AAPA 2020 Environmental Improvement Awards Application

Integrated Algal Flow-Way, Digester, and Fuel Cell Demonstration Project

Maryland Department of Transportation - Maryland Port Administration,

University of Maryland and the Maryland Environmental Service

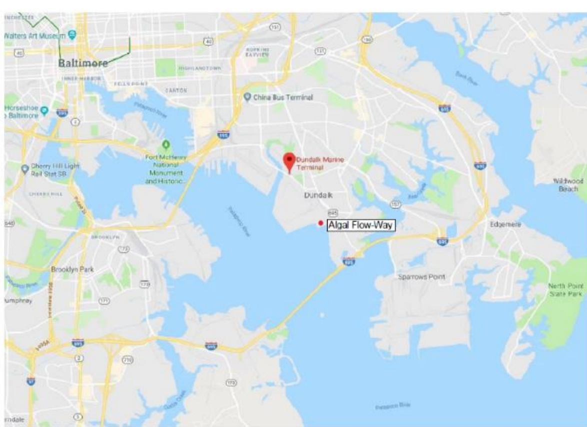
with funding support from the U.S. Department of Transportation Maritime Administration

Award Category: Mitigation

1) Project Summary

The Maryland Department of Transportation – Maryland Port Authority (MDOT-MPA) operates a number of marine terminals with multiple tenants for the Port of Baltimore. All of the Port facilities are located on Chesapeake Bay, which is the focus of a major water quality restoration effort by federal, state and local governments of 6 states and the District of Columbia. MDOT-MPA is a key participant in the restoration effort for Maryland and is actively investigating and evaluating innovative and alternative methods of meeting the restoration challenges in a way that is compatible with Port operations. Conventional stormwater treatment on marine terminals is nearly impossible, the Port's business is maximizing usable space for cargo and it is critical that impacts to port operations are minimized.

Figure 1-1
Location of Algal Flow-Way at DMT



Basemap Source: Google Maps

MDOT-MPA has been leading the way in the Chesapeake Bay with its integrated Algal Flow-Way Technology (AFT), Digester, and Fuel Cell Demonstration Project , initiated in 2013 to evaluate the technology as an innovative nutrient removal practice for improving water quality and help Maryland meet its Chesapeake Bay Total Maximum Daily Load (TMDL) pollution reduction requirements. Since then, the AFT has been removing excess nitrogen, phosphorus and suspended sediment from Baltimore Harbor and producing valuable data and information that is being used to prove the pollutant removal value and energy production potential of biogas from this innovative technology. The project is also providing critical feasibility data and design evaluation information for a possible full scale, half-acre AFT being considered for construction on beneficially reused dredged material at MDOT-MPA's Hawkins Point Facility.

MDOT MPA originally partnered with the University of Maryland to develop the system and Maryland Environmental Service to operate it. The AFT is a linear raceway constructed at the Dundalk Marine Terminal (DMT) located on the Patapsco River (Figure 1-1). The AFT uses water from the Patapsco River, which is pumped from the adjacent water way and allowed to flow down the raceway to grow algae on a surface specifically designed to enhance algal growth. The algae grows rapidly with nutrient-rich water flowing continually over it and is periodically removed by vacuum. As the algae biomass grows it takes up nitrogen, phosphorus and sediment from the water and improves the quality and oxygen levels of the water returned to the river from the AFT. The algae and nutrients and sediment it takes up is removed, dried and weighed to determine the quality of nitrogen, phosphorus and sediment removed from the waterway.

Algae grown on the flow-way are also being used as feedstock for an algal digester system, developed by the University of Maryland, engineered by a team led by Anchor QEA and generously funded by the U.S. Department of Transportation Maritime Administration (MARAD), that uses anaerobic digestion (AD) to produce biogas used to generate electricity for lights and a recirculation pump on site.

