

Brodrene Aa and The Fjords pioneering with "Future of The Fjords" – offering zero emission fjord cruise

The environmental profile and commercial sustainability of the tourism industry is under increasing scrutiny. This article discusses how designer and shipbuilder Brodrene Aa has assessed the market's needs, solved a number of technical and regulatory challenges, and designed and built a completely new type of environmentally friendly vessel with zero emission operation. The article ends with an insight into the experiences after almost one year of vessel operation.



Photo 1. "Future of The Fjords" in the World Heritage Nærøysfjord, Western Norway. Photo: Sverre Hjørnevik

Technical data for "Future of The Fjords"

Build number: 291

Construction year: 2018

Shipping company: The Fjords DA

Loa: 42.49 m

Width: 15.2m

Pax: 400

Building material: Carbon fibre sandwich

Electric motors: 2 x 450 kW

Battery system: 2 x 900 kWh

Challenges in the transport sector require new solutions

The maritime sector is responsible for about 2.5% of global greenhouse gas emissions. In order to achieve international climate goals, comprehensive actions to reduce emissions and environmental impact from shipping must be introduced in the period until 2050. In 2011, the International Maritime Organization (IMO) set regulations for future emissions of greenhouse gases from international shipping. Two years later, the EU followed this with a strategy to cut 40-50% of

maritime sector emissions by 2050. Emissions reductions must come by streamlining operations, improving existing solutions and using new and innovative environmental technology.

Brødrene Aa is a world leader in the design and construction of high-speed lightweight carbon fibre passenger boats. The company is constantly working to improve the design and minimise the environmental impact of the vessels. The most important factors to achieve this are a reduction of weight and energy consumption. The use of carbon fibre as a building material in hull, deck and superstructure and the development of new structural production methods have yielded good results. Since 2002, Brødrene Aa has developed and produced 60 carbon structured vessels from 20 to 50 meters.

In 2014, Brødrene Aa developed and built "M/S Terningen" for the Trondheim-Kristiansund route in mid Norway. The boat replaced the aluminium vessel "M/S Ladejarl" built in 2002. The carbon structure of "M/S Terningen" has significantly lower weight and therefore operates at the same speed but using a lower engine power. The diesel consumption on the route is reduced by 40% or about 1.3 million litres per year. CO₂ emissions have been reduced by 3,370 tonnes of CO₂ equivalents per year and NO_x emissions by 55%. "M/S Terningen" alone contributes 3.5% of the annual Norwegian cut target in the sector "Aviation, shipping and fishing". Overall, the vessels Brødrene Aa delivered in 2014 contributed to 10% of the Norwegian cuts in the sector.

The tourism industry wants to improve its environmental profile

In 2015/2016, Brødrene Aa designed and developed the new vessel type 'Seasight', a 43-meter-long carbon fibre structured catamaran with a 400 passenger capacity. The purpose was to offer a vessel with reduced or zero emission to satisfy requirements in an increasing and more environmentally conscious international tourist market. The Seasight class is designed to give passengers the best possible view from positions all over the vessel, both on deck and in the interior lounges. Universal and modern design and a green profile were demands of the operator.

"Vision of The Fjords" was built as a battery/diesel hybrid for the Flåm-Gudvangen route. The vessel was handed over to the operator The Fjords in July 2016. The vessel sails with pure battery operation in the World Heritage area Nærøyfjord and Gudvangen at the bottom of the Sognefjord. Transit between Nærøyfjord and Flåm is under diesel power.

In April 2018, the sister ship "Future of The Fjords" was delivered as a clean, zero emission vessel with 100% battery operation. The orderer had clear wishes to reduce emissions, have a good environmental profile, strengthen the customer experience and reduce operating costs. "Future of The Fjords" has a 1800 kWh battery pack and can run 2,5 hours at 16 knots speed before the batteries have to be charged. The ship is designed for future hydrogen-based propulsion solutions to be installed to extend its range.



Figure 1. «Future of The Fjords» sails between Flåm and Gudvangen at the bottom of the famous Sognefjord. Gudvangen is located in the World Heritage area Nærøyfjord. Screenshot: www.marinetraffic.com

Battery technology has previously not been used for these types of vessel and routes. The design concept needed the latest technology to achieve the required energy density. The estimated requirement of 2000 kWh made the design the largest battery-based project within marine transport in Norway in relation to performance. Development and building of "Future of The Fjords" cost 130 MNOK. Adaptation and development of the vessel for clean battery operation cost 34 MNOK. In addition, extensive investments in infrastructure on the land side and upgrading of existing charging stations were necessary.

