Washington Maritime Blue is the newly formed cluster organization that is working in collaboration to implement the state's strategy for the Blue Economy- for a thriving maritime economy, a healthy ocean and marine environment, and equitable and resilient communities. The vision is to make WA State home to a world class, thriving and sustainable maritime industry by 2050.

The Maritime Blue cluster organization is charged to work in collaboration across industry, government, research and community organizations to implement maritime decarbonization and other joint innovation projects. Working in a strategic alliance across public and private entities, we are finding new ways to tap into funding opportunities, bring together necessary expertise, and accelerate innovations through cooperative implementation of key projects. It is also critical to work in collaborative planning efforts to develop roadmaps and share lessons learned in order to scale the innovations.

We are facing an incredible opportunity and need to accelerate the commercialization of difficult to decarbonize sectors, such as the Maritime industry. What we see regionally and globally, is that opportunities for electrification and alternative fuels in the maritime sector are abundant. The reductions in costs and weight for battery technology have resulted in increased utilization of batteries and hybrid technology for ships such as ferries, tugs, offshore supply, and short sea cargo vessels[1]. Local, regional, and international ambitious targets for emission reductions means new storage technologies and alternative fuels must advance at a faster pace than they are now, in order to meet the forthcoming regulations and goals. This was the conclusion of DNV GL's recent Maritime Forecast to 2050 report[2].

Washington state's pulp and paper industry has seen a huge decline in the last two decades. However, the kraft paper segment is seeing millions of dollars invested in new plants and equipment, and the inspiration for all that investment can be found as close at hand as the deliveries arriving on your front porch…what some are calling the 'Amazon Effect.'

It is against this backdrop that we examined ways to address a regional need for improved access to a recycled feedstock (Old Corrugated Containers or OCC), and an opportunity to accelerate innovation in decarbonization for short sea cargo vessels such as barges. The report that follows is two-fold:

1. An examination of the feedstock options for "Recycled Paper Barging to Washington State Mills." The study identifies feedstock locations, availability and industry interest from both barge and mill operators.

[1] The latest statistics on uptake of batteries and alternative fuels in vessels are available at DNV GL's Alternative Fuels Insight platform: www.afi.com

[2] **DNV GL.** Energy Transition Outlook. [Online] 2019a. https://www.dnvgl.com/publications/energy-transition-outlook-2019-162874.

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2. "Zero emission Barge Feasibility Study" examining the potential for a zero-emission battery barge for the route that was identified to have the most economic feedstock potential.

The first report found that, barging should theoretically reduce recycled paper transportation costs, the costs of shipping paper from the mills to boxboard producers and the costs of shipping residual materials from the mills to approved landfills. Industry interest was also confirmed among the Mill operators, such as McKinley Mill in Port Angeles, and barge operators, such as Brusco Tug and Barge.

While the battery barge study determined that current battery technologies were un-feasible solutions for barges designed for the longest route identified (Los Angeles to Port Angeles), shorter routes within the Puget Sound (i.e. Tacoma) or to British Columbia (i.e. Vancouver) could make the battery powered barge/tug option technical and financially feasible. Low emission alternative fuel and hybrid operations could also have potential. However, more detailed analysis is required to determine feasibility.

Another factor to keep in mind is the traffic and emission reduction potential of barging versus trucking. The new recycled paper-based containerboard mill's needs for large volumes of recycled paper deliveries and the needs for the shipment of paper products (and the contaminates in the recycled paper) back out won't just create new road congestion problems and higher trucking costs. All of those new truck trips will create a major increase in the state's carbon emissions.

Finally, increased access to barge capabilities in rural communities can increase economic opportunities through improved access to supply chain. For Port Angeles, the economic development potential for finished products and essential feedstocks are constrained to trucking and limited airport access. Barging, whether utilizing new technologies or traditional fuels, can improve access and opportunities for supply-depended businesses.

Thank you for your consideration of the findings in this report. We look forward to working in collaboration with regional and global partners to advance these concepts further. Please reach out to Washington Maritime Blue at the contact information below to find out how to get engaged.

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WASHINGTON MARITIME blue

May 2020

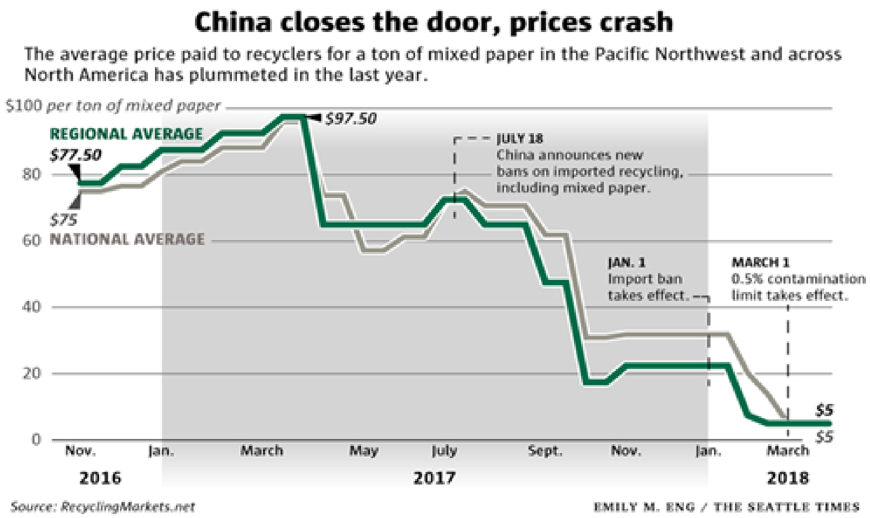
RECYCLED PAPER BARGING TO WASHINGTON STATE MILLS

In the January/February 2020 edition of Seattle Business Magazine, author Bill Virgin described a recent, very remarkable development in Washington State's pulp and paper industry:

> *"The pulp and paper industry in Washington have become a shadow of its former self as economic trends and changing business practices have combined to shrink demand for paper products. As recently as 1990, paper manufacturing accounted for about 16,500 jobs. Today, it's about 7,600... There is one segment of the state's pulp and paper industry, however, that is seeing millions of dollars invested in new plants and equipment. The inspiration for all that investment can be found as close at hand as the deliveries arriving on your front porch... Longview-based North Pacific Paper Co. (Norpac) recently announced plans to convert one of its three machines to making kraft paper (a heavy brown paper most commonly seen in grocery bags), linerboard and corrugating medium — the fluted material that separates the inner and outer walls of boxes... Norpac's announcement represents the third major conversion project for machines or entire mills to packaging papers. In 2017, Packaging Corp. of America announced a $150 million conversion of a machine making office and printing papers to production of linerboard at its Wallula mill in southeastern Washington. McKinley Paper Co., meanwhile, has begun hiring for a planned restart of a Port Angeles mill that once produced telephone-directory paper... Norpac adds that it will recycle more than 400,000 metric tons per year of waste paper, 'the equivalent of all available mixed paper grades recovered in Washington, Oregon and Idaho."*

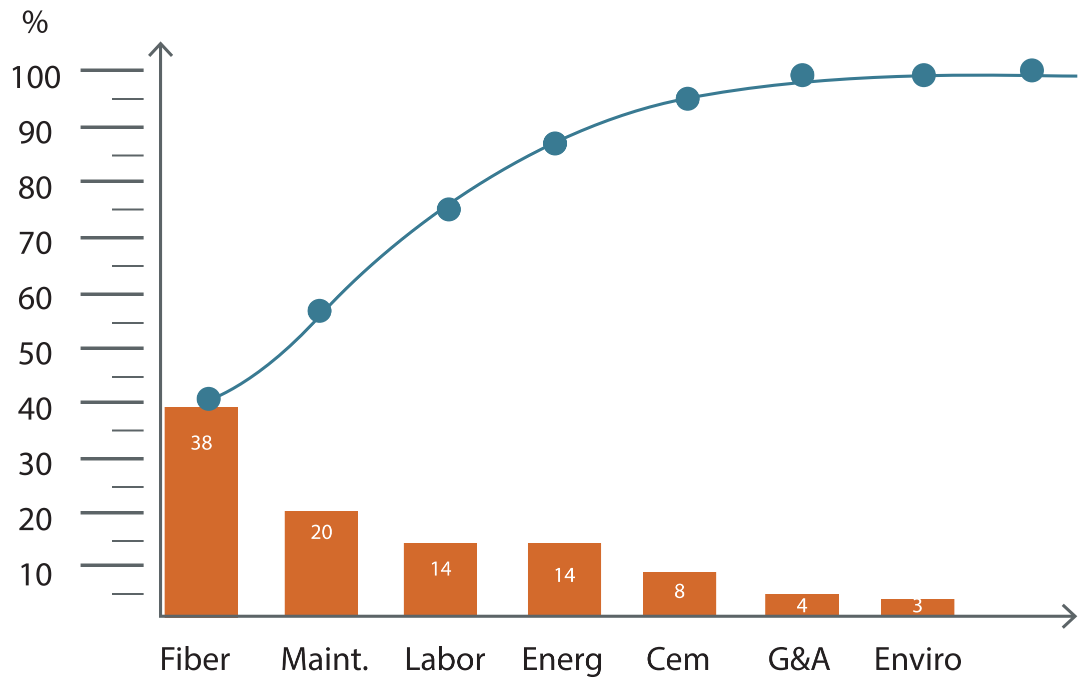
Virgin's article actually understates the dramatic recycled paper-based pulp and paper mill renaissance in and around the state. In October of last year, Port Townsend Paper Company started up a new OCC (Old Corrugated Containers - a good quality recycled raw material) process that expands that mill's consumption of OCC from 400 TPD (Tons per Day) to 750 TPD. Kapstone's mill in Longview already consumes 1,000 TPD of OCC and Westrock's mill in Tacoma presently consumes 500 TPD of OCC. Georgia Pacific is currently starting up a new pilot plant at their Toledo, Oregon mill (which currently consumes 1300 TPD of OCC). The new pilot plant will reportedly consume 200 TPD of MWP (Mixed Waste Paper). International Paper Company's Springfield, Oregon mill also consumes over 600 TPD of OCC.

