Taking Advantage of Multiple Renewable Resources

TOWER OF POWER

Product:

ToP co. members:

Syed H. Ali	Derek Tran	Anthony Newlin	Joseph Pacheco	Adnan Dzebic	Augustus Ma
Wind Energy Expert	Team Lead and Solar Energy Expert	Geothermal Energy Expert	Schedule Manager and Chief Finance Officer	Hydropower Expert	Mechanical Design Engineer

Abstract:

With renewable energy harvesting a growing demand, solar and wind farms are cropping up in the country. Geothermal harvesters are also being taken advantage of to reduce building electricity bills and research into offshore hydropower energy harvesters is growing. However, these are individual energy harvesters with unstable power output. Therefore, the Tower of Power company (ToP co.) proposes to construct a single, offshore tower that incorporates four different types of energy harvesters: solar, wind, geothermal, and hydropower. How the tower is constructed and how the four harvesters are integrated into the same tower will be discussed. In addition, the best technology for each harvester will be presented, explaining specifically how each will harvest renewable energy. Because of the integration of different types of energy harvesters, the location of the location becomes important, and the reason why the Caribbean was chosen as the best location will be discussed. Finally, the overall budget and time necessary to complete the tower will be shown.

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Purpose:

With a higher demand in renewable energy, the primary purpose of the Tower of Power is to incorporate multiple energy harvesters into one module that supplies energy directly to the power grid.

Introduction:

Renewable energy has become a significant topic in the recent years. As the planet is getting warmer, one of the major contributors is carbon emissions released from the burning of fossil fuel. Fossil fuel has been the energy source that has allowed for society to function, but it has contributed to the climate crisis that the planet is experiencing. To lessen the carbon emissions and become less reliant on fossil fuel, renewable energy sources are vital. The four reliable renewable energy sources that can take the place of fossil fuels are wind, solar, geothermal, and hydro power.

Wind, solar, geothermal, and hydro power are reliable alternatives to fossil fuel and do not populate the atmosphere as much. There are more abundant supplies of these energy sources compared to fossil fuel because they occur naturally on the planet. These characteristics make wind, solar, geothermal, and hydropower a renewable energy source due to the ability to have a constant supply with little carbon emissions. Since these energy sources are renewable, it is possible to help supply the power grid with the excess power gathered. However the amount of power obtained is heavily dependent upon the location.

The proposal of the Tower of Power is to incorporate the four most reliable renewable energy sources into a single module that can supply energy to the local power grid. The Tower of Power’s concept is to utilize the efficient methods of wind, solar, geothermal, and hydro power to obtain the most optimal amount of power.

Credentials:

Below, a brief background of each team member is presented to show how each is qualified for the particular section of the tower he worked on.

Syed H. Ali (Wind energy Expert):

As a chemical engineer, Ali is familiar with concerns of harmful chemicals and how they would affect the environment. After researching these concerns, Ali looked in depth at the science behind wind and how wind energy harvesters such as wind turbines extract energy from wind.

Derek Tran (Team Lead and Solar Energy Expert):

As an electrical engineer with interest in power system design, Tran had looked into solar energy harvesting before. With experience in designing a power system for a robot, Tran decided to take lead for the Tower of Power project.

Anthony Newlin (Geothermal Energy Expert):

An avid reader and an electrical engineer, Newlin familiarized himself with renewable energy harvesters. In particular, geothermal energy harvesting struck as the most promising technology for him.

Joseph Pacheco (Schedule Manager and Chief Finance Officer):

Because of how large this project would be, someone would have to be in charge of watching the budget and ensuring that the tower construction stay on schedule. Pacheco took responsibility for this, and, as an electrical engineer, he would have an idea of how long the project should take.

Adnan Dzebic (Hydropower Energy Expert):

Another electrical engineer, Dzebic was always interested in radio technology. Since radio transmitters require large amounts of power, Dzebic took courses on large power systems, which included a brief look into renewable energy, hydropower energy harvesting in particular.

Augustus Ma (Mechanical Design Engineer):

Having experience in constructing a robot in previous years, Ma as an electrical engineer was exposed to the mechanical engineering side. Knowing the importance of the integrity of the structural design, Ma took up the task of researching the mechanical design of the tower.

Proposed Procedure:

As mentioned previously, this particular tower will contain the facilities to harvest energy from four different renewable energy sources: wind, solar, hydro, and geothermal. Thus, the tower will be constructed to contain four sections that each specialize in harvesting their respective energy sources. Locating these four sections on the tower itself will be one of the easier tasks due to their immediate requirements, as shown in Figure 1. For instance, harvesting wind energy requires a greater height to access strong winds, so that particular section will be at the top of the top. Geothermal energy originates from underground, so that section of the tower will be located at its base which lies beneath the seafloor. The particular design of each section will be expounded in further detail below.

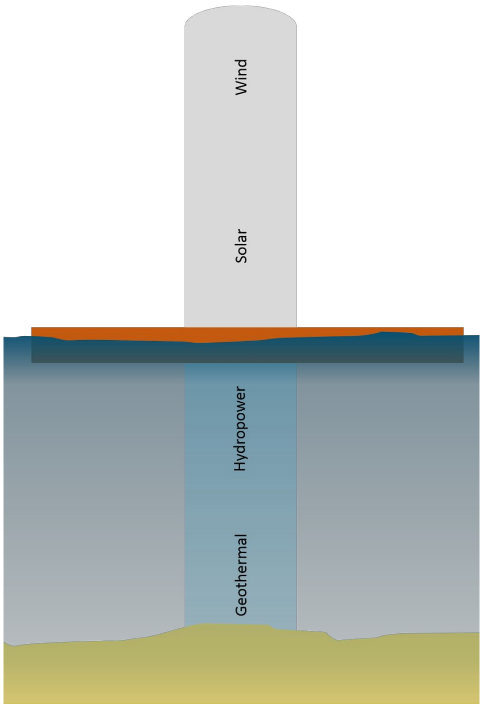


Figure 1. Sketch of basic tower structure. This provides a basic idea of the organization of the harvesters in the tower.

