UNH Tidal Energy Cats (TECats) – Tidal Energy Conservation Co-Located with Estuarine Bridges for Coastal Infrastructure Resiliency

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Executive Summary

Estuarine bridges could serve as ideal locations to deploy marine hydrokinetic (MHK) energy conversion systems. The hydrokinetic energy resource (water currents) is often strongest at the narrow locations where bridges are located. The bridge piers can serve as supporting structure for both the bridge and hydrokinetic turbines, reducing both support structure and deployment or installation costs. For standalone hydrokinetic energy systems, support structure and installation costs are a significant part of capital expenditure (Segura et al. 2017, Astariz et al. 2015). Further, the permitting process (Roberts et al. 2018) for the turbines can take advantage of the permitting work and various studies already required for bridge construction, thereby significantly reducing its cost. The integration of MHK energy conversion with estuarine bridges introduces resiliency to transportation infrastructure for coastal communities.

The most cost-effective way to develop this technology will be to proceed with integrated bridge pier-MHK turbine system configurations for new bridge construction, to be installed as aging estuarine bridges are replaced or new bridges are constructed. We believe that the key to keeping cost acceptable (CapEx) is to consider an integrated pier-MHK design from the bridge project programming and development stage. We envision pier-turbine systems that will augment the locally available energy resource while providing attachment points and a bridge grid connection or on-site energy storage for modular turbine systems. By focusing on integrated systems that would be installed when existing bridge infrastructure is replaced, or when new bridges are constructed, this approach takes the “long view” of deploying marine energy conversion systems at an intermediate scale in a paradigm-shifting way, with potential for cost-competitive deployments at utility scale in the future.

Table of Contents

1.0 Concept Overview

“Tidal Energy Cats” (*TECats*) is developing a tidal turbine array modular array to provide clean and reliable energy using hydrokinetic energy from estuarine currents. The array consists of a series of modular cross flow turbine units connected to individual platforms. *TECats* is proposing the deployment of a tidal turbine array at the Sarah Mildred Long Bridge, spanning the Piscataqua River from New Hampshire to Maine. However, the simplicity in this design and technology allows for the creation of customized arrays tailored to specific site locations and other bridge pier designs worldwide. Bridges over fast moving water (tidal estuaries, rivers) can double as hosts for hydrokinetic energy conversion – with shared bridge infrastructure, reduced permitting – which will result in production of predictable and renewable electric energy. The power generated has the ability to offset bridge electric energy usage or turn these bridges into net power plants, thereby increasing resiliency of transportation infrastructure in coastal communities.

The integration of MHK energy conversion with transportation infrastructure is considered a paradigm shift compared to traditional MHK device development and use of transportation infrastructure. The innovation can provide predictable and forecastable renewable electric energy. The most important innovation and Intellectual Property is not necessarily in the parts, but instead in the know-how and understanding how this integration can be accomplished in a challenging environment. *TECats* is proposing a tidal turbine array installation at the Sarah Mildred Long Bridge spanning the Piscataqua River. This business plan highlights the development and operations of the installation while assessing the overall global opportunity of our vision.

2.0 Global Market Opportunity

2.1 Marketability

TECats goal was to develop clear and simple technology to provide a reliable and robust turbine that requires minimal in-water maintenance, with long design-life expectancy in order to maximize competitive advantage. By developing a single modular product with little variation in arrangement, the simplicity provides a more reliable and cost-effective overall product. All manufacturing needs must be minimized to lower costs, without sacrificing reliable and long-lasting materials. Materials must be able to withstand extreme conditions and an infinite fatigue life cycle, for long term success. The deployed assembly should allow a maintenance worker easy access to any areas that require it. Complicated designs and elements can increase expenses and decrease reliability, which raises overall capital expenditures. Maintenance is expected every 5 years of continuous operation. Due to the modular nature of this product, individual units can be deployed for prototype testing before they are deployed in arrays.

2.2 United States Market Opportunity

In 2018 17% of electrical energy was from renewable energies in the United States and 42% of that was in hydropower (Primary Energy Production). A study done in 2019 by expert Jack Unwin, predicts hydropower to grow by 125 GW by 2023 (Unwin). The market for hydrokinetic energy production is limited to areas of strong tidal currents, often found at constrictions in tidal estuaries. Bridges are typically located at the narrowest sections of waterways, which generate the fastest moving currents, allowing high potential for marine energy generation. These bridges are the primary target location for installations of the *TECats* modular hydrokinetic turbine system.

Globally there are an estimated 150 locations where tidal energy conversion could be co-located with existing bridge infrastructure based on current speed, water depth, and bridge dimensions. To implement our crossflow turbine, array the bridge must stretch at least 50 meters over waters that have a depth of 15 meters, and current speeds moving at least 1 meter per second. A 50-meter span would be long enough to host six cross flow turbines. The longer the bridge is, the more turbines can be added to the array. Each turbine is powered by its own power generating unit. Using a location specific LCOE, we can provide stakeholders with accurate costs and predicted power generation for each location. The primary targets for approval and purchase will be from bridge owners and stakeholders of each applicable bridge. The local utility companies will also be subjects since the power generated will need to be attached to their communal grid.

UNH TECats team has cross referenced tidal current data from the National Oceanic Atmospheric Administration (NOAA) with bridges around known tidal coordinates. The search criteria consisted of locating known tidal currents on average greater than 1 m/s. Those tidal locations were then investigated further by cross referencing with existing bridge infrastructure within the area. Figure 1 illustrates the locations of these bridges.

Figure 1: United State Market Opportunity Map

3.0 Relevant Stakeholders

3.1 NH Port Authority

A meeting with the New Hampshire Port Authority was conducted on February 12th, 2020 to present the project scope and help the team receive feedback on the next steps moving forward. Some insightful feedback resided around debris encounters, recreational boaters and fishers, the economic feasibility, studies to conduct, permitting, and operation and maintenance. For debris encounters, it was mentioned the structure of the design must be able to withstand trees, ice flow during the winter months, seaweed, chairs, bags, and other miscellaneous objects floating at all depths. It was noted that recreational boaters and fishman commonly use the non-shipping channel lane as passage under the bridge, which would cause problems if proper signage and signal lighting was not implemented. This led to the discussion of having a surface present, acquiring all permitting (specifically a FERC license), and correlating the lighting scheme with the National Guard. Further discussion resulted in an encouraging product that would potentially grab the interest of the community.

3.2 Northeast Integration Systems

A phone call was made to Dylan Kimmel, Principal Engineer at Northeast Integration: a systems integration and engineering company based in New England. From this phone call, much was learned about grid connection requirements and the need to work with local utility companies. A certified UL1741 grid tie inverter is needed to connect to the grid without special involvement of local utility companies. Most modern large bridges have an existing machinery room/Motor Control Center (MCC) where electrical connections are made and run to the grid. For bridges of interest in the scope of this project, there will likely be existing spare spaces to connect these systems. For systems too large in scale to run into this center, the local utility company will need to approve the grid connection. This process involves a site visit and presentation of stamped electrical drawings by a licensed electrician and engineering firm. This approval process introduces a significant added cost to the project and can be avoided by using a generator from the aforementioned UL1741 list.

