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Wind solar wave and tidal

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TECHNOLOGY SURVEY

RENEWABLE ENERGY INTEGRATED WITH BRIDGE CONSTRUCTIONS

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ATTACHMENT I – TECHNOLOGY MAPPING

ATTACHMENT II – MAPS OF FJORD CROSSINGS FERRY FREE E39

ATTACHMENT III – BRIDGE DESIGN VALUES

EXECUTIVE SUMMARY

This feasibility study has mapped renewable energy production technologies utilizing sun, wind and marine energy suitable for integration with bridge constructions. The technology survey has been performed as a part of the «*Ferry Free E39*» project.

Parallel with this work, analyses of wave and currents have been performed for the fjord crossings. The results from this work indicate low levels and inaccessible amounts of energy potentials. Some of the fjords may have current velocities up to 1-2 m/s, but the mean value is expected to significantly lower than 1 m/s.

The feasibility study conclusions show there are few synergies and added value with wind and solar energy conversion technologies along E39 fjord crossings. There are different levels of synergies depending on where the technologies are integrated, e.g. in the immediate surroundings of the bridge, but not directly on the construction, in connection with the bearing constructions and on the bridge span.

There are some synergies in connection with wind turbines in the immediate vicinity of the bridges, which may include utilization of construction sites and roads for transport and mounting of the wind turbines as well as connection to the electrical grid. Solar energy installations could benefit from easy mounting when the bridge is constructed. These installations will not have a significantly positive added value for the solar energy conversion system as whole, but with some reduced costs and positive synergies for the panels and the bridge construction.

Marine energy conversion systems, such as wave and tidal current installations, could have some positive synergies. The floaters for floating or submerged tube bridges could be part of the wave energy conversion systems absorbing harmful waves and destructive energy and convert this to electricity. The added value could arise from reduced operation and maintenance costs, marine operations, under water cabling, and foundation works.

There are various challenges to integration of renewable energy conversion technologies, but also many possible synergies. The main challenge is to capture the limited resources at the fjord crossings with existing technologies. The recourses are in many ways limited or less optimal than other locations further west towards the North Sea or at higher altitudes, especially for wind with less terrain turbulence, but also for waves not dampened by the islands or refraction by the fjord curves.

The added value and challenges are shown in the table below.

ADDED VALUE OF SOLAR TECHNOLOGY INTEGRATION

Possible synergies	Challenges
– Large available areas on bridge shoulder and pillars with relatively easy access for maintenance – Existing constructions can be used without major modifications – Can be used on all relevant bridge types – Can be used to reduce wind loads and turbulence and protect the roadway and pedestrians	– Low sunlight intensity in Norway will result in low amounts of energy produced, but the rapid development of solar cells and solar heat applications could make the installations much more competitive within 5-10 years

ADDED VALUE OF WIND TURBINES

Possible synergies	Challenges
– Existing infrastructure can be used for transport and mounting of turbines – Construction machines and equipment being used for the bridge can be used for the wind turbine installations – Shared surveillance and control facilities – Utilization of existing electrical grid in connection with the bridge construction – Reduced visual noise compared to other wind turbines due to the bridge construction	– In most cases increased costs to reinforce pillars and bridge construction – Increased design and engineering costs – Increased visual noise compared to a standalone bridge

ADDED VALUE OF WAVE AND TIDAL CURRENT INSTALLATIONS

Possible synergies	Challenges
– Reduced costs for generators and electrical systems due to dry surroundings and access in bridge floaters – Reduced overall costs for foundations when bridge floaters are utilized – Reduced costs concerning electrical systems due to dry connections on top or inside bridge – Fewer marine operations reduce costs	– Increased design and engineering costs – Increased stress on the whole construction, but wave installations could function as dampening devices and produce energy simultaneously

1. INTRODUCTION

The Norwegian Public Roads Administration has received a mandate from the Ministry of Transportation for feasibility studies for the road E39 from Kristiansand to Trondheim.

The project consists of four subprojects which are:

- Subproject Community
- Subproject Fjord Crossing
- Subproject Energy
- Subproject Execution strategy and contract terms & condition

The main objective in this report is to investigate the possibilities for using bridge constructions in order to increase the potential for renewable energy production. An assessment of a combined exploitation of infrastructure and energy production has been carried out with a feasibility study with a focus on the fjord crossings in Ferry free E39 project.

Integration of energy conversion installations comprise of various challenges, but also possible synergies. There are different degrees of challenges and synergies. The total investment costs as well as the total operation maintenance costs can be reduced compared to having two independent projects and locations. Some energy production plants have high investments costs, which can be reduced when integrated with bridges. The main challenge with the installations are higher bridge construction loads, but to a different extent depending on technology and location relative to the anchoring points for the bridge construction.

The optimal energy conversion technologies utilize existing anchoring connections, reduce construction loads and/or contribute to multiple functions to reduce the total costs of the bridge and the energy production installations combined.

This report documents a technology survey of wind, solar, wave and tidal current technologies suitable for bridge integration. Integration solutions are presented and discussed, and an attachment includes a long list of possible promising technologies and manufacturers, as well as E39 fjord crossings maps.

The integration possibilities, synergies and challenges are discussed qualitatively. A more detailed analysis and quantification of potentials and consequences should be performed on a later stage when the initial design of each bridge commence. The solutions discussed needs further research and development to be seamlessly integrated with bridge constructions.

2. BACKGROUND

The Norwegian Public Roads Administration has performed several studies related to E39. In 2011 the crossing of the Sognefjord was finished. The report gives a detailed description of relevant bridge types for wide fjord crossings[1]. Additionally, SINTEF has analysed wave and currentpatterns in the Sognefjord [2]. The results have been guiding principle for the technology survey and are in brief presented below.

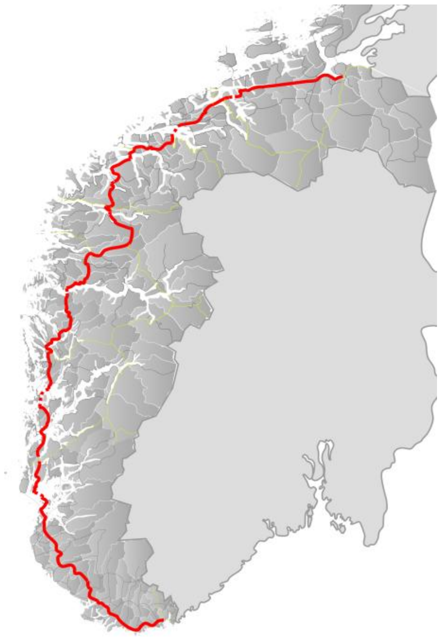

Figure 2-1 European Highway E39

2.1 Ferry free E39 fjord crossings

The Ferry free E39 project consists currently of 8 planned crossings. Today these crossings are handled by ferries, but on the long view these will be replaced by bridges.
These fjords are typically wide, deep and long surrounded with high mountains.

The eight fjord crossings are

FJORD CROSSING	LENGTH	WATER DEPTH
Kanestraum - Halsa (Halsafjord)	5,4 km	485 m
Vestnes – Molde (Moldefjord)	9,3 km	500 m
Festøy – Solavågen (Storfjord)	4,3 km	450 m
Volda – Folkestad (Voldafjord)	3,1 km	600 m
Anda – Lote (Nordfjord)	2,1 km	250 m
Oppedal – Lavik (Sognefjord)	3,7 km	1250 m
Sandvikvågen – Halhjem (Bjørnafjord)	6,2 km	550 m
Mortavika – Arsvågen (Boknafjord)	8,3 km	575 m

Table 2-1 Fjord crossings Ferry free E39

2.2 Bridge types for Ferry free E39

Bridge constructions stretching several kilometres need further research and development, innovation and new thinking to be realized. The suggested crossing of the Sognefjord is estimated to 3,7 km and has a water depth of 1250 meters. The current conclusions has

[1] Statens Vegvesen (2011): Mulighetsstudie - Kryssing av Sognefjorden. Oppsummering etter idéfasen.
[2] SINTEF Byggforsk (2010); Mulighetsstudie for kryssing av Sognefjorden Opedal-Lavik. Estimat på bølger og strøm. Rapport for Statens Vegvesen

identified three possible bridge designs: suspension bridge, floating (pontoon) bridge, submerged tube bridge (both negative or positive buoyancy in water).

SUSPENSION BRIDGE

Figure 2-2 Suspension bridge across the Sognefjord, proposed design (SVV)

The supporting structure of suspension bridges consists of suspension cables, while the stiffening girder is the secondary supporting structure. The bridge deck is on top of the girder which is held up by the cables with suspenders. Towers, standing on foundation blocks, elevate the cables which are anchored to anchorage blocks. The girder can be made of beams, trusses, or steel boxes.

To be able to construct large centre spans, such as for the Sognefjord, existing solutions must be modified to be able to withstand wind loads as well as the dead loads. The girder must be relatively much wider than existing bridge constructions to be able to withstand horizontal wind loads. Accouplement beams between dual carriegeways could be one solution. In addition the bridge should be aerodynamically designed to reduce wind loads.

Cable weight and tower design should also be modified for such extreme centre spans. Cable weight could be reduced by new materials, e.g. carbon fibre. Higher tower could also be a solution to increase the versed sine of the cables. The tower height could then be as high as 500 meters. The tower legs must also have aerodynamically designs.

FLOATING BRIDGE

Figure 2-3 Floating (pontoon) bridge (SVV)

Floating bridges have continuous or separate floaters, also called pontoons. Bridges with continuous floaters have the structural bearing included in the floater. Large floating bridges have dominant loads perpendicular to the bridge, e.g. from waves, currents and wind. These large bridges can be constructed with an arched shape (horizontal projection). Floating bridges in shallow water could have anchoring points through cables or chains to absorb horizontal loads. On deep water the end points and bearings, together with the arched shape, will absorb the horizontal loads.

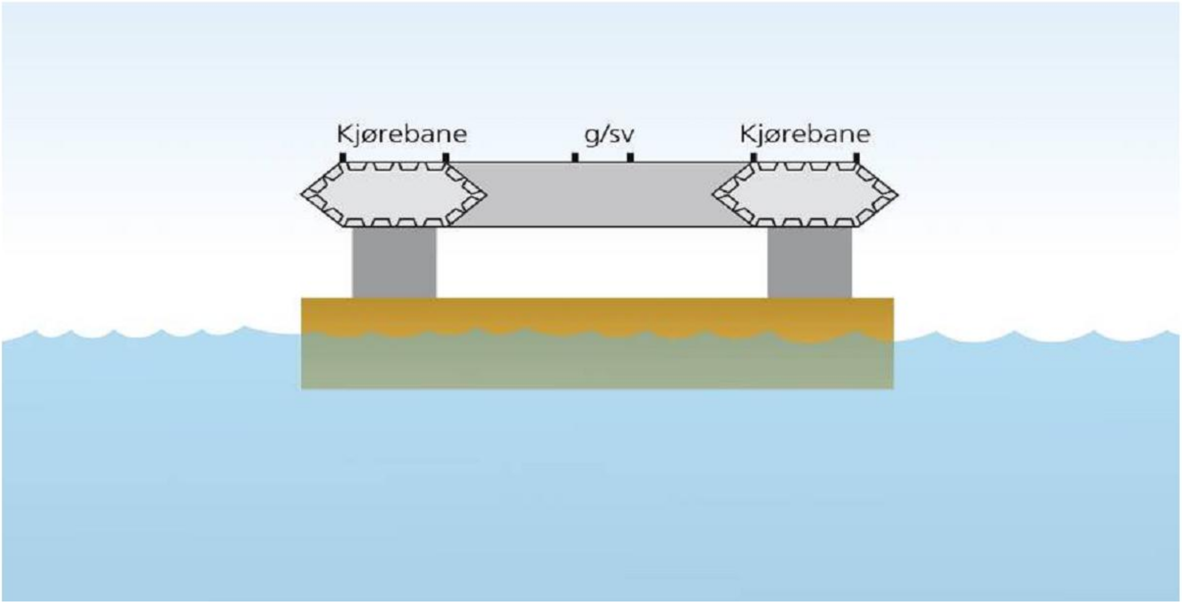

Figure 2-4 Cross section of floating bridge (SVV)

The largest floating bridge in the world without anchoring points at the fjord floor, the Nordhordaland bridge in the Salhus fjord in Norway, has a horizontal arched span of 1245 meters. A bridge with this design has to be dimensioned to handle the dynamic loads from wind and more importantly waves, as well as dead load and traffic.

There are substantial challenges with resonant frequencies. Additional equipment and energy conversion installations could lead to new frequencies and destructive resonance. Many and costly iterations are needed to identify a secure design. Floating bridges must also make room for ship traffic either with parts of the bridge suspended or parts submerged.

SUBMERGED TUBULAR BRIDGE

Figure 2-5 Tubular submerged bridge (SSV)

The concept submerged tubular bridge has not yet been built. There have, however, been performed some feasibility studies, e.g. the Høgsfjord close to Stavanger. The submerged bridge can have positive or negative buoyancy made from steel or concrete, either with floaters or cables attached to the ocean floor. Negative buoyancy with floaters is probably the most suitable solution for fjords with large depths. This bridge type must also be dimensioned for accidents from ship collisions, with for instance extra floaters.

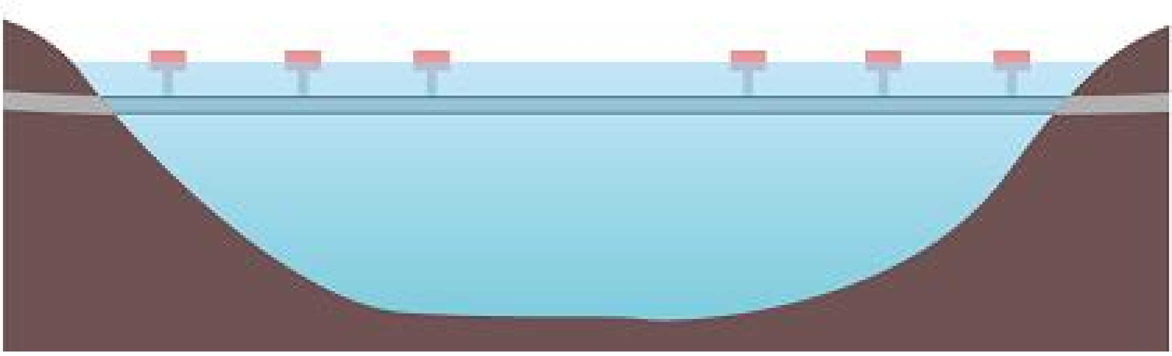

Figure 2-6 Tubular submerged bridge, side view (SSV)

2.3 Energy resources and potentials

As of today, there is inadequately public energy resource data to perform detailed studies of energy potentials at each E39 fjord crossing. The Norwegian Public Roads Administration has recently published some data and calculations[3].

CURRENTS AND TIDAL POTENTIAL

There are large variations from area to area, and there are at the time not identified optimal locations for installations converting current and tidal energy to electricity. The SINTEF study and Ramboll evaluations conclude with an average velocity flow of 0,1 – 0,5 m/s, with a maximum flow of 1,5 – 2,0 m/s (return period of 100 years).

WAVE POTENTIAL

The wave potentials are low, mainly due to waves dampened by the reefs, islands and straits. Based on the SINTEF study and Ramboll evaluations, maximum wave height could be 1,5 – 2,5 meters, with a maximum period of 3-5 seconds. The actual wave potential will be during the year be significantly lower.

[3] The attachments contain further data

WIND POTENTAL

The annual mean wind speed, based on the wind atlas from Kjeller Wind[4], is as follows:

FJORD CROSSING	MEAN WIND SPEED (120 meters altitude)
Kanestraum - Halsa (Halsafjord)	5-6 m/s
Vestnes – Molde (Moldefjord)	4-6 m/s
Festøy – Solavågen (Storfjord)	3-5 m/s
Volda – Folkestad (Voldafjord)	3-5 m/s
Anda – Lote (Nordfjord)	3-5 m/s
Oppedal – Lavik (Sognefjord)	4-6 m/s
Sandvikvågen – Halhjem (Bjørnafjord)	5-7 m/s
Mortavika – Arsvågen (Boknafjord)	7-8 m/s

Table 2-2 – Expected mean wind speed for each fjord crossing

SOLAR RADIATION AND INTENSITY POTENTIAL

Annual solar radiation towards a horizontal surface in Norway is 600 – 1000 kWh/m^2 [5]. However, the difference between summer and winter is substantial, with close to nothing in November-December until January-February.

2.4 Renewable energy technologies

The technology survey data is attached to reduce the report size. The overview include available technologies as well as an description of how each technology works.

4 Kjeller Vindteknikk (2009); Vindkart for Norge

5 Solenergiressurs i Norge: http://www.fornybar.no/sitepageview.aspx?sitePageID=1648

3. ANALYSIS AND METHOD

The evaluation of integration possibilities and synergies, a *load zone approach* has been developed for the project. The project team divided the bridges into three main zones and evaluated the integration possibilities for each technology.

As shown below, the figures illustrate different integration zones for different bridges, following the same approach for each bridge type.

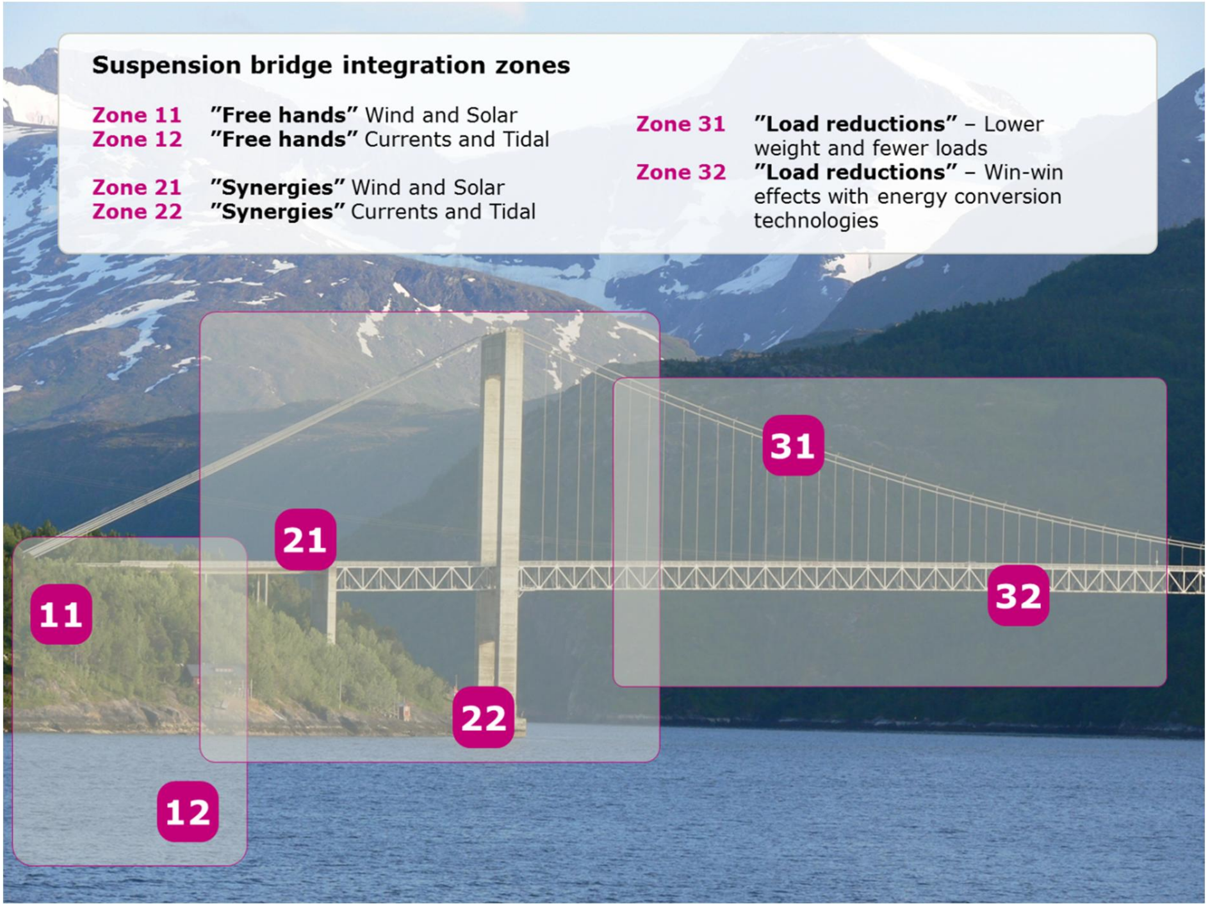

Figure 3-1 Suspension bridge integration zones

Zone 1 (11 and 12) is in the immediate vicinity of the bridge, e.g. construction site and set back areas. This zone is assumed to have “free hands” to install any kind of installations and will not affect the bridge in any negative way concerning new loads and stress. These areas or zones will benefit from reduced construction costs and connectivity to existing infrastructure.

Zone 2 (21 and 22) consists of areas or structural parts of the bridge with well anchored foundations, mostly the side span. This zone is less susceptible to new loads compared to zone 3, but installations here will in most cases lead to modified bridge structures and anchoring points.

Zone 3 (31 and 32) consists of the centre span and has no possibilities for extra loads or installations other than installations that could reduce the loads or have any other positive effect.

The figures below show the same approach with a floating bridge and a tubular submerged bridge.