Mechanical design:

The Tower of Power will be situated on an offshore, fixed platform, specifically the jacket platform structure shown in Figure 2. This platform design is chosen for its stability within the water and minimal obstruction to the water current. Essential for the implementation of the geothermal energy harvester, the most important attribute of this platform is stability. The platform will be constructed with A36 grade steel. If more strength is required, additional grade X52 steel will be used (Sadeghi, 2007).

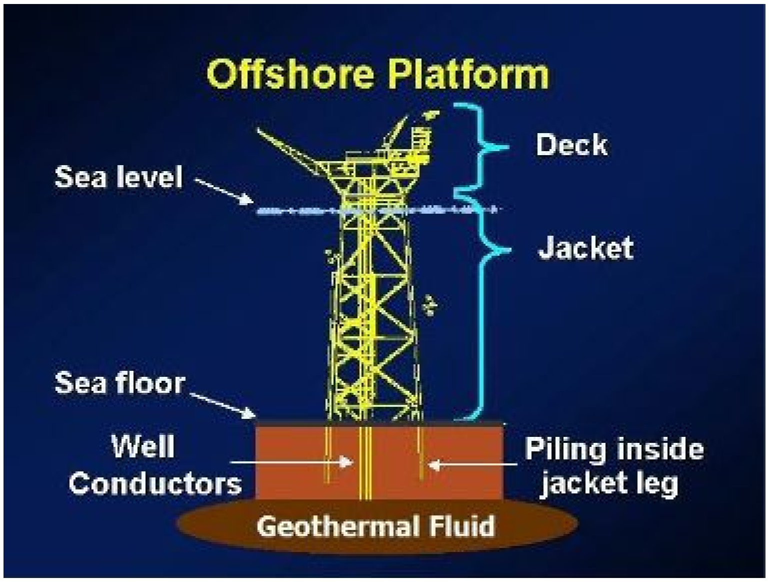


Figure 2: Jacket Platform Schematic. This shows from an example of how the tower is supported (NOAA, 2011).

There will be two units attached along the structural columns of the tower for the hydropower energy harvester. Each unit consists of two turbines that are connected at either end of an extended beam. The units are going to be mounted onto the center crossbeam of the structural poles and placed directly opposite one another. These extended beams will be slightly longer than the length of the structural beam of the tower. This will ensure that the water current that is flowing to the turbines will not be obstructed by the tower. Each of the turbine blades will be about 10 meters in length, ensuring that the turbines will turn slowly and reduce any risk of harming sea creatures. On another note, to combat the weight of the heavy turbines that may affect stability, the support and extended beams will be made hollow, so the air within them will create buoyancy.

On the deck of the platform, a power plant will be constructed. This power plant will be the main gate for each of the harvesters to connect to the power grid. To avoid instability due to varying power outputs, the harvesters will be connected to the grid separately. A bonus benefit from this design is that even if one or more energy harvesters stopped outputting energy entirely, there will be other harvesters that can compensate. From the power plant, transmission lines will connect to the local power grid, providing electricity there. In addition, the power plant will be equipped with a control system that will monitor the amount of energy gathered from each harvester.

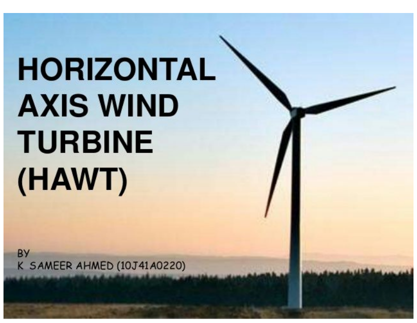
From the roof of the power plant, the top of the tower will extend, bearing the solar and wind energy harvesters. Since the solar energy harvester requires the use of a farm of mirrors concentrating sunlight at a focal point in the tower, the plant's rooftop will also serve as a platform for all these mirrors. Near the top of the tower, the large wind turbine of the wind energy harvester will be located in the center of the structure. The turbine itself will have blade lengths of 43.5 meters while the height of the wind energy harvester will be 78 meters. The focal point of mirrors from the solar thermal farm will be directed toward a hyperboloid mirror installed a few meters below the wind turbine blades.

Wind Energy Harvester:

To generate electricity from wind a wind turbine will be used. Before discussing the design of the wind turbine itself, a background behind the science of wind energy harvesting will be discussed below. After presenting the actual design of the wind turbine, the pros and cons and such a design will be compared.

Due to an increased international focus on climate change, many types of renewable energy sources have been made, one of them being wind power. Uneven heating of the Earth's atmosphere by the sun creates areas of low and high pressure in the atmosphere, and the movement of air from high pressure to low pressure is called wind. Factors that influence the wind's speed and direction are: bodies of water, mountains, hills, valleys, and elevation. The terms "wind energy" or "wind power" describe the process by which wind is used to generate mechanical power or electricity.

