time](#)

This google sheet has all of the data collected and used in timing the motor and calculating the spacer value.

16) [testing observations](#)

This google sheet includes tables for data collection of testing.

17) [Regressions analysis](#)

These photos are screenshots of the regressions performed in Desmos in order to create a formula relating motor value to time

18) [RobotC Program](#)

This text file is the code used in the RobotC program that, combined with the vex cortex, drives and controls the motors

19) [Final edited drawing and Cad files](#)





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