In August 2016, "Vision of The Fjords" was awarded "Ship of the Year" during the international shipping fair SMM Hamburg. In September 2018, "Future of The Fjords" in combination with PowerDock received the same award.

Further development of the Seasight class

"Future of The Fjords" was constructed to meet the following challenge proposed by the operator to Brødrene Aa: Can a combination of modern battery technology and optimal hull design using lightweight carbon sandwich construction produce a vessel that can operate with zero emission propulsion for up to 3 hours at 10-18 knots speed and transport 450 passengers?

The development of a full-electric vessel which met the range and other specified requirements needed several new solutions that were not available in the maritime market. Brødrene Aa and project partners analysed the proposal and defined a number of sub-challenges that had to be solved in order to achieve the new vessel concept. The challenges were as follows:

- Emission-free operation
- Technical and operational solutions must have commercial sustainability
- Minimise energy consumption
- Develop optimal battery and charging solutions
- Vessel design shall prevent wash induced erosion of the shoreline

- Technology solutions must be transferable in the Norwegian and international tourist market
- Include the possibility of hydrogen propulsion technology in the design

The following sections describes the various components and elements of a full-electric propulsion system. During the work on "Future of The Fjords", Brødrene Aa had close dialogue with DNV GL, the Norwegian Maritime Authority and several subcontractors. The subsidiaries Paradis Nautica and Marcontrol have been heavily involved in the design phase.

Power system with energy from battery

Design of the propulsion system for battery powered vessels differs significantly from those with diesel engines. An electric propulsion system consists of the following main components:

- Battery modules with control system for charging and consumption
- Converters and switchboards for shore power and charging
- Converters from DC to AC power
- Keyboards for power distribution to onboard consumers
- Power cables and rail systems for energy distribution onboard
- Electric propulsion motors with power and speed control
- Propulsion control systems
- Control system for power distribution and charging
- Auxiliary systems for cooling, remote control etc.

The solution for "Future of The Fjords" is shown in figure 2.

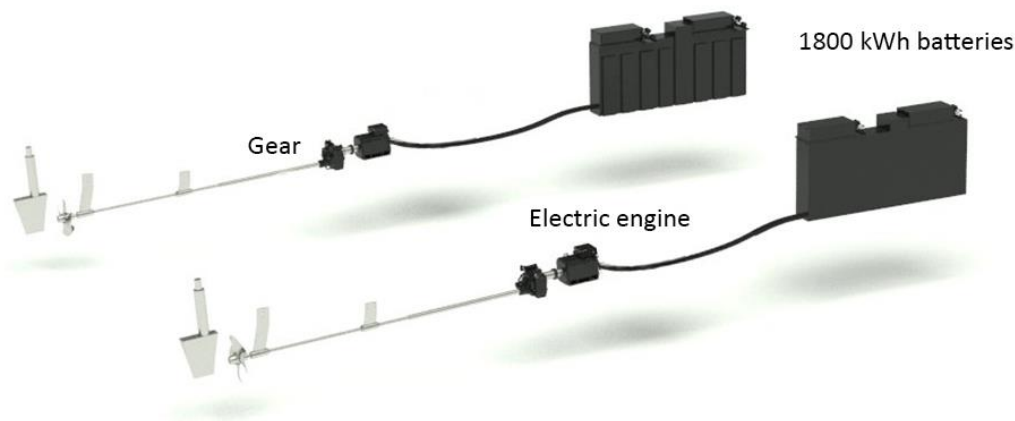


Figure 2. Driveline for "Future of The Fjords". Illustration: Brødrene Aa

Zero emissions operation

The driveline in "Future of The Fjords", with the exception of the electric motors, is specially developed by Servogear. All energy for propulsion and hotel consumers comes from electrical energy stored in two battery packs. Two 450 kW electric motors give the propulsion. This solution provides zero emission operation of the vessel. CO₂ emissions will nevertheless be included in the energy supply chain if fossil fuels are used to produce a share of the electrical energy, for example by importing European power mix to Norway.

Commercial sustainability

It is valuable to have an excellent environmental profile when promoting tourist destinations, especially the unspoilt and magnificent scenery of Norway. Experience from "Vision of The Fjords" shows that there is considerable consumer willingness to pay for the extra experience of being on-board zero emission electrically powered vessels, compared to alternative diesel vessels.

Competition in the tourist market is fierce and The Fjords did not have margins for reduced net earnings for the new vessel. The investment in a battery powered vessel of this type was estimated to be 20% higher than for a diesel vessel. The challenge for The Fjords would be to balance the extra investment cost by reducing operating costs and increasing the earnings potential which lies in having an excellent environmental profile. Price considerations were therefore one of the criteria for selecting the technology solutions on board "Future of The Fjords".



