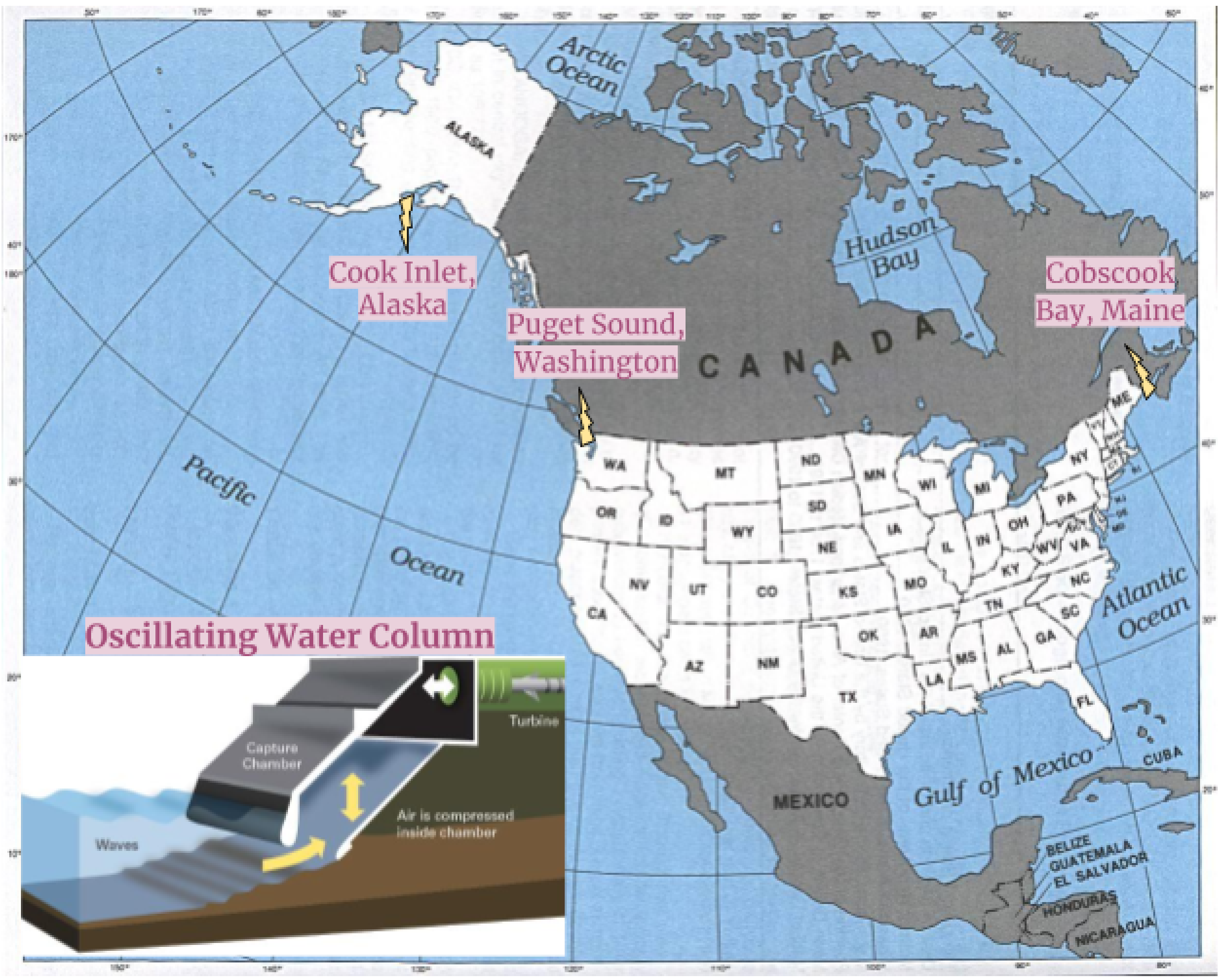
Environmental Impact of Wave Energy Converter Technology Grant Proposal

