2024 Hydropower Collegiate Competition

Conceptual Design Report

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NORTHERN
ARIZONA
UNIVERSITY

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Faculty Advisor: Carson Pete
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DISCLAIMER

EXECUTIVE SUMMARY

Northern Arizona University's mechanical engineering capstone team is competing in the 2024 Collegiate Hydropower Competition. The competition is structured around siting a non-powered dam (NPD) that has the potential to be converted into a hydropower dam. The competition features a siting challenge, design challenge and a community connections challenge. The siting challenge is where potential sites will be evaluated and eventually chosen based on the challenge requirements for power generation between one and ten megawatts. For the design challenge, an overall conceptual design of the full powerhouse will be modeled. Finally, the community connections challenge will connect the team to the hydropower community, students, and the local Flagstaff community. Members of our team have traveled to Clean Currents 2023 conference in Cincinnati, Ohio, and gained valuable connections with professionals in the hydropower industry. The mechanical engineering team and the electrical engineering sub-team have utilized various software such as Oak Ridge National Laboratory's NPD Explorer and ArcGIS Pro software to map out potential dam sites.

The project's design is driven by six key customer requirements, emphasizing effective risk mitigation, cost optimization, environmental impact mitigation, scalability, efficient energy production, and community engagement. These requirements were carefully quantified and equipped with specific targets to ensure alignment with the customer's needs and competition standards. Engineering requirements are the technical prerequisites guiding the project, and each is quantifiable with specific targets. These requirements include energy output (1-10 MW), aquatic ecosystem preservation, plant efficiency, hydrologic data utilization, feasibility, and site interconnectivity. The House of Quality (QFD) provides a tool for understanding the correlations between customer and engineering requirements. Through systematic assessments, we rated the degree to which each requirement influences others and established their absolute technical importance. The insights gained have helped us make well-informed decisions and understand how changes in one technical requirement impact other aspects of the project.

Throughout the rest of the report, we delve into the mathematical modeling, literature review, benchmarking, and decision matrix selection criteria. This extensive exploration forms the bedrock of our project. The mathematical modeling section lays the foundation for our design by applying mathematical principles, hydropower engineering theories, and environmental impact assessments. Concurrently, our literature review provides a comprehensive overview of existing research and technical resources, incorporating valuable insights from previous work in the field. We leverage this knowledge to ensure our project builds upon the expertise of past researchers and engineers.

As we advance, the report unveils the results of our benchmarking efforts, unveiling industry best practices and areas for improvement. The functional model offers a visual representation of the project's critical functions and processes, providing clarity regarding how the system operates. The concept generation phase is guided by a set of established selection criteria, enabling us to identify the most promising ideas and innovations. Our evaluation of each concept using these criteria is presented, marking a clear direction for our project's development. Additionally, we present the current state of our CAD drawings, showcasing the tangible progress made toward realizing a transformative hydropower project. At the time of writing this document, our project has achieved significant milestones and is pushing forward in the Siting Challenge and Design Challenge.

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1 BACKGROUND

This chapter lays the foundation for our capstone project, which is structured within the parameters of the Hydropower Collegiate Competition (HCC) and NAU's capstone course. Our problem statement, which is in line with the core objectives of the HCC, states that we want to locate and convert a non-powered dam (NPD) into a hydroelectric plant. Examining the deliverables, we determine the essential milestones that direct the development of our project and group them into tasks that are specific to the competition, the client, and the course. In addition, we establish the success metrics, which include a variety of competition-based elements and will ultimately determine the project's success.

1.1 Project Description

Our capstone project is a dynamic response to the Hydropower Collegiate Competition (HCC), a distinguished platform sponsored by the United States Department of Energy's (DOE) Water Power Technologies Office (WPTO). The HCC wants our interdisciplinary team of undergraduate and graduate students to actively participate in their described sequence of various competition challenges that have the potential to change the hydropower industry. With this, our primary goal is to select and convert a non-powered dam (NPD) to a hydroelectric dam, which falls under the mandate of the HCC. This topic resonates with the hydropower industry's current demands and untapped potential, as it contains a possibility to harness clean energy from over 80,000 NPDs in the United States. Additionally, our project aligns perfectly with the broader HCC and federal government's goal to attain a carbon-pollution-free power sector by 2035. With this, we aim to efficiently create sustainable electricity while assisting local communities by repurposing existing infrastructure.

In addition to the competition, our project serves as our capstone initiative, which requires us to adhere to a strict budget and fundraising goals. The HCC provides an established funding schedule, which we will strictly adhere to. It includes cash incentives of up to $20,000 for participating in various competition phases, ensuring that our project has the resources to proceed forward effectively. Our budget and fundraising strategy includes working with our faculty advisor, Carson Pete, who will help with financial planning and resource allocation through organizations like Equal Partners in Inclusive Community (EPIC) and National Renewable Energy Laboratory (NREL). By adhering to the funding schedule, securing additional financial support, and aligning with the clean energy objectives of the HCC, we are able to make a meaningful impact in the field of hydropower. Our project demonstrates not only our commitment to sustainability, but also our dedication to inspiring the next generation of engineers who will drive the clean energy revolution ahead.

1.2 Deliverables

The deliverables for our project can be divided into three categories: competition-specific, client-specific, and course-specific. These deliverables enable a seamless integration of our academic course requirements, the demands of our client (The US Department of Energy) and the objectives of the competition. They also serve as milestones to steer the project's progress. In this section, we elaborate on these deliverables, offering a disciplined framework for carrying out our capstone project successfully.

1.2.1 Course Deliverables

Our academic course requirements mandate the fulfillment of numerous deliverables, which include:

1. Staff Meetings: Periodic updates on project progress, difficulties encountered, and potential solutions are provided during staff meetings, assuring compliance with the goals and milestones of the course.
2. Oral Presentations: As part of the academic assessment process, scheduled presentations to the course instructors and classmates highlight the project's development, outcomes, and conclusions.
3. Written Reports: Complete project reports that outline the research, methodologies, findings, and recommendations in order to demonstrate academic proficiency and understanding of the project's intricacies.

1.2.2 Client Deliverables

These deliverables are designed to meet the expectations and requirements of our Faculty Advisor, Carson Pete, who plays a critical role in guiding and supervising the team throughout the course and the competition:

1. Regular Team Updates and Meetings: The team will schedule regular meetings with the Faculty Advisor to provide updates on project progress, discuss challenges, and receive guidance and feedback.
2. Advisory Support: The Faculty Advisor will provide advisory support to help students develop the skills necessary to compete effectively in various aspects of the competition.
3. Guidance on Compliance: The Faculty Advisor will ensure that the team's activities and deliverables align with the competition's guidelines and requirements.
4. Communication Liaison: The Faculty Advisor will serve as the primary point of contact between the team and the competition Prize Administrators, disseminating relevant information and ensuring clear communication.
5. Assistance in Decision-Making: The Faculty Advisor will offer guidance and insights to assist the team in making critical decisions related to the project, challenges, and competition strategies.
6. Input on Project Planning: The Faculty Advisor will provide input on project planning, budgeting, and fundraising targets, ensuring alignment with the course and competition objectives.

1.2.3 Competition Deliverables

The Hydropower Collegiate Competition (HCC) encompasses various challenges, each with specific deliverables that contribute to our overall participation in the competition. These deliverables are classified into midyear submissions and presentations for the various challenges. Here, we outline the major deliverables required for each challenge in the competition:

1. Siting Challenge:
    a) Midyear Submission: The Site Selection and Justification document that includes the team’s down-select process in determining a site, risk identification, and the approach to minimizing risk.
    b) Presentation: Teams will present their Siting Challenge and Design Challenge results.
    c) Poster: A visually appealing poster representing their Siting Challenge and Design

Challenge activities.

2A. Design Challenge (Track 1 - Facility Conceptual Design):

  a) Midyear Submission: The Design Selection and Justification document that details the selected design challenge, planned approach, associated risks, and risk management strategy.
  b) Presentation: Teams will participate in a presentation describing their design activities.
  c) Poster: A visually appealing poster summarizing their Siting and Design Challenges.

****OR****

2B. Design Challenge (Track 2 - Hydropower Component Deep Dive):

  a) Midyear Submission: The Design Selection and Justification document, similar to Track 1.
  b) Presentation: Teams will participate in a presentation describing their design activities.
  c) Poster: A visually appealing poster summarizing their Siting and Design Challenges.

**** ***Note:*** *Whether we choose 2A or 2B as Design Challenge deliverables will depend on our project's direction and objectives heading into the end of the semester, as we've directed most of our focus towards the siting challenge over the first half of this semester. ***

3. Community Connections Challenge:
   a) Midyear Submission: This includes the team roster, team story, and details on the team's project, objectives, and game plan. Additionally, hydropower industry interview slides and thoughts on the competition experience are required.
   b) Presentation: A presentation showcasing the team's community engagement activities and educational webinars, if applicable.
4. Optional Build and Test Challenge:
   a) Midyear Submission: Teams opting for this challenge will need to submit a Build and Test Strategy document outlining their proposed testing and experimentation strategy, materials to be purchased, risk identification, and risk minimization strategies.
   b) Presentation: A presentation describing their build and test activities, including video footage or photographs of testing and/or experimentation.

By explicitly outlining these deliverables, we establish a comprehensive framework for our project execution. These deliverables ensure that we achieve both academic standards and competition objectives, as well as the expectations of the Hydropower Collegiate Competition.

1.3 Success Metrics

Several crucial parameters that coincide with the competition's main aims and objectives will determine the success of our project in the Hydropower Collegiate Competition. The following are the essential success metrics that align with the overarching goals and objectives of the competition:

1. Performance Testing: Our prototype will undergo extensive testing in real-world settings to assess

this. The ability to generate electricity within the designated range of 1–10 MW, power generation capacity, and system efficiency are the main characteristics that need to be evaluated. Our capacity to attain and maintain the desired power output under a range of operating situations will serve as the yardstick for success in this respect.

2. Cost Efficiency: Extensive cost assessments, encompassing capital and operating expenditures, will be undertaken to ascertain this. Our capacity to provide a solution that maximizes costs within the specified restrictions and produces clean electricity will serve as a barometer of our success in this field.
3. Environmental Impact: Reducing negative effects on the nearby ecology, making sure water is used efficiently, and using eco-friendly products and technology are all part of our site's environmental sustainability. Compliance with sustainability standards and adherence to environmental regulations will be key indicators of success.
4. Community Engagement: Given the Community Connections Challenge, our success will be influenced by our ability to foster strong connections with local communities and industry professionals. Our ability to effectively communicate with stakeholders, explain the advantages of hydropower, and inform the public about clean energy options will be an indication of our success in this project.
5. Safety and Reliability: To ensure sure that our infrastructure will operate safely under a variety of circumstances, everything will be evaluated using risk assessments and strong design computations. The system's ability to adhere to strict safety requirements will serve as a sign of success.
6. Competition Objectives: This includes the successful completion of all deliverables for the Siting Challenge, Design Challenge, Community Connections Challenge, and the Optional Build and Test Challenge. Our ability to meet these deliverables based on the scoring criteria outlined in the HCC rubric, as well as our ability to effectively present our work, will determine our success and competition placement.

Each of these measures will be carefully handled and quantified as the project advances, resulting in the establishment of a successful and sustainable hydropower project.

2 REQUIREMENTS

Moving forward with the project our team had to identify the project requirements, and specifically those set by the completion deliverables. These requirements, including energy output and feasibility, are the technical prerequisites that will enable us to meet the customer's expectations and competition standards. The final subsection, Section 2.3, unveiled the House of Quality (QFD), a pivotal tool in understanding the relationships between customer and engineering requirements. The knowledge gained through these sections illustrates the critical significance of our requirements, highlighting why they are the cornerstones of our project's success.

2.1 Customer Requirements (CRs)

This section examines the fundamental customer requirements that inform the foundation of the project. These requirements are critical in establishing our strategy and determining the project's success using the metrics outlined in Section 1.3. The ranked customer requirements outlined below define the important components of the project that must be targeted, ensuring alignment with competition deliverables, and laying the groundwork for a sustainable and impactful hydropower conversion. While feasibility is crucial, teams will be scored based on the thoroughness and transparency of their assessment, allowing for a high score if reasonable assumptions are made and the quantitative analyses are accurate. Therefore, these requirements call for a thorough assessment of the selected non-powered dam site, focusing on how and why a location is chosen and the identification and mitigation of potential risks related to the power generation systems' installation. Risks include high-level costs, resource and generation availability, dam safety, grid integration, transportation access, environmental factors, cultural effects (e.g., historical landmarks), etc. The project should demonstrate a comprehensive evaluation of the site's suitability, using the following requirements to provide insights into the decision-making process.

1. Environmental Impact Mitigation: The construction and operation of a hydropower plant conversion will have inherent abiotic and biological impacts on its surrounding environment. To align with sustainability goals, it is important to identify potential environmental risks and avoidance measures. Impact analysis should consider flow regime, sedimentation, water quality, fish passage, and sensitive species, among other topics.
2. Project Expenditures: Economic viability is essential, and a cost analysis must justify a return on investment for stakeholders. To ensure an economically feasible solution, the cost of development should be optimized while considering elements such as initial capital cost, operation and maintenance expenses, and long-term profitability.
3. Accessibility: The location of the dam with respect to transmission lines, substations, and transportation access will have a significant impact on capital costs. Ideally the amount of civil work required to connect the plant to a substation is minimized.
4. Co-Development Proposal: The site design should include at least one new co-development opportunity. These may include hybrid renewable energy designs, environmental improvements, recreation, food and/or energy security, etc. The project must explore and outline how these opportunities can be integrated with hydropower and ensure adaptability to the geographical location.

5. Energy Production: This requirement entails the primary objective of the project – generating

electricity efficiently. The system should be designed to produce a specific range of energy, within 1 to 10 megawatts (MW), adhering to the competition standards. The energy production should also be sustainable and reliable, ensuring a consistent power output within the specified range under various operating conditions.

6. Community Engagement: In line with the Community Connections Challenge, the project must actively engage with the local community, industry professionals, and stakeholders. Effective communication, educational webinars, and community outreach programs should be employed to inform and engage the community in the benefits of hydropower and clean energy alternatives.

These customer requirements define the key objectives of the project, serving as a roadmap for meeting the expectations and standards set by the Faculty Advisor, Carson Pete, the Hydropower Collegiate Competition, and the capstone course. In the subsequent sections, a detailed House of Quality (QFD) is provided, correlating these customer requirements with the engineering requirements explored in Section 2.2. By fulfilling these requirements, the project aims to create a sustainable and impactful hydropower solution while meeting academic and competition objectives.

2.2 Engineering Requirements (ERs)

The engineering requirements serve as the backbone of the project, guiding its design and development to meet the essential criteria set by the competition. Each requirement is carefully quantified, equipped with specific targets, and aligned with the corresponding customer requirements. Each of the engineering requirements below are the cornerstones of the project's technical success, interwoven with customer demands for energy production, environmental impact mitigation, economic viability, and scalability.

1. Energy Output: This requirement focusses on the primary objective of the project, which is to generate electricity efficiently within the range of 1-10 MW. Achieving this target ensures alignment with the customer's demand for energy production. It also correlates with customer requirements regarding economic viability, as meeting this energy production goal is essential for a return on investment.
    a. Units: Megawatts (MW)
    b. Target: 1-10 MW as specified by the competition standards
2. Aquatic Ecosystem Preservation: The team is dedicated to preserving aquatic ecosystems surrounding hydropower dam sites, with the aim of minimizing the impact and preserving as many square miles of habitat as possible. This engineering requirement, quantified in square miles, necessitates comprehensive data collection and analysis, employing tools like flow duration curves and hydrological modeling to assess the project's environmental impact. However, quantitative data alone cannot address the complete spectrum of aquatic ecosystem preservation; consequently, qualitative assessments will be required to achieve this technical requirement. Water temperature management, shoreline vegetation preservation, seasonal/daily flow changes, and other factors will all necessitate qualitative assessments.
    a. Units: Square Miles
    b. Target: Minimize the impact on aquatic ecosystems to preserve as many square miles of habitat as possible
3. Plant Efficiency: Efficiency is a critical engineering requirement that ties into customer needs for energy production and environmental impact mitigation. Achieving high turbine efficiency is vital for maximizing power output, ensuring that energy production is reliable. The capacity factor is also an indicator of the system's efficiency in producing power relative to its maximum potential. Meeting these efficiency targets will be essential for calculating the Levelized Cost of Energy (LCOE) and

evaluating the project's feasibility.

   a. Units: Percentage (%)
   b. Target: Turbine Efficiency > 70% & Capacity Factor > 30%

4. Hydrologic Data Utilization: This engineering requirement relates to customer needs for hydrologic engineering data. The effective utilization of hydrologic data, including streamflow information and flow duration curves, is crucial for site selection, design, and assessing environmental impact. Accurate use of hydrologic data will be instrumental in performing calculations related to flow curves, spillway design, and water resource assessments.
   a. Units: Cubic Feet per Second (cfs)
   b. Target: Accurate utilization of hydrologic data, as required for project design and environmental impact assessment.
5. Feasibility: The feasibility engineering requirement focuses on determining the project's financial viability. It comprises a thorough examination of project costs, financial projections, and investment returns to ensure the project's economic viability. The team will evaluate the minimum cost of generating to market-level factors such as baseload power pricing using financial modeling and computations such as the Levelized Cost of Energy (LCOE) and Power Purchase Agreements (PPA). This study is crucial to meeting customer expectations and establishing the hydropower project's economic viability, while also ensuring that development costs are minimized and a return on investment is justified for stakeholders and the community.
   a. Units: 2023 US Dollars ($)
   b. Target: A feasible project with a return on investment justifiable through cost optimization.
6. Site Interconnectivity: Site interconnectivity is essential for effective power distribution and grid integration. Achieving the target in MW ensures that the project can interconnect with the grid and contribute power effectively. This engineering requirement aligns with customer requirements for scalability and community engagement, as grid interconnectivity enables the project to adapt and expand to different geographical locations and engage with local communities through effective power distribution.
   a. Units: Megawatts (MW)
   b. Target: Ensure grid interconnectivity with a capacity of MW.

These engineering requirements are not isolated elements; they are interconnected facets that will be central to the successful completion of the hydropower project. The House of Quality (QFD) will highlight the relationship between these engineering criteria and the related customer demands in the following section, offering a formal framework for evaluating how well the project design matches with customer expectations.

2.3 House of Quality (QFD)

In our pursuit of designing an effective and well-structured hydropower project, we have created a House of Quality (QFD) diagram, which can be found in **Appendix A.1**. Our analysis has revealed significant insights into the technical importance of each engineering requirement relative to the customer's needs, reflecting the challenges and priorities inherent in our project. Our initial focus during this study was on evaluating the correlations between each engineering requirement and how they relate to other technical criteria. By using a systematic rating system that includes strong positive correlations ("++" QFD cells), positive correlations ("+"), no correlation (blank QFD cells), negative correlations ("-"), and strong negative correlations ("--"), we were able to precisely determine the degree to which each requirement influences other technical aspects of the project. For example, boosting energy output could have a beneficial effect on plant efficiency (labeled with “++”) but a negative effect on the maintenance of aquatic ecosystems (labeled with “-”). This degree of specificity and the interdependencies between the needs are crucial for helping us make well-informed decisions during the project's design and development. It also helps us understand how changing one technical requirement can have an impact on other project components.

To determine the relative importance of each engineering requirement, we assigned numerical values to their associations with the customer needs, including strong associations marked as 9, medium associations rated at 6, weak associations designated with 3, and no associations represented by blank cells in the QFD. These ratings were calculated based on the correlations between the engineering requirements and the customer needs, as established during the QFD analysis. As we examined the correlations between customer needs and engineering requirements, it became evident that feasibility, assessed in 2023 dollars, holds the highest absolute technical importance score of 721.3. This high ranking of relative technical importance is not only a reflection of its intrinsic importance but also stems from its strong alignment with customer needs. Assessing the site’s feasibility directly addresses critical customer concerns related to risk mitigation. validating its worth in terms of return on investment and associated risks. In the case of site interconnectivity, its high ranking acknowledges its vital role in aligning with customer requirements for scalability and community engagement. A high score for aquatic ecosystem preservation underscores our strong commitment to minimizing environmental impacts, which is essential for the sustainability and reputation of the project.

These findings are invaluable in prioritizing our technical efforts and allocating resources effectively to address customer needs and meet competition expectations. The QFD diagram not only provides us with a clear understanding of these relationships but also guides us in setting targets, constraints, and ultimately, designing a hydropower project that successfully aligns with the demands of our customers and competition criteria. Going forward, this QFD will remain a pivotal tool for tracking our project's progress and ensuring we meet the key requirements of our stakeholders, while section 3.1, Benchmarking, will delve further into benchmarking analysis, offering an additional dimension of comparison and validation for our project's performance and technical importance.

3 Research Within the Design Space

3.1 Benchmarking

[Describe System-level benchmarking identifying at least three systems that you consider state-of-the-art. Describe all other sub-system-level benchmarking. Cite each benchmarked system/sub-system per IEEE citation style.]

- **(A) Red Rock Dam, IL**

  New intake, penstock and powerhouse adjacent to the spillway. *Challenging because of existing and active flood control dam* Earthfill dam with a chimney filter and blanket drain. [RR Stantec]

  USACE Dam, Hydroelectric developed by Western Minnesota Municipal Power Agency contracted with Ames, Stantec, Braun Intertec

    - Environmental Impact Mitigation – (5)
    - Project Expenditures – (2)
    - Accessibility – (2)
        - Marion County Highway T15 traverses the crest of the dam [RR Stantec]
        -
    - Co-development – (5)
        - Local recreation
    - Energy production – (1)
        - 55.2 MW capacity [US Hydropower market report]
        - 178 GWh average energy output [RR Stantec]
        - Minimum continuous release of 300 cfs [RR Stantec]
    - Community engagement – (X)
        -
- **(B) Lake Livingston Dam, TX**
    - Environmental Impact Mitigation – (3)
        -
    - Project Expenditures – (3)
    - Accessibility – (3)
    - Co-development – (5)
    - Energy production – (3)
        - 26.7 MW [US Hydropower market report]
    - Community engagement – (X)
- **(C) Willow Island Dam, WV**

  Run of river project on the Willow Island Locks and Dam, located on the Ohio River near St. Marys, West Virgina, using Voith turbines [AMP Factsheet]

Project includes existing dam and impoundment, a power canal, an intake structure, and a powerhouse. [Low Impact Hydropower Institute]

USACE contracted with Ruhlin, Voith

- Environmental Impact Mitigation – (4)
    - Impacts determined to be insignificant or may be successfully mitigated [Willow Island EA – US Army Corps]
    - Hosts a healthy aquatic community and is designated 'good' or 'very good' habitat for macroinvertebrates; fish protection measures include a fixed weir allowing fish passage during high flow, two lock chambers for downstream passage; minimum 2,000 cfs flow within tailrace during periods of plant shutdown for protection of aquatic habitat; large diameter Kaplan bulb turbines, with low rotational speed of 64rpm, wide blade gaps and smooth leading edges minimize mortality to entrained fish, native species reintroduced to the area after construction [Low Impact Hydropower Institute]
    - Surrounding area revegetated after construction with a high rate of successful ground cover and tree survival. Areas of erosion have occurred and are being addressed and monitored on a yearly basis [Low Impact Hydropower Institute]
    - Five sites of historic or cultural significance were identified (three prehistoric archeological sites, a historic dwelling, and the Willow Island Locks and Dam). One site was recognized to have the potential for adverse impacts, then addressed appropriately and leading to the development of a Cultural Resources Management Plan. [Low Impact Hydropower Institute]
- Project Expenditures – (5)
    - Estimated capital cost to develop: $276.1 million [AMP Factsheet]
    - $27 million negotiation for excavation and coffer dam construction [AMP Factsheet]
    - High operating cost burden, over 12.5 cents/KWh; $2.2 billion total construction cost, estimating a gross $150/MWh over the next five years. (AMP Combined Hydro Project: Cannelton, Smithland, Willow Island, Meldahl) [Fitch Ratings]
    - FY18 Maintenance Funding Request for $4.7 million [USACE Willow Island Final]
    - Project delayed and additional expenses incurred with Voith equipment failure, resulting in a $40 million lawsuit [Findlaw]
    - Actual cost of power from the Combined Hydro Project for AMP's member communities is significantly higher than the projected estimate by 167%, and 269% more expensive than the same amounts of capacity and energy from PJM markets [IEEFA]
- Accessibility – (5)
    - 1.6 mile, 138 kV transmission line [Willow Island EA – US Army Corps]
    - Main transportation routes readily available (required excavation of 980 ft approach channel and an 865 ft exit channel, to and from the proposed powerhouse location). Operation would not disrupt traffic patterns, though there may be slight

    - delays during construction [Willow Island EA – US Army Corps]
- Co-development – (3)
    - Regulates pool elevation in locks and dams series for commercial navigation [Low Impact Hydropower Institute]
    - Recreation at the project includes a tailrace fishing pier, downstream fishing pier, parking area, picnic/day area, two boat launches upstream, group picnic shelter [Low Impact Hydropower Institute]
- Energy production – (4)
    - 35 MW [Willow Island EA – US Army Corps] (Draft, 2010)
    - 44 MW, installed capacity [LIHI] verified
    - 215,910 MWh, average annual generation [Low Impact Hydropower Institute]
    - Guaranteed, regulated minimum flow to insure commercial navigation [Low Impact Hydropower Institute] – security in reliable production
- Community engagement – (5)
    - 79 communities receiving power, 5 states [AMP]
    - Estimated construction jobs: 200-400 peak, 4 year construction [AMP Factsheet]
    - Estimated permanent jobs: 7-9 [AMP Factsheet]
    - Averages 52 thousand visitors annually, contributing $1.6 million to local economy [USACE Willow Island Final]

3.2 Literature Review

A comprehensive literature review is an essential phase in any research project, as it establishes a strong basis by identifying the existing knowledge and the gaps that the project aims to address. Under this circumstance, thorough research and annotation is critical to our decision-making process in selecting a site, determining its feasibility, and developing new hydropower design components. It is crucial that we evaluate the current hydropower landscape, the components involved, and the potential hurdles in order to effectively traverse these complex competition challenges. With this, our group began this semester by completing extensive research on hydropower and an in-depth review of the competition rules document. In the subsections that follow, we explore each team member's literature review of sources, which includes books, peer-reviewed papers, and additional resources such as online articles, videos, testing codes, and more.

3.2.1 Evan Higgins

Books:

1. “The Guide to Hydropower Mechanical Design” [1]

   This comprehensive reference offers a detailed exploration of mechanical design aspects, components, and design considerations in hydropower systems. It covers critical topics such as turbine selection, material choices, and mechanical design practices. Our focus on repurposing non-powered dams

(NPDs) into hydroelectric dams requires an in-depth understanding of mechanical design to ensure system efficiency and sustainable energy generation. This source will be instrumental in our component selection and design choices.

2. “Design of Hydroelectric Power Plants – Step by Step” [2]

   This textbook serves as a useful resource for understanding the planning and design phases of hydropower projects. It covers various aspects, including types of studies, layouts, conveyance, and equipment considerations. By providing a step-by-step method to project creation, we have an industry-standard guide to planning and designing our NPD conversion, which is critical to the success of our campaign.

Papers:

3. “Design models for small run-of-river hydropower plants: a review” [3]

   This paper discusses modest run-of-river hydropower plant design models and considerations. It discusses critical components such as penstock design, turbine choices, and cavitation models. This source is useful for our HCC project as it gives certain design models that we may use to our project. Our goal of repurposing NPDs into hydropower dams necessitates comprehensive design considerations, and the insights in this study will help us make educated design decisions.

4. “A high-resolution hydro power time-series model for energy systems analysis: Validated with Chinese hydro reservoirs” [4]

   The paper presents a high-resolution hydro power time-series model for energy system analysis that has been tested using Chinese hydro reservoirs. It includes models and graphs that can be used to analyze energy systems, such as power production modeling and daily inflow statistics. This source is important for our HCC research since it helps us analyze energy systems. It enables us to predict electricity generation, evaluate inflow data, and optimize our system while taking wind, solar, and carbon reduction into account.

5. “Hydropower development potential at non-powered dams: Data needs and research gaps” [5]

   This source analyzes the possibilities for hydropower development at non-powered dams, emphasizing data requirements and research gaps. It provides insights into emerging technology, socioeconomic factors, and successful NPD retrofit initiatives. Our HCC project closely resonates with this source because we are committed to converting NPDs into effective hydropower dams. This reference provides us with a variety of knowledge spanning from technological breakthroughs and economic evaluations to an in-depth understanding of the numerous parties engaged in the hydropower development process.

6. “Headgate Rock Hydroelectric Project – Advanced Planning Report” [6]

   This report that was written in 1980 that provides all of the planning that was done to install hydropower at Headgate Rock Dam. Not only does this report provide excellent planning strategies for construction and design, but it also provides a lot of insight into how projects are managed under the Bureau of Indian Affairs, which is a stakeholder that structures water rights much differently compared to the Bureau of Reclamation. We’ve been using this report more recently, along with help from outside stakeholders, to help ensure that our planning process is correct and accurate as compared to real world hydropower conversion projects in Arizona.

Other:

7. “ASME PTC 18-2011” [7]

   The performance testing and measurement guidelines for hydropower systems are included in this publication, ASME Performance Test Codes. It describes the requirements to guarantee effectiveness and performance. This reference is essential to our HCC project because it acts as a performance testing guide. It assists us in making sure that our hydropower system satisfies industry standards and runs effectively.

8. “Hydropower dams make a fish-friendly slash” [8]

   This website article provides important insights into the ecological aspects of hydropower, focusing on the abundance of hydropower plants in Europe and their effects on upstream fish migration. Since the goal of our HCC project is to convert NPD into sustainable energy, understanding ways of assessing the ecological impact is crucial to the accuracy of our site assessment. We can decide on the ecological viability of our project by carefully considering the data linked to fish-friendly hydropower measures and the findings in the article.

9. “How a hydro generator works” [9]

   This animated YouTube video is a great way to get visual help for understanding the fundamentals of hydropower systems. It provides a thorough grasp of the essential elements and processes involved in the production of hydropower. This document helps our HCC project by providing an explanation of these basic principles to external stakeholders as well as team members. It is essential for laying the groundwork for a solid grasp of hydropower and for efficient project comprehension and communication.

10. “Voith StreamDiver – A solution for low head hydropower (EN)” [10]

    This is another very detailed and animated YouTube video put together by Voith Group, a technology company that designs and manufactures a small, compact propellor turbine unit for low head dams. While we learned about this technology in Cincinnati at the Clean Currents conference, this video has been crucial in helping explain to industry professionals, SRP, and other advisors as to what our project entails. By showing this animation, everyone is able to get an idea of how the technology we’re implementing works, how it’s installed, and how the design ultimately saves money in the long run.

3.2.2 Riley Frisell

[Create an annotated bibliography of your references for the project. This is simply the reference title followed by a paragraph summarizing the material in the reference and how it applies to your project. Cite each reference per IEEE citation style. Separate sections per student along with their name (Example: 3.2.1 John Doe). At this point you should have ***10+ references per student****.]*

**PUT REFERENCES IN NUMERICAL ORDER THROUGHOUT REPORT*

Books:

1.

Papers:

2.

3. “American Municipal Power Inc. Generation Projects Fact Sheet” – AMP [11]

4. “LIHI Certificate #187 – Willow Island Lock and Dam Project Ohio/West Virginia” – Low Impact Hydropower Institute

5. “Willow Islands Locks and Dam AMP Proposed Hydroelectric Power Project, Pleasants County, West Virginia; *Draft;* Environmental Assessment” - USACE
6. “Willow Island Locks and Dam – FINAL” – USACE
7. “American Municipal Power Inc v. Voith Hydro Inc (2022)” – Findlaw
8. “Costs of Buying Power from AMP’s Prairie State and Combined Hydro Project Continue to Mount for Municipal Ratepayers” – Institute for Energy Economics and Financial Analysis []

Other:

9.
10. **“**Fitch Downgrades AMP’s Combined Hydro Project Bonds to ‘BBB+’; Outlook Stable” - FitchRatings

3.2.3 Trevor Senior

Books:

1. “Small Hydropower Design and Analysis” [21]

   This book is a powerful resource for many design aspects of a hydropower dam, specifically on the smaller scale which our project is based on. The book provides detailed classifications of components, and multiple approaches to dam design based on head, discharge and flow and capacity analysis.

2. “Renewable Energy Volume 131” [22]

   This textbook helps with calculations relating to fluid dynamics. There is information on head losses, volumetric flow rate and applying them to analyze the arrangements of system components inside a hydropower dam. It will especially be useful in the coming weeks as we being to gather flow data on our selected site.

3. “Hydro Turbine Failure Mechanisms: An overview,” [26]

   This textbook analyzes the potential failures in a dam, and specifically hydropower dams. This was a valuable resource to reference when we were going over the failure modes and effects analysis of a hydropower dam. The resource provided a few good modes of failure that may occur, like cavitation.

Papers:

4. “Combined-Cycle Hydropower Systems – The potential of applying hydrokinetic turbines in the tailwaters of existing conventional hydropower stations” [23]

   This paper includes an in-depth analysis of the feasibility of adding hydropower generators and the math needed to validate these selections. This resource also includes other types of renewable energy generation which can be used to validate our selections and will also benefit our design by giving us ideas for additional sustainable energy generation at the site.

5. “Non-Stationary Hydropower Generation Projections Constrained by Environmental and Electricity Grid Operations Over the Western United States” [24]

   This paper provides research on the electricity grid and how current proposed additions to hydropower generation would impact the current electric grid. Since our dam selection is close to transmission lines, this recourse will be vital to the proposed integration of new electric generation into the grid.

6. “Dams and Tribal Loss in the United States” [25]

This paper identifies areas where misuse of land and property has taken place. Specifically, it researches the ownership of dams and talks about how the United States has acquired the land which current dams have been built upon.

Other:

7. “Oak Ridge National Laboratory Website – NPDamCAT” [27]

   This is an online tool that is used to assist the site selection process. We have utilized this tool to check hazard classifications, potential energy generation and numerus other dam specifications. Our team has used this tool, along with ArcGIS Pro to compare sites and filter out non-powered dams across the United States to those within Arizona since we decided to site a dam in Arizona.

8. “Ownership Responsibility and Liability” [28]

   This site helps with dam safety research. It will be especially beneficial for research on the safety of our selected dam as it will provide us with failure and loss research. The article also provides insight into various owner classifications and their roles in maintenance and upkeep of the dam.

9. “The Voith StreamDiver” [29]

   The detailed pamphlet includes specifications on the design of the Voith StreamDiver turbine model that our team has selected. There is information on the locations where this turbine is suitable for, and the design applications that we could consider. This design can be installed vertically or horizontally. The source also provides case studies to validate the design and back up claims made by Voith.

10. “The Salt River Blw Steward Mountain Dam, AZ” [30]

    This government website provided our team with stream flow data dating back over 20 years. While this is not the exact location where our selected site is located, it is a close approximation since it is located upstream from Granite Reef Diversion Dam. The Verde River also meets up with the Salt River before the stream reaches our dam so the flow should be greater at our site.