The modern method for harvesting wind energy is through the use of wind turbines, so the Tower of Power will also utilize a wind turbine. As wind push against the turbine blades, a shaft turns about 18 revolutions per minute (rpm). Internally, the shaft turns a series of gears, where the total gear ratio will increase the speed to about 18,000 rpm, fast enough for a generator to produce electricity. There are two types of wind turbines based on the axis of orientation: horizontal and vertical, depicted in Figure 3. Wind turbines are most efficient in generating electricity if they are located in open areas with nothing blocking the wind.



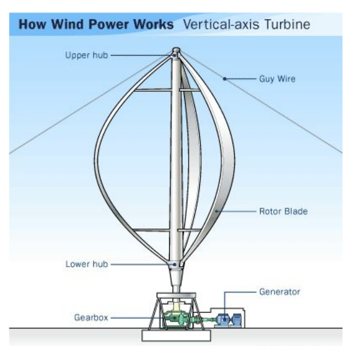


Figure 3. Types of wind turbines. Seen here is a comparison of horizontal-axis turbines (left, Ahmed, 2014) and vertical-axis turbines (right, Layton).

The majority of modern wind turbines are horizontal-axis turbines because they are more efficient in generating electricity. The reason is that the blades of the horizontal-axis turbine follow the wind while the blades of a vertical-axis turbine move against the wind, meaning there some energy lost to physical resistance.

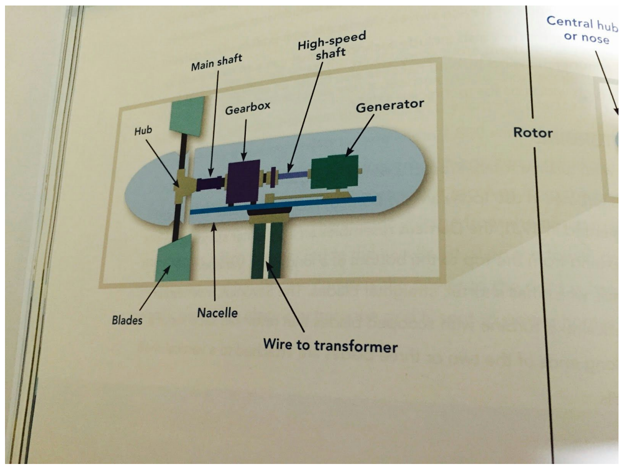


Figure 4. Design of a horizontal-axis turbine. This shows a sketch of the design of the turbine that will be used in the Tower of Power (Higgins, 2013).

For higher efficiency, the Tower of Power will use the horizontal-axis turbine design as shown in Figure 4. Since the Tower of Power will be located offshore because of the hydropower energy harvester, there will be an absence of obstructions, meaning the wind turbine will generate more electricity. Thus, the harvester shall have only one turbine. Constructing a wind turbine offshore does increase initial cost by 30 to 50%, but this higher expense will be compensated by higher energy production (Higgins, 2013).

Like every technology present, wind turbines have pros and cons. Some of the disadvantages of wind turbines include: inconsistent wind speed and threats to wildlife. Wind travels at variable speed, sometimes even stopping. This creates periods of low energy production, which makes location of the tower important, such that an area with high wind speeds and consistent wind would be preferable. A second drawback of wind energy is the threat to wildlife. A report conducted by the US National Wind Coordinating Committee (NWCC) in 2001 stated that the 15,000 wind turbines in operation at the time killed 33,000 birds every year (Higgins, 2013). With risk of accidentally killing a large number of birds, designing a safer and lower profiles turbine becomes paramount. This is a major factor in why the tower will bear only one turbine in the center, making it easier for birds to see and avoid the tower. On the other hand, some benefits of wind energy are: little pollution, constant energy source, and low impact on the environment. It has been estimated that if the US taps into 10% of its wind energy potential, then US's CO_2 emissions would reduce by 33% (Higgins, 2013). Wind energy will not run out because wind is always produced naturally all over the Earth. Wind farms in Texas, the number one producer of wind energy in US in 2011, helped prevent blackouts during the state's record heat wave as well as drought since wind energy does not require water in its production (Higgins, 2013).

Solar Energy Harvester:

To maximize the energy harvested from sunlight, the solar energy harvester will utilize two technologies. The first is silicon photovoltaic solar cells. Photovoltaic (PV) cells can be found in common solar arrays on many buildings, harvesting energy from sunlight through the absorption of photons at specific wavelengths. The other technology is concentrated solar power (CSP), basically a farm of mirrors that concentrate sunlight at a central point to run a thermal electricity generator, which most commonly is a steam engine. Specific to this combined solar technology, the mirrors target a hyperboloidal mirror mounted inside the central tower (Segal et al., 2004, p. 592). On this mirror, an array of PV cells will be mounted to capture approximately 20.5% of the light (Segal et al., 2004, p. 597). The rest of the sunlight will be reflected by the central mirror down to heat a reservoir of water to drive a steam engine. This will add an efficiency of 51.7%, totalling the efficiency of the solar harvester at 72.2% (Segal et al., 2004, p. 597). For generating electricity during the night or cloudy conditions, heat generated by the CSP will first be stored in molten salt containers, which will in turn power the steam engine. Further explanation of each part of the solar harvester is discussed below.