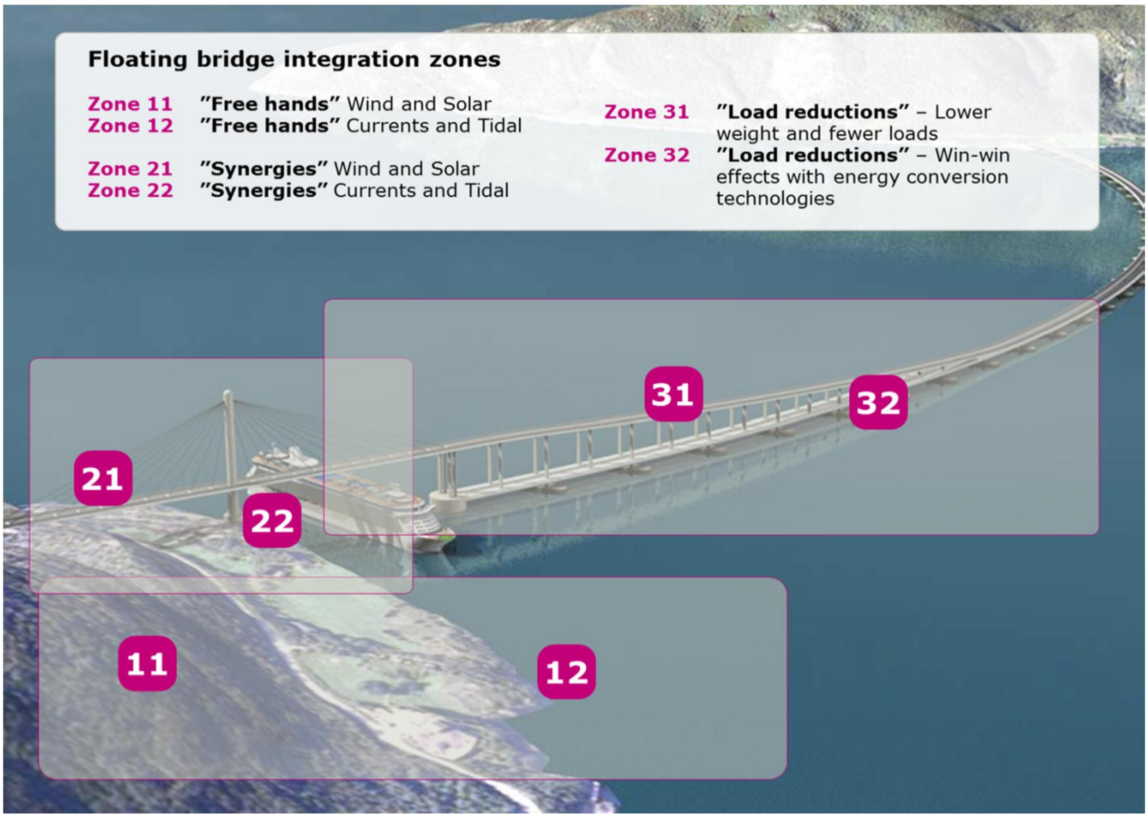

Figure 3-2 Floating bridge integration zones

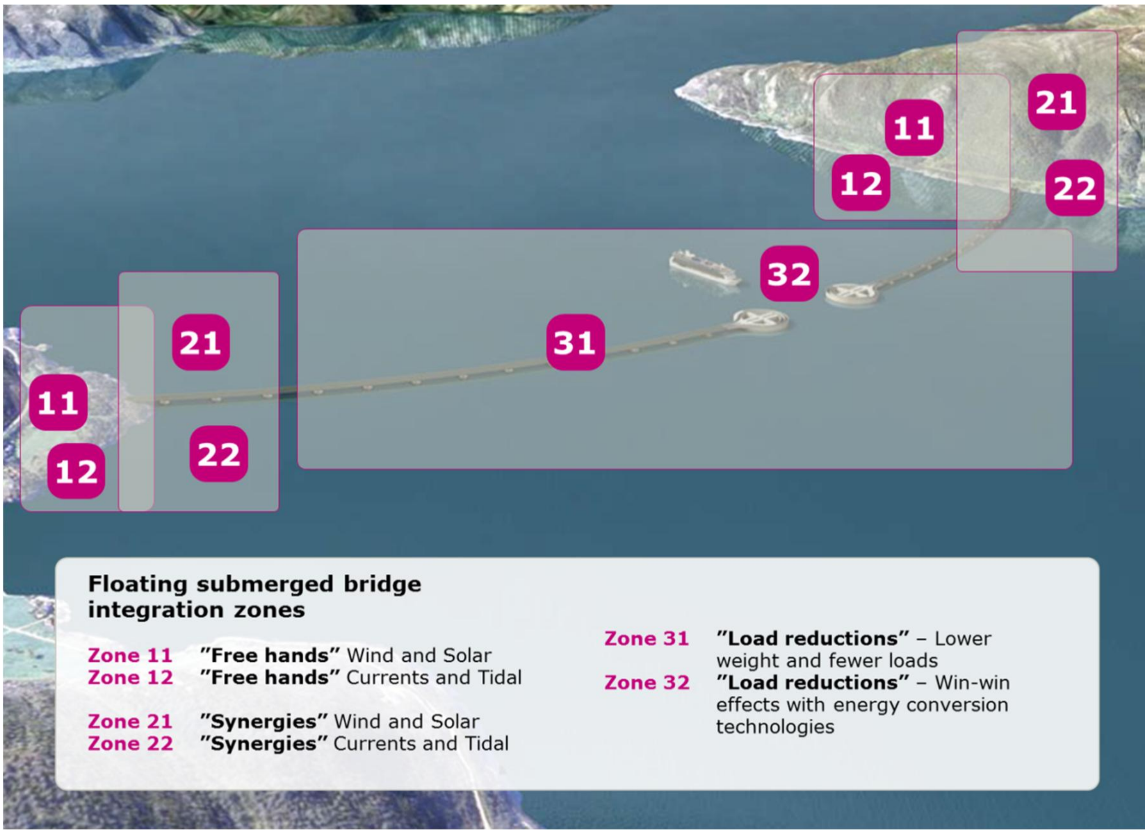

Figure 3-3 Floating submerged bridge integration zones

3.1 Technology evaluations

The table below summarize positive (green), neutral (grey) and negative integration possibilities for the different energy conversion technologies.

INTEGRATION	WIND HORIZONTAL	WIND VERTICAL	CURRENTS	WAVE	SOLAR
ANCHOR POINTS AND UTILIZATION OF EXISTING INFRASTRUCTURE	→	→	↑	↑	→
BRIDGE LOADS	↓	↓	↓	↓	→
MOUNTING AND CONSTRUCTION	↑	↑	↑	↑	↑
OPERATION AND MAINTENANCE	↑	↑	↑	↑	↑
VISUAL LOOK AND DESIGN	↓	↓	→	→	→
ENVIRONMENTAL CONSEQUENCES	↓	→	→	→	→
TECHNOLOGICAL MATURITY	↑	→	→	↓	↑

Table 3-1 – Possible positive, neutral and negative integration aspects

It is expected all technologies will benefit from shared operation and maintenance systems as well as coordinated construction and mounting of the installations.

All the technologies will add extra loads to the bridge construction, exept solar panels which could be used to create aerodynamically bridge constructions instead of other steel or concrete structures. This effect is considered the most important advantage with solar energy.

The visual impressions concerning the installations, especially large wind turbines, could be considered both negatively as well as positively and is hard to predict and measure. Due to rotating and moving parts the visual experience is most likely to be negative for the bridge users, but it depends on the location and size of the turbines. The other technologies are expected to have a lower negative visual impact than wind turbines.

Tidal and wave installations could utilize the bridge anchor points, or strengthened anchor points in connection to the bridge. The installations are already developed with floaters and should have a minimal effect on the bridge. If completely integrated with the bridge floaters this would be a different matter, but would be positive for the energy installations.

The following chapters explain the challenges and the considerations for an integration in more detail.

4. WIND TURBINE INTEGRATION

Wind turbine technologies can be divided into two main groups, horizontal and vertical axis. Today, horizontal axis turbines are deployed widely across the globe. The turbines vary greatly in size (height, weight), power (kW) and actual production (kWh) between manufacturers. The largest commercial turbines deployed are more than 120 meters high and up to 10 MW. However, small scale turbines down to 1 kW are sold for remote locations for households, cabins etc.

Large conventional wind turbines can produce energy at a cost down to 0,5 NOK/kWh. A wind turbine consists of a nacelle on top of a tower with foundation and large blades connected to a hub. Globally, manufacturers perform extensive research and development to develop more competitive turbine technologies. The development focus on new and improved turbines, high voltage electronics, new gears (e.g. permanent magnets), lighter materials, more efficient installation procedures (especially offshore) as well as upscaling. Additionally, wind measurements and prognosis tools are being developed.

Below, some examples and challenges of wind turbine integration is presented.

4.1 Integration possibilities

The integration challenges and synergies depend largely on the turbine size and weight. Dynamic resonance is critical for bridges and rotating installations could magnify the resonance effects, both for lower wind speeds and extreme conditions. Due to challenges with weight, wind break and turbulence, wind turbines should not be installed on the centre span, as shown as zone 3 on Feil! Fant ikke referansekilden., Feil! Fant ikke referansekilden. and Feil! Fant ikke referansekilden..

EXAMPLE 3 MW WIND TURBINE

The most likely location for conventional turbines (2-5 MW) is in zone 1 and in some cases zone 2. One possibility is to use the pillars for wind turbines. The added value for wind turbine integration are numerous, e.g. possible reduced foundation and tower costs, reduced costs for access roads, infrastructure and construction sites. The mounting and construction will also benefit from shared machinery, personnel and other equipment. The wind turbine will also benefit from electrical grid integration, shared operation and maintenance, surveillance and system control centre.

Wind turbine integration on bridge pillars will add extra loads. Dead weight, shear loads and torque are the most important loads. Additionally, there are challenges related to vibrations from moving and rotating parts. An exact calculation of load changes is complex and is not part of the project scope. To evaluate the feasibility some assumptions can be made,

The table below shows some general weight assumptions for a 3 MW wind turbine and tower.

Component	Weight (ton)
Nacelle	80
Rotor (diameter ~90 m)	60
Tower (~80 m)	100

TOTAL	240

Table 4-1 - Estimated 3 MW wind turbine weight

Extra weight and new loads is a substantial challenge to handle on bridges and will result in expensive upgrades of traditional bridge design. To exploit wind resources from all directions, a vertical axis turbine is most suited, and if a horizontal axis turbine should be installed it has to be mounted at least 50 meters above any surrounding obstacles due to the rotor length. If the turbine should be placed on top of a pillar, for instance 100 meters high, the total hub height will be 150 meters. With the assumption of a maximum wind load of 59,5 m/s (corresponding to IEC wind load class II[6]), the maximum bending moment at the foundation of the pilar will be approx. 95.000 kNm. Additional torque will be approx. 3500 kNm, while additional shear load will be approx. 700 kN.

The suspension bridge pillars will most likely be much higher than 100 meters, which means an even more challenging task to mount the wind turbines.

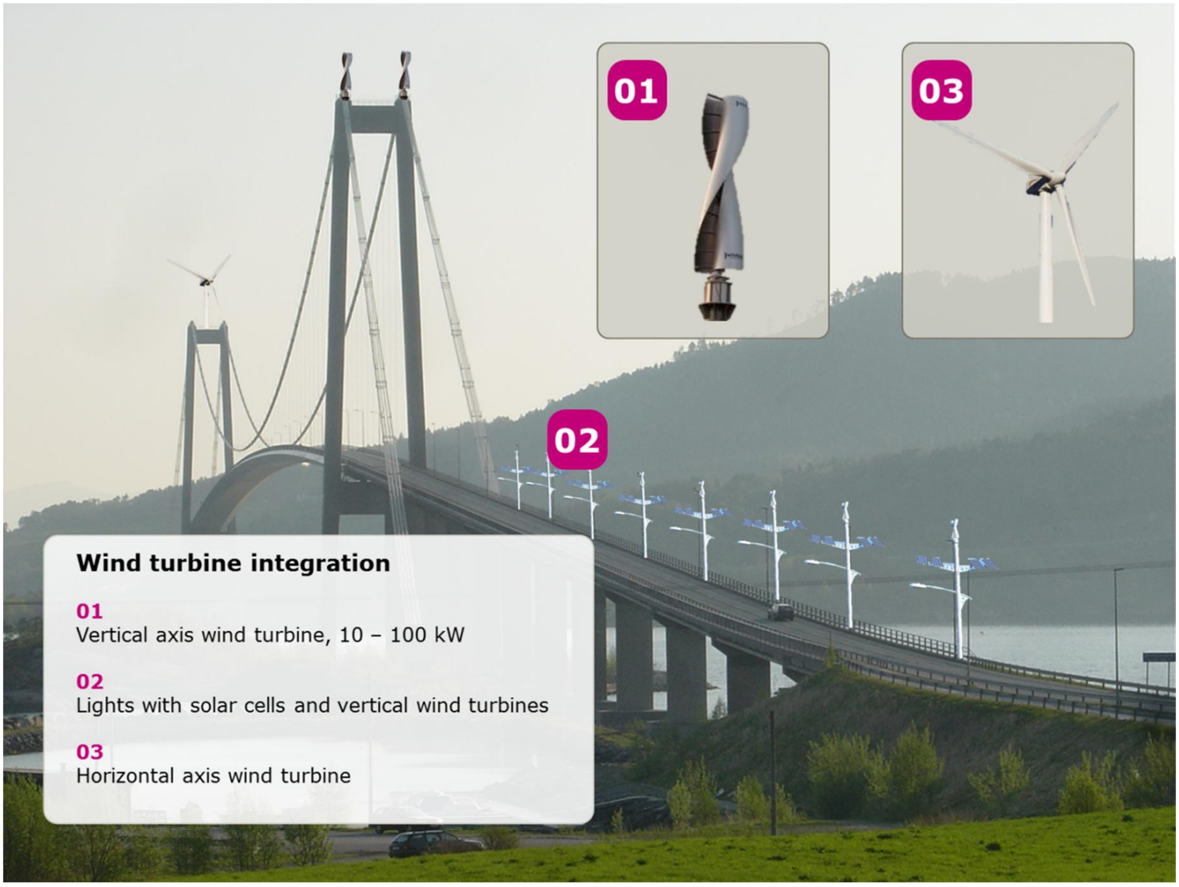

Figure 4-1 Wind turbine integration on a suspension bridge

Alternative solutions is to install smaller vertical axis turbines in different zones at or close by the bridge. Vertical axis turbines is easier to mount with more concentrated wind area which also could fill out space between pillars, as seen on the picture below.

[6] http://www.vestas.com/en/wind-power-plants/wind-project-planning/siting/wind-classes.aspx#/vestas-univers

Figure 4-2 Wind turbine integration concept #1, Rambøll Energy

Figure 4-3 Wind turbine integration concept #2, Rambøll Energy

EXAMPLE 45 KW WIND TURBINES

One wind turbine alternative could be a 45 kW sized turbine which could be mounted close to the roadway. The size could range from typically 10-50 kW. The 45 kW alternative has a rotor diameter of 15 meters and tower height range of 15-30 meters.

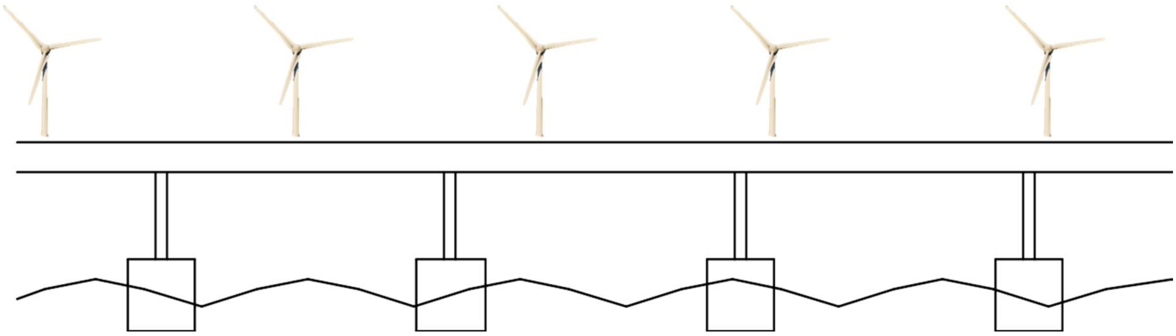

Figure 4-4 Wind turbines on a floating bridge

Wind turbines should always be placed in relation to the dominant wind direction to avoid lower production and worse conditions for the downwind or leeward turbines. The dominant wind direction at a fjord crossing will in most cases be perpendicular to the bridge, which is an advantage. The optimal distance between the turbines downwind is approximately five times the rotor diameter. The distance between the turbines should be two to three times the diameter to avoid turbulent conditions. With these assumptions it would be space for 3 turbines with a capacity of 45 kW per 100 meters.

A 45 kW turbine with 30 meters tower height weighs about 7 tons, and will add a 69 kN vertical load. A turbine of this size can withstand gusts of wind up to 52,5 m/s during a 50 year return period (IEA wind load class III). For this scenario, each turbine would add a maximum bending moment at the road shoulder of 1350 kNm and the additional shear load would be 65 kN. These loads would induce a reinforcement of the bridge structure which would lead to extra weight and costs.

The advantages would foremost be more efficient installation of the wind turbines related to less time and costs for foundations, digging, freight and logistics. This type of integration would also benefit from existing electrical infrastructure.

Total CAPEX for this kind of wind turbines is approximately 800.000 NOK. With a utilization time of 2000 hours per year, each turbine could produce up to 90.000 kWh per year. The energy production costs would be approximately 0,9 NOK/kWh. Operation and maintenance costs would be added to the costs. The advantages with smaller wind turbine integration is more efficient logistics and installation.

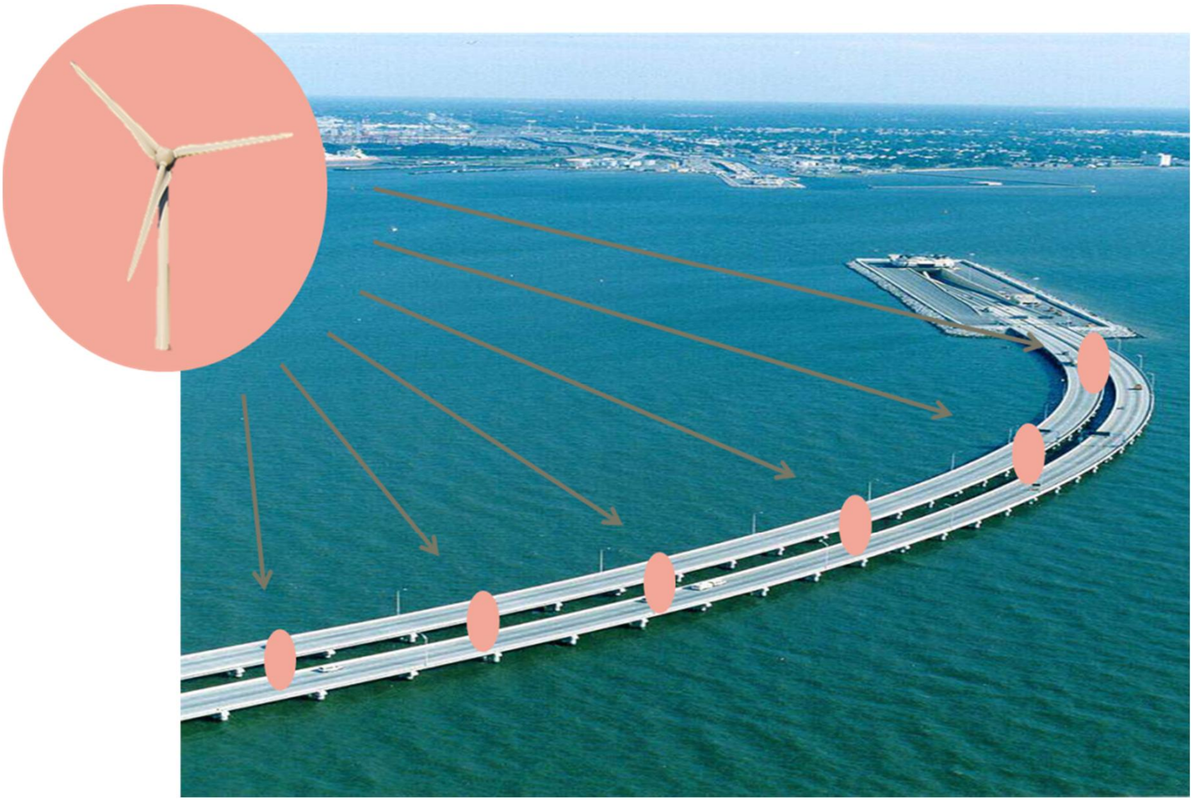

Figure 4-5 Smaller wind turbine integration on bridge deck (Rambøll)

4.2 Added value and costs

Wind turbine investment costs consist mainly of turbine, tower, foundation, electrical grid connection and mounting costs. The added value of integrating wind turbines with bridges is expected not to be high, since the turbine costs are the same independent foundation type. The table below show the cost distribution of a wind turbine installation.

Wind turbine investment cost distribution	
Turbine, rotor, generator	65 %
Tower and foundation	15 %
Internal grid and cabling	3 %
Grid connection	7 %
Mounting, construction, logistics and engineering	10 %

Table 4-2 – Investment costs wind turbines (Rambøll Energy)

The table below shows some typical costs for a standard 3 MW wind turbine. The investment costs are typicaly 12 million NOK per MW installed capacity. A 3 MW wind turbine will therefore usually cost approx. 36 million NOK. The column *Potential cost reduction* show possible cost reduction in percentage and NOK from promising synergies with the bridge construction. These cost reductions is just an example to illustrate the potentials, and the real costs has to be investigated further.

3 MW Wind Turbine	Costs	Potential cost reductions	
Investment costs	Mill. NOK	%	Mill. NOK
Turbine, rotor, generator	23,4	0	-
Tower and foundation	5,4	-50 %	-2,7
Internal grid and cabling	1,1	-80 %	-0,9
Grid connection	2,5	-80 %	-2,0
Mounting, construction, logistics and engineering	3,6	-50 %	-1,8
Total	36,0		-7,4

Table 4-3 – Theoretical wind turbine cost reductions (Rambøll Energy)

This example show a possible cost reduction of 7,4 mill NOK for the wind turbine only. However, the bridge construction must be reinforced which imply additional costs. The bridge reinforcement costs as well as the bridge design and engineering costs are not estimated.

The wind resources at the bridge crossings is most likely not ideal and worse than closer to the North Sea coast. This will represent an additional cost with lower energy production than an optimal location. Combined and probably new environmental challenges could arise as well which could affect the bridge integration. The visual aspect could also be a challenge with a bridge in large extent visible to the surroundings.

4.3 Summary

Added value and synergies from total integration is expected to be low from wind turbines. Traditional horizontal wind turbines could be located close by the bridge (zone 1), either on the nearby construction site or an elevated site nearby, but not on the bridge construction itself. Vertical axis wind turbines should be easier to integrate, both due to smaller size, but also optimized windbreak area.

The costs of integrating wind turbines will in most cases most likely exceed the benefits due to increased bridge loads which need to be addressed. Turbines attached as shovels around the pillars or vertical axis turbines in zone 2 seems to be the most promising wind integration technologies.

The wind resources are in most cases worse on a bridge with turbulence from the bridge construction, lower wind speeds due to the location of the bridge between high mountains and so forth so the relative production costs will be higher than an optimal location along the coast. Further calculations are needed to estimate the full potential and added value.

Possible synergies	Challenges
– Existing infrastructure can be used for transport and mounting of turbines – Construction machines and equipment being used for the bridge can be used for the wind turbine installations – Shared surveillance and control facilities – Utilization of existing electrical grid in connection with the bridge construction – Reduced visual noise compared to other wind turbines due to the bridge construction	– In most cases increased costs to reinforce pillars and bridge construction – Increased design and engineering costs – Increased visual noise compared to a standalone bridge

Table 4-4 – Potential added value and challenges

5. WAVE AND TIDAL INTEGRATION

As opposed to wind and solar energy, wave and tidal technologies are still in an early phase of development. The main cause is due to the need of large scale installations because of demanding marine conditions. During the last 10 years a large amount of innovative wave and tidal technologies have been developed and tested globally. The vast amount of various and partly developed technologies makes it difficult to assess the possible solutions most suitable for integration.

In spite of the large variation, marine energy conversion technologies have common challenges. A main challenge is the robustness of the installation to withstand demanding conditions and extreme weather. The structural dimensions therefore need to be much larger than the average loads. Another important challenge is the marine operations with installation, operation and maintenance. This is by itself a high cost operation. The supply vessels are usually dependant on calm conditions during installations as well.

The technical survey has not been able to identify technologies with optimal integration possibilities. Each technology has distinctive characteristics which make the integration even more challenging for deep fjords. One well-known tidal technology is barraging of straits or inlets along the coast to utilize the tidal height difference to produce electricity. A rule of thumb is that a difference of five meters is needed to be able to generate electricity from the potential energy stored behind the dam. This technology is suited for E39 due to many reasons, e.g. the fjord depths, little difference in tidal levels and wide crossings. Below is an example of a barrage located in France, with a capacity of 240 MW.

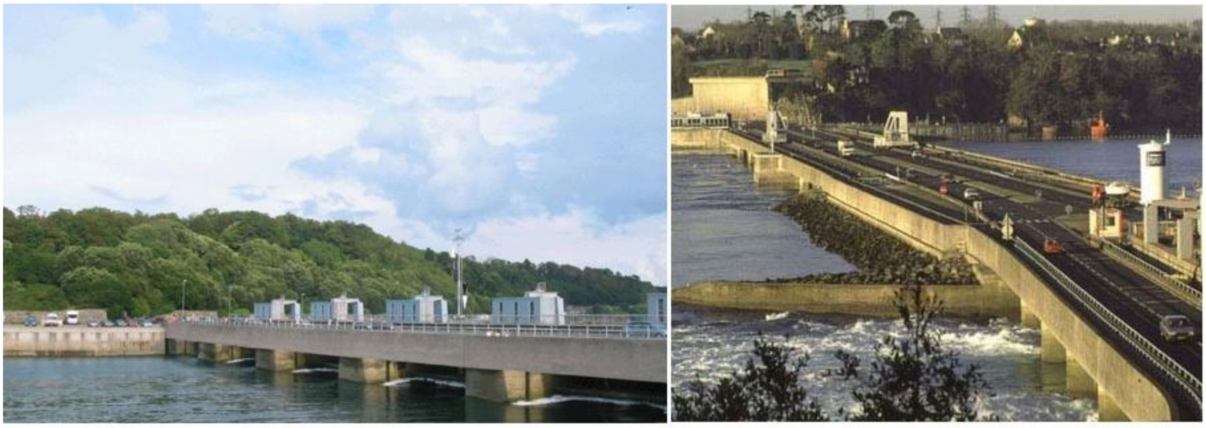

Figure 5-1 La Rance Power Station, France

Few wave and tidal technologies are suitable for bridge integration. One reason is that bridges are placed at locations with a minimum of external loads, this is working against developing integrated tidal and wave solutions. However, some technologies could have some added value related to development and construction of bridge constructions, especially floating bridges. Suspension bridges are less relevant in relation to tidal and wave technologies due to the distance above the water surface, however the pillars could be used as an anchor point. Below, challenges and synergies for tidal and wave technologies, are presented.