Photo 2. The "Future of The Fjords" design allows passengers to enjoy views and proximity to nature and the surroundings from all places on deck. The design is very well suited for a tourist vessel. Photo: Maria Górzynska

Electric propulsion is almost silent and is far quieter than any other technology available today. This is an advantage for all transportation, but especially important in connection with sightseeing, where there is often spoken guiding, and proximity to bird and wildlife, nature and waterfalls is an important factor. The difference in nature experience from conventional vessels must be experienced to be believed. Design and environmental profile also gives "Future of The Fjords" a great potential for use for conferences and other events outside the main season. Both factors significantly increase earnings compared to existing vessels in the tourist industry.

Minimise energy consumption

Comprehensive analysis was required for mapping and calculating of energy consumption. This was done in detail for the best possible utilisation of available energy. Low weight and optimal hull design are the two most important factors to minimise energy consumption. Carbon sandwich construction is the key to achieving this. Brødrene Aa is world leading in the construction of lightweight carbon fibre structures, working continuously to minimise weight of the hull, structure and all equipment on board.

Weight optimization applies to equipment such as the switchboard systems, cables, electric drives, electric motors and piping systems. Weight reduction on electrical components is discussed in the following sections. The pipe systems on board the "Vision of The Fjords" are for hot and cold fresh water and for cooling of electric motors, power electronics and battery systems. The heat is recovered and used for waterborne heating of the vessel. Brødrene Aa has used new and lighter types of pipes on board the "Future of The Fjords". Simplified solutions and better design mean that the new system is lighter than in the sister ship.

Many sightseeing and tourist vessels have strict requirements for engine performance and reduced energy consumption. The boats operate at relatively low speed and the routes are not particularly long. Brødrene Aa already had an efficient hull design, but chose to develop the design to further reduce the hull resistance. 100% battery operation and larger battery packs did not lead to increased total weight of the vessel. The latest generation of batteries was lighter than those used on "Vision of The Fjords" and removal of the diesel engine fuel tanks and accessories allowed for increased battery pack weight. New reduced resistance hull design led to new requirements for the dimensioning of the carbon structure.

Further development was mainly done by starting from the existing 43 meters structure and increasing the length of the waterline and the size of the volume to withstand greater weight. There had to be global analysis and the calculation of strength of the modified structure. Global analysis is a strength calculation method that includes the entire boat. Development of the hull was done in collaboration with Paradis Nautica, Sintef Marintek and SINTEF Ocean, including testing a model in a tank and implementing CFD calculations for different hulls and speeds. The result led to the hull being extended by 1.8 meters. This was expected to give 5-10% less energy consumption. FiReCo AS was a partner in optimizing the strength calculation of structure and on global analysis. The company is an approved R&D institution with very good experience in dimensioning and material optimization on carbon structures in larger vessels. Norsk Marinteknisk Forskningsinstitutt AS (MARINTEK) was also a central partner and performed hull development and model testing. The company is a leader in its field.

Energy for hotel operation amounts to 30-35 kW, equivalent to about 3-4% of the energy consumption on board. "Future of The Fjords" has large exterior windows and deck housing surfaces and large internal volume to be heated. Operation with up to 400 passengers also requires some energy for heating hot water. Brødrene Aa have optimised the energy consumption by using LED lighting, heat pumps/heat recovery and have insulated all outer bulkheads well to reduce heat loss to the external environment.

Choice of powertrain and type of electric motors, speed and propeller solution are also crucial for energy utilisation. Experiences from "Vision of the Fjords" provided the basis for developing an improved and optimised version of the existing permanent magnet synchronous motor. This was done by Westcon Power & Automation. A good propeller solution can provide up to 5-10% reduction in energy consumption for propulsion. Relatively large propellers with low rotation speed was chosen for "Future of The Fjords".

Operating system, control system and propulsion control system

Although vessels and components are designed for the lowest possible energy consumption, an optimised control system is an important factor in achieving an energy-efficient operating profile. Such systems must be adapted to the vessel. A crucial principle is that a large degree of autonomous operation will minimise energy consumption. The "Future of The Fjords" control system was

developed and built from scratch. It involved extensive programming work and the development of a simulator for testing and certification of the system.

Conversion to electric operation also required some components that were not optimised for use on smaller and light vessels, especially in terms of volume and weight. Brødrene Aa and the partners had close dialogue with subcontractors. By defining needs and requirements for weight and function for all components, Brødrene Aa achieved some weight reduction for operating system, control system and propulsion control system. New solutions and choice of components were approved by DNV GL and the Norwegian Maritime Authority.