11. “SRP Lakes and Dams” [31]

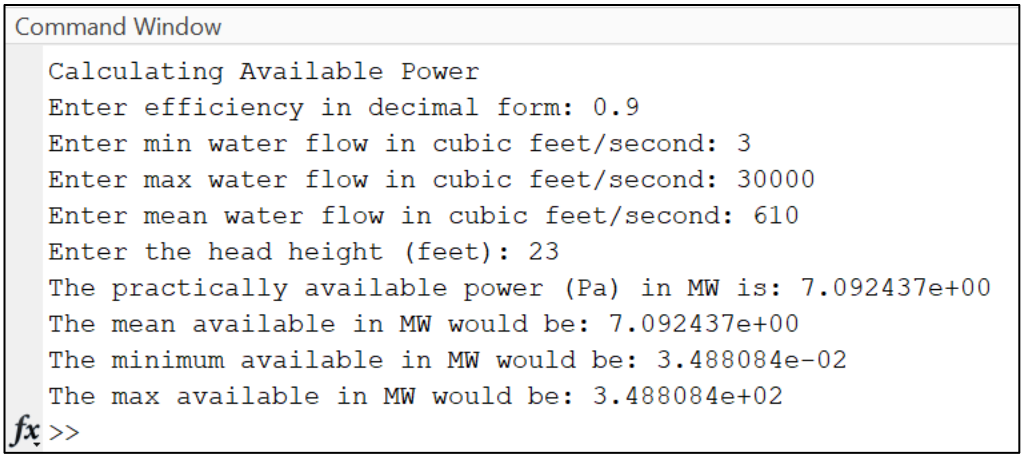
    This website provides information on the dams in Arizona. Cross examination of the different dams around the Salt River region is important when studying ours. From this site, we were able to see which dams in Arizona are powered. The site also provides information on the purpose of these lakes and reservoirs, including recreational activities that take place here to help with our assessment.

3.3 Mathematical Modeling

In this section, mathematical models and data analysis tools are employed to validate the feasibility and potential of our hydropower initiative. It commences with the development of a MATLAB code, enabling the assessment of available power for the converted dam by considering critical parameters such as turbine efficiency, water flow rate, and head height, all vital in ensuring our power generation aligns with the competition's stringent range. Additionally, mathematical equations and assumptions come to the forefront, empowering the estimation of potential energy output at Non-Powered Dams (NPDs) within our design space. This modeling lays the foundation for crucial assessments, including the capacity factor, which gauges energy harnessing efficiency. While using these equations, we outline the significance of ArcGIS Pro, a Geographic Information System (GIS) software tool, in streamlining the selection process for potential NPDs. It provides a systematic and data-driven approach to narrowing down the extensive dataset, ensuring a concise and informed selection of viable hydropower sites.

3.3.1 Modeling Available Power in MATLAB – *Trevor Senior*

To validate whether the power generation by our selected dam falls within the required range of one to ten megawatts of power, a MATLAB code (**Figure A.2.1**) was created to accept inputs of turbine efficiency, maximum, minimum and mean water flow rate, and head height. This code outputs the available power produced to quickly allow us to verify the result (figure 1**Figure 1**) and decide if it is worth moving forward with the dam.



```
Calculating Available Power
Enter efficiency in decimal form: 0.9
Enter min water flow in cubic feet/second: 3
Enter max water flow in cubic feet/second: 30000
Enter mean water flow in cubic feet/second: 610
Enter the head height (feet): 23
The practically available power (Pa) in MW is: 7.092437e+00
The mean available in MW would be: 7.092437e+00
The minimum available in MW would be: 3.488084e-02
The max available in MW would be: 3.488084e+02
fx >>
```

Figure 1: Available power MATLAB code results

This will allow us to analyze when the slow monthly flow takes place and determine how low power generation may drop. This will allow us to investigate solutions to maintain consistent generation. We will also be able to use this data to determine where there will be an excess in energy production. Since we have selected a dam in Arizona, flow rates throughout the year will be volatile so the mean flow rate will give us our best estimate on the power that we will be able to rely on as a benchmark of annual energy production.

3.3.2 Estimating Potential Energy – Riley Frisell

In the process of evaluating Non-Powered Dams (NPDs) as potential sites for hydropower generation, we employ a series of mathematical equations and assumptions to estimate the potential energy output at each NPD. These estimations are integral to our decision-making process in selecting the most suitable NPDs for hydropower conversion within the specified design space. Here, we outline how these equations and assumptions relate to the design space and their practical application in modeling potential energy. These equations and assumptions, outlined in the study by National Renewable Energy Laboratory (NREL) [X], provide the foundation for our mathematical model and are rooted in the principles of hydropower generation.

3.3.2.1 NPD Potential Generation

Our mathematical model centers around the calculation of potential hydropower generation. It incorporates parameters such as the flow rate (Q), net head (ΔH), assumed efficiency (η), and the duration of generation (T). The underlying equation allows us to estimate the potential energy output (in megawatt-hours) for each NPD under consideration.

$$Potential\ Annual\ Generation = \frac{Q \times \Delta\mathrm{H} \times \eta \times \mathrm{T}}{11{,}800}\ \ \mathrm{MWh} \qquad (1)$$

Once this potential annual generation is calculated, we can use this value to estimate the capacity factor of the selected site (2). The capacity factor, denoted as C_f, represents the ratio of actual energy generation to the maximum possible energy generation that a hydropower system could produce when operating at its full capacity throughout the year. It considers the temporal variability of water flow and, therefore, plays an essential role in evaluating the feasibility and reliability of a hydropower system.

$$C_f = \frac{Annual\ Generation\ (MWh)}{Installed\ Capacity\ (MW) \times 8760\ hours}\ \ (unitless) \qquad (2)$$

While Potential Annual Generation (MWh) gives us the total energy produced, the capacity factor helps us understand how efficiently that energy can be harnessed throughout the year. Therefore, we employ this metric to gauge the consistency and reliability of hydropower generation at each NPD we assess. This is where we extend our analysis to include Potential Capacity in megawatts. Potential Capacity represents the maximum power output (in megawatts) a hydropower system can achieve based on the estimated energy generation and the corresponding capacity factor. This metric is calculated using the following equation:

$$Potential\ Capacity = \frac{Potential\ Generation\ (MWh)}{C_f \times 8760\ hours}\ \ \mathrm{MW} \qquad (3)$$

By applying this equation, we assess whether the NPDs' potential capacity aligns with the competition's criteria, ensuring that our selected sites are capable of generating power within the specified range of 1-10 MW. We display the top 6 dams assessed using these equations from a screenshot of our Excel model in Appendix A.2.

3.3.2.2 NPD Hydraulic Height Assumptions

Four key assumptions regarding hydraulic height are applied in our assessment, as outlined in "An Assessment of Energy Potential at Non-Powered Dams in the United States" [15]. These assumptions are vital in our analysis due to the limitations in the available data and the need to ensure consistent and accurate estimations of hydropower potential. The necessity of these assumptions stems from the inherent data gaps and inaccuracies often encountered in the National Inventory of Dams (NID) database. The four assumptions are as follows:

1. If Hydraulic Height is not provided, use 0.7 * NID Height.
2. If Hydraulic Height and NID Height are both provided and are equal, use 0.7 * NID Height.
3. If Hydraulic Height is provided but is greater than 0.7 * NID Height, use 0.7 * NID Height.
4. If Hydraulic Height is provided and is less than 0.7 * NID Height, use Hydraulic Height.

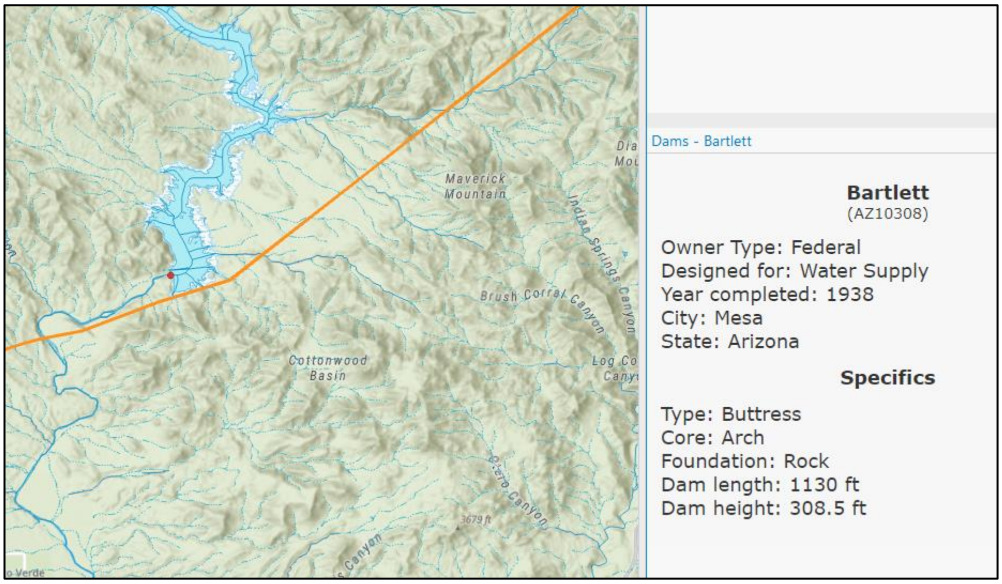
By accounting for the limitations of the available hydraulic height data, we aim to maintain the accuracy and reliability of our hydropower potential estimates in our study.

3.3.3 ArcGIS Pro Selection Process – Evan Higgins

The successful transition from data collection to data-driven decision-making in our project hinged significantly on the application of ArcGIS Pro, a robust and versatile GIS software tool. The primary challenge we encountered was the sheer volume of available data, which necessitated a systematic approach to filter and identify potential NPDs within the state of Arizona. To achieve this, we utilized ArcGIS Pro to combine and analyze various spatial data layers, including the USACE National Inventory of Dams (NID), National Hydrography Dataset (NHD), Homeland Infrastructure Foundation-Level Data (HIFLD), and others outside the ArcGIS Living Atlas. By integrating these datasets, we created a comprehensive map (**Figure A.2.3 in Appendix A.2**) that provided a visual representation of potential NPDs and their geographic relationships.

ArcGIS Pro allowed us to apply decision queries to the extensive dataset, enabling us to systematically reduce the initial pool of over 80,000 NPDs in the United States to a more manageable count of 174. These filters specifically focused on identifying NPDs in Arizona, excluding those with purposes other than hydroelectric, and incorporating specific criteria such as structural height and acre storage. We also eliminated any streamlines with an annual mean flow rate of less than 4 cfs using these definition queries since these small streamlines are only connected to small creeks that are unsuitable for hydropower generation.

This map serves as a pivotal asset, enabling a clear understanding of potential NPDs and their spatial relationships. Additionally, the software's capabilities allowed for the creation of pop-up text, enhancing the user experience, and providing in-depth information on selected sites. Incorporating pop-up text, we conducted practical analyses on specific dams to highlight the platform's usefulness. For example, we assessed Bartlett Dam located in Mesa along the Verde River. In this initial assessment outlined in **Figures 2-4**, we were able to find that the dam is over 300 feet tall, has a mean annual flow rate of 692 cfs, is near a 345 kV transmission line that would be viable for hydropower conversion.



Bartlett
(AZ10308)

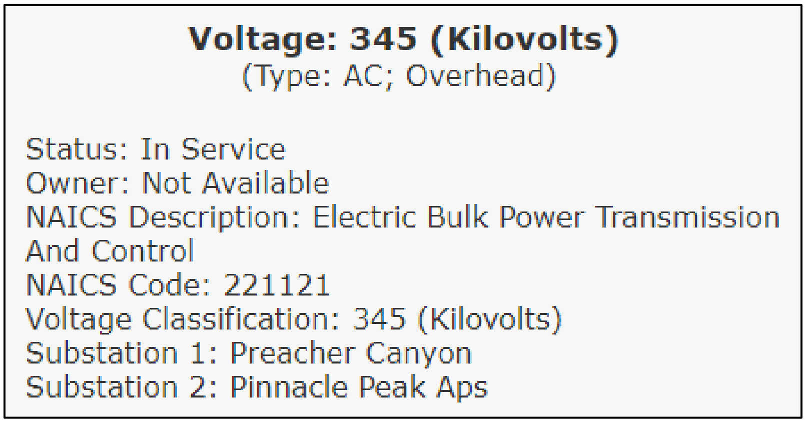
Owner Type: Federal
Designed for: Water Supply
Year completed: 1938
City: Mesa
State: Arizona

Specifics

Type: Buttress
Core: Arch
Foundation: Rock
Dam length: 1130 ft
Dam height: 308.5 ft

Figure 2: Overall topographic view of Bartlett Dam (red dot) near the 345 kV transmission line (orange line).

Figure 3: Zoomed in aerial view of Bartlett Dam, where we see it's buttress-type structure, and the highlighted blue line that gave us details on an annual mean flow of 692 cfs.



Voltage: 345 (Kilovolts)
(Type: AC; Overhead)

Status: In Service
Owner: Not Available
NAICS Description: Electric Bulk Power Transmission And Control
NAICS Code: 221121
Voltage Classification: 345 (Kilovolts)
Substation 1: Preacher Canyon
Substation 2: Pinnacle Peak Aps

Figure 4: Example of specifications provided when clicking on different shapefiles, such as the orange transmission line.

The use of this GIS tool has laid the foundation for our project's data-driven approach, ensuring that our selection process aligns with the objectives of the Hydropower Collegiate Competition (HCC) while enhancing our understanding of potential NPDs. In the following sections, we will delve into the selection criteria used to examine the performance and viability of various NPDs for hydropower conversion, leveraging the useful insights generated from ArcGIS Pro.

4 Design Concepts

4.1 Functional Decomposition

For the functional decomposition, a black box model of a simple hydropower plant is used to demonstrate the understanding of the system by simplification. In this model (figure 5**Figure 5**) the black box model represents the hydropower dam with the input and outputs seen on the model.

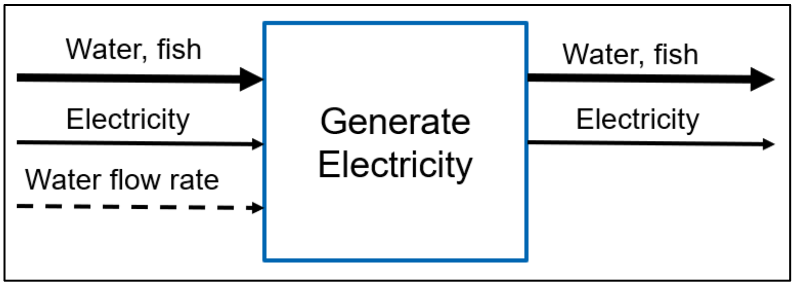


Figure 5: Black Box Model of a simple hydropower plant.

Functional decomposition is important to understand the design and operation of converting a non-powered dam to a hydropower dam. Specially, it is important to understand the systems and components that are critical to the function of a hydropower dam. Some of these include turbines, generators, gates, and penstocks. All the pieces contribute to the overall design of a hydropower dam. Since our project takes a site that does not produce power, functional decomposition is crucial to our proposed design.

4.2 Concept Generation

For the concept generation section, our team created a morphological matrix [**Table A.2.1 in Appendix A.2**]. Our group began researching which dams were most beneficial for their location, the dam type chosen was solely based on its purpose and location. One of the most common dam structures is an arch dam great for tall, narrow canyons and strong since they support large bodies of water. The strength comes from the arch shape which disperses the weight of the water into the canyon walls. While we initially looked at some of these dams, most of these are already hydroelectric dams. Another structure we looked at were buttress dams, which rely on the vertical columns in from of the dam to resist the pressure of the water behind it. Narrowing our dam selection down to Arizona excluded most of these types of dams. Rockfill is another type of dam structure that uses earth materials to create a wall blocking off an area for a reservoir. The rockfill structure is a cheap option but is not as strong as the opposition. Our last selection was a gravity dam which relies on its weight to resist the pressure of the water behind it. Since we are looking for a site to convert to small-scale hydropower, arch and rockfill were mostly excluded from our potential sites since those are used primarily for large dams, which would produce power exceeding our range.

Looking at intake systems, we saw a few common options. First off, the capped intake controlled the water coming out of the reservoir for efficient utilization. It also helps with deterring fish from entering the penstocks. The intake tower is also a popular dam intake, but mostly for large-scale dams. The intake tower is effective at allowing water to be sucked into the penstocks, without taking debris and sediment. Direct flow intakes are a basic but effective intake system, but they are more prone to debris and fish getting trapped or sucked into them.

For the turbine selection, we looked at the three main types of turbines. Francis, Pelton, and Kaplan. The Francis is one of the most popular turbines due to its wide range of head and flow requirements. It also has one of the highest efficiencies. The Pelton turbine is effective at taking high heads without as much flow, maintaining a high efficiency as well. Lastly, Kaplan turbine operates best with higher flow rates, but allowing a lower head than some of the others.

Lastly, we examined fish passage and the possible routes of moving fish from either the top of the dam downstream, or upstream past the dam. One of the methods of transporting juvenile fish is the bypass system that acts as a long water slide to gradually transport them down. This is a good option for movement downstream but does not allow the fish to travel up it. An option that allows for movement in both directions is the fish ladder which acts as little waterfalls for fish to jump up until they reach the reservoir. Sluiceways and spillways with a raised weir allow fish to swim over the top of the dam and slide down to the bottom without harming themselves. This passage is limited to downstream passage only for fish.

Our concept generation combined options which fit together the best, by researching real world dams that utilize these features. We made a few concepts and ranked them in a Pugh chart [**Table A.2.2 in Appendix A.2**]. While it was a requirement for the second presentation, it does not apply directly to our competition. This is because we are sitting in an existing location and designing the dam based on the features and specifications of that location. So, the dam type will already be established. At this point, the concept generation can help us create the unique features of the dam. Specifically, we will be designing the method of fish passage, updating, or constructing a new water intake and selecting the ideal turbine for the dam based on its characteristics.

4.3 Selection Criteria

We've developed a thorough set of selection criteria that meet both customer and engineering requirements for NPDs that could potentially be used to generate hydropower. These criteria encompass a wide array of quantitative and qualitative factors, each playing a distinct role in our evaluation. Every criterion is vital to our decision-making process and has been given a particular weight according to its relative significance. They are quantifiable through calculations and specifications, which provide us with a systematic and structured approach to rank and assess each NPD. Our focus on quantitative criteria involves rigorous calculations, such as estimating potential energy, flow rate, distance to existing infrastructure, and other key parameters. These calculations draw upon industry-standard formulas and specifications, allowing us to quantitatively evaluate each NPD. For qualitative criteria, we delve into complex and nuanced aspects like dam ownership type, potential environmental impact, and community support. These factors influence our decision matrix, guiding us toward the selection of NPDs with the highest potential for successful hydropower conversion. Additionally, we emphasize that these criteria, based on specified data, align with the broader objective of identifying NPDs that are not only promising in terms of energy potential but also meet sustainability and safety standards. Below is a further breakdown of these requirements:

4.3.1 Quantitative Criteria

1. Potential Energy (5%):

   This component, which accounts for 5% of our decision matrix (**Appendix B.1**), is primarily responsible for an NPD's capacity to produce hydropower. Our research has demonstrated that potential energy is quantified in megawatts (MW), and the calculation method outlined in our literature review [15] helps determine the power generation capacity of each NPD. Despite being one of the main indications of hydropower potential, it is given less weight in our matrix since potential energy values must fall inside a specific range (1–10 MW) as specified by the competition requirements. Furthermore, if a dam has little to no community impact or is not feasible for upgrades, its greater potential energy score is meaningless, regardless of whether it generates 1 MW or 10 MW.

2. Flow Rate (8%):

   Flow rate is an important quantitative factor that accounts for 10% of our choice matrix since it has a large impact on the NPD's ability to generate hydropower. Furthermore, a larger flow rate means more water availability, which improves energy generation reliability. This criterion is based on the NHD database's mean annual flow rate of water flow at each NPD, measured in cubic feet per second. Naturally, as flow rate directly affects hydropower generation capacity and consistency, greater flow rates translate into higher scores. With this, our assessment aims to ensure that NPDs with strong flow rates receive a higher ranking.

3. Distance to Existing Electrical Infrastructure (15%):

   Proximity to existing infrastructure, specifically transmission lines and substations, is the most important selection criteria in our assessment, accounting for 15% weight in our decision matrix. Shorter distances to these infrastructure components lower transmission losses and increase energy distribution efficiency. Transmission line construction can be expensive, with expenditures ranging from $2 million to $7 million per mile. Reducing the requirement for major infrastructure construction improves our project's cost-effectiveness. Closer proximity to transmission lines and substations obtains greater scores in this area because it is a direct indicator of infrastructure benefits.

4. Distance to Alternative Energy Sources (7%):

   The availability of complementary energy sources near an NPD, such as solar power (which is abundant in Arizona), could influence our site choices. The proximity of these various sources offers potential collaboration and shared infrastructure, potentially improving operational efficiency. As a result, NPDs located near alternative energy sources may obtain a higher score in this category. While assessing this is difficult, it still bears a relatively high weight since it directly affects our customer's requirement to maximize the utilization of existing infrastructure and resources that favor hydropower generation.

5. Distance to Nearest City (5%):

   The distance from an NPD to the nearest city or town is an influential factor in assessing accessibility and community impacts, accounting for a 5% weight in the decision matrix. This measured distance was acquired from the NID database and is analyzed in our raw data collection using color-coded cells and conditional formatting in Excel. This metric aids in the reduction of construction and maintenance difficulties, which may improve cost-effectiveness. As a result, NPDs located near urban centers perform better in this area, indicating improved accessibility for project development and maintenance.

6. Amount of Watershed (7%):

   The size and extent of the watershed area significantly impacts the flow consistency and potential of an NPD for hydropower generation. This criterion is quantitative because we have data on the watershed area in square miles from the NID. A bigger watershed area often indicates a more stable and continuous flow of water, which improves hydropower generation reliability. NPDs with greater watershed areas score higher, indicating a better fit for our project.

7. Water Storage Capacity (4%):

   Our decision matrix also includes a 4% weight for water storage capacity, which measures the reservoir's storage capacity in acre-feet. Adequate storage capacity is required for efficient water resource management. NPDs with larger water storage capacities score better in this category because they can store water for longer periods of time, which benefits the project's energy generation and reservoir management. However, given the limited supply of water in Arizona, high water storage isn't as vital as ensuring that the dam has adequate water supply on hand. It was therefore given a lower weight than the other elements.

4.3.2 Qualitative Criteria

1. Dam Ownership Type (7%): Dam ownership can significantly influence the ease of collaboration and obtaining necessary permits for hydropower projects. Federal-owned NPDs are subject to specific regulations, permitting processes, and funding mechanisms, depending on the agency responsible. For instance, dams owned by the Bureau of Reclamation may have different protocols compared to those owned by the Bureau of Indian Affairs. Private ownership involves negotiations with individual dam owners, and their willingness to convert to hydropower may vary. Local government-owned dams may require community approvals, but they can be more adaptable to local development initiatives, and the ease of obtaining permits may depend on the specific locality and its policies.
2. Potential Environmental Impact (10%):

   Dams can have a substantial impact on local ecosystems, thus assessing the potential environmental impact is critical. Understanding the environmental impact of an NPD requires assessing the presence of endangered species nearby. Dams can also affect ecosystems by altering water flow and sediment movement. Understanding the broader environmental impact requires assessing how the dam may affect fish migration and local aquatic life. On top of this, since this is outlined as a heavy deliverable in the competition rulebook, we are forced to weigh the criteria much higher than the others. Furthermore, we must give this a significantly greater weight than the other criteria because the competition rulebook lists it as a substantial deliverable.
3. Dam Integrity (4%):

   The long-term operation, safety, and viability of hydropower generation of a dam depend heavily on its structural integrity. The safety of a dam and any future improvements are directly impacted by its hazard categorization (low, significant, and high). Furthermore, the dam's overall integrity depends on how well-maintained it is and when improvements were last implemented. In general, an NPD with a track record of well-kept infrastructure is more advantageous. The examination of known structural problems is crucial since they directly affect the longevity and integrity of the dam, such as seepage or concrete degradation. We cannot, however, give this dam more weight than other criteria because all of our options were constructed no later than 1960, which means that the integrity of this dam will likely have to be evaluated regardless.
4. Cost of Development/Economic Viability (10%):

   The project's economic viability will be evaluated using a Levelized Cost of Energy (LOCE) study. To ascertain if the project is competitive and cost-effective in the energy market, the LOCE considers a number of factors, including development, maintenance, and operating expenses. An additional component of the economic study is assessing the possibility of signing Power Purchase Agreements (PPAs) with nearby utilities. The production of revenue and the overall return on investment can be greatly impacted by a PPA. Additionally, doing sensitivity assessments on variables such as building costs and energy prices will contribute to a more thorough understanding of the project's financial risks and economic viability. For now, while only considering site selection and not future analysis, we can assess cost of development by simply assessing the dam type and height of the dam, as the taller dams would tend to cost more to upgrade and require more civil work as compared to a small dam.

5. Availability of Historical Flow Data (3%):

   This metric is critical in assessing what types of turbines we will install here and the efficiency and capacity factors of power here. However, most nonpowered dams with potential between 1-10 MW have limited data access anyway, so chances this won’t heavily influence our dam selection. Regardless, we would still have to do more digging into actually finding that data, so we can’t base our selected site based on the fact that we haven’t looked in the right places for data.

6. Accessibility (5%):

   This criterion encompasses a variety of factors, including the condition and accessibility of access roads leading to the dam site. Efficient access to the site is essential for transporting equipment, machinery, and construction materials. Additionally, the ability to access and maintain the dam structure itself is crucial. In our assessment, we will evaluate the existing infrastructure for access, assess the condition of access roads, and consider any necessary modifications or improvements to ensure the smooth implementation and long-term maintenance of the hydropower facilities.

7. Local Community Support (5%):

   We aim to assess community engagement, which includes the local population's willingness to endorse and contribute to the project. To achieve this, we plan to engage with local stakeholders to understand their perspectives and address their concerns. Additionally, the social impact of the project on the community, such as the potential for job creation, infrastructure enhancements, and overall improvements to the quality of life, will be considered. In cases where the NPD potentially holds historical significance in terms of cultural heritage, we will study its impact on local heritage. Understanding these social dynamics and fostering positive community relationships is paramount for the long-term sustainability and success of the project.

8. Technical Feasibility (4%):

   The technical feasibility criterion comprises multiple crucial elements, such as the physical structure of the dam's suitability, its capacity to convert hydropower, and the area that is available for the infrastructure that is required. Since we can't evaluate this as thoroughly as we'd like to for numerous dams at once, we've given it a lesser weight in our decision matrix for site selection. However, in the future we want to carry out site-specific engineering studies to evaluate this criterion for the Siting Challenge. These studies will include a detailed assessment of the dam's structural integrity, geological and geotechnical conditions, and hydraulic analysis. This will assist us in assessing if building hydroelectric facilities in accordance with technical, safety, and environmental standards is feasible. If we come across major technical challenges throughout the evaluation process that make a location not feasible, we may consider reevaluating the selected site from further consideration.

4.4 Concept Selection

In Chapter 4, we shift our focus from broad assessments to specific dam selections by employing a comprehensive Decision Matrix. This tool, which is based on the weighted criteria described in Section 3.3, directs our search for Arizona Non-Powered Dams (NPDs) that meet customer expectations and engineering standards in the competition's design space. Our in-depth analysis of five selected dams helps us spotlight promising candidates, such as Granite Reef Diversion, and address challenges presented by others, setting the stage for a future powered by sustainable and efficient hydropower generation. Furthermore, the chapter acknowledges our shift towards considering purchased turbines and collaborative industry engagement, enhancing the project's practicality, and aligning it with recognized standards.

4.4.1 Decision Matrix

A key component of our selection process is the decision matrix, based on the criteria listed in section 4.3. As discussed, each criterion was carefully weighed to represent its importance in meeting engineering requirements and customer needs. It offers a methodical framework for assessing and prioritizing Arizona's prospective NPDs, ensuring that our selection is in line with the allotted design space. The decision matrix, which is shown in **Appendix B**, ensures that the qualitative and quantitative considerations covered above have been appropriately assessed in relation to our dam selection.

The initial evaluations have provided crucial insights into the feasibility of different dams for small-scale hydro upgrades. By referring to the comprehensive decision matrix, we conducted a detailed assessment of five selected dams: Granite Reef Diversion, Palo Verde Diversion, Bartlett Dam, Horseshoe Dam, and Morelos Dam. Among the assessed dams, Granite Reef Diversion has emerged as the most promising candidate, ranking first in our decision matrix. This NPD combines several favorable attributes, including a structural height of less than 30 feet, a high flow rate of 1966 cubic feet per second (cfs), and a potential energy output of approximately 4 MW. These factors align perfectly with our design space, making it a front-runner in our selection process. While Granite Reef Diversion emerges as the leading candidate, Palo Verde Diversion shows significant promise with its exceptionally high flow rate of 11,068 cfs and structural height of 50 feet. However, we are cautious of its potential deviation from the energy potential range specified by the competition, indicating a need for further evaluation.

While Bartlett Dam and Horseshoe Dam, ranked third and fourth, exhibit some merit, they face significant challenges. The structural height of Bartlett Dam exceeds the competition's recommended range, and the mean annual flow rate is just 692 cfs, resulting in a cost-prohibitive scenario with limited energy returns. While Horseshoe Dam has a relatively high structural height, it is also over eight miles from the nearest transmission line, resulting in significant installation costs. As previously mentioned, we applied acceptable assumptions and concluded that taller dams result in greater complexity in construction and civil work, resulting in a very high estimated cost of development. These findings compelled us to carefully evaluate dam potential for small-scale hydro enhancements. The ownership and logistics constraints of the Morelos Dam, which is located outside of the United States, caused significant obstacles. We prioritized dams within our authority based on this important information.

We are committed to ensuring that our chosen NPDs are not only technically viable but also closely connected with customer needs, engineering requirements, and competition stipulations as we go forward with the search. To make educated decisions, we will constantly modify our assessments, considering both quantitative and qualitative data. The extensive selection criteria provide us with a solid framework for narrowing our list of NPDs and setting the stage for the project's succeeding stages. Furthermore, our benchmarked small-scale hydro concepts, such as the Voith StreamDiver, will inform our design approach. By matching our project with benchmarked concepts and drawing on industry expertise, we hope to ensure that our chosen dams not only fulfill but exceed the standards of the competition, producing an efficient and sustainable source of electricity. With our decision matrix serving as a foundation for our selection process and our partnership with key industry players, we are well-positioned to achieve success in our pursuit of sustainable hydropower generation at the identified NPDs. Our approach is rooted in thorough evaluations, robust assessments, and careful consideration of the engineering and customer demands, paving the way for a future powered by clean, renewable energy.

4.4.2 Current state of CAD drawing

Since our project is more conceptual compared to the other capstone teams, our CAD model will not only consist of SolidWorks drawings, but a combination of them and layers and data from ArcGIS Pro and NPDamCAT. To highlight our turbine selection from Voith, we created a CAD drawing to show the current state of the proposed design. This turbine is used as a model to help visualize our design and integration into the gates at Granite Reef Diversion Dam. Our turbine assembly CAD model is designed with equations so we can scale our model up or down depending on circumstances. This will make the design easily able to be 3D printed. The assembled model of the turbine can be seen below in figure 6**Figure 6**, and additional subcomponents are viewable in **Figures A.2.5 and A.2.6 in Appendix A**.

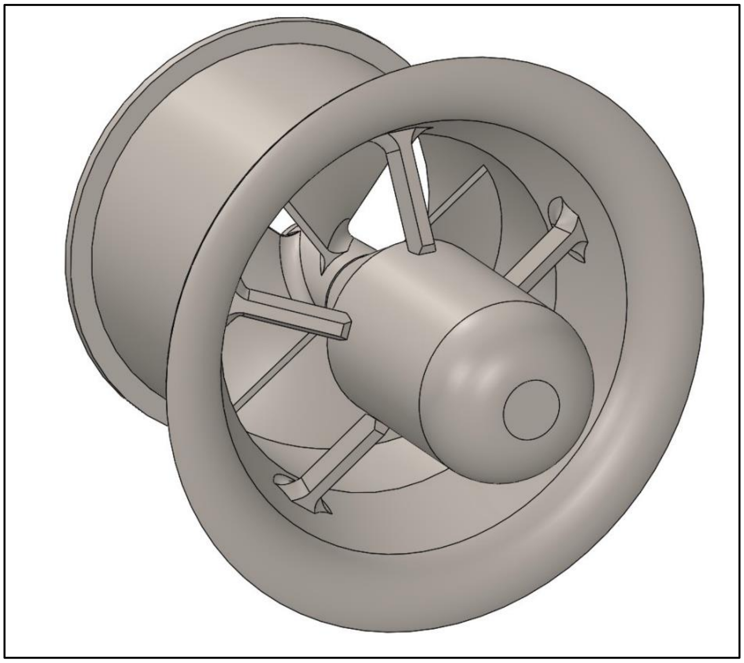
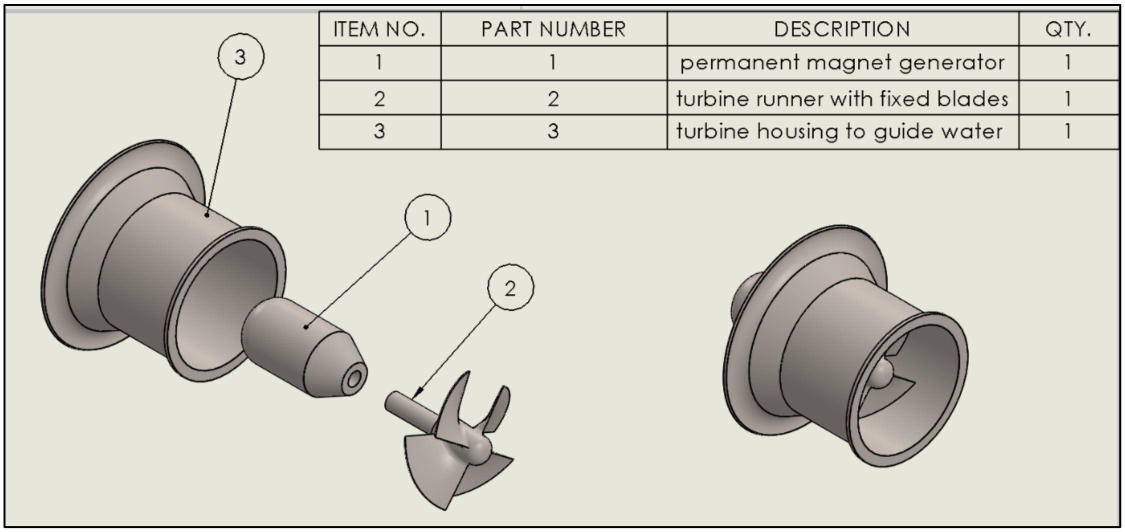


Figure 6: Model of Voith StreamDiver CAD Model

4.4.3 Final Concept CAD Model

The final concept of our CAD model (**Figure 7**) contains a permanent magnet generator, a turbine runner blade made from stainless steel with fixed blade components. Guiding the water and encasing those components are the casing with guide vanes. These subcomponents make up the most important parts of the hydropower turbine.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	permanent magnet generator	1
2	2	turbine runner with fixed blades	1
3	3	turbine housing to guide water	1

Figure 7: Selected CAD Model Assembly

4.4.4 Flow Data and Diagrams

Since our team is waiting on flow data from SRP specific to our site, we went ahead with calculations for a different location on the same river, the Salt River. This data, provided by the United States Geological Survey allowed us to being calculations with data that will be very similar to ours. In theory, our flow data should be greater since the Verde River meets the Salt River before reaching Granite Reef Dam. In **Figure 8**, the discharge data below Stewart Mountain Dam is provided over a four-year span.