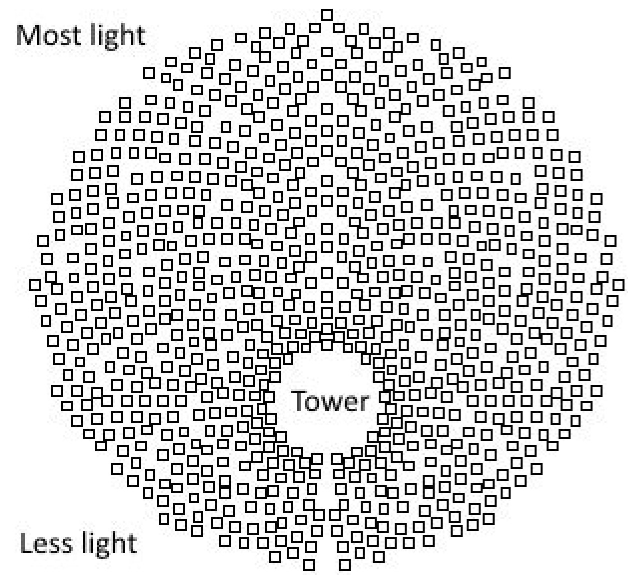


Figure 5. Mirror arrangement. This visualizes the arrangement of mirrors around the tower. (Segal et al., 2004).

First, sunlight must be directed toward the hyperboloidal mirror. This consists of constructing a farm of mirrors surrounding the base of the tower. The layout of the mirrors will resemble an ellipse with low eccentricity, nearly a circle, where the tower will sit at one of the major foci. The orientation of the ellipse will depend on the location of the tower. For example, if the tower were placed in the Northern hemisphere, the side opposite of the tower will point north to capture the most sunlight during the summer solstice. This is shown in Figure 5. In addition, since this tower will be located offshore, the area of the mirror farm must be minimized to cut down cost and increase practicality. To accomplish this, the area of the mirror farm will be restricted to 250 m by 250 m. The number of mirrors will also be replaced by longer, parabolic-like mirrors to help reflect as much sunlight as possible at the central tower mirror.

Next, the light from the mirrors will be directed at a large, central reflector covered in a ring of PV cells as depicted in Figure 6, where both will be mounted just below the wind energy harvester at the top of the tower, also shown in Figure 6. This design of placing the cells near the center of the mirror is preferred over using a partially reflecting mirror (to reflect some light to an array of PV cells to the side) since the latter would require a wider tower, affecting the total area of the mirror farm. This also allows the solar cells to sit upside-down inside the tower, meaning little dust will settle on the cells and reduce maintenance cost.

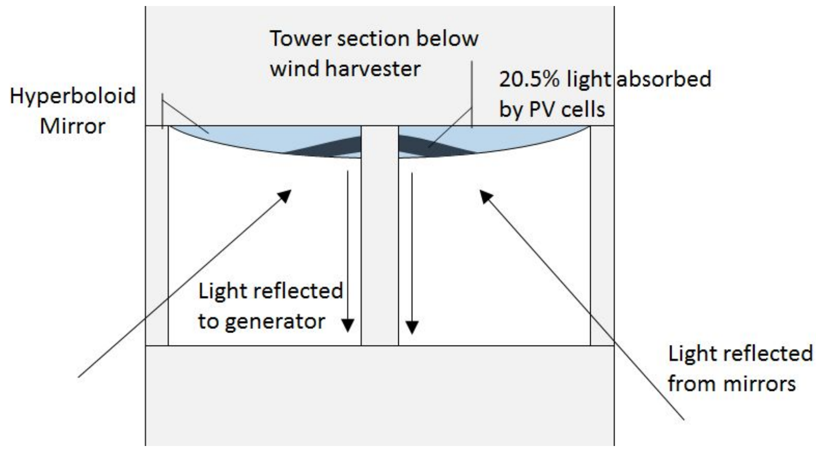


Figure 6. Solar harvester in tower. This illustrates how light is collected by the solar harvester.

Hydropower Energy Harvester:

The use of hydropower has been steadily increasing over the years and is currently responsible for around 20% of our global electricity consumption (Use and Capacity of Global Hydropower Increases, 2015). Hydropower does not have a big negative impact on the environment since there is minimal gas emission that are harmful to the climate. Hydropower also has the potential to lower our dependence on nuclear power and the added radiation risks that come with nuclear power.

There are a few types of hydropower technologies available, some of which were quickly eliminated from our discussion due to their infeasibility with the rest of the Tower of Power system. Traditionally, hydropower solutions require a large dam or a waterfall for harnessing energy, but a large dam cannot be constructed to keep the system relatively small and modular. One encouraging form of hydropower is tidal power. Similar to how wind turbines are used for harnessing the energy from the wind, tidal turbines can be used for harnessing the energy from currents beneath the ocean, as shown in Figure 7, which looks like an upside down wind turbine below the water surface. This type of power arises naturally from the ocean and is very similar to wind power since both systems use the kinetic energy of a fluid that pushes turbine blades and drives an electric generator. Although these currents beneath the water have lower speeds than those of the wind, the density of water is much higher than air and this allows for smaller turbines. The density of water is about 800 times higher than air and, for this reason, the water turbines will be built stronger and sturdier to withstand the pressure (Wave Power, 2015).