Optimal battery and charging solutions

Batteries have large volume and high weight in relation to stored energy. Prior to "Vision of The Fjords" battery technology had not been used on this type of vessel and routes. "Future of The Fjords" had an estimated energy requirement of 2000 kWh. This made the design the largest battery project in marine transport in Norway ever in relation to performance. Experiences from the hybrid solution on "Vision of The Fjords" were important in order to develop the best solutions for the new vessel. The new solutions involved extensive analysis work, development of a test regime, as well as testing and verification of the analysis.

There is generally very limited space for battery systems on board passenger vessels. With "Future of The Fjords" as a pilot vessel for 100% battery operation, Brødrene Aa and partners had to optimise and adapt the mounting system and cooling system for the battery packs. Solutions developed for the automotive industry are very compact and several of these solutions were adapted to maritime use.

Westcon Power & Automation was responsible for the energy system and had to use the latest in power electronics and engine and battery technology to achieve the solution for full electric propulsion. An extensive safety regime had to be put in place to safeguard passengers when using batteries with several MWh of energy content. Westcon Power & Automation carried out the analysis work related to risks. These analyses were partly related to the battery system's energy content. Installing a large battery pack in a light weight composite vessel was a challenge regarding fire technology. FiReCo AS was involved in the development of fire technology solutions.

After compiling Westcon Power & Automation's battery analysis and Brødrene Aa's energy analysis for propulsion, the players chose to install two lithium ion battery packs with a total capacity of 1800 kWh. Lithium-ion batteries was chosen because this battery type is lightweight and air-cooled. The batteries were supplied by the company ZEM. There is a battery pack in each hull. DNV GL (class for battery-powered ships) and the Norwegian Maritime Authority approved the battery solutions. See table 1 for data.

Number of cells	Weight	Volume	Capacity	Max charge power	Max number of charging cycles
3808	8400kg	Ca. 21 m ³	1800 kW/900 kWh	1800 kW	3000 – 10000

Table 1. Data for both battery packages as a total

The number of charging cycles depend on how the charging is performed. Factors that affect are charging power, how much energy that is transferred per charging and how full the batteries are charged.

In recent decades, battery energy density has been improving. Figure 3 shows development for volumetric energy density and weight density.

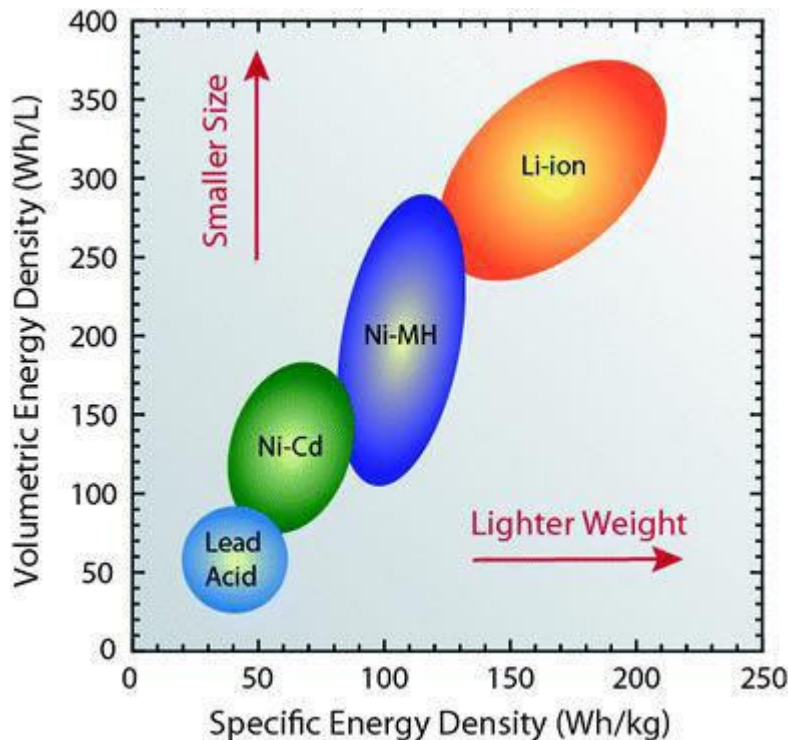


Figure 3. Battery technology has evolved considerably in recent decades. The figure shows how the energy density has steadily improved. Figure from Veerapandian Ponnuchamy; Towards A Better Understanding of Lithium Ion Local Environment in Pure, Binary and Ternary Mixtures of Carbonate Solvents : A Numerical Approach, januar 2015

Based on data for the energy system, Brødrene Aa specially designed the vessel's arrangement. Use of large battery packs led to analysis of explosion risk and fire technical issues as well as new requirements for building the hull structure. The battery compartments have mechanical ventilation.