The AFT, Digester and Fuel Cell Demonstration Project has proved to be a very fruitful effort for MDOT-MPA, resulting in a number of benefits to the Port, the Chesapeake Bay region and other areas similarly impacted by excess nutrient pollution. Benefits include:

- Removal of excess nutrients and sediment from eutrophic water bodies
- Nutrient and sediment reduction credit to meet MDOT-MPA's Municipal Separate Storm Sewer System (MS4) permit Chesapeake Bay restoration requirements
- 24/7 operation providing constant removal of nutrients not just during rain events
- Cost effective nutrient removal compared to conventional stormwater treatment technologies

- Delivers increased dissolved oxygen to the water body, which improves aquatic habitat
- Demonstrates a very effective pollution control measure that could be applied to other properties similar to the Port, with onsite and property boundary constraints and water access
- Demonstrates the feasibility of integrating an algal flow-way, an anaerobic algal digester, a biogas collection and conditioning unit, and a fuel cell to convert algae to energy.

The project demonstrated the integration of several innovative technologies in a marine industrial environment and supported the MDOT MPA's commitment to the environment by improving water quality, reducing air emissions, and incorporating alternative energy sources. The results from this project will provide researchers, engineers, and large-scale system designers information needed for future algal flow-way technology, digester, and fuel cell projects.

2) Goals and Objectives

The goals of this project are to:

1) Demonstrate and optimize the effectiveness of the AFT by testing various methods of operation and provide data and design parameters necessary to support development of a large scale project at the MDOT-MPA's Hawkins Point Facility that will help MDOT-MPA to cost-effectively meet its MS4 permit requirements for Chesapeake Bay Restoration; and

2) Evaluate the feasibility and develop a system, including operation and design parameters, to integrate the algal flow-way with an anaerobic algal digester, a biogas collection and conditioning unit, and a fuel cell to convert the algae grown by the AFT to energy that can be used to help meet onsite needs for power.

The specific objectives of the project are to:

1) Test how changes to operational conditions such as the water flow rate and the surface material of the flow-way influence total algal growth
2) Evaluate methods for harvesting and dewatering algal biomass to increase efficiencies for biomass recovery, handling, and transport

3) Calculate total nitrogen and total phosphorus removal based on the total algal biomass (productivity)
4) Optimize operating conditions of the AFT to maximize the efficiency of nutrient and sediment removal from adjacent surface waters of Baltimore Harbor.
5) Optimize operating conditions to harvest algae from the AFT for an algal-based digester to produce and capture a consistent, high-quality biogas that can be used to generate electricity on site.

3) Discussion

- **Background**

AFT's have been used previously to remove nutrients from ambient water in other areas, including Florida and Texas with good success. In 2013, MDOT-MPA initiated a partnership with the University of Maryland and the Maryland Environmental Service (MES) to construct and operate an AFT in order to evaluate its nutrient and sediment removal effectiveness for the Patapsco River tributary of Chesapeake Bay. The AFT was constructed at DMT to assess the potential for improving water quality by removing nutrients and sediment from the Patapsco River. Since then, the AFT has operated for over 7 years, from 2013 to the present, removing nutrients and sediments from the Patapsco River. At the same time, the partners have been collecting data and making improvements to the system design, method of operation, and biomass handling techniques have been implemented to improve the nutrient removal and biogas generation potential of the system.

MDOT-MPA and its partners have experimented with various lengths of flow-way surface, different pump rates at which Patapsco River water was delivered to the flow-way, using tipping buckets to deliver Patapsco River water to the flow-way in a pulsed manner, operating for varying lengths of time and seasons, various manual harvest methods, transporting via vacuum truck, and air drying by evaporation in an open area. Dried algal biomass was periodically collected, weighed, and disposed of in a local landfill.

Using data from the MDOT-MPA AFT Demonstration Project and other sources, in October 2015, the Chesapeake Bay Program (CBP) published the final report of an expert panel convened to evaluate the nitrogen, phosphorus and sediment reductions that could be achieved by AFT's. The expert panel concluded that the AFT was an effective way to remove nutrients and sediments to meet the nutrient reduction requirements of the federal Clean Water Act Total Maximum Daily Load (TMDL) for Chesapeake Bay and its tributaries. The recommendations of the Expert Panel were reviewed and formally adopted by the Water Quality Goal Implementation Team of the Chesapeake Bay Program. The AFT became an approved management practice for removing nutrients and sediments to meet the requirements of the TMDL.