iCons 1 - Independent Case Study



Sources: *UIowa Wiki* and *1Up Travel*

Team Letter: G

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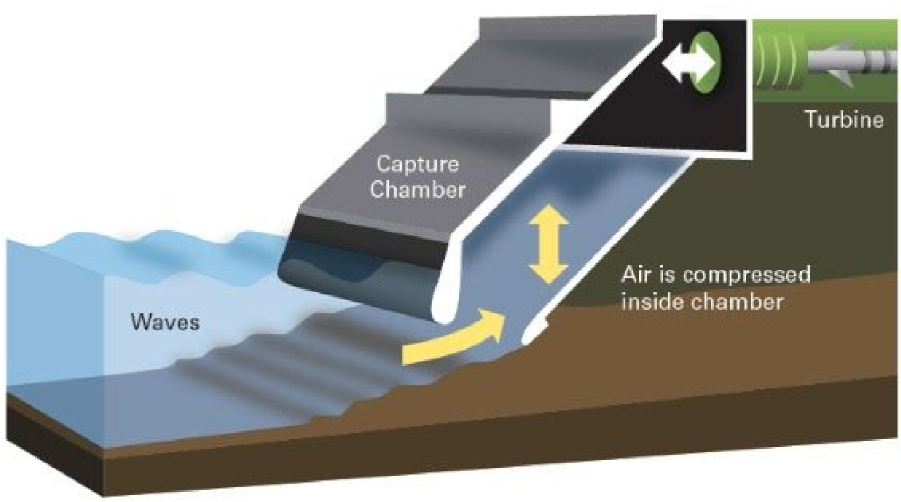
Project Summary

Our main goal for this project will be to measure the effect that tidal plants have on the ecosystem. We would complete a field study by surveying possible locations to implement smaller models of tidal energy plants. Each of the 3 locations (Alaska, Maine, and Washington) will house a control group (no tidal energy system) and an experimental group (with installed tidal energy system) within a 5 miles radius of each other. To be consistent, we decided to plan implementation of the oscillating water column for our studies so that we have a consistent form of energy converter. For our purposes, we decided it would be best to pick a tidal energy converter that is land based, so therefore maintenance and data collection of the system will be easier. We examined the relatively similar prices of tidal energy converters due to all using very similar materials arranged in different orientations.

For the experimental group, changes in ecosystem viability will be measured. Ecosystem viability is its capacity to preserve both its integrity and stability for supporting its original biodiversity (Nasiri, Fuzhan). Ecosystem viability can be measured by dissolved oxygen levels, suspended sediment concentration and organism counts made by SONAR devices. These values will be compared to the control group where an oscillating water column tidal energy system has not been installed. We hypothesize that the dissolved oxygen, suspended sediment concentration, and average number of organisms will all decrease slightly, but that these effects will have no effect on the greater ecosystem. (For more information on our predictions, see our anticipated results section).



(Source: UIowa Wiki)

Background

Tidal energy is an exciting source of renewable energy source due to its potential to generate reliable electricity with little impact on the environment. Tidal energy converters take advantage of the natural rise and fall of tides to produce power without producing air, water, or thermal pollution. Tidal energy technology is promising because it emits zero greenhouse gases and does not require fuel transport or disposal of waste products. When compared to wind turbines, tidal energy converters are significantly smaller and can be placed much closer together. Tidal energy technology is much more powerful than wind turbines since water is 800 times denser than air. Therefore, several miles per hour flow of water is equal to 300 miles per hour of wind energy. Tidal energy is predictable and reliable since it is driven by the moon's gravitational force by providing a consistent source of kinetic energy tides.

The Department of Energy has located 40 places in the world where the differences between the low and high tides are big enough to generate commercial levels of tidal electricity. However, the most significant social barrier for tidal energy system implementation is the common "Not-In-My-Backyard" mindset. Coastal populations have prevented tidal energy technology from being built since they do not want it to taint their personal ocean. This problematic mindset allows continued reliance on damaging fossil fuels.

To determine the most ideal method for tidal method conversion, we must first have a basic understanding of the different models for tidal energy. Some of the current types of wave energy converters are attenuator, point absorber, terminator, oscillating wave surge converter, tidal barrages, oscillating water column, etc. While all of the models have their own differences the main difference in terms of structure between most tidal energy converters is whether or not they are working parallel or perpendicular to the motion of the waves. For example, the attenuator and the point absorber both act parallel to the motion meaning there is no motion disruption in the waves; the attenuator looks like a big tube lying parallel to the shore and the point absorbers look very similar to buoys on top of the water and have machinery underneath on the ocean floor. Both systems get energy through the natural conversion from potential energy to kinetic energy back to potential energy as the water particles circulate up and down. The other kind of system works perpendicularly to the wave by breaking it up - the terminator, the oscillating wave surge converter and the oscillating water column all share this basic principle. They also share the similar quality of being based on the shore, which has a lot of benefits in terms of easier maintenance access and such. There are also several other less well known variations of wave energy converters, but they all have the same basic concepts as the systems listed above *(Drew, B).* Pilot scale installations are smaller versions of tidal systems that states can implement if there is a lack of funding for a commercial scale installation.