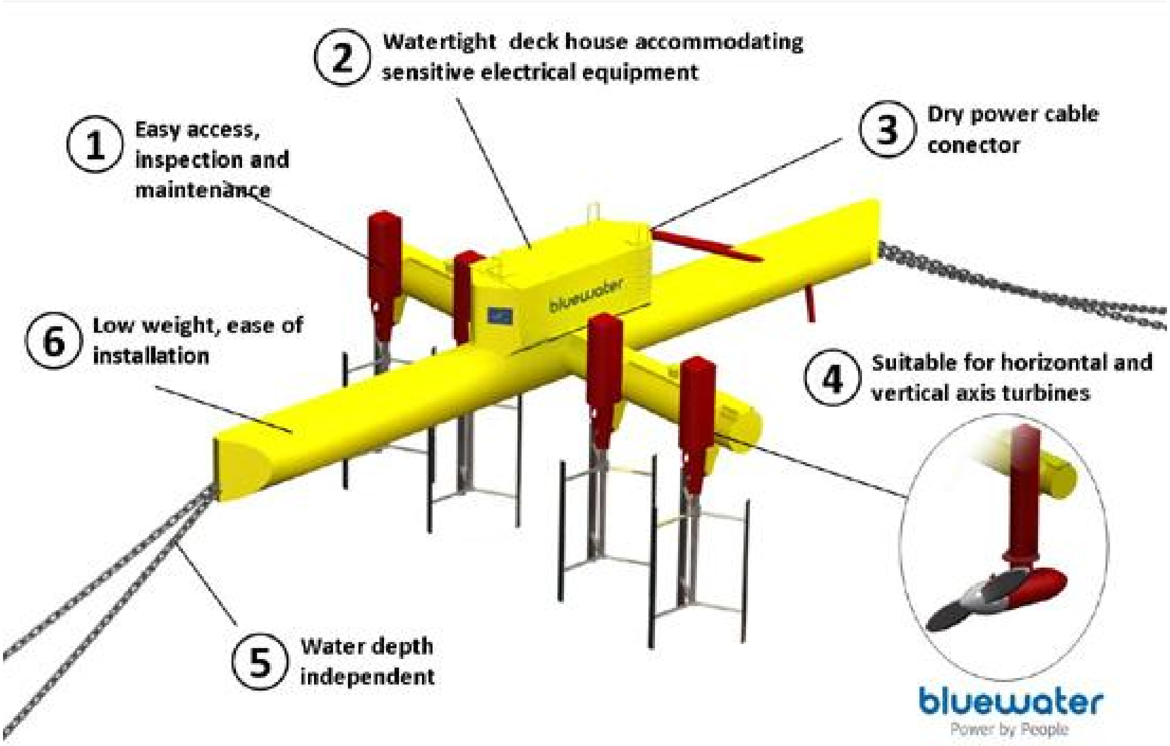

Figure 5-2 Floating tidal current turbines (Bluewater)

5.1 Possible integration solutions for wave and tidal

Integration of wave and tidal technologies with bridge constructions is challenging. Large floating bridges are affected by loads from natural forces. The structural dead weight must be kept at a minimum, including traffic loads, and by balanced by the updrafts in the pontoons.

Horizontal loads from waves, but also primarily from wind power, must be carried by the system and lead to land. The floating bridge pontoon dimensions relevant to the E39 fjord crossings may be up to 60 meters in length, 40 meters wide and 20 meters deep. It is also reasonable to assume that pontoons will be designed to withstand much greater loads than a smaller tidal plant would be able to inflict on the construction.

Generally, it is crucial that the cross section area of the pontoon underwater body is as small as possible. Increased weight will cause the pontoons flows deeper, and then be occupied with larger loads from the waves and currents, which could lead to a "vicious circle". The most optimal solution would be to have an independent floater for the energy conversion unit attached to the pontoon.

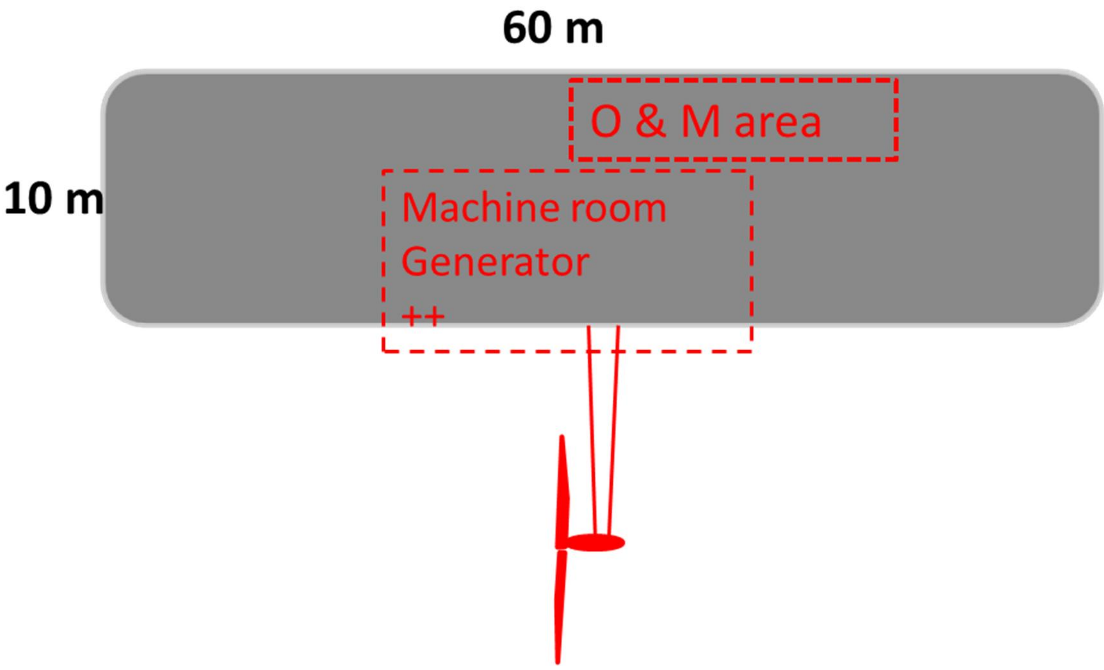

Figure 5-3 Current turbine in pontoon

Installation and construction of wave and tidal plant has high costs associated with the foundation and anchoring of the facility. For fixed installations the costs are related to usage of installation vessels and marine operations, as well as preparing the bottom conditions at the site. For floating plants the business concept are often to reduce costs associated with preparing the ocean floor surface. It is expected to be some positive added value in using the bridge pontoon as a foundation and floater for the energy plant as well.

Such integration will be able to provide significant added value for the actual installation of the power plant. Today most wave and tidal facilities are installed by using installation vessels (boats). These operations can be very costly. The rates for renting this type of boats can be very high, while the boats are dependent on satisfactory weather conditions to complete the installation. Use of bridge construction and its roads might reduce setup cost for a wave or tidal energy plant.

Wave and tidal energy facilities are also characterized by the high costs associated with underwater cables and power to the shore. Cabling technology under water is a well-known technology, however these costs are still far higher compared to onshore power plants (such as wind and solar facilities). By integrating energy plant in a bridge construction marine cables could be replaced with ordinary onshore grid connection. The cables can be included in the surface of the bridge road before being fed into a substation on land. In addition, the pontoon will be able to house the generator and other electronics that traditionally would be under water for a conventional tidal plant.

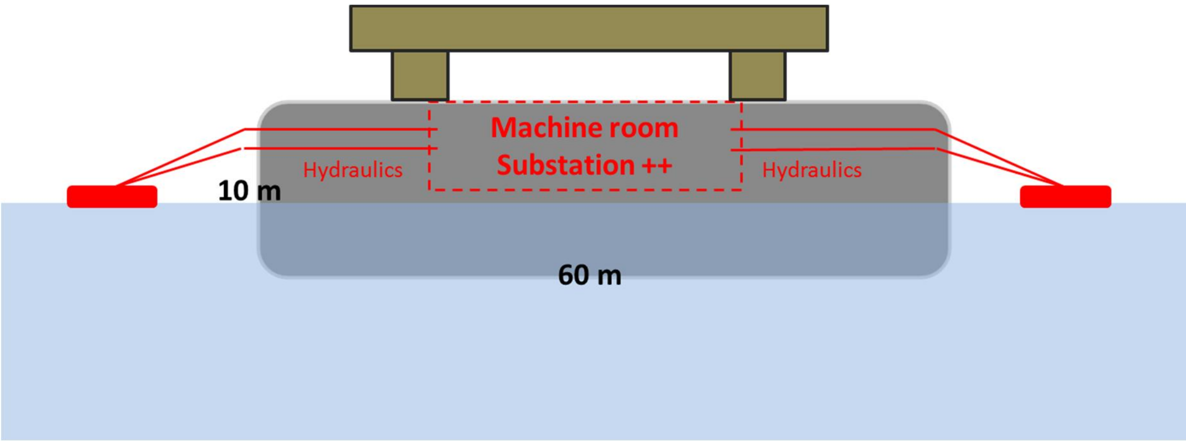

Figure 5-4 Point absorber integrated in pontoon

Development of wave and tidal power plants are technologically and financially demanding. For most systems there are high costs associated with adapting the various fixed components of marine conditions. Compared to onshore facilities (land-based wind and solar energy) a power plant underwater sustains significant additional costs. A lot of research and development is done to reduce the costs of ocean energy systems. It would therefore be a significant added value for a wave and tidal technologies if critical components can be placed in the "dry" pontoon. The pontoons in floating bridge concepts for E39 fjord crossings will be large enough to easily carry out maintenance work physically inside the pontoon. Another important element is that the unit should be able to be lifted up from the water in case of storms or periods when it’s exposed to bad weather. If the turbine can be lifted and lowered it will also have benefits in connection with the operation and maintenance work.

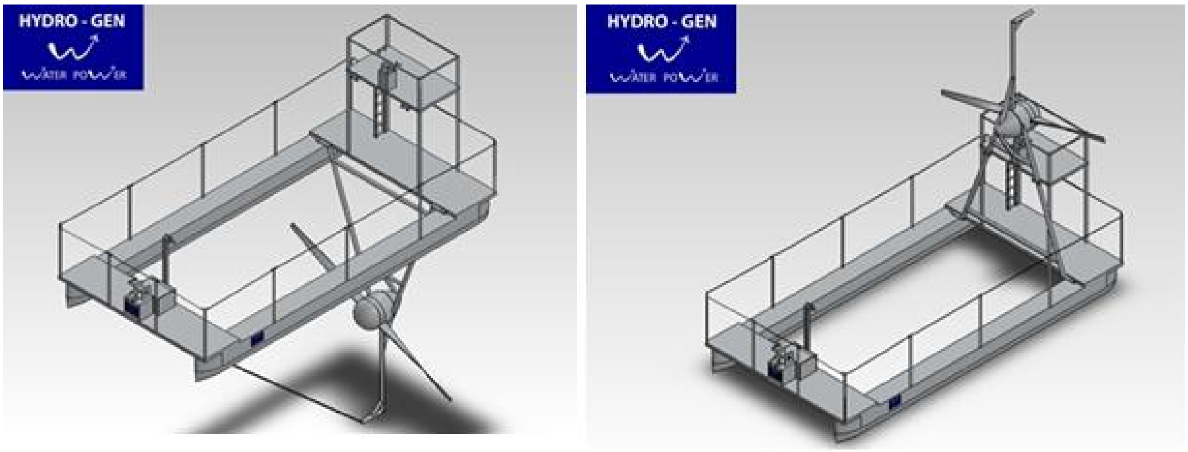

Figure 5-5 Lifting and lowering of current turbine (Hydro-Gen)

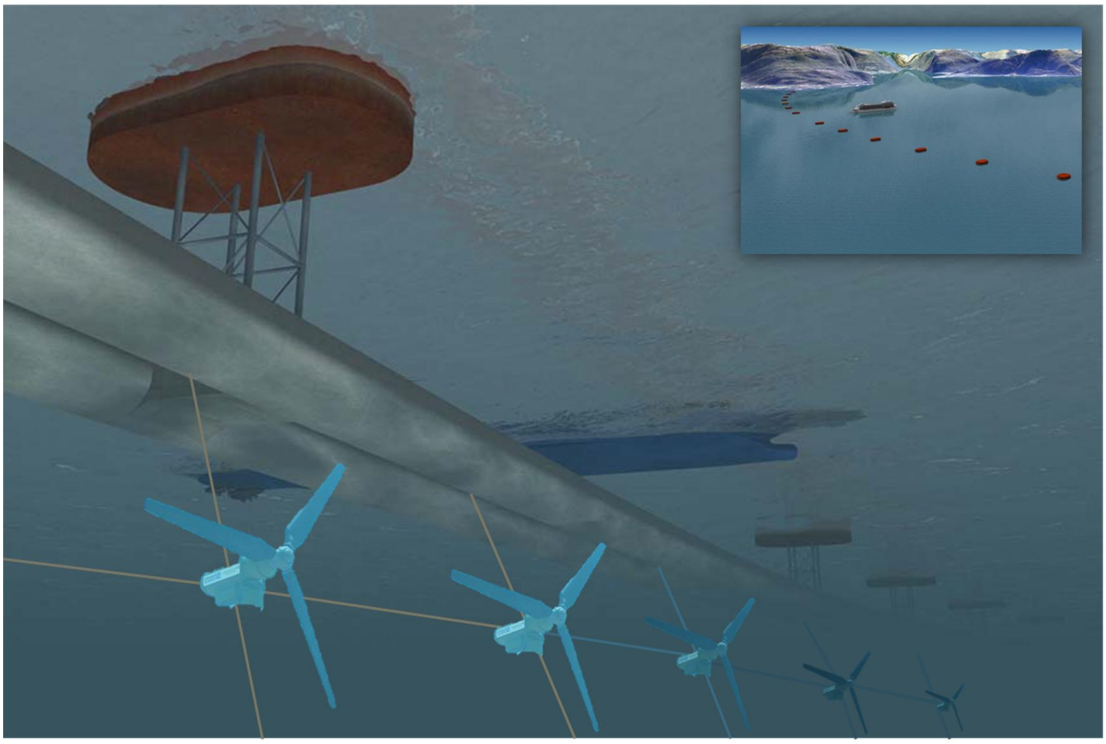

Figure 5-6 Current turbines in submerged tubular bridge

The above and below figures shows two concepts proposed by the project team.

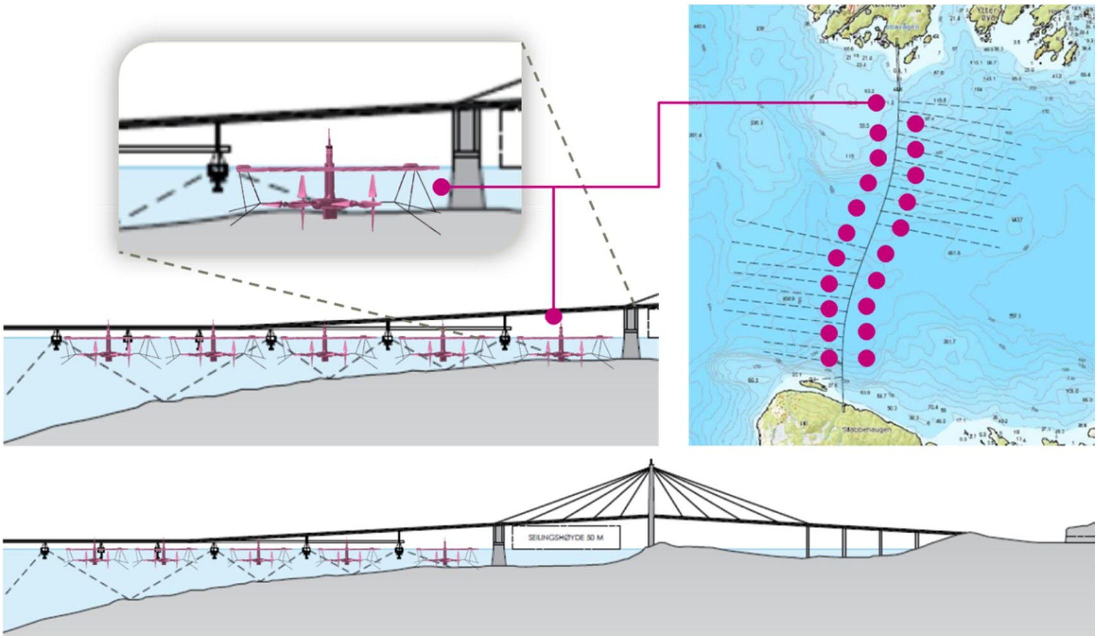

Figure 5-7 - Current turbines in floating bridges

5.2 Wave and tidal system synergies

Although there is a number of wave and tidal projects built and installed successfully generating electricity, there are still very few plants that stand out as clear "winners" which could point out a preferred technological solution. As a result of the large amount of concepts, there are still few plants representing State of the Art with respect to standardized solutions and energy cost per kWh produced.

Compared to wind and solar energy the empirical basis for the assessment of costs of wave and tide is far worse. However, Rambølls experience is, that the production today is expected to be between 1.5 to 3 NOK per kWh. It is also Rambøll's experience that utilization of energy from current turbines is closer to a commercial breakthrough than wave power plants.

The table below shows an example of a tidal current turbine investment cost distribution. In the example, it is anticipated that the investment cost is NOK 40,000 per kW, with a 20 year life time, Internal Rate of Return of 8% and full load hours (kWh/kW) of 3,000 hours. It is likely that this production is far higher than expect in the fjords along E39. It must also be underlined that the allocation of costs in the table under differ significantly from one technology to the other, and the capacity factor may vary with different technologies.

Example of allocation of investment cost for a tidal current turbine		
Turbine and generator	30 %	12 000 000
Anchoring and foundation	35 %	14 000 000
Internal cabling and grid connection to shore	15 %	6 000 000
Project management and installation	20 %	8 000 000
Total		40 000 000
CAPEX 1,36 kr/kWh		

Table 5-1 - Example of allocation of investment costs for ocean energy power plants (Rambøll)

With regards to the earlier mentioned potential benefits of integrating a wave or tidal technology in bridge constructions, the next table presents a case study on how these added values will be able to reduce the investment costs for the power plant.

1 MW current turbine	Costs	Cost reduction	
	Mill. NOK	%	Mill NOK
Turbine and generator	12	-25 %	-3,0
Anchoring and foundation	14	-50 %	-7,0
Internal cabling og grid connection to shore	6	-50 %	-3,0
Project management and installation	8	-20 %	-1,6
Sum	40	-36 %	-14,5
CAPEX (NOK/kWh)	*1,36 NOK/kWh*		*0,87 NOK/kWh*

Table 5-2 - Case study cost reduction when integrating a tidal current power station with a floating bridge (Rambøll)

The case study assumes that the investment costs for the generator and electronics can be reduced by 25% because the components may be placed in dry pontoons. By also using the pontoons as infrastructure, foundation and anchoring the power unit plant may reduce these costs 50%. The example also takes into account that reduced demand for marine cables to will reduce costs by connecting the power plant to the onshore grid with 50%. The case study assumes also reduced engineering costs by 20%, due to shared costs with planning of the bridge construction. The total reduction is 14.5 million NOK per power plant. If it is assumed that it integrates 10 tidal plants in 10 pontoons along a floating bridge the theoretical cost reduction for the whole installation can be 145 million NOK.

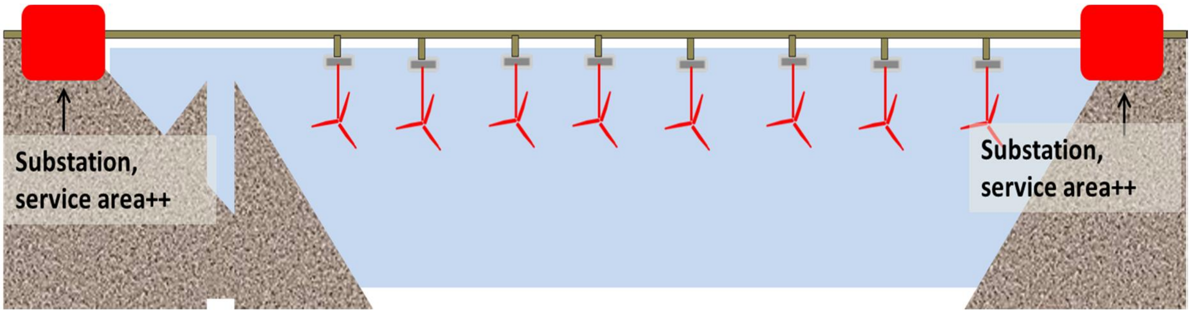

Figure 5-8 - Current turbines integrated in floating bridges

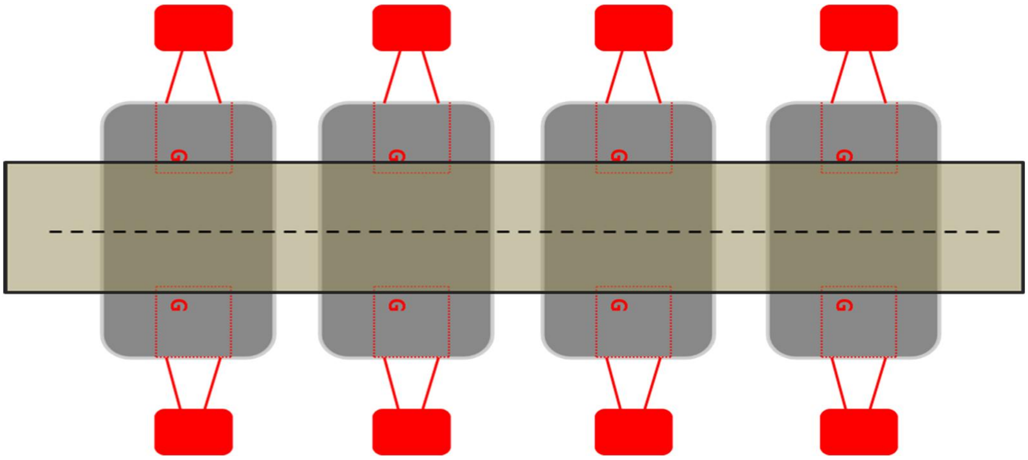

Figure 5-9 - Point absorber in pontoons in floating bridges

Another important factor is the actual flow conditions in the fjords of E39. As mentioned earlier, many flow conditions in the fjords are assumed to be far less than 1 m/s. This will result in a lower production compared to other optimal locations not too far away from the bridge crossing. . Power curve for a flow turbine is exponential. For many of the turbines the effect curve (kW) is flat from 0 to 1 m/s, but increases significantly between 1.5 to 3.0 m/s. A broader description of this relationship is described in the attachment of the report.