Special customisation of vessel arrangements included room arrangements, insulation and fire protection, explosion hatches, fire extinguishing systems and fire and gas detection systems. Explosion hatches were developed as a new concept for "Vision of The Fjords", and the same concept was used on "Future of The Fjords". The hatches act as pressure reliefs if gas formation occurs from the battery packs and this gas ignites. The explosion hatches open at overpressure and release the pressure of the explosive gas fire. This will prevent deformation of the main deck or hull structure. The design and dimensioning of the hull and superstructure provided the basis for the design report and global analysis carried out by FiReCo. The final concept for hull, superstructure and vessel arrangement was approved by DNV GL.

Charging solutions were already established in Flåm and Gudvangen for "Vision of The Fjords". The two charging stations each had a capacity of 1.2 MW. This is a big load for the local power grid. "Future of The Fjords" would need a 2.4 MW charging effect. This exceeded the capacity of the power grid. The Fjords, Brødrene Aa and Westcon Power & Automation took the challenge of preparing a new charging solution. The two latter actors have very good expertise and use analytical tools that provide the best solutions for transmission and storage of electrical energy.

With 2.4 MW of charging power, it was important and necessary to optimise the transmission and storage of electrical energy. The solutions had to be consistent to ensure high transmission power,

minimum charging time, long battery life and maintain battery performance and system operation for a high number of charge cycles. At the same time, the energy loss had to be the lowest possible and the price of battery and charging system had to be harmonised in relation to optimal operation and all safety aspects. Due to weight limitations, it was important that charging transformers and, as far as possible, the charging system were not placed on board.

Preparing charging solutions was a challenging process. The route pattern for "Future of The Fjords" was laid up to five departures per day, with a 30-minute stay at the quay in Flåm between each trip. The Fjords had defined a maximum of 20 minutes of charging time between departures during the day. Although the local electric grid in Flåm could have the capacity to charge the battery packs with low power during the night, there would not be enough capacity in the grid to top the battery packs between each daytime departure. The Fjords, Brødrene Aa and Westcon Power & Automation developed the concept PowerDock as a solution.

The concept consists of a floating dock with battery packs stored under deck. The PowerDock concept provides a solution for being able to transfer large amounts of energy in a short time in places where the power grid is too weak to directly charge a vessel or other installation. The size of the battery packs is adapted to the storage requirements for energy. One advantage of PowerDock is that charging of the dock's battery packs can occur at relatively low power around the clock or with higher power in periods where the grid is able to deliver more power or when the energy price is low. Figure 4 shows the schematic solution for transferring energy from power grid and PowerDock to vessels.