Once the AFT was approved by the Chesapeake Bay Program, the technology became eligible for generation of credits for MS4 permits, however, the Maryland Department of the Environment (MDE) had not yet developed specific methods and procedures for those credits to be adopted into State water quality regulations and permits. MDOT-MPA approached MDE and offered to work with them in partnership using its AFT system data as a demonstration case for regulatory adoption of the credits. MDOT-MPA and MDE technical staff met, agreed upon an appropriate methodology and worked together to modify the NPDES Discharge permit for the AFT to allow it to be used to generate nutrient credits by establishing a nutrient baseline in the permit and including annual reporting requirements in the permit. MDOT-MPA then worked with MDE to complete the necessary data analysis and reporting to register the credits in the Maryland Water Quality Trading Program. The MDOT-MPA AFT became the first such facility approved for credits in Maryland in 2018. Additional credits were registered in 2019 and MDOT-MPA plans to keep operating the system in the future.

In addition, recognizing the potential for productive use of the algae grown in the AFT, in 2016, the MDOT-MPA team applied for and received a grant from MARAD to initiate Phase 1 laboratory studies to support integrating the AFT with a biogas production system. In Phase 2 (2017) and Phase 3 (2018) the project moved into field studies to enhance biomass handling procedures and use the algae grown on the AFT to produce biogas and power a fuel cell. In Phase 4 (2019) the focus was on refining flow-way operation and biomass handling approaches and increasing energy production from digestion using the algal flow-way feedstock.

- **Objectives and methodology**

The ultimate objective of the project is to develop, construct and operate an AFT-digester-fuel cell system that is capable of removing algae from eutrophic waters of Chesapeake Bay and converting the algae grown into useable energy. This is a difficult scientific, technical and engineering challenge. An adaptive management approach was necessary for the project to provide the flexibility to respond to changes in on-site conditions, to replace project components that were not effective in meeting the project objectives, to integrate new knowledge or new technologies, and to test alternative project hypotheses.

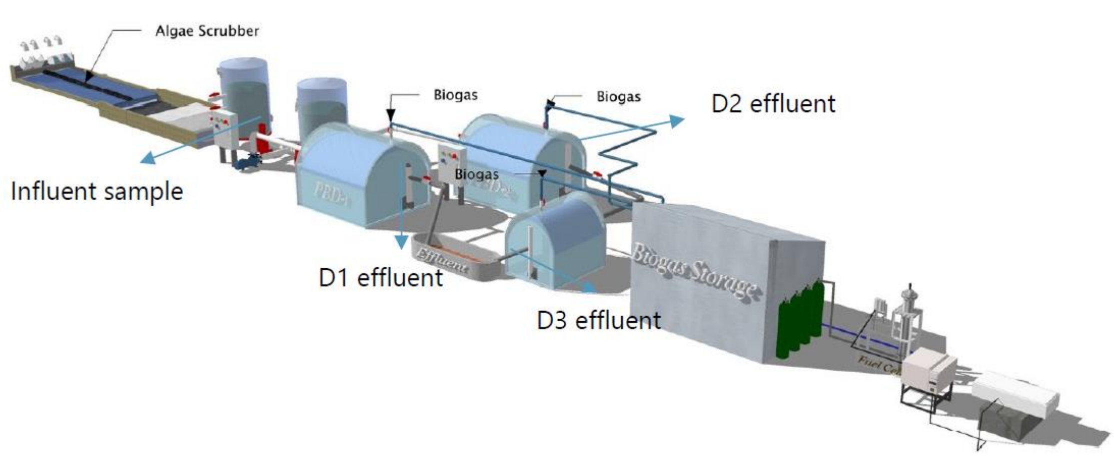
It was apparent early in the project that the originally proposed dewatering approaches – the concrete dewatering pad and the evaporation bed – were insufficient to provide the dewatering capability required for the project given the dominance of filamentous diatoms. The project team worked on a weekly basis to design, discuss, and implement multiple new strategies for biomass handling that were based on observed site conditions and constraints, previous project experience from the MDOT-MPA AFT, expertise from operating AFTs in other parts of the United States, and experience working within MDE's regulatory framework. Additional dewatering strategies implemented blended engineering and scientific expertise and had the dual goals of enhancing the percent solids of algal biomass to make biomass handling easier and quantifying TN and TP concentrations to understand the potential for water quality improvements from AFT operations.