The major disadvantages of tidal energy systems are high initial cost, potential environmental degradation, limited locations with real potential, transmission difficulties, and system corrosion. Specifically, tidal barrages are one example of a more problematic tidal energy converter, because they change the movement of water into and out of estuaries which can disrupt the life cycles of certain marine life. Further, barrages can prevent movement of fish and wildlife which disrupts spawning. The turbines can kill wildlife that tries to swim through them and can also increase silt deposits which blocks out sunlight and therefore prevents plant growth. Tidal barrages can also change the structure of coastlines by leading to erosion of dunes and other critical habitat. Another type of tidal energy system, tidal stream generators, have spinning blades that can kill marine wildlife and cause acoustic disturbances that can affect marine life migration. Tidal stream generators, a point absorber system, can change the movement and rise of tides which can disrupt ecosystems. These generators are the most prone to damage by high waves and rough water compared to other systems. (Disadvantages of Tidal Power).

With plants only being used for 10 hours a day (during the tidal surge), this leaves 14 hours each day where the plant does not produce any energy and may not be able to keep up with the energy needs of coastal populations. Additionally, tidal energy comes with high construction costs, disturbance of nearby wildlife, and can only be implemented in specific locations, not allowing for versatile implementation (Walker).

However, there are several really important advantages of tidal energy including the expanse of completely untapped power. Theoretical estimates predict tidal energy could produce around 25,880 TWh per year (Tidal range energy resource and optimization: page 769). Additionally, tides are very predictable allowing for guaranteed energy production for around 10 hours per day. Tidal plants are very cheap to maintain after construction, produce no waste and are very reliable when active. This type of energy production is also more energy dense than other forms of renewable energy, and can be up to 80% efficient with current technology (Walker).

Lack of research on the environmental impact of tidal energy further prohibits it's conventional use. Studies have shown that fish are attracted to new structures, but how that affects the rest of the ecosystem is less understood. Different structures in different ecosystems could either increase the resident fish population or draw fish away from their natural habitat. Fish behavior could be studied by observing bridge pilings or offshore wind turbines that are already being constructed. Observations on fish behavior before and after the construction of potential ecosystem-affecting structures could be made using drifters/drogues (big tubes that go into the water and collect data on ocean conditions) or camera/acoustic cameras (NOAA Technical Memorandum NMFS F/SPO-116: page 28).

One study modeled the changes on morphodynamics of sandbanks that would be caused by a large-scale tidal energy extraction. Since power extraction by a turbine causes a pressure drop, there will be a lower velocity behind the turbine and a thrust force will be created. Their model measured average changes in sediment thickness, natural sea bed variability, and residual sediment transport decreases over a one month simulation. Results from this study determined that a thrust coefficient less than 0.45 had no noticeable effect on the morphodynamics of sandbanks (3D Modeling). Many other studies have been done showing the specific environmental impacts on locations including the inner sound of the Pentland Firth in Northern Island, the Gulf of Maine, and Nova Scotia in Canada (Science Direct).

While tidal energy is one of the smaller forms of energy production in today's world, many countries have found it to be a viable form of power. The La Rance barrage facility in France, the Kislaya Guba plant in Russia, the Annapolis Royal plant in Canada and the Jiangxia Tidal plant in China are some of the world's largest facilities today. What many of these plants have in common, along with smaller plants, is that they are all built in large basins. The barrage type plant requires a very large, flat underwater basin near the surface, and connects to the coast in some way. The area required to build this type of plant could disrupt many coastal ecosystems during its construction and operation. The other type is a lagoon-type plant, where the entire facility is located offshore, often built in deeper water than barrage plants (Tidal range energy resource and optimization: page 766).

Ultimately, the goal with our proposed research is to find optimal locations for a tidal energy system in the United States and investigate the possible environmental impact from implementing these systems. Alaska "contains the largest number of locations with considerably high kinetic power density" (Assessment of Energy Production Potential). Cook Inlet, Alaska has a large tidal stream power density sustained over a large area. Therefore, there is a high potential for successful tidal energy system implementation. Other states that have locations with high potential for implementing tidal energy are Maine, Washington, Oregon, California, New Hampshire, Massachusetts, New York, New Jersey, North and South Carolina, Georgia, and Florida (Assessment of Energy Production Potential). This leads us to our research question: what is the environmental impact of implementing an oscillating water column in these different locations?