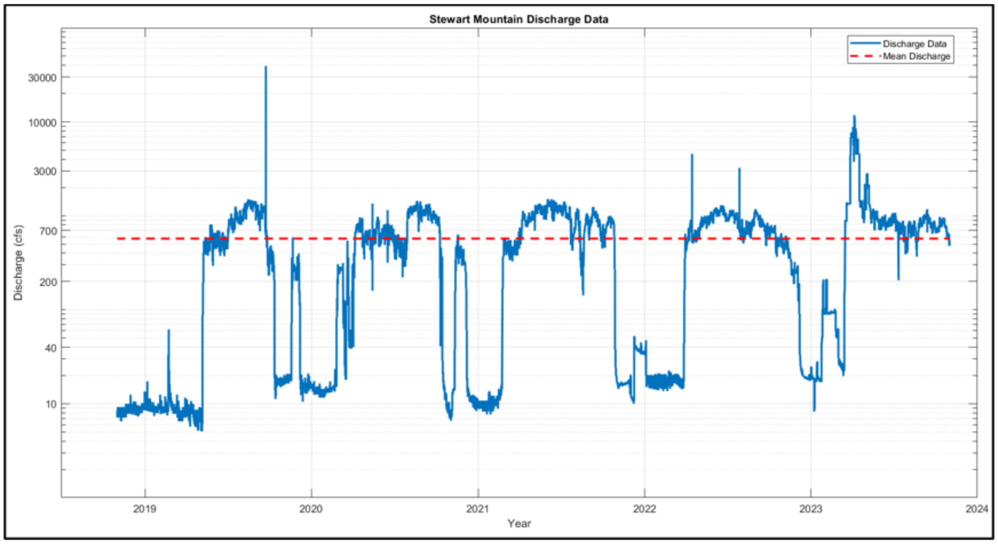
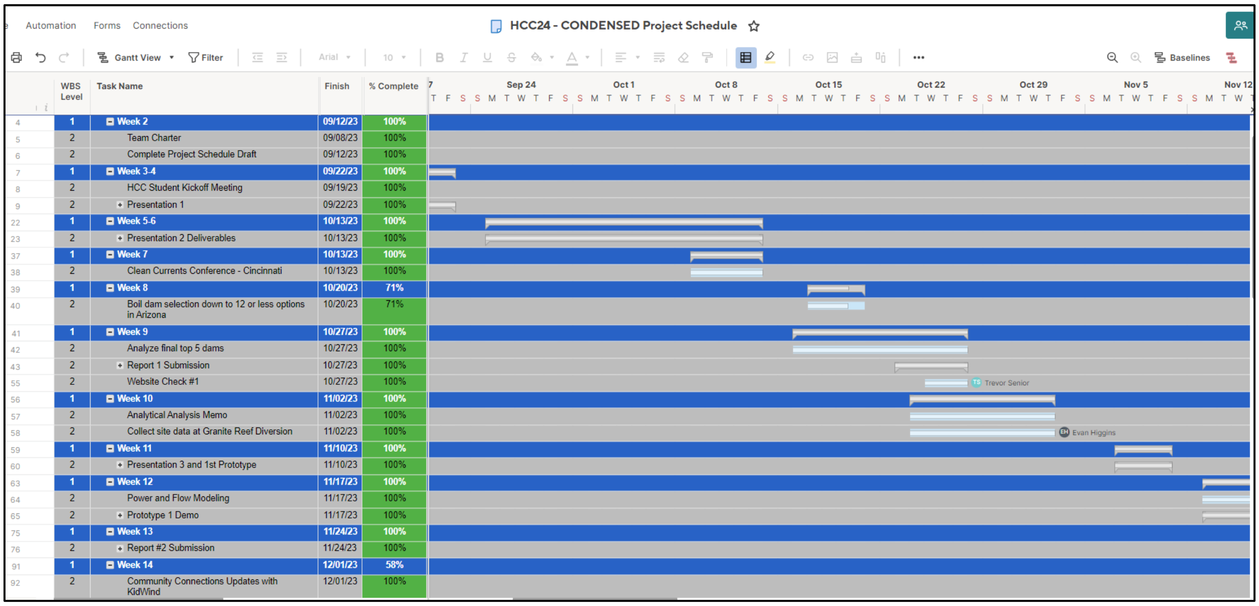


Figure 8: Daily discharge data from November 2019 to November 2023

5 Schedule and Budget

5.1 Schedule

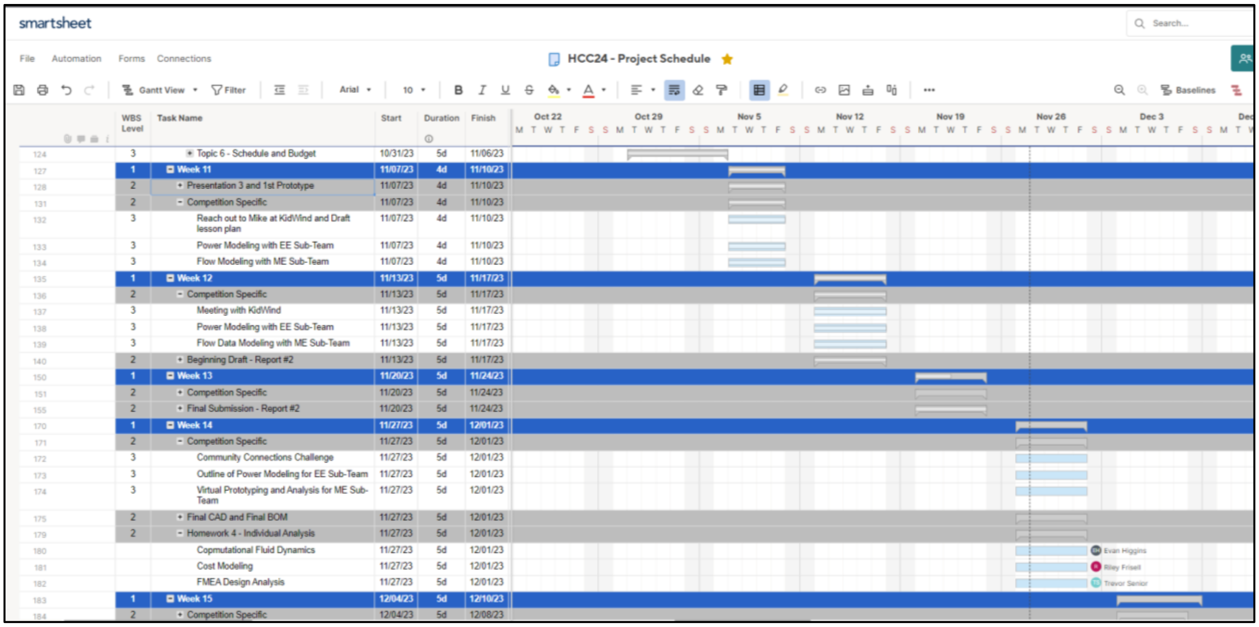
The project schedule, meticulously crafted in Smartsheet, has been an indispensable tool throughout this semester, serving as a dynamic platform for tracking both major milestones and weekly tasks. Given the extensive nature of the schedule, we have included two figures below to provide a condensed overview of our semester-long project timeline (**Figure 9**) and a more detailed representation of our recent activities.



	WBS Level	Task Name	Finish	% Complete
4	1	Week 2	09/12/23	100%
5	2	Team Charter	09/08/23	100%
6	2	Complete Project Schedule Draft	09/12/23	100%
7	1	Week 3-4	09/22/23	100%
8	2	HCC Student Kickoff Meeting	09/19/23	100%
9	2	Presentation 1	09/22/23	100%
22	1	Week 5-6	10/13/23	100%
23	2	Presentation 2 Deliverables	10/13/23	100%
37	1	Week 7	10/13/23	100%
38	2	Clean Currents Conference - Cincinnati	10/13/23	100%
39	1	Week 8	10/20/23	71%
40	2	Boil dam selection down to 12 or less options in Arizona	10/20/23	71%
41	1	Week 9	10/27/23	100%
42	2	Analyze final top 5 dams	10/27/23	100%
43	2	Report 1 Submission	10/27/23	100%
55	2	Website Check #1	10/27/23	100%
56	1	Week 10	11/02/23	100%
57	2	Analytical Analysis Memo	11/02/23	100%
58	2	Collect site data at Granite Reef Diversion	11/02/23	100%
59	1	Week 11	11/10/23	100%
60	2	Presentation 3 and 1st Prototype	11/10/23	100%
63	1	Week 12	11/17/23	100%
64	2	Power and Flow Modeling	11/17/23	100%
65	2	Prototype 1 Demo	11/17/23	100%
75	1	Week 13	11/24/23	100%
76	2	Report #2 Submission	11/24/23	100%
91	1	Week 14	12/01/23	58%
92	2	Community Connections Updates with KidWind	12/01/23	100%

Figure 9: Outline of the all-semester milestones. Note that this is our condensed schedule that we follow to identify the project dependencies of milestones in a neater format.

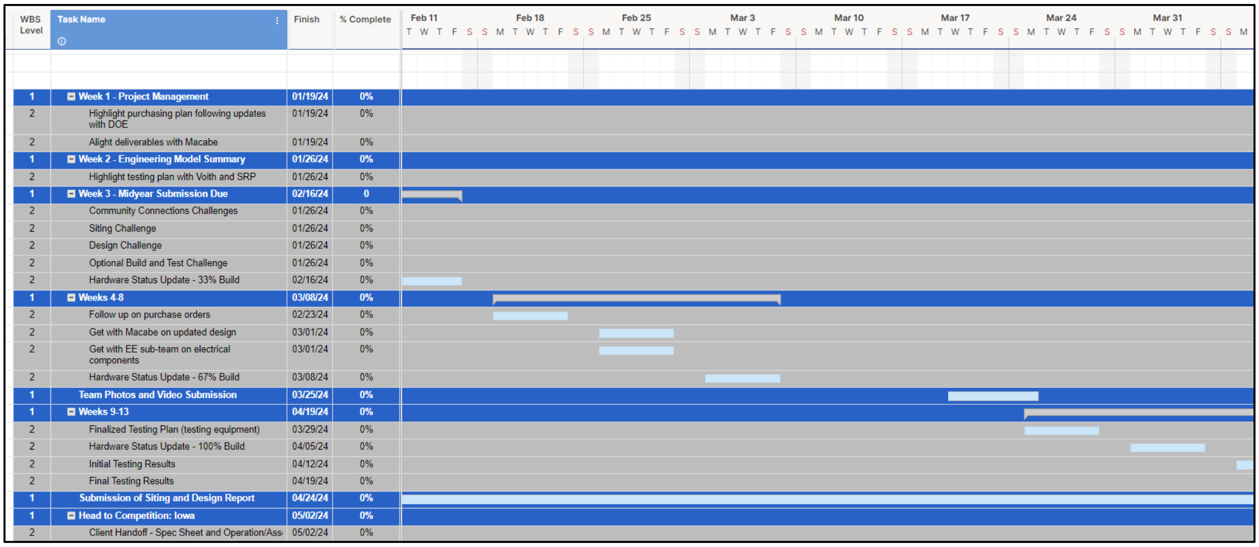
Throughout the semester, ME-476C assignments, presentations, and report deadlines have served as crucial milestones guiding our progress. Despite the broader scope of our project, we strategically aligned these academic milestones with our competition deliverables, translating different presentation topics into actionable tasks. For instance, in **Figure 10**, the utilization of the Presentation 3 deadline as a three-quarter semester milestone enabled us to efficiently allocate three weeks for building our prototype and addressing key topics like the FMEA chart and additional calculations essential for a successful virtual model in MATLAB. Looking ahead, our focus for the remaining semester involves the completion of siting and design validation tasks for our small-scale hydropower facility, as well as initial planning for the upcoming semester.



	WBS Level	Task Name	Start	Duration	Finish
124	3	Topic 6 - Schedule and Budget	10/31/23	5d	11/06/23
127	1	Week 11	11/07/23	4d	11/10/23
128	2	Presentation 3 and 1st Prototype	11/07/23	4d	11/10/23
131	2	Competition Specific	11/07/23	4d	11/10/23
132	3	Reach out to Mike at KidWind and Draft lesson plan	11/07/23	4d	11/10/23
133	3	Power Modeling with EE Sub-Team	11/07/23	4d	11/10/23
134	3	Flow Modeling with ME Sub-Team	11/07/23	4d	11/10/23
135	1	Week 12	11/13/23	5d	11/17/23
136	2	Competition Specific	11/13/23	5d	11/17/23
137	3	Meeting with KidWind	11/13/23	5d	11/17/23
138	3	Power Modeling with EE Sub-Team	11/13/23	5d	11/17/23
139	3	Flow Data Modeling with ME Sub-Team	11/13/23	5d	11/17/23
140	2	Beginning Draft - Report #2	11/13/23	5d	11/17/23
150	1	Week 13	11/20/23	5d	11/24/23
151	2	Competition Specific	11/20/23	5d	11/24/23
155	2	Final Submission - Report #2	11/20/23	5d	11/24/23
170	1	Week 14	11/27/23	5d	12/01/23
171	2	Competition Specific	11/27/23	5d	12/01/23
172	3	Community Connections Challenge	11/27/23	5d	12/01/23
173	3	Outline of Power Modeling for EE Sub-Team	11/27/23	5d	12/01/23
174	3	Virtual Prototyping and Analysis for ME Sub-Team	11/27/23	5d	12/01/23
175	2	Final CAD and Final BOM	11/27/23	5d	12/01/23
179	2	Homework 4 - Individual Analysis	11/27/23	5d	12/01/23
180		Copmutational Fluid Dynamics	11/27/23	5d	12/01/23
181		Cost Modeling	11/27/23	5d	12/01/23
182		FMEA Design Analysis	11/27/23	5d	12/01/23
183	1	Week 15	12/04/23	5d	12/10/23
184	2	Competition Specific	12/04/23	5d	12/08/23

Figure 10: Outline of week 11-15 tasks. Note that this schedule is more than 184 rows long (as shown in the left column) and it is continuously updated to fit our project needs.

Given that our challenges are oriented towards large-scale design rather than a fixed number of components, adjustments to the project schedule and ME-486C assignment milestones (**Figure 11**) are anticipated. A primary challenge this semester has been aligning course deliverables with competition requirements, particularly in relating site feasibility assessments and large-scale designs to our design-specific objectives. Considering the expansion of our work on siting and design challenges in the next semester, along with additional interviews and community engagement activities, we anticipate modifying the course outline for ME-486C. As we currently plan for the Optional Build and Test Prototype challenge, Figure Y outlines our project schedule, integrating course milestones, midyear, and final submission deadlines, leading up to our participation in the competition in Des Moines, Iowa, from April 29th to May 1st, 2024. This integrated approach ensures a comprehensive alignment of academic objectives with competition goals, reflecting our commitment to delivering a successful and impactful project in the field of sustainable hydropower.



WBS Level	Task Name	Finish	% Complete
1	**⊟ Week 1 - Project Management**	**01/19/24**	**0%**
2	Highlight purchasing plan following updates with DOE	01/19/24	0%
2	Alight deliverables with Macabe	01/19/24	0%
1	**⊟ Week 2 - Engineering Model Summary**	**01/26/24**	**0%**
2	Highlight testing plan with Voith and SRP	01/26/24	0%
1	**⊟ Week 3 - Midyear Submission Due**	**02/16/24**	**0**
2	Community Connections Challenges	01/26/24	0%
2	Siting Challenge	01/26/24	0%
2	Design Challenge	01/26/24	0%
2	Optional Build and Test Challenge	01/26/24	0%
2	Hardware Status Update - 33% Build	02/16/24	0%
1	**⊟ Weeks 4-8**	**03/08/24**	**0%**
2	Follow up on purchase orders	02/23/24	0%
2	Get with Macabe on updated design	03/01/24	0%
2	Get with EE sub-team on electrical components	03/01/24	0%
2	Hardware Status Update - 67% Build	03/08/24	0%
1	**Team Photos and Video Submission**	**03/25/24**	**0%**
1	**⊟ Weeks 9-13**	**04/19/24**	**0%**
2	Finalized Testing Plan (testing equipment)	03/29/24	0%
2	Hardware Status Update - 100% Build	04/05/24	0%
2	Initial Testing Results	04/12/24	0%
2	Final Testing Results	04/19/24	0%
1	**Submission of Siting and Design Report**	**04/24/24**	**0%**
1	**⊟ Head to Competition: Iowa**	**05/02/24**	**0%**
2	Client Handoff - Spec Sheet and Operation/Ass	05/02/24	0%

Figure 11: Rough draft of anticipated project milestones during the course of ME-486C in Spring, 2023.

5.2 *Budget*

[Show your total project budget including prototyping, final design build, travel, and any other expenses.]

The current budget includes our estimated and known travel expenses, as well as a rough bill of materials for our build component. At this time, the bill of materials for both our conceptual design and the build component are being developed continuously as our siting component becomes further informed.

5.3 *Bill of Materials (BoM)*

The bill of materials was created for both the conversion at the site of the dam, and for the build and test prototype. For the site of the dam, we took the materials, equipment rentals, and the labor costs into account. This overview is just a rough estimate of what will go into converting this site into a powered dam. As we dive deeper into the study at the site, we will get a better understanding of how long the conversion would take to be completed. The team has also reached out to SRP for the flow data at the site, as well as Voith, the company which we plan to purchase the StreamDiver turbines from. With the addition of both these assets, our cost assessment will be able to be reevaluated and corrected to account for new information and touch on the specifics. The bill of materials for the dam conversion can be viewed later in the report in **Table A.2.3 in Appendix A**.

For the build and test challenge bill of materials, we have finalized an estimate of most of the materials we will need to build a small-scale hydropower dam. There are a few items that were not included in there, such as glue and epoxy since we have not finalized the methods, we will use to construct the model. There is also no mention of a hydraulic bench, as we have one available to use in the Thermal Fluids lab at no cost. The full bill of materials can be found in **Appendix A, Table A.2.35.** As we begin our model, most of the components are going to be purchased, while a fraction of them will just be altered slightly. We have not finalized any plans on which parts are going to need to be manufactured by our team. There is the possibility the turbine runner blade will be machined by us if we are unable to purchase one that matches our desired specifications.

6 Design Validation and Initial Prototyping

6.1 Failure Modes and Effects Analysis (FMEA)

For the failure modes and effects analysis on Granite Reef Diversion Dam, the team investigated potential failures by the dam structure or those of which the dam components may be susceptible to. We focused on the generator, fixed runner blade and, the StreamDiver outer casing and the dam structure itself. Critical failures on the generator include electrical generation failure or rotation stopping due to debris or sediment. We researched a trash rack as a solution for debris, but for sediment buildup we may have to consider dredging which comes with environmental concerns.

For the potential of cavitation, which is the formation and bursting of air bubbles around the runner blade, which can cause chips and cracks in the runner blade leading to reduced efficiency and possibly failure. This can be solved by increasing the aerodynamics of the leading edge, as well as causing the water to create an outward spiral from the rear side of the blade to prevent bubbles from busting around the blade.

The entirety of the selected components we studied for the failure modes and effects analysis can be seen in **Appendix A, Table A.2.4**.

6.2 Initial Physical Prototype

6.2.1 Prototype Question

Our team created a physical prototype of Granite Reef Diversion Dam to examine how well the proposed turbine integration aligns with structural and spatial constraints at the site.

6.2.2 Answer

The existing infrastructure on the north and south gates would provide suitable conditions for installation of Voith StreamDiver turbines. The dam structure has 18 seven by five-foot regulatory gates on the north canal and the cement columns are about 30 feet wide each. The north gates which feed into the Arizona Canal can be seen below (**Figure 12**).

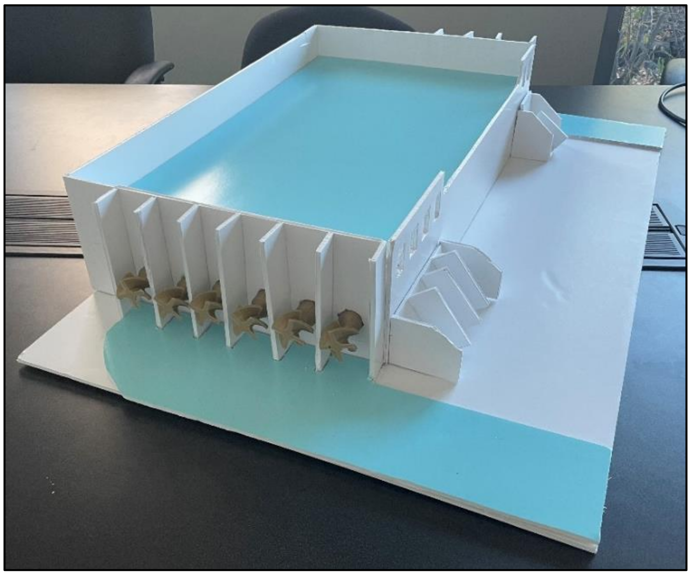


Figure 912: Arizona Canal turbines

6.2.3 Plan for New Design Based on Information

Since the StreamDiver turbines are around 6 feet in diameter, we can utilize more turbines in our proposed design than we originally planned. Based on the sizing, current spacing would allow for up to 18 turbines in the north canal and 9 on the south canal. The final number of turbines selected will be determined by flow data from SRP for this site.

6.3 Initial Virtual Prototype

Our initial virtual prototype involves the utilization of MATLAB code to simulate and analyze the relationship between daily flow data and estimated energy generation. Although this is more of a calculation model than a traditional virtual prototype with VR and AR, this approach aligns closely with our project deliverables, providing valuable insights into energy generation patterns.

6.3.1 Prototype Question

In our pursuit of a comprehensive hydropower solution, we sought to understand the intricate relationship between daily flow data and estimated energy generation. Recognizing the limitations of relying solely on average annual flow data, we delved into the nuances of dam discharge flow rates influenced by seasonal variations, government standards, and weather conditions. The exploration led to the critical question:

How do the trends in daily flow data influence the patterns observed in estimated energy generation?

6.3.2 Answer

When calculating energy generated each day using daily flow rates, we observe correlations throughout the year. Our MATLAB code processes the last five years' daily flow data (**Figure 13**), plotting daily estimated energy and potential energy each month. Notably, there are identifiable dips in potential energy during winter and spikes in the summer, corresponding to increased water usage from Arizona's reservoirs.

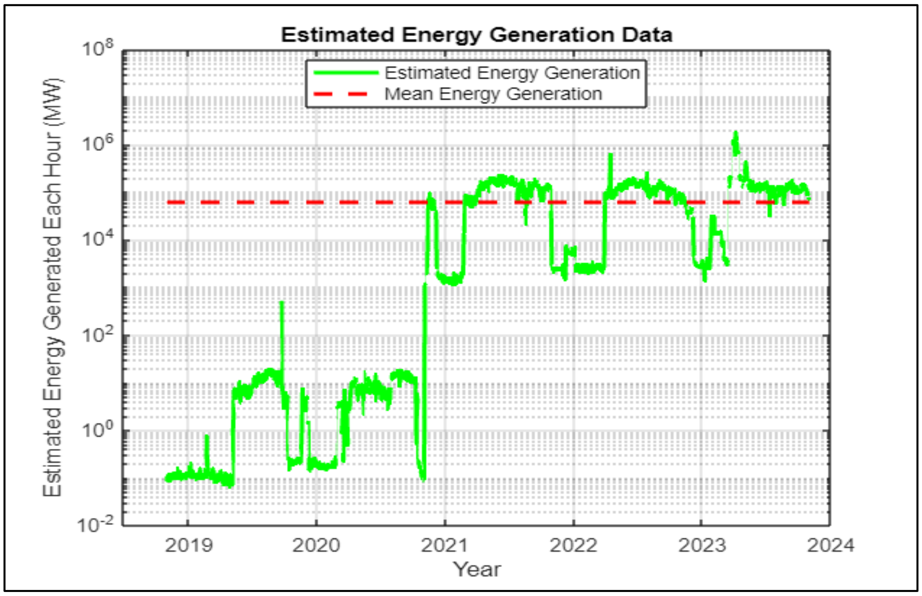


Figure 13: *Estimated Energy Generation from 2018-2023.*

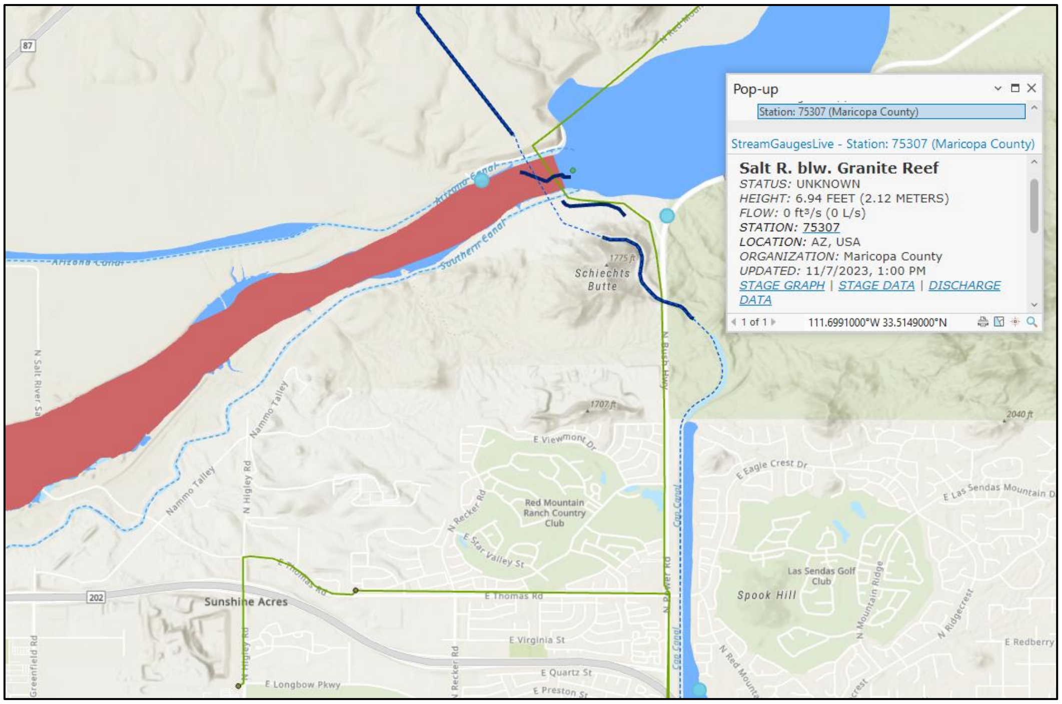
6.3.3 Plan for New Design Based on Information

The insights gained from the virtual prototype provide valuable information for our design and feasibility assessment. We plan to refine our turbine design and enhance our site feasibility assessment, incorporating more accurate LCOE calculations and daily pricing models. This iterative process aims to optimize overall project economics, ensuring a robust and efficient hydropower system.

6.4 Other Engineering Calculations

Since the engineering calculations dating back to Presentation 2, the continued refinement of our modeling efforts has played a pivotal role in substantiating the viability of our chosen dam site. In this section, we delve into the technical aspects of our ArcGIS Pro model, focusing on the additions made to our dataset to enhance our engineering calculations and support the justification for the dam site.

Our main update in ArcGis Pro, shown in **Figure 1014**, provides a detailed topographic view of the site, highlighting crucial flood zones downstream of the dam. The red area represents the floodway, while the blue area designates the 100-year flood zone outlined by Maricopa County. This detailed mapping allows us to assess potential environmental impacts, optimize turbine design based on various water levels and flow rates, and effectively manage flood risks by adapting operational procedures to changing conditions.



Station: 75307 (Maricopa County)

StreamGaugesLive - Station: 75307 (Maricopa County)

Salt R. blw. Granite Reef
STATUS: UNKNOWN
HEIGHT: 6.94 FEET (2.12 METERS)
FLOW: 0 ft³/s (0 L/s)
STATION: 75307
LOCATION: AZ, USA
ORGANIZATION: Maricopa County
UPDATED: 11/7/2023, 1:00 PM
STAGE GRAPH | *STAGE DATA* | *DISCHARGE DATA*

111.6991000°W 33.5149000°N

Figure 14: Detailed topographic view of dam. Note the red and blue flood zones, along with the bright blue dots shown as our live stream gauges.

In conjunction with the flood zone assessment, **Figure 15** captures live stream-discharge data collected from an onsite pressure transducer and maps it onto the ArcGIS model. The pressure transducer, positioned on the right bank of the river, offers real-time information on water levels. As of October 26, 2023, the PT diaphragm is at a gage height of 6.94 feet. This hydrological data is instrumental in understanding the dynamics of water flow during flood events, contributing to the assessment of water availability at the dam site.

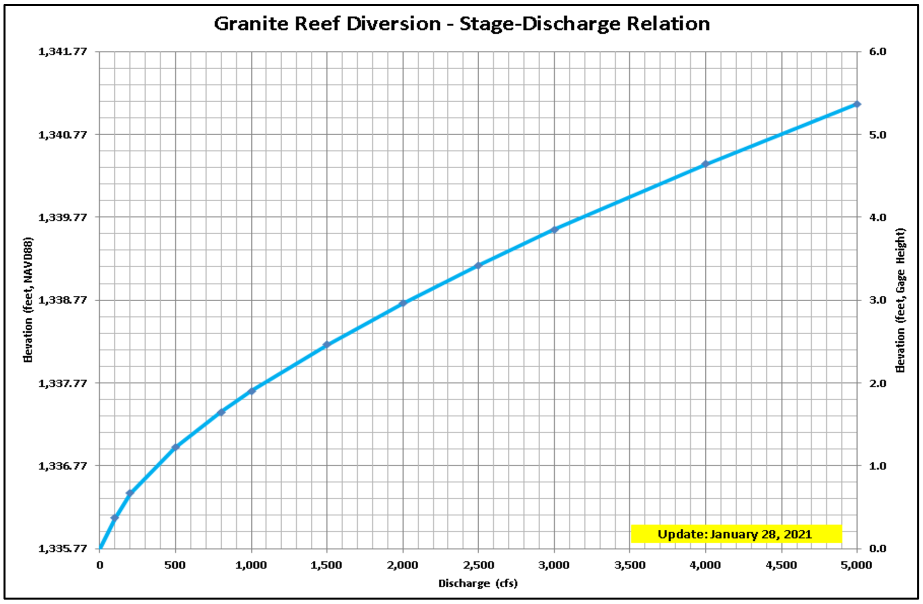


Figure 15: Live data feed from Maricopa County's pressure transducer measuring stream gauge on site.

These ArcGIS models and datasets are integral components of our engineering calculations, providing a comprehensive framework for evaluating environmental impact, optimizing turbine design, managing flood risks, and understanding the hydrology of the site. The incorporation of real-time stream-discharge data ensures that our modeling efforts are not only robust but also reflective of current conditions, further reinforcing the reliability and sustainability of our proposed hydropower project.

Furthermore, as previously discussed, we've used our virtual prototype to calculate daily energy production for a non-powered dam based on five years of historical flow data. As we've stated, this code yields a comprehensive dataset, enabling us to derive valuable insights into the complex dynamics of hydropower generation. In summary, the calculations, and findings from the multitude of graphs, including 60 monthly charts, 5 yearly charts, and an encompassing daily energy overview are outlined in **Appendix C**. The 60 monthly charts illustrated the nuanced variations in estimated energy production for each month over the past five years, as seen in **Figure 16**. By examining these charts, we discerned seasonal trends and fluctuations, providing a detailed understanding of the monthly energy generation patterns. This information is instrumental for designing energy-efficient systems that adapt to the dynamic nature of water flow.

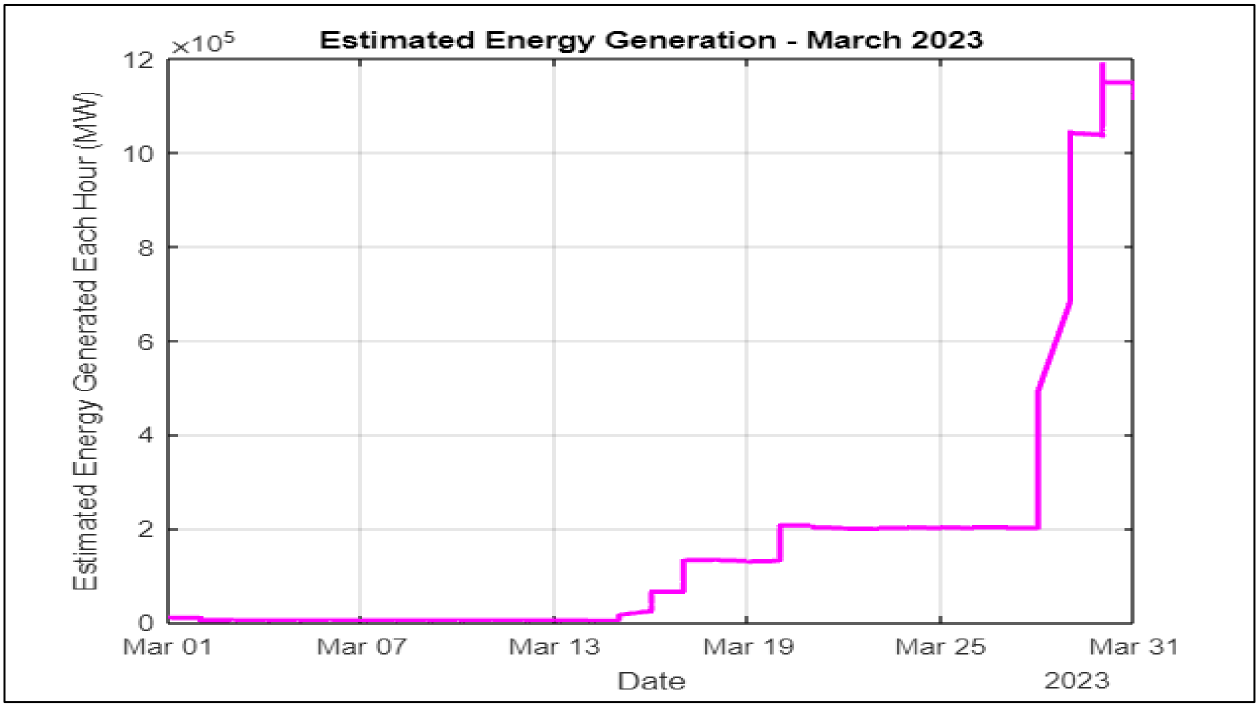


Figure 16: Estimated Energy Generation during March of 2023.