A particular challenge was identifying the right combination of design elements and operational components that would: 1) maximize algal biomass productivity for the digester; 2) result in implementable options for large-scale construction, and 3) provide low-maintenance options for frequent reoccurring harvests. Algal growth is highly variable and susceptible to changes in a variety of ambient environmental conditions that cannot be controlled. Water temperature, light availability, and water quality conditions such as concentrations of available TN and TP and salinity are all important environmental conditions that influence algal growth and species composition, and these conditions are known to vary widely in the Patapsco River during planned AFT operations (April to November). These environmental conditions were measured throughout the project testing program to provide information to interpret data and to evaluate if variability of one or more of these parameters impacted algal growth. The intent was not to conduct a detailed study on algal biomass in response to environmental conditions, but to use environmental data as necessary to interpret data collected for algal biomass growth and total productivity.

The project included experiments to determine the effectiveness of an anaerobic digestion (AD) system capable of producing renewable energy from the algae harvested from the AFT. Batch-scale experiments in Phase 1 concluded that anaerobic digestion of the harvested algae could successfully produce biogas and support the design of a system for collecting the expected biogas production. In Phase 2, the process was scaled up to a pilot-scale AD unit, which was installed in 2017. For Phase 3, the pilot-scale AD system was modified to improve the anaerobic digestion process and increase methane output. In Phase 4 investigations focused on addressing three challenges encountered during Phase 3 that affected the operating efficiency of the algal digesters: 1) increasing the total amount of algae (i.e., productivity) available for testing; 2) increasing the percent solids of the harvested algae through improved biomass handling; and 3) increasing energy production from AD of the harvested algal biomass. The additional testing completed in Phase 4, led the investigators to conclude that the AFT produced algae from the Patapsco River is a viable feedstock for AD. The biogas produced from AD of algae was comparable in methane content to biogas derived from more traditional digestion feedstocks, with notably lower hydrogen sulfide production due to the high iron content of the feedstock.

When high-quality biogas is successfully produced from an algal digester system, the biogas can be used to power a fuel cell, using a cleaner fuel source to reduce dependence on the existing electrical grid. The pilot system tested here - growing algae on an AFT, using a digestor to breakdown the algae and create biogas, and using the biogas to feed a fuel cell – creates a closed energy loop to produce on-site electricity. Biogas generated from the algal digesters for this project was successfully used as supplemental fuel to natural gas and achieved a steady power output.

Figure 1-8
Algal Digestion System at the Port of Baltimore, with Sampling Points Noted with Blue Arrows



Additional testing of the system is recommended to allow for modification the system design to include a more efficient recirculation system to completely mix the digestate and enhance full digestion of nutrients and to install and operate a heating system to maintain internal temperatures during a full operating season. Future testing may also include a system redesign to identify the optimal configuration - such as the number of digesters, running single digester units, running multiple digesters connected in series, and/or the type of digester units to use - to achieve maximum biogas production.

- **How the project fulfills the Award Criteria**

1. **The level and nature of benefits to environmental quality, beautification or community involvement;**

The AFT, Digester and Fuel Cell Demonstration Project has proven to be a very fruitful effort for MDOT-MPA, resulting in a number of benefits to the Port, the Chesapeake Bay region and other areas similarly impacted by excess nutrient pollution. Benefits include:

- **Removal of excess nutrients and sediment from eutrophic water bodies**

The AFT constructed for this demonstration project has been consistently removing excess nutrients and sediment from the Patapsco River tributary of Chesapeake Bay for over 7 years. Nitrogen, phosphorus and sediment reductions achieved by the AFT, which is less than 200 m^2 (0.05 acres) in total surface area, removes nutrients at the rate of 1250.7 pounds N/acre/year and 170.3 pounds P/acre/year. Using MDE's published values for impervious surface nutrient loading, the 0.05 acre pilot scale AFT removes the equivalent of 8 acres of impervious surface treatment for nitrogen and 4.5 acres for phosphorus.