Methods

Funding and permit allowing, we intend to study the oxygen levels, organism behavior using SONAR, and the suspended sediment concentration to assess any differences in the environment because of the installation of a tidal energy system. Oxygen levels will be measured to assess the balance between autotrophic and heterotrophic organisms in the water column, the acoustic readings will be used in tandem with the oxygen levels to assess the biodiversity changes, and the suspended sediment concentration will be measured to assess changes in water dynamics. The assumption that any changes in the environment are because of the tidal energy system will have to be made, although we acknowledge that this may not be realistic with the drastically changing climate. Control and test areas are fairly close together, but we recognize that there still may be natural differences in these sites that could still increase the variability of our results.

In the event of difficulties obtaining funding or permits we will reduce the number of sites we use for testing. Reducing the number of locations that we use for testing will greatly reduce the cost of the entire project as each site requires materials, hired experts, plane tickets, and construction vehicles. Although this is not an ideal situation, in the event that we get absolutely no permits to implement our own wave energy converters, we will adjust our methods to study only existing wave energy converters and compare these areas to similar areas that don't have these structures implemented. It's important to note that these new methods will weaken the potential correlation between the environmental effect and the implemented tidal system.

Dissolved oxygen level measurements will be taken using a DO sensor. The temperature, pressure, and salinity will need to be measured in order to normalize these DO measurements. Oxygen levels in the area surrounding the tidal energy system may change, post implementation. Higher oxygen levels post implementation indicate there is a greater presence of phytoplankton, marine plants, and algae that are photosynthesizing and/or water is moving at a faster rate (because of wind and waves). Lower oxygen levels post implementation indicate there is a greater presence of heterotrophic organisms that convert oxygen into carbon dioxide and consume the autotrophic organisms that produce oxygen (Precision Measurement Engineering). Because higher oxygen levels could indicate higher levels of photosynthetic organisms or increased water dynamics, supplemental testing of water acoustics (SONAR) and suspended sediment concentration will be taken to confirm which changes in the environment affected the oxygen level.

Measuring biodiversity is made possible in part by using instruments that use echolocation. Active sonar transducers emit a pulse of sound into the water and bounce off organisms in the water column. The device reads the "echos" and creates a "video" of the sound that can be analyzed by researchers and computers in a lab (NOAA). Much of the zooplankton that could contribute to differences in the oxygen levels are <5mm, and sonar technologies are still being developed to detect these smaller organisms (Briseno-Avena Et al.). Regardless, sonar technology will still give us a good idea of the abundance and diversity of larger organisms in the water column, and will suffice for our purposes. Given ample funding, microscopy of water samples could also be analyzed to identify the concentration of the micro-sized zooplankton.

Using a DH-48 Depth Integrating Suspended-Sediment Sampler, suspended sediment concentration can be evaluated. Increased movement in the water column will result in an increased concentration of suspended sediment (Federal Interagency Sedimentation Project). Changes in water dynamics can affect organism behavior and thus affect the overall health of the ocean. Finding a way to measure water dynamics is vital because changes in the biodiversity (as measured by DO and SONAR) can suggest a correlative relationship between decreased water dynamics post implementation and changes in biodiversity. This relationship may suggest that changes in the health of the ecosystem was the result of decreased water dynamics because of the implementation of the tidal energy system.

The assumption is to be made that changes in the measured variables (DO levels, echo readings, and suspended sediment concentration) post-implementation are the result of the tidal energy system and not some plausible external factor that could change oxygen levels, sediment levels, etc. All of these potential environmental changes are presumed to have a negative effect on the ecosystem.