The five yearly charts encapsulate the cumulative yearly trends in estimated energy production. These charts serve as a macroscopic view, highlighting overarching patterns and anomalies. Analysis of the yearly data enhances our ability to optimize long-term energy output and informs strategic decision-making for sustainable hydropower solutions, as shown in **Figure 17**. The chart depicting daily estimated energy generation over the last five years offers a holistic perspective. It synthesizes the intricate interplay of daily flow data and energy production. Insights from this comprehensive overview are crucial for understanding the diurnal variations, guiding operational decisions, and enhancing the overall efficiency of the hydropower system. In essence, the extensive analysis of these engineering calculations not only refines our understanding of hydropower dynamics but also lays the foundation for data-driven design and optimization of non-powered dams. **Appendix C** serves as a repository of the detailed graphs, ensuring transparency and accessibility to the wealth of information derived from our virtual prototype.

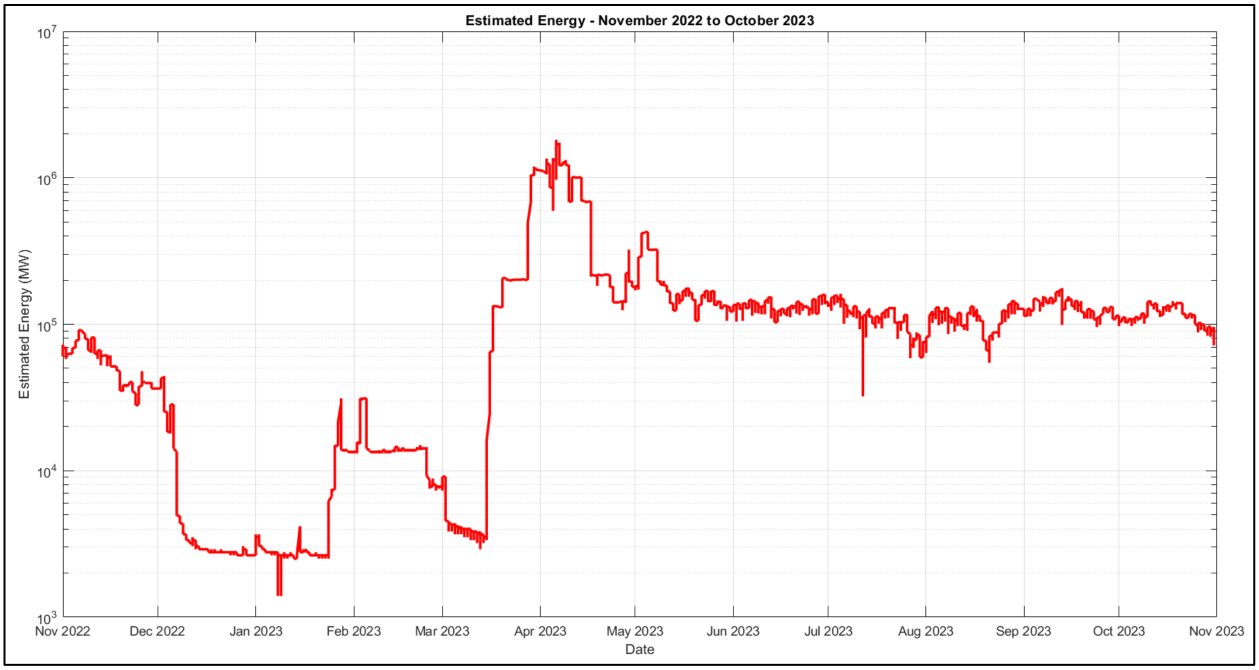


Figure 17: Estimated Energy Generation from 2022-2023.

6.5 Future Testing Potential

Based on the completion of the optional build and test portion of the competition, we have a few potential tests that we will conduct on our scale model. First off, we will be scaling down the flow data from our dam based on the scale of our dam model. Using a hydraulic bench in from the Thermal Fluids Lab, we will be able to test the scaled volumetric flow data with our model. The *Buckingham Pi theorem* will be used to benefit our experimental setup by identifying the dimensionless groups that govern the standard behavior of fluid flow. This allows for simplification when designing a scale model since only the key dimensionless groups that influence the flow are included in the equations.

Once we have scaled the flow down, we will be able to test the design of our proposed hydropower dam, the efficiency of the runner and the electricity generation. Since our model will be a very small scale (likely one inch equals one hundred feet) efficiency and power generation may not be feasible. We would still be able to test for electricity generation by having the generator turn on a small LED light or something similar. We would also be able to test for turbine rotations per minute, and then scale that back up to the actual size to back up our calculations for electricity generation.

7 CONCLUSIONS

In summary, our project is driven by a profound commitment to the 2024 Collegiate Hydropower Competition's objectives. We have meticulously assessed the critical customer and engineering requirements that guide our design, ensuring that our hydropower project aligns with the client's needs and competition standards. This holistic approach has allowed us to grasp the intricate interplay between various technical aspects and the customer's expectations.

As we navigate the mathematical modeling, literature review, benchmarking, and concept selection phases, we have gained valuable insights from existing research, industry practices, and our own rigorous analysis. The functional model serves as a visual blueprint for our project's essential functions, providing clarity on the operational aspects. Granite Reef Diversion was our top choice after thorough assessments utilizing our Decision Matrix. With a structural height of under thirty feet, a strong flow rate of 1966 cubic feet per second (cfs), and the capacity to produce about 4 MW of electricity, Granite Reef Diversion fits into our design space very well and satisfies engineering and customer standards. It is the perfect location for our project because of its proximity to infrastructure and its advantageous environmental features. The culmination of this meticulous work has brought us closer to realizing a transformative hydropower project, with CAD drawings serving as a testament to our tangible progress.

At this juncture, our project stands at a pivotal stage, advancing within the Siting Challenge and Design Challenge of the competition. This initiative aims to shape a sustainable energy future in addition to maximizing the potential of hydropower. We are persistent in our commitment to bridging the gap between engineering restrictions and design needs. With this project, we hope to significantly impact the field of small-scale hydropower generation and meet the growing demand for clean, renewable energy sources. The journey is far from over, and we are excited to see the project continue to evolve and make strides toward a sustainable energy future.

8 REFERENCES

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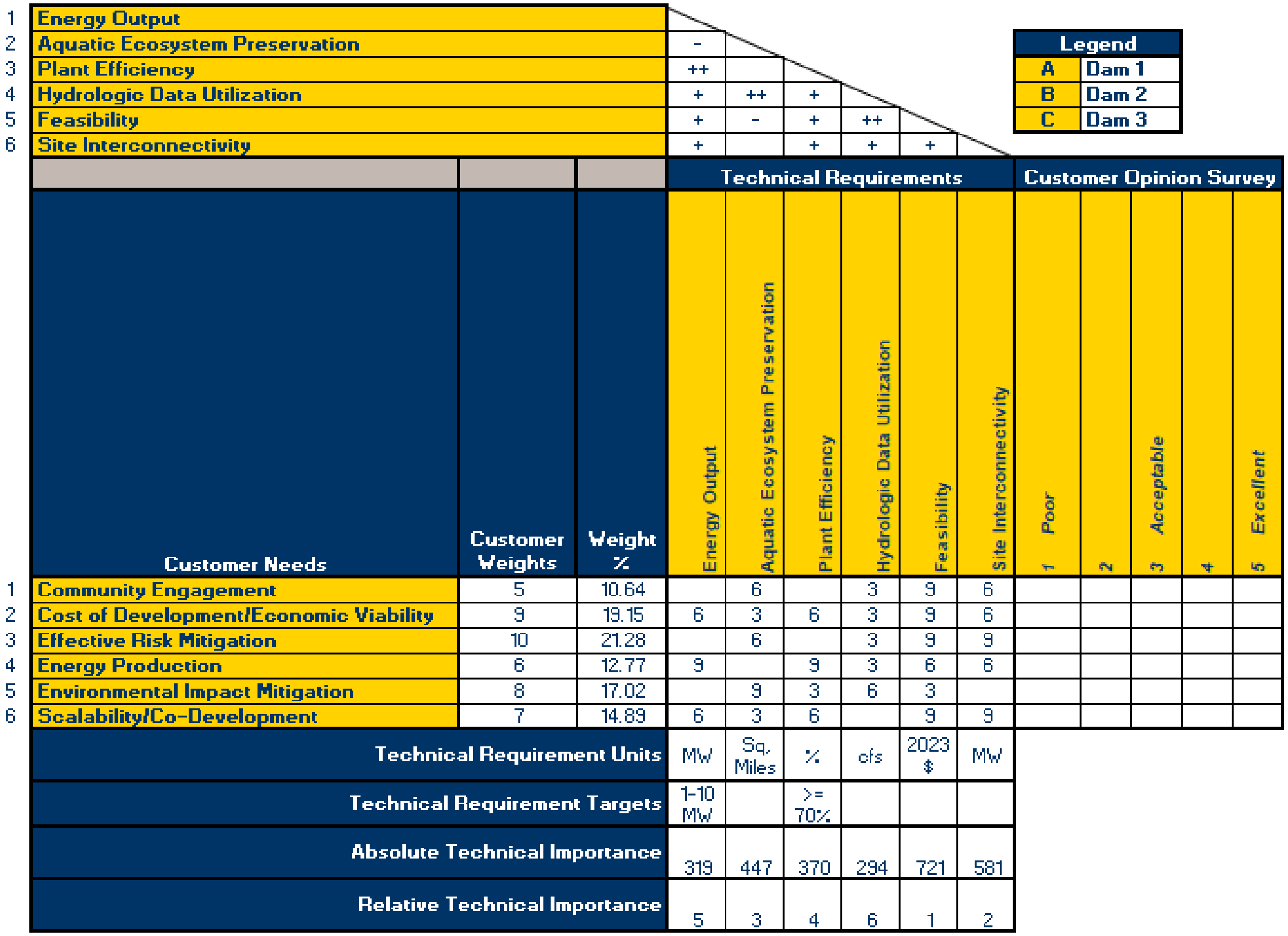
9 APPENDICES

9.1 *Appendix A.1 – House of Quality (QFD)*



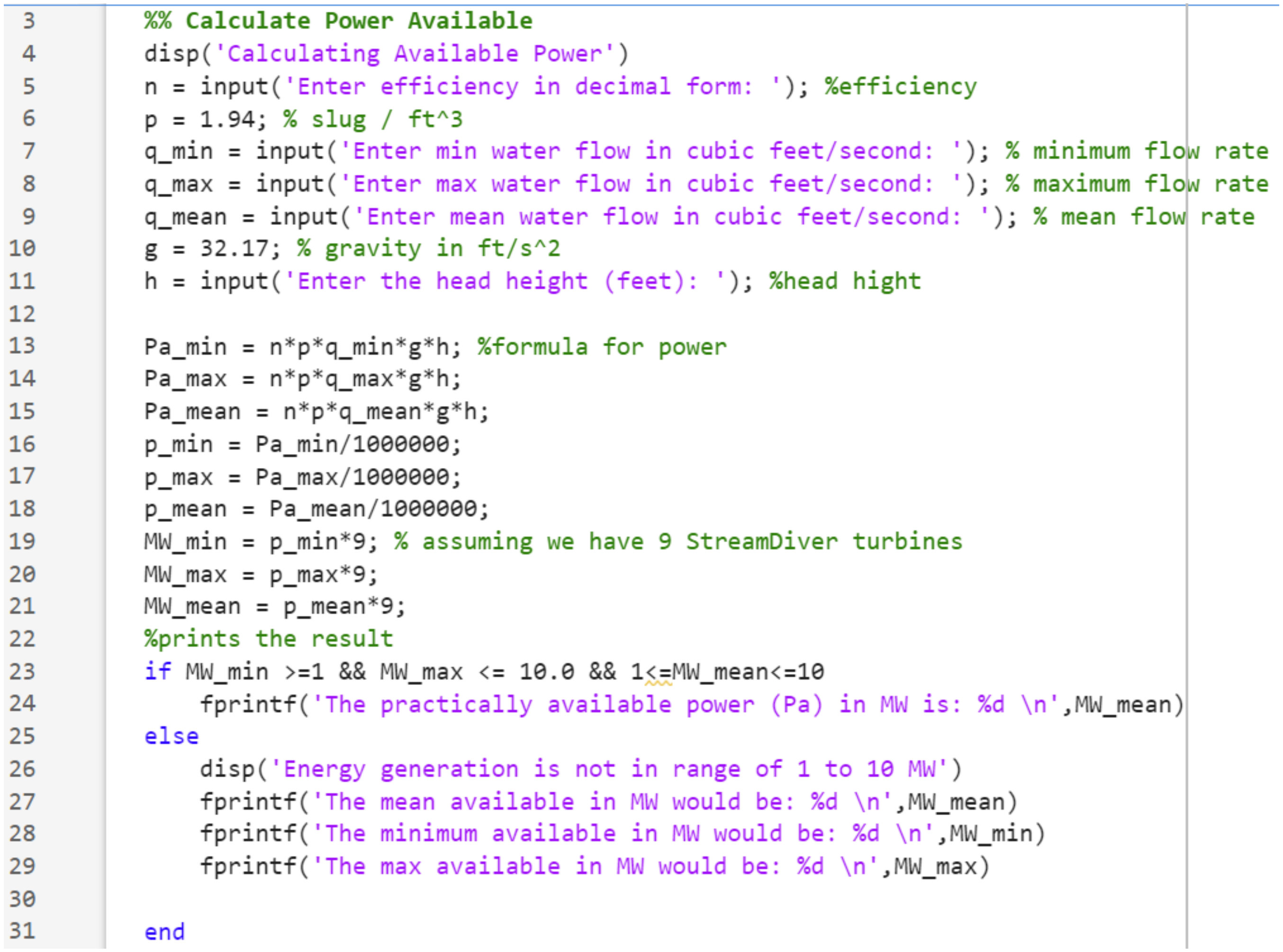
		Energy Output	Aquatic Ecosystem Preservation	Plant Efficiency	Hydrologic Data Utilization	Feasibility
1	Energy Output					
2	Aquatic Ecosystem Preservation	-				
3	Plant Efficiency	++				
4	Hydrologic Data Utilization	+	++	+		
5	Feasibility	+	-	+	++	
6	Site Interconnectivity	+		+	+	+

Legend	
A	Dam 1
B	Dam 2
C	Dam 3

	Customer Needs	Customer Weights	Weight %	Technical Requirements Energy Output	Aquatic Ecosystem Preservation	Plant Efficiency	Hydrologic Data Utilization	Feasibility	Site Interconnectivity	Customer Opinion Survey 1 Poor	2	3 Acceptable	4	5 Excellent
1	Community Engagement	5	10.64		6		3	9	6					
2	Cost of Development/Economic Viability	9	19.15	6	3	6	3	9	6					
3	Effective Risk Mitigation	10	21.28		6		3	9	9					
4	Energy Production	6	12.77	9		9	3	6	6					
5	Environmental Impact Mitigation	8	17.02		9	3	6	3						
6	Scalability/Co-Development	7	14.89	6	3	6		9	9					
	Technical Requirement Units			MW	Sq. Miles	%	cfs	2023 $	MW					
	Technical Requirement Targets			1-10 MW		>= 70%								
	Absolute Technical Importance			319	447	370	294	721	581					
	Relative Technical Importance			5	3	4	6	1	2					

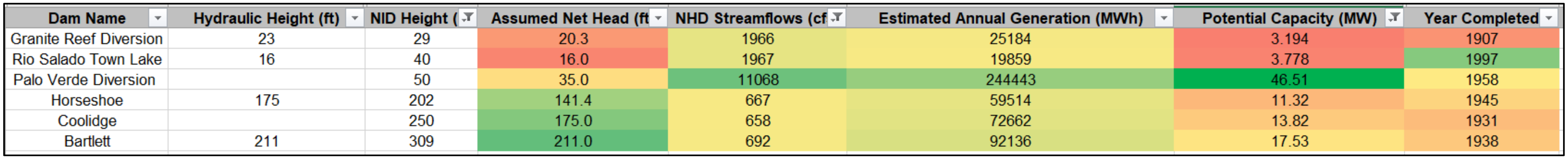
Figure A.1.1: HCC House of Quality analysis.

9.2 Appendix A.2: Referenced Figures and Images



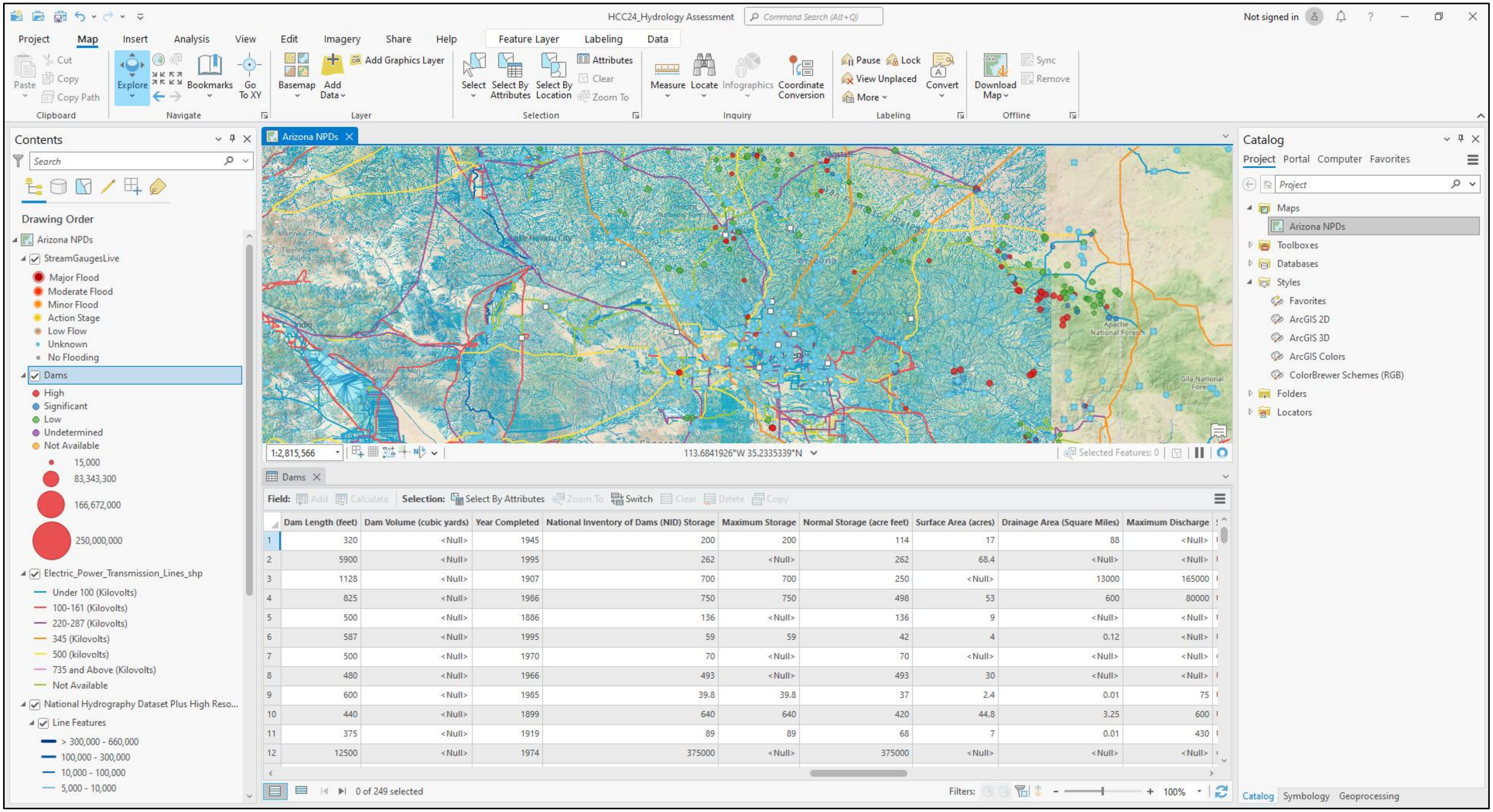
```
%% Calculate Power Available
disp('Calculating Available Power')
n = input('Enter efficiency in decimal form: '); %efficiency
p = 1.94; % slug / ft^3
q_min = input('Enter min water flow in cubic feet/second: '); % minimum flow rate
q_max = input('Enter max water flow in cubic feet/second: '); % maximum flow rate
q_mean = input('Enter mean water flow in cubic feet/second: '); % mean flow rate
g = 32.17; % gravity in ft/s^2
h = input('Enter the head height (feet): '); %head hight

Pa_min = n*p*q_min*g*h; %formula for power
Pa_max = n*p*q_max*g*h;
Pa_mean = n*p*q_mean*g*h;
p_min = Pa_min/1000000;
p_max = Pa_max/1000000;
p_mean = Pa_mean/1000000;
MW_min = p_min*9; % assuming we have 9 StreamDiver turbines
MW_max = p_max*9;
MW_mean = p_mean*9;
%prints the result
if MW_min >=1 && MW_max <= 10.0 && 1<=MW_mean<=10
    fprintf('The practically available power (Pa) in MW is: %d \n',MW_mean)
else
    disp('Energy generation is not in range of 1 to 10 MW')
    fprintf('The mean available in MW would be: %d \n',MW_mean)
    fprintf('The minimum available in MW would be: %d \n',MW_min)
    fprintf('The max available in MW would be: %d \n',MW_max)

end
```

Figure A.2.1: Available Power MATLAB code



Dam Name	Hydraulic Height (ft)	NID Height (	Assumed Net Head (ft	NHD Streamflows (cf	Estimated Annual Generation (MWh)	Potential Capacity (MW)	Year Completed
Granite Reef Diversion	23	29	20.3	1966	25184	3.194	1907
Rio Salado Town Lake	16	40	16.0	1967	19859	3.778	1997
Palo Verde Diversion		50	35.0	11068	244443	46.51	1958
Horseshoe	175	202	141.4	667	59514	11.32	1945
Coolidge		250	175.0	658	72662	13.82	1931
Bartlett	211	309	211.0	692	92136	17.53	1938

Figure A.2.2: Initial Assessment of NPD Energy Potential in Arizona (see section 3.2.2.1)



	Dam Length (feet)	Dam Volume (cubic yards)	Year Completed	National Inventory of Dams (NID) Storage	Maximum Storage	Normal Storage (acre feet)	Surface Area (acres)	Drainage Area (Square Miles)	Maximum Discharge
1	320	<Null>	1945	200	200	114	17	88	<Null>
2	5900	<Null>	1995	262	<Null>	262	68.4	<Null>	<Null>
3	1128	<Null>	1907	700	700	250	<Null>	13000	165000
4	825	<Null>	1986	750	750	498	53	600	80000
5	500	<Null>	1886	136	<Null>	136	9	<Null>	<Null>
6	587	<Null>	1995	59	59	42	4	0.12	<Null>
7	500	<Null>	1970	70	<Null>	70	<Null>	<Null>	<Null>
8	480	<Null>	1966	493	<Null>	493	30	<Null>	<Null>
9	600	<Null>	1985	39.8	39.8	37	2.4	0.01	75
10	440	<Null>	1899	640	640	420	44.8	3.25	600
11	375	<Null>	1919	89	89	68	7	0.01	430
12	12500	<Null>	1974	375000	<Null>	375000	<Null>	<Null>	<Null>

Figure A.2.3: Overview of comprehensive map in ArcGIS; contains attributes table with over 60 columns of raw data from NID database, all streamlines relative to each dam (blue lines), all transmission lines, stream gauges, and more to accurately assess our site selection process.

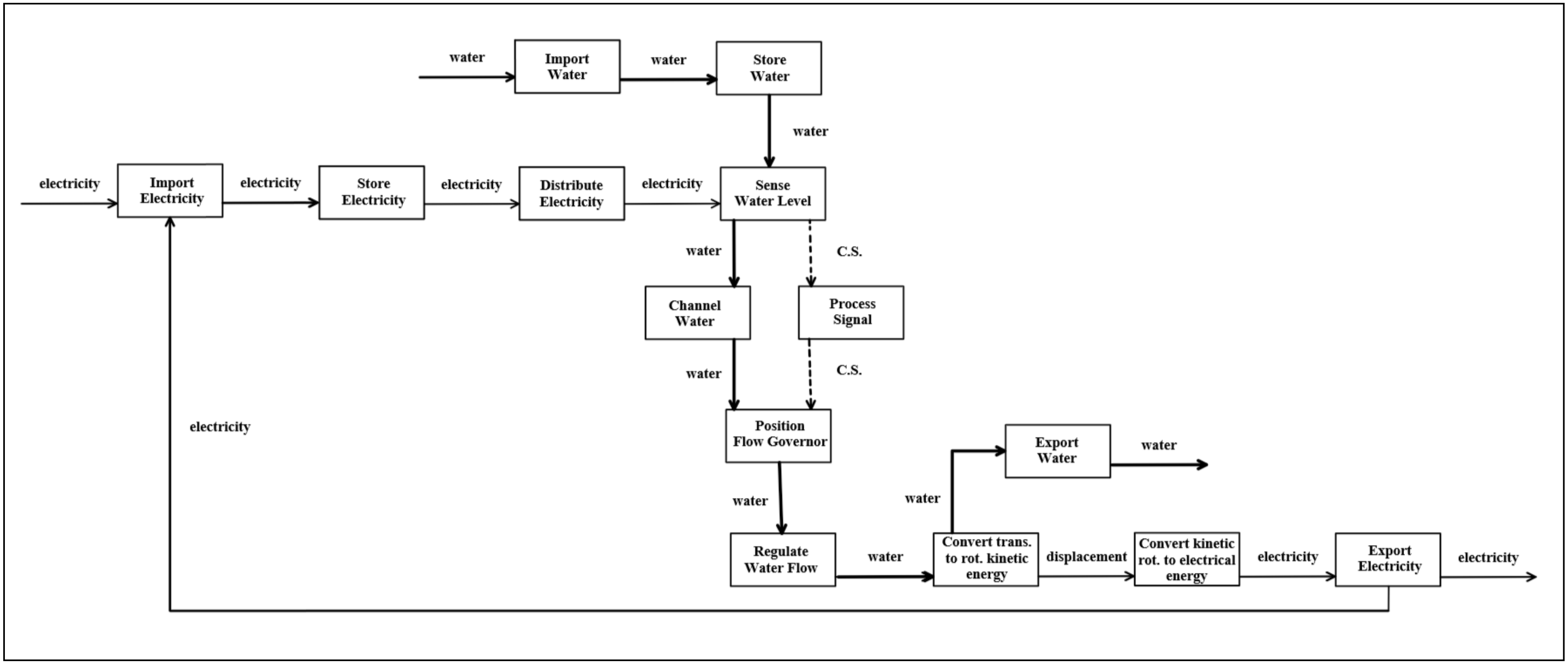


Figure A.2.4: Functional Model of a simple, single turbine, hydropower plant.

Table A.2.1: Morphological Matrix

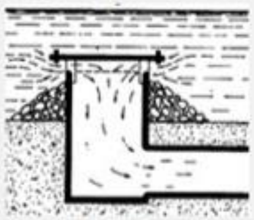
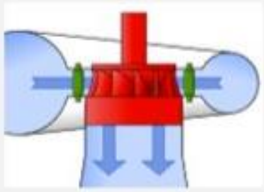
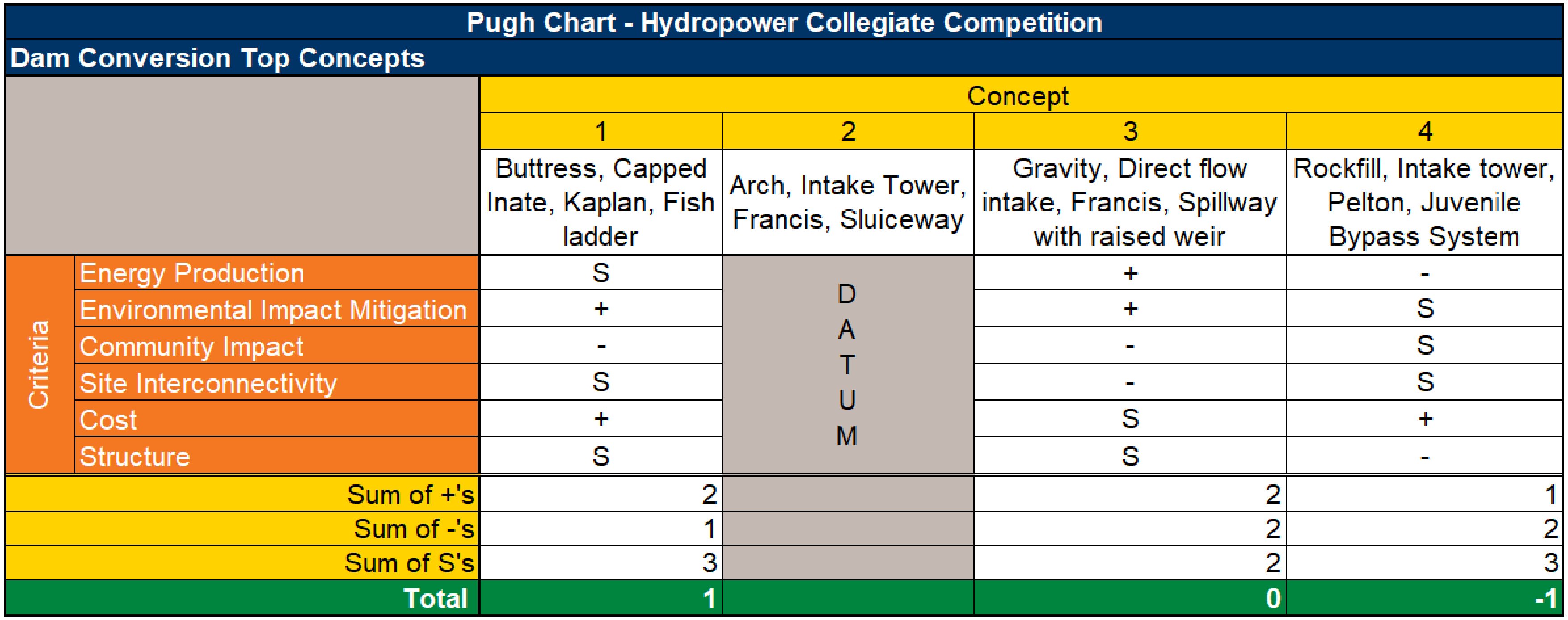
Concept	Option 1	Option 2	Option 3	Option 4
Dam Structure	Arch	Buttress	Rockfill	Gravity
The primary function is to resist the pressure of the water behind it				
Water intake	Capped intake	Intake tower	Direct flow intake structure	
Controlled and efficient utilization of the water coming out of the reservior				
Turbine	Francis	Pelton	Kaplan	
Converts the kinetic energy from the flowing water into mechanical energy for electricity generation				
Fish Passage	Juvenile Bypass System	Fish Ladder	Sluiceways	Spillway with raised Weir
Allows fish to pass through the dam without harming them				

Table A.2.2: Pugh Chart



Pugh Chart - Hydropower Collegiate Competition					
Dam Conversion Top Concepts					
		Concept			
		1	2	3	4
		Buttress, Capped Inate, Kaplan, Fish ladder	Arch, Intake Tower, Francis, Sluiceway	Gravity, Direct flow intake, Francis, Spillway with raised weir	Rockfill, Intake tower, Pelton, Juvenile Bypass System
Criteria	Energy Production	S	DATUM	+	-
	Environmental Impact Mitigation	+		+	S
	Community Impact	-		-	S
	Site Interconnectivity	S		-	S
	Cost	+		S	+
	Structure	S		S	-
Sum of +'s		2		2	1
Sum of -'s		1		2	2
Sum of S's		3		2	3
Total		**1**		**0**	**-1**

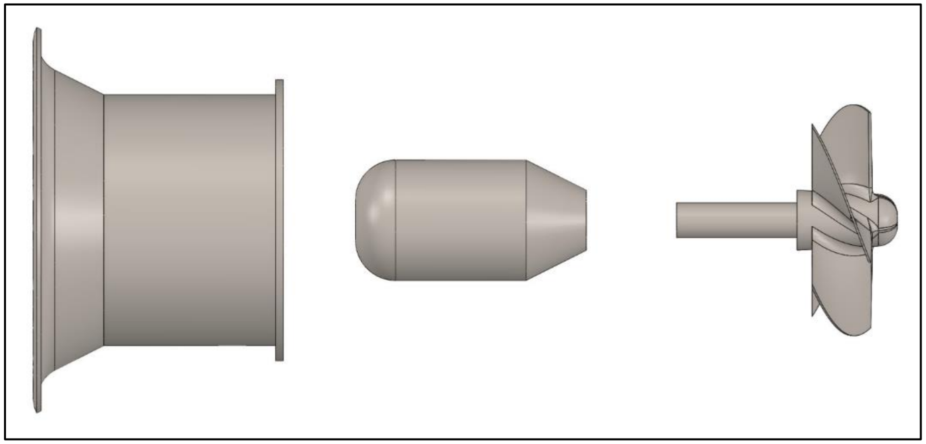


Figure A.2.5: Exploded view of CAD model.