- **Nutrient and sediment reduction credit to meet MDOT-MPA's Municipal Separate Storm Sewer System (MS4) permit Chesapeake Bay restoration requirements**

MDOT-MPA worked with MDE to develop the registration process for the State's Water Quality Trading Program and has registered nutrient and sediment credits from the AFT for 2018 and 2019.

- **24/7 operation providing constant removal of nutrients not just during rain events**

The AFT operates continuously as long as the pumps are running, unlike conventional stormwater treatment systems that only function when it rains.

- **Cost effective nutrient removal compared to conventional stormwater treatment technologies**

Cost analysis conducted by the University of Maryland Center for Environmental Science for MDOT-MPA has shown that the AFT can be a very cost effective treatment practice compared to conventional stormwater treatment methods, particularly for sites like the Dundalk Marine Terminal that have significant space constraints.

- **Delivers increased dissolved oxygen to the water body, which improves aquatic habitat**

The treated water returned to the Patapsco River by the AFT has lower nutrient and sediment levels and higher oxygen than the ambient water.

- **Demonstrates a very effective pollution control measure that could be applied to other properties similar to the Port, with onsite and property boundary constraints and water access**

The scientific, technical and engineering studies conducted for this project provide valuable guidelines for development of AFT installations on other sites in the Port and potentially other similarly space-constrained facilities. MDOT-MPA is using the information gained from this project and is in the process of designing a much larger ½ acre AFT on the Hawkins Point Facility, using reclaimed dredged material to construct the foundation.

- **Demonstrates the feasibility of integrating an algal flow-way, an anaerobic algal digester, a biogas collection and conditioning unit, and a fuel cell to convert algae to energy.**

Not only does the AFT remove nutrients and sediments from the water, use of the algae grown to generate biogas in an anerobic digester and a fuel cell to convert the gas to electricity has been demonstrated to be feasible and design parameters have been developed for scaling the system up to produce energy for the full scale AFT MDOT-MPA is considering for Hawkins Point.

2. The level of independent involvement and effort by the port;

The demonstration project was conceived by MDOT MPA in partnership with the University of Maryland and initially constructed with funding from MDOT-MPA. Subsequent grants from MARAD, also obtained through the initiative of MDOT-MPA, allowed the project to expand to incorporate the development and testing of the anaerobic digester and fuel cell.

Recognizing the potential for broader application of the AFT, members of the MDOT MPA team participated as members of the Chesapeake Bay Program Expert Panel that evaluated and approved the AFT for use as a nutrient and sediment removal practice for the Chesapeake Bay restoration.

MDOT-MPA wrote to MDE Secretary Ben Grumbles suggesting that the Departments work together on the development of procedures for permitting the AFT and registering credits with MDE to allow the AFT to be used for meeting MS4 permit requirements for Chesapeake Bay restoration.

MDOT-MPA is currently funding design of a 10x larger version of the AFT, using the information and lessons learned from the 0.05 acre pilot demonstration project, to develop plans for a possible ½ acre AFT at its Hawkins Point Facility.

3. **The creativity of the solution or programs;**

Although the AFT has been used in other locations, the MDOT MPA AFT is one of the first developed in the Chesapeake Bay region. There were a number of scientific, technical and engineering obstacles to overcome in applying the technology in Maryland and the MDOT-MPA team exhibited their creativity through an adaptive management process to develop and refine the system to make it function efficiently in the Chesapeake Bay environment. A particularly difficult challenge was fine-tuning the operation of the AFT to obtain maximum algal growth and modifying the handling and drying process to maximize the biogas production and quality from the naturally occurring algal assemblage in the Patapsco River.