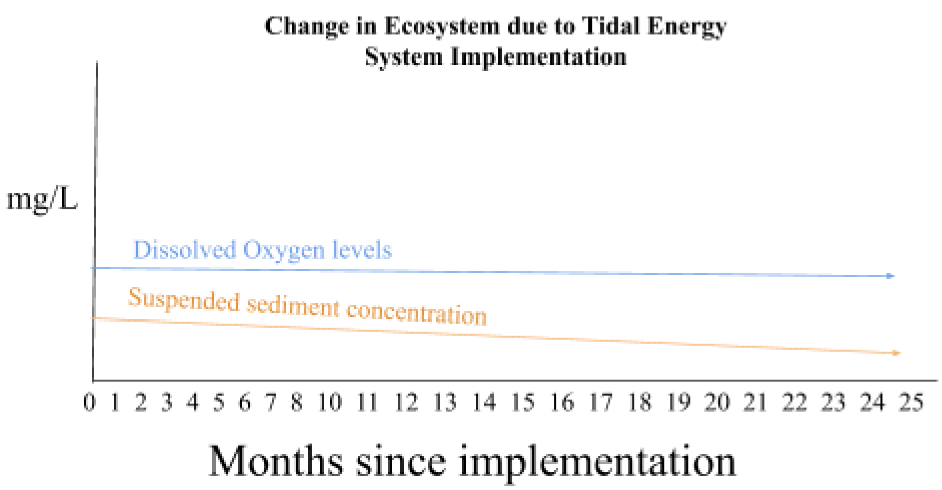
Measurements taken from the corresponding experimental and control location will be compared. On Day 0, all locations will be surveyed to measure base lines and measurements from successive days will be compared to these established baselines. Measurements taken on Day 0 are presumed to be valid and representative of the following days.

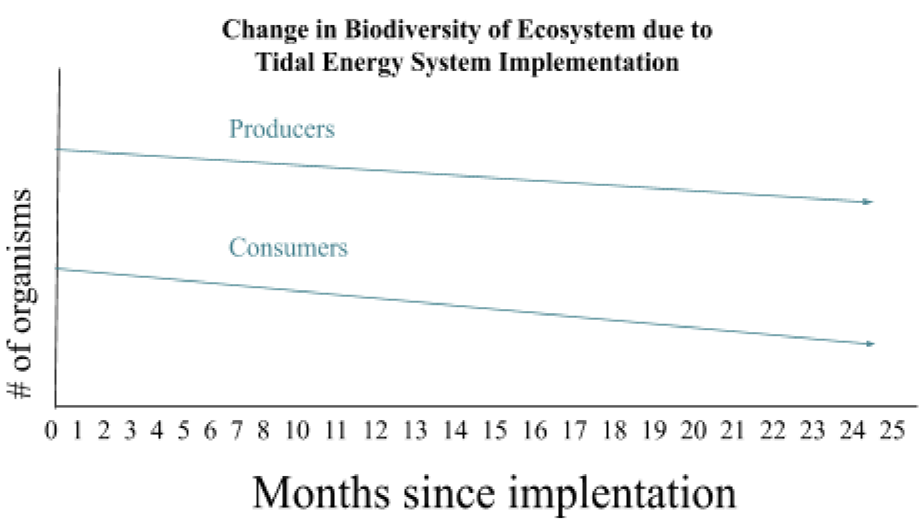
Because a tidal plant works by “harvesting” energy from the movement of the tides, a larger difference in the tides would lead to a more effective plant overall. The Cook Inlet, Alaska; Cobscook Bay, Maine; and Puget Sound, Washington have some of the highest tidal ranges in the world, all being above 30 feet between high and low tide. By installing a pilot scale oscillating water column in these areas, and conducting our study, we can begin the possible implementation of some of the most effective tidal power plants in the world.

Data on oxygen levels, echo readings, and suspended sediment concentration will be collected at the locations listed above. Analyzing the data in the lab will lead to conclusions regarding the effect of a tidal plant on the environment.

Anticipated Results

Since there is limited research on this tidal energy, the National Oceanic and Atmospheric Administration outlined the research categories that have highest priority. For pilot scale deployment of tidal systems, the areas that are at the greatest risk of suffering detrimental effects are the habitat and invertebrates above and below the surface of the water, and ecosystem interactions below the surface of the water. Although we hope the installed tidal system has no effect on the greater ecosystem, we recognize that introducing a large system into an environment is expected to have some effect. It is possible that the introduction of a system can reduce livable space by reducing sunlight for the organisms that live along the shore. Nonetheless, we hypothesize that because of the expanse of the shoreline area, these changes will have negligible effects on the greater ecosystem. We hypothesize that the dissolved oxygen, suspended sediment concentration, and average number of organisms will all decrease slightly, but that these effects will have no effect on the greater ecosystem.