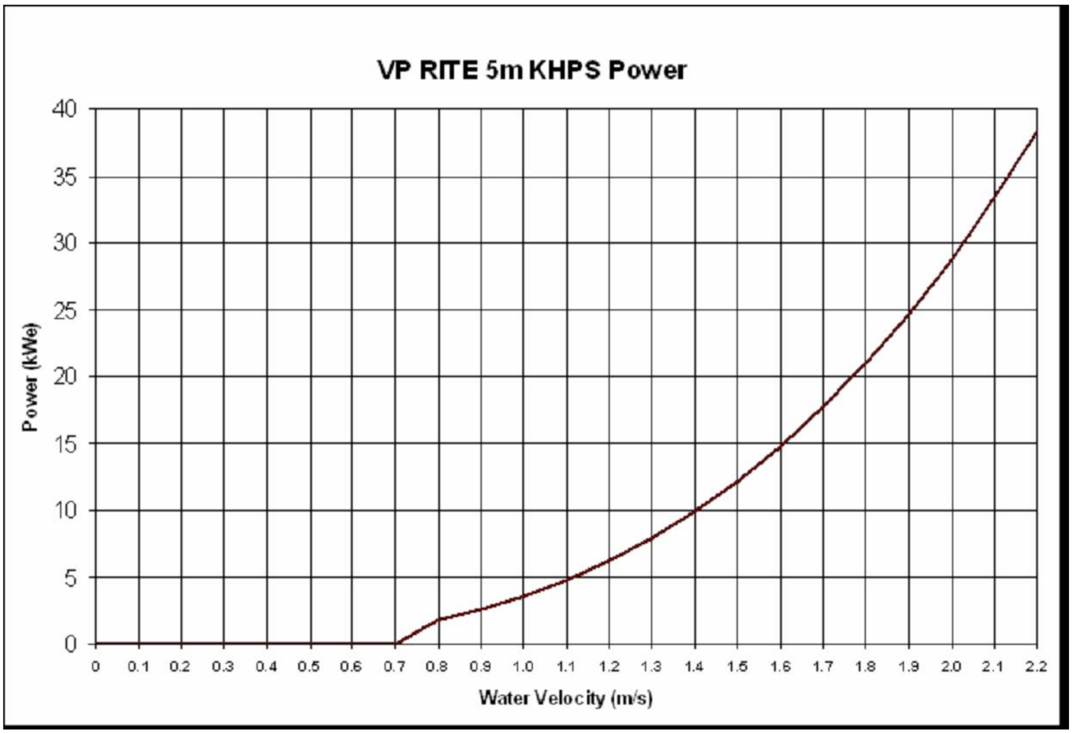

Figure 5-10 - Power Curve, Verdant Power

5.3 Summary

There might be several added values by integrating wave or tidal power stations in a floating bridge construction. First and foremost, it could install the device in or in close association with the pontoon. The pontoon might work as a floater for both the bridge and the power plant. In addition to the bridge and the pontoon might be able to include the electronics and mechanical components, as well as providing excellent (dry) conditions for the operation and maintenance of the facility.

The costs of such an integration is first and foremost linked to the costs of the development and installation of new pontoons, compared to the ordinary pontoons that are used today. In addition, the weak wave and flow conditions in the fjords lead to a substantially lower energy production than what most technologies are designed for.

It must also be pointed out that the better conditions for wave and tidal energy the less applicable it would be for a floating bridge in the area. Bridge construction made for the E39 fjord crossings will be of a size which so far has not been built. It is therefore reasonable to assume that the bridge constructions will be built where loads from wind, currents and waves are at a minimum.

The added values by integrating a wave or tidal technology in bridge structures along E39 are summarized in the table below.

Possible synergies	Challenges
– Reduced costs for generators and electrical systems due to dry surroundings and access in bridge floaters – Reduced overall costs for foundations when bridge floaters are utilized – Reduced costs concerning electrical systems due to dry connections on top or inside bridge – Fewer marine operations reduce costs	– Increased design and engineering costs – Increased stress on the whole construction, but wave installations could function as dampening devices and produce energy simultaneously

Table 5-3 - Potential added values by integrating wave and tidal energy devices with floating bridges

6. SOLAR INTEGRATION

Solar energy production today is done mainly in two ways; solar heaters or solar cells (photovoltaic PV, electricity). Freely hanging bridges have large areas without a lot of shadow and is well suited for solar collectors for thermal energy production or solar panels for electricity generation. This is the case for suspension bridges and floating bridges which have large available areas. The climate in Norway is not well suited for solar energy, because of little direct sunlight, but there is still much indirect diffuse sunlight that might lead to some production, especially for thermal solar collectors.

Compared to wind, wave and tidal technologies in bridge construction, integration of solar might have great advantage because the photovoltaic and solar collectors have low weight and no rotating installations. Solar collectors and panels can also be used as surface protection, or be a part of turbulence and wind load reducers. The construction can be included with narrowed panels that make the bridge more aerodynamic, see figure below for a possible concept. Pillars and other surfaces can have panels protecting the construction.

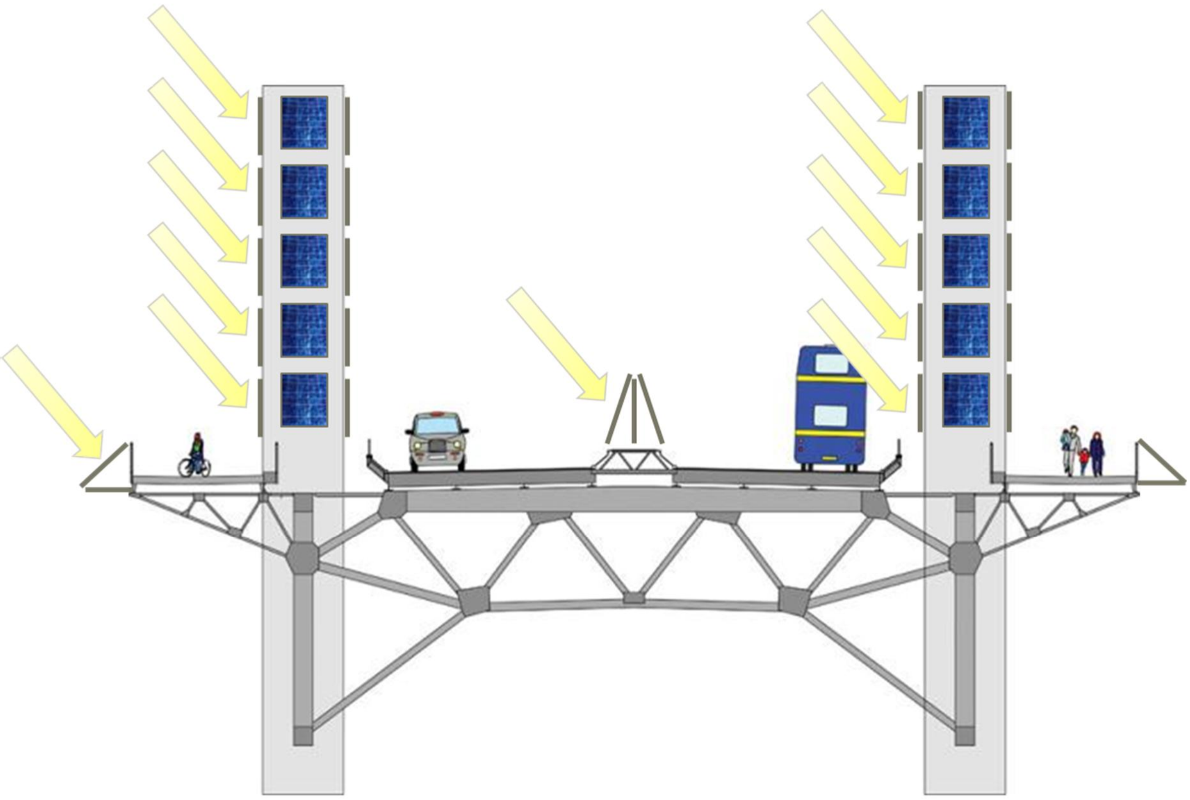

Table 6-1 - Solar collectors and PV integrated in suspension bride

6.1 Solar radiation

The solar intensity in Norway is low, and it is lowest when the energy is needed most, which is in the cold and dark winter days. In the summer there is less need for energy, but still some for cooling. Data and operating systems require a lot of cooling and the need is at its maximum when the solar intensity and outdoor temperature peaks during the summer.

Simple solar panel and collector potentials calculations with climate data from the west coast of Norway can easily be done with available software. In Norway the radiation is approximately 1000 kWh/m^2 in total during a year. The levels are about 150 kWh/m^2 during the summer, but almost zero in December and January. In contrast, Spain has double the radiation annually and varies from around 100 to 200 kWh/m^2 on a monthly basis.

6.2 Solar panels

Different solar panels have different system efficiency and thus the amount of electricity produced per area. The area can typically range from ca. 5-10 m^2 per kW_p. If a bridge include 200 m^2 of PV panels with 1 kW_p per 10 m^2 (20 kW_p power), an energy production of 10.000 – 15.000 kWh_{el} each year should be expected. A bridge might include up to 1000 m^2 of PV panels and the energy production in this case will be close to 75.000 kWh_{el} each year, which accounts for the annually energy consumption for approx. three average Norwegian households.

Below is a table of two identical plants, one located in Sognefjorden (Norway) and one in Madrid (Spain). The plant size is 200 m^2, and the panels have a 35° slope and are oriented 5° against south. The power output of the photovoltaic system in this case is 20 kW (crystalline silicon). Estimated losses due to temperature relative to the local ambient temperature is 11%. Losses associated with mirroring are estimated at around 3%. Other losses from cables, inverter, etc. are estimated at 14%. System losses in total are estimated at 26%. A solar cell in Norway is likely to transform about 5-10% of the solar energy to power but it depends heavily on technology, localization, system maintenance, climate etc. The plant is estimated to produce 15.000 kWh_{el} at the Sognefjord, and almost the double, 30.000 kWh_{el}, in Madrid.

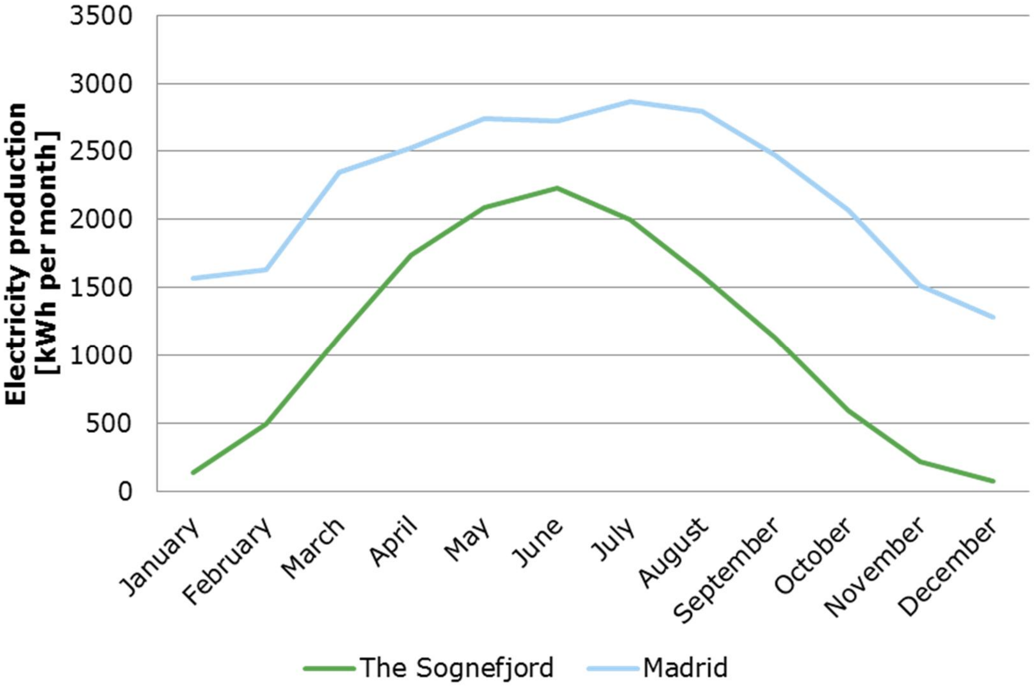

Table 6-2- Electricity production from a 200 m^2 solar plant in Norway vs. Madrid

6.3 Solar collectors

Large solar collector plants (1.000 - 10.000 m^2) deliver up 430-450 kWh/m^2 annually for district heating in southern parts of Scandinavia. The advantage of district heating system in for instance

Denmark is the low return temperature (30-40 degrees) which make more heat transferable to the district heating system from the collectors. In Denmark large seasonal storage pools are being built to use solar heating all year round. In Norway, a collector facility of 10,000 m^2 in Lillestrøm is being built. This will be connected to the district heating system during 2012 and is expected to produce 350-400 kWh/m^2 on average per year. Solar collectors can convert more solar energy than panels measured in kWh, but the heat has lower energy quality. If the heat had to be converted into electricity, the losses would have been very high, not to mention the physical constraints of producing electricity without steam or high temperatures.

Empirical data[7] from flat solar collectors at facilities with 5,000-15,000 m^2, mounted on horizontal and even ground, costs approx. 2000 kr/m^2, all included. Integrating this kind of facilities to a bridge would probably result in higher costs. A 1000 m^2 installation can thus deliver approximately 350,000 kWh of heat with a temperature range of 30-80 ° C, but little or no heat supply between November and February. A collector contains glycol and the quality of the glycol could affect the costs, but also the heat delivery and frost protection characteristics.

Table 6-3 - Geothermal heating and cooling to avoid icing and extreme heating (Germany/Forever open road)

The collector heat can supply heat to nearby buildings, visitor centers, petrol stations or small industry. An optimal solution could be a swimming pool which also has large heating needs in the summer, which need low-grade heat. An advantageous characteristic with pools is thermal energy store which makes the system less sensitive to uneven production and a maximum utilization of the solar heating system. Another possibility is to use low grade heat production which cannot be sold during the winter months to melt snow on exposed places on bridge construction, such as road, pillars, the bridge's contact to sea water levels or similar. Table 6-3

[7] projects run by Ramboll

show an example of bridge heating and cooling with indirectly use of solar heating from a river and geothermal storage. The same system can also refrigerate the road in the summer to avoid high temperatures. By having more stable temperatures, road maintenance can be reduced.

The table below shows potential added value and possible costs of integrating solar energy technologies at bridge crossings along E39.

Possible synergies	Challenges
– Large available areas on bridge shoulder and pillars with relatively easy access for maintenance – Existing constructions can be used without major modifications – Can be used on all relevant bridge types – Can be used to reduce wind loads and turbulence and protect the roadway and pedestrians	– Low sunlight intensity in Norway will result in low amounts of energy produced, but the rapid development of solar cells and solar heat applications could make the installations much more competitive within 5-10 years

Table 6-4 - Possible solar integration synergies and challenges

7. TECHNOLOGY DEVELOPMENT

IEA specify general learning rates for each category of energy technology (hydro, wind, solar, geothermal, bio and marine), both for investment and production costs. The UN Panel on Climate Change (UPCC) has documented learning rates from a wide range of publications. The learning rates are presented for the categories in general, but also for several energy technologies and various components, different geographical regions and different periods in time.

Technological developments and breakthroughs depend on the interaction between technology research and industry and market development. Technological learning is a key factor for the alternative cost of energy technologies. Many of the conventional technologies used today have had a long time to be developed. Most renewable energy technologies and fossil energy technologies with cleaning have higher production costs, but lower greenhouse gas emissions and usually fewer environmental impacts than conventional technologies. Many of the newer energy technologies are still immature, but development rates are high compared to the conventional technologies. The gap is expected to be reduced, and eventually closed completely.

According to UPCC the main cost reductions learning mechanisms are:

- ✓ Learning by searching, which consists of improvements from research, development and demonstration projects (RD&D), and not only for innovation before commercialization
- ✓ Learning by doing, which consist of improvements to the production process (for example, the efficiency of labor, specialization of duties)
- ✓ Learning by using, which consists of improvements based on feedback from users after the technologies have been sold in niche markets
- ✓ Learning by interacting ("spill overs"), which consists of a strengthening of the mechanisms mentioned above as a consequence of increased interaction between all actors
- ✓ Large scale benefits, both the size and number of installations including mass production

These mechanisms can occur at the same time in different development stages.

With a doubling of cumulative installed capacity empirical data show technologies have a more or less constant percentage decrease in the cost level (both specific investment costs and total production costs).

Learing rates[8] are defined as a percentage cost reduction with every doubling of cumulative capacity or energy production[9].

Learning curves are often illustrated as a straight line in a logarithm diagram. The figure below gives an overview of such a diagram where the learning curve drops and after some time reach the cost for conventional technologies.

IEA defines the development cost for a technology as "total costs of cumulative production needed for a new technology to stay competitive." "The investment of learning" is defined as the additional investments needed for a new technology. The alternative development costs related to produce a certain amount of new and more expensive (renewable) energy is therefore equal to the development costs of the new technology, minus the cumulative cost of conventional

[8] Learning rate, LR

[9] Graden av utvikling (progress ratio, PR) brukes gjerne som et alternativ til læringsrate. PR defineres som PR = 1 - LR (for eksempel en LR på 20 % tilsvarer en PR på 80 %) PR angir helningen til erfaringskurver

technology. The cost of conventional technologies can have a flat, slightly ascending or descending curve depending on fuel costs, demand and supply, increased fixed costs or similar.

Variable fuel costs may also be included. If variable costs are included, the alternative renewable energy investment costs will be lower due to avoided carbon costs. The figure shows that the cost is equal to the area under the learning curve, calculated up to the junction. After the junction is reached, the innovative technologies provide energy with lower costs than conventional technologies. These cost savings can offset the value from previous investments, but this depends on the internal rate of return, climate emission obligations and future development of competing technologies (SRREN).

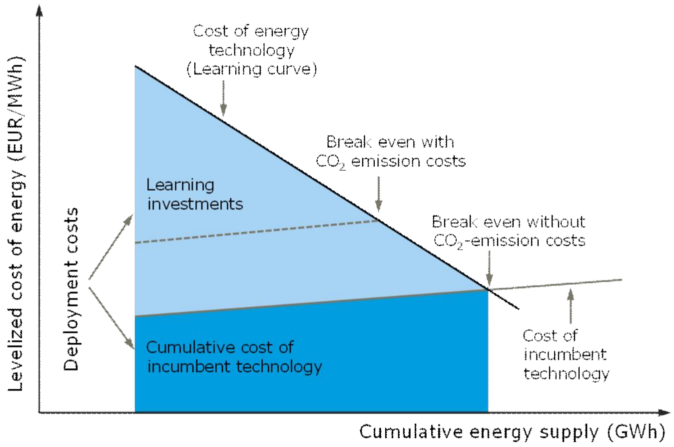

Figure 7-1 – Schematic overview of learning curves (IEA/SRREN)

7.1 Wind energy technology development

Wind is the largest renewable electricity producing technology globally after hydro power. Onshore wind energy technologies are being deployed on a large scale, while offshore technologies are less mature and floating installations require the greatest development. Wind energy production is variable (intermittent), and in many cases difficult to forecast, both in shorter and longer term (hours to days). Experience and in-depth studies from several regions have shown that integration of moderate amounts (10-15%) of wind does not pose any major technological barriers.

The main technology developments which stands out are advanced tower constructions, advanced rotors, reduced energy loss and more robust solutions as well as new driving lines (gear, generators, and power electronics). Weight reduction is the most important aspect for further wind turbine development. Weight reduction is achieved by new materials with a greater weight strength ratio, but also new technology made up of fewer components. Within the turbine there is great effort put into development of new gear boxes, or direct drive systems, i.e. direct-driven systems with permanent magnets, which has benefits for both the operation and weight reduction. New blade materials will also help reducing the weight while maintaining strength. Another important technological challenge is control systems for better regulation of the turbine, especially important for offshore installations. Remote surveillance (condition monitoring) is increasingly a key part of the wind turbine parks, particularly for offshore.

Turbine manufacturers will in the future provide magnetic boxes, which today are used in submarines and formula 1 cars. The technology can lead to a dramatic weight reduction and a lot less wear and tear when there is no physical contact between the rotating parts. The turbine will be more robust with a higher reliability, eliminating errors, providing more optimal transmissions and less use of lubricants reducing contamination risks and oxidation of components. In addition, it is a good protection for overload. This technology will also increase the transmission speeds, beneficial for electricity production. Weight reductions from these technologies are also important for onshore facilities for a simpler and less expensive anchoring. For the near future (5-10 years) it is expected a great evolution in forecasting, e.g. up to 6-48 hours. In a longer perspective (10-

20 years) it is expected that the storage technologies for different timescales (minutes to months) in direct interaction with wind energy production plants will significantly increase the share of wind power in the energy mix.[10]

7.1.1 Onshore wind

A challenge with many wind projects is to find better methods for measuring wind speed and turbulence to utilize most suitable turbines. A challenge with many projects is a lower production than expected due to incorrect measurements or wrong interpretation of the result. Technological development for onshore wind is primarily on improving energy from rotor designs, especially for low speeds, and in complex terrain and turbulent relationship that largely apply to Norwegian conditions. Tower cost reductions could be reached with more advanced use of concrete. The IEA believes the learning rate of investment cost for the onshore winds will remain at 7%. SRREN specifies a learning rate of 11% for investment costs worldwide from 1980 to 2004, and 9% until 2009. Electricity production costs have had a learning rate of about 17-18% in the EUROPEAN UNION from 1980-1995, more than 30% in the United States during the same period, while the learning rates for turbine costs have large differences for different countries, up from 19% in relation to the various components.

7.1.2 Small scale wind

There are many different sizes of wind turbines. Small scale is defined as turbines with nominal performance under 500 kW turbines, but for smaller buildings turbines are usually under 25 kW and down to 5 kW. Micro wind turbines are referred to as everything less than 5 kW, but also down to 0.5-1.5 kW. The main challenge small individual turbines are very high costs, but in areas with poor grid connection it can be a competitive solution if storage challenges can be solved with optimum energy efficiency.

7.2 Technology development solar energy

A number of solar technologies are modular, making it possible to use technologies in both centralized and decentralized energy systems, and deployed as needed. Solar energy is variable and relatively unpredictable. In Norway's heat production from the sun could be exploited to a much greater extent in large parts of the year from March to October. Thermal storage can improve power management and energy return, e.g. for CSP and solar collectors[11].

7.2.1 Thermal solar collectors

Plane thermal solar collectors are a mature technology, and solar collectors with vacuum tubes are largely in the process of becoming a well proven technology with high effeciency levels. Technologically, multilayer vacuum tubes could perform well in Nordic climate conditions and prices are lowered additionally due to mass production in China. Vacuum tube collectors of metals are mature in China, with some challenges with material fatigue due to high temperatures, while the flat plastic based collectors are at an early commercial stage. Regions with a well-functioning solar collector market can benefit from competitive prices for heating tapped water, even in Northern Europe. For district heating plane thermal collectors is a well proven technology in some regions, even as far north as Denmark since the 1990’s.

7.2.2 Solar cells, PV

Solar cells convert solar radiation into direct current electricity (DC) with semiconductors. Solar cells are interconnected in modules, and can have a capacity of up to several hundred watts, and

[10] IEA Wind task 11

[11] Se kapittel Feil! Fant ikke referansekilden. for utfyllende informasjon om lagring

modules can be combined into systems with multiple megawatts of capacity. The systems can be used for grid connected installations, or independent systems.

Commercial solar cell technologies can be divided into two main groups; wafer-based crystalline (mono or multi) silicon and thin film. New technologies, including solar cells utilizing a larger portion of the light spectrum, concentrating solar cells and organic solar cells are currently being developed and have great potential for better performance and cost reductions. Technologies vary greatly in terms of cost and performance. Thin film represents the currently lower costs, but lower performance. Concentrating solar cells have higher costs and higher performance. Solar cell market is dominated by silicon technologies of medium and medium-cost efficiency level (wafer-based, 85-90% of the solar cell market, while thin film has the rest). Solar cells can be used in many different ways, e.g. directly on a building or bridge, by utilities for electricity generation and stand-alone systems. An important technical challenge for solar systems is integration in the grid. Focus today is on technological, functional, cost efficient and esthetic aspects of facades and roofing solutions for direct use in construction or in industry.

Solar cells have had an increase in installed capacity of more than 30% per year for the past 10 years.