3.3 Tetra Tech Inc. – Boston, MA

Nick Welz, a senior marine scientist and subsea cable lead from Tetra Tech Inc. in Boston, MA provided knowledge and support through an over-the-phone interview during the *TECats* research. As a professional involved in the business of installing electrical systems in public waterways, he provided insightful advice about community challenges in doing so. He recommended approaching public groups like fishermen and lobstermen early on in the design process, to ensure that the physical build of such a system will not interfere with their livelihood and cause pushback to the construction and operation. He also provided information on the Little Bay Eversource Project, which involved the installation of a 13-mile transmission line across the Seacoast Region near the University of New Hampshire this past summer. This project serves an example of one which received lots of public pushback, and in response, Eversource published a public information sheet listing out the coordination of groups involved, scheduling of construction, and environmental protection and monitoring practices that would follow the construction of the project. To value New Hampshire's opinion, *TECats* published questions in the Granite State Survey to seek residents' thoughts on renewable energy and specifically hydrokinetic energy.

3.4 Interviews, Research, Surveys

Each month the University of New Hampshire Survey Center conducts a "Granite State Poll" through phone calls to New Hampshire residents. The poll interviews a random sample of approximately 500 people from around the state and asks a variety of questions submitted by researchers. In 2018, the University submitted various questions concerning renewable energy and public infrastructure to the poll, as well as three other surveying projects. These three other surveys were the US Polar, Environment, and Science (POLES), the Northeast Oregon Communities and Forests in Oregon (CAFOR), and the North Country Survey. In a briefing by Dr. Erin Bell, residents were asked the two following questions with the given possible answers, and the results were plotted.

Question 1: Which do you think should be a higher priority for the future of this country, increased exploration and drilling for oil, or increased use of renewable energy such as wind or solar?
Possible Answers:
a. renewable
b. drilling
c. DK/NA

Results:

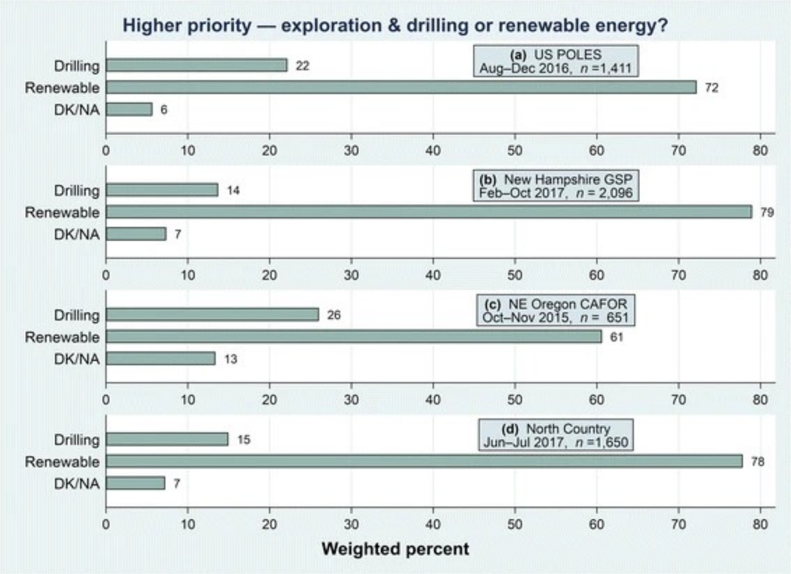


Figure 2: Granite State Poll Question 1 Results

The results from question 1 show that from all four surveys, residents agreed that renewable energy was a higher priority for the future of the US than drilling for oil. The Granite State Poll specifically had the highest weighted percent in renewable energy priority. The second question is stated below.

Question 2: Which of the following three statements do you think is more accurate? Climate change is happening now, caused mainly by human activities; climate change is happening now, but caused mainly by natural forces; or climate change is not happening now.

Possible answers:
a. Now/human
b. Now/natural
c. Not now
d. DK/NA

Results

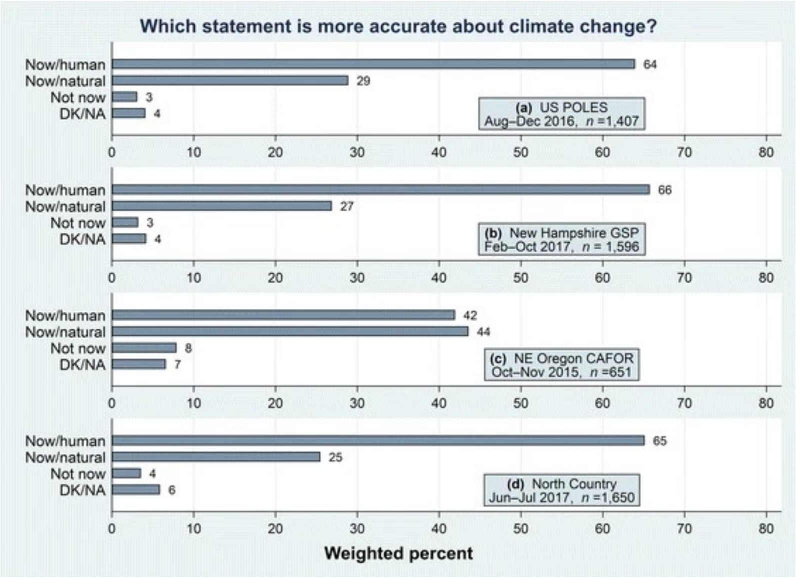


Figure 3: Granite State Poll Question 2 Results

Question 2 focused on statements concerning climate change and whether it was happening, and if so, what was causing it. The results from all four surveys showed significant results that people believed climate change was caused by humans. The follow up questions as to what was causing climate change was substantially higher in three out of the four surveys for human induced. In only one survey in the CAFOR survey were people torn between whether climate change was human, or nature caused, with a slight lean towards naturally caused.

4.0 Development and Operations

4.1 Site Resource Assessment: ADCP Field Testing

In order to further understand the current profiles surrounding our targeted pillar sections of the Sarah Mildred Long Bridge, we set out to obtain the most accurate data we could possibly record. To do so, *TECats* utilized a 600 kHz downward-facing ADCP (Acoustic Doppler Current

Profiler) mounted to the underside of a small vessel to conduct transects on each side of the bridge during the peak flow rates of an ebb and flood tide. This instrument projects sound in four different directions, allowing one to resolve current velocity, direction, and what depths these characteristics are occurring at.The data was collected within 24 hours of a full moon, which allows us to look specifically at peak current velocity conditions. The ADCP is also coupled with GPS granting the ability to distinguish current profiles relative to the bridge pillar locations, and more specifically our targeted area of implementing the turbine array. With the assistance of Dr. Tom Lipmann and Jonathan Hunt, who built the custom scientific Zego Boat, significant current profile data was recorded. With this data in our hands, *TECats* was able to optimize the depth range at which our array should sit within the water column, as well as estimate the power output with respect to current velocities at our turbine locations.