Timeline

Our timeline regarding data collection spans over 2 years starting from implementation of the system to the end of the two years with data collection and analysis every month ending with an overall analysis of the effect of the system. However, we do expect to spend about a year before the start of the implementation, modify plans and obtaining grants and permits.

Time	Process
A year in advance	Obtain permits, get grants, & solidify plans.
Day 0	Initial data collection before the energy system is in place.
Month 1	Implementation of tidal energy system, data collection, qualitative observations
Month 2-24	data collection, qualitative observations
End of Month 24	Analyze results, compile findings for presentation

Materials and Budget

Item	Description	Approximate Cost
F4 DO Meters	Measurement device for dissolved oxygen concentration	$700
DH-48 Sediment Sampler	Measurement device for sediment concentration	$310
DH-48 Sampler Wading Rod with Handle, 1ft	Part of measurement device for sediment concentration	$25
SCAN-650 Scanning Sonar	Measurement device for marine acoustics to measure biodiversity	$7000
Salinity Sensor	Salinity levels needed for use of use of DO meter	120$

Tidal plant cost estimate to build	System materials	$3-4 million
Installation Fees	Covers construction costs of the implementation in terms of putting pieces together and fitting the machine to the location	$5,000+ for a week of installation fees
Plane Tickets	Will be required to get equipment and team members to site location	Vary in cost $500+
Total		~$4,013,775

Key Personnel

Our group has a perfect mixture of skill sets and interests for this project. The critical needs that our proposed study relies on are: knowledge of biology/chemistry/environmental science in order to study and understand the effect of tidal energy systems on the ocean ecosystem, and an understanding of the different tidal systems and how best to implement them according to the different environments. All four of our group members are passionate about creating energy solutions that are safe for our planet and our choice of majors demonstrates that: Civil and Environmental Engineering, Biomedical Engineering, Chemistry, and Environmental Economics and Policy. In order to understand and study the biological/chemical effects that the tidal energy systems will make on the environment, Nick's chemistry, Ryanne's biology, and Ariel's environmental expertise will come into great use. In understanding how to build and implement the tidal systems, Kitty's structural/civil engineering skills will also come in great use. In general, we are the best group to carry out this project because we know there is not enough research about tidal energy systems and we are all excited about this untapped source of energy.

Relevance of Proposed Study and Broader Impacts

The scientific value of our work is the developed understanding of environmental impacts of tidal energy while simultaneously providing a clean energy source. Our data comparisons between 3 control locations and 3 experimental locations that tidal energy systems were implemented in will provide ethical guidelines for further tidal energy system implementations. The societal value of our work is that we are continuing the work to transition to renewable energy sources in a sustainable way. Tidal energy produces no fossil fuels and extracts energy from the tides to provide electricity. Many communities located near the ocean can tap into the technology and wane off non sustainable energy sources. Since tidal energy does not produce any air pollution, future generations will maintain healthier respiratory systems which prevents many health issues. Further, the tidal energy systems will require maintenance which provides jobs and boosts the economy.

If our findings prove that these tidal energy converters do not significantly impact the ecosystem, and also prove to be durable, then outcomes of our work could end up being very beneficial for everyone considering everyone uses energy in some respect. Our findings could lead to further implementation of tidal energy on a large scale, so more specifically energy companies could benefit from more information on how these systems work.

Broader than the scientific community, our work may be meaningful to the general public if tidal energy proves effective with negligible effects on ecosystems. These results could lead to a change in where our primary energy source comes from which could drastically slow down climate change. Climate change should be considered a public health emergency and, therefore, our work could help the current public health crisis. Further, the cost benefits of switching to tidal energy could be economically beneficial for many and more reliable.

Our basic plan is to communicate our results via a report and a presentation with a compilation of all of our findings. By conducting preliminary research on the viability of tidal energy and the environmental impacts that come with its implementation and operation, we can create a presentation that incorporates all of the data that we find to a broad audience. The best audience to present to would be one with a possible interest in supporting the creation of more tidal energy plants. Additionally, we will eventually need to move away from the consumption of fossil fuels and toward the production of clean energy. Proposing this grant to the federal government could eventually lead to policy change which would require federal funding for research and implementation of renewable energy.

References

Administrator. “Tidal Barrage and Tidal Barrage Energy Devices.” *Alternative Energy Tutorials*, 1 Jan. 1970, www.alternative-energy-tutorials.com/tidal-energy/tidal-barrage.html.