7.3 Ocean energy technologies

Ocean energy consists of potential, kinetic, thermal and chemical energy, which can be converted into electricity and heat. A variety of technologies can be used, e.g. dams, underwater tidal turbines for tidal and ocean currents, heat exchangers and heat pumps for thermal energy, a wide variety of technologies to convert the motion of the waves energy to electricity as well as osmosis pressure from salt gradients between fresh and salt water into electricity. For ocean energy technologies, except tidal dams, is today demonstrated through R&D and pilot projects. Some marine technologies have variable production (waves, tides, currents), while others have the opportunity to virtually constant energy production, e.g. heat exchangers and osmosis.

An important aspect for ocean energy technologies is the need for relatively large pilot projects in order to withstand tough conditions offshore. Such projects require large investments, with a high risk and usually depend on governmental support. Other technological aspects which need to be developed is mapping of resources, standardization, and guidelines on performance requirements, as well as forecasts of energy production. Environmental effects are expected to be small, but are uncertain. In terms of grid connection, similar technological challenges facing the offshore wind may arise for ocean energy technologies.

At least 25 countries have different projects with the exploitation of ocean energy, i.e. electricity generation from wave and tide technologies, which have made great progress toward commercialization in 2010. Towards the end of 2010 had it been installed 2 MW new wave power and 4 MW of new tidal power, most in Europe.

7.4 Technological maturity

Technological maturity of different renewable technologies is shown in the table below. This table comply with the IEA and UPCC classification (bioenergy, hydro turbines, and geothermal reservoirs or rivers are not included).

Table 7-1 – Overview of renewable energy technologies, maturity and the primary distribution method- Sun, Ocean and Wind energy

			Technological matureness				Primary distribution method	
Source	Technology	Primary energy sector	RND	Demo, pilot	Early phase Commercial	Late phase Commercial	Centralized	De-centralized
Direct sun	PV	Electricity				X	X	X
Direct sun	Concentrated PV	Electricity			X		X	X
Direct sun	Concentrated solar capture (CSP)	Electricity			X		X	X
Direct sun	Low temperature solar capture	Thermal				X		X
Direct sun	Sun energy driven cooling systems	Thermal		X				X
Direct sun	Passive exploitation of sun in architecture	Thermal				X		X
Direct sun	Concentrated heat, food cooking	Thermal			X			X
Direct sun	Fuel for transport	Transport	X				X	
Ocean energy	Wave energy	Electricity		X			X	
Ocean energy	Tidal barrage	Electricity				X	X	
Ocean energy	Tidal current	Electricity		X			X	
Ocean energy	Ocean current	Electricity	X				X	
Ocean energy	Thermal ocean energy	Electricity Thermal		X			X	
Ocean energy	Osmosis	Electricity		X			X	
Wind energy	Onshore, large turbines (1-8 MW)	Electricity				X	X	
Wind energy	Offshore, large turbines (1-8 MW)	Electricity			X		X	
Wind energy	Smaller turbines, stand alone	Electricity				X		X
Wind energy	Turbines for water pumping or mechanical work	Mechanical				X		X
Wind energy	Kite, screen	Transport		X				X

Based on the literature survey and reviews by Rambøll Energy, some technological breakthroughs expected the next 10, 20 and 30 years have been identified. The table below provides an overview of some key developments and possible breakthroughs.

Table 7-2 – Possible technological and commercial breakthroughs

Year	2010-2020	2020	2030	2050
Wind	- Better wind prognosis - Advanced rotor blades, higher strength and lower weight. - New installation strategies, and the gradual development of floaters - Continued growth in average turbine size, particularly at sea	- New turbine technology with permanent magnets. - Better turbines for low speeds and turbulent conditions - Continental scale on offshore development	- The first commercial offshore wind farm - Magnetic gear, high voltage power electronics, - Short-term storage contributes to > 10-15% share from the wind in the grid - Other turbine concepts are commercial (vertical axis, etc.)	> 30% share of wind energy in the grid by using the smart grid, good storage solutions
Solar capture	- Increase the proportion of collectors - Solar collectors supplying heat to two district heating network in Norway	- Solar collectors integrated as standards i buildings in Norway	- Standard that spring water are heated with solar colectors, even in Norway from Mars to November	
PV	- Better performance and scale. - Integration in buildings	- Use in Smart Grids and better storing	- Ultra high performance and low cost - Solar cells on house roofs and walls in Norway (no longer just cabins and boats)	

8. CONCLUSION

In the absence of high intensity energy resources at the E39 fjord crossing locations, and few available technologies, it is considered costly to develop bridge concepts to seamlessly integrate energy technologies from wind, solar, wave and tidal. Technologies need to be much more effective in order to be considered as applicable. When it comes to solar and wind there are good prospects for cost reductions in a 10-20 year perspective.

In cases where bridges will cross fjords with high intensity energy resources, wave or tidal energy technologies might have added value of being integrated with a bridge construction. The added value will, among others, could be reduced costs associated with the installation of the plant, as well as foundation and anchoring of the turbine, generator and other electronic components. There will also be added values related to operation and maintenance, as this can be accomplished in a dry environment in the pontoon of a floating bridge.

It is not found essential added value in integrating horizontal axis wind turbines and solar power plants in a bridge construction. A solar power plant will be easy to install on a bridge, but the solar system will have little benefit of a bridge construction. Wind turbines will only achieve added value by being mounted close to the bridge. The wind turbine costs could be reduced related to investment costs associated with the construction of roads and infrastructure for transport and installation of turbine and tower. For “offshore” turbines there might an added value in installing turbines on floating bridges, by utilizing the open space between the bridge deck and pontoons.

In the same time, it must be underlined that it is very challenging to develop bridges for such large span or bridge lengths that would be appropriate for the E39 fjord crossings. Both dead loads and variable loads from wind, waves and currents, as well as accidental loads from underwater avalanches and, earthquakes will be of an entirely different magnitude than existing bridges. These bridges must be put into an extensive development program to improve the material strength, weight, capacity and design. The aero and hydro dynamic design will be very crucial to the design of the bridge elements, such that the bridge be subjected to minimal resistance from wind and water. This development work will likely be directly contradictory to the requirements for the production of energy, where the goal is to capture more of the energy from the wind, currents and waves, except in very special cases where reduction and more aerodynamic installations can make possible win-win effects.

How this can be utilized is uncertain and involves great challenges. One solution might be to make sure that additional loads from energy installations are low in relation to the overall loads on the bridge. This means that weight, location, shape and surface area of the exposed nature of the loads (wind, currents and waves), is not determining the bridge construction, but is within the construction specifications.

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ATTCHMENT I – MAPPING OF ENERGY TECHNOLOGIES

The study has included a mapping of the current technologies in wind, solar, wave and tide which may be appropriate to be integrated in bridge construction in connection with Ferry free E39. This attachment provides a general description of how the different technologies work, as well as a list of new, innovative concepts for the respective renewable areas.

WIND POWER

A wind power station transforms the kinetic energy in wind into electricity by means of a wind turbine. A wind turbine is a mechanical device that is powered by the leaves on a rotating shaft, which causes motion energy from the wind. The rotating shaft will once again drive the generator.

There are mainly two types of wind turbines; horizontal and vertical axis turbines;

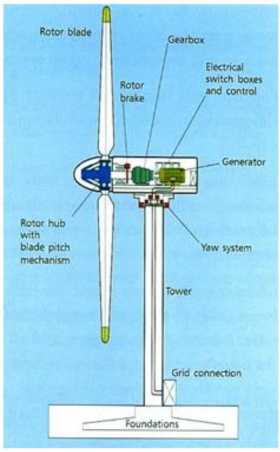
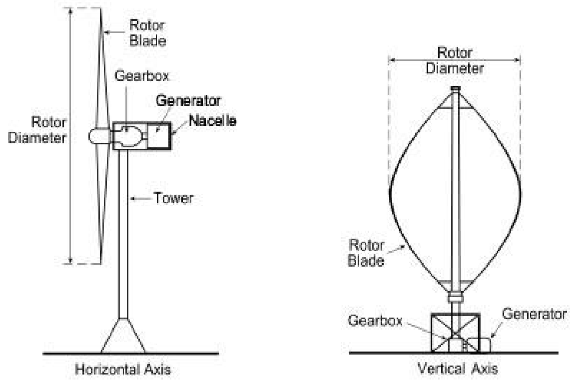


Image and sketch of HAWT-turbines.

1. Horisontal axis wind turbines (HAWT) are today the most common technology. The wind hits the blades, which makes the a horizontal moving. The number of turbine blades are usually three and the generator is placed at the top of inside the nacelle. The Nacelle and rotor blades are placed on a tower which is place on the foundations on the ground. Wind power plant is turning towards the wind direction and the most turbines can rotate 720 degrees

   HAWT comes in many different sizes. One of the largest turbines are Vestas ' 7 MW, which was launched in 2011. At the other end of the scale, one can shop for small wind turbines in kW for eg. installation on cabin roof. The product range is very wide.

2. Principles of energy production from the vertical acceleration turbines (VAWT) is very similar to a HAWT. In contrast, the shaft is a VAWT vertical and plant rotating around its axis. In addition, the generator is located on the bottom of the unit. VAWT Rotor blades on the plant will also look different. Some idea of VAWT-plants is that they can be placed on rooftops, buildings and other areas without power supply.



HAWT and VAWT (www.direct.gov.uk)

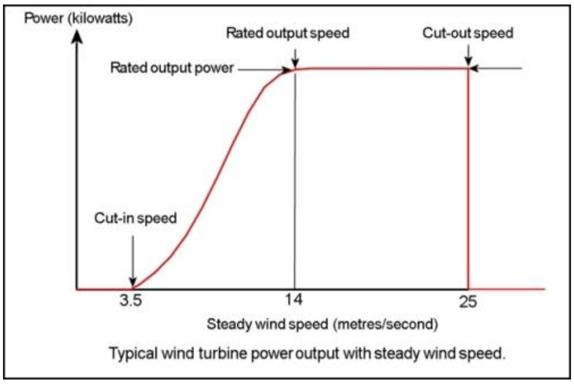
Wind power can be said to be a mature technology. The most cost efficient wind power plants have an energy cost of under 40 øre/kWh. In total, there are over 190,000 MW installed wind power worldwide, primarily onshore wind power. In the future it is assumed that the proportion of offshore wind will increase significantly. Offshore wind is, however, far more expensive than land-as of today.

The last ten years, the wind energy had an annual growth rate of 30 %, but the development of wind power is expected to increase further in the years ahead.

Technology development in recent years has largely been about upsizing the turbines, and this has been an important driver of cost reductions. A wind turbine of 2 MW with blades and a tower can weigh approximately 300 tons. The technological trend in the years ahead will be that wind power plants to be bigger and lighter, through new and lighter materials and gear boxes.

Energy output from a wind farm of course depends on the wind conditions the wind turbine is located. The full load hours for new Norwegian wind power plants today is between 2500 and 3500 hours (kWh/kW). There are additional sites which has reached full loads hours over 4000 hours. The Hywind project, developed by Statoil, produced 10,1 GWH in 2011. With an installed power of 2.3 MW this gives a capacity factor of approximately 50% (4390 full load hours).[1]

In the picture below it is given an example of an effect curve for a wind turbine.



Example of a power curve for a wind turbine (http://www.wind-power-program.com)

[1] Norsk Vindkraftforening 9.1.2012: http://norwea.no/Default.aspx?ID=287&PID=699&M=NewsV2&Action=1&NewsId=1798

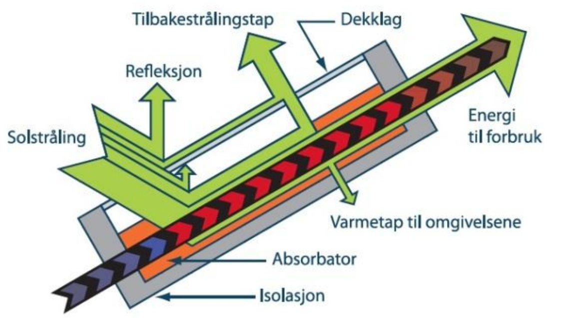
THE WIND ENERGY RESOURCE IN NORWAY

In 2008, the wind resources in Norway were mapped by Kjeller Vindteknikk AS, on behalf of NVE. The results from this are presented in the report "Vindkart for Norge". The mapping is based on a numerical simulation combined with wind data from measuring stations around in Norway. By entering in the maps of each fjord crossing you can find the calculated annual mean wind speed. The results from this are showed in the table to the right.

FJORD CROSSING LOCATION	EXPECTED WIND (m/s) 120m HIGHT
Kanestraum - Halsa (Halsafjorden)	5-6 m/s
Vestnes – Molde (Moldefjorden)	4-6 m/s
Festøy – Solavågen (Storfjorden)	3-5 m/s
Volda – Folkestad (Voldafjorden)	3-5 m/s
Anda – Lote (Nordfjorden)	3-5 m/s
Oppedal – Lavik (Sognefjorden)	4-6 m/s
Sandvikvågen – Halhjem (Bjørnafjorden)	5-7 m/s
Mortavika – Arsvågen (Boknafjorden)	7-8 m/s

SOLAR ENERGI

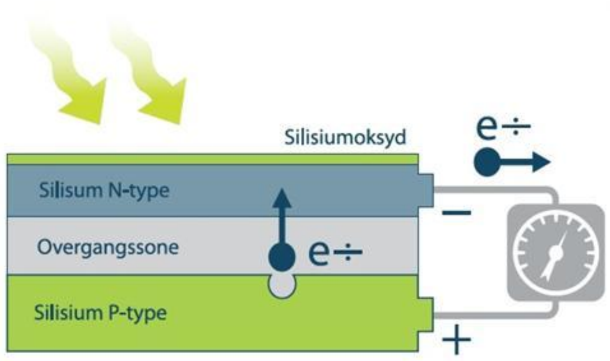
Direct insolation can convert sunlight to heat or electricity in solar collectors in solar cells (fotovoltaisk, PV). By converting the sun's energy to heat up a liquid medium which is used for heating of water and buildings. [2] A collector includes isolation, an absorber and a transport medium. The absorber converts sun to heat and usually consists of a thin metal plate. Hot wire sticking out of the absorber and lead it away from the collector.



Sketch for solar capture (fornybar.no/Kim Brantenberg).

Thermal solar collectors is considered a mature technology, and solar collectors with vacuum tubes are largely in the process of becoming a well proven technology with high effect levels. Technological have multilayer vacuum tube enabled a good dividend also for Nordic climate conditions and additionally mass production reduced price from China. Vacuum tube collectors of metals are mature in China, while the flat plastic based collectors are in a early commercial phase. Where there is a well-functioning market it is competitive with solar collectors for heating tap water electricity, even in Northern Europe. For district heating it is a well proven technology in some regions, even as far north as Denmark since 1990's.

When converting into electricity the sun's energy is used to create a voltage difference between the discs of silicon, one of which is that the voltage difference as directed power. A solar cell is made of a semiconductor in which the front and back are treated (drugged) so that the front page usually has surplus of free electrons and back deficit. Sometimes it is the opposite. The boundary layer between the two areas is formed an electric field that drives free electrons toward the front of the cell. Bound electrons in the solar cell can absorb a photon and thus become free. The vast majority of them will be caught by the boundary layer and is transported to the cell's front side. If one connects the front and back of an electrical circuit, electrons are accomplishing useful work in a light bulb, electric motor, or the like.



Sketch for PV. (Fornybar.no/Kim Brantenberg)

Solar cells are interconnected in modules, and can have a capacity of up to several hundred watts, and modules can be combined into systems and multiple megawatt. The systems can be used for net associated installations, or independent systems.[3]

Commercial solar cell (PV) technologies can be divided into two main groups; wafer-based crystalline (mono or multi crystalline) silicon and thin film. Technologies vary greatly in terms of cost and performance. Currently thin film represents lower costs but lower performance. Concentrating solar cells have higher costs and higher performance. Solar cell market is dominated by Silicon technologies of medium and medium-cost efficiency level (wafer-based, 85-90% of the solar cell market, while thin film has the rest).

Solar cells can be used in many different ways, eg. directly at the building, both households and commercial buildings, for electricity generation

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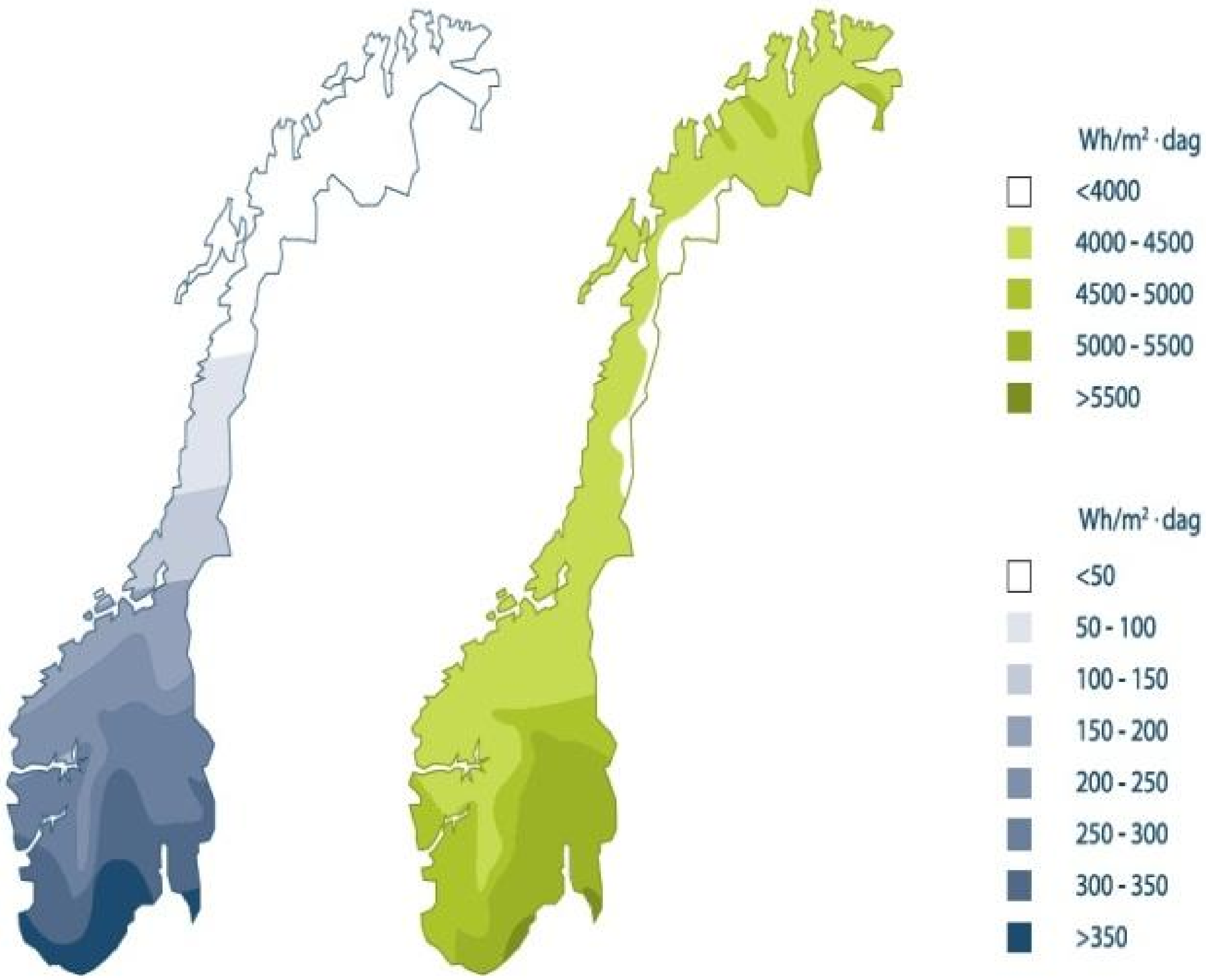
[2] Wikipedia: http://no.wikipedia.org/wiki/Solvarme

[3] IEA (2010). Energy Technology Perspectives.

and systems that are not connected to a grid. An important technical challenge for solar systems is integration to the grid. Focus is also on technological, functional, cost efficient and aesthetic aspects of the great facade and roofing solutions for direct use in construction or in industry (ETP2010).

SOLAR ENERGI IN NORWAY

According to www.fornybar.no annual insolation against a horizontal surface in Norway is between 600-1,000 kWh/m2 [DNMI, 1985]. There's a big difference between the different parts of the country, and between summer and winter; the figure below shows the energy against a horizontal surface for January and July, respectively. The figure, however, does not give an accurate picture of the amount of energy that can be exploited. By placing the panels toward the sun, one can reduce the difference as shown in the figure. During the winter months, there is still little energy to capture, bacause of less sun hours.



Sun insolation against horizontal surface in January and July in Norway. Illustration: Endre Barstad

WAVE ENERGY

Wave power technologies that rely on exploiting wave energy must use the wave's movement to generate a mechanical movement that can be transferred to energy (electricity).

To achieve a good utilization of the power of the waves the phase and amplitude (wave height) to wave power plant must be optimized. Wave frequency and the frequency of the wave absorber has to be equal.

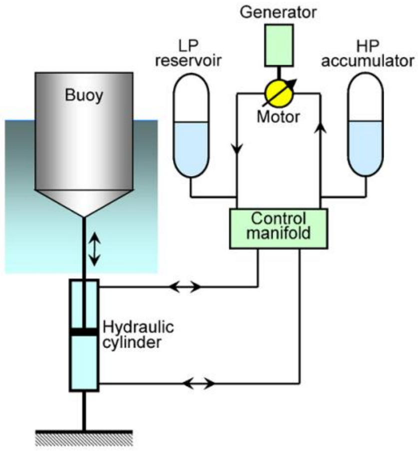
Wave power plant consumes the energy from waves and the power plant must work against the waves. This is categorized as destructive interference, i.e. waves that apply to each other.

The easiest way is to use a computer system that calculates wave phase/amplitude of the wave's period. Wave period is a key parameter in this context because this determines the wave frequency (inverse of phase). A period of longer than 8-10 secondary is considered optimal for wave power station.

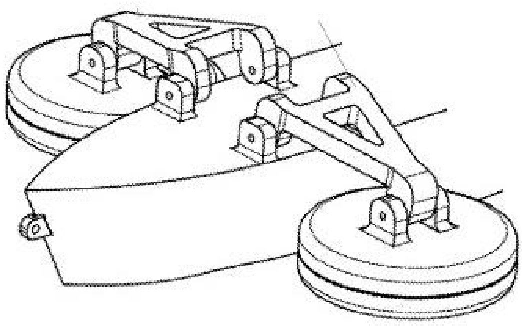
Different technological solutions within wave energy

Like a tidal energy wave energy is also a technology that currently is considered immature. A similar resemblance is that it simultaneously exists a whole host of different technological solutions based on a unique concept. Unlike the tides, there are many more methods and techniques for harvesting energy from waves. In this study two following two categories will be presented: (1) point absorber and (2) Oscillating water coloumn

Point absorber:



A common method for exploiting wave power is point absorber. This is a type of technology that makes use of a float element into the sea to create mechanical movement relative to a fixed anchor point to the top or bottom. The floatation element absorbs the energy from the wave front in a certain width greater than floater's own width, making it effective.



The vertical motion of the buoy drives a piston, which can be a part of a hydraulic system or a linear generator.

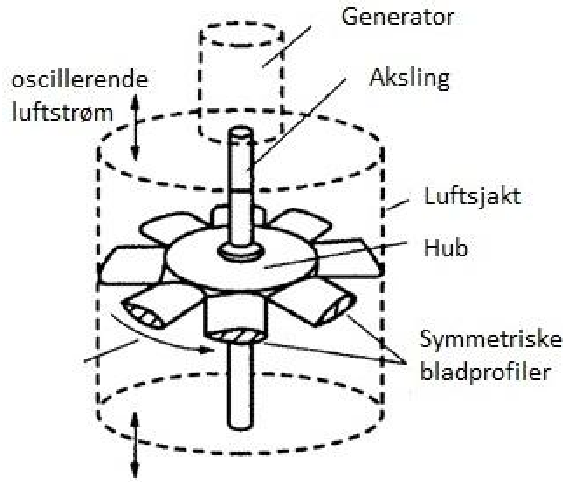
For the hydraulic system mechanical energy is converted to energy through a fluid pressure in a stamp set. The pressure from the hydraulic system can be exploited in a turbine which drives a generator. In order to accumulate the pressure you need a high-and low-pressure reservoir that the piston alternately draws from and pumps to as shown in the outline. Wave power is then transformed then into electric power.