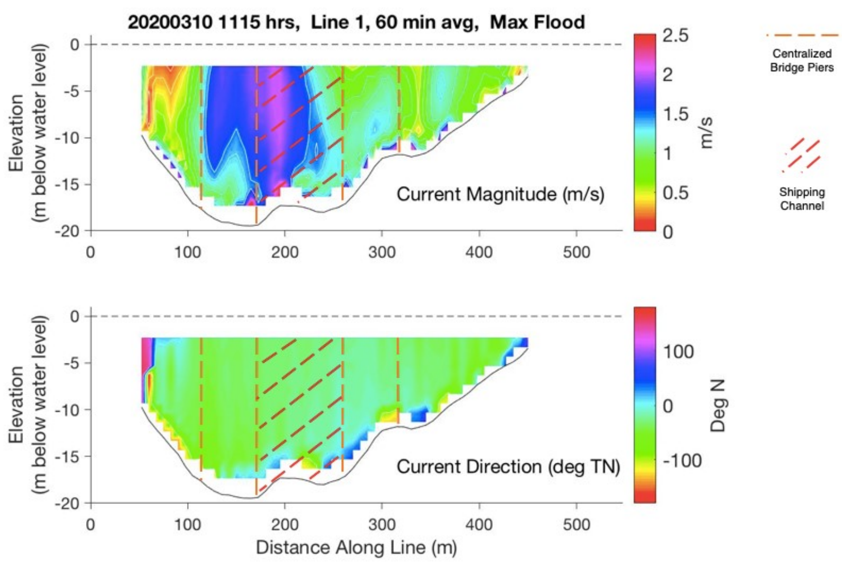


Figure 4: ADCP Flood Tide Data, Cross Section Just South of Sarah Mildred Long Bridge

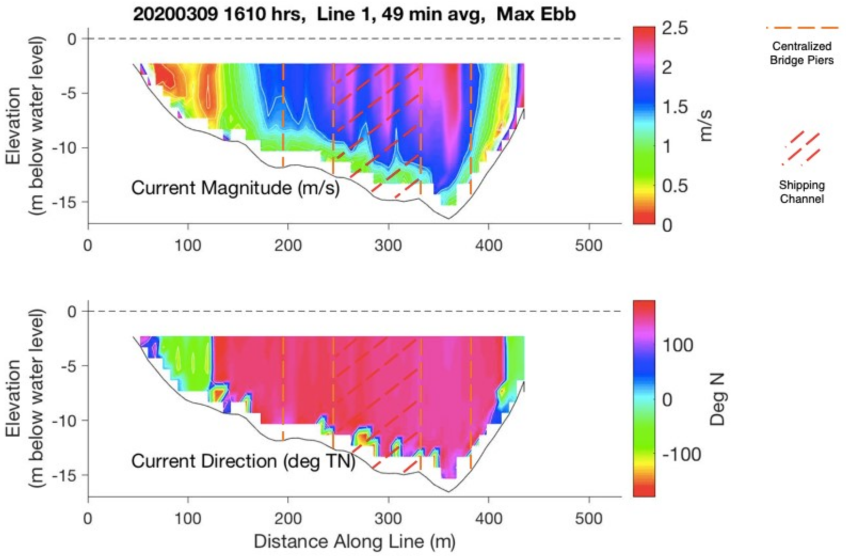


Figure 5: ADCP Ebb Tide Data, Cross Section Just North of Sarah Mildred Long Bridge

A max flood and max ebb tide were evaluated, as we conducted transects during the middle of the tides where the velocities were predicted to be at a peak flow. The peak ebb tide was evaluated first. As seen in Figure 5 above, there are areas in this transect where the tidal currents reach up to 2.5 m/s (approaching 5 knots). In addition, you can see that one of these spots occurs between a two of our target piers where the turbines would lie. These results are great for considering the design of the turbine array, as it would output a large sum of power. Overall, the highest velocity of current flow tended to be more prominent on the north side of the bridge during a max ebb tide.

Displayed above in Figure 4, the max flood tide shows that the significant flows tended to be located on the south side of the bridge. Average flows ranged between 1.5 and 2 m/s between our targeted piers on the Portsmouth side of the Sarah Long Bridge. Despite this flow section representing a relatively fast area of moving water, the north side of the bridge exhibits velocities ranging roughly 1-1.5 m/s. Overall, the highest velocity of current flow tended to be more prominent on the north side of the bridge during a max flood tide.

In conclusion, the tidal energy moving through this section of the river where the Sarah Long Bridge is sufficiently strong and represents a good opportunity in terms of where the “sweet spots” of the tidal current are located with regards to where it would be feasible to install a turbine array. Regards to our design within the sections of bridge pillars, the arrays would be exposed to the “sweet spots” of the current flow during a flood and ebb tide.

4.2 Permitting

One of the most common appropriate licenses that would pertain to our design would be a viable FERC license from the Federal Energy Regulatory Commission. A license of this type would include investigations regarding potential interactions like biological assessments, seal interaction, DIDSON observations, and hydrodynamic assessments.

For a grid-connected hydrokinetic energy system to be installed in the United States, it must first receive a license from the Federal Energy Regulatory Commission. The process behind this entails a preliminary license which grants the applicant the right to study the environmental characteristics of the site for four years, at which point a finding of no significant impact (FONSI) may be issued by FERC. This leads into eligibility for a license, which is granted after review of a license application, detailing environmental, flow, and power generation plans.

Outside organizations that would also have to be taken into consideration in terms of permission are the Army Corps of Engineers, Coast Guard, relevant stakeholders such as regionally local lobsterman/fisherman, and the NH fish and Game.

What sets *UNH TECats* apart from other Blue Economy initiatives is the versatility and modularity of our vision. Competitors are located far offshore, require complicated designs and high deployment and maintenance costs. This raises prices, risks, and more room for error or technology failures. *TECats* bridge infrastructure incorporated modular arrays set us apart from other initiatives as it provides a location for close bridge grid connection, reduced permitting, and ease of access, which drives down the levelized cost of energy.

4.3 Environmental Management Plan

The environmental management plan for the Sarah Mildred Long installation is straightforward given its limited interaction with the waterway and marine life. The only direct interaction with the benthos is the bridge pier itself, whose impacts have presumably already been assessed in the permitting process and been approved for installation. The main challenge when accounting for environmental factors in such a project is evaluating the specific site characteristics and ensuring all aspects are considered.

The endangered marine or shoreline species found in New Hampshire and Maine are listed in Table 2 below; this information was retrieved from U.S. Fish and Wildlife Services' online resources. Of the seven listed, the latter three are birds, which would have little to no interaction with a submerged hydrokinetic array. The hawksbill, loggerhead, and green sea turtles are all known to forage in estuaries, so there is a possibility that they may be present in the area. However, there is ample space below and adjacent to the turbines for the turtles to maneuver around them. The leatherback sea turtle is a deep-water species and would not be typically found in estuaries. These conclusions imply that the threat to endangered species is minimal.