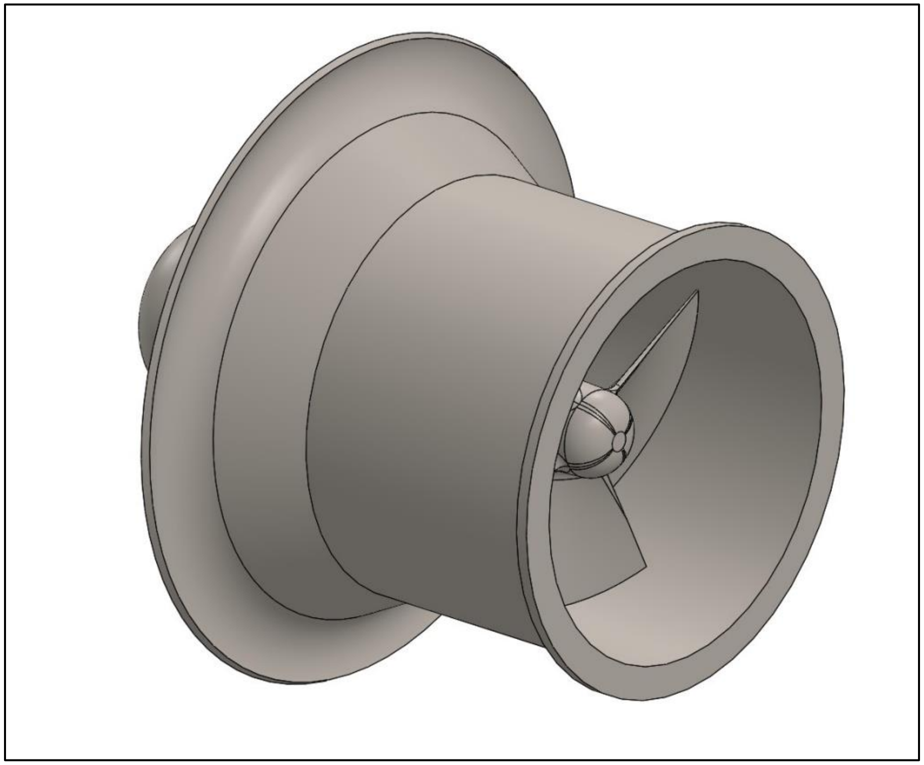
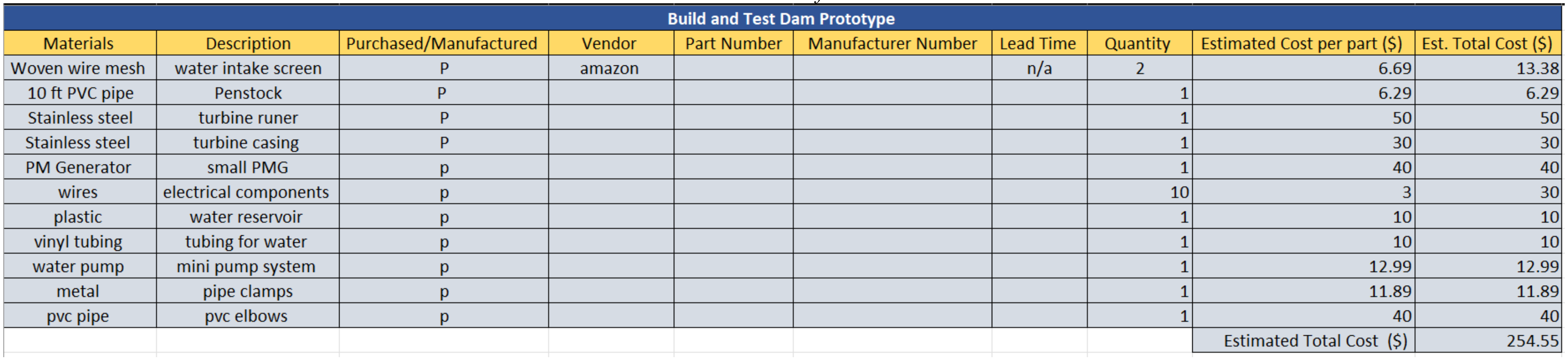


Figure A.2.6: Water flow outlet CAD model

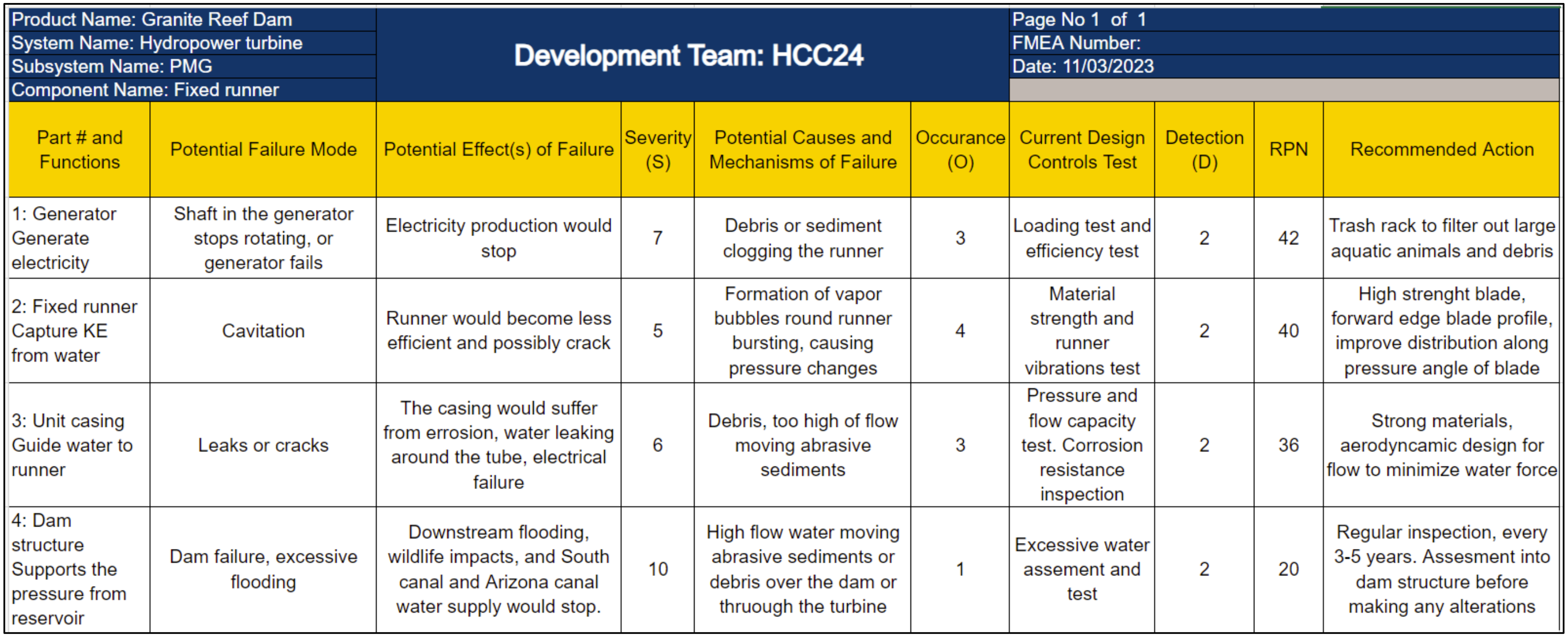
Table A.2.3: Bill of Materials



Build and Test Dam Prototype

Materials	Description	Purchased/Manufactured	Vendor	Part Number	Manufacturer Number	Lead Time	Quantity	Estimated Cost per part ($)	Est. Total Cost ($)
Woven wire mesh	water intake screen	P	amazon			n/a	2	6.69	13.38
10 ft PVC pipe	Penstock	P					1	6.29	6.29
Stainless steel	turbine runer	P					1	50	50
Stainless steel	turbine casing	P					1	30	30
PM Generator	small PMG	p					1	40	40
wires	electrical components	p					10	3	30
plastic	water reservoir	p					1	10	10
vinyl tubing	tubing for water	p					1	10	10
water pump	mini pump system	p					1	12.99	12.99
metal	pipe clamps	p					1	11.89	11.89
pvc pipe	pvc elbows	p					1	40	40
								Estimated Total Cost ($)	254.55

Table A.2.4: FEMA worksheet



Product Name: Granite Reef Dam
System Name: Hydropower turbine
Subsystem Name: PMG
Component Name: Fixed runner

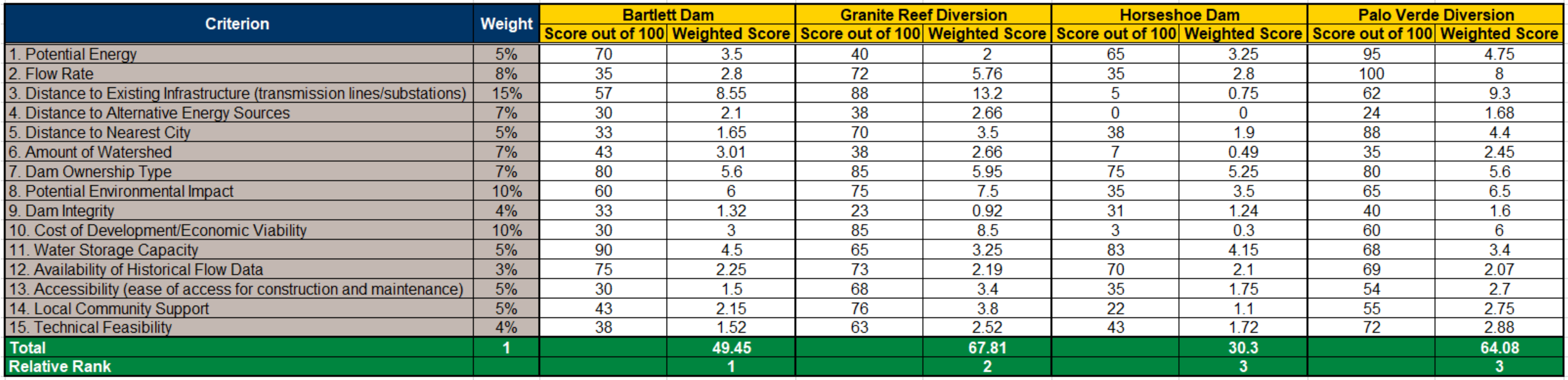
Development Team: HCC24

Page No 1 of 1
FMEA Number:
Date: 11/03/2023

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
1: Generator Generate electricity	Shaft in the generator stops rotating, or generator fails	Electricity production would stop	7	Debris or sediment clogging the runner	3	Loading test and efficiency test	2	42	Trash rack to filter out large aquatic animals and debris
2: Fixed runner Capture KE from water	Cavitation	Runner would become less efficient and possibly crack	5	Formation of vapor bubbles round runner bursting, causing pressure changes	4	Material strength and runner vibrations test	2	40	High strenght blade, forward edge blade profile, improve distribution along pressure angle of blade
3: Unit casing Guide water to runner	Leaks or cracks	The casing would suffer from errosion, water leaking around the tube, electrical failure	6	Debris, too high of flow moving abrasive sediments	3	Pressure and flow capacity test. Corrosion resistance inspection	2	36	Strong materials, aerodyncamic design for flow to minimize water force
4: Dam structure Supports the pressure from reservoir	Dam failure, excessive flooding	Downstream flooding, wildlife impacts, and South canal and Arizona canal water supply would stop.	10	High flow water moving abrasive sediments or debris over the dam or thruough the turbine	1	Excessive water assement and test	2	20	Regular inspection, every 3-5 years. Assesment into dam structure before making any alterations

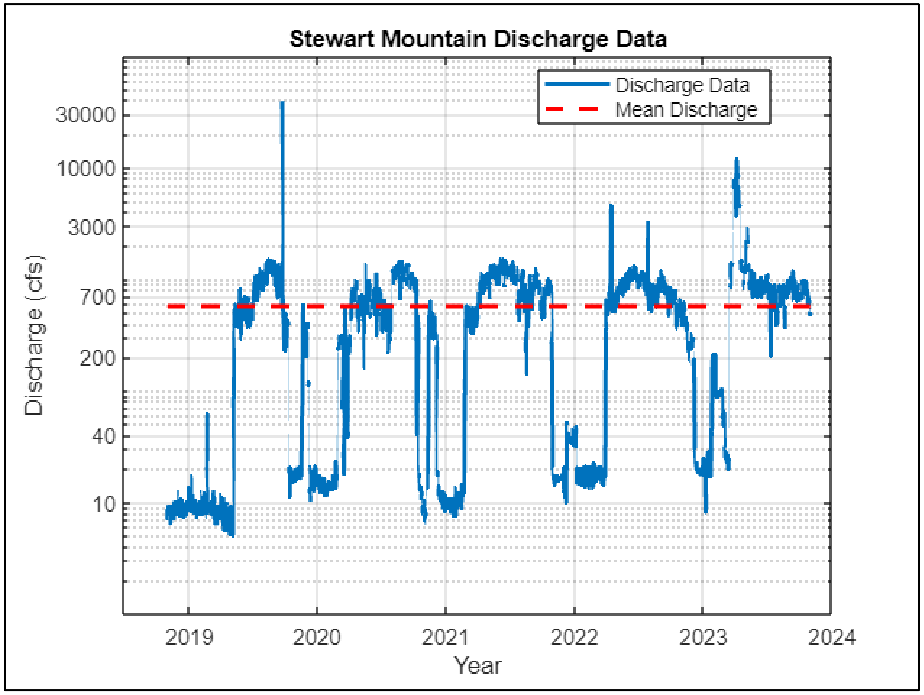
9.3 Appendix B: NPD Selection Decision Matrix

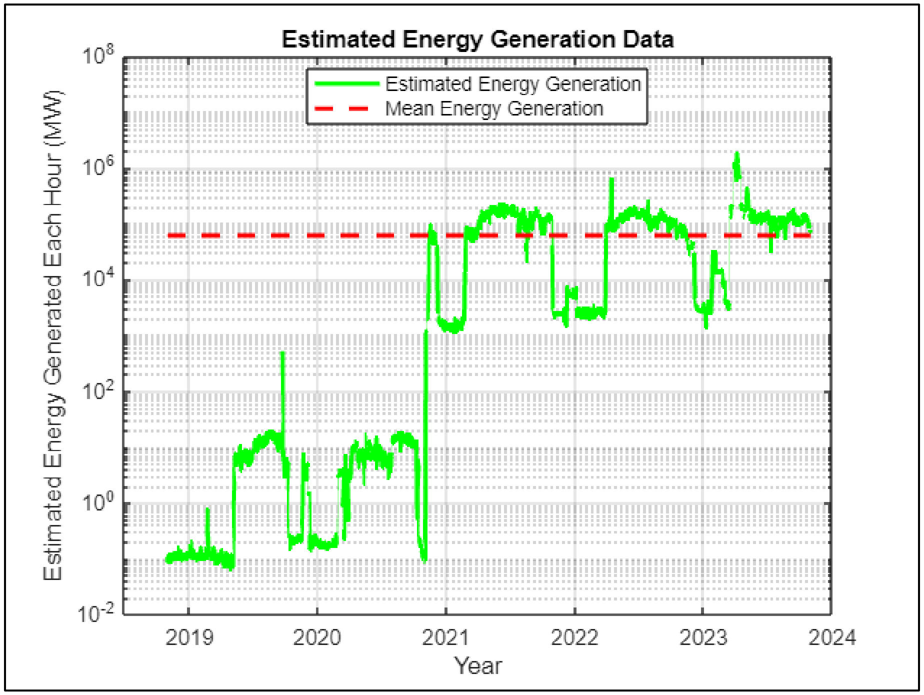
Table B.1: Decision Matrix with weighted selection criteria (outlined in Section 4.3) and scores for top 4 dams (excluded Morelos Dam due to its location in Mexico and struggle for attaining historical data).

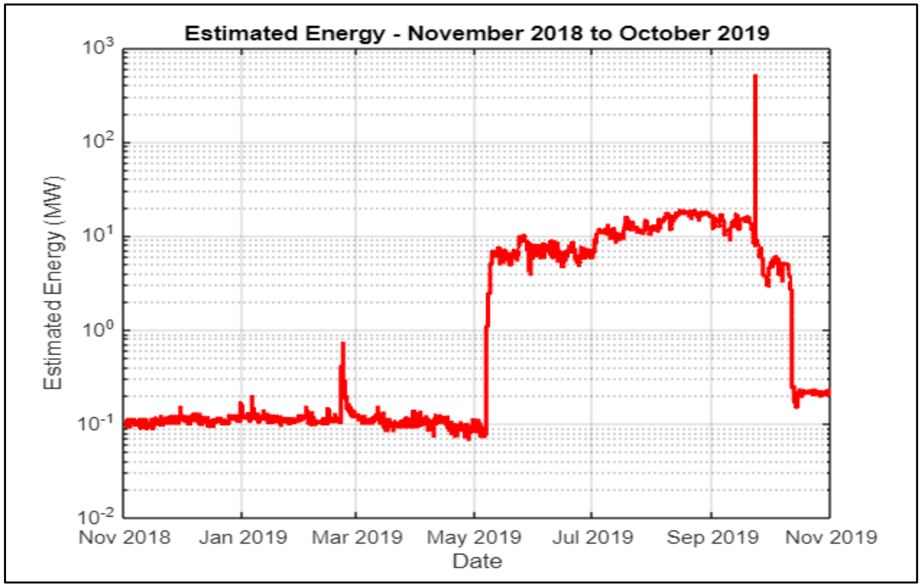


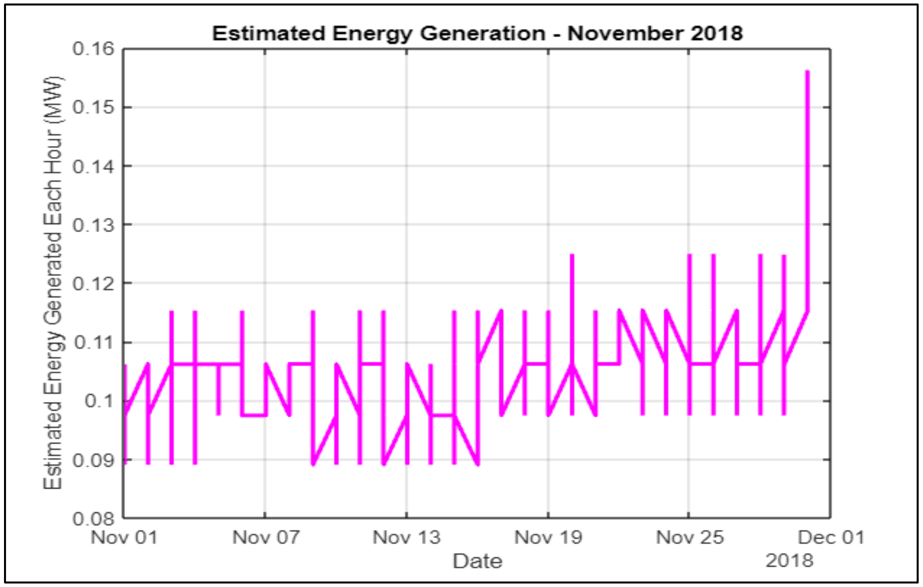
Criterion	Weight	Bartlett Dam		Granite Reef Diversion		Horseshoe Dam		Palo Verde Diversion	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	5%	70	3.5	40	2	65	3.25	95	4.75
2. Flow Rate	8%	35	2.8	72	5.76	35	2.8	100	8
3. Distance to Existing Infrastructure (transmission lines/substations)	15%	57	8.55	88	13.2	5	0.75	62	9.3
4. Distance to Alternative Energy Sources	7%	30	2.1	38	2.66	0	0	24	1.68
5. Distance to Nearest City	5%	33	1.65	70	3.5	38	1.9	88	4.4
6. Amount of Watershed	7%	43	3.01	38	2.66	7	0.49	35	2.45
7. Dam Ownership Type	7%	80	5.6	85	5.95	75	5.25	80	5.6
8. Potential Environmental Impact	10%	60	6	75	7.5	35	3.5	65	6.5
9. Dam Integrity	4%	33	1.32	23	0.92	31	1.24	40	1.6
10. Cost of Development/Economic Viability	10%	30	3	85	8.5	3	0.3	60	6
11. Water Storage Capacity	5%	90	4.5	65	3.25	83	4.15	68	3.4
12. Availability of Historical Flow Data	3%	75	2.25	73	2.19	70	2.1	69	2.07
13. Accessibility (ease of access for construction and maintenance)	5%	30	1.5	68	3.4	35	1.75	54	2.7
14. Local Community Support	5%	43	2.15	76	3.8	22	1.1	55	2.75
15. Technical Feasibility	4%	38	1.52	63	2.52	43	1.72	72	2.88
Total	**1**		**49.45**		**67.81**		**30.3**		**64.08**
Relative Rank			**1**		**2**		**3**		**3**

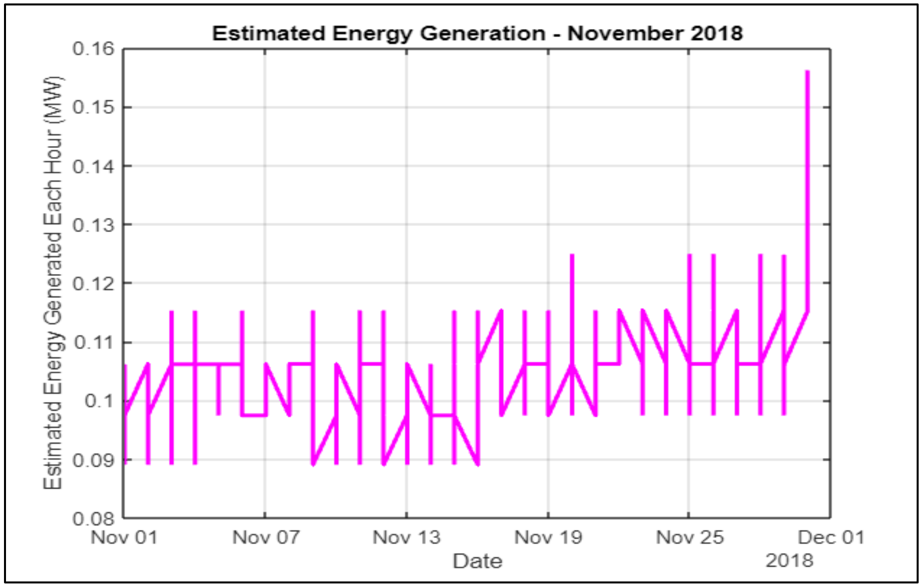
9.4 Appendix C: Virtual Prototype Resulting Graphs

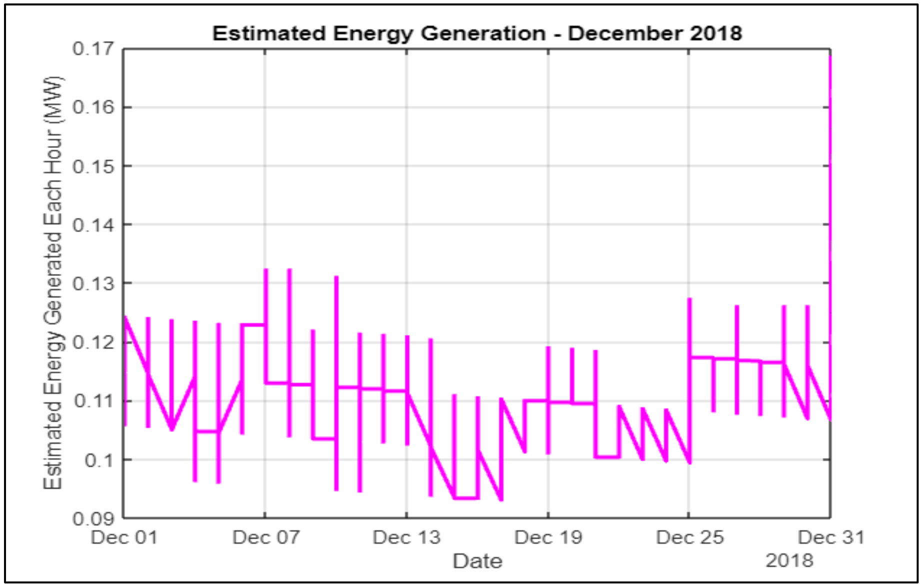


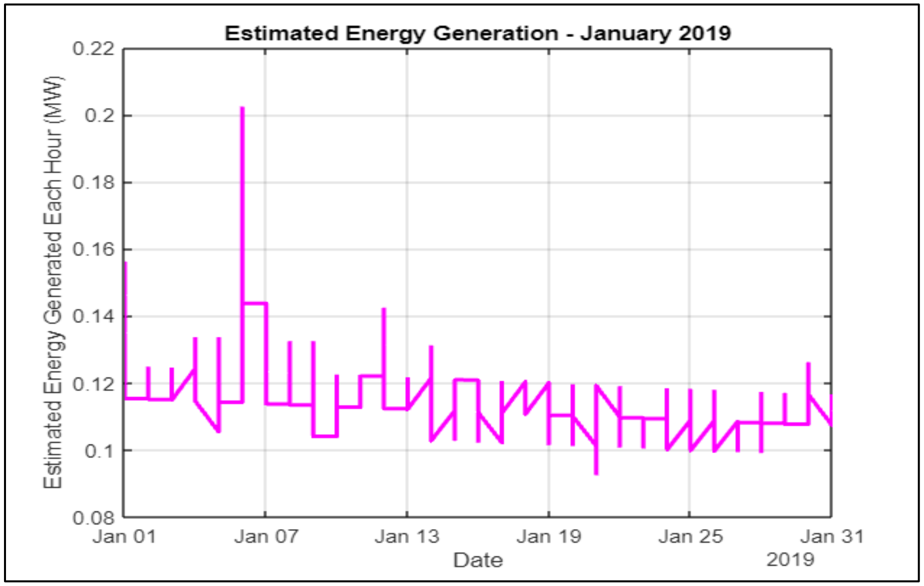


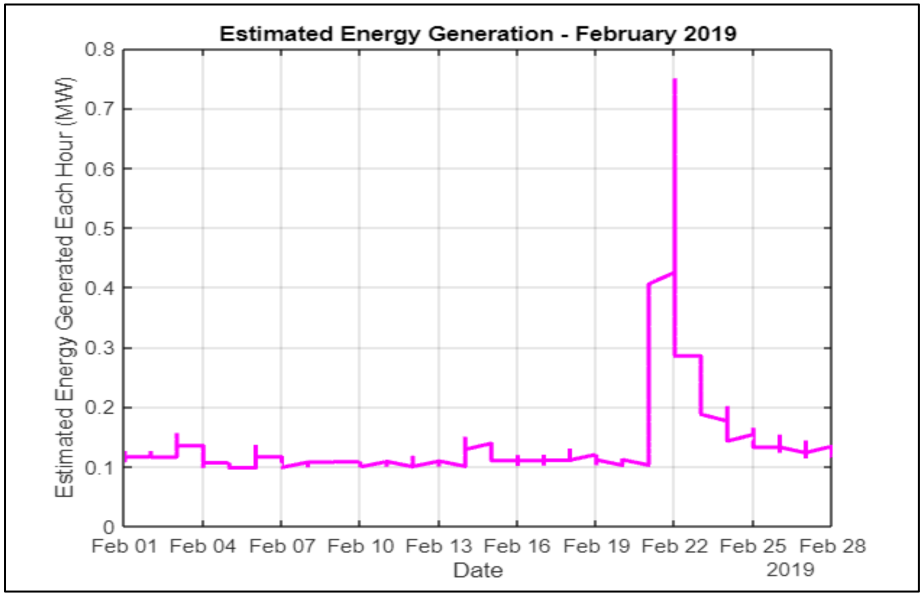

Estimated Energy - November 2018 to October 2019
Estimated Energy (MW)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
Nov 2018
Jan 2019
Mar 2019
May 2019
Jul 2019
Sep 2019
Nov 2019
Date

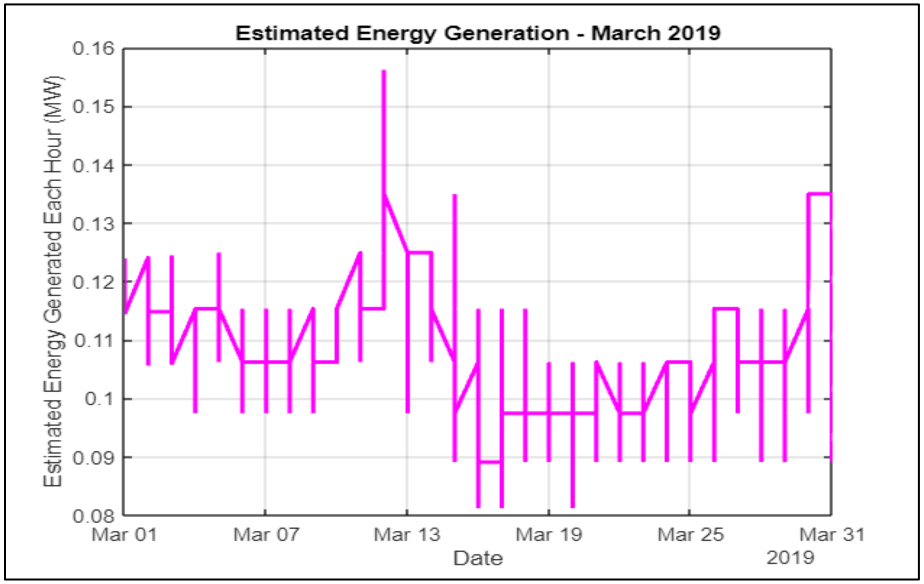

Estimated Energy Generation - November 2018
Estimated Energy Generated Each Hour (MW)
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
Nov 01
Nov 07
Nov 13
Nov 19
Nov 25
Dec 01
2018
Date

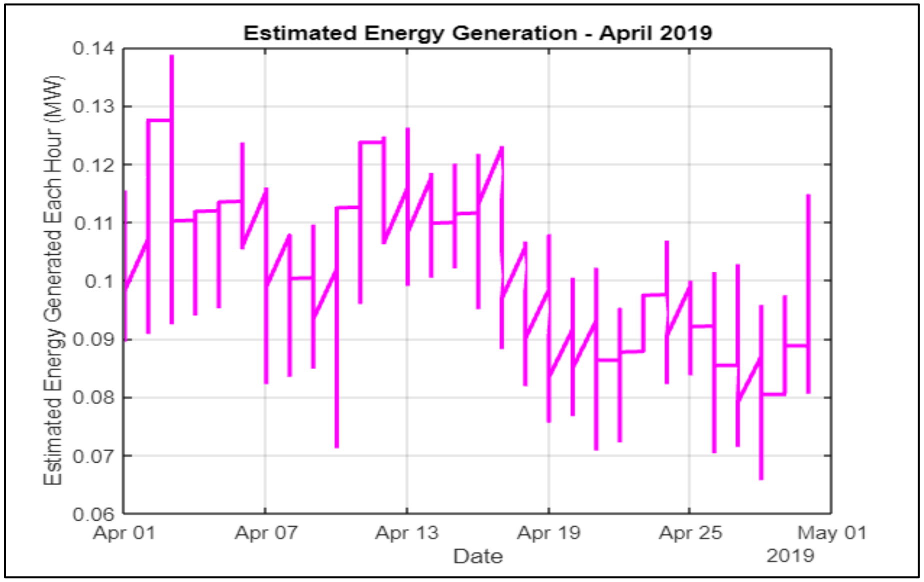

Estimated Energy Generation - November 2018
Estimated Energy Generated Each Hour (MW)
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
Nov 01
Nov 07
Nov 13
Nov 19
Nov 25
Dec 01
2018
Date

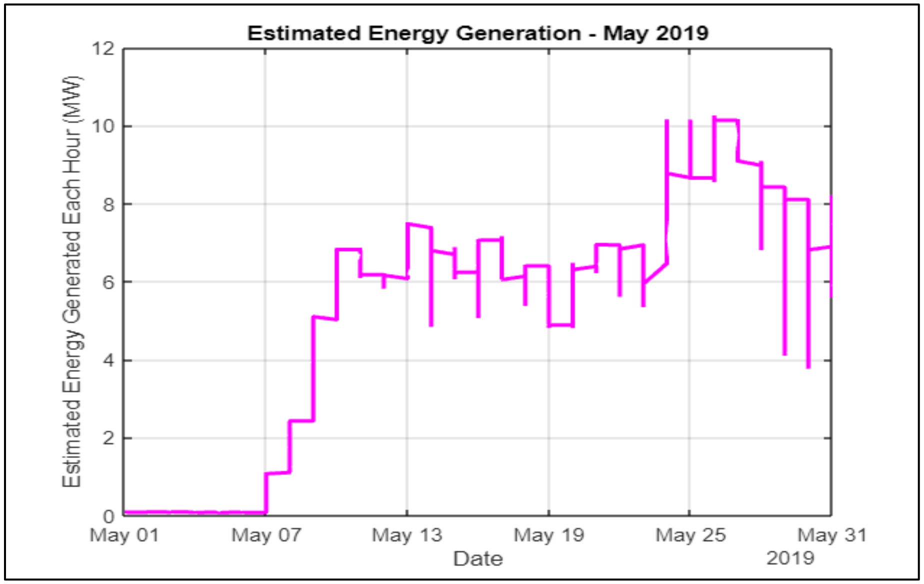

Estimated Energy Generation - December 2018
Estimated Energy Generated Each Hour (MW)
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
Dec 01
Dec 07
Dec 13
Dec 19
Dec 25
Dec 31
2018
Date

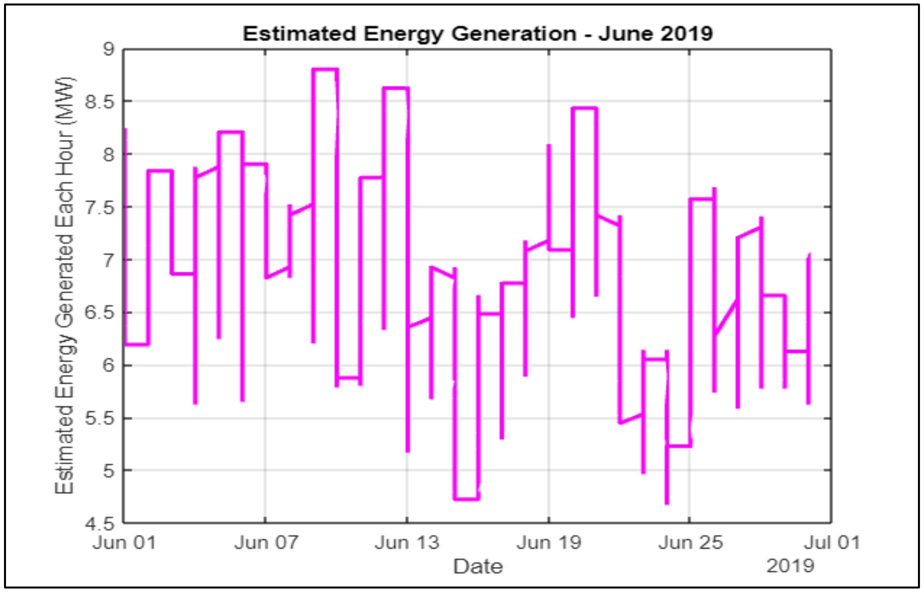

Estimated Energy Generation - January 2019
Estimated Energy Generated Each Hour (MW)
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
Jan 01
Jan 07
Jan 13
Jan 19
Jan 25
Jan 31
Date
2019

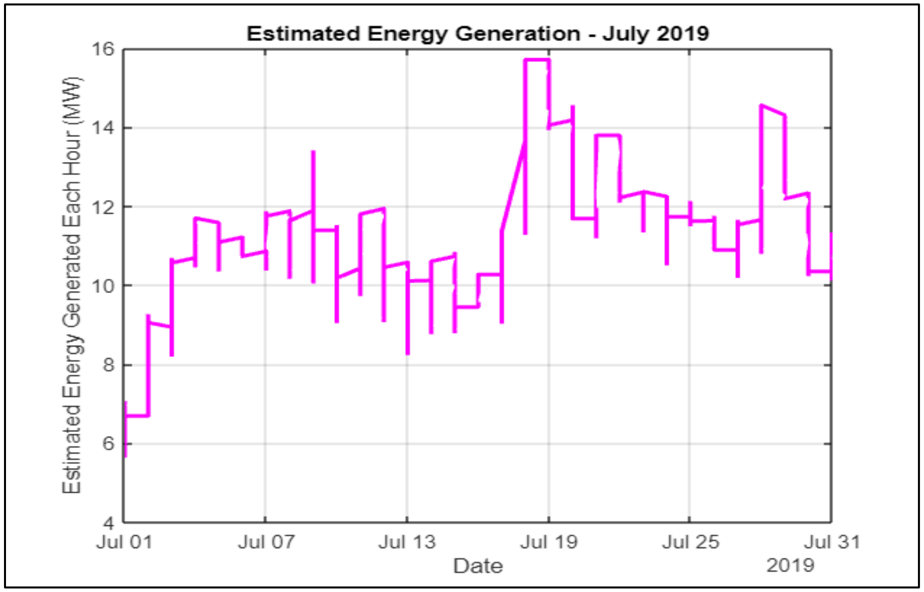

Estimated Energy Generation - February 2019
Estimated Energy Generated Each Hour (MW)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Feb 01
Feb 04
Feb 07
Feb 10
Feb 13
Feb 16
Feb 19
Feb 22
Feb 25
Feb 28
Date
2019