Oscillating water coloumn (OWC):

Another idea to exploit wave energy is a technology termed as OWC (Oscillating Water Coloumn).

Energy utilization happens when the wave creates a movement in a water column inside a sealed chamber. Inside the chamber higher swing/lower air pressure is created. The swing chamber is vertically docked to exploit the wave's vertical motion.

The differential pressure between the pressure in the chamber and outside can be exploited in a Wells turbine-to have the ability to utilize air flow in both directions.



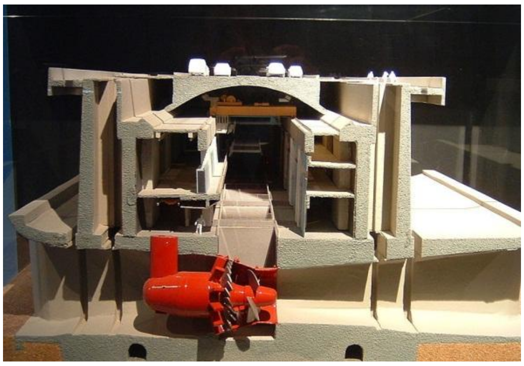
The specificity of this turbine is that it rotates in the same direction regardless of whether the airflow going up/down-stream through the turbine.

TIDAL ENERGY

Tidal power is a form of power generation where the tide produces energy by driving a generator. The water power plants are also good for big difference between flo and ebb. There are essentially two methods that is used to exploit this energy, (1) containment of water and (2) current turbines.

Containment of water

Containment of water is taking advantage of the potential energy in water fall height in the vertical difference between tide and ebb. The tide is contained outside of a barrage when it comes in to land, and then it is checked against a turbine. The water is contained up again on the way out, and can be checked against the same turbine. There are several plants that make use of this principle. The world's first full-scale tidal power station was built at La Rance in France in the 1960s. Here is the high water captured by a large artificial barrage that creates a large pool of 22 square kilometers. When the water level is dropping the outgoing water flows through 24 turbines. The power plant will reportedly produce 240 MW.[4]



Model of La Rance power station (Wikipedia)

Picture of La Rance power station (Wikipedia)

Current turbines

A current turbine is an underwater turbine that utilizes kinetic of the water flow in the water. One can compare it with a wind turbine that is under water. The power plant has one or two (or several) turbines attached to a shaft that powers a generator. In practice this will resemble a sea power generating station.[5]

A current turbine will require a water flow of a certain speed. In tidal currents with a speed of 1 meter per second has an energy effect of 0.5 kilowatts per square meter in the plan across the stream. A turbine with a wingspan of 10 meters will cover 130 square meters when it rotates. This turbine would then theoretically be able to reap a 164 kilowatt. Secondly, the efficiency and the fluctuating currents can be very critical for the yearly production.[6]

As with wind turbines, current turbines are also in the same categories; horizontal and vertical axis turbines. Although there are different vendors with different ranks of innovative and technological solutions, the principles of generating energy is roughly equal.

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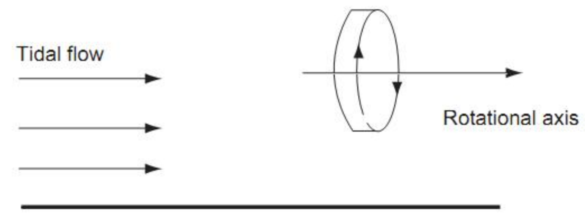
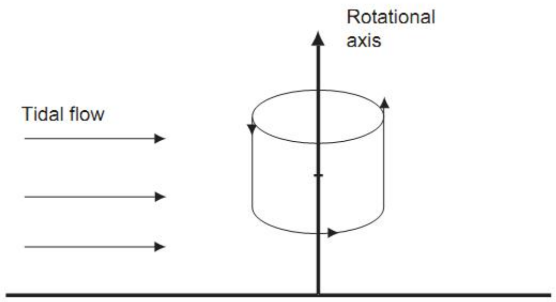
[4] Gjevik, Bjørn (2009); *Flo og fjære langs kysten av Norge og Svalbard.* Farleia Forlag, s. 189.

[5] Wikipedia: http://no.wikipedia.org/wiki/Tidevannskraft

[6] Gjevik, Bjørn (2009); Flo og fjære langs kysten av Norge og Svalbard. Farleia Forlag, s. 191.



Horisontal axis current turbine (Bryden, 2005)



Vertikal axis turbin (Bryden, 2005)

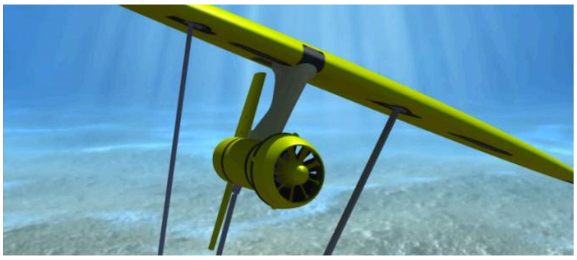
Examples of tidal energy technologies that can be integrated in bridges

Minesto Deep Green

As mentioned earlier, the flow conditions in the fjords that are relevant to the Ferry Free E39 is not believed to be very well suited to reap the huge amounts of energy. However, there are several requirements for technologies that are specifically designed to operate in environments with low flow speeds. One of these is Minesto Deep Green. This technology is designed to operate in currents of 1-2 m/s, this is certainly still far higher than with a flow rate of many of the fjord crossings (under 1 m/s), but the product can still serve as an example of an integration solution.

The Minesto technology consists of a wing with a turbine hanging underneath, attached to an anchor (85-120 m). When the water is flowing over the wing this causes the wing "lift"-forces that put the device in motion. The movement follows a pattern of eight, with a much higher speed than the actual water flow.

The concept is based on the dock at the ocean floor, but it is possible to imagine an upside-down solution, where the waier is anchored to the bridge's pontoons.



DeepGreen/Minesto

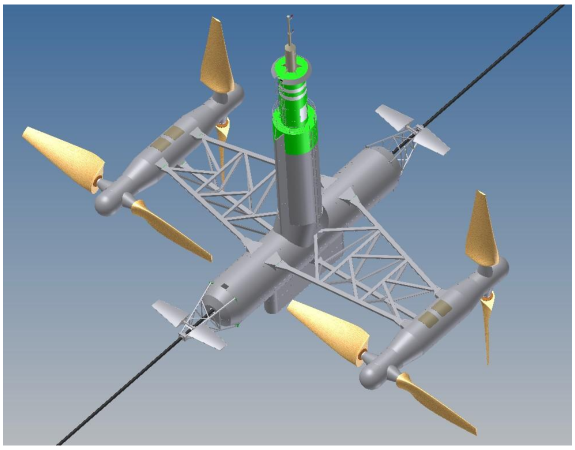
The Minesto DG-12 unit is designed for a maximum flowrate of 18 m/s, resulting in "lift"-forces up to 2400 kN. The device weighs about 7 tons. A mooring in pontoons will result in dynamic loads in both vertical and horizontal directions (as a result of eight movement), but it can be assumed that it will be the horizontal forces that will constitute the biggest challenge since the pontoons can better handle the vertical forces. In addition, it considers how own frequency-/ vibrations will affect the bridge.

Minesto plans to have the first prototype of 100 kW in operation in 2013, and the first full scale unit (500 kW) in 2015. Full version (DG-12) will have a wingspan of 12 m and an effect of 500 kW is achieved by a flow rate of 1.6 m/s, the Cut-off speeds for this release is estimated at respectively 0.5 and 2.5 m/s. Assuming a 3000 full load hours the annual power production is equal to approximately 1.5 GWh per DG-12 unit.

Example Morild

In the last few years the tidal energy business has also developed several current turbine concepts based on floating foundation. One of these technologies is Hydra Tidal Morild II. This is the world's first floating tidal power plant. Since august 2010 a full-scale prototype has been tested in Gimsøystraumen in Lofoten.

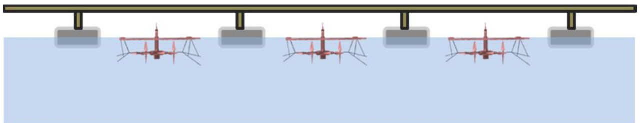
The primary benefit of the Morild concept is that a floating device will provide easier access to the turbine in connection with the operation and maintenance work. The device is also relatively easy to move physically. It will also be synergies in the installation phase, and the ability to dock the device on bridge construction (eventually in the bridge's anchor points).



Hydra Tidal Morild II (Straum Group AS)

Morild II has 4 turbines with a rotor diameter up to 23 m, with a total output of 1.5 MW. The possibilities of integrating Morild into a bridge construction are multiple. The Morild concept already includes a floater, and this can be installed between the pontoons, and by anchored in these. A possible advantage of such a solution is that the pontoons can be designed in such a way that the tidal flows towards the turbines, while the forces of the pontoons are being reduced. Another option is that the pontoons also can be used as floater for the Morild power plant, and at the same time places the generator, electronics and control system inside the pontoon house.

The Morild concept is, however, designed to be able to produce energy production by far higher flow rates than what is found in the fjords that are relevant to the Ferry Free E39 project.



Morild integrated into a floating bridge.

PARAMETERS THAT EFFECTS THE ENERGY PRODUCTION FROM CURRENT TURBINES

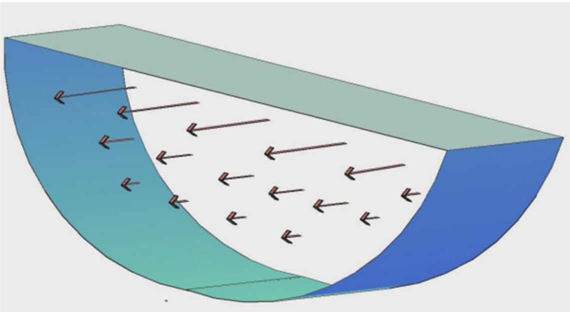
The most important parameters that effects the energy production from current turbines are as follows:

- The difference between tide and ebb
- Current speed (v)
- Variation of time, which is unique for each fjord – v(t)
- Variation of speed with respect of height (h)
- The width of the fjord(b)
- The direction of the current

The speed of the flow will be crucial for the effect of the turbine. Therefore, the flow profile in relation to the depth, width and time is critical in selecting the location of tidal turbines.

The tidal flow in and out of the bay are somewhat simplified in figure below. Typically, it is the upper layer where the flow is strongest. This is measured in different fjords.

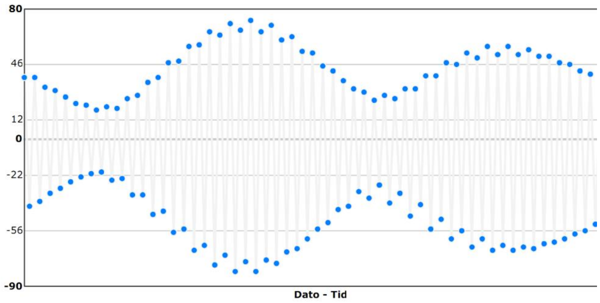
- Flow rate is highest in the top 10-20 meters of water column. See figure below.
- Flow rate are also often lower along the bottom and sides because of friction.
- Flow rate is the very time these rages and is affected by local flo/ebb-dynamics, snow melting, precipitation, as well as several other parameters. The full load hours will therefore be low



Strength of the current (v) with respect to depth and width.

Tidal movements

The tidal level is dependent on 2 cycles. Tidal level is both dependent on the moon's position and the sun's position. The moon affects the tides the most (2/3) and this cycle is repeated 2 times a day.



Tidal movements in Bergen

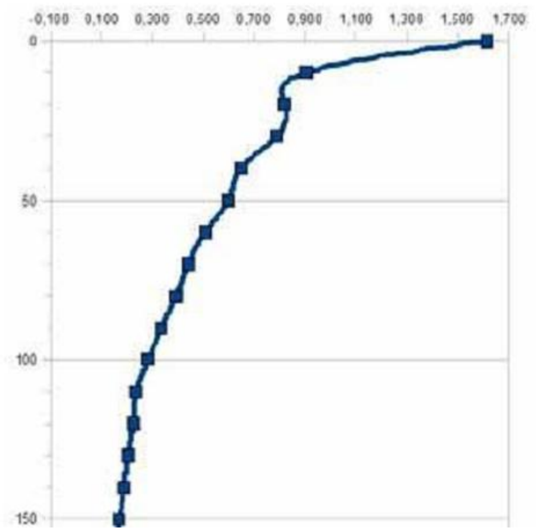
Tidal movements increase in the northern parts of Norway. The differences are, therefore, at small in Stavanger and the larger in Trondheim for possible fjord crossing locations for Ferry Free E39. By floods, snow melting, the water in the bay is changed so that the water flows on top of brackish and tidal-flow streams below. This may change the currents locally.

The current profile with respect to time

The water is normally flowing in and out of a fjord in 6 hour intervals. Tideway does not turns instantaneous, so it is natural that there will be a small amount of power for the space between the tide and the ebb. Tidal flow will most likely follow a sine curve.

When the sun, earth and the moon are aligned it is spring tide and therefore stronger tidal currents. This happens 2 times per month.

The current profile with respect to depth



Current speed and depth in Salhusfjorden (Spiss 2010)

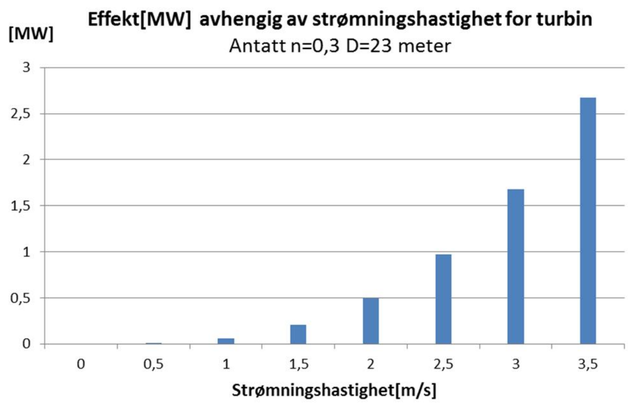
The speed of tidal flow is highest at the surface (0-10 metres).

Maximum flow rate decreases with depth. The speed gradient is rapidly decreasing, which leads to a much lower flow velocity in 30 meters depht compared to 10 meters depth.

This limits the cross section area of the Bay that it is possible to generate large amounts of power. Also, the declining of the flow rate is local so this needs to be examined for each case.

Current profile with respect to depth

The speed of the current will decline along the fjord due to lower water levels and friction from the bottom/fjord Bank. However, the flow rate can vary widely depending on the width of the submarine landscape.



Example of a power curve for a current turbine

DIFFERENT WAVE ENERGY CONCEPTS

Technology	Wave energy	Point Absorber
Product name and company	Wavestar	Wave Star A/S (Denmark)

The Wavestar machine draws energy from wave power with floats that rise and fall with the up and down motion of waves. The floats are attached by arms to a platform that stands on legs secured to the sea floor. The motion of the floats is transferred via hydraulics into the rotation of a generator, producing electricity.

Waves run the length of the machine, lifting 20 floats in turn. Powering the motor and generator in this way enables continuous energy production and a smooth output. This is a radical new standard and a unique concept in wave energy; it's one of the few ways to convert fluctuating wave power into the high-speed rotation necessary to generate electricity.

Prototype tested in 2009.

Source: http://wavestarenergy.com/concept

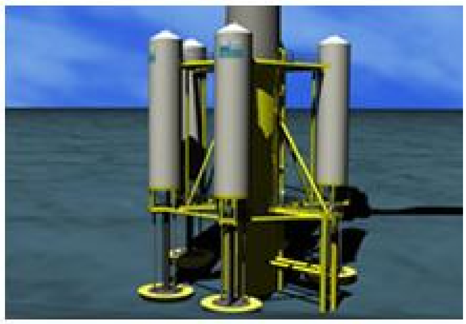
Technology	Wave energy	Point Absorber
Product name and company	The Linear Generator	Trident Energy (UK)

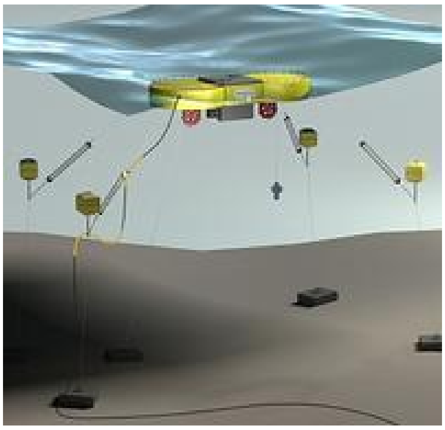
PowerPod contains a patented direct drive linear generator. This converts linear motion directly into electricity and has been designed specifically for the offshore renewable energy industry.
The generator is tubular with a cylindrical central magnet stack. Linear motion, captured from the movement of waves or tides, moves a set of wire coils up and down the magnet stack.

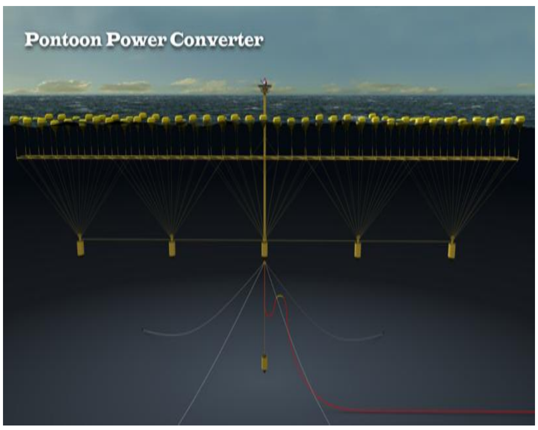
Electricity is generated in the coils as they pass through the magnetic field surrounding the stack. This electricity is conditioned and fed into the National Grid.

In 2011 we built an onshore test rig to assess the operation of our full scale prototypes. We are using this test rig to characterise the performance of our generator and support the development of new control system strategies

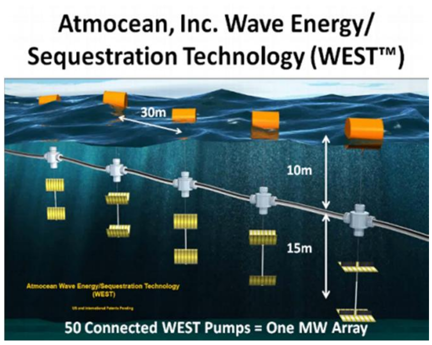
Source: http://www.tridentenergy.co.uk



Technology	Wave energy	Floating Attenuator
Product name and company	Ocean Harvester	Ocean Harvesting Technologies AB (SWE)
The Ocean Harvester has undergone 4 years of engineering and development including patenting, computer simulations, testing in a water laboratory, prototpe demonstration in a test rig and the complete design of a 1/2 scale wave energy converter (WEC). The results are very promising and have proven the power smoothing capabilities in the test rig and excellent behaviour and survivability in extreme wave conditions during scale model testing in the water laboratory. They are currently preparing for the build and sea trials of 1/2 scale WEC model, supported by the Fred Olsen company Fobox AS at their test site in Risör, Norway. The 1/2 scale WEC model sea trials is followed by the build and sea trials of a full scale 100 kW pilot WEC unit, connected to a test grid. After the pilot phase, the technology will be ready for a demonstration wave farm with 5-10 WEC units connected to the power grid, follwoed by production of WEC units for large scale customer projects. At a later stage, OHT expects to develop larger WEC units. Source: http://www.oceanharvesting.com/roadmap		

Technology	Wave energy	Floating Attenuator
Product name and company	Pontoon Power	Pontoon Power AS (NOR)
The Pontoon Power Converter (PPC) is a floating wave energy converter based on working pontoons, hydraulic pumping cylinders, hydroelectric turbine and generator mounted on a patent pending ballasting and load-bearing structure, with slack moorings suitable for a wide range of water depths and many offshore locations. Relatively large-scale power production (15-20 MW) produced on one turbine/generator. A solution to avoid the extreme wave conditions is incorporated and will protect the system against extreme environmental forces. Profitable production compared with other offshore renewable energy production according to own estimates. The Pontoon Power Converter provides easy access via helicopter for service personnel and serviceable from seagoing vessels. Source: http://www.pontoon.no/		

Technology	Wave energy	Floating Attenuator
Product name and company	Vigor	Vigor Wave Energy AB
Vigor Wave Energy AB develops a brand new concept to convert wave energy into electricity: the Vigor Wave Energy Converter. The Vigor Wave Energy Converter is based on a floating hose, using water and air as mechanical parts to absorb the wave energy. The principle has the potential to produce large amounts of electricity at low cost and the Vigor Wave Energy Converter will be one of the power plant solutions supplying renewable and cost efficient energy to a future sustainable society. Source: http://www.vigorwaveenergy.com/start/the-principle		

Technology	Wave energy	Point Absorber
Product name and company	WEST	Atmocean, Inc. (USA)
WEST uses wave motion to operate pumps which generate pressurized seawater fed into a hose. The hose extends from the WEST units located far offshore where the waves are bigger and more consistent, to the onshore generating facility, where the pressurized seawater is sent into a Pelton motor connected to electrical generators. Underneath each pump are Atmocean's patent-pending Variable Sea Anchors (VSA's) which reset the pump while producing upwelling of nutrient-enriched deep water. In the presence of sunlight, these upwelled nutrients help trigger photosynthesis to stimulate the ocean food chain. By connecting many WEST devices inline in serial fashion, with each device rising and falling randomly on passing waves, the individual pulses of pressurized seawater merge into a constant flow inside the hose. Source: http://www.atmocean.com/7.html		

<table>
<tr><td>Technology</td><td>Wave Energy</td><td>Point Absorber</td></tr>
<tr><td>Product name and company</td><td>Direct Drive</td><td>Columbia Power Technologies, LLC (USA)</td></tr>
<tr><td colspan="2">

Columbia is developing technologies that will generate energy between one and three miles offshore - where the available wave energy is greatest. We believe that direct drive systems, which avoid the use of pneumatic and hydraulic conversion steps, are more efficient, more reliable and easier to maintain, and are therefore the most likely to deliver the lowest cost of energy. Our research path focuses on:

- Point absorbers
- Direct coupling of the wave motion to the generator
- Innovative use of permanent magnets and other highly-efficient components
- Reducing the number of moving parts
- Minimizing the number of conversion steps and associated losses

Having completed tank testing at OSU, Columbia Power has deployed an intermediate scale prototype near Seattle and code named SeaRay. The device is tuned to the Puget Sound environment and is controlled remotely from Corvallis Oregon.

Source: http://www.columbiapwr.com/technology.asp

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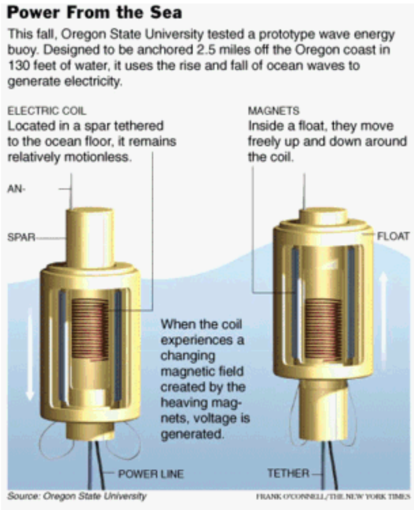

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<table>
<tr><td>Technology</td><td>Wave energy</td><td>Point Absorber</td></tr>
<tr><td>Product name and company</td><td>OSWEC (Ocean Swell Wave Energy Conversion)</td><td>Aqua Magnetics Inc. (USA)</td></tr>
<tr><td colspan="2">

AMI's OSWEC (Ocean Swell Wave Energy Conversion) system is an energy system that directly converts motion to electric power and poses no threat to the environment. This cost effective system utilizes a linear reciprocating generator to directly convert wave energy to electric power.