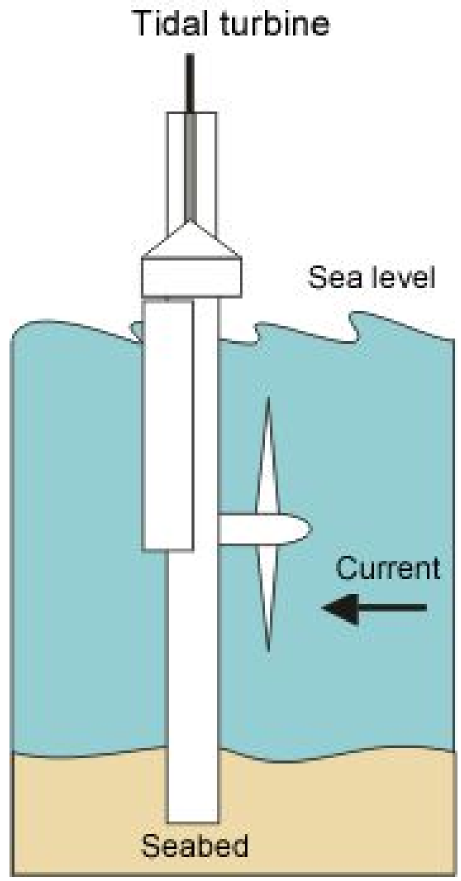


Figure 7. An illustration showing how a simple water turbine would operate (NEED Project).

Harnessing tidal energy is still in its infancy and research started only 20 years ago in energy hungry places around Europe. Many experts in the field, such as Andy Baldock who is a wave energy analyst from an engineering firm in the UK, believe that the technology can indeed be successful commercially (Wave Power, 2015). Over the next decade, tidal power technologies are expected to grow at a very quick pace and multiple tidal projects around the world are already underway, some of which have even been implemented already. Two big companies in the industry at the moment are Marine Current Turbines Ltd (MCT) and Atlantis Resources Ltd (AR), both of which have large projects around the world. The common place where all the big companies seem to be constructing their tidal power systems is around the Scotland, Ireland and United Kingdom region. This region has bodies of water with marine current which flows at acceptable rates for harnessing energy through the turbines, such as the Strangford Lough in Northern

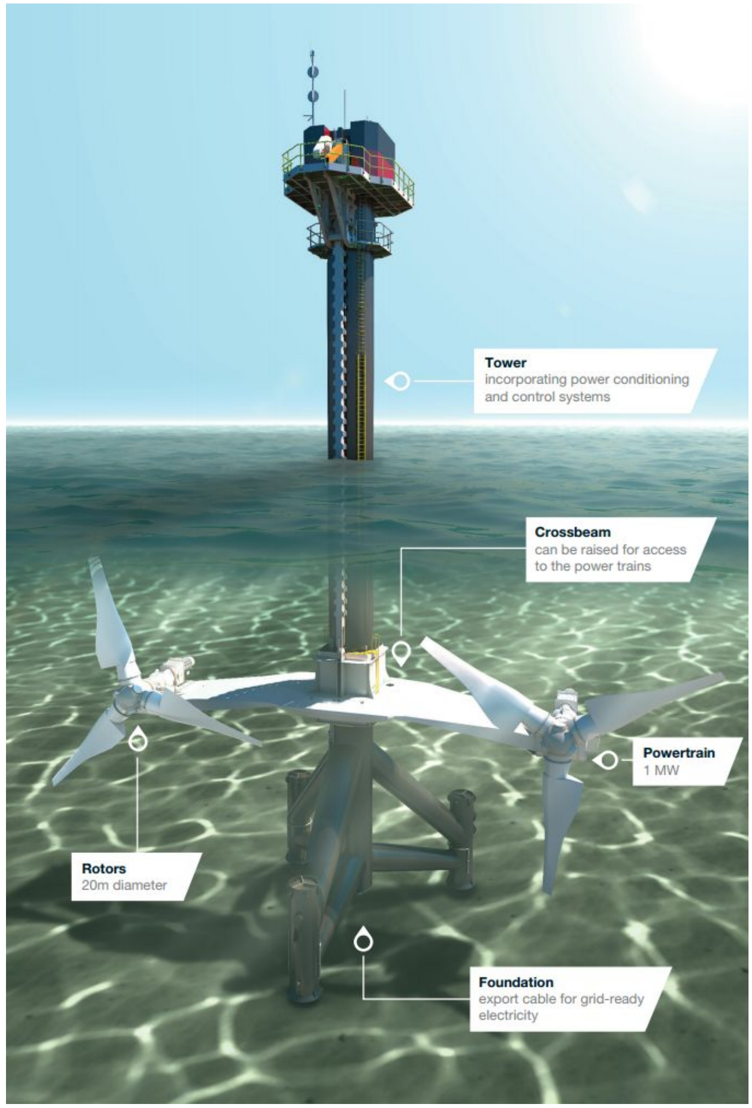


Figure 8. SeaGen S. An image of the first commercial tidal energy generator (MCT, 2013).

Ireland that has currents that flow at around 4 m/s (Kregting & Elsäßer, 2014). In 2008, the first commercial tidal power station was constructed at Strangford Lough and, given the name SeaGen S, is considered a groundbreaking success for tidal energy harnessing systems like the ones that we wish to incorporate into the Tower of Power. The SeaGen S device, as shown in Figure 8, delivers two megawatts of electricity to the grid and has an interesting feature to its design that allows the crossbeam to rise above the surface for easy maintenance, a feature that will definitely be considered for the Tower of Power.

Geothermal Energy Harvester:

A single flash system will be used to harvest the energy from an offshore geothermal source because these systems are well documented and well researched. There are two major parts to harvesting offshore geothermal energy using a single flash system: a well, which supplies the geothermal fluid, and a power plant, which houses the necessary equipment to create energy from the geothermal fluid.