Table 1: Endangered Marine or Shoreline Species in New Hampshire and Maine

Common Name	Scientific Name	Interaction Likelihood	State(s) Endangered
Green sea turtle	*Chelonia mydas*	Moderate	NH
Hawksbill sea turtle	*Eretmochelys imbricate*	Moderate	NH
Leatherback sea turtle	*Dermochelys coriacea*	Low	NH
Loggerhead sea turtle	*Caretta caretta*	Moderate	NH
Piping plover	*Charadrius melodus*	Low	NH, ME
Red knot	*Calidris canutus rufa*	Low	NH
Roseate tern	*Sterna dougallii*	Low	ME

The turbines will always be within 10 m of the surface, making its likelihood of fish or marine mammal strikes in a high boat-traffic area unlikely. The array configuration leaves the shallow sections of the bridge as well as the shipping channel open for wildlife navigation. A consideration that was brought to our attention during a meeting with the NH Port Authority is debris strikes, which can include trees, trash, or ice flows. A panel of basic metal cage or mesh could be applied to the front of the array if debris poses a significant threat to the turbine structure. This is not desirable though because it may decrease the quality of the flow coming into the turbines.

As it is common in any ocean setting, fouling due to marine growth is expected. A study conducted through the Pacific Marine Energy Center has shown that while barnacles can have a significant impact on the power output of the turbine, it does not significantly threaten its structural integrity (Sringer/Biofouling). In extreme cases of biofouling, where the barnacles are both large and densely packed, the turbine actually draws power to rotate instead of producing power. This is not expected to become a problem for this installation, because routine maintenance will be performed during inspections, at which point barnacle growth can be scraped off to mitigate drag and turbulence.

Changes in flow behavior around hydrokinetic turbines have been known to disrupt the greater hydrodynamics and sediment movement of the channel, however, due to the configuration and size of this model relative to the body of water, downstream turbulence is not expected to interact with benthic sediment. This issue is a greater consideration in tidal barrage designs, where the water has nowhere else to go, or bottom-mounted turbines, where the turbulence directly interacts with the benthic sediment and vegetation.

Lastly, manmade subsea noise can facilitate a phenomenon known as auditory masking, in which auditory signals important to marine life are drowned out by unimportant noise. This can impact a range of wildlife, such as seals, porpoises, and fish. The specific turbine's continuous noise frequency would need to be measured to know the potential impacts because its frequency may or may not fall within the auditory range of local species. In the case of crabs, one study found that juveniles took longer to mature when exposed to continuous tidal or wind turbine noise compared to those exposed to ambient mudflat noise (Pine et al).

One of the most common appropriate licenses that would pertain to our design would be an viable FERC license from the Federal Energy Regulatory Commission. A license of this type would include investigations regarding potential impacts such as seal interaction, DIDSON fish observations, and hydrodynamic assessments. A preliminary license for a project is first granted to study the installation site for 4 years in order to gather information on these topics. If it can be proven that there will be minimal to no environmental impact as a result of the operation of the device, FERC will issue a finding of no significant impact, at which point the project is eligible to undergo the full license application process.

Outside organizations that would also have to be taken into consideration in terms of permission are the Army Corps of Engineers, Coast Guard, relevant stakeholders such as lobsterman and fisherman, and the NH Fish and Game.

5.0 Financial and Benefits Analysis

In order to establish a levelized cost of energy for our design, the Capital Expenditures (CapEx) and Operational Expenditures (OpEx) were estimated. Table 3 illustrates the CapEx and OpEx broken down into a cost breakdown structure (CBS) for a 12-unit turbine array.

Table 2: Capital and Operational Expenditures

Capital Expenditures (CapEx)	Value ($)	Operational Expenditures (OpEx)	Value ($)
Development	100,000.00	Post Installation Environmental	100,000.00
Infrastructure	317,870.00	Marine Operations	50,000.00
Device Structural Components	1,500,000.00	Shoreside Operations	10,000.00
Subsystem Integration	38,431.00	Replacement Parts	25,000.00
Installation	100,000.00	-	-
Engineering and Management	300,000.00	-	-
Plant Commissioning	20,000.00	-	-
Site Access, Port, and Staging Costs	10,000.00	-	-
CapEx Contingency	151,695.00	OpEx Contingency	35,250.00
Total	**$2,537,996.00**		**$270,250.00**

Table 4 and Table 5 further breaks down the structural and electrical system costs. These values are incorporated into Table 3 above.

Table 3: Cost Estimates for Structural Components of SML Turbine Deployment

Group	Item	Cost (USD)	Unit	Quantity	Raw Cost (USD)
Steel	24” Pipe	2.5	$/lb.	79548	198,870.00
	Bracing	2.5	$/lb.	333600	84,000.00
Erection	Erection	2500	$/day	14	35,000.00
Total	-	-	-	-	**$317,870.00**

Table 4: Cost Estimates for Electrical Systems

Group	Item	Cost (USD)	Unit	Quantity	Total Cost (USD)
Array	Cable	2.50	$/ft	3000	7,500.00
Transmission	Cable	27.74	$/ft	300	8,322.00
Transmission	AC Bus	3000	$/unit	1	3,000.00
Power Fixing	Rectifier	175	$/unit	12	2,100.00
Power Fixing	Inverter	1460	$/unit	12	17,520.00
Total	-	-	-	-	**$38,442.00**

The levelized cost of energy (LCOE) was calculated according to the equation:

$$LCOE = \frac{(FCR\ x\ CapEx) + OpEx}{AEP}$$

where the fixed charge rate (FCR) was 0.03. The annual energy production was calculated using the method of bins. The AEP is calculated by summing the power at each current speed and weighting it by the frequency the current speed occurs. Figure 6 represents the theoretical power curve of how much power would be converted at each current speed.

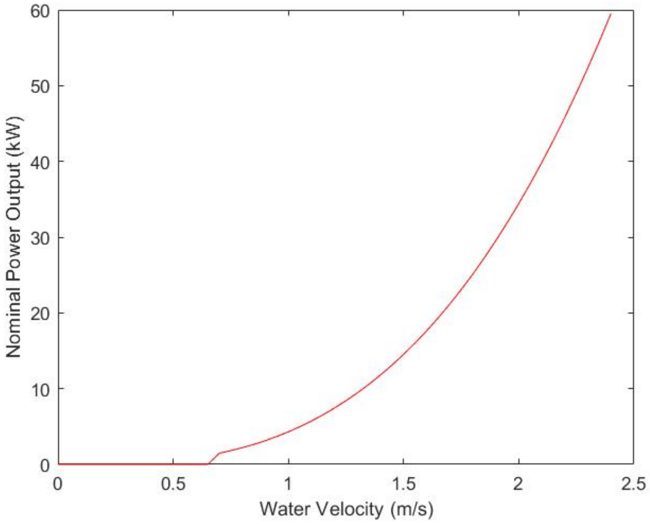


Figure 6: Theoretical Power Curve Used for Annual Energy Production

A histogram of occurrences was used to calculate the probability of each current speed in Figure 7. Combined, the AEP was calculated according to the equation:

$$AEP = H * \sum_{i=1}^{N_B} P_i * f_i$$

Where P_i is the power at a certain current speed, i is the index corresponding to a certain bin of speeds, f_i is the frequency of occurrence of that current speed, and H is the number of hours in a year.