Why the sudden surge in paper mill conversions? To begin with, the US demand for most grades of paper is plummeting. But, in part because of the 'Amazon Effect', the US demand for cardboard boxes is actually increasing. Furthermore, China- which has very recently built an entire, new containerboard industry based upon recycled fiber- has severely restricted imports of recycled fiber. Near term US recovered fiber prices have fallen accordingly.



For a paper producer, this is a very big deal. As the following exhibit illustrates, the cost of fiber- virgin or recycled- is typically the most significant cost in the production of the 'medium' and 'liner' papers that are ultimately purchased by cardboard box producers.

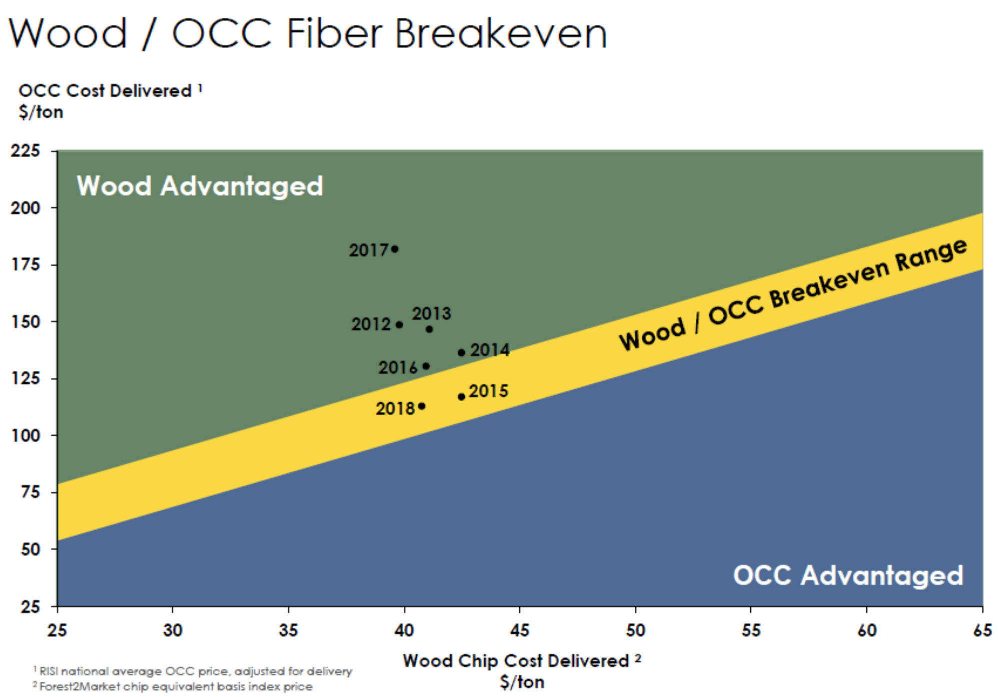
TYPICAL WA CONTAINERBOARD MILL PARETO COST ANALYSIS



But there is a limit to the price containerboard mills can afford to pay for recycled papers. To begin with, not all recycled old cardboard containers and mixed waste papers have the same value to mills. There is a substantial difference in the fiber lengths and the recycled paper contamination levels. Furthermore, there is paper market competition from the containerboard mills that can utilize virgin fiber. Following is a fiber supply tradeoff graph from a recent International Paper Company (IP) Investor roadshow. The cluster of data points shows actual fiber costs. As you can see, in general over the 2012 to 2018 time period, IP's (generally southern pine) virgin fiber costs were lower than their OCC prices.

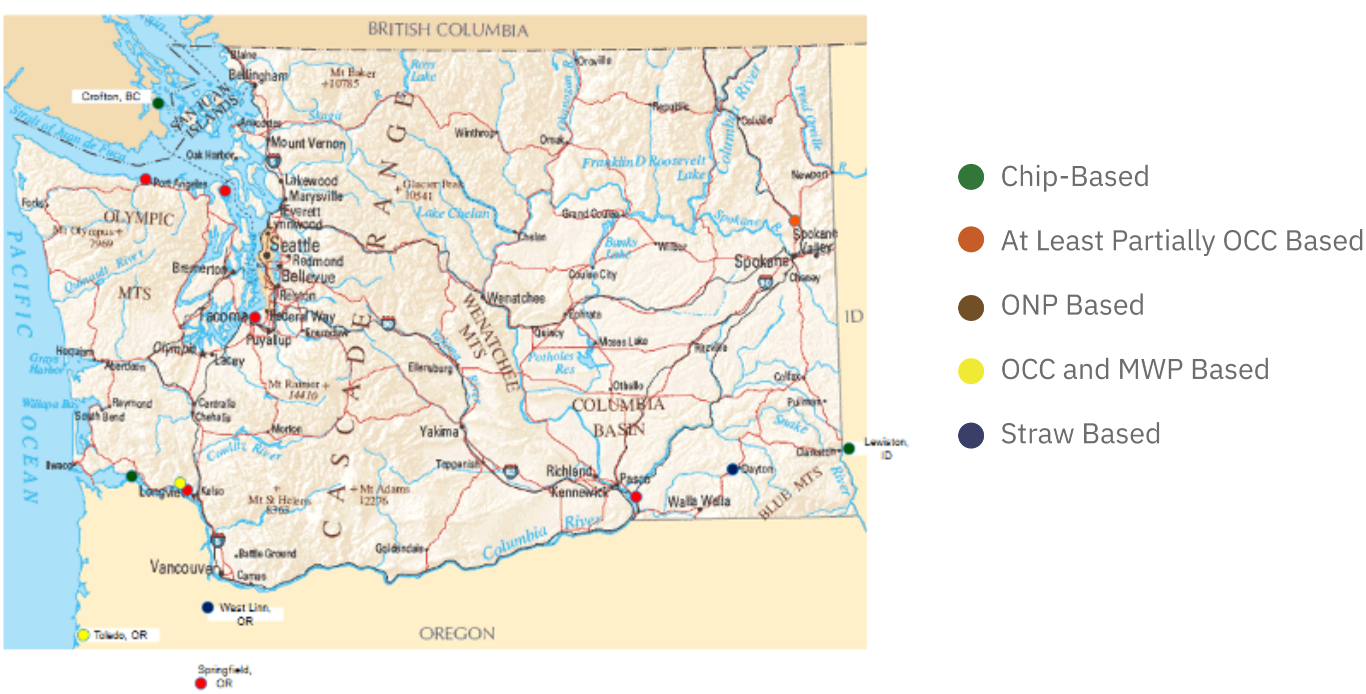
In response to the new China import restrictions, Lee and Man Paper Company, China's second largest containerboard producer, is now starting up three new recycled paper-based containerboard mills in SE Asia and sourcing those mills with inexpensively-transported, 'back haul' containers of OCC from the US and Europe.

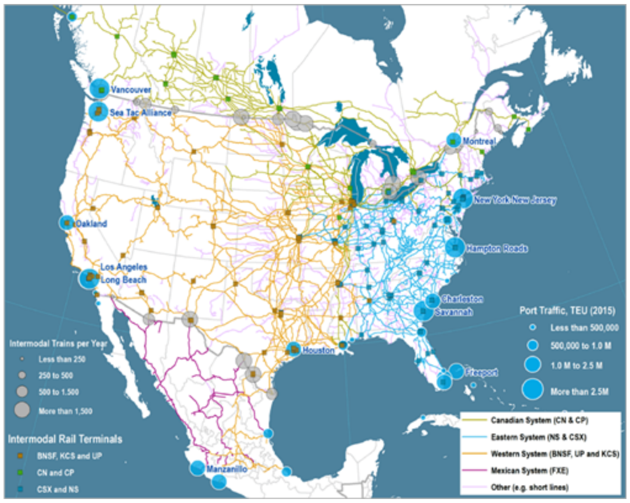
Let's add up the Washington-based mills' new demand for OCC. Port Townsend's demand has apparently grown from 300 TPD to 750 TPD, or by roughly 160,000 TPY (Tons per Year). The McKinley mill's demand will reportedly grow to 350,000 TPY. The PCA mill's demand will also reportedly grow to roughly 350,000 TPY. That is a total increase in Washington mill OCC demand (we'll leave Norpac's projected recycled paper demand of 400,000 TPY- reportedly demand for just MWP- out for now) of 860,000 TPY. The Chinese mills' demands for OCC has not permanently disappeared either. In response to the new China import restrictions, Lee and Man Paper Company, China's second largest containerboard producer, is now starting up three new recycled paper-based containerboard mills in SE Asia and sourcing those mills with inexpensively-transported, 'back haul' containers of OCC from the US and Europe. As recently as 2016, 670,00 tons of waste paper was exported to Asia from the State of Washington. Roughly 215,000 tons of that volume was likely MWP but that also included 455,000 tons of OCC. A portion of that OCC was sourced by rail from inland sources, intermodally (see the intermodal map on page #4) but most of it was trucked from Washington and Oregon municipal recovery facilities (MRF's) to the Ports of Tacoma and Seattle.