With a 15 meter buoy with AMI's generator can create between 145 and 330 KW in a 2 meter swells. The actual amount of power output depends on the wave period and form.
For ocean data buoys, we anticipate an Ocean Electric Buoy with a 2-meter buoy can generate approximately 11 KW, while a 4-meter buoy should generate approximately 40 KW in a 2-meter swell.

Source: http://www.amioceanpower.com/home.html

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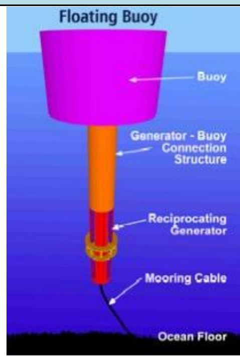

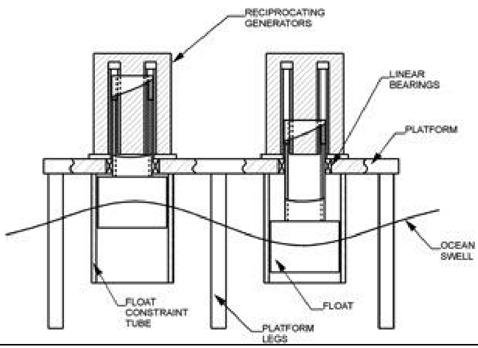

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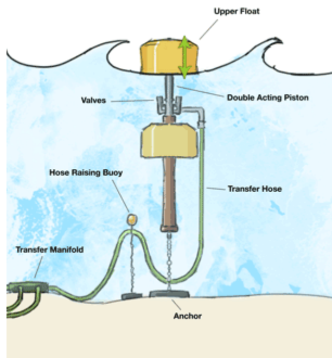
<table>
<tr><td>Technology</td><td>Wave energy</td><td>Point Absorber</td></tr>
<tr><td>Product name and company</td><td>Searaser</td><td>Ecotricity (UK)</td></tr>
<tr><td colspan="2">Searaser pumps seawater using a vertical piston between two buoys – one on the surface of the water – the other suspended underwater and tethered to a weight on the seabed. As the ocean swell moves, the buoys move up-and-down and the piston pumps pressurised seawater through pipes to an onshore turbine. This produces electricity.

Searaser units could also supply energy on-demand by pumping seawater into a coastal reservoir, with a hydropower turbine, solving renewable energy's problem of fluctuating output.
Our investment in Searaser will drive the next phase of development. We aim to have a product ready for market in 2014.

Source: http://www.ecotricity.co.uk/</td><td>
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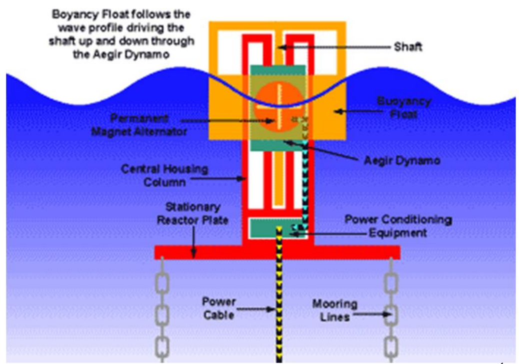
<table>
<tr><td>Technology</td><td>Wave Energy</td><td>Point Absorber</td></tr>
<tr><td>Product name and company</td><td>The Aegir Dynamo</td><td>Ocean Navitas (UK)</td></tr>
<tr><td colspan="2">The name is derived from the name for the Norse god of the sea 'Ægir' and the definition of a dynamo 'an electrical generator'. The Aegir Dynamo™ functions in a unique fashion by generating electrical current from the motion of the prime mover in one phase via a direct mechanical conversion and the use of a bespoke buoyancy vessel.

As can be seen in the simplified diagram on the right: The principle is fairly simple, an Aegir Dynamo is housed in a sealed central column which remains in a relatively stationary position due to ballast and the moored reactor plate at its base. The Buoyancy float moves up and down due to its reaction to the change in water level and the effect of gravity.
The motion of the buoyancy float is transferred to the Aegir Dynamo by a shaft.

The Aegir Dynamo converts both the upward motion of the waves and the downward motion of gravity into singular direction rotational energy.
Source: http://www.oceannavitas.com/technology.html</td><td>
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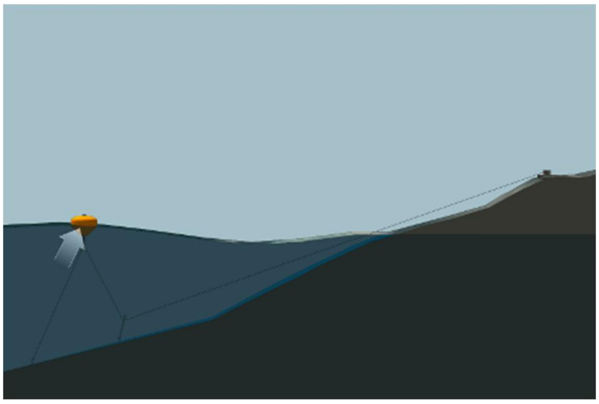
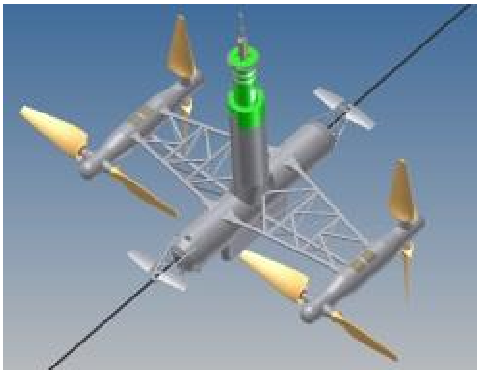
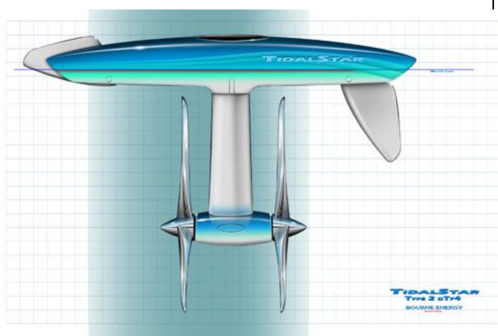
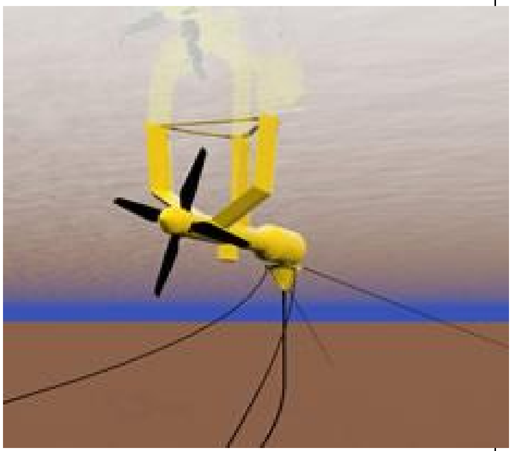
Technology	Wave Energy	Point absorber
Product name and company	purenco	Purenco AS (Norway)
Purenco's WEC (wave energy converter) absorbs energy from ocean waves, and converts it to useful energy, in the form of a controlled flow of hydraulic high pressure fluid. The hydraulic energy is then either converted further into electrical electricity through a turbine and a generator, or is used to pressurize seawater to power a reverse osmosis plant producing freshwater. The patented Purenco concept is based on floating buoys connected by wire to a self-tightening winch, further connected to a gear transfer machinery and a hydraulic conversion system which outputs energy in a useful form (e.g. electricity or pressure for desalination of seawater). When a buoy is moved by the waves, the wire is pulled out, and the winch is forced to rotate outward, by means of which mechanical energy is transferred from the waves into the winch machinery. From this outward rotation is mechanical energy is tapped, which is converted mechanically (geared up) and then hydraulically smoothed and temporarily stored. Source: http://www.straumekraft.no/Core_technology.aspx		

TECHNOLOGY CONCEPTS TIDAL ENERGY

Technology	Tidal current turbines	Floating
Product name and company	Hydra Tidal Morild II	Straum Group AS (Norge)
The Norwegian company Hydra Tidal Energy Technology (HTET) has developed a concept based on a floating, anchored steel structure that produces electric power, with four tidal current turbines. Turbines and generator will lie below the water line, but can easily be brought up to the surface for maintenance. Since the tidal power plant floats on the water, there will be no major permanent retainer on the ocean floor, and the project has little environmental impact. In May 2009, Morild was awarded a concession from The Norwegian Water Resources and Energy Directorate for the deployment of its in-concept Morild in Gimsøystraumen in Lofoten. In august 2010 was a full scale prototype of tidal power plant put into operation in Gimsøystraumen in Lofoten. Source: www.fornybar.no		

Technology	Tidal current turbines	Floating
Product name and company	Tidal Star	Bourne Energy
Each TidalStar tidal power system uses a proprietary turbine design to produce approximately 50 kW at peak capacity. TidalStar has many advantages over current tidal power systems. It does not require tidal barrages, embankments, caissons or sluices. Environmentally neutral, TidalStar does not increase sediment, accumulate pollution nor affect the salinity of the water. TidalStar utilizes an interconnected arrays of energy absorbing modules placed across a tidal flow. Source: http://www.bourneenergy.com		

<table>
<tr><td>Technology</td><td>Tidal current turbines</td><td>Floating</td></tr>
<tr><td>Product name and company</td><td>Evopod</td><td>Ocean Flow Energy</td></tr>
<tr><td colspan="2">4 different concepts, with varying number of turbines per unit. Designed for efficient operation in exposed sea areas where waves coexist with tidal current. Can be easily disconnected from its mooring system and removed off-site for essential maintenance in safe sheltered non-tidal areas.
Does not require long duration, expensive and risky installation operations as required for fixed seabed mounted devices.
Overall improved economics of power production compared to bottom mounted devices through lower installation costs and greater annual generating uptime through better access for repair in the event of component failure.

Source: http://www.oceanflowenergy.com/</td><td></td></tr>
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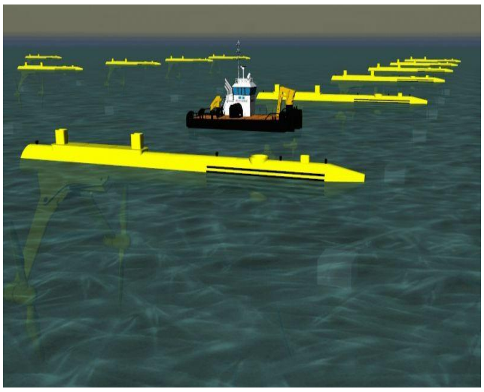
<table>
<tr><td>Technology</td><td>Tidal current turbines</td><td>Floating</td></tr>
<tr><td>Product name and company</td><td>Scotrenewables Tidal Turbine</td><td>Scotrenewables Tidal Current Ltd</td></tr>
<tr><td colspan="2">The Scotrenewables Tidal Turbine is a unique floating tidal technology designed to minimise installation and operational costs. The system has been extensively trialled through scale model testing and a 250kW prototype, the SR250, is currently generating power in a two-year test programme in Orkney.
The main structure comprises a floating cylindrical tube to which dual horizontal axis rotors are attached. The rotors extract the kinetic energy of the tidal flow, which is converted to electricity though the power take-off system for export to shore. The hydraulically retractable rotor legs give the tidal turbine two configurations - operational with the rotors down to generate power, or transport/ survivability mode with rotors retracted to decrease draught allowing the system to be towed into harbour or to reduce loads in heavy seas. In extreme storm conditions power generation will cease automatically and the rotor legs will retract up in to a transport /survivability mode.

Source: http://www.scotrenewables.com/</td><td></td></tr>
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<table>
<tr><td>Technology</td><td>Tidal current turbines</td><td>Bottom fixed</td></tr>
<tr><td>Product name and company</td><td>AK-series</td><td>Atlantis Resource Corp.</td></tr>
<tr><td colspan="2">The AR series turbines are commercial scale Horizontal Axis Turbines designed for open ocean deployment in the harshest environments on the planet. AR turbines feature a single rotor set with highly efficient fixed pitch blades. The AR turbine is rotated as required with each tidal exchange. This is done in the slack period between tides and fixed in place for the optimal heading for the next tide. AR turbines are rated at 1MW @ 2.65m/s of water flow velocity.

In early 2009 Atlantis successfully ocean tested the most efficient bi-directional tidal turbine blades ever fabricated at large scale. During 2010, Atlantis validates its deployment credentials by successfully installing its GBS Foundation and AK1000 demonstrator at EMEC
During 2011, Atlantis released its 1MW AR1000 turbine rated at 2.65 m/s which is deployed and commissioned to grid at EMEC

Source: http://www.atlantisresourcescorporation.com/the-atlantis-advantage/atlantis-technologies.html</td><td>AR SERIES
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<table>
<tr><td>Technology</td><td>Tidal current turbines</td><td>Bottom fixed</td></tr>
<tr><td>Product name and company</td><td>C-Energy</td><td>Ecofys (Nederland)</td></tr>
<tr><td colspan="2">Ecofys combined two types of rotor on a single axis of rotation. The so called Wave Rotor is able to convert not only tidal currents, but also waves into electricity. The latter is possible because waves are made up of circulating water particles.
The energy from tides and waves is directly converted into rotational movement, driving a generator. Therefore the system does not need any inefficient conversion steps.
In order to tap the kinetic energy in waves, the following two rotors are combined: a Darrieus rotor with more or less vertical (or slanted) rotor blades and a Wells rotor which has radial blades. These are respectively an omni-directional and a bi-directional rotor which are known to operate in fluctuating currents.
Source: http://www.c-energy.nl/</td><td></td></tr>
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<table>
<tr><td>Technology</td><td>Tidal current turbines</td><td>Floating</td></tr>
<tr><td>Product name and company</td><td>Bluetec</td><td>Bluewater Energy Services B. V. (NL)</td></tr>
<tr><td colspan="2">Installation, operation and maintenance of a tidal power generation farm absorb most of the total costs of a tidal farm. Not the cost of failed components, but the cost of entire marine operations to diagnose and replace these parts under water can be extremely high. To counter this, Bluewater has designed a floating platform ‘Bluetec’ that provides easy access from the water surface, can hold multiple tidal turbines and is moored with anchor lines to the sea floor.

The Bluetec platform is a unified floating support structure which can hold any type of turbines in any waterdepth. It offers waterproof housing for vulnerable systems above the waterline unique in the tidal industry. Power cables are connected dry rather than under water, reducing risks and costs significantly. The Bluetec structure is much lighter than the gravity based designs, requiring less tonnage steel per MW. The device itself is floating and therefore installation can be executed with widely available vessels, without the need for expensive floating cranes or jack-ups.
Source: http://www.bluewater.com/bluetec/</td><td>
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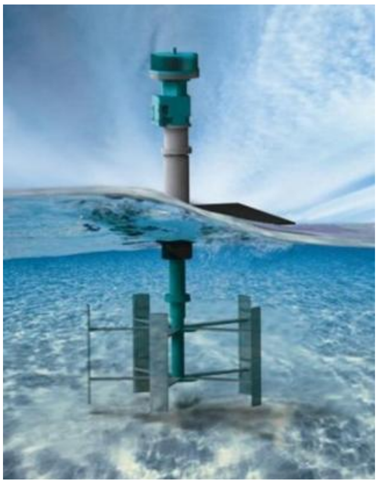
<table>
<tr><td>Technology</td><td>Tidal current turbines</td><td>Floating</td></tr>
<tr><td>Product name and company</td><td>EnCurrent</td><td>New Energy Crop. (USA)</td></tr>
<tr><td colspan="2">New Energy’s proprietary EnCurrent Turbine converts the energy inherent in moving water into electricity. The technology is based on the Darrieus wind turbine, also called an eggbeater or whisk turbine due to its shape. The EnCurrent Turbine is a cross-flow turbine, meaning that the direction of rotation is perpendicular to direction of water flow.

When the turbine rotor is placed within a water current, the hydrofoils generate a lift vector in the forward orientation which can be captured at the shaft as a positive rotation. The hydrofoils experience their maximum forward torque at the top and bottom of their rotation, when the water moving past them is tangential. The turbine rotates in the same direction regardless of the direction of the water current and captures between 35% and 40% of the energy in moving water. It rotates at a very low speed, between 2 and 2.5 times the speed of the water in which it is submerged.

Source:http://www.newenergycorp.ca/About/Technology/tabid/62/Default.aspx</td><td></td></tr>
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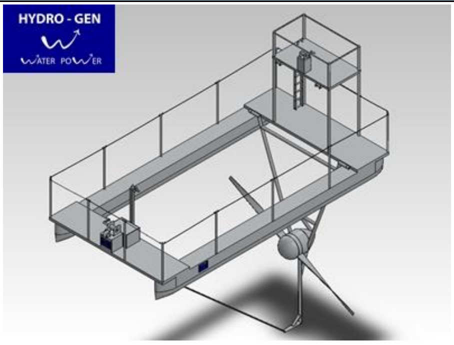
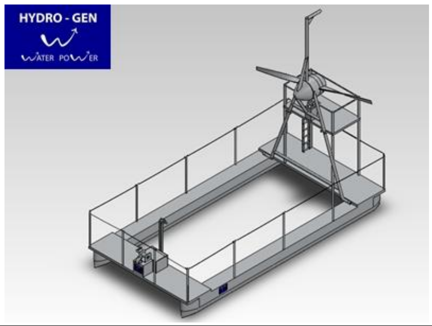
<table>
<tr><td>Technology</td><td>Tidal current turbines</td><td>Floating</td></tr>
<tr><td>Product name and company</td><td>Hydro-Gen</td><td>Hydro Gen (Fra)</td></tr>
<tr><td colspan="2">The Hydro-Gen converters are well adapted to low depths locations (a situation frequently experienced where the current is strong in sea, river and estuary). The turbine can be more or less put in the water as needed or possible. It allows an easy and reliable neutralization by getting the turbine out of the water
Building and maintenance are standardized, like any vessel, and performed by a shipyard or a metal work maker, close to the exploitation sites

Hydro-Gen integrates current proven equipments. The generator and the power converter are standard. We do not develop any specific technology or component
The devices are removable, tough, lightweight (90% of the components are in aluminium or composites), possibly sent in container

They perfectly fit the power needs for remote communities and isolated areas, particularly along rivers or estuaries

Source : http://www.hydro-gen.fr/</td><td>
</td></tr>
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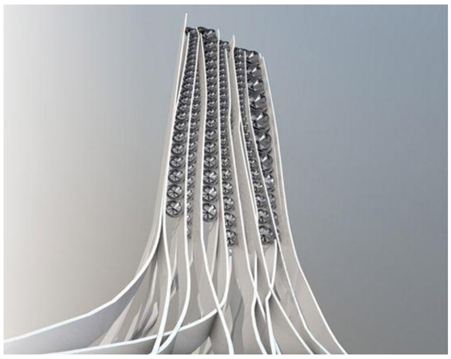
NEW AND INNOVATIVE WIND ENERGY CONCEPTS

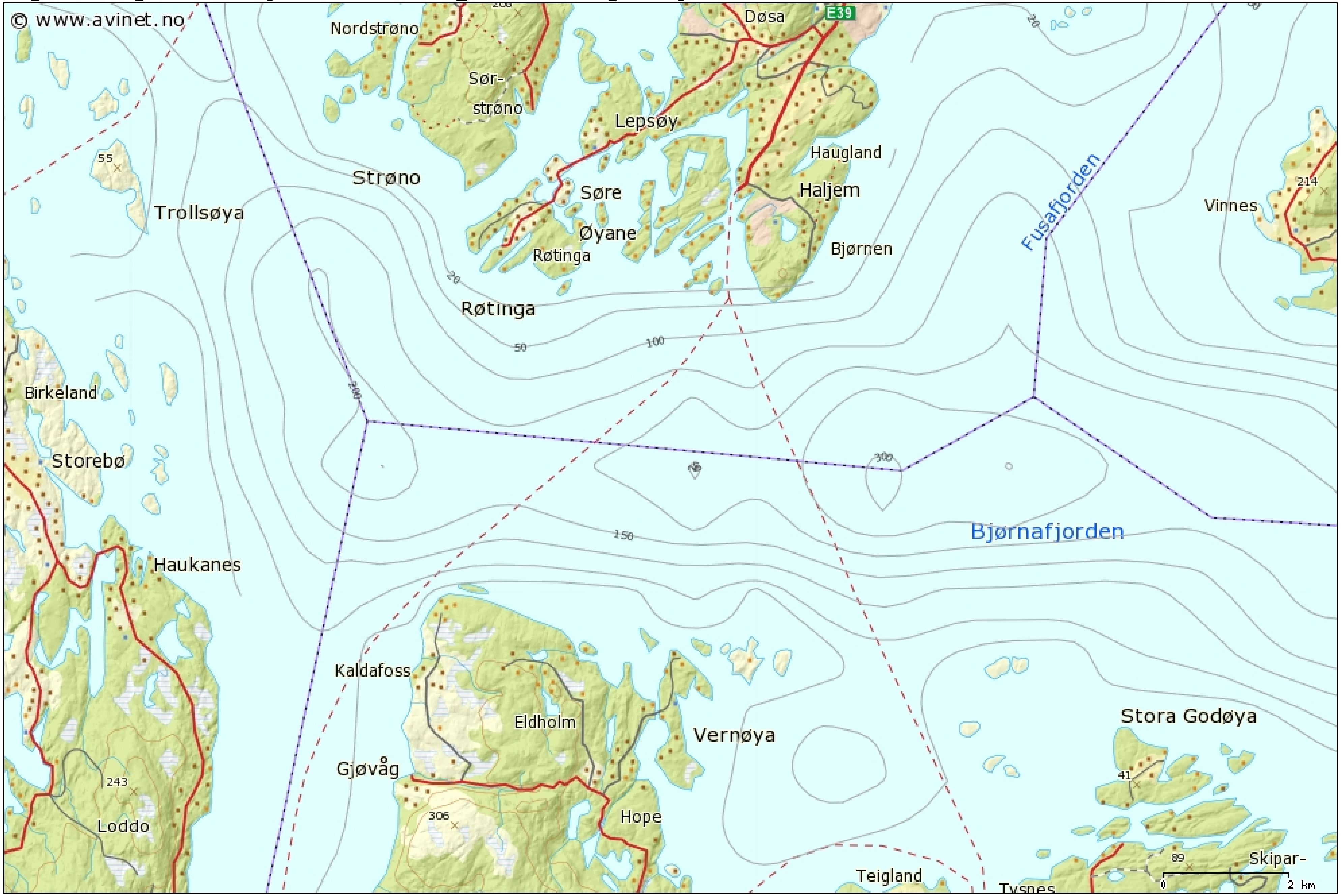
Technology	Wind Energy	
Product name and company	Wind Tunnel Foot Bridge	Unknown
The Wind Tunnel Foot Bridge is a new covered bridge for the 21 st century; a design proposal for a new kind of wind activated footbridge made of steel and aluminium. As the wind blows, the five wind turbine wheels turn at different speeds around the people who are walking through to reach the other side. Three of the five wheels turn in one direction while the other two turn in the opposite direction. As the wind driven wheels turn in different directions and at different speeds, the can produce different electronic corresponding sounds. The wind tunnel Footbridge was designed to be constructed in various types of public venues as an architectural attraction. The wheels also produce and store electrical energy much like a windmill. Source: http://oursurprisingworld.com/wind-tunnel-foogbridge-by-michael-jantzen/		

Technology	Wind Energy	
Product name and company	Solar Wind bridge	Francesco Colarossi
The proposed bridge would harness solar energy through a grid of solar cells embedded in the road surface, while wind turbines integrated into the spaces between the bridge's pillars would be used to generate electricity from the crosswinds. Source: http://www.gizmag.com/solar-wind-bridge-concept/17771/picture/129526/		