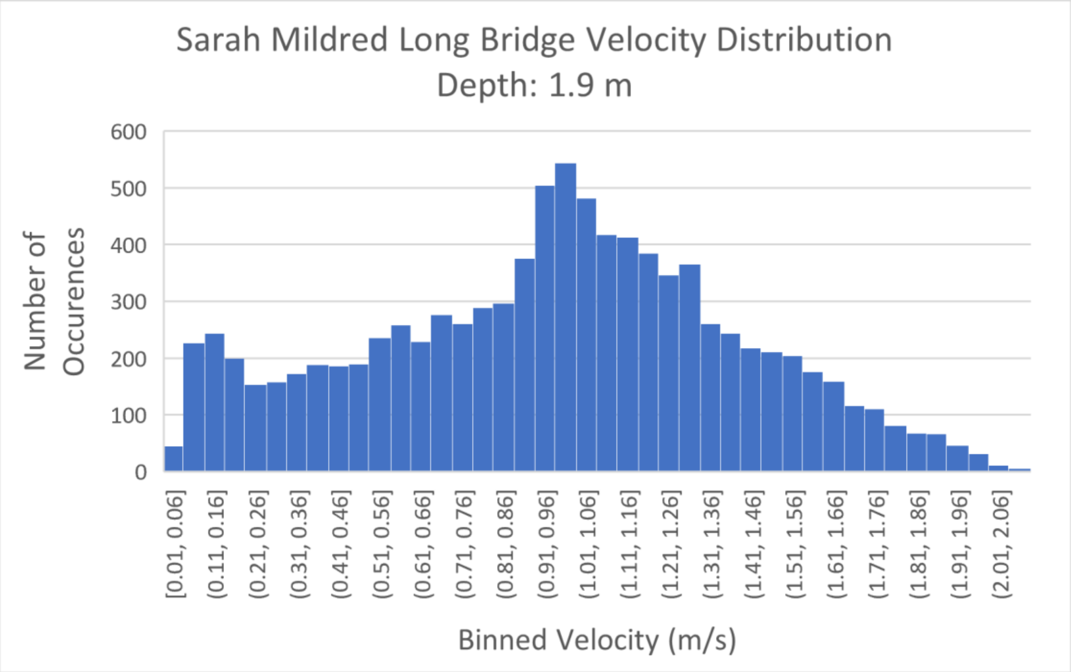


Figure 7: Sarah Mildred Long Velocity Distribution (Depth: 1.9 m)

After calculating the AEP for various installed capacities, the following LCOE curve was produced in Figure 8.

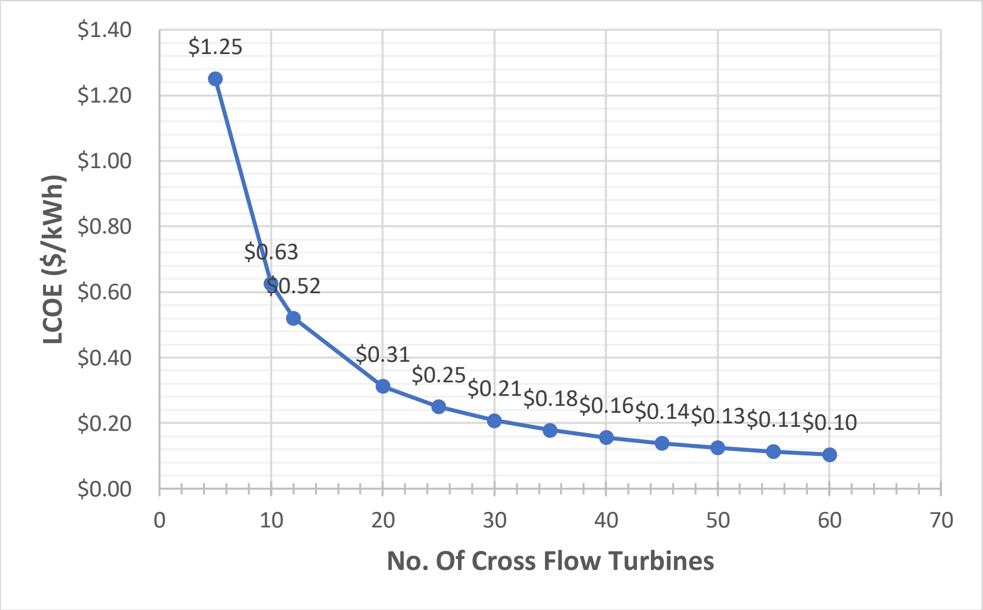


Figure 8: LCOE for Various Installed Capacities at Sarah Mildred Long Tidal Resource (1 Turbine = 25 kW Rated Capacity)

According to UNH *TECats* analysis the maximum allowable number of tidal turbines that could be implemented in an array within the Sarah Mildred Long Bridge infrastructure is 12 turbines. This results in a LCOE of $0.53/kWh which does not seem feasible considering the average household pays about $0.20/kWh. However, if you were to consider the design of a tidal turbine array from the start of the bridge construction and were able to install 25 turbines in an array the LCOE would drop down to $0.25/kWh which is more feasible. Additionally, if larger cross flow turbines were installed with a higher rated capacity the LCOE would decrease as well.

Table 5: Tidal Resource Assessments in U.S.

Bridge	State	ADCP Data Depth (m)	Available Energy [MWh/yr.*m^2]	12-Unit Turbine Array LCOE ($/kWh)
Penobscot Narrows Bridge	ME	3.0	3.91	0.86
General Sullivan Bridge	NH	2.5	15.64	0.19
Memorial Bridge	NH		9.16	
Sarah Long Bridge	NH	1.9	6.42	0.53
I-95 Bridge	NH	2.7	16.04	0.21
Tacoma Narrows Bridge	WA	4.9	16.33	0.21
Golden Gate Bridge	CA	9.1	29.8	0.97
Bay Bridge	CA	3.7	21.3	1.35

From Table 4 it can be observed different tidal resources can increase or decrease the LCOE. However, at each location the number of turbines capable of being installed could vary drastically, which would also decrease the LCOE. This sort of analysis is specific to each cite location. Figure 9 works to illustrate and compare how different installed capacities could drive down the LCOE.

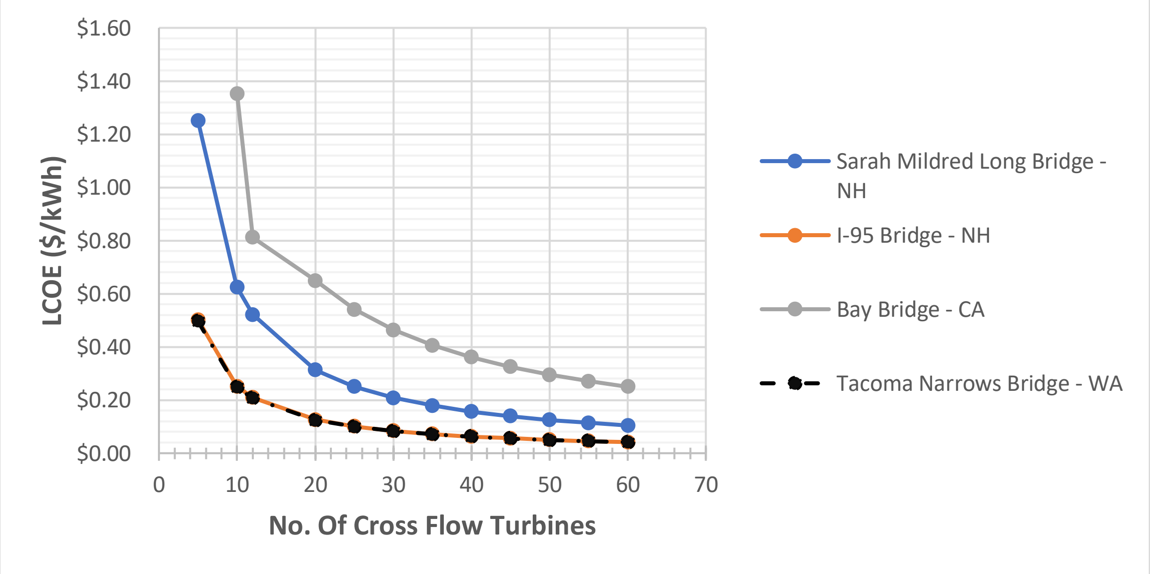


Figure 9: LCOE for Different Installed Capacities for Various Tidal Resources

(1 - Turbine = 25 kW Rated Capacity)