The well would be created using current drilling methods that are very similar to those used for wells based on land and also by oil companies. The drilling would be done using a drilling vessel equipped specially for the job. Like on land, the drilling uses a cooling system that utilizes water or mud to both keep the drill cool and to remove the cuttings. When used offshore, this cooling system requires more care because it is important that the mud does not drop below a certain temperature threshold. If the mud were to fall below the threshold, it would hydrate and become more viscous, causing it to behave unexpectedly. Since the geothermal vents tend to be plugged by the mud, water will be used instead of mud when drilling the section of the well called the liner. The casing is the largest part of the well, consisting of three strings and a liner. The three casing strings are the surface casing, the anchor casing, and the production casing. The liner is typically perforated to allow the geothermal fluid to flow through the entire well to the wellhead. The last piece of the well is the wellhead, which will be installed following the offshore standard. A depiction of the whole well can be seen in Figure 9.

As mentioned in the mechanical design, the power plant will be housed on a platform above water. Therefore, current land power plant designs will be sufficient along with structural modifications. The method utilized by the plant is a single flash system. In this method, the geothermal fluid is converted into steam, or flashed, and moved into a separator. The separator separates the steam from the water since only the steam is desired. The steam is then moved into the demister to remove the last bits of water so only steam is left. Afterward, the steam travels through a turbine, rotating it and producing energy. A transformer converts this energy into electrical energy. After passing through the turbine, the steam passes through a condenser to turn into water. Next, the water is injected back into the geothermal reservoir along with the water obtained from the separator and demister, completing the cycle. Being over the ocean, the tower will use ocean water to cool the working fluid of the condenser. This whole process can be seen in Figure 10.

A plant like this produces roughly 10,000 kW of energy. More specifically, the turbine creates 10,946 kW of mechanical energy. The energy is then converted into electrical energy with a generator, which runs at 95% efficiency, resulting in 10,399 kW of electrical energy. The water pump that keeps the condenser fluid flowing requires 406 kW of electrical energy. In total, the net energy produced is 9,993 kW of electrical energy (Karason, 2013).

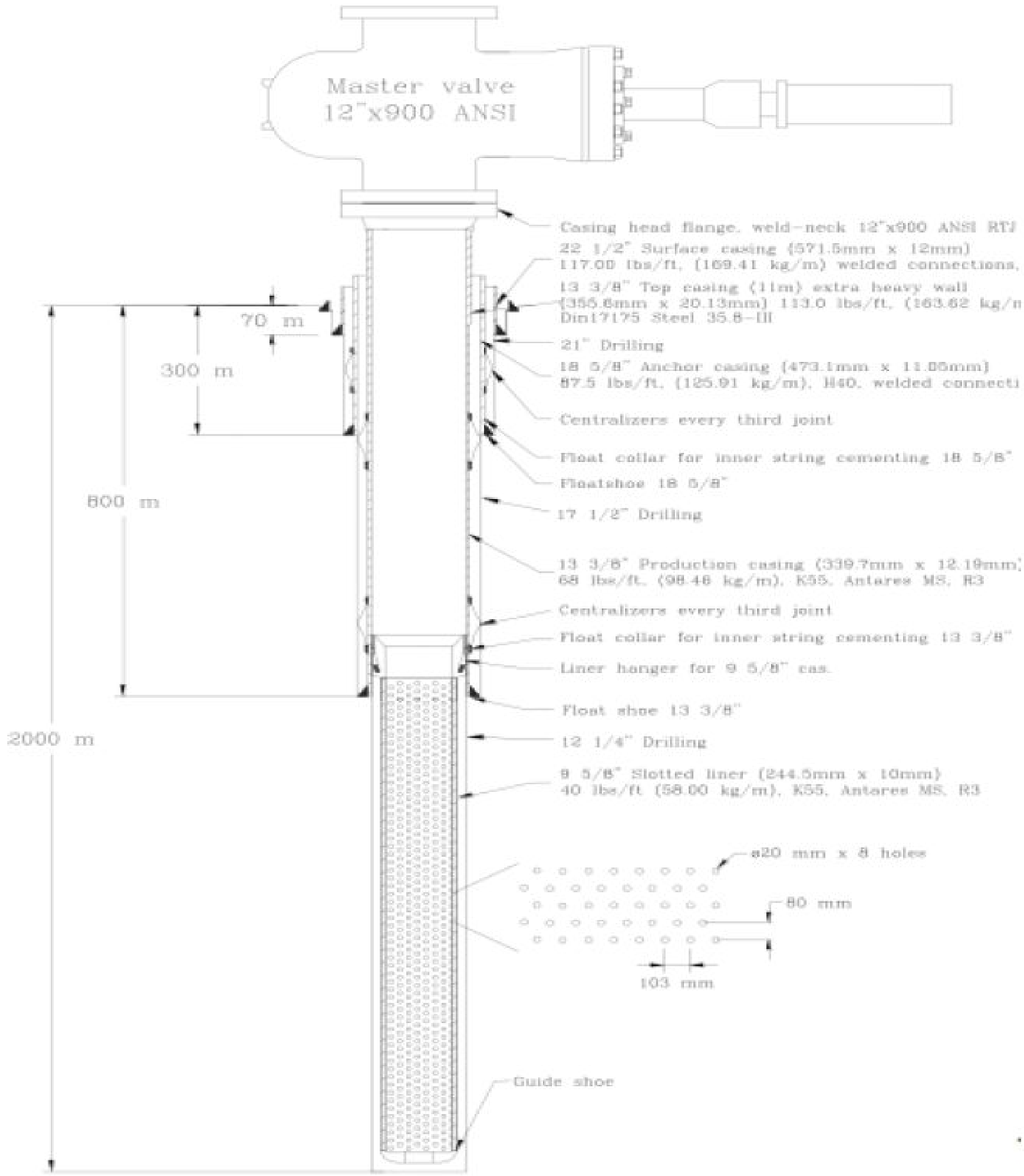


Figure 9. Geothermal casing design (Kárason 2013)