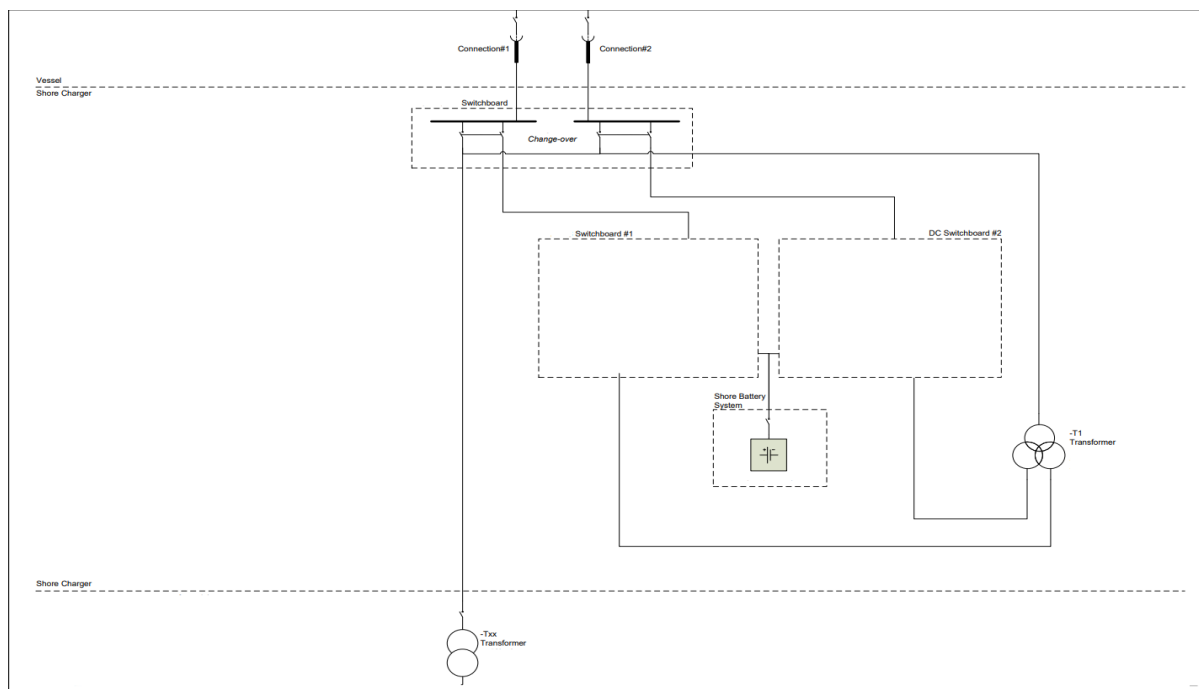


Figure 4. Sketch of system for transferring energy to battery on board vessel. Electric energy from land comes either directly from the grid (Txx Transformer), from the PowerDock or battery pack on the shore battery system or both in combination. Connection # 1 and Connection # 2 are each connected to their own battery pack. Design by Westcon Power & Automation, August 2018

"Future of The Fjords" has double charging effect in relation to the sister ship. For practical reasons, there was a desire to use the same cables for charging both vessels. To transfer double power to the new vessel, the charging voltage was increased from 400 volts AC as on "Vision" to 1000 volts DC on

"Future". Change from AC to DC was done because DC requires less cross-section than AC for the same current.



Figure 5 and photo 3. Brødrene Aa and Westcon Power & Automation's newly developed concept PowerDock solves the challenge of charging when the grid on land has low capacity. The illustration at the top shows principle outline of the concept. Photo at the bottom shows PowerDock in use by "Future of The Fjords". Figure: Brødrene Aa. Photo: Lars Haugnes

The concept PowerDock was set in operation in Gudvangen in September 2018 for the supply of energy to "Future of The Fjords". The vessel is supplied with energy at each stop. The PowerDock in Gudvangen has a battery capacity of 700 kWh. The dock transmits energy via two charging cables, which each can deliver 1.2 MW of power to its battery pack. The cables are attached to two charging towers which makes it easy to connect the cables manually to the charging plugs on board. In addition to the battery packs, two transformers and power electronics make up the main components of the PowerDock. With increased power access from land, the PowerDock concept can easily be scaled up in capacity. It is also possible to increase the charging effect if new battery solutions allow for more intense charging. In Flåm there are two similar systems on land in two containers.



Photo 4. Connection of a charging plug to "Future of The Fjords". Two plugs are used to charge the battery packs. Each plug can charge with 1.2 MW power. Photo: Severin Synnevåg

The size of the PowerDock is 40 x 5 x 3.5 meters (length, width, height). Practical experience shows that "Future of The Fjords" is transferred approx. 800 kWh within 20 minutes of charging time. The energy is transferred in parallel from the PowerDock and the grid on land. "Future of The Fjords" has 1.8 MWh of battery capacity installed. During each docking, the PowerDock can only charge a portion of this amount of energy. However, the charging quantity is optimal, because the battery packs on board the "Future" are designed for 10 years of life and are normally not discharged by more than 60% during use. The development of PowerDock was done in collaboration with the Norwegian Directorate for Civil Protection (DSB).

Inverters, chargers and motor drivers

Traditional ship equipment is not designed for minimal weight or compact construction and is not suitable for use on lightweight vessels. There was equipment on the market, but it was mainly adapted to land-based transport, bus and construction machinery. Brødrene Aa and Westcon Power

& Automation chose the lightest and best components that were available in the market. Some light components from the land-based transport industry were used and some components were rebuilt or adapted to reduce weight. Modifications, rebuilding and reprogramming were partially needed to meet current maritime regulations. Cables were laid with the shortest path and all switchboards were placed optimally in relation to cabling. Selection of components and cabling led to significant weight reduction compared to the first Seasight vessel. DNV GL and the Norwegian Maritime Authority approved solutions for inverters, chargers and motor drives.

Power management system

These systems control the charging processes and energy delivery for propulsion and hotel load. The systems were specially adapted to the vessel for the best possible operation and minimal energy consumption by using Westcon Power & Automation's automation system e-SEAMatic BLUE. This system ensures optimal energy flow between energy storage, electric engine and various other loads. The process is advanced and requires good management to ensure optimal utilisation of the energy. Parameters that affect the system are distribution of power between the engines, energy for hotel operation and other loads and remaining energy in the batteries.