In Figure 9 it can be observed in order to drive down the LCOE a larger installed capacity is necessary. However, at a certain threshold these installed capacities become unrealistic as the site characteristics prohibit it due to geometry constraints. The integration of hydrokinetic turbines within existing bridge infrastructure drives down LCOE to within a feasible range. The challenge is determining the correct site locations where this can occur.

6.0 Preliminary Technical Designs

6.1 Design Description

The design objective for this project is a modular system containing a turbine and power generation system. This will allow a variable number of tidal turbines to be mounted between two bridge piers spanning an estuarine flow and connected in parallel to an AC power bus. This bus will carry electricity to the grid, battery bank or Main Control Center of a bridge, which supplies power to any sensors or lights that could be on the bridge.

A series of crossflow turbines were designed and chosen for this application. Axial-flow turbines were studied but were determined to limit the total amount of the water column that can be harnessed due to their design. See figure below for a comparison of the geometries of each.

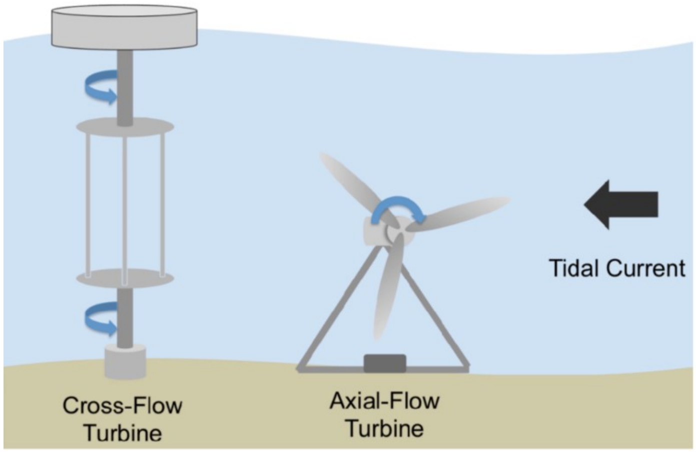


Figure 10: Comparison of Cross Flow vs. Axial Flow Turbine Geometries

The Sarah Mildred Long Bridge, which spans the Piscataqua River between Portsmouth, NH, and Kittery, ME, is the case study used for implementing tidal energy at an existing estuarine bridge. This section will discuss the challenges associated with retrofitting an existing bridge and how a more optimal system design can be achieved by incorporating a tidal energy device in the original design of the bridge.

Each turbine dock will carry an individual generator to convert the rotational kinetic energy to electric power. Instead of connecting the rotation output of each turbine in series to a single generator, having multiple generators increases the application's modularity. In the modular case, differing numbers of turbines can be implemented in various current environments and differently sized waterways. Multiple generators allow for simplified and modular conversion of energy through rectification directly after power generation. After inversion at each module, the systems are linked in parallel through an AC bus. Not only does this design allow for flexibility in sizing of a system, the output of each module will be ensured to be in phase with each other when they join at the bus.

The basic design of this system implements the Permanent Magnet Synchronous Generator. These types of generators are known for their relatively high efficiency (~.31% from New Energy Corporation) and reliability. To connect a power generation system to the Main Control Center present on most bridges, output voltage of the system needs to be matched to that of the MCC. Typical voltage levels of such a center are around 480 volts with a 3-phase power distribution bus. If the voltages are not inherently matched, a transformer would be needed to raise or lower before connection.

6.2 TEC Device / Array Information

Table 6: TEC Sarah Mildred Long Array Design Specifications

Description	Specification	Justification	Details
Deployment Depth	0 – 10 m	Resource Location	Sufficient depth for cross flow rotor height
Operational Depth	0 – 20 m	Site resource characteristic dependent	The floating cross flow turbine platform deployed in non-shipping channels under bridge infrastructure allows for a wide range of operational depth dependent on site location.
Fixed Support Depth	3.8 m	New Energy Corporation Specification (ENC-025L)	Floating structure contingency.
Floating Support Depth	4.3 m	New Energy Corporation Specification (ENC-025L)	Double pontoon platform design.
Number of Rotors Per Device	1	Economics / Modularity	1 Rotor / Cross Flow Turbine
Power Per Rotor	25 kW	New Energy Corporation	ENC-025L Rated Capacity

		EnCurrent 025 Series	
Overall Installed Capacity	300 kW	Site characteristics geometry constraints.	Cross flow turbines spaced between bridge piers.
Operational Current Speeds	0.7 – 3 m/s	Site Resource Characteristics	NOAA ADCP Data 2007
Array Configuration	Linear with rotor axis longitudinal separation	Engineering Judgement	Longitudinal separation was chosen to mitigate wake effect.

6.3 First Order Performance Analysis

In this design, the generators will be controlled by a series of power converters to output power at necessary voltage and currents for desired output connection. See block diagram below. Note that this figure models a 3-phase output from the generator, but a similar system could be designed for any number of phases depending on the environment of installation.

In this model, a 3-phase diode bridge is used to rectify the AC output of the generator into DC voltage. A DC/DC Boost converter will step up the voltage and step down the current coming out of the generator in order to match to the grid connect specifications. Here, a Maximum Power Point Tracker will optimize the efficiency of connection characteristics between turbine and load.