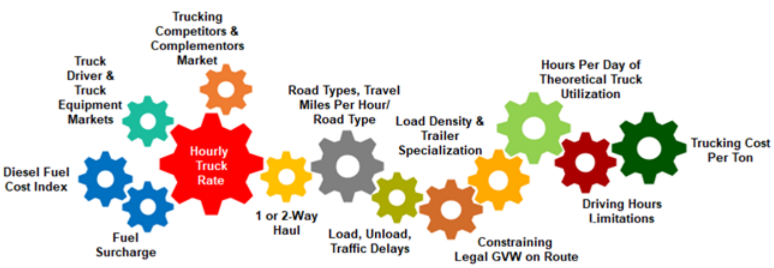
PULP AND PAPERMILLS IN AND NEAR WASHINGTON STATE

Where will all of the OCC supply for the current and renovated Washington mills come from? According to the Washington Department of Ecology, Washington's 7.31 million citizens generated 180,000 tons of MWP and a little over 500,000 tons of OCC in 2017, roughly 140 #'s of OCC and 50 #'s of MWP per person. Assuming similar waste paper generation rates, British Columbia's population of 5 million people likely generated 350,000 tons of OCC and 125,000 tons of MWP. Idaho's population of 1.75 million generated only 122,000 tons of OCC and 35,000 tons of MWP. Oregon's more substantial population of 4.19 million generated 293,000 tons of OCC and 105,000 tons of MWP. It is not until we move down the west coast to Northern California, with a population of 15.31 million people and no pulp and paper mills, that the volumes of recycled paper supply really become substantial, over 1 million tons of OCC and almost 400,000 tons of MWP. Even more substantial are the generation rates in Southern California which has a population of 24.12 million, almost 1.7 million tons of OCC and over 600,000 tons of MWP. The LA-Long Beach area is also the nation's biggest intermodal hub. The area handles many containers of recycled paper that are accumulated inland across the country and shipped to Asia. It is not by coincidence that Lee and Man Paper Company's global recycled paper procurement business, WinFiber, is headquartered in the LA area. As a general rule of thumb, OCC values in the PNW are $10/ton higher than OCC values in Oakland which are $10/ton higher than OCC values in LA.





Why won't suppliers simply truck the required volumes of OCC to the renovated Washington mills? Let's look at a generic trucking cost model.

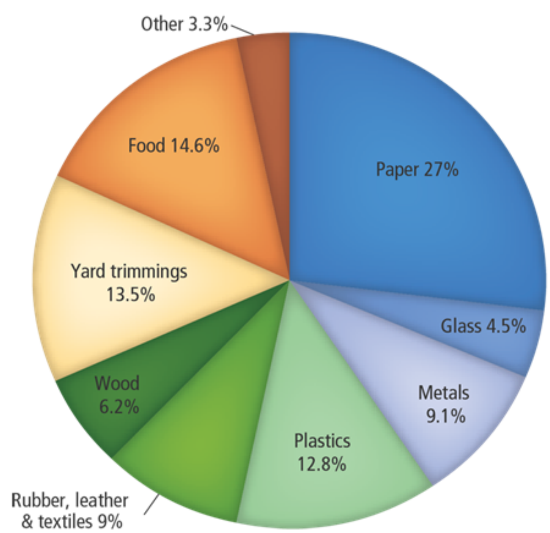


Trucking costs vary with local markets for drivers and trucking equipment but, in general, they are most variable with respect to: 1) current diesel fuel costs, 2) the opportunities for two-way or backhauls, 3 road types and legal travel speeds, 4 load and unload times and traffic delays and 5) load-specific trailer specialization (how efficiently does the truck's trailer/s capitalize on the character of the material being hauled and the state's or province's legal load limits?). Accessing California's abundant recycled paper supplies by truck is a special trucking cost challenge. British Columbia, Washington and Oregon all permit truck configurations with 105,500 GVW (Gross Vehicle Weight) but 80,000 GVW trucks are common on Interstate 5 because that is the legal limit on trucks that haul into or out of California and the other states with lower load limits. Another special trucking cost challenge are the Puget Sound and Portland traffic delays. A final waste paper trucking cost challenge is obsolete waste paper baling technology. Many MRF balers are so old and inefficient that trucks also struggle to get up to their legally permissible load weights.

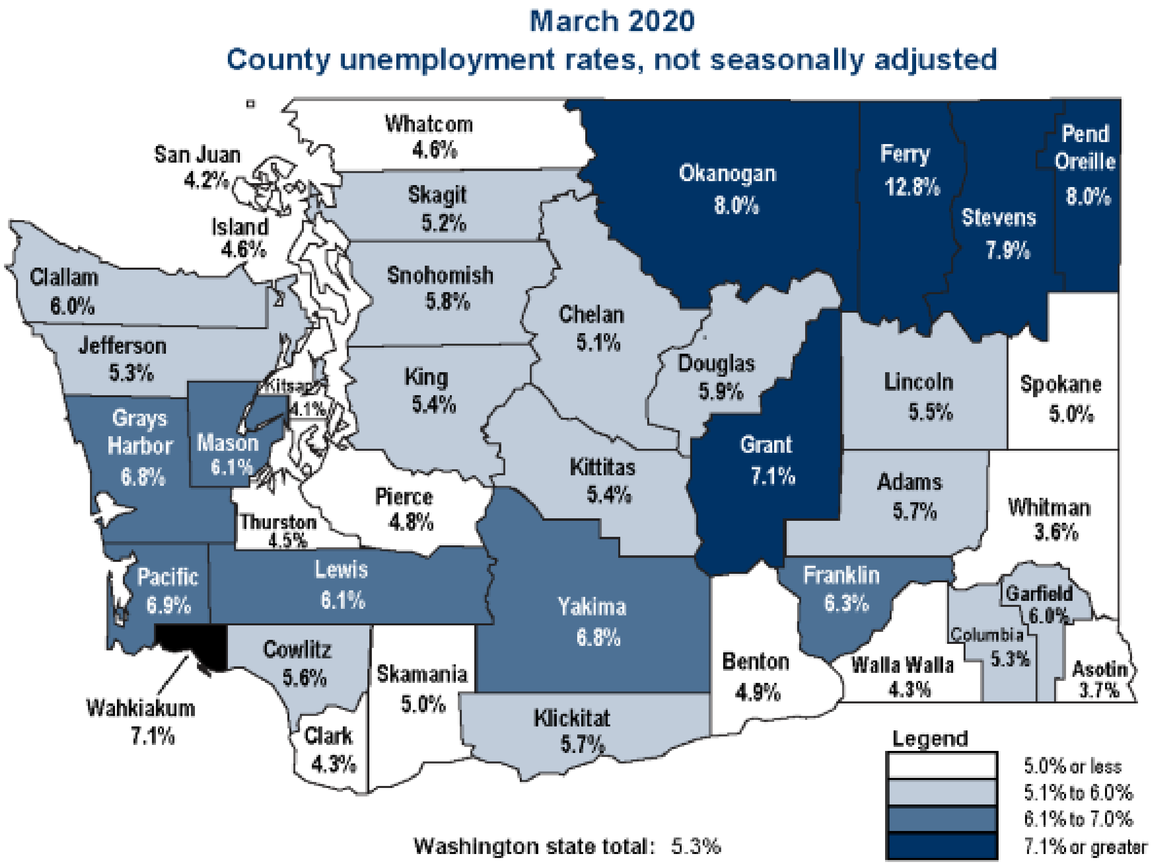
As a result of the preceding factors, the OCC trucking cost from Vancouver, BC to Tacoma, Washington could be over $35/ton. The trucking cost from Oakland, California to Tacoma, Washington could be well over $100/ton. The OCC trucking costs from Los Angeles to Tacoma, Washington could be well over $150/ton. Referring back to the graph on page #2, the delivered costs of OCC trucked from Vancouver, BC are also high. From OCC-plentiful LA where OCC sells for roughly $90/ton for export quality and $32/ton for domestic quality, the delivered OCC trucking costs are likely too high for the new OCC-consuming mills.

What about rail? Published Union Pacific boxcar rates from Los Angeles to Tacoma were recently $95/ton for high cube boxcars, $112/ton for regular boxcars. Published high cube and regular boxcar rates from Dallas, Texas and Chicago to Tacoma were similar, all well over $100/ton. And these rail costs don't include the additional costs of loading and unloading boxcars, the costs of rail delays and the additional intransit inventory and the requirements for specialized, rail-compatible warehouses and transloads. Intermodal costs should be explored but they appear to be similar.

Expanded production of recycled-paper based containerboard, produced in renovated and converted pulp and paper mills in Washington State, should also reduce the state's landfilling needs. As this exhibit from the EPA illustrates, waste paper is usually the largest component of municipal waste streams.



Washington State mills that are currently being augmented by, or converted to, recycled paper-based containerboard production are generally located in rural communities. And, as illustrated by the following map, these mills are located in communities and counties that have suffered comparatively high unemployment rates as the supply of virgin fiber chips has declined.



The trucking cost model on page 5 illustrates the significant costs of traffic congestion, a serious and growing trucking cost problem in the state. The most obvious problems are with trucking through the urban areas but the rural roads serving the pulp and paper mills are also becoming more congested. These roads were generally designed to handle far less traffic. Congestion was already a growing problem, before these new and converted mills have been built, especially during the tourist season.

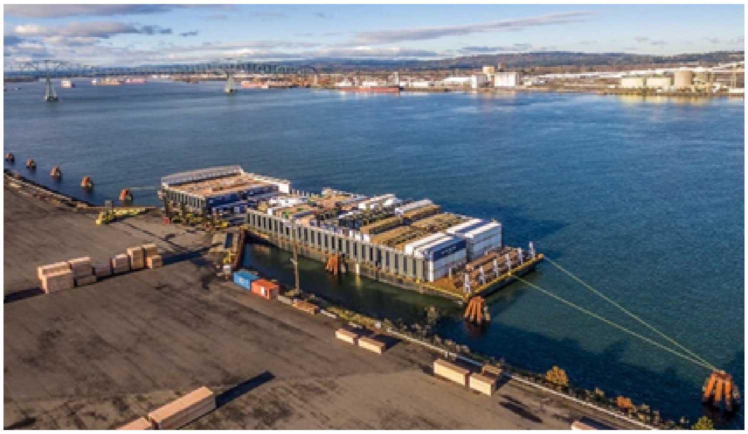
The new recycled paper-based containerboard mill's needs for large volumes of recycled paper deliveries and the needs for the shipment of paper products (and the contaminates in the recycled paper) back out won't just create new road congestion problems and higher trucking costs. All of those new truck trips will create a major increase in the state's carbon emissions.