Amanda. “Home.” *Young Leaders*, 27 Jan. 2020, www.sdgyoungleaders.org/blog/how-much-does-crane-rental-cost-a-guide-on-the-average-prices

Assessment of Energy Production Potential from Tidal Streams in the United States Final Project Report. June 29, 2011. https://www.energy.gov/sites/prod/files/2013/12/f5/1023527.pdf.

Briseño-Avena, Christian, et al. “ZOOPS- O2: A Broadband Echosounder with Coordinated Stereo Optical Imaging for Observing Plankton in Situ.” *Methods in Oceanography*, Elsevier, 13 Aug. 2015, www.sciencedirect.com/science/article/pii/S2211122015000237.

Bosserelle, Cyprien. “Mean Available Wave Power.” *WACOP Wave Atlas*, wacop.gsd.spc.int/RegionalWaveEnergy.html.

Chatzirodou, Antonia, et al. “3D Modelling of the Impacts of in-Stream Horizontal-Axis Tidal Energy Converters (TECs) on Offshore Sandbank Dynamics.” Applied Ocean Research, Elsevier, 5 Aug. 2019, www.sciencedirect.com/science/article/pii/S0141118719300896.

“DH-48 Sediment Sampler.” *Rickly Hydrological Co., Inc.*, rickly.com/dh-48-sediment-sampler/.

“The Disadvantages of Tidal Power.” *Tidal Power - Disadvantages of Tidal Power*, tidalpower.co.uk/disadvantages-of-tidal-power.

Drew, B, et al. “A Review of Wave Energy Converter Technology.” *Https://Journals.sagepub.com/Doi/Pdf/10.1243/09576509JPE782*, Department of Mechanical Engineering, University of Bath, Bath, UK, 29 Mar. 2009, A review of wave energy converter technology.

“Environmental Effects of Tidal Energy Development: Proceedings form a scientific workshop.” https://spo.nmfs.noaa.gov/sites/default/files/tm116.pdf.

“Measuring Dissolved Oxygen Levels in Seawater.” *PME*, www.pme.com/case-studies/measuring-dissolved-oxygen-seawater.

"Mettler Toledo FiveGo F4 DO Meters - Thermometers, PH Meters, Timers and Clocks,PH and Electrochemistry." *Mettler Toledo FiveGo F4 DO Meters:Thermometers, PH Meters, Timers and | Fisher Scientific*, www.fishersci.com/shop/products/fivego-f4-do-meters-3/p-7070341.

Nasiri, Fuzhan, and G.H. Huang. "Ecological Viability Assessment: A Fuzzy Multiple-Attribute Analysis with Respect to Three Classes of Ordering Techniques." *Ecological Informatics*, Elsevier, 13 Aug. 2007, www.sciencedirect.com/science/article/abs/pii/S1574954107000349.

Neill, Simon P, et al. "Tidal Range Energy Resource and Optimization - Past Perspectives and Future Challenges." Renewable Energy, edited by Athanasios Angeloudis, vol. 127, Elsevier, 2018, pp. 763–778.

"Salinity Sensor." *Vernier*, www.vernier.com/product/salinity-sensor/.

"Sampling With the US DH-48 Depth-Integrating Suspended-Sediment Sampler" *Federal Interagency Sedimentation Project,* https://water.usgs.gov/fisp/docs/Instructions_US_DH-48_001010.pdf

Sonar Systems, www.jwfishers.com/products/sonar.html.

"Top Ten Locations with Largest Tidal Ranges in the World." *Top Ten Locations with Largest Tidal Ranges in the World*, 2010, www.top-ten-10.com/science/geography/tidal-range.htm.

UIowa Wiki, wiki.uiowa.edu/display/greenergy/Oscillating+Water+Column.

US Department of Commerce, and National Oceanic and Atmospheric Administration. "SONAR." *NOAA Ocean Explorer: Technology: Observation Tools*, 30 Oct. 2012, oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html.

WalkerJan, Kris. "Is Tidal Power a Viable Source of Energy?" *AZoCleantech.com*, 4 June 2019, www.azocleantech.com/article.aspx?ArticleID=350.

"1Up Travel - Maps of United States Of America.United States Including Alaska and Hawaii

Outline Map, 1992 (291K) U.S. Bureau of the Census, 1990 Census of Population (1990 CP-1-1)." *1*, www.1uptravel.com/worldmaps/unitedstates5.html.