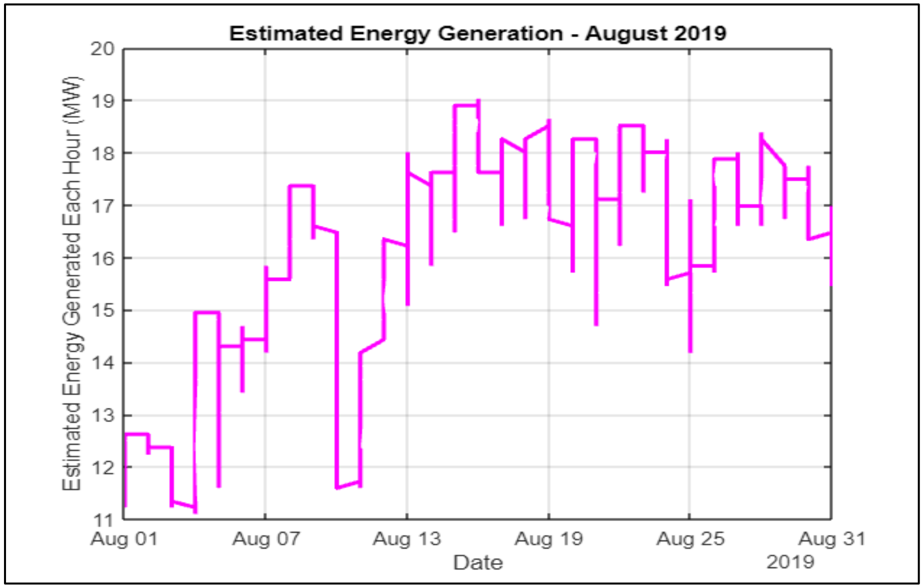

Estimated Energy Generation - March 2019
Estimated Energy Generated Each Hour (MW)
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
Mar 01
Mar 07
Mar 13
Mar 19
Mar 25
Mar 31
Date
2019

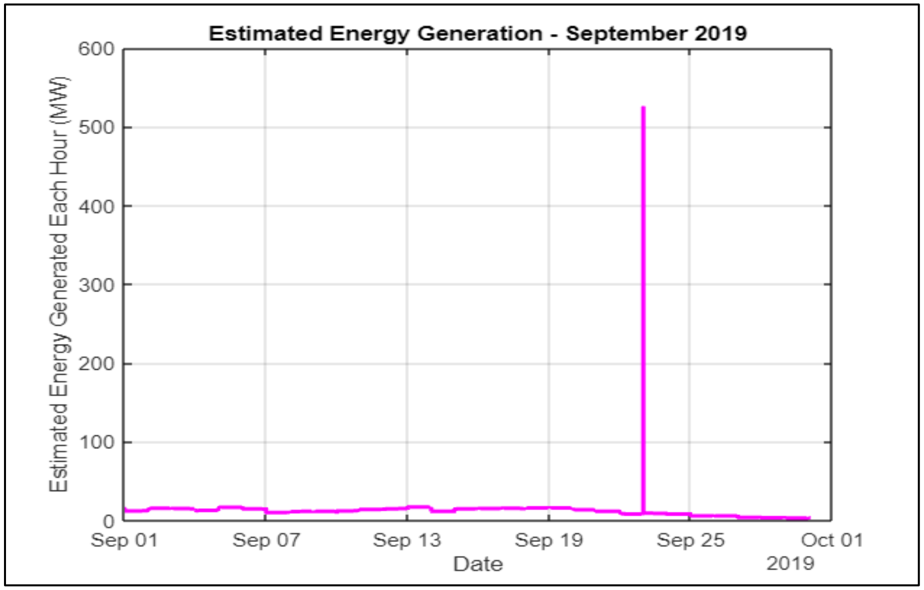

Estimated Energy Generation - April 2019
Estimated Energy Generated Each Hour (MW)
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
Apr 01
Apr 07
Apr 13
Apr 19
Apr 25
May 01
Date
2019

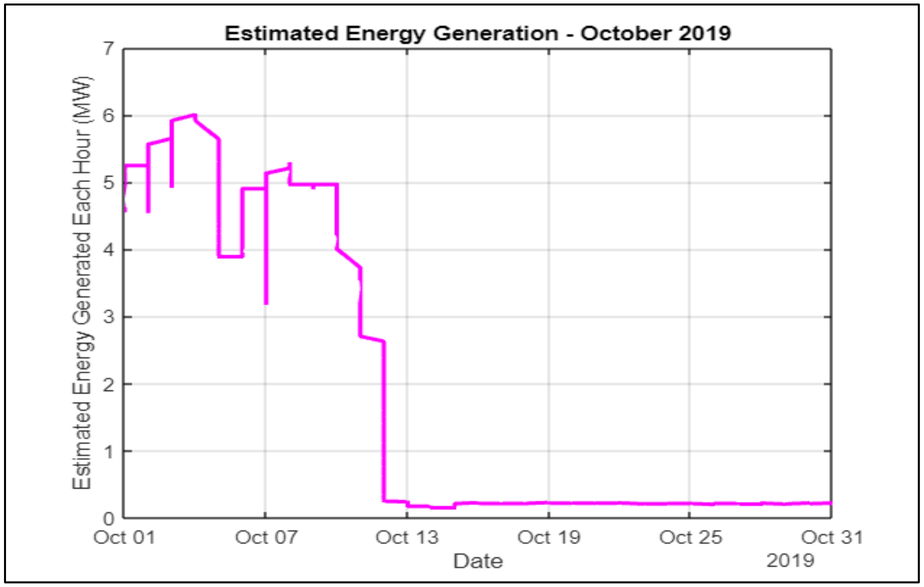

Estimated Energy Generation - May 2019

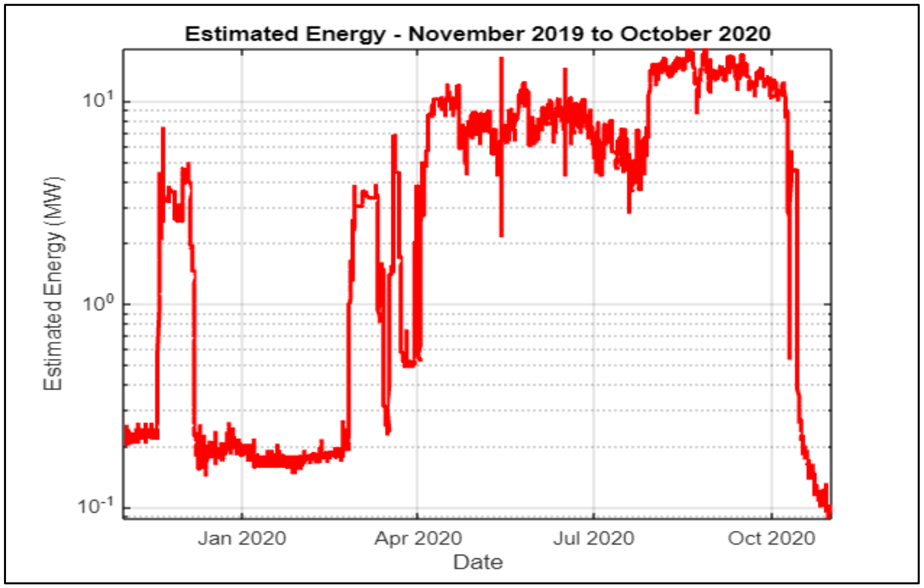

Estimated Energy Generation - June 2019

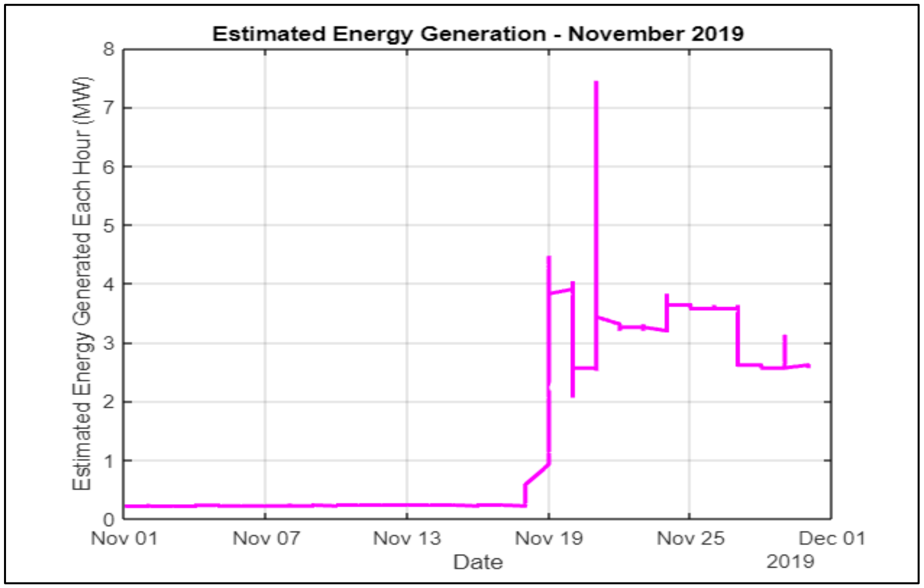

Estimated Energy Generation - July 2019

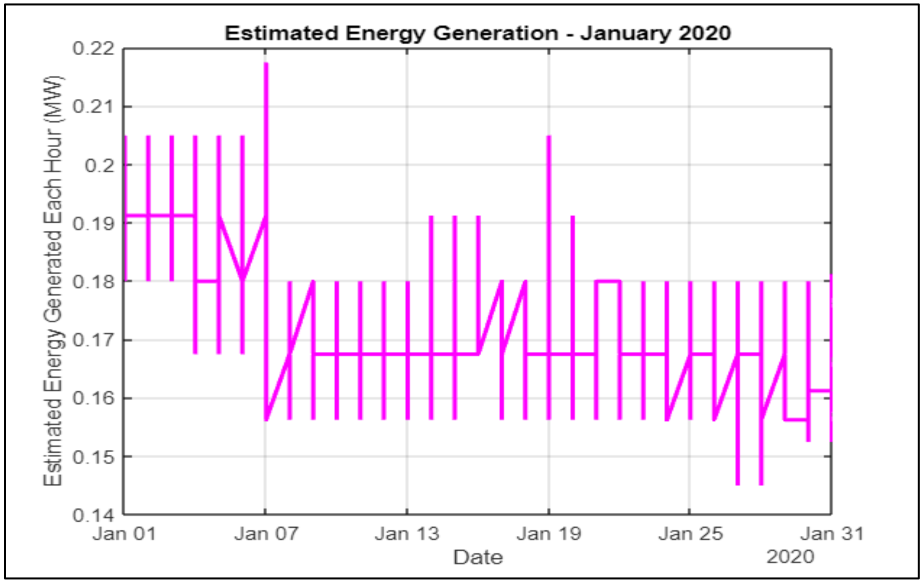

Estimated Energy Generation - August 2019

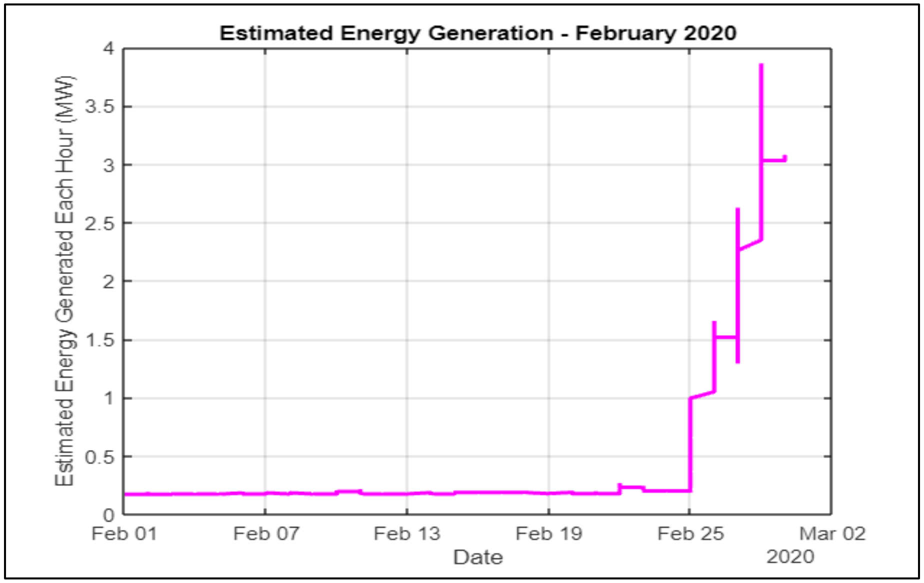

Estimated Energy Generation - September 2019
Estimated Energy Generated Each Hour (MW)
600
500
400
300
200
100
0
Sep 01
Sep 07
Sep 13
Sep 19
Sep 25
Oct 01
Date
2019

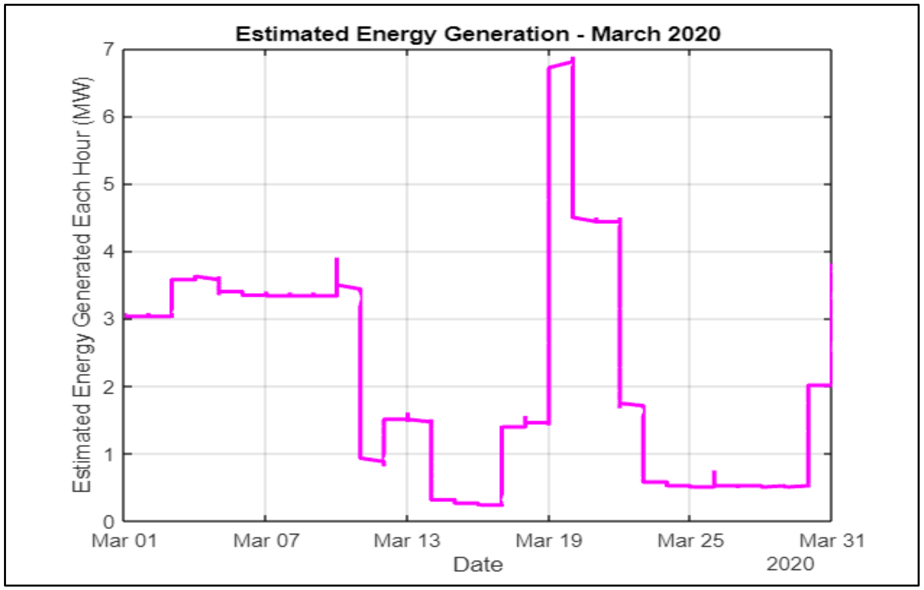

Estimated Energy Generation - October 2019
Estimated Energy Generated Each Hour (MW)
7
6
5
4
3
2
1
0
Oct 01
Oct 07
Oct 13
Oct 19
Oct 25
Oct 31
Date
2019

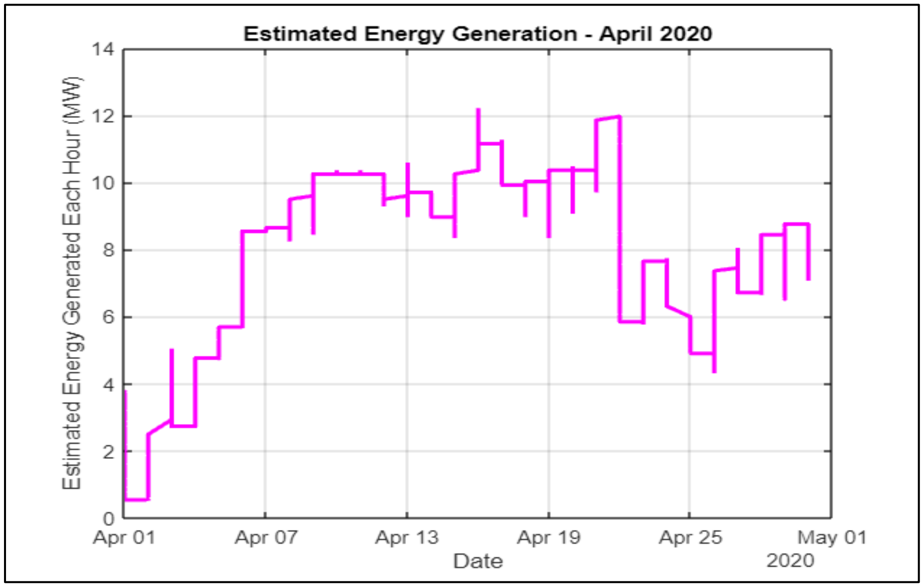

Estimated Energy - November 2019 to October 2020
Estimated Energy (MW)
10^1
10^0
10^{-1}
Jan 2020
Apr 2020
Jul 2020
Oct 2020
Date

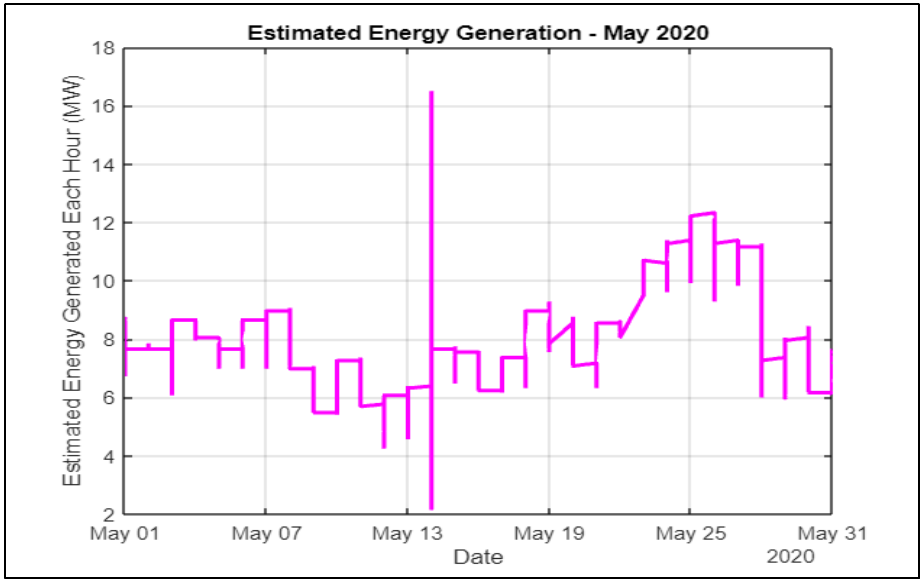

Estimated Energy Generation - November 2019
Estimated Energy Generated Each Hour (MW)
8
7
6
5
4
3
2
1
0
Nov 01
Nov 07
Nov 13
Nov 19
Nov 25
Dec 01
Date
2019

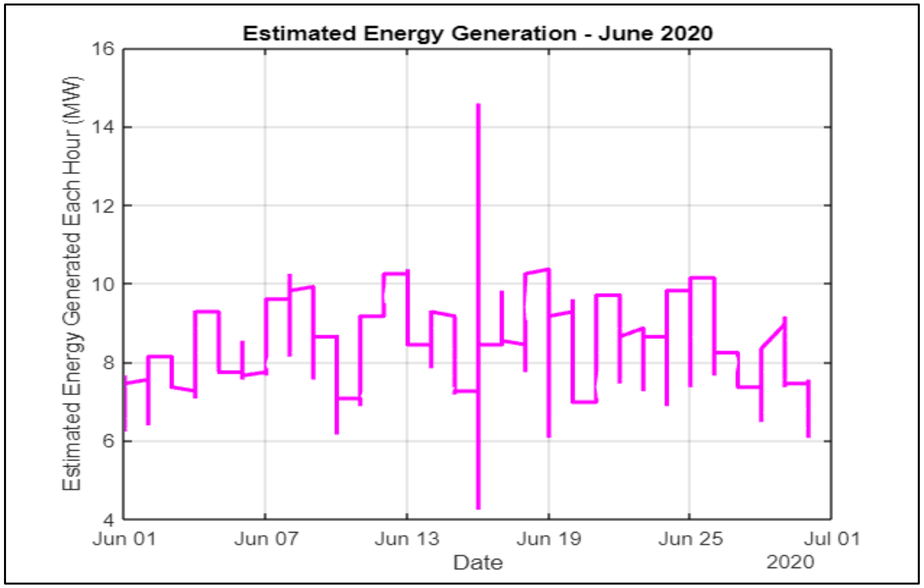

Estimated Energy Generation - January 2020
Estimated Energy Generated Each Hour (MW)
0.22
0.21
0.2
0.19
0.18
0.17
0.16
0.15
0.14
Jan 01
Jan 07
Jan 13
Jan 19
Jan 25
Jan 31
Date
2020

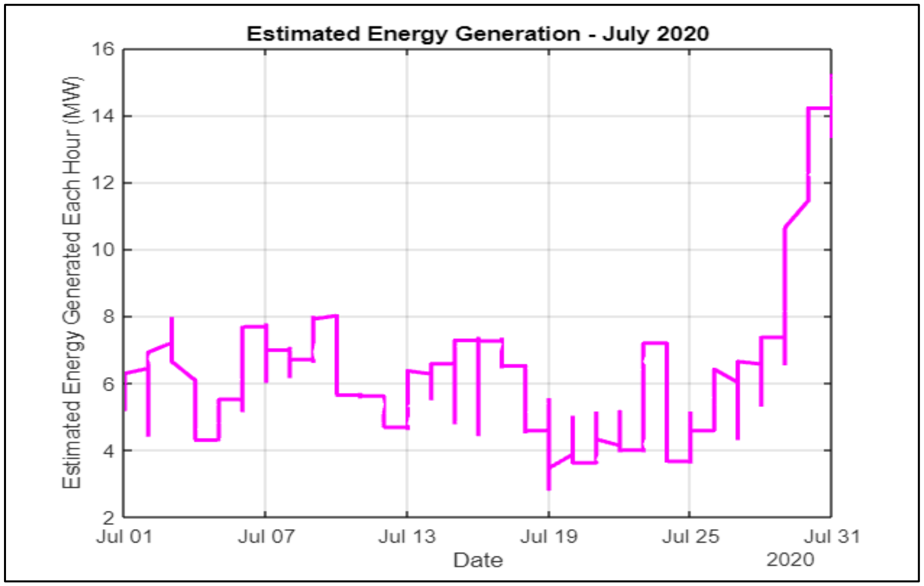

Estimated Energy Generation - February 2020
Estimated Energy Generated Each Hour (MW)
4
3.5
3
2.5
2
1.5
1
0.5
0
Feb 01
Feb 07
Feb 13
Feb 19
Feb 25
Mar 02
Date
2020

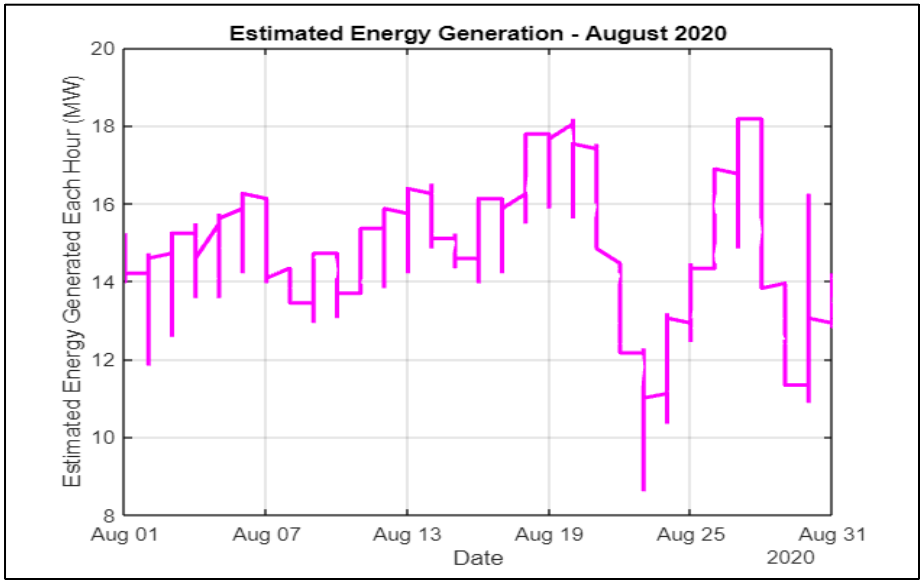

Estimated Energy Generation - March 2020
Estimated Energy Generated Each Hour (MW)
7
6
5
4
3
2
1
0
Mar 01
Mar 07
Mar 13
Mar 19
Mar 25
Mar 31
Date
2020

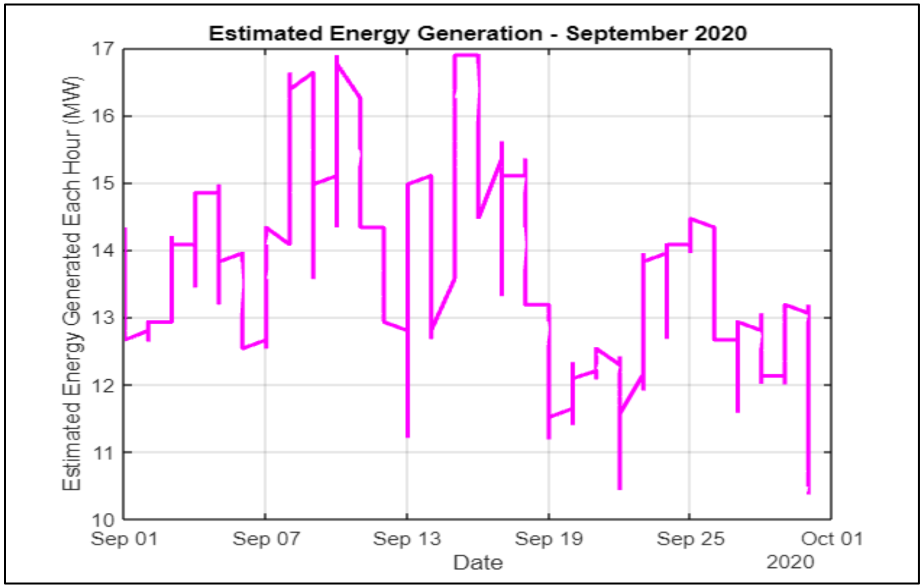

Estimated Energy Generation - April 2020
Estimated Energy Generated Each Hour (MW)
14
12
10
8
6
4
2
0
Apr 01
Apr 07
Apr 13
Apr 19
Apr 25
May 01
Date
2020

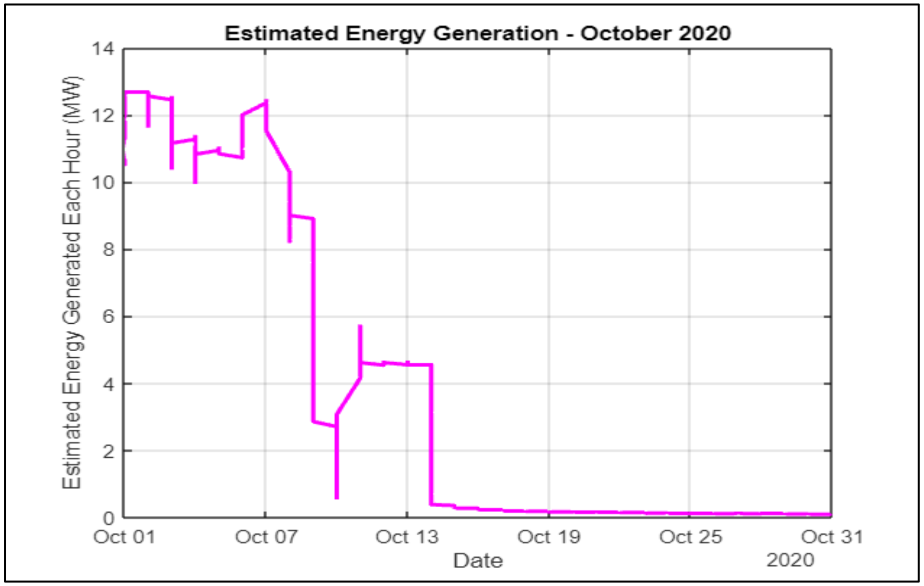

Estimated Energy Generation - May 2020
Estimated Energy Generated Each Hour (MW)
2
4
6
8
10
12
14
16
18
May 01
May 07
May 13
May 19
May 25
May 31
Date
2020

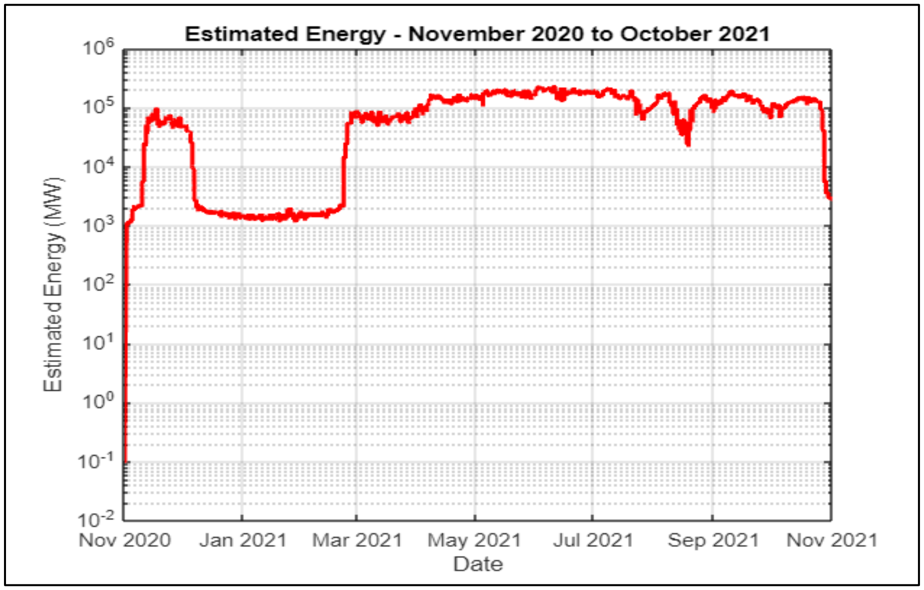

Estimated Energy Generation - June 2020
Estimated Energy Generated Each Hour (MW)
4
6
8
10
12
14
16
Jun 01
Jun 07
Jun 13
Jun 19
Jun 25
Jul 01
Date
2020

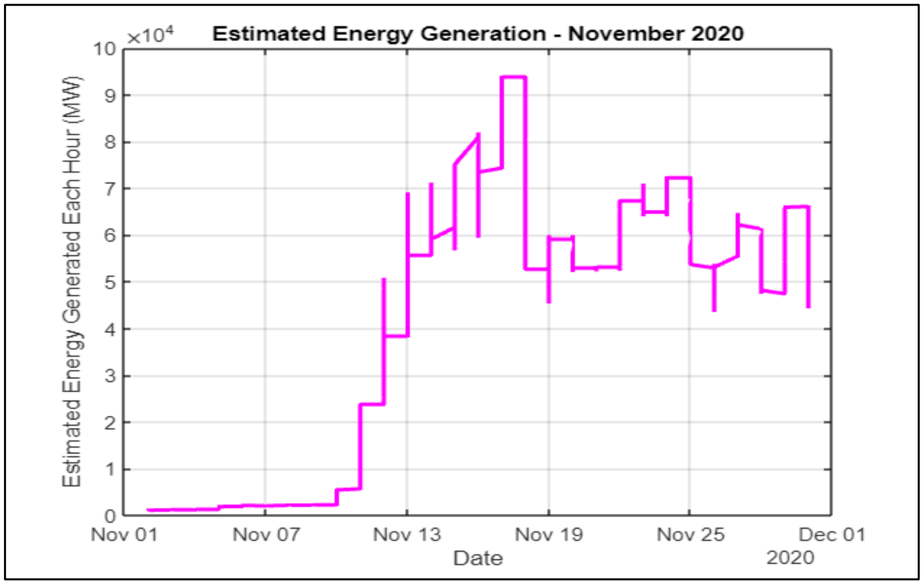

Estimated Energy Generation - July 2020
Estimated Energy Generated Each Hour (MW)
2
4
6
8
10
12
14
16
Jul 01
Jul 07
Jul 13
Jul 19
Jul 25
Jul 31
Date
2020

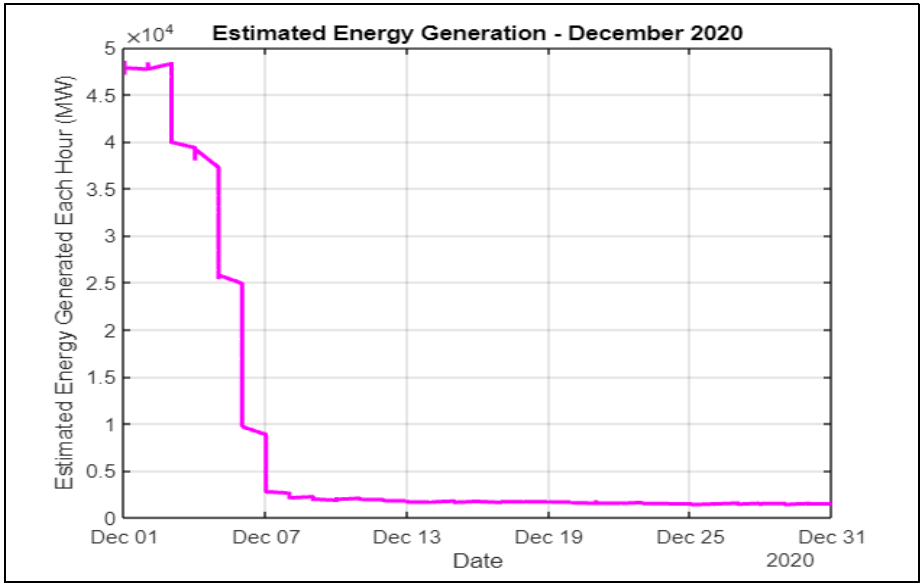

Estimated Energy Generation - August 2020
Estimated Energy Generated Each Hour (MW)
8
10
12
14
16
18
20
Aug 01
Aug 07
Aug 13
Aug 19
Aug 25
Aug 31
Date
2020