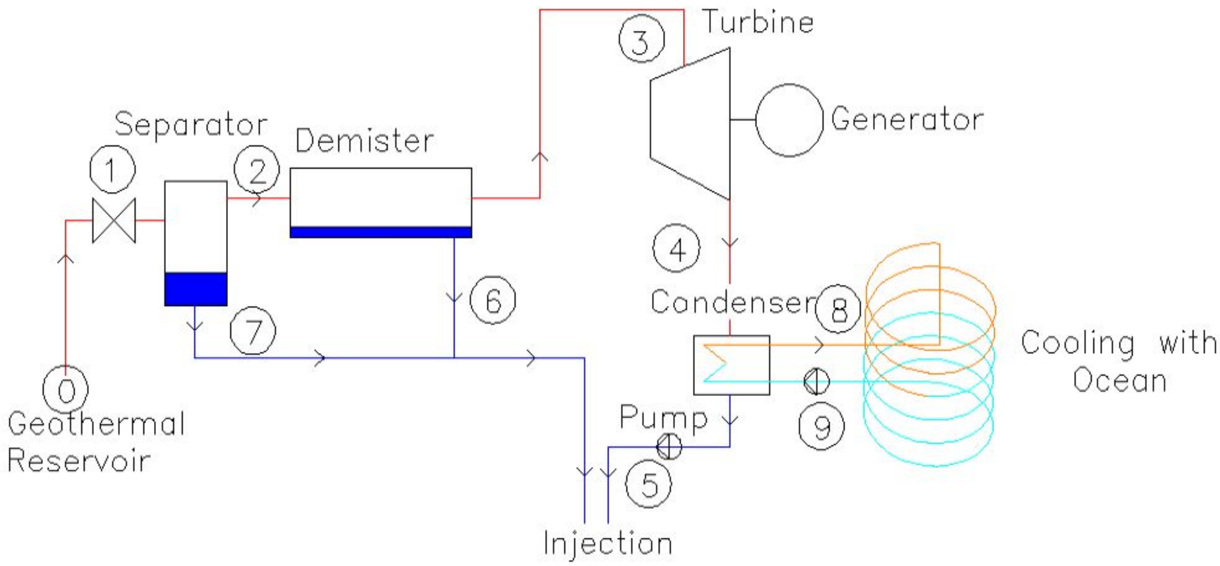


Figure 10. Single Flash System Process Diagram (Kárason, 2013).

Tower Location:

Due to the nature of the various harvesters, possible locations for the tower is limited. Obviously, the hydro energy harvester limits possible locations to open water while the geothermal section restricts the location to be at relatively shallow depths near thermally active regions. Locations that receive the most sunlight while boasting strong winds also limit the locations at which the tower can be constructed.

Finally, one of the key factors in deciding where the tower would be best located is how much variance in power output the harvester would yield. With the right location, the hydropower and geothermal energy harvesters will provide a constant energy supply, but the wind and solar energy harvesters will have variable yield. Thus, as Santos-Alamillos et. al. (2015) mentioned in their article, a preferable location would yield wind and solar energy such that there are less periods in which no power is generated. In the same article, the region of study was Andalusia, the southern portion of Spain. Thus, the final location for the Tower of Power will satisfy the following conditions:

- Be in open water where the underwater current is stable enough to make hydropower practical
- Be at a shallow enough depth to make geothermal energy harvesting practical
- Be an Andalusia-like region to have enough sunlight for the solar energy harvester to compensate for the wind energy harvester when needed and to have enough wind for the wind energy harvester to compensate for the solar energy harvester

One of the first places that we considered for placing the Tower of Power was near the Gulf Stream near Florida for the strong winds and ocean currents. Figure 11 shows wind speeds along the Atlantic Ocean as well as other potential areas in the world which may be able to supply strong wind. The drawback to choosing the Gulf Stream as the preferred location was the lack of geothermal activity in the region.

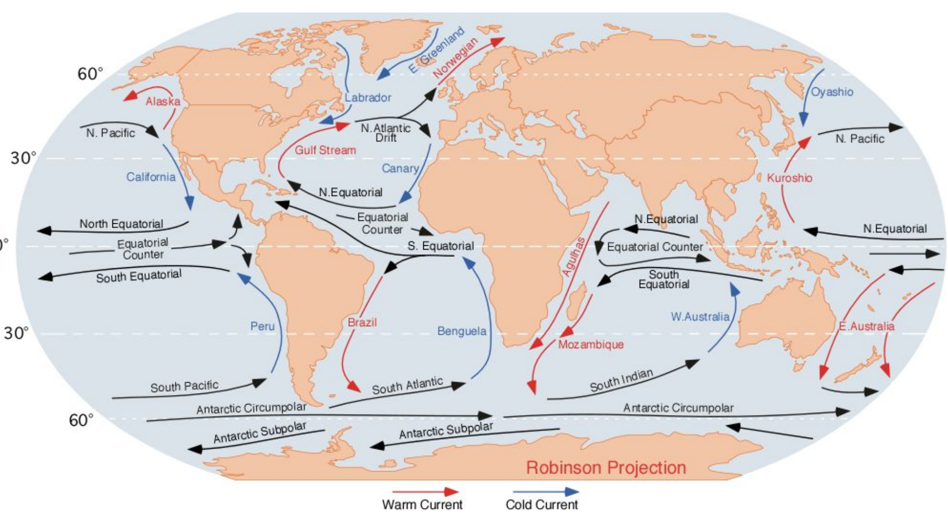


Figure 11. Ocean Current Map. This picture shows the major ocean currents around the world (2006).