The control system also includes automated charging and mooring solutions. The e-SEAMatic BLUE automation system has built-in functions to prevent damage to components of the energy system in the event of a short circuit, instantaneous loss of load or unplanned disconnection of the batteries. The consequences of such events can be serious if the management system is not designed for these events.

Westcon Power & Automation designed and optimised the electrical system with automatic control for minimal energy consumption. Standard components were used for this system. Extensive programming was required for adaptation to the vessel and subsequent adjustments to the operating mode for optimal energy consumption. Adjustment and adaptation of the system were performed during a test run and in the first operating weeks. Good adaptation was crucial to minimise energy consumption. The power management system is approved by DNV GL and the Norwegian Maritime Authority.



Photo 5. The energy and propulsion system on "Future of The Fjords" is highly automated. Monitoring, control and possible override is performed from the steering position on the bridge. Photo: Lars Haugnes

Preventing wash induced shoreline erosion

Low weight and efficient hull design have not only economic and practical implications, but also environmental. Optimal hull design must also include the vessel being able to operate as a "low-wash" concept. The beaches along Nærøyfjord and the adjacent Flåmsfjord have been unaffected by human activity until the cruise and tourist traffic made its large-scale entry in modern times. An increasing amount of large cruise ships and high-speed sightseeing boats create waves that hit land and cause erosion of the beach zone. This is an increasing problem with negative consequences for the world heritage site and adjacent fjords. Brødrene Aa has taken the problem into account when designing the hull structure on "Future and The Fjords". The modified hull structure reduces the height of the wash by approx. 30%.

Transferable technology solutions

The technology solutions from "Future of The Fjords" are transferable to other vessel concepts and marine industries. The development work done by Brødrene Aa and partners can benefit other players. The list below shows the most important points that have transferable value.

- Zero emission operations will have increasing demand in the future. General methodology and solutions for zero emission operations is directly transferable to other maritime sectors and marine industries, e.g. aquaculture.
- Propulsion system using energy from batteries has led to the development of a new control system, components and to adapting of existing components. This has given new commercial solutions that can be transferred either directly or in a modified version to other types of vessels

- Minimizing energy consumption will apply to all types of sea transport. Analysis methods, test algorithms and experience from hull design and control and operation systems will have use across all vessel types
- Manoeuvring, steering and control systems for propulsion can be transferred to other types of vessels such as high speed passenger boats, service vessels for the aquaculture industry, etc.
- Optimal battery and charging solutions will benefit existing and future maritime and marine sectors to a large extent. Brødrene Aa and Westcon Power & Automation's research and development work has produced state-of-the-art solutions that provide the basis for energy efficiency and are directly transferable to national and international industry. The solutions have the potential for great value creation by production and delivery to both the domestic and the export market
- Development or modification of inverters, chargers and motor drives adapted and approved to the maritime sector have a direct transfer value to corresponding vessels and other vessels with energy wholly or partly based on battery, and where minimal weight or space requirement is a factor to be taken into account
- The power management system has been developed, tested and been in use since April 2018 and has worked very well. The system can be used on other vessels with individual modifications
- In general, all the technology solutions in the above are directly transferable to the next generation of zero emission vessels that will get energy from hydrogen with electric power generation by fuel cells
- Infrastructure with charging facilities are in operation in the current operating areas of Flåm and Gudvangen. Together with charging stations on Norwegian ferry quays, these form the start of a large-scale national development of this type of infrastructure, especially in places with poor network capacity. The PowerDock concept is very energy efficient, can be scaled in size and capacity and is also a removable installation. All these four factors mean that the use of PowerDock is highly relevant both nationally and internationally

Development and construction process

The most important milestones for the development and construction of "Future of The Fjords" are shown below.

15.12.2016 Contract signed
 31.03.2017 Completed model test at SINTEF Marintek
 30.04.2017 Completed finite element calculations and global analysis of structure
 01.06.2017 Start of construction
 01.03.2018 Start testing of vessels
 15.04.2018 Delivery to The Fjords

Experiences from the operation of "Future of The Fjords"

Technical system

The operation of "Future of The Fjords" has been in line with expectations. The propulsion system, power management and charging has worked very well. With the exception of some cancelled trips due to ice on the fjord, the operating regularity has been 98,04%.