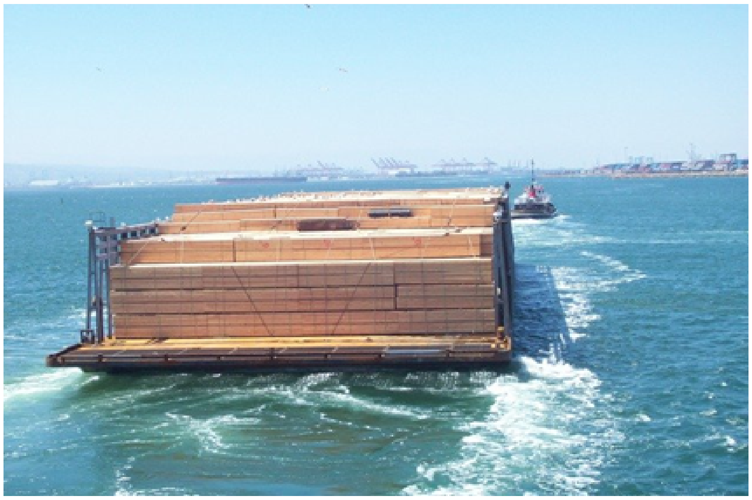
This brings us to the possibility of using barge transportation. Theoretically, barging should reduce recycled paper transportation costs (which, as saw earlier, are the dominant component in recycled paper sourcing costs), the costs of shipping paper from the mills to boxboard producers and the costs of shipping residual materials from the mills to approved landfills.

Barging pulp and paper in the Washington State intercoastal waterways and rivers has always been (many Washington mills were originally located and built to take advantage of water transportation), and it still is, common. Dunlap Towing (Dunlap), pulling a small covered barge owned by Pacific Terminals in Seattle, transports pulp and paper to Seattle from both Port Townsend Paper Company and Paper Excellence Canada's Croften, BC mill (see map on page 4). Tidewater Transportation and Terminals (Tidewater) has towed paper products from GP's Wauna, Oregon mill to the company's Columbia River paper distribution warehouse, also in small barges, for many years. The tow distances are relatively short, intercoastal and river weather conditions aren't bad and the barges that are serving both Canada and the U.S. aren't required to meet the U.S. Jones Act requirements (U.S.-built 'bottoms' must be towed by U.S. operators between U.S. ports). Tidewater has a barge loading terminal in Vancouver, Washington and Mike Fournier of Antares Consulting in British Columbia regularly helps barging operators find suitable terminal locations for their products in B.C. For the OCC-consuming Puget Sound mills (McKinley Paper, Port Townsend Paper Company and WestRock Paper), barging OCC from B.C. seems like a very advisable thing to consider. Likewise for the PCA Wallula mill on the Columbia River System.

Theoretically, barging should reduced recycled paper transportation costs, the costs of shipping paper from the mills to boxboard producers and the costs of shipping residual materials from the mills to approved landfills.

Island Tug and Barge of Seattle (ITB), working in conjunction with Seatac Marine (also in Seattle) currently has access to a 300' x 100' barge with 20' high walls. ITB's General Manager Erik Ellefsen has estimated that the barge could be covered for roughly $1 million and thereafter suitable for pulp and paper transportation. With roughly 4,000 tons of capacity, it could make a round trip from Richmond, B.C. or Nanaimo, B.C. to a Puget Sound mill in 40 hours. At $3,000/day for the barge, $14,000/day for a tug and 12 hours load and 12 hours unload (64 hours round trip time), that is roughly $45,000 tug and barge cost for 4,000 tons or $11/ton. That is similar to the barging costs/ton that the dredging companies have recently quoted for similar movements. Barging OCC from BC to the Puget Sound mills seems like a project worth further consideration for the Puget Sound OCC-consuming mills.





As the photos on these pages illustrate, tug and barge companies also regularly operate up and down the U.S. West Coast, even to and from Hawaii. Sause Brothers (Sause) regularly tandem tows Weyerhaeuser lumber from Teevin's barge terminal in Rainier, Oregon to an LA terminal. Sause returns from LA empty but the company doesn't have an interest in modifying their barges to haul break bulk paper- loading it with OCC bales and bringing it back to Oregon or Washington. But they do have an interest in two-way barge hauls from Puget Sound or the Columbia to/from LA with OCC and finished papers both loaded into containers. Pasha Stevedoring and Terminals has a terminal available in LA that they have also expressed an interest in commiting to paper loading, unloading and storage. They would need to add container 'top picks'.

Sause would need to build new ' tow line-barges' specifically for this movement, likely at Gunderson in Portland where they built their current LA lumber barges. Such barges would take roughly 18 months to build and they would cost an estimated $12 million each. Each barge would hold rough 400 containers stacked 5 high, 8,000 tons of net cargo. At $10,000/container and 900 required containers, that is $9 million in new container investments, also. Sause focuses on tow line barges because that is their operating experience and philosophy. They also believe containers are required to minimize potential paper quality issues and minimize stevedoring costs.

What would the rough economics be of a Sause OCC barge movement from LA to/from Puget Sound or the Columbia River? Sause estimated a totall of $170,000 for each round trip with 10,000 tons, two trips to/from LA per month. At $10/ton to load and unload, that is $20/ton plus $21.25/ton for barging or $41.25/ton to/from LA one way. Two way finished paper down- OCC hauls back- would obviously cost much less. Hauls from Portland, Oregon- Vancouver, WA would be much faster. Two days was estimated. Hauls from Oakland would be of intermediate duration. Five days was estimated.

Dunlap would also be interested in a similar barge movement but they suggested that it would be advisable to look at used barges in the Gulf of Mexico before considering new barge investments. They estimated that buying and renovating such barges could cut the estimated new investments in half. Or less. And they are more amenable to breakbulk shipments.

Western Tug and Barge also has an interest in the move and they suggested that Lynden Barge may have existing barge/s that might be available and suitable. The picture at the bottom of the previous page is one of Lynden's barges.

Burnaby, BC's Island Tug and Barge (not Seattle's Island Tug and Barge) is, along with Tidewater, owned by Upper Bay Infrastructure Partners, a New York-based investment firm. We have been told they may also be interested in a new barging opportunity like this. Their preferred equipment would probably be an 'articulated tug and barge' (ATB), however, a tug that is integrated with a barge like this. Like Olympic Tug and Barge (which has also expressed an interest in the opportunity), they have extensive interest in ATB petroleum barging up and down the West Coast.

While all of these barging options are worth consideration, the best option may be provided by a collaboration between Brusco Tug and Barge (Brusco) and Pasha Terminals and Stevedoring (Pasha). Pasha has a barge terminal in Los Angeles area.

The two Crimson Shipping barges that Brusco currently tows in the Gulf of Mexico look like the ideal barges for these moves. 312' long, 80' wide, 18' moulded depth and climate-controlled, they can handle roughly 6500 tons with 15' of draft. They seem ideal for these paper moves, and one of the two barges is currently available. As an example of barge repositioning costs, Brusco is currently in the process of relocating an ABS barge, a 343' x 86' barge equipped with container rails, to the West Coast. It will cost a little under $1 million including $200,000 for canal crossing fees.

Not including stevedore costs, Brusco could make two trips per month between Port Angeles and Pasha's LA terminal. Depending upon standby time, the barge cost per day would be $2,000, the tug cost per day, $13,000 underway, $7500/day standby. Provided sufficient paper load densification and 24-hour barge loading and unloading, that would be under $35/ton one way, under $20/ton two-way haul. Brusco would want a five-year agreement for this equipment and these rates.

Brusco and Pasha seem to have a unique working relationship and close collaboration between the LA terminal and barging company seems very important:

- ✓ Brusco/Crimson Shipping barging of recycled paper north and finished liner and medium paper rolls south
- ✓ Pasha's LA Terminal for trucked recycled bale receiving and storage, re-baling for densification (if needed)
- ✓ Finished paper barge unloading, storage and truck reloading
- ✓ Pasha's potential ability to also provide containers, if required.

Brusco feels comfortable that the Crimson Tide barges could now be unloaded at the Port of Port Angeles with readily available leased or purchased forklifts. As you can see on the photo on the previous page, the Crimson Shipping barges have two side ramps.

Brusco has agreed to provide a pro forma for stevedoring costs both in LA and in Port Angeles as further details on the likely moves are finalized.

Brusco has experience working in California on the Stockton-Sacramento-Oakland 'short haul shipping' project to reduce road traffic. They have also worked very closely with the Port of Hueneme on new, lower emissions tug power options.

Brusco recently retrofitted a tug in Portland at Diversified Marine at a cost of $9 million to meet 'Tier 4'- tug certification standards. They are currently in discussions with the Port of Hueneme over hydrogen-powered tug options.

New options to further lower barge transportation carbon emissions are the focus of DNV-GL as the technical maturity of maritime battery systems for propulsion is currently at a level such that fully electric or hybrid solutions are available for many types of vessels sizes and types. A discussion of feasibility for such a low carbon emission solution is shown in Appendix A .