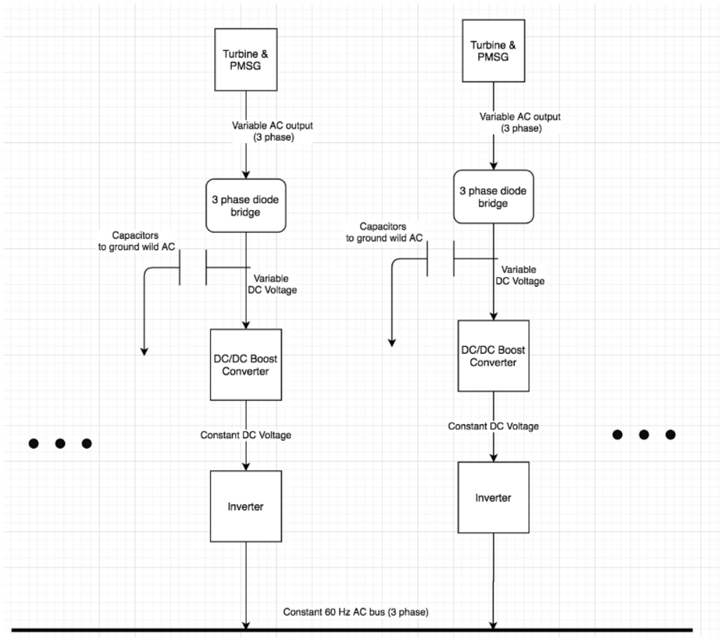
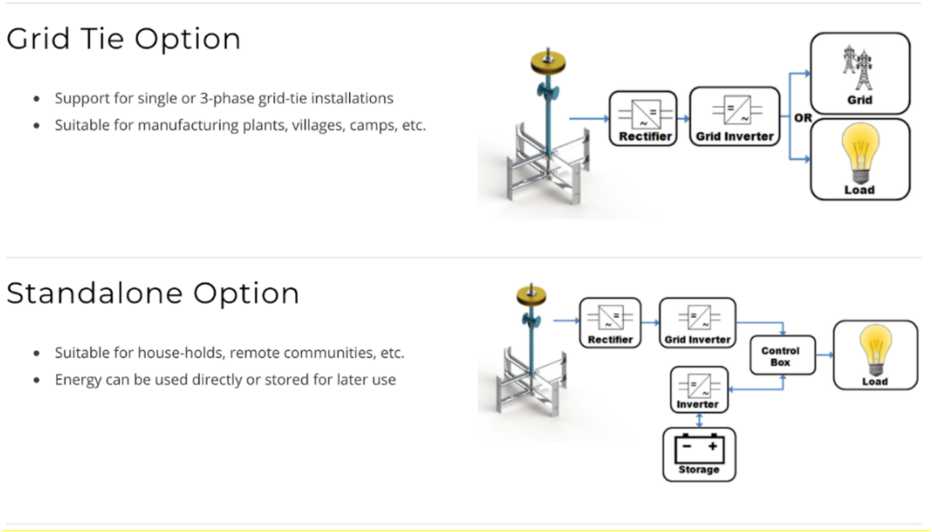


Figure 11: Block diagram of modular electrical system from grid connection

This modular set up allows for any number of turbine systems to connect to one AC bus matched to grid voltage, current, and frequency. From this point, a design decision would be made by individual consumers. Energy from this bus could be attached to the grid, fed to a load (lights, sensors, mechanical bridge components), or stored in a battery bank to provide resiliency in case of system failure.



Grid Tie Option

- Support for single or 3-phase grid-tie installations
- Suitable for manufacturing plants, villages, camps, etc.

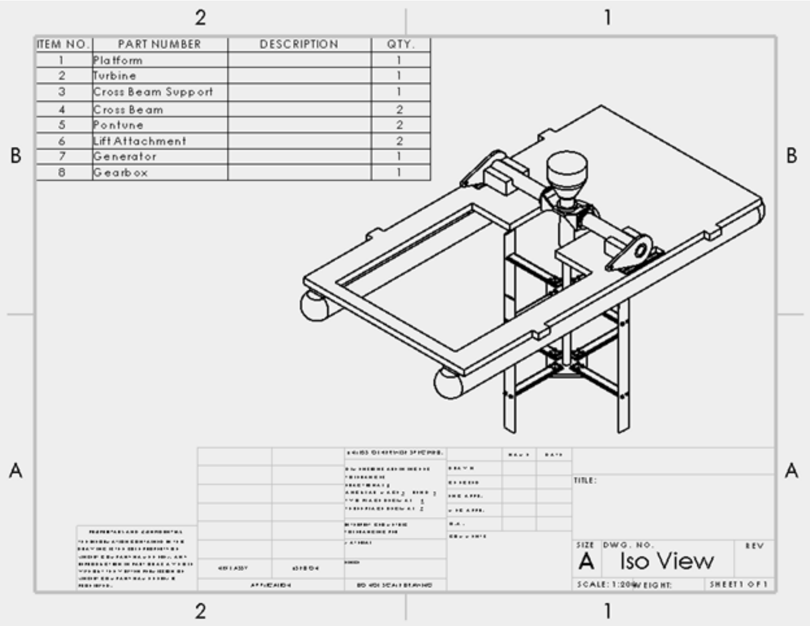
Standalone Option

- Suitable for house-holds, remote communities, etc.
- Energy can be used directly or stored for later use

Figure 12: Electrical Connection Options from New Energy Corporation

In the case of battery storage, it is recommended that Deep Cycle Lead Acid Batteries be used, due to their economical nature. However, the challenges of installing a battery bank on a bridge are significant since they present a high weight to energy storage capability ratio. Choosing to connect the designed system to a battery bank would be a case-by-case decision and would only be recommended for low load bridges.

Engineering Diagrams



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Platform		1
2	Turbine		1
3	Cross Beam Support		1
4	Cross Beam		2
5	Pontune		2
6	Lift Attachment		2
7	Generator		1
8	Gearbox		1