Linking the AFT to a digester and fuel cell was creative in that it coupled the benefits of nutrient removal from the water with reducing energy consumption and improving air quality. It also recognized the algae as a resource rather than treating it as a waste product. Beginning with Phase I of the project to bench-test the feasibility of the process, the MDOT-MPA project team was able to obtain and maintain MARAD grant funding through all 4 phases of the project. With its strong support, MARAD certainly recognized the creativity and potential of the MDOT-MPA demonstration project as well.

MDOT-MPA further developed the potential of the AFT by working with MDE to obtain permit modifications and approvals necessary for registering the nutrient credits from the system for Chesapeake Bay Restoration purposes. MDOT MPA has always been willing and able to see the broader application of its work to other applications and has worked to share its success with other State agencies, port businesses, environmental groups, and adjacent communities.

4. **Whether the project or program results are apparent (the project must be complete through some beneficial increment);**

Every step of the way with the project, the MDOT-MPA team has worked to make sure environmental regulators and the public were aware of the potential and success of this project. Regulators at the Chesapeake Bay Program and MDE have reviewed the data, visited the site several times and approved the AFT for use in the Chesapeake Bay and Maryland water quality restoration. Environmental groups like the Chesapeake Bay Program and Blue Water Baltimore have been briefed and have toured the site.

The AFT installation at DMT is also a feature of regular public tours of the Port and MDOT-MPA facilities offered by the Baltimore Port Alliance, a group of port-related businesses and agencies.

The specific results of the Demonstration Project are clearly apparent as documented above:

- the AFT has been in operation and removing nutrients from the Patapsco River and Baltimore Harbor for over 7 years
- the MDOT MPA Demonstration Project has been instrumental in obtaining Chesapeake Bay Program approval and establishing the MDE regulatory and crediting process for AFTs in Maryland
- the adaptive management approach applied by the MDOT-MPA team has resulted in significant design and operational refinements to the system that are being applied in design of a scaled-up system for development at the Port of Baltimore.

5. **The cost effectiveness of the activity or the program; and**

Nitrogen, phosphorus and sediment reductions achieved by the AFT, which is less than 200 m^2 (0.05 acres) in total surface area, remove nutrients at the rate of 1250.7 pounds N/acre/year and 170.3 pounds P/acre/year. Using MDE's published values for impervious surface nutrient loading, the 0.05 acre pilot scale AFT removes the equivalent of 8 acres of impervious surface treatment for nitrogen and 4.5 acres for phosphorus. This is 160x the nitrogen and 90x the phosphorus removal efficiency of impervious surface treatment with conventional stormwater controls. MDOT MPA's planned scaled up version of the AFT at ½ acre in size will produce 10x the nutrient removal benefit of the demonstration AFT.

Cost analysis by the University of Maryland Center for Environmental Sciences for MDOT MPA estimated the $/lb of nitrogen and phosphorus reductions at similar levels to the cost for stormwater treatment using wetlands and wet ponds, which require much more space than the AFT. This makes the AFT much more cost effective per acre consumed than almost any other stormwater treatment measure available.

6. **The transferability of the technology or idea to the port industry.**

As noted above, the AFT has already been transferred from Florida and Texas to the Chesapeake Bay Region. The refinements made through the adaptive management process used by the MDOT MPA team to refine the design and operation and successfully link the AFT to an anaerobic digester and fuel cell that utilizes the algae produced to make electricity, make the technology even more valuable to the port industry.

Most ports are constrained by space. The AFT has been demonstrated to be cost-competitive with other stormwater pollution control methods, but it uses only a fraction of the space required by traditional measures. This makes it particularly well suited to the port environment.

The MDOT MPA project was funded by MARAD and extensive documentation of the results is available that has been prepared by Anchor QEA, MDOT-MPA’s lead consultant on the project. Results have already been shared with the Chesapeake Bay Program, MDE and MARAD. The same documentation of results and recommendations for scale up designs are also available to others in the port industry that are interested in exploring the use of this innovative new technology to clean up their waterways and produce clean energy.