Emission reductions

Operation of the two Seasight vessels has provided major environmental benefits, especially for the "Future of The Fjords". The diesel consumption on the hybrid vessel "Vision of The Fjords" makes it

possible to calculate the annual diesel consumption if it were solely a diesel powered vessel. Calculations for emissions of CO₂ equivalents per year with different energy carriers are shown in the table below. The share of CO₂ for pure battery operation is due to some import of power to Norway from the European power mix.

Energy carrier	Diesel consumption per year (litres)	CO ₂ equivalents (kg)
Diesel	650.000	1.716.000
Hybrid - diesel/battery, «Vision of the Fjords»	460.000	1.286.100
Battery, «Future of The Fjords»	0	187.500

Table 2. The figures are based on 2500 operating hours per year, engine power of 1000 kW and 75 grams of CO₂EKV / kWh for the electricity grid

Net gain from battery operation for "Future of The Fjords" on the Flåm-Gudvangen route is approx. 1,500 tonnes of CO₂ equivalents per year. This amounts to 0.75% of the estimated effect of the Government's *Green Tax Shift* in the National Budget 2017.

Sustainability

Experience from the Nærøyfjord confirms that an increasing number of customers are demanding experiences with a good environmental profile. Such a profile is merchandise and gives advantages over existing operators. This applies both nationally and internationally. In Nærøyfjord, customers have demonstrated a great willingness to pay to upgrade tickets for the two Seasight vessels. This is due to both a better experience and excellent environmental profile of the vessels.

Economy

With conventional diesel operation, "Future of the Fjords" would have had a fuel consumption of 650,000 litres per year. Experience shows that operation with electrical energy saves on operating costs. Based on normal depreciation and longevity, the savings exceed the extra investment costs. In addition, there are gains from higher ticket prices, reduced maintenance and an increased secondary value.

Good response in the tourist industry

Brødrene Aa's concept has received overwhelming reception in the maritime sightseeing and tourist transport market. Much of the key to success lies in the fact that the vessel is arranged in such a way that the travellers get extremely good views of the surroundings from the deck. Silent propulsion means that passengers will come closer to animal and bird life and magnificent nature. In bad weather, passengers can stay indoors and still experience the view through the large windows. Universal design is very well taken care of. In October 2017, "Vision of The Fjords" received the Innovation Award for universal design.

Conference Use

The unique design of the SeaSight class has provided great potential for the use of the vessels for conferences and other events. The interest in this has been great and gives increased earnings during the winter months with little tourist traffic.



Photo 6. The Vision of The Fjords was used as an arena during parts of the international Maritime Hydrogen and Marine Energy Conference in Florø in October 2018. The conference participants were impressed with the vessel and that the design includes future implementation of hydrogen technology for energy supply and propulsion. Photo: Roger Anzjøn

National and international market

Brødrene Aa believe there will be a market for at least 10 vessels of the Seasight class in Norway. There is potential for at least three vessels on the Nærøyfjord and a corresponding number on the Lysefjord. The Geirangerfjord and Northern Norway are other potential areas for such vessels. Brødrene Aa are now building the third SeaSight vessel, "Legacy of the Fjords" for The Fjords. The vessel is a direct copy of "Vision of The Fjords".

Maritime sightseeing and tourist transport is offered worldwide, and the Seasight concept has a great interest far beyond Norway. Actors in San Francisco, Sydney, Hong Kong, Hamburg, UK, Sweden and New Zealand have made contact with Brødrene Aa about the new vessel concept. The players are tourism operators and shipping companies that currently operate in the tourist market and have the necessary licenses.

The technology is now ready for zero emission requirements for other types of passenger transport. In connection with public ferry offers and speedboat routes, there are already zero emission requirements. The potential environmental benefit in the speedboat segment, where the vessels operate at high speed and have a high power propulsion system, is considerably larger than in the sightseeing and tourist segment. Successful operation of the "Future of The Fjords" as a purely zero emission vessel means that environmental requirements can also be imposed on the tourist transport in Norwegian fjords.

Design for future hydrogen technology

Battery technology has limited the possibility for high speed and long distance routes. The next phase in the development of the Seasight class is to use hydrogen as the energy carrier and fuel cell technology as the basis for a zero emission propulsion solution. "Future of The Fjords" is designed to accommodate hydrogen-based energy systems when the technology is commercialised. Hydrogen technology for propulsion will have applications in both conventional high speed vessels and other types of maritime transport.

Local use of excess electric energy

In many Norwegian fjords, there is great production and overcapacity in electrical energy. This overcapacity is an argument for increased focus on battery or hydrogen-powered passenger vessels. The use of locally produced energy has a positive effect both environmentally and economically. The wider deployment of the required charging facilities strengthens the commercial value of battery-powered vessels and positively affects second-hand value.

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