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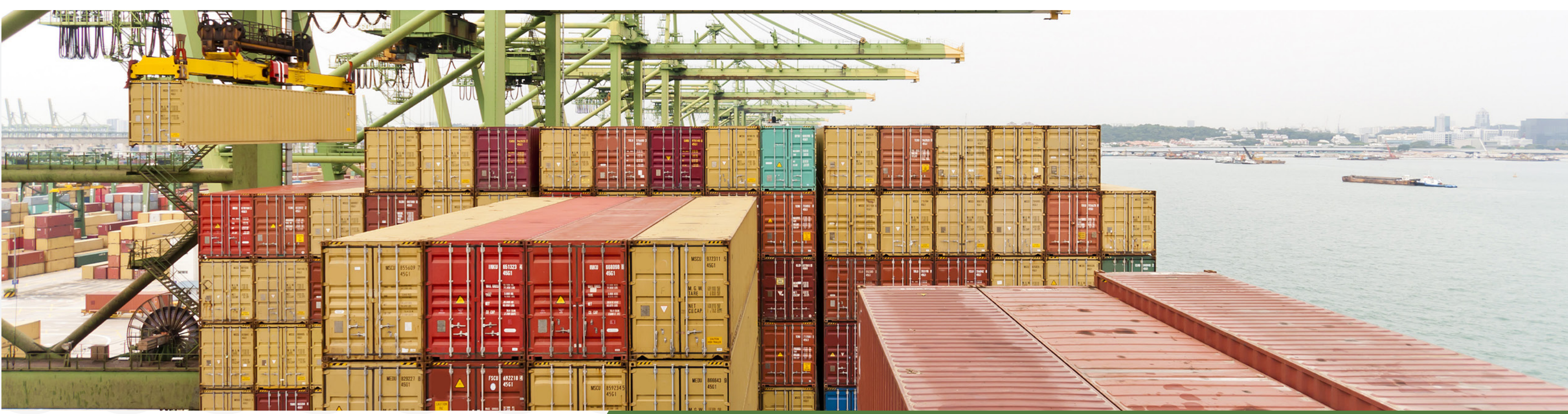

WASHINGTON MARITIME BLUE

Zero emission Barge Feasibility Study

Impact Washington

Report No.: 2020-9183, Rev. 0
Date: 2020-04-27

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Report title:	Zero emission Barge Feasibility Study	
Customer:	Impact Washington	
Customer contact:	Geoff Lawrence	
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Applicable contract(s) governing the provision of this Report:

Objective:

A high-level assessment of the feasibility of towing a barge using tug with a low carbon emitting energy converter from Port of Los Angeles to Port Angeles

Prepared by:	Verified by:	Approved by:
Eduardo Rodrigues Senior Consultant	Jan Hagen Andersen P.E. Senior Principal Engineer	Simon Mockler Head of Section

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1 INTRODUCTION

Washington Manufacturing Services dba Impact Washington (the Client) has asked DNV GL Maritime Advisory (the Consultant) to conduct a high- level assessment of the feasibility of towing a barge using a tug with a low carbon emission solution, for one specific route from Port of Los Angeles to Port Angeles. This work is being conducted for the cluster organization, Washington Maritime Blue, as part of their mission to implement the state's strategy for the Blue Economy.

Initial assumptions on barge size, cargo capacity, and speed were provided by the client.

DNV GL assessed the power demand required for the abovementioned route to determine if a fully electric or battery powered barge transportation option is feasible, or what other zero or low GHG emission measures should be considered going forward.

The work is set up in line with the DNV GL "Alternative Fuel Ready/Battery Ready" service, which is a methodology developed to prepare ship owners, designers, yards, and other stakeholders for alternative fuels and technologies. The report provides decision support which can show that fitting alternative fuel system and machinery on a vessel is technically feasible and can be financially attractive. Moreover, the report provides the Client with a good decision basis to select the best available technology option based on operational requirements, and financial and environmental considerations.

2 BACKGROUND

There is a regional need in Washington State for recycled paper feedstock and delivery of manufactured "craft paper" to be made into shopping bags and shipping boxes. The pulp and paper industry in Washington State has seen a renaissance, especially around the use of Old Corrugated Cardboard (OCC) as a major feedstock. However, the supply chain, availability and pricing of the OCC feedstock are challenging the business case for some.

In Port Angeles, the McKinley Paper Mill has reopened and is using OCC as feedstock. A barrier that has been identified is the expected increase in traffic from diesel trucks on the local roads on the Olympic Peninsula, both from the supply of OCC and moving finished product to the customers. In addition, the future demand for OCC appears to outstrip the supply available within the trucking cost effectiveness range of the mill.

However, there is potential for barge transportation options for moving recycled paper to the renovated mill and moving finished paper products away. Transportation of cargo by the waterways, if possible, is a preferred supply chain mode, because the cost of tonne-mile of cargo is often lower than road transportation, and in terms of GHG emissions per tonne mile, ocean transportation is by far the most efficient for point to point movement of cargo.

The concept of using low/zero carbon fuels or battery power onboard ships has become an attractive possibility, driven by the goals to reduce the GHG emission and other air pollutions (SOx, NOx, Particulate Matter) from the diesel engine exhaust. Additionally, the technical maturity of maritime battery systems for propulsion is currently at a level such that fully electric or hybrid solutions are available for many types of vessels sizes and types. The regulations and technical standards, like marine classification rules, are also in place to ensure reliability and safety.

For the latest update on the uptake of alternative marine fuels, including battery, visit the DNV GL Alternative Fuel Insights portal, https://afi.dnvgl.com/. The site has detailed insights on the uptake of alternative fuels and technologies on ships, including batteries. It is possible to filter on ship types, region, technology and more.

3 REFERENCE PROJECTS

Worldwide and in the US, the use of low carbon barge transportation concepts for short sea shipping has gained a lot of interest, driven partly by the desire to move cargo from the highways and to the waterways, as well as by the reduced cost and overall environmental benefits.

In Norway, two projects with similarities to the concept discussed in this feasibility study are being developed. The first is the Yara Birkeland, a fully electric and partly autonomous/remote controlled container vessel under construction. It launched in April 2020 and will gradually move from manned operation to fully autonomous operation during its first two years of operation. It will replace 40,000 truck journeys a year, reduce NOx and CO2 emissions and improve road safety in a densely populated urban area in Norway.

Figure 1: Yara Birkeland at the shipyard

Another project that is under development in Norway, is the ASKO electric push tug-barge concept to move truck trailers across the Oslo Fjord. ASKO is a wholesale distributor to grocery stores and is building a new central distribution warehouse to serve Eastern Norway. To avoid the estimated 150 daily heavy truck trips around the fjord and through a very congested tunnel, the company, together with the ship technology provider, Kongsberg, is designing an electric pusher tug that will move barges across the fjord as seen in Figure 2. The use of autonomy is also considered in this project.

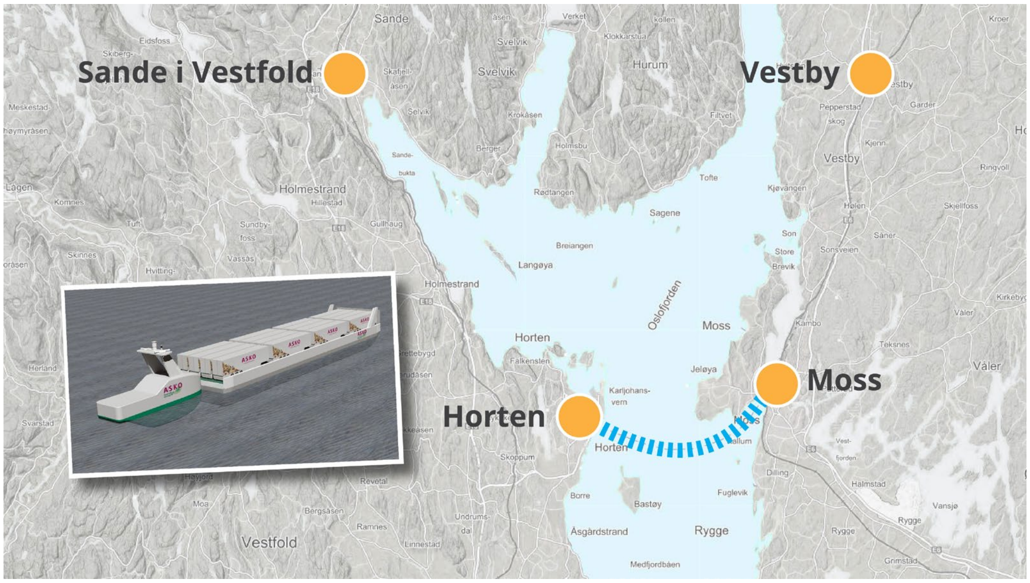


Figure 2: ASKO concept and route (Picture credit: TU/Kongsberg)

A project using an inland waterway barge is the Sendo Liner, which is used on the Rhine in the Netherlands. It is a hybrid electric push barge using lithium-ion batteries and two internal combustion engines. Compared to a traditional Rhine river container barge, it is designed to reduce CO2 emissions with 40% and have an increase load carrying capacity of about 100 tons. It can also be updated to use fuel cells and containerized battery packs in the future.

Figure 3: Sendo Liner (Picture credit: Sendo Shipping)

In the US, the company Harbor Harvest, is using a battery hybrid vessel to transport locally made produce and other cargo from Connecticut to Long Island to avoid the heavy traffic on the highways in the area. It is a small 65-foot cargo vessel that is considered the first hybrid electric cargo vessel in the US. It received funding from the US Maritime Administration (MARAD) through the Marine Highway program. In addition to the Harbor Harvest vessel, there are some fully electric battery powered passenger vessels and ferries in the US.

Figure 4: Harbor Harvest vessel (Picture credit: MarineLink)

4 BASIS FOR WORK

The feasibility study is based on using the Crimson Tide barges currently used in the Gulf of Mexico by Brusco Tug and Barge. The barges are covered barges, 312' long, 80' wide, 18' moulded depth, climate-controlled, they can handle roughly 6500 tons with 15' of draft. Based on information from Brusco, this type of barge could make two round trips per month between Port Angeles and the Pasha terminal in the Port of Los Angeles towed by a single tugboat.

Figure 5: Brusco Crimson Tide barge   (Picture credit: Brusco Tug & Barge)

4.1 Operational profile

As informed by the client, the voyage between Los Angeles, CA and Port Angeles, WA (1070 NM) will be done at in 5.75 days at a speed of approximately 8 knots.

A tug with the capacity of 3,000 hp will be used for this operation. The expected fuel consumption for the loaded northbound trip is 125 gallons per hour (421 kg/h) and for the light return southbound trip 100 gallons per hour (337 kg/h).

4.1.1 Assumptions

No information was provided on actual loads for the tug's engine(s) during the trip. Typically, the loads are not constant for the whole voyage. The loads can be higher during manoeuvring operations and at the beginning of the sailing and can be lower when sailing at constant speed ,depending on the sea condition (mostly wind, current, and waves). This study is a high-level evaluation of the potential for battery powered system, so load oscillations and weather conditions would only be taken in consideration on a detailed review.

This study will assume the tug will sail a constant load throughout the trip, with three scenarios: full load (2,240 kW), 90% (1,904 kW), and the light conditions. For the return trip in a light condition, the load is estimated using the provided hourly fuel consumption and considering a linear SFOC distribution.