The next place we looked at was Iceland, a country with

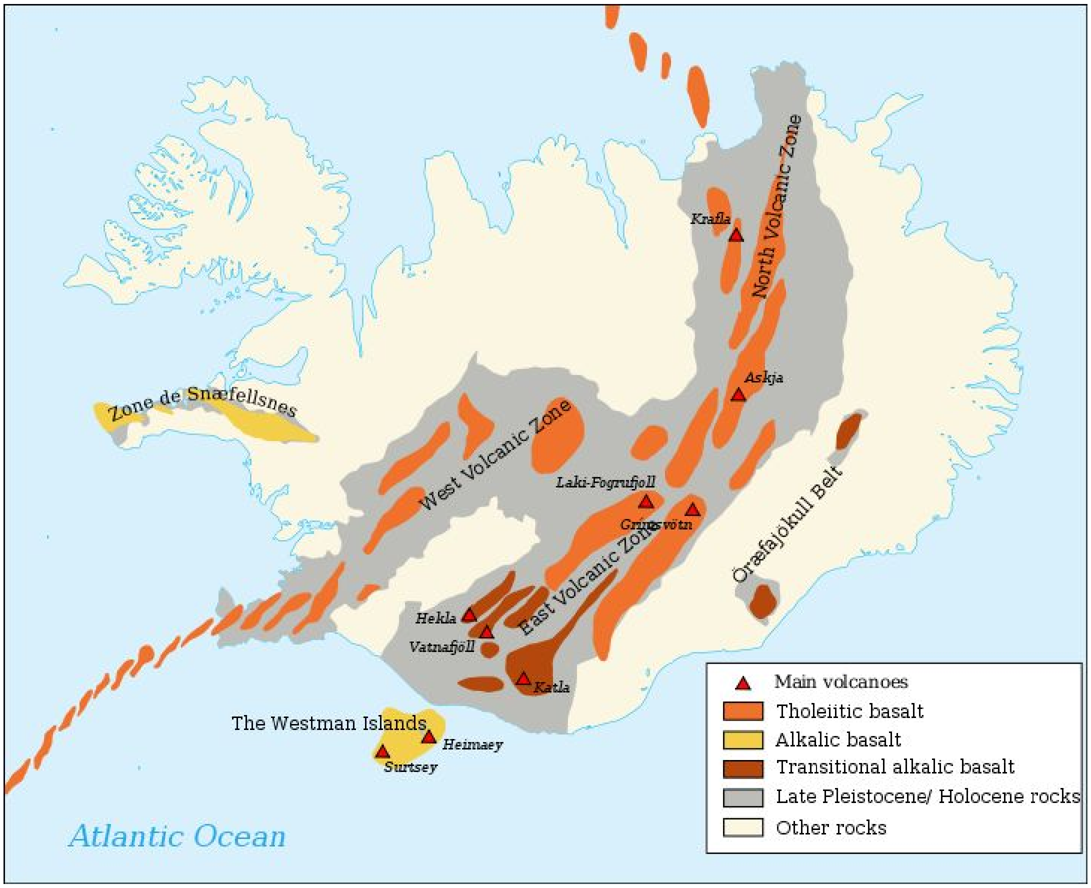


Figure 12. Main Volcanic Zones. A map of Iceland showing the regions with geothermal and volcanic activity (2014).

enough geothermal activity from which the Tower of Power's geothermal harvester can extract energy.

Unfortunately, a closer look at the surrounded tidal current speeds around Iceland revealed too low ocean current speeds for the hydropower energy harvester. Therefore, the most promising location was the Caribbean Sea. Boasting strong winds, high geothermal activity, consistent sunlight, and powerful tidal currents, the Caribbean Sea would be well suited for all four harvesters on the Tower of Power.

Tower of Power Schedule

Table 1. Break down of schedule. The construction row includes: three years for geothermal, two years for hydro, and two for solar and wind.

TASK	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Identify Prefered Technologies and Design										
Siting Tower Requirement and Identify Suppliers										
Construction										
Start-Up/Commercial Operation										

Cost Benefit Analysis

Table 2. Detailed look at the product budget. This table compares the cost of constructing and maintaining the tower with the benefits it provides.

COSTS		
	Construction	Maintenance
Wind	$3,000,000.00	$90,000.00
Solar	$48,000,000.00	$960,000.00
Hydro	$15,000,000.00	$450,000.00
Geothermal	$100,000,000.00	$3,000,000.00
BENEFITS		
	Direct	Indirect
Wind	2,000 kWh	
Solar	50MW/y	
Hydro	1.2 kWh	
Geothermal	10,000 kWh	

Budget $173,000,000.00

Construction $166,000,000.00

Maintenance $4,500,000.00

Conclusion:

Renewable energies are the future of the energy industry, cutting down emissions that pollute the atmosphere and are sustainable, meaning the supply of energy will never run out. With the Tower of Power, renewable energy systems will become more accessible to the public. The buy-in cost of such a project is high, but the year-to-year expenses are low and the reduced environmental impact compared to current energy systems justifies the cost. The Tower of Power breaks the ground of multi-system harvesters, showing the world what renewable energies technologies can do and encouraging others to pursue similar technologies and ideas.

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