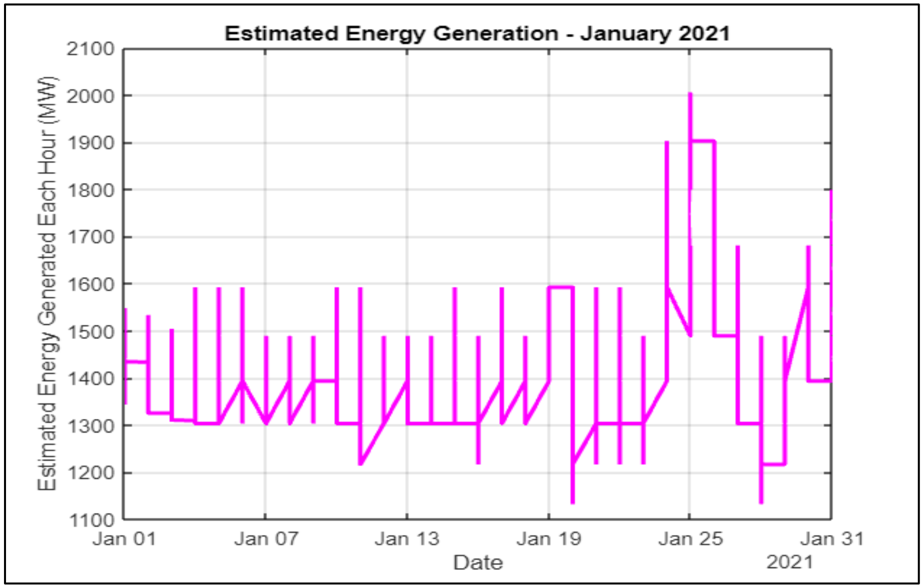

Estimated Energy Generation - September 2020

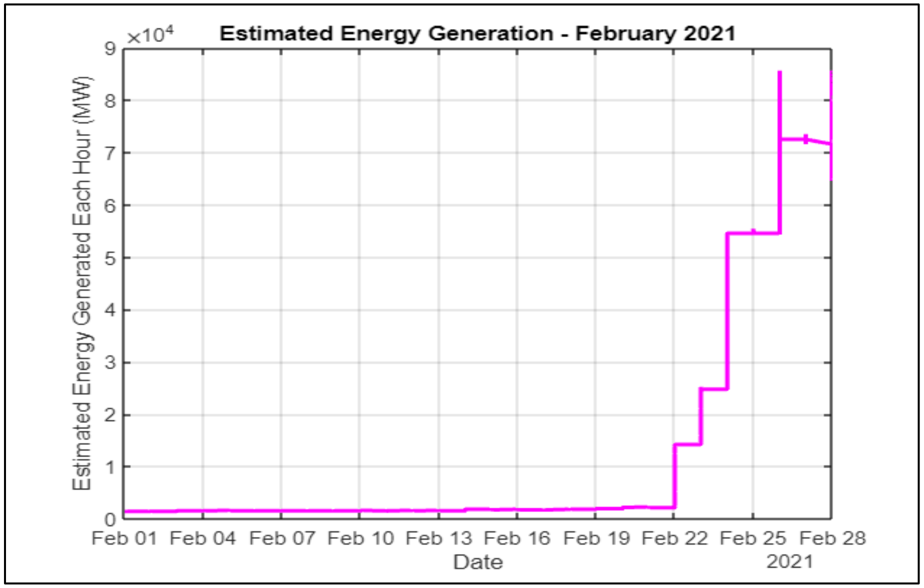

Estimated Energy Generation - October 2020

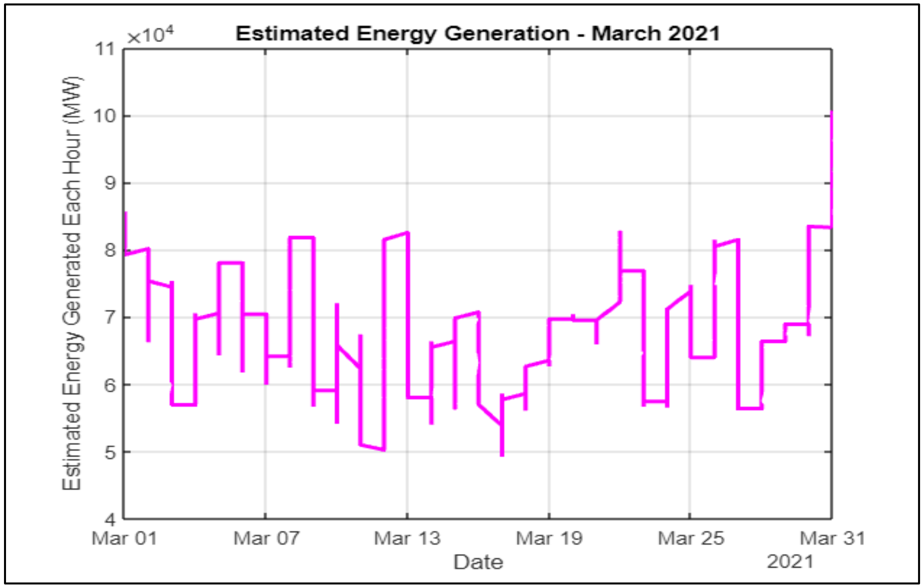

Estimated Energy - November 2020 to October 2021

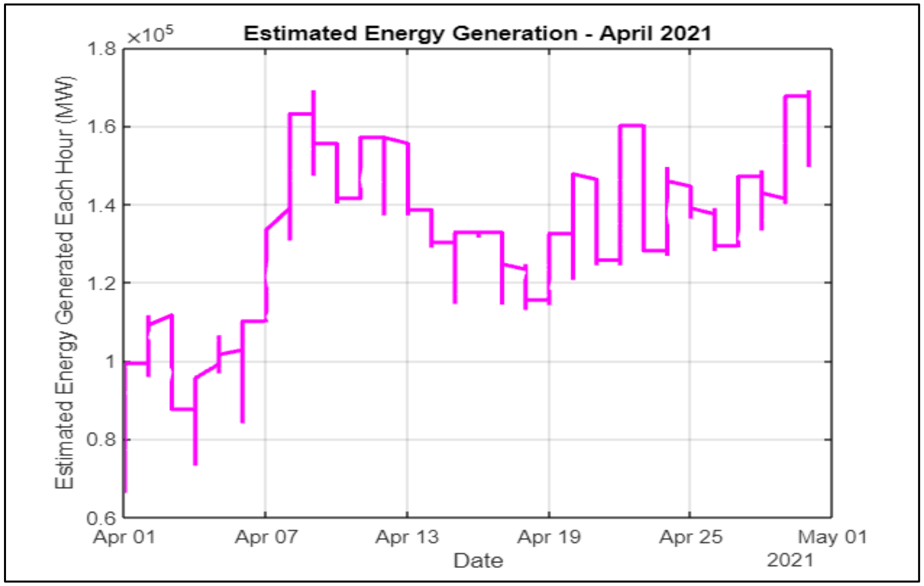

Estimated Energy Generation - November 2020

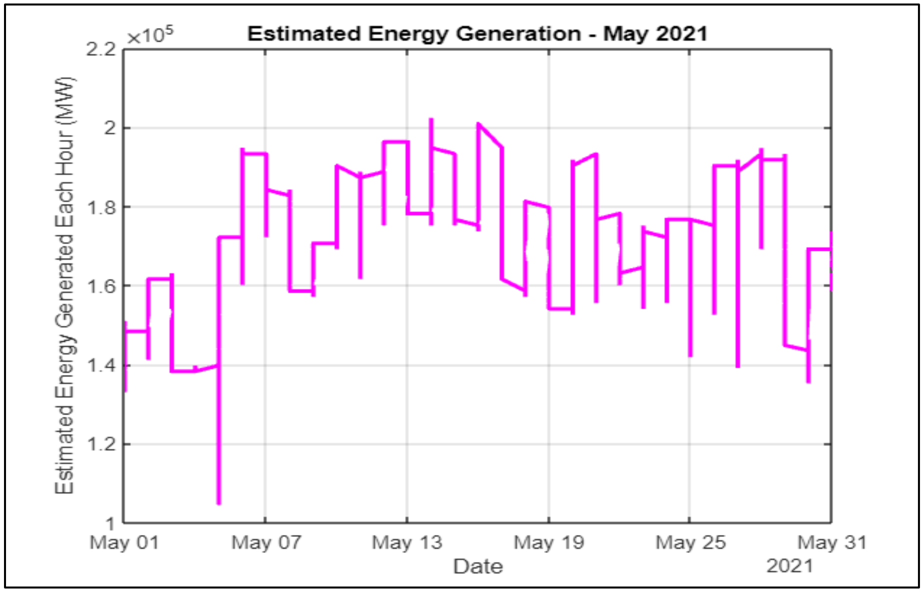

Estimated Energy Generation - December 2020
×10^4
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Estimated Energy Generated Each Hour (MW)
Dec 01
Dec 07
Dec 13
Dec 19
Dec 25
Dec 31
Date
2020

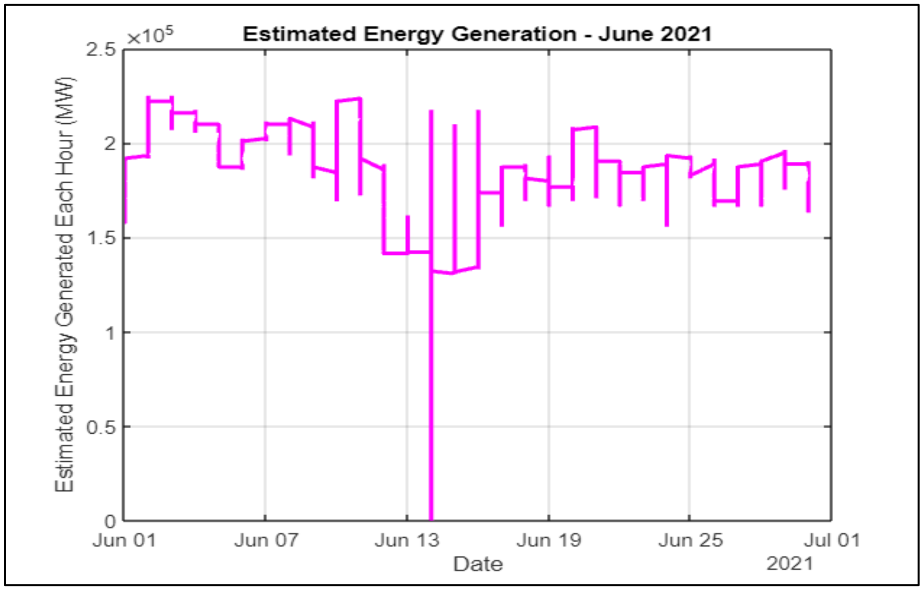

Estimated Energy Generation - January 2021
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
Estimated Energy Generated Each Hour (MW)
Jan 01
Jan 07
Jan 13
Jan 19
Jan 25
Jan 31
Date
2021

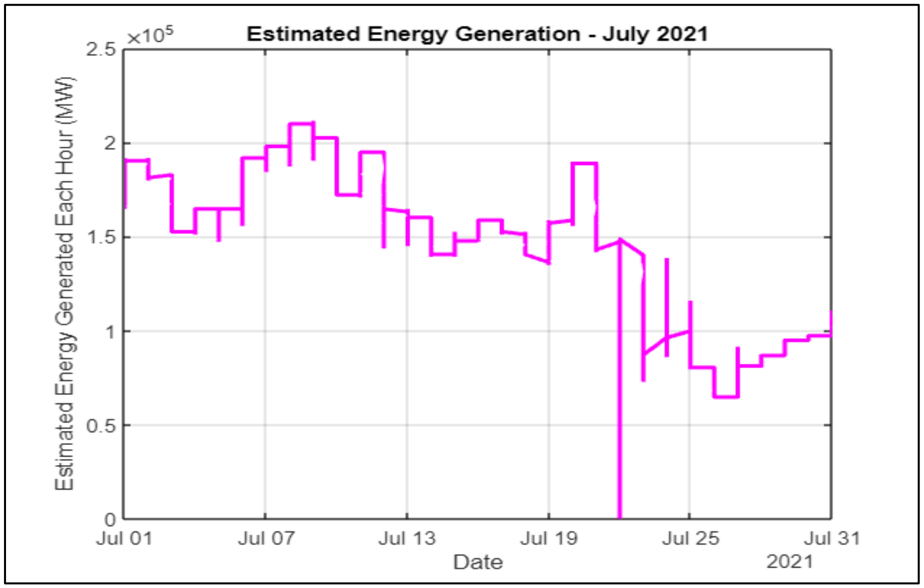

Estimated Energy Generation - February 2021
×10^4
9
8
7
6
5
4
3
2
1
0
Estimated Energy Generated Each Hour (MW)
Feb 01
Feb 04
Feb 07
Feb 10
Feb 13
Feb 16
Feb 19
Feb 22
Feb 25
Feb 28
Date
2021

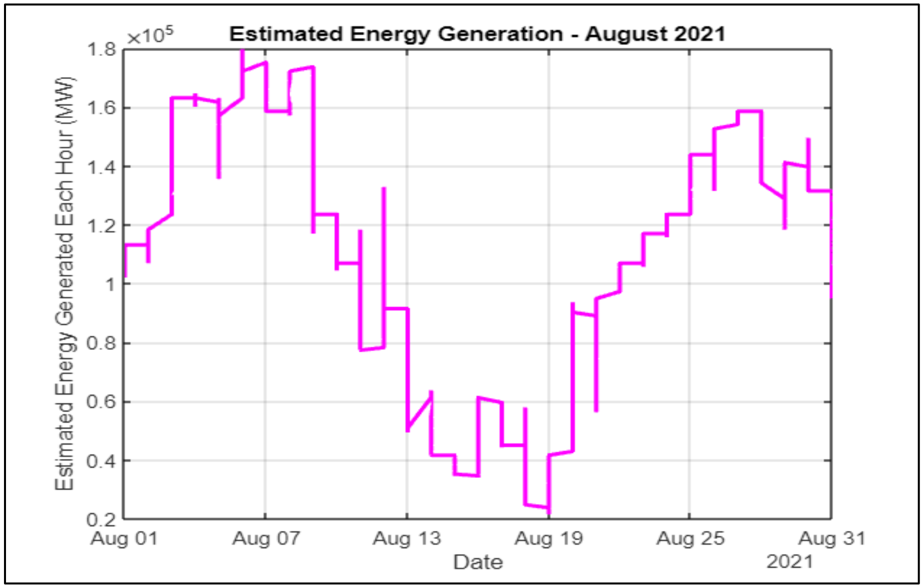

Estimated Energy Generation - March 2021
×10^4
11
10
9
8
7
6
5
4
Estimated Energy Generated Each Hour (MW)
Mar 01
Mar 07
Mar 13
Mar 19
Mar 25
Mar 31
Date
2021

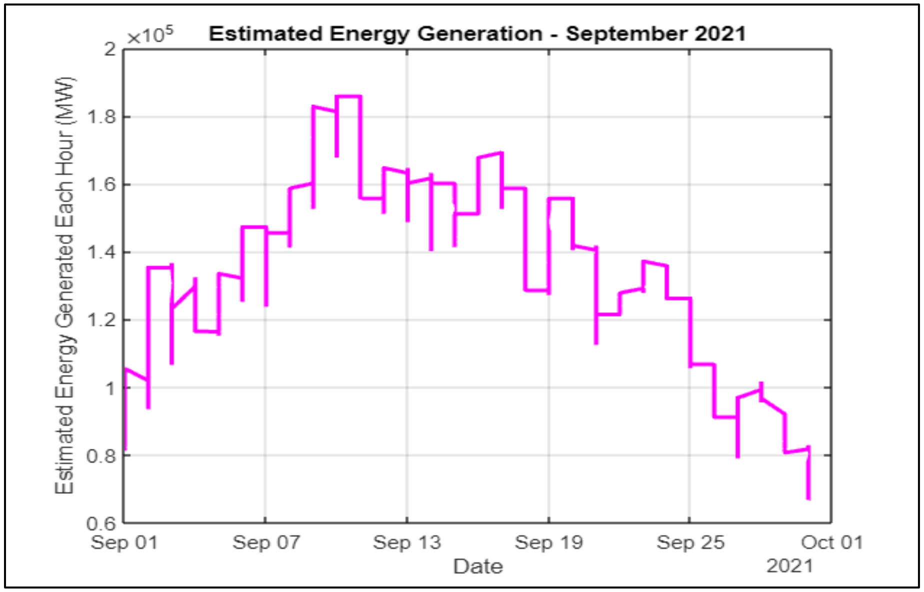

Estimated Energy Generation - April 2021
×10^5
1.8
1.6
1.4
1.2
1
0.8
0.6
Estimated Energy Generated Each Hour (MW)
Apr 01
Apr 07
Apr 13
Apr 19
Apr 25
May 01
2021
Date

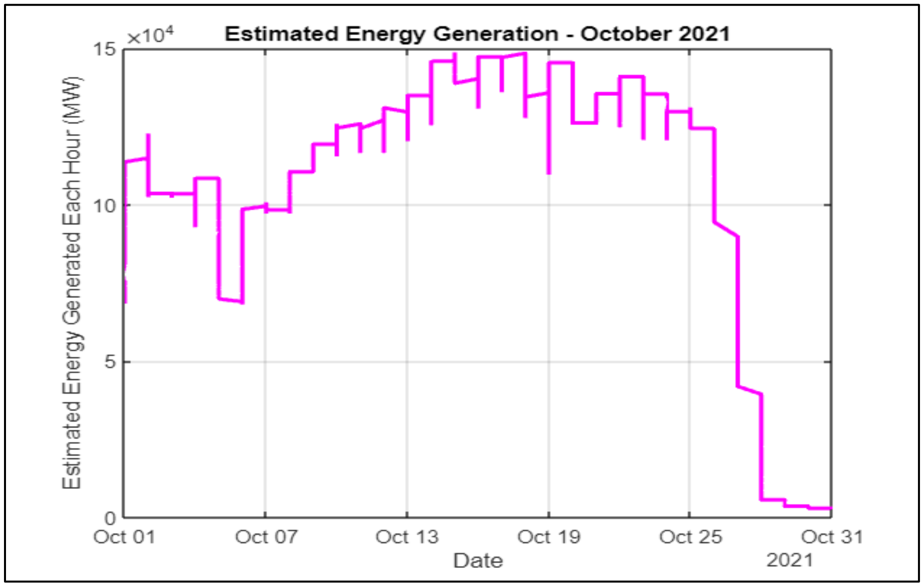

Estimated Energy Generation - May 2021
×10^5
2.2
2
1.8
1.6
1.4
1.2
1
Estimated Energy Generated Each Hour (MW)
May 01
May 07
May 13
May 19
May 25
May 31
2021
Date

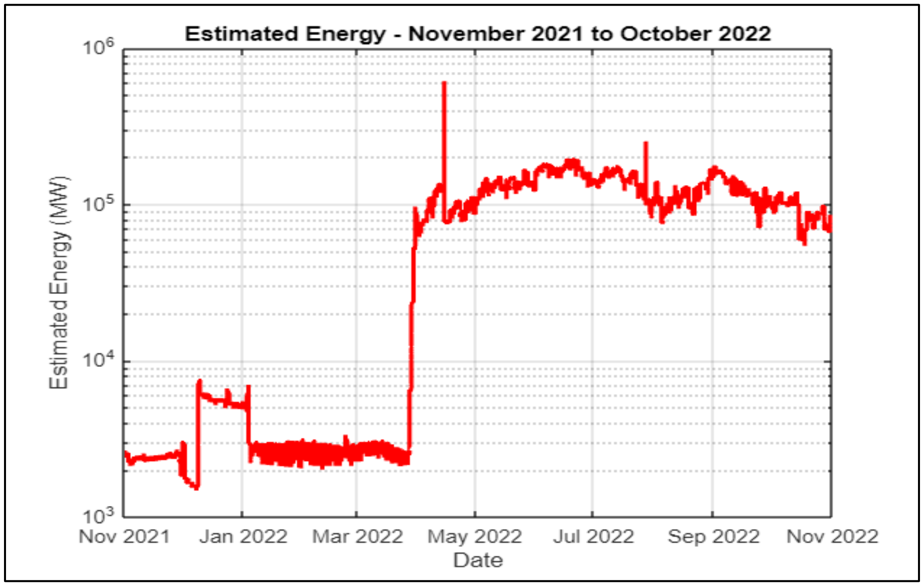

Estimated Energy Generation - June 2021
×10^5
2.5
2
1.5
1
0.5
0
Estimated Energy Generated Each Hour (MW)
Jun 01
Jun 07
Jun 13
Jun 19
Jun 25
Jul 01
2021
Date

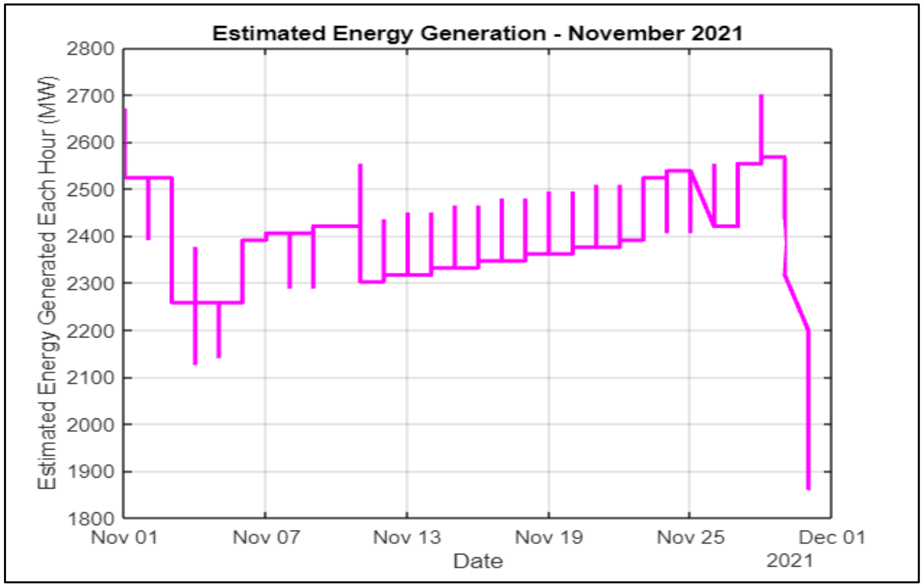

Estimated Energy Generation - July 2021
×10^5
2.5
2
1.5
1
0.5
0
Estimated Energy Generated Each Hour (MW)
Jul 01
Jul 07
Jul 13
Jul 19
Jul 25
Jul 31
2021
Date

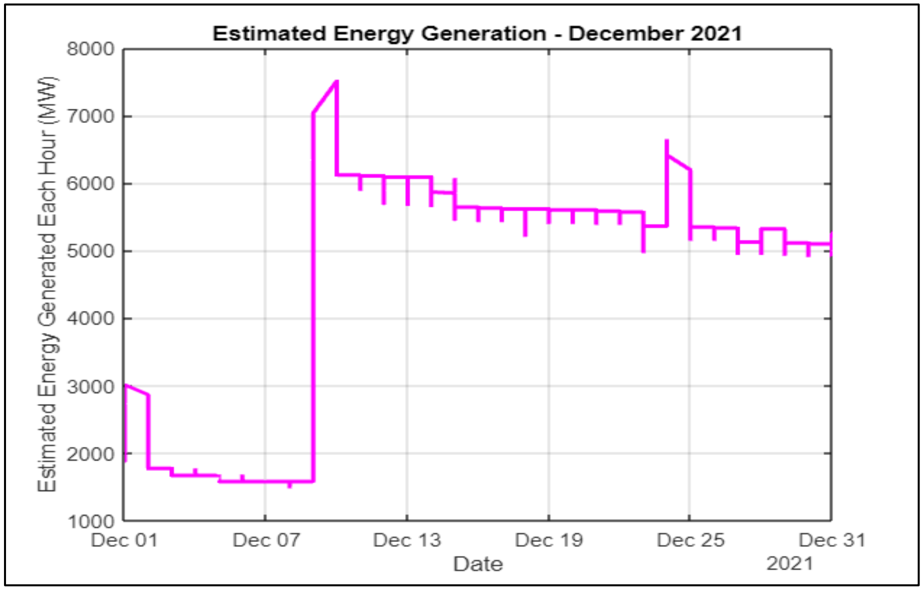

Estimated Energy Generation - August 2021
×10^5
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
Estimated Energy Generated Each Hour (MW)
Aug 01
Aug 07
Aug 13
Aug 19
Aug 25
Aug 31
2021
Date

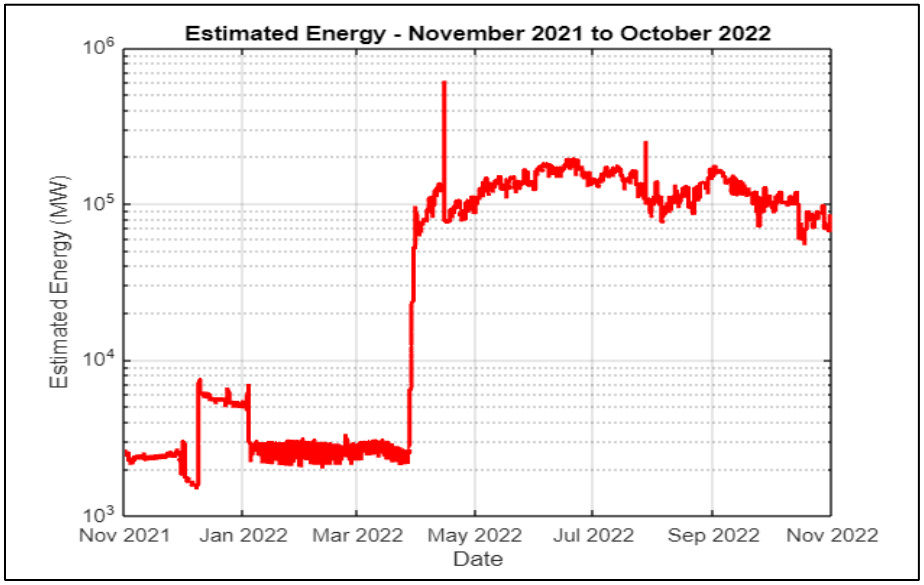

Estimated Energy Generation - September 2021
×10^5
2
1.8
1.6
1.4
1.2
1
0.8
0.6
Estimated Energy Generated Each Hour (MW)
Sep 01
Sep 07
Sep 13
Sep 19
Sep 25
Oct 01
2021
Date

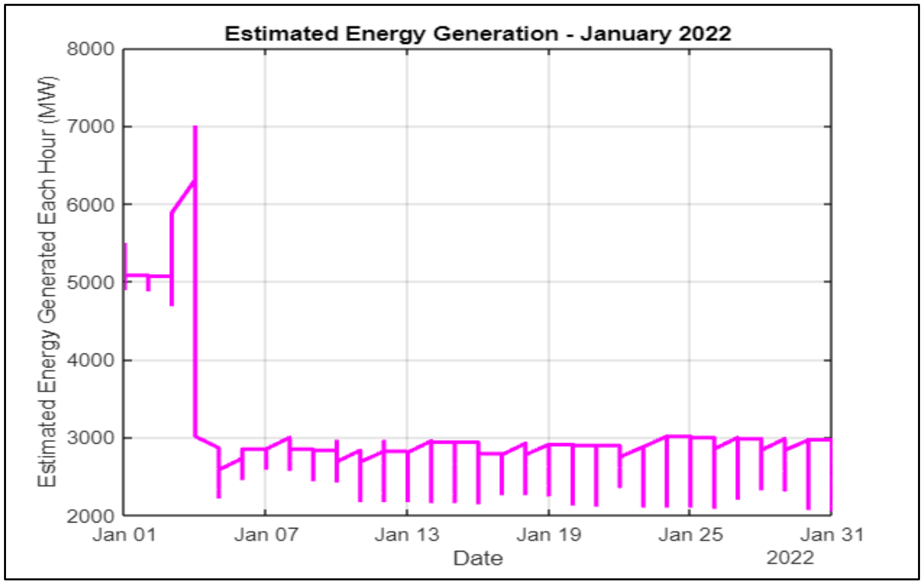

Estimated Energy Generation - October 2021
×10^4
15
10
5
0
Estimated Energy Generated Each Hour (MW)
Oct 01
Oct 07
Oct 13
Oct 19
Oct 25
Oct 31
2021
Date

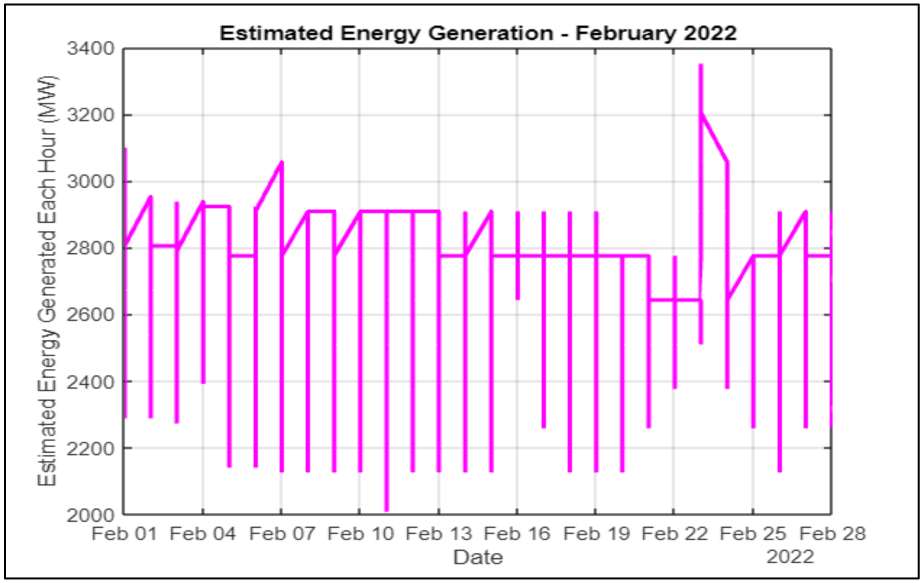

Estimated Energy - November 2021 to October 2022
10^6
10^5
10^4
10^3
Estimated Energy (MW)
Nov 2021
Jan 2022
Mar 2022
May 2022
Jul 2022
Sep 2022
Nov 2022
Date

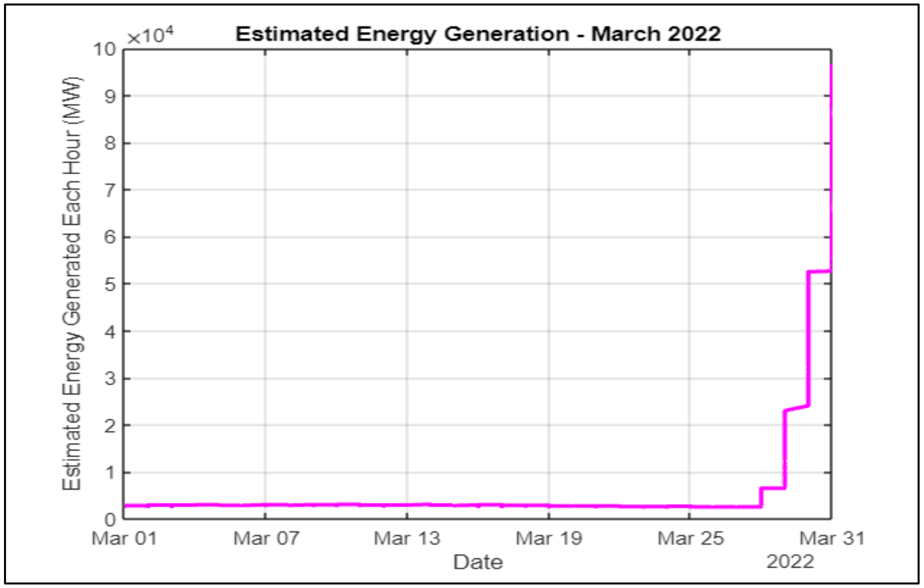

Estimated Energy Generation - November 2021
Estimated Energy Generated Each Hour (MW)
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
Nov 01
Nov 07
Nov 13
Nov 19
Nov 25
Dec 01
2021
Date

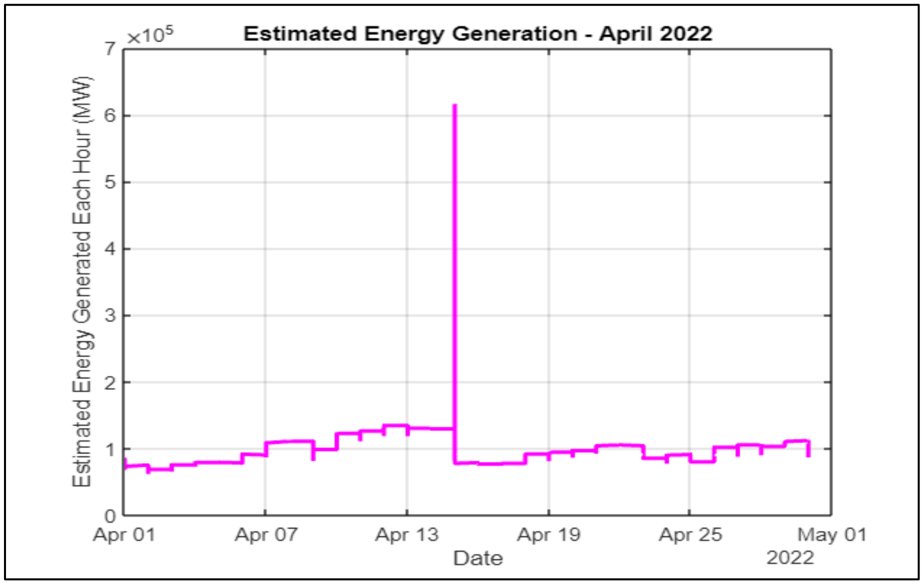

Estimated Energy Generation - December 2021
Estimated Energy Generated Each Hour (MW)
8000
7000
6000
5000
4000
3000
2000
1000
Dec 01
Dec 07
Dec 13
Dec 19
Dec 25
Dec 31
2021
Date

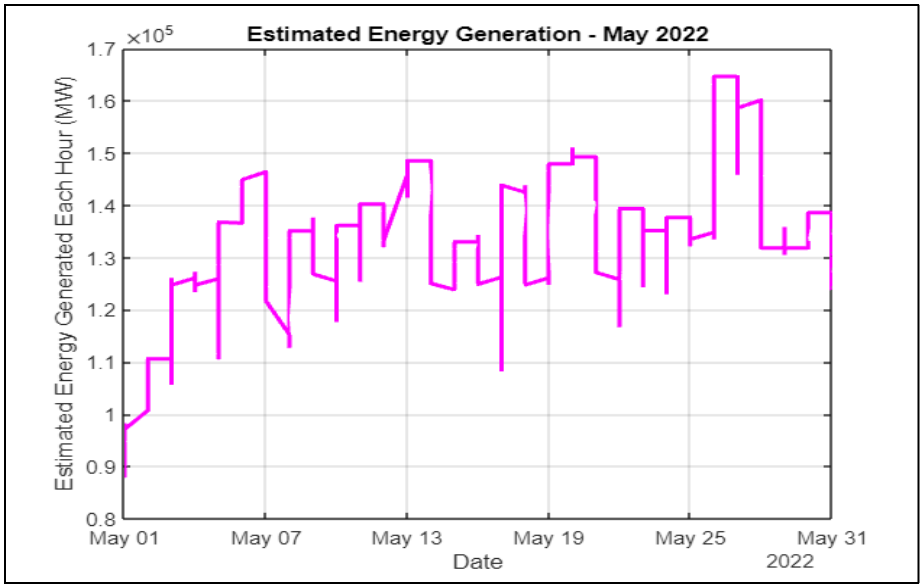

Estimated Energy - November 2021 to October 2022
Estimated Energy (MW)
10^6
10^5
10^4
10^3
Nov 2021
Jan 2022
Mar 2022
May 2022
Jul 2022
Sep 2022
Nov 2022
Date