The study will determine only the minimum power capacity required. The charge/discharge capacity (C-rate) would only be considered in a detailed study assessing the peak loads to ensure these will be able to supply power for critical scenarios. Last, the residual capacity of the battery is ignored, but it should be noted that this would decrease the actual capacity of the battery.

4.2 Batteries as main source of power

The use of batteries in transportation is a fast-developing technology. Fully battery powered or hybrid powered systems are currently available for maritime use. Traditionally when designing vessels, designers have ensured that there is sufficient power by dimensioning the engines to be able to take peak loads the vessel will experience. The fuel capacity is typically not a challenging parameter. When battery systems are designed, energy storage capacity, consumption and vessel operating range are critical parameters, as energy density of batteries is many times lower than for oil based fuels. An engine's energy output is limited to the amount of stored electrical energy that is on board, which will be limited due to weight constraints and available charging capacity.

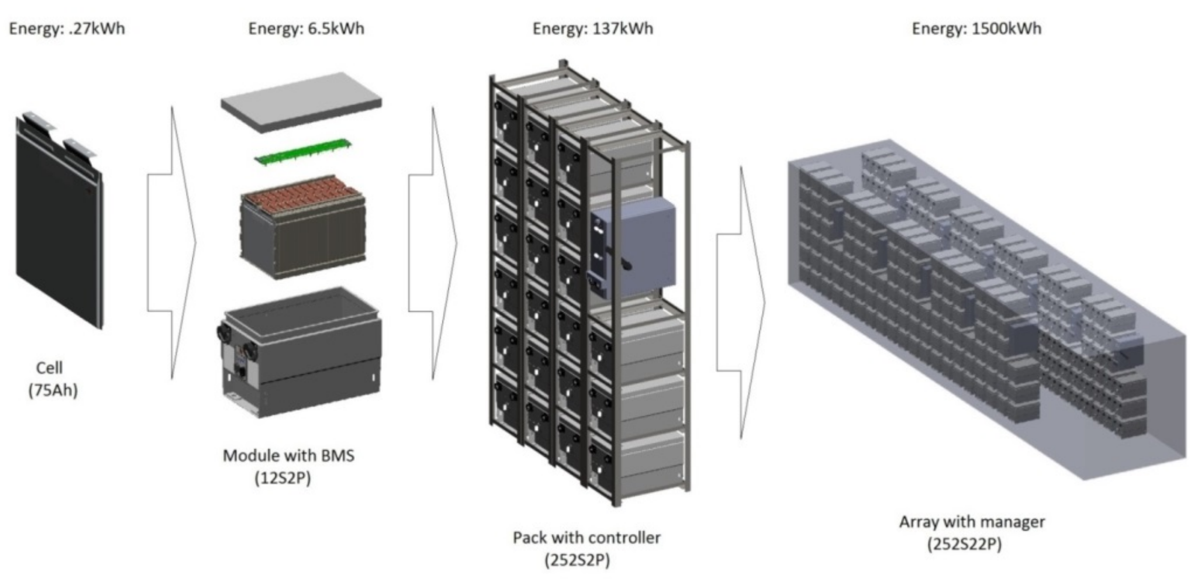


Figure 6: Build-up of a battery system

A battery deteriorates over its lifetime due to two effects. The battery ages even when not used and will also lose effect as it is used (number of charging/discharging cycles). The general rule of thumb is that the battery will need to be oversized (compared to the actual needed capacity between charging) by about 2 - 2.4 times for the battery to deliver the designed energy over a 10-year lifespan.

4.2.1 Battery dimensioning

The estimated power demand in kWh is determined by multiplying the load in kW by the number of hours of operation, which according to the owner is 5.75 days (138 hours):

- At 100% capacity (3,000hp/ 2,240 kW), the total power is 309,120 kWh.
- At 90% capacity (1,904 kW): 262,752 kWh.
- For the light condition (1,790 kW): 247,020 kWh.

In order to understand how this power demand translates into installation requirements, information from a known manufacturer who provides similar batteries for cruise and cargo vessels will be used.

Battery data for one pack only:

- Energy capacity: 2,400 kWh
- Weight: 51,400 lbs (abt. 23 tons)
- Dimensions (mm): height 2000, width 1200, length 8600, feet: (6.5 x 4 x 28)

The table below shows the number of packs requires for each of the scenarios, and the result in terms of additional weight. The area shown are of occupied area by the batteries only, the real installation would occupy an area significantly larger due to other needed equipment, ventilation and circulation requirements.

	Total power (kWh)	Number of packs	Total weight (tons)	Area - Batteries only (m^2)
Full Load	309,120	129	3,005.70	1,331.28
90%	262,752	110	2,563.00	1,135.20
Light	247,020	103	2,399.90	1,062.96

If the Los Angeles – Port Angeles trade was to be operated purely on battery, assuming batteries will be charged in both ports, both the batteries and the charging systems becomes very large and far outside what is considered feasible today.

In this study, there has been no analysis of the best battery technology or life-cycle analysis for the operation profile and the application.

In Appendix A, there is some basic data from marine battery manufacturers of the weight, size, and capacity of different technologies. It should be noted that new and potentially improved technologies. e.g. solid-state batteries are being introduced in the marine market.

5 ALTERNATIVE SOLUITONS

It was not within the scope of this study to determine feasibility of additional alternatives for reduction of elimination of carbon emissions, but some options are identified along with challenges and advantages to each. in the scope of this study to determine alternatives for reduction or elimination of carbon emissions, but we have decided to list some options, identifying some of the challenges and advantages to each.

5.1 Shorter routes

Since the distance route from Port of Los Angeles to Port Angeles is not technical feasible, two shorter routes within Puget Sound/Salish Sea are were also looked at with the same basic assumptions related to tug and barge combination, power demand, and speed. Alternative route 1 is from Port Angeles to a barge terminal inside Fraser River in Richmond BC (the City Transfer Richmond Yard and Barge Terminal).

Alternative route 2 is from Port Angeles to Port of Tacoma. Both routes are about 90 NM, or within 12-15 hours run one way, assuming an average speed of 6-8 knots. Maps of the two alternative routes are shown in Figure 7.

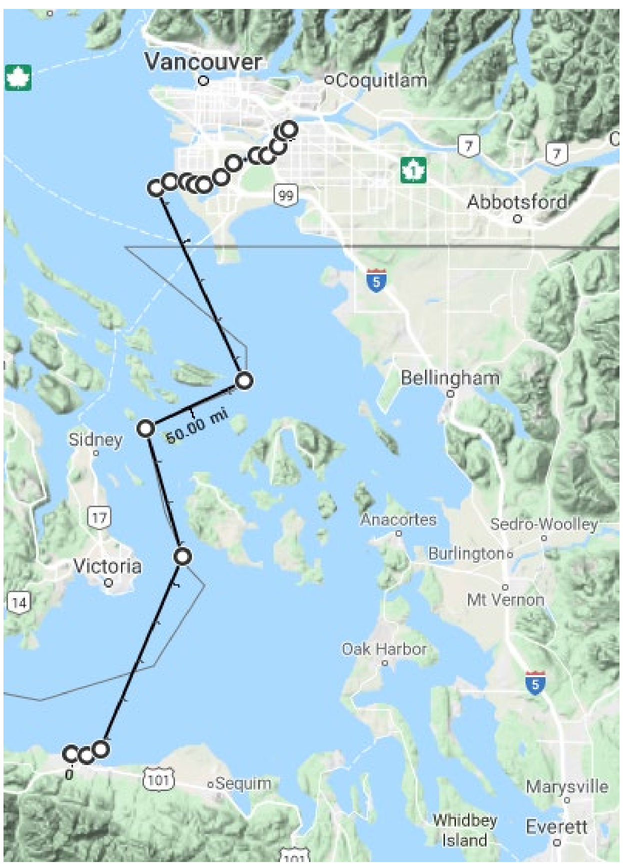


Figure 7: Short route Alternative 1 and 2

Since both routes are about 90 NM, so using the same assumption for the long route, the estimated size of the required battery pack for a fully electric tug propulsion is shown in the table on the next page.

	Total power (kWh)	Number of packs	Total weight (tons)	Area - Battery only (m^2)
Full Load	25,200	10.50	244.65	108.36
90%	21,420	8.93	207.95	92.11
Light	20,138	8.39	195.50	86.59

As shown in the Table above, the capacity of the battery pack is roughly estimated to be 20 MWh, which is bigger than what has been deployed to date, but technically feasible. With an optimized barge and propulsion design, operating profile, and loading capacity, significant reduction in the power demand can likely be achieved. Battery technology is also improving that could reduce the weight and footprint of the battery systems.

5.2 Hybrid Configuration

A hybrid configuration consists of a main source of power with higher density (usually internal combustion engines) supported by a battery, which provides additional power. The main advantage of the configuration is that it can keep the engines running close to its optimal operation load by adding power to the system when load is high and charging the batteries when the load is low. This option could be considered for both newbuilds and existing vessels. Related safety and integration will need to considered for either vessel type, but this is typically more challenging for a retrofit because of cost and lack of information and documentation for the existing design and construction.

Since the main source of power is most commonly from fossil-based diesel fuels, this configuration only has a partial impact to the vessel's emissions.

However, using batteries in combination with low carbon fuels as an additional energy carrier could achieve significant reductions in CO2 emissions, as well as other air emissions, SOx, PM, and NOx. The most mature and relevant alternative fuels are described in the next sections.

5.3 Biodiesel

Another solution to reducing GHG emissions is the use of sustainable sourced Biodiesel, either blended with diesel or in pure form (B100). One biodiesel type, called Hydrotreated Vegetable Oil (HVO) are produced in a process that makes the fuel a drop-in substitute for diesel. Since properties of HVO are similar to that of diesel (Marine Gas Oil), no modifications should be required onboard and fuel can be quickly switched back to regular diesel if needed.

Since 2006, several demonstration projects have tested the technical feasibility of various Fatty Methyl Esters (FAME) biodiesel blends in shipping. Challenges reported for FAME biofuels include fuel instability, corrosion, susceptibility to microbial growth, and poor cold-flow properties.