Figure 13: Isometric View of Modular Turbine Unit

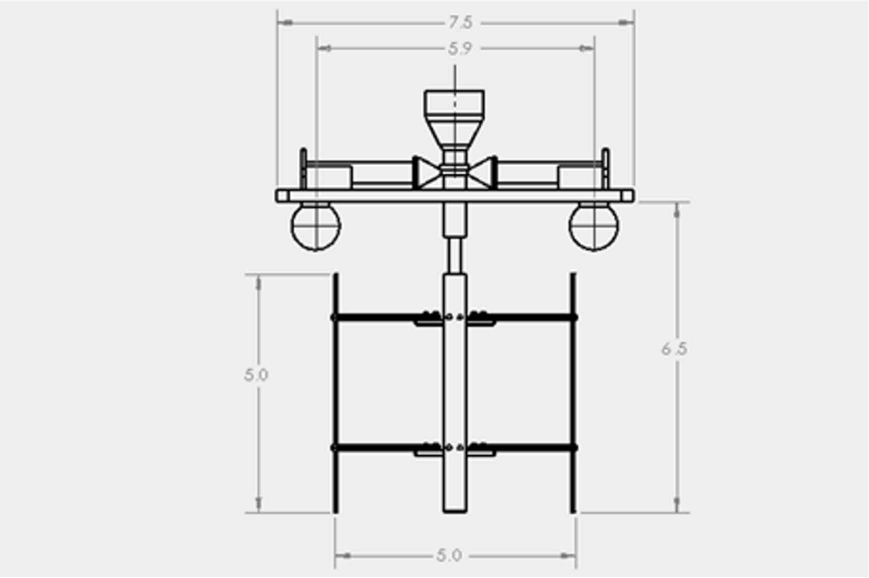


Figure 14: Front Dimensioned View of Modular Turbine Unit

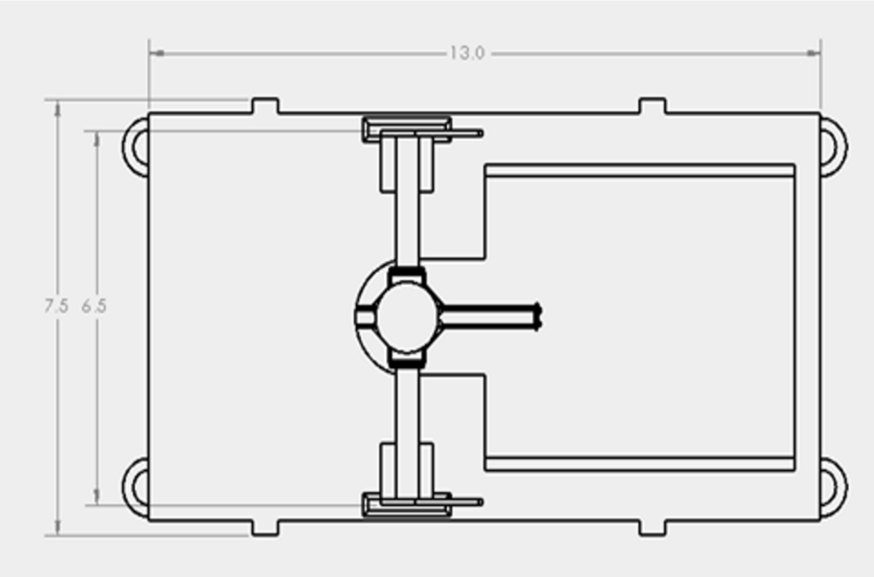


Figure 15: Top Dimensional View of Modular Turbine Unit

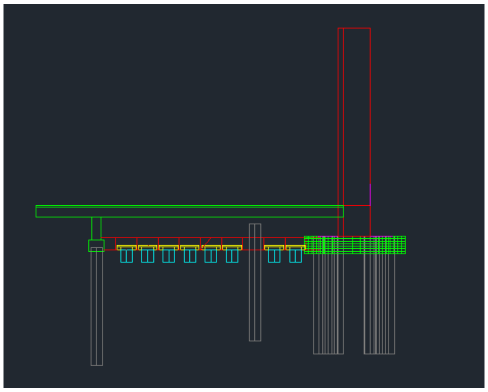


Figure 16: AutoCad Drawing of Turbine Array

6.5 Optimization of System

An optimal cross flow turbine with a diameter of 5 meters and length of 5 meters is selected in order to harness the energy from approximately half of the water column under the Sarah Mildred Long Bridge. Components on the design, shown in figure 11, are optimized to reduce weight while adhering to appropriate factors of safety. A series of static simulations has been conducted to maintain structural integrity. Rough buoyancy calculations justify the placement of the turbine on the platform, but further investigation, along with prototypes, will test to affirm the design.

6.6 Environmental and Sustainability Factors

Any installation of man-made machinery into an ecosystem will impact the local flora and fauna in some way and will have long-term sustainability implications for the larger socio-ecological system it enters. Unfortunately, the environmental impacts of hydrokinetics are not widely known and tend to be extremely site-specific due to the vast differences between habitat and species characteristics. The main concerns surrounding a hydrokinetic turbine array are entrainment of fish and marine mammals, subsea noise, changes in flow, and alteration of migratory routes.

The most intuitive environmental issue involving hydrokinetic turbines is fish strikes, which can be expanded to include marine mammals and reptiles. One study which involved freshwater fish subjected to an axial flow turbine found that greater than 95% of each of the three species studied survived turbine entrainment, a survival rate not far off from the control group which was subjected to the same containment and transportation (Amaral et al). In addition, the injury rate was not greater than 20% for any species of entrained fish. Another study involving a vertical axis turbine and tropical fish found that fish instinctively avoided the turbines, and even when entrained, they never collided with it. Larger fish especially avoided the turbine, allowing more than 1.5 m of berth (Hammar). While the rotor was determined to be “nonhazardous to fish” under the study configuration, it was noted that avoidance behavior may pose a problem in an array configuration. It was recommended that gaps be implemented into the design to allow migratory fish to navigate an array with minimal entrainment. The Sarah Mildred Long case study is a great example of this because the shallow portions of the bridge and shipping channel are free for marine wildlife to avoid entrainment. This means that fish are actually a relatively minimal concern with a free-stream turbine array, however, gaps in the array should be implemented to reduce the disruption of migratory routes.

Marine mammals are less likely to be found in estuaries than in the open ocean but should still be considered in this environmental assessment due to their importance to the marine ecosystem. Similar to fish, they are not likely to be struck by a hydrokinetic turbine, especially turbines that are mounted in a free stream rather than a barrage configuration. However, arrays of turbines create more noise than a single installation. The Sarah Mildred Long design would need to be individually analyzed to determine the magnitude and frequency range of the continuous noise produced by the turbines, which is not very predictable in the design phase. This information would need to be cross-checked with known auditory ranges of local marine mammals, as well as other species. Studies have shown that while the continuous noise is generally not loud enough to be physically damaging to marine life, it can drown out important sounds that animals such as seals and porpoises use to echolocate or communicate. Two studies performed in the Strangford Lough in Northern Ireland, and the English Channel near Brittany, France claim that harbor seals experienced upwards of 80% listening space reduction within 60 meters of the tidal device, and harbor porpoises can be affected by auditory masking in some capacity from as far away as 1 kilometer (Pine et al; Lossent et al). It is important to note that these outcomes were heavily dependent on turbine design, the target species' auditory range, and the comparative ambient noise in the surrounding waters. Due to the presence of boat noise in the area, the comparative loudness of the turbines may be negligible aside from the fact that it is constant. Similar to wind turbine development, further research could be done to reduce the noise produce by marine energy devices.

Lastly, the introduction of a hydrokinetic energy system has the potential to alter the flow in an estuary by extracting kinetic energy from the water. The implications here can be either positive or negative depending on the species and its preferred flow conditions (du Feu et al). A more detailed explanation of the impacts would come from an in-depth analysis of the local species and the habitat suitability of the Piscataqua River before and after potential flow alterations. Additionally, turbine turbulence can affect sediment travel through waterways and sediment deposition, potentially altering benthic topography. This phenomenon is especially important in the case of bottom-mounted turbines and tidal barrages, where sediment is in close proximity to the system. A surface-mounted installation similar to the Sarah Mildred Long Bridge tends to be farther from the bottom, making the direct impact of its wake less prominent. Additionally, it is not a barrage where majority of the flow is compromised by the turbines; the fastest flow in the Piscataqua River actually falls within the shipping channel, so the sediment travel characteristics should not be heavily altered.

Sustainability is defined as being able to meet the needs of the present without compromising the needs of future generations. In this context, we are trying to generate clean, affordable, renewable energy that does not have significant adverse impacts on the environment, economy, or society that it is incorporated into. The above business plan denotes exactly where the Sarah Mildred Long installation would fit into the local economy, but also, more broadly, how the concept of estuarine hydrokinetic arrays could play a supportive role in the global energy market. Likewise, the environmental considerations in the prior section explain how a tidal array may have an impact on an estuarine ecosystem, and the methods of minimizing that. Going through the proper channels of permitting, regulation, and abiding by the local policies are the keys to successful integration with the community where renewable energy is installed. In the case of the Sarah Mildred Long installation, we discussed potential conflicts with the NH Port Authority, Tetra Tech, and others to ensure that we were considering all aspects of implementing this theoretical design into the socio-ecological system properly.

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