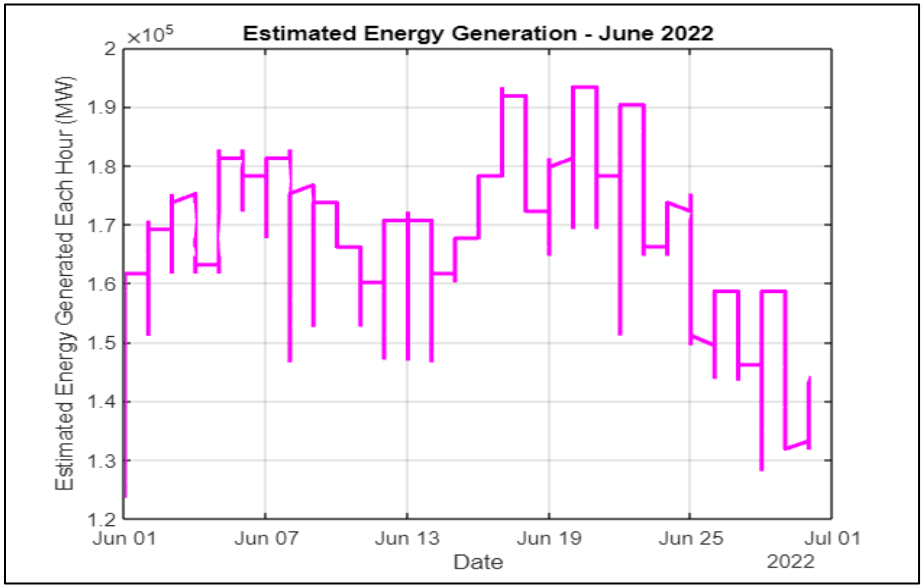

Estimated Energy Generation - January 2022
Estimated Energy Generated Each Hour (MW)
8000
7000
6000
5000
4000
3000
2000
Jan 01
Jan 07
Jan 13
Jan 19
Jan 25
Jan 31
2022
Date

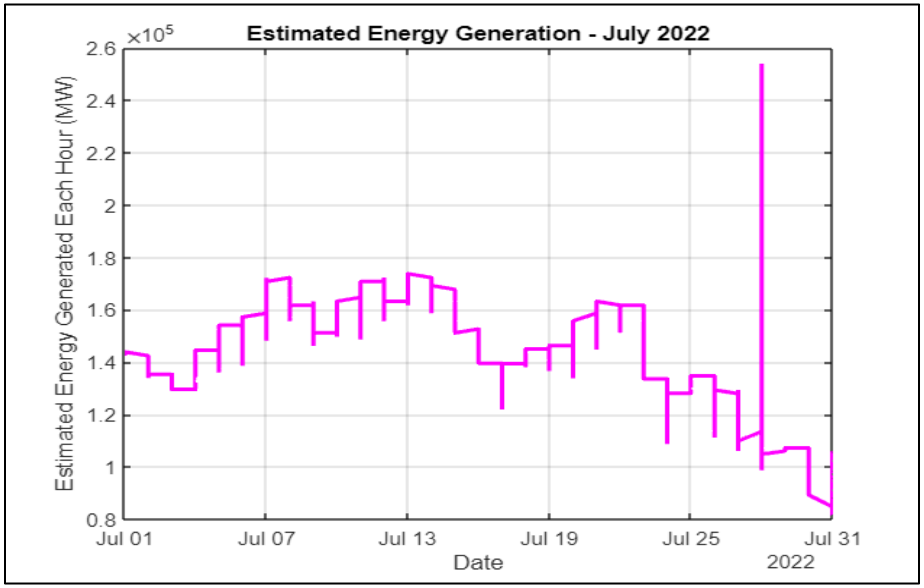

Estimated Energy Generation - February 2022
Estimated Energy Generated Each Hour (MW)
3400
3200
3000
2800
2600
2400
2200
2000
Feb 01
Feb 04
Feb 07
Feb 10
Feb 13
Feb 16
Feb 19
Feb 22
Feb 25
Feb 28
Date
2022

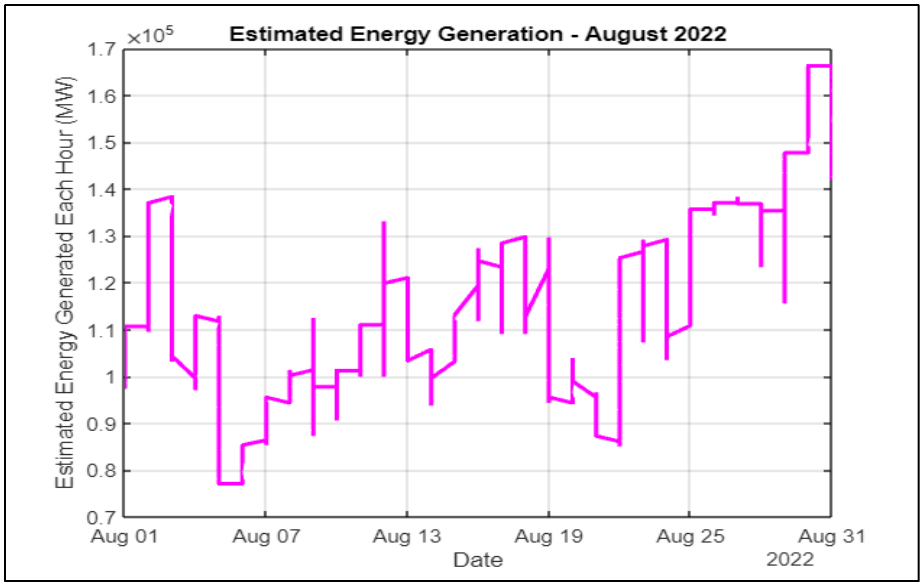

Estimated Energy Generation - March 2022
$\times10^4$
Estimated Energy Generated Each Hour (MW)
10
9
8
7
6
5
4
3
2
1
0
Mar 01
Mar 07
Mar 13
Mar 19
Mar 25
Mar 31
Date
2022

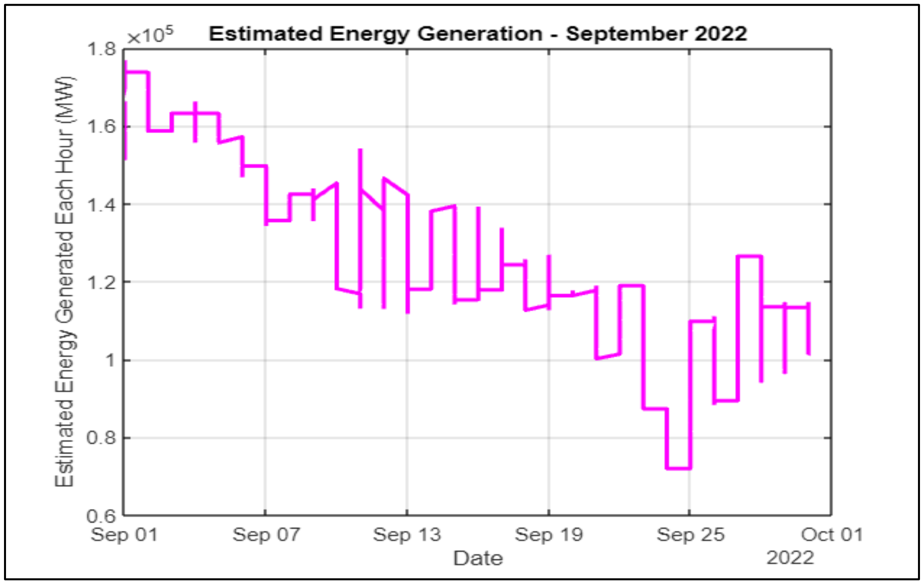

Estimated Energy Generation - April 2022
$\times10^5$
Estimated Energy Generated Each Hour (MW)
7
6
5
4
3
2
1
0
Apr 01
Apr 07
Apr 13
Apr 19
Apr 25
May 01
Date
2022

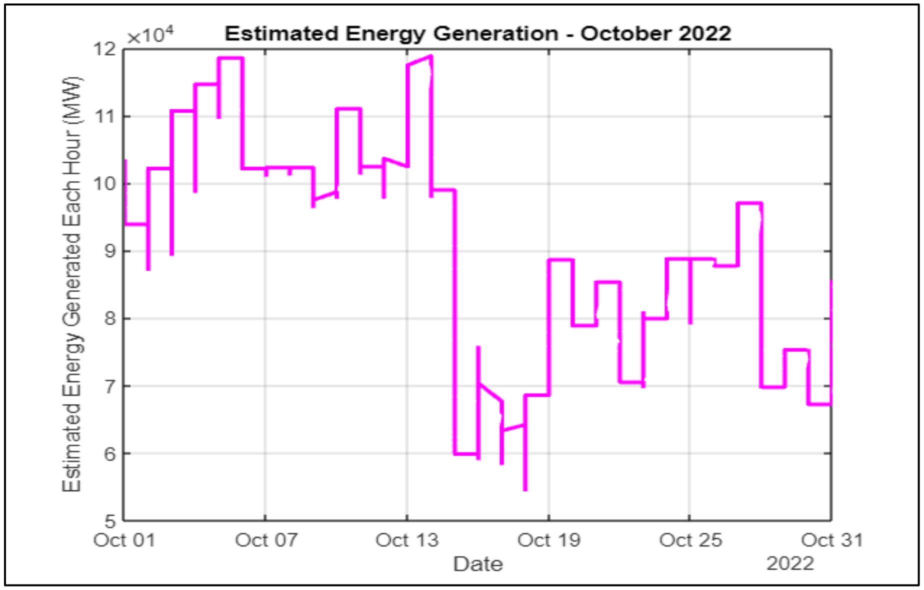

Estimated Energy Generation - May 2022
$\times10^5$
Estimated Energy Generated Each Hour (MW)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
May 01
May 07
May 13
May 19
May 25
May 31
Date
2022

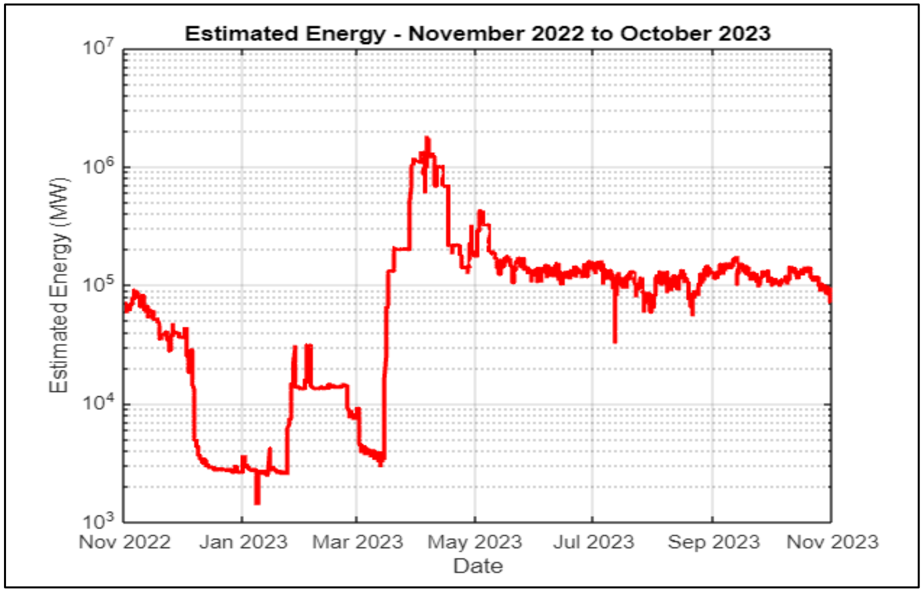

Estimated Energy Generation - June 2022
×10^5
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
Estimated Energy Generated Each Hour (MW)
Jun 01
Jun 07
Jun 13
Jun 19
Jun 25
Jul 01
2022
Date

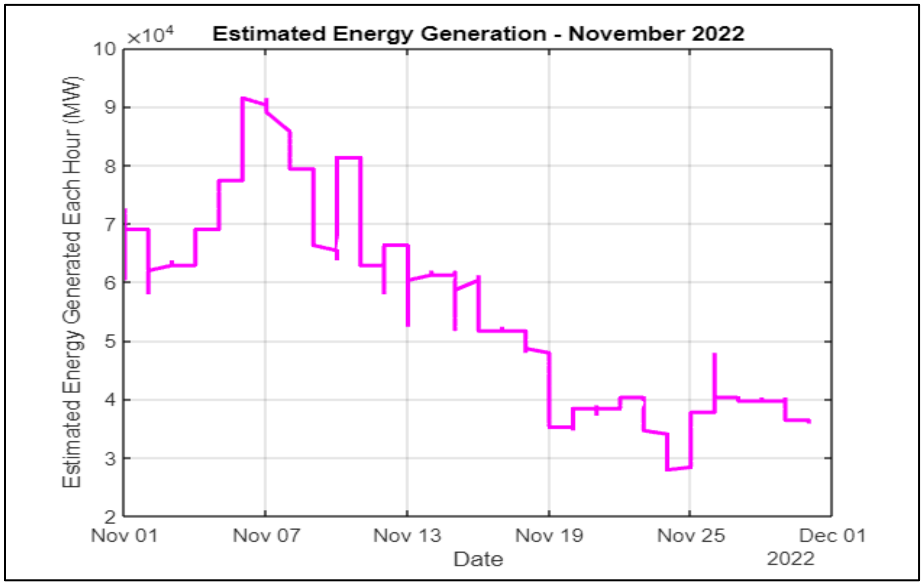

Estimated Energy Generation - July 2022
×10^5
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
Estimated Energy Generated Each Hour (MW)
Jul 01
Jul 07
Jul 13
Jul 19
Jul 25
Jul 31
2022
Date

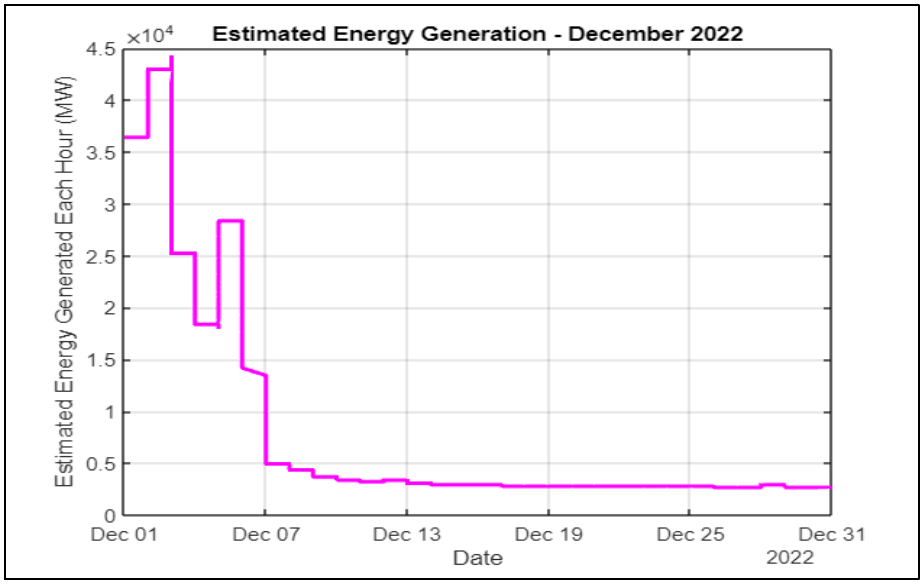

Estimated Energy Generation - August 2022
×10^5
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
Estimated Energy Generated Each Hour (MW)
Aug 01
Aug 07
Aug 13
Aug 19
Aug 25
Aug 31
2022
Date

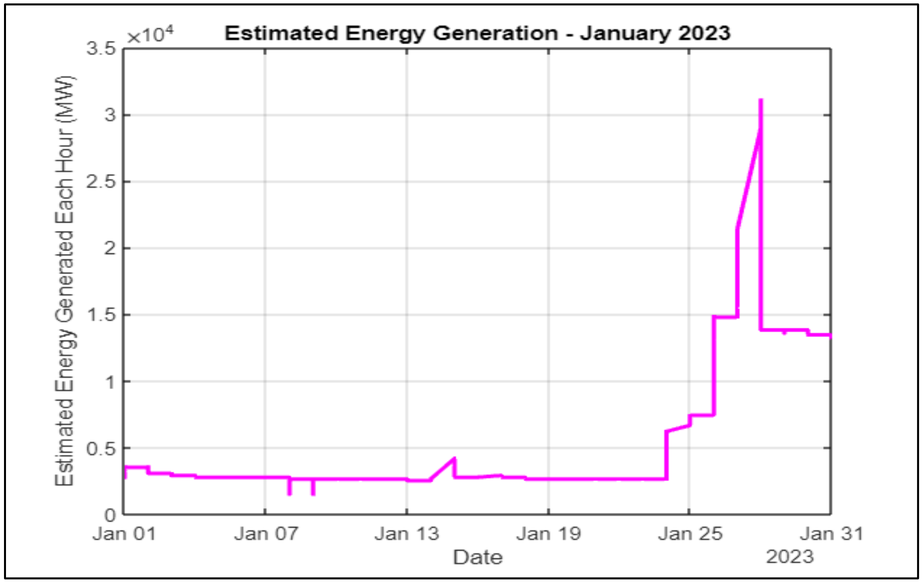

Estimated Energy Generation - September 2022
×10^5
1.8
1.6
1.4
1.2
1
0.8
0.6
Estimated Energy Generated Each Hour (MW)
Sep 01
Sep 07
Sep 13
Sep 19
Sep 25
Oct 01
2022
Date

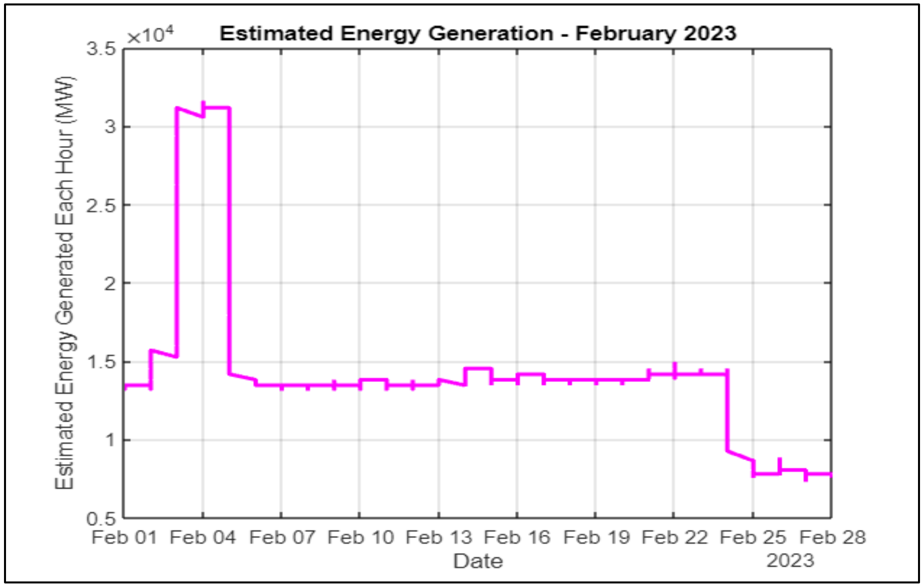

Estimated Energy Generation - October 2022
×10^4
12
11
10
9
8
7
6
5
Estimated Energy Generated Each Hour (MW)
Oct 01
Oct 07
Oct 13
Oct 19
Oct 25
Oct 31
Date
2022

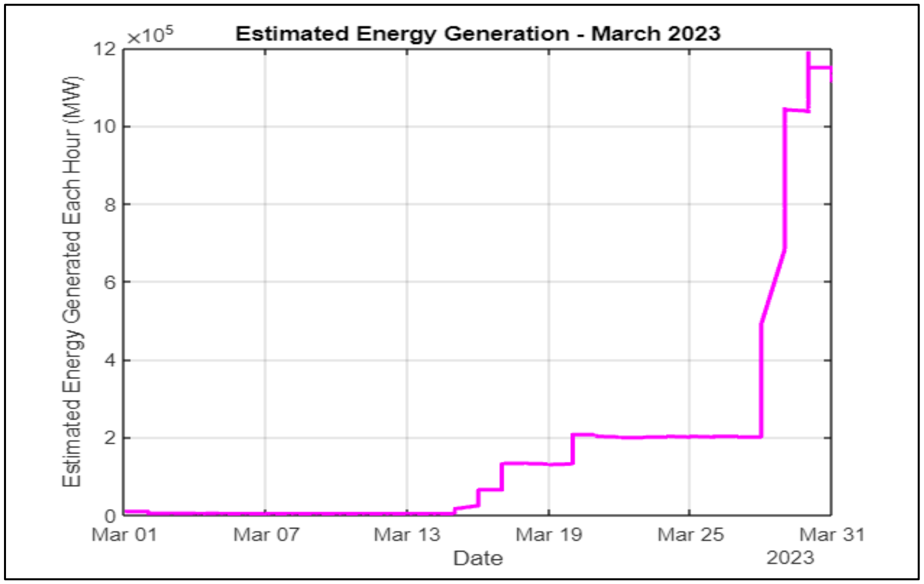

Estimated Energy - November 2022 to October 2023
10^7
10^6
10^5
10^4
10^3
Estimated Energy (MW)
Nov 2022
Jan 2023
Mar 2023
May 2023
Jul 2023
Sep 2023
Nov 2023
Date

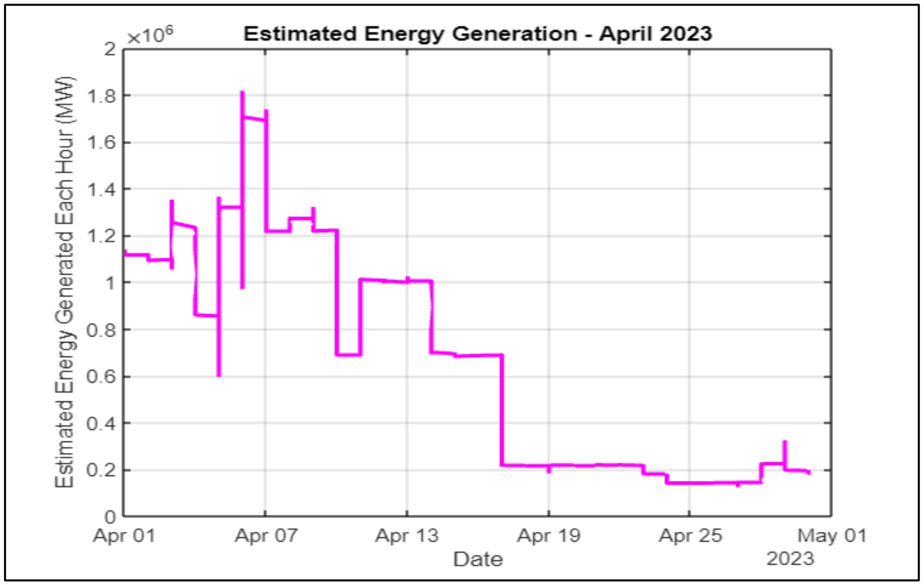

Estimated Energy Generation - November 2022
×10^4
10
9
8
7
6
5
4
3
2
Estimated Energy Generated Each Hour (MW)
Nov 01
Nov 07
Nov 13
Nov 19
Nov 25
Dec 01
Date
2022

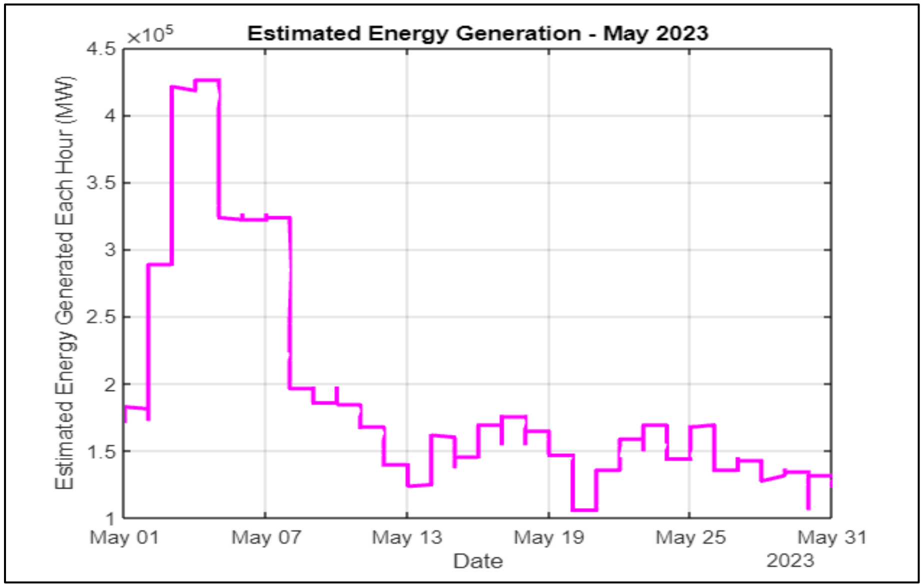

Estimated Energy Generation - December 2022
×10^4
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Estimated Energy Generated Each Hour (MW)
Dec 01
Dec 07
Dec 13
Dec 19
Dec 25
Dec 31
Date
2022

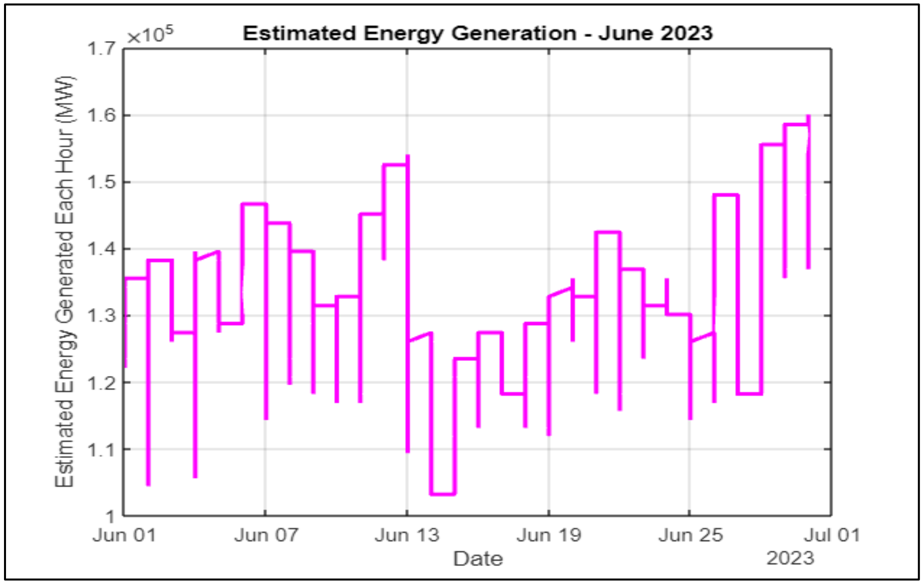

Estimated Energy Generation - January 2023

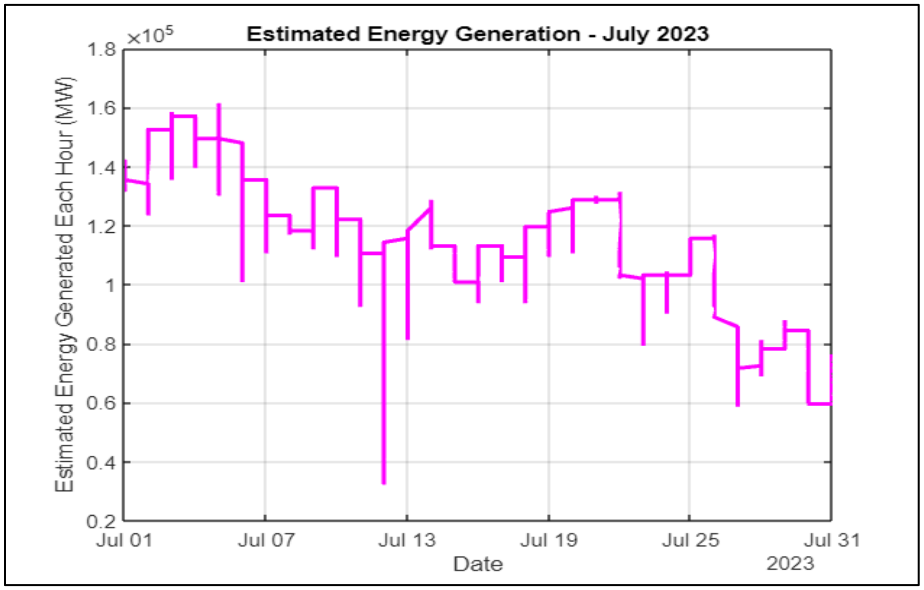

Estimated Energy Generation - February 2023

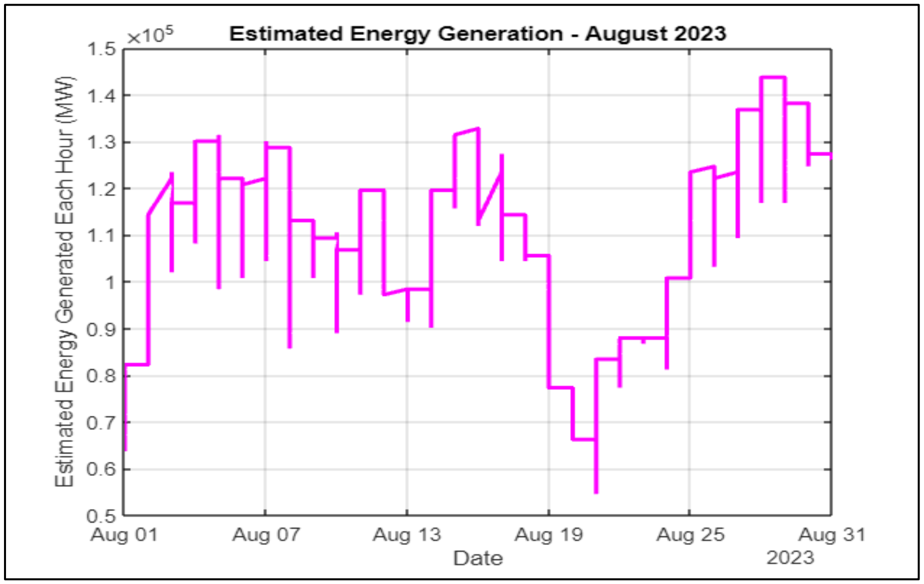

Estimated Energy Generation - March 2023

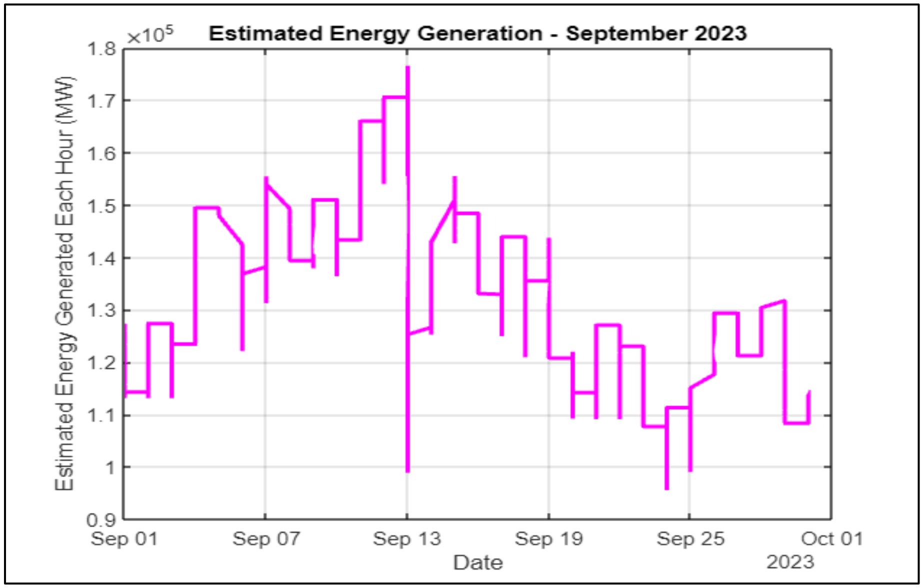

Estimated Energy Generation - April 2023

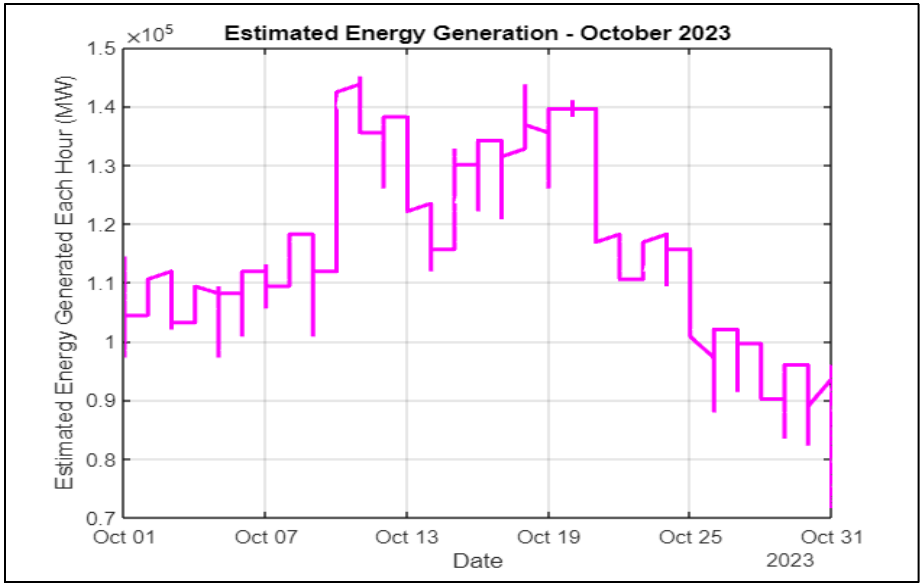

Estimated Energy Generation - May 2023
×10^5
4.5
4
3.5
3
2.5
2
1.5
1
Estimated Energy Generated Each Hour (MW)
May 01
May 07
May 13
May 19
May 25
May 31
Date
2023


Estimated Energy Generation - June 2023
×10^5
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
Estimated Energy Generated Each Hour (MW)
Jun 01
Jun 07
Jun 13
Jun 19
Jun 25
Jul 01
Date
2023


Estimated Energy Generation - July 2023
×10^5
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
Estimated Energy Generated Each Hour (MW)
Jul 01
Jul 07
Jul 13
Jul 19
Jul 25
Jul 31
Date
2023


Estimated Energy Generation - August 2023
×10^5
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
Estimated Energy Generated Each Hour (MW)
Aug 01
Aug 07
Aug 13
Aug 19
Aug 25
Aug 31
Date
2023


Estimated Energy Generation - September 2023
×10^5
Estimated Energy Generated Each Hour (MW)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
Sep 01
Sep 07
Sep 13
Sep 19
Sep 25
Oct 01
2023
Date


Estimated Energy Generation - October 2023
×10^5
Estimated Energy Generated Each Hour (MW)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
Oct 01
Oct 07
Oct 13
Oct 19
Oct 25
Oct 31
2023
Date