Renewable HVO biodiesel is a high-quality fuel in which the oxygen has been removed using hydrogen, which results in long-term stability. It is compatible with existing infrastructure and can be used in existing engines, subject to approval by the manufacturer.

The emission reduction potential of biofuels varies widely, depending on the specific feedstock, the biofuel generation, the engine type/model, and the supply chain. CO_2 reductions of up to 80 to 90 per cent for certain types of biofuels are possible, based on life-cycle assessments. The highest reduction potential is reported for advanced biofuels. There are no sulphur emissions. Recently, ferries operating in Norway have started to use HVO biodiesel.

in most cases biofuels will be more expensive than fossil fuels.

5.4 LNG

LNG use as marine fuel in internal combustion engines has been increasing significantly, and so is the availability of parts, suppliers, and bunkering facilities.

The main component of liquefied natural gas (LNG) is methane (CH_4), the hydrocarbon fuel with the lowest carbon content and therefore with the highest potential to reduce CO_2 emissions compared to diesel. LNG has more or less the same composition as natural gas used in households, for power generation and by the industry. The production process of LNG ensures that it is practically sulphur-free. Therefore, using LNG as fuel does not produce any SO_x emissions. Since the boiling point of LNG is approximately –261°F at atmospheric pressure, LNG must be stored in insulated tanks. The energy density per mass (LHV in MJ/kg) is approximately 18%t higher than that of diesel, but the volumetric density is only about 40% of diesel. This results in roughly twice the volume compared to the same energy stored in the form of diesel. Factoring in the shape-related space requirements, cylindrical LNG tanks typically occupy three times the volume of an equivalent amount of energy stored in the form of fuel oil. Other than reduction of carbon emissions, no SOX, and little emission of NO_x and PM.

There are LNG fuelled tugboats in operation, including pusher tug designs, and these tugs were built and designed as LNG fuelled vessels. Since the use of LNG as fuel onboard a vessel in operation requires installation of pressurized tanks onboard, cooling systems, and new/modified engines, the retrofit and integration for an existing tug could be expensive and challenging.

There is also natural gas, both in the form and LNG and CNG in the Puget Sound region. There is CNG being transported by trucks on the Olympic Peninsula to pulp and paper mills, as well as to other industrial consumers. In the Port of Tacoma, PugetLNG is building a LNG facility; that is focused on delivering LNG as a fuel to maritime customers. In Vancouver BC area, there are already several LNG fuelled vessels in operation which are receiving LNG as bunker fuel supplied by tanker trucks. Both in Tacoma and in Vancouver the uptake and as use of LNG as fuel is expected to increase because of the demand from the domestic and international shipping fleet.

5.5 Hydrogen

Hydrogen (H_2) is a colourless, odourless and non-toxic gas. For use on ships, it can either be stored as a cryogenic liquid, as compressed gas, or chemically bound.

The boiling point of hydrogen is very low: 20 K (–423°F) at atmospheric pressure. It is possible to liquefy hydrogen at temperatures up to 33 K (–400°F) by increasing the pressure towards the "critical pressure" for hydrogen, which is 13 bar (188 psi). The energy density per mass (LHV of 120 MJ/kg) is approximately three times the energy density of diesel. The volumetric density of liquefied H_2 (LH_2) (71 kg/m3) is only 7% that of diesel. This results in approximately five times the volume compared to the same energy stored in the form of diesel. When stored as a compressed gas, the volume is roughly ten to 15 times (depending on the pressure [700 to 300 bar]) the volume of the same amount of energy when stored as diesel.

Hydrogen is an energy carrier and a widely used chemical commodity. It can be produced from various energy sources, such as by electrolysis of renewables, or by reforming natural gas. Today, most hydrogen is produced from natural gas.

For applications in the transport sector, production by reforming from natural gas is currently the most common method. If the resulting CO_2 would be captured, this could result in a zero-emission value chain for shipping.

Together with CO_2, hydrogen can be used to produce methane, which can be used similar to LNG or synthetic liquid fuels which can be used as substitutes for diesel or gasoline. Production of hydrogen by electrolysis is viewed as an opportunity to store and transport surplus renewable energy, thereby stabilizing the energy output of solar or wind power plants.

Hydrogen used in fuel cells energy converters do not produce any CO_2 emissions and could eliminate NO_x, SO_x and particulate matter (PM) emissions from ships. Hydrogen-fuelled internal combustion engines for marine applications could also minimize greenhouse gas (GHG) emissions, while NO_x emissions cannot be avoided when using combustion engines. If H_2 is generated using renewable energy, nuclear power or natural gas with carbon capture and storage, zero-emission ships are possible.

Though fuel cells and hydrogen storage have been installed onboard vessels, technology is still in development and is not as technical mature as batteries and LNG. The availability and infrastructure to bring hydrogen onboard the ship can be challenging.

Like LNG, hydrogen as fuel will required installation of cryogenic pressure vessels and dedicated piping/equipment.

6 CONCLUSIONS

1. A zero-emission propulsion solution utilizing a fully electric powered tug for the proposed configuration – tug and barge - is not feasible considering the length of the route between Los Angeles and Port Angeles, the energy density of existing battery technology, based on the operational profile considered in this study.

2. A shorter route within the Puget Sound or to British Columbia could make the battery powered barge/tug option technical and financially feasible, two alternative routes was considered in this study. However, a more detailed operational profile and power consumption analysis is required to determine feasibility.

3. Reduction of GHG emissions can be achieved by using a hybrid electric system and/or utilizing alternative fuels. These would have to be studied in detail in order to determine the actual potential for reduction in emissions and the financial gain by implementing these modifications.

4. It should also be noted that by using a conventional diesel fuelled waterborne transportation option, e.g. the tug and barge base case, instead of a diesel truck-based option, would likely result in overall GHG reductions and other environmental benefits.

7 RECOMMENDATIONS

1. Develop a specific operational profile, including a speed/power curve for the barge. This would enable the optimization the battery size, energy consumption and other operating costs on a total life-cycle basis, considering the supply chain and OCC feedstock requirements.

2. The use of the other alternative fuels for reducing the emissions should also be considered in a more detailed techno-economic feasibility study. The first step in such a study should be a workshop with relevant stake holders to select the relevant options and assumptions.

3. Perform an analysis of the environmental impact in terms of GHG emissions using a diesel truck supply chain of OCC, compared to the waterborne case using the Brusco Tug and Barge combination used as the base case in this study.

APPENDIX A

Marine Battery Datasheets

Corvus Orca Energy

Designed and built specifically for the maritime industry, the Orca ESS product line from Corvus Energy represented a shift in maritime Energy Storage when launced in 2016. No other ESS can compete with the installation count that Orca Energy represents. Outstanding results and the highest level of safety has set the new industry standard for maritime batteries.

When launched, Corvus Energy combined its industry leading research & development capabilities and knowledge gained from having the largest global installed base of ESS solutions, to build the industry's safest, most reliable, highest-performing and most cost-effective maritime ESS.

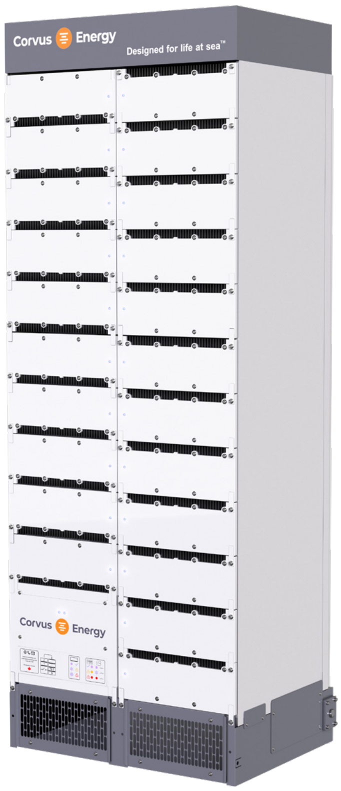
Applications

Orca Energy is ideal for applications that are in need of both energy and high power, moving large amounts of energy at an inexpensive lifetime cost per kWh. ORCA ESS is suitable for both all-electric and hybrid installations.

- Ferries
- Cruise ships
- Ro/Ro – Ro/Pax
- Yachts
- Offshore vessels
- Rigs
- Tugs
- Fishing vessels
- Merchant vessels
- Port cranes
- Shore charging
- Fish farms

Features

- High C-Rate - up to 6C peak C-Ratee
- Flexible and modular design
- Low installatuon and commissioning time
- Contained power connections – enhanced reliability
- Enhanced EMI immunity design for maritime environments
- Safety beyond class requirements
- Designed for pack voltages up to 1200VDC
- Scalable beyond 10MWh
- Industry-proven 4th generation BMS
- Easily monitored through the Watchman™ ESS Advisory Portal



Technical Specifications

Performance Specifications	
C-Rate - Peak	6C
C-Rate - Continous	3C

Operational Specifications	
Pack Sizing	350-1200V/ 38-136kWh

Standard Pack example	
Energy	125kWh
Voltage	Max: 1100 VDC I Nominal: 980 VDC I Min: 800 VDC
Cooling	Forced Air/ Liquid Cooling
Dimensions (vertical)	Height: 2241mm I Width: 865mm I Depth: 738mm
Dimensions (Horizontal)	Height: 1260mm I Width: 1730mm I Depth: 738mm
Weight	1620kg (3571lb)

General Specifications	
EMC	IEC 61000-4, CISPR16-1, 2, IEC60945-9
Ingress Protection	System: IP44
Vibration and Shock	UN 38.3, DNV 2.4, IEC 60068-2-6
Class Compliance	DNV-GL, Lloyds Register, Bureau Veritas, ABS
Type Approval	DNV-GL, Bureau Veritas, ABS, RINA

Safety Specifications	
Voltage Isolation	7,2 kV (IEC 60947-2)
Thermal Runaway anti-propagation	Passive cell-level thermal runaway isolation with exhaust gas system
Fire suppression reccomended	Per SOLAS (machinery space)
Disconnect circuit	Hardware-based fail-safe-for over-temp, over voltage
Maximum current parameter	Updated 2x per second
Faults communicated	Over-voltage, under-voltage, over-temperature
Short Circuit protection	Fuses included
Disconnect switchgear rating	Full load
Emergency stop circuit	Hard-wired
Ground fault detection	Integrated

Corvus Energy safety innovations

Passive-Single -Cell-level Thermal Runaway (TR) Isolation

- True cell-level thermal runaway isolation
- TR does not propagate to neighbouring cells
- Isolation NOT dependant on active cooling

Exceeds Class and Flag standards TR Gas venting

- Integrated thermal runaway gas exhaust system
- Easily vented to external atmosphere rather than the battery room

Additional fire suppression system not required.

DNV·GL

Certificate No:
TAE000026N

TYPE APPROVAL CERTIFICATE

This is to certify:

That the Battery (Accumulator)

with type designation(s)
ORCA Energy

Issued to
Corvus Energy Inc.
Richmond BC, Canada

is found to comply with
DNV GL rules for classification – Ships, offshore units, and high speed and light craft

Application :

Product(s) approved by this certificate is/are accepted for installation on all vessels classed by DNV GL.

Issued at **Høvik** on **2017-08-14**
This Certificate is valid until **2022-08-13**.
DNV GL local station: **Vancouver**

Approval Engineer: **Marta Alonso Pontes**

for **DNV GL**

Andreas Kristoffersen
Head of Section

This Certificate is subject to terms and conditions overleaf. Any significant change in design or construction may render this Certificate invalid.
The validity date relates to the Type Approval Certificate and not to the approval of equipment/systems installed.

Corvus Energy

Corvus Blue Whale

Corvus Energy has combined its industry leading research & development capabilities and knowledge gained from having the largest global installed base of ESS solutions, to develop a new groundbreaking energy storage system. The new ESS meets vessels power needs required to operate emission free for longer periods of time

The Corvus Blue Whale ESS is different than the ESS technology already in use. It is designed for vessels that are in need for slow charge and discharge rate like Cruise, Ro-Pax, Ro-Ro, Mega Yachts etc. in order to sail emission free for longer periods of time or need to stay emssion free in port. Size is typically from 20 -50 MWh which means that low weight and volume is required.

Applications

- Cruise ships
- Ro-Ro/Pax
- Yacht
- Merchant
- Sightseeing/Workboats
- Inland Vessels

Features

- Low C-Rate – designed for slow charge and discharge
- Weight reduced approximately 30% compared to Corvus Orca Energy
- Volume reduced approximately 50% compared to Corvus Orca Energy
- Cost optimized
- Flexible and Modular design
- Enhanced reliability
- Low installation and commissioning time
- Safety beyond class requirements
- Enhanced EMI immunity design for maritime environment
- Contained power connections, enhanced reliability
- Designed for pack voltages from 571V – 1142V
- Unlimited Scalability
- Economical upfront & through-life costs = lower total cost of ownership
- Industry-proven 5th generation BMS
- Easily monitored through the Watchman™ ESS Advisory Portal

Corvus Energy

Technical Specifications

Performance Specifications	
C-Rate - Peak	1C
C-Rate - Continous	0,5C

Operational Specifications	
Pack Sizing (single pack)	571-1142V/ 300-2400 kWh

Pack example (Config. 4)	
Energy	2400 kWh
Voltage	Max: 1142 VDC I Nom: 1075 VDC I Min: 1108 VDC
Cooling	Forced air
Dimensions (vertical)	Height: 2000mm I Width: 1200mm I Length: 8600mm
Weight	23300kg

General Specifications	
EMC	IEC 61000-4, CISPR16-2-1,3, IEC 60945
Ingress Protection	System: IP44
Vibration and Shock	UNT 38.3, DNVGL-CG-0339, IEC 60068-2-6
Class Compliance	DNV-GL, Lloyds Register, Bureau Veritas, ABS

Safety Specifications	
Thermal Runaway anti-propagation	Passive cell-level thermal runaway isolation with exhaust gas system
Fire suppression reccomended	Per SOLAS (machinery space)
Disconnect circuit	Hardware-based fail-safe-for over-temp, over voltage
Faults communicated	Over-voltage, under-voltage, over-temperature
Short Circuit protection	Fuses included
Disconnect switchgear rating	Full load
Emergency stop circuit	Hard-wired
Ground fault detection	Integrated

Battery Management System	
Battery management system	Corvus Gen. 5
Control Interface	ModbusTCP
Corvus WatchmanTM Compatibility	Integrated
Cell Balancing	Dynamic

SPBES

SPBES Specification Sheet

TYPE APPROVED PRODUCT DNV·GL DNVGL.COM/AF

QUALITY SYSTEM CERTIFICATION DNV·GL ISO 9001

Lithium Industrial Batteries

All SPBES systems use the same form factor and are backed by industry leading safety, performance, and recycling systems. CellCool™, ThermalStop™ and CellSwap™ provide ideal operating conditions, thermal runaway prevention and best industry value.

Titanate 35 (T35) is the flagship lithium battery from SPBES. Designed for ultra high discharge rates and extreme cycle life, the T35 is the ultimate powerhouse for your industrial application.

Power 65 (P65) is designed for high discharge power applications requiring high C-rates and faster cycling, the system provides 15,000 charge/discharge cycles at 80% DoD.

Energy 88 (E88) has been designed for applications requiring lower discharge rates and greater energy density. A decrease in cost and weight provides the end user with a faster path to ROI and decreased footprint and weight.

General SPBES Features	Specifications
BMS (Battery Management System)	MegaWatt ++
IMS (Information Management System)	API Interface
Engineered Design Life	5/10 year
CellCool™ Liquid Cooling	Yes
TCP Ultra Fast Internal Comms	Yes
Thermal-Stop™ Thermal Runaway Protection	Yes
E-Vent™ Safety Venting System	Yes
Operating Temperature (active heating/cooling)	15°C to 30°C
Operating Ambient Temperature Range	-40°C to +60°C
Internal Active Working Temperature	20°C to 25°C
Series Configurable	Yes
OnPoint™ Remote Active Monitoring	Yes
OnPoint™ Remote Active Programming	Yes
Parallel Configurable (capacity scalable)	Unlimited
System Voltage Range	300V to 1500V

*Specifications subject to change

Experience

Over 17MWh of installed systems. PBES batteries power the world's largest electric ferries, workboats and industrial machinery.

Liquid Cooling

Precisely manages internal cell and battery temperature to provide greater safety and best in class cycle life.

CellSwap

Replace only the cells at end of system life instead of the whole system.

SPBES Specification Sheet

System Specifications for the SPBES Lithium Industrial Batteries

Single Module (BBU)	Titanate 35	Power 65	Energy 88
C Rate RMS (Continuous)	4C	3C	1.4C
Cycle Life @ 80% DoD	90000 cycles	15000 cycles	TBA
Cell Chemistry	LTO	NMC	NMC
Dimensions	L 580mm, H 380mm, W 320mm	L 580mm, H 380mm, W 320mm	L 580mm, H 380mm, W 320mm
Weight	90kg	90kg	90kg
Energy	3.5kWh	6.5kWh	8.8kWh
Capacity	60Ah	75Ah	100Ah
Voltage Range	44 - 64VDC	77-100VDC	77-100VDC
Nominal Voltage	54 VDC	88.8VDC	88 VDC
RMS Continuous Current	240A	225A	140A
Max Discharge Current	450A	450A	200A
Max Charge Current	450A	225A	100A
Connectors	IP67	IP67	IP67
Terminal Isolation at Module	Contactor	Contactor	Contactor
Thermal-Stop™ Thermal Runaway Protection	Yes	Yes	Yes
Self Discharge Rate/Month	<2%	<2%	<2%
Internal resistance	13mΩ	17mΩ	13mΩ
Efficiency (at 1C)	>99%	>98%	>98%
Electrical Isolation	Open circuit when not in operation	Open circuit when not in operation	Open circuit when not in operation

Series String (1000V)	Titanate 35	Power 65	Energy 88
Dimensions (including racking, venting and lifting apparatus)	W 1303mm, H 2550mm, D 632mm	W 896mm, H 2550mm, D 632mm	W 896mm, H 2550mm, D 632mm
Weight	1650 kg	950 kg	950 kg
Energy	56kWh	65kWh	88kWh
Capacity	60Ah	75Ah	100Ah
Voltage Range	710 - 1000VDC	770-1000VDC	770-1000VDC
Nominal Voltage	864 VDC	888VDC	880VDC
RMS Continuous Current	240A	225A	140A
Max Discharge Current	450A	450A	200A
Max Charge Current	450A	225A	100A
Internal Resistance	205mΩ	180mΩ	128mΩ
Electrical Isolation at DC Bus	Breaker	Breaker	Breaker
Integrated Racking System	Included	Included	Included
Communication to Higher Level System	Modbus/TCP	Modbus/TCP	Modbus/TCP

*Specifications subject to change

DNV·GL

Certificate No:
TAE0000271

TYPE APPROVAL CERTIFICATE

This is to certify:

That the Battery (Accumulator)

with type designation(s)
Basic Battery Unit (BBU), Main Battery Unit (MBU), Parallel Battery Unit (PBU)

Issued to
PBES Ltd.
Vancouver BC, Canada

is found to comply with
DNV GL rules for classification – Ships, offshore units, and high speed and light craft

Application :

Product(s) approved by this certificate is/are accepted for installation on all vessels classed by DNV GL.

Issued at **Høvik** on **2017-10-12**
This Certificate is valid until **2022-10-11**.
DNV GL local station: **Trondheim**

Approval Engineer: **Sverre Eriksen**

for **DNV GL**

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Andreas Kristoffersen
Head of Section

This Certificate is subject to terms and conditions overleaf. Any significant change in design or construction may render this Certificate invalid.
The validity date relates to the Type Approval Certificate and not to the approval of equipment/systems installed.

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our professionals are dedicated to helping our customers make the world safer, smarter and greener.