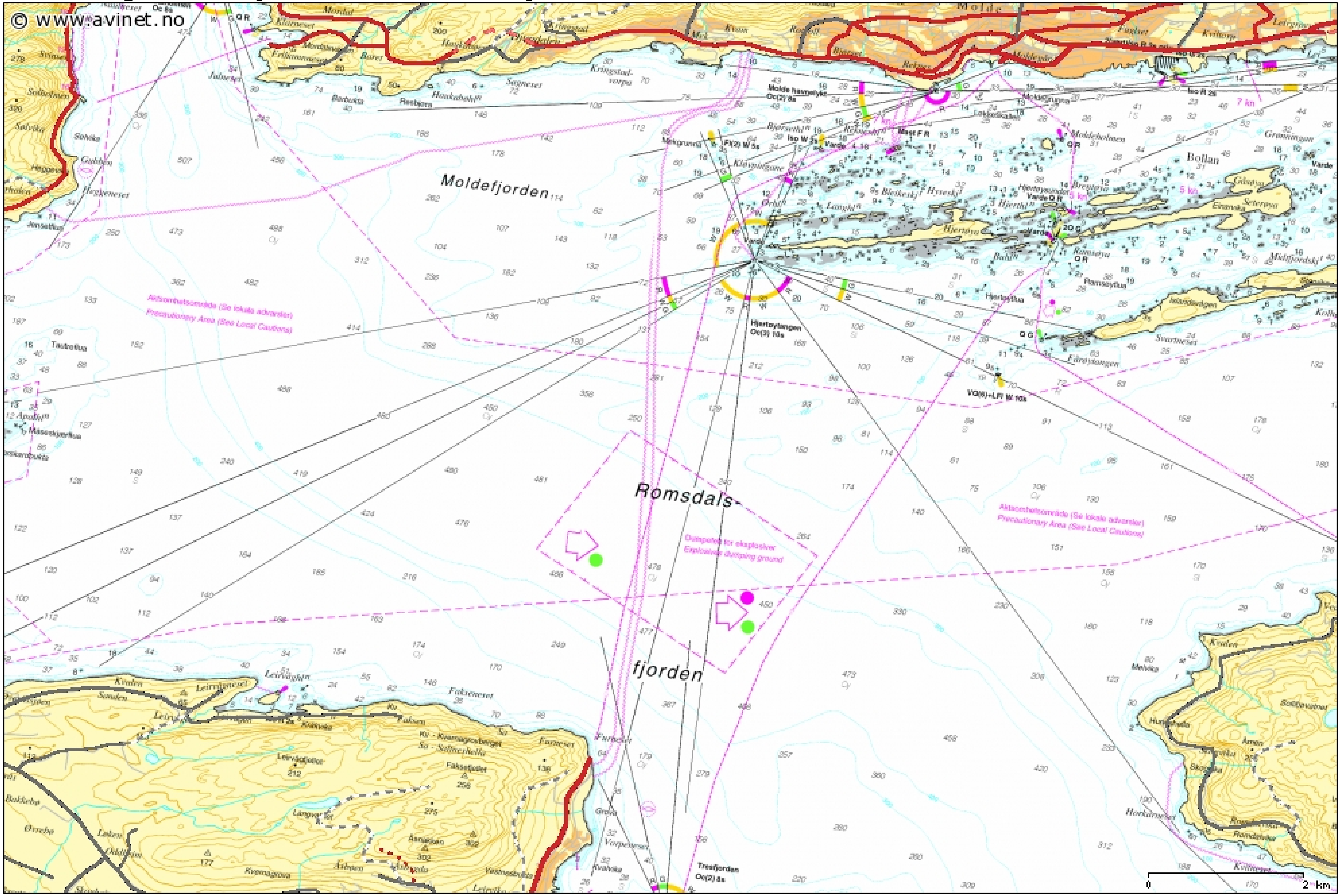
Technology	Wind Energy	
Product name and company	Gesterbine Skyscraper	Lina Architektura & Consulting
This pasta shaped building, to be built by Polish architecture firm for eVolo Skyscraper Competition, will be fitted with several wind turbines to generate energy from wind. They call it the Gesterbine skyscraper. The powers generated from the wind turbines will perform different functions during day & night. During the day the wind turbines will provide electricity to households. But when the darkness falls, the turbines would power pumps that transport river water into the land. Source: http://www.ecofriend.com/entry/future-perfect-sustainable-skyscrapers-with-integrated-renewable-energy-generators/		

Technology	Wind Energy	
Product name and company	Bahrains World Trade Center	
Bahrain's World Trade Center, when it became operational in 2008, became the first building in the world to have integrated wind turbines for meeting its electricity needs. The three 29m diameter wind turbines will meet approximately 11-15% of the tower's electricity needs. The concept of sustainable skyscrapers with integrated with integrated energy generator is certainly here to stay. In fact this is the future as far as building architecture is concerned. The success and potentiality of this concept have already been proven by buildings like the World Trade Center in Bahrain. It will not just reduce the carbon footprints of skyscrapers, but it will also eliminate the need for the residents to venture out of their surrounding to meet their daily needs. Source: World Trade Center		

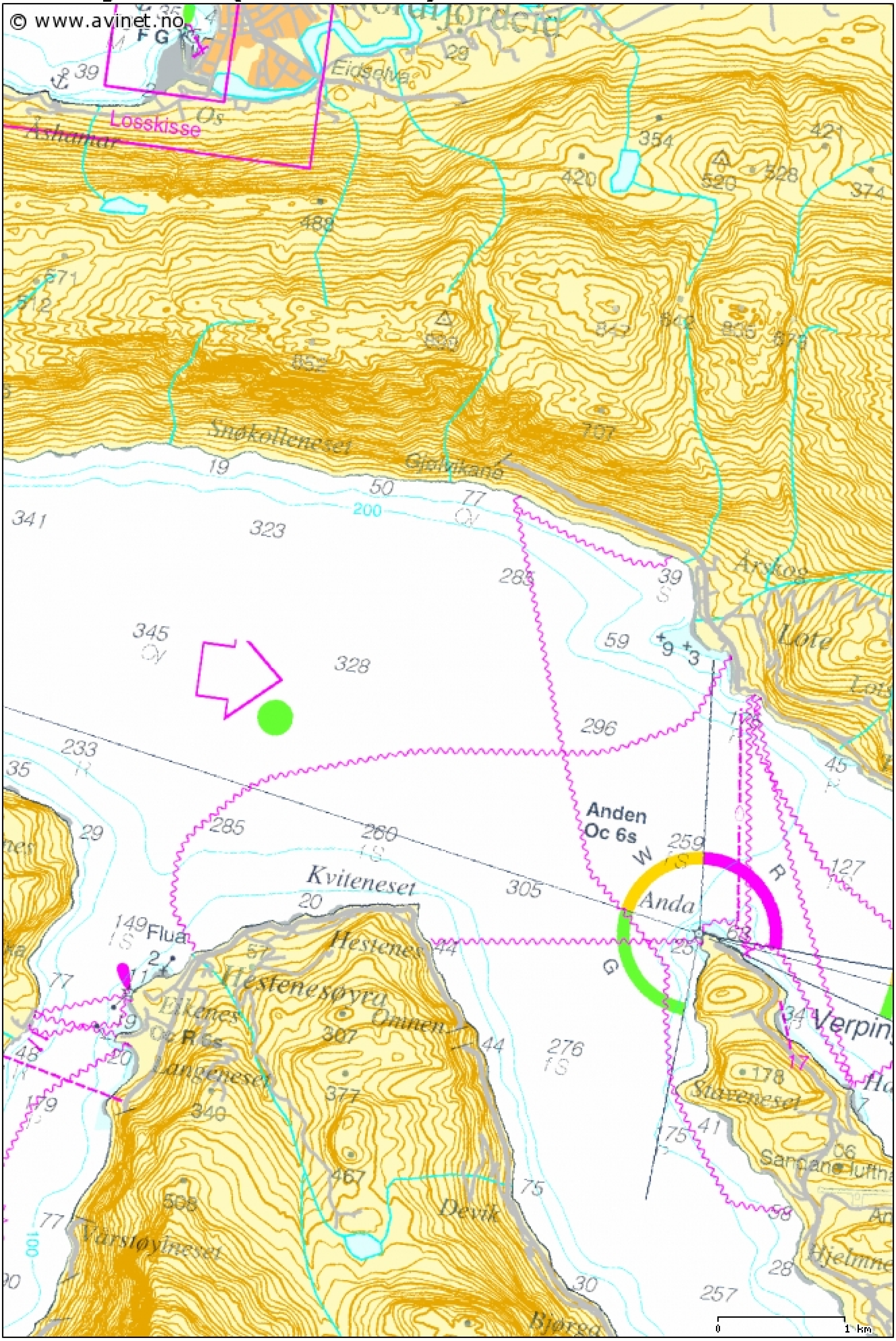
Bjørnafjorden (Sandvikvågen-Halhjem)



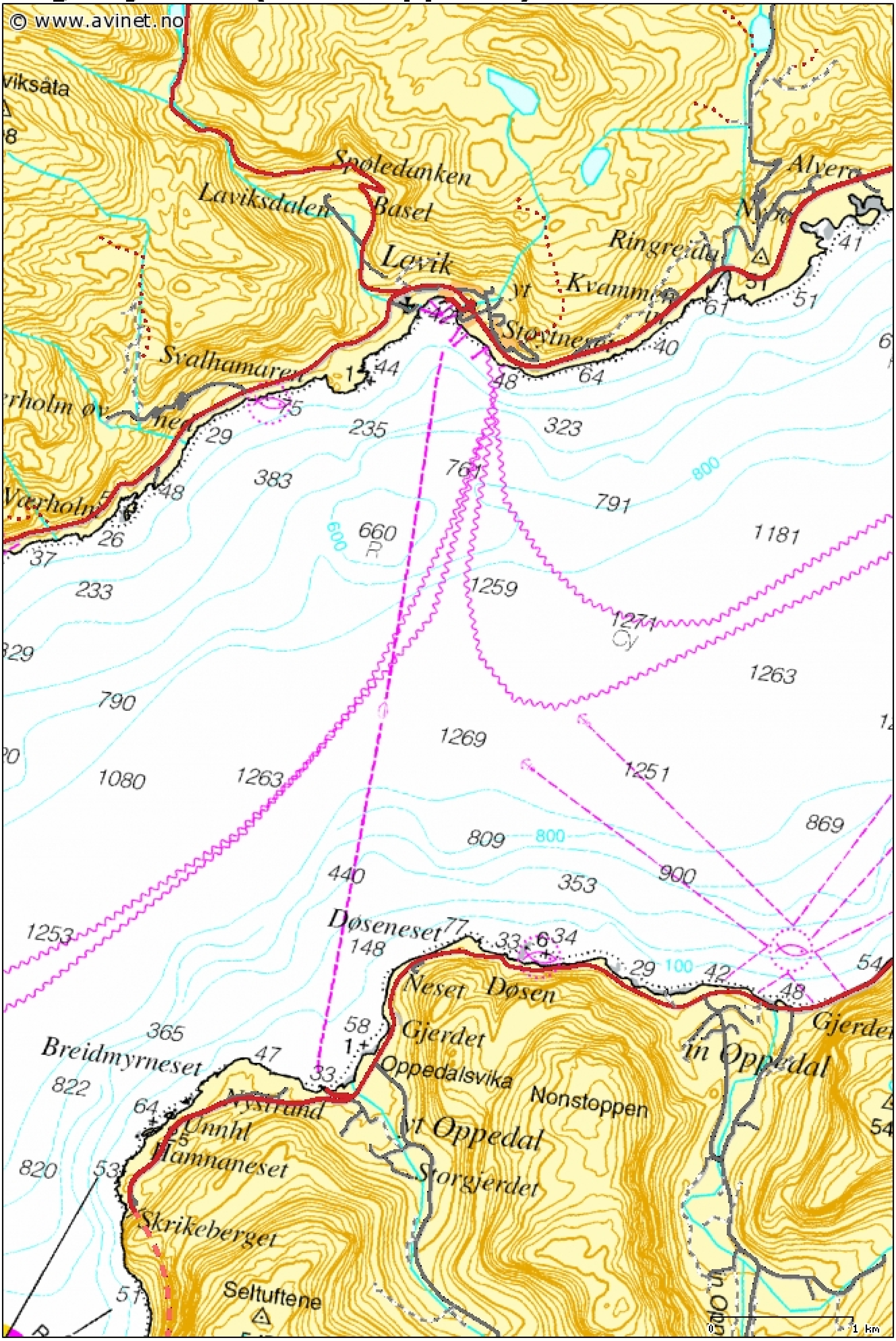
Moldefjorden (Vestnes-Molde)



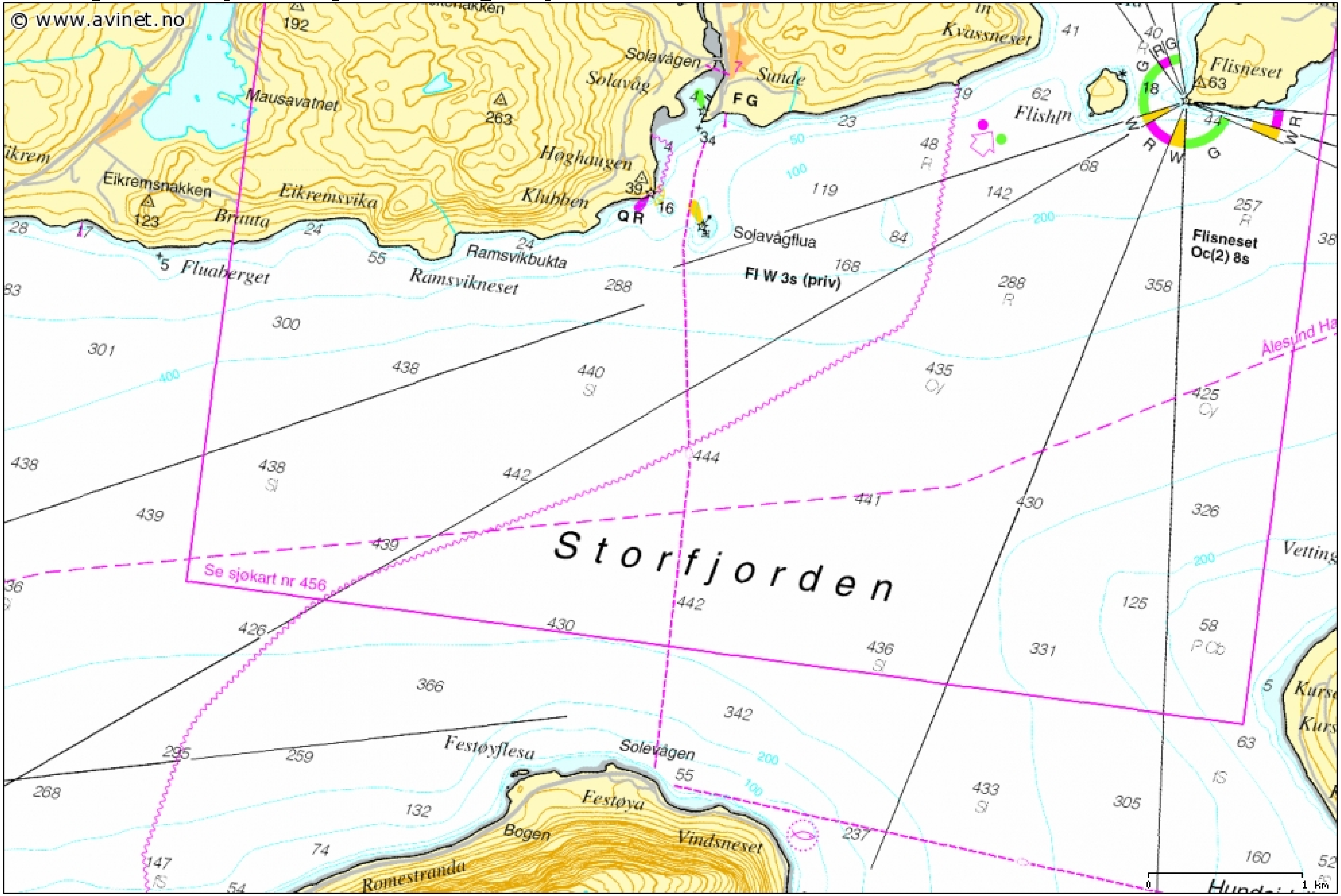
Nordfjorden (Anda-Lote)



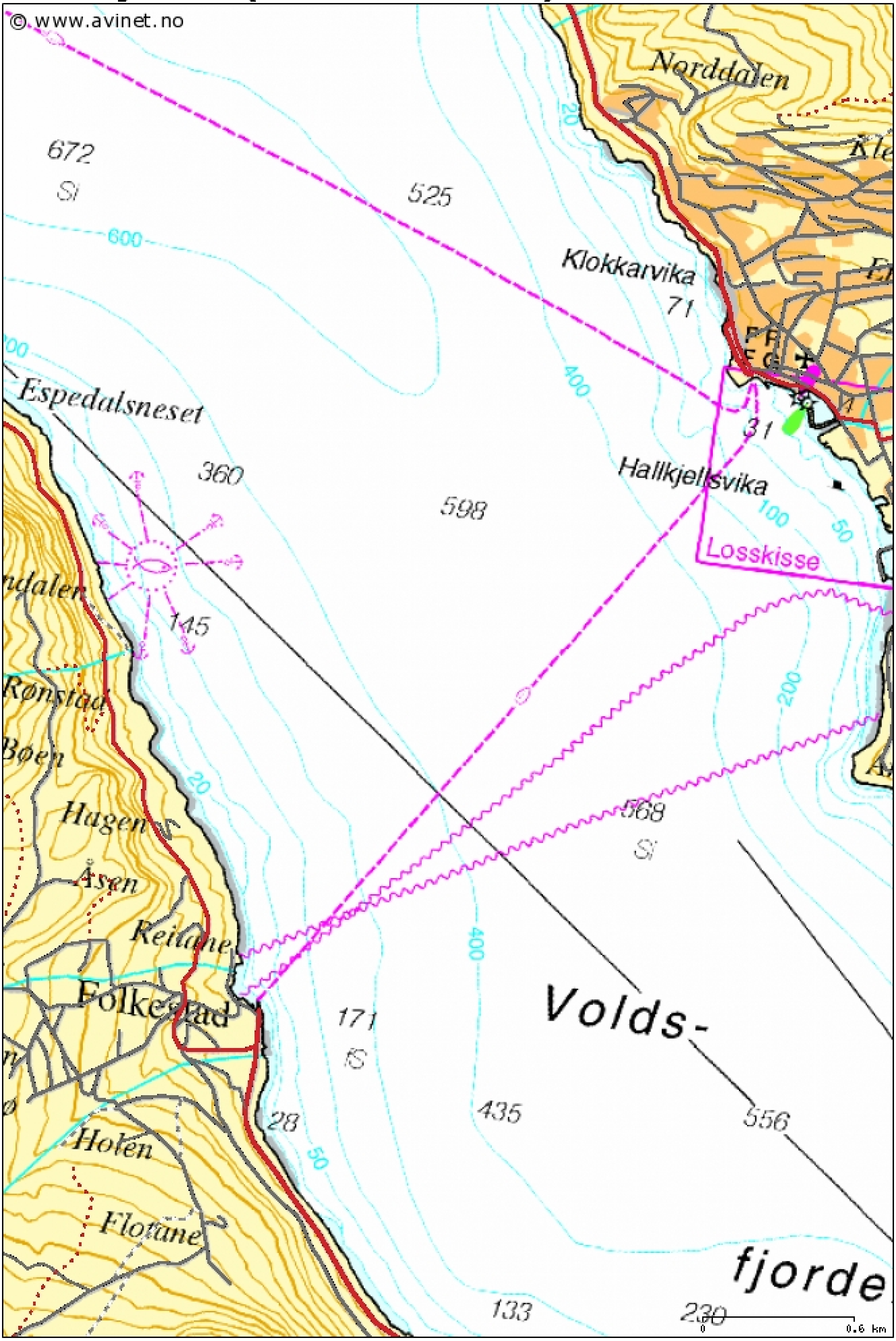
Sognefjorden (Lavik-Oppedal)



Storfjorden (Festøy-Solevågen)

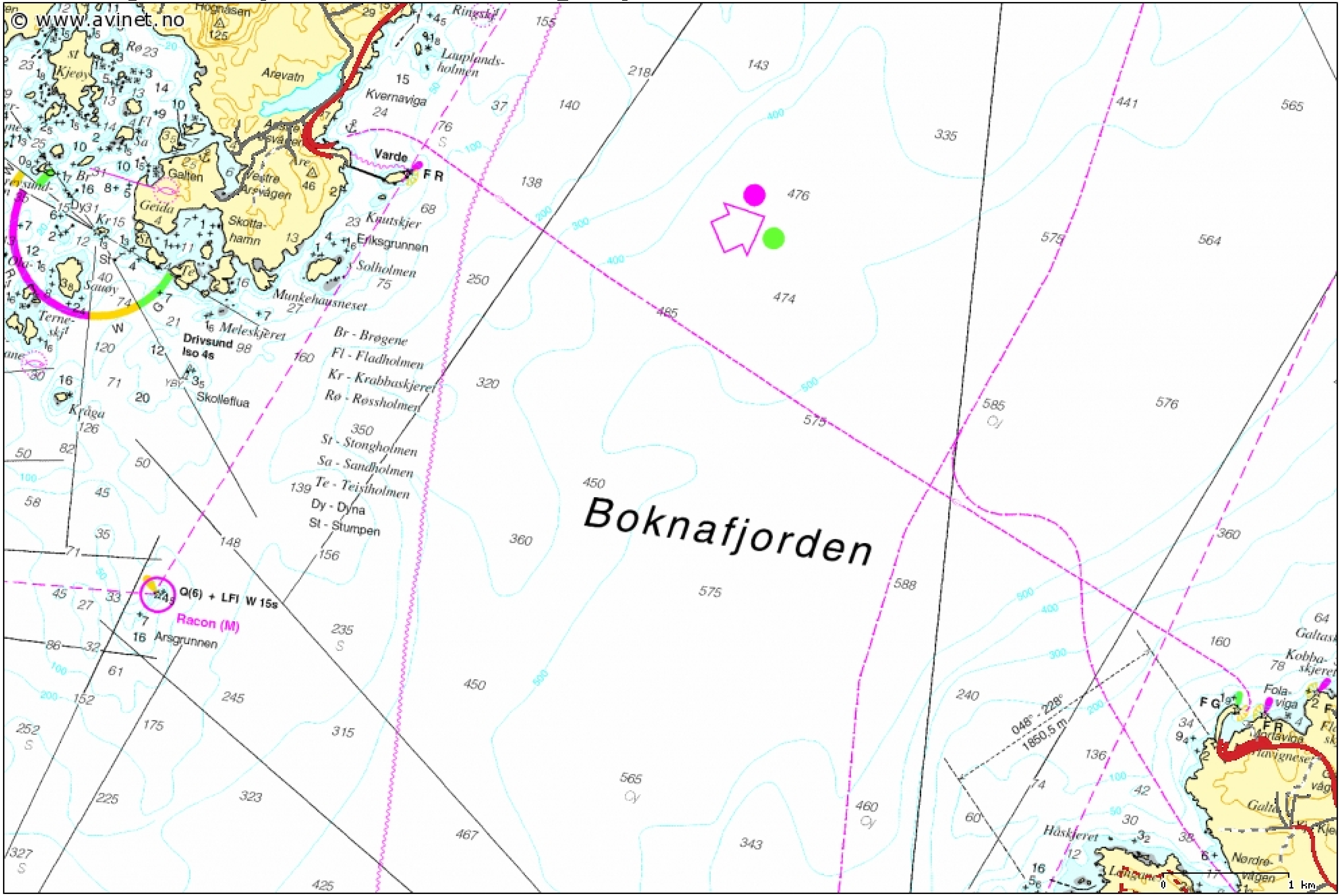


Voldafjorden (Volda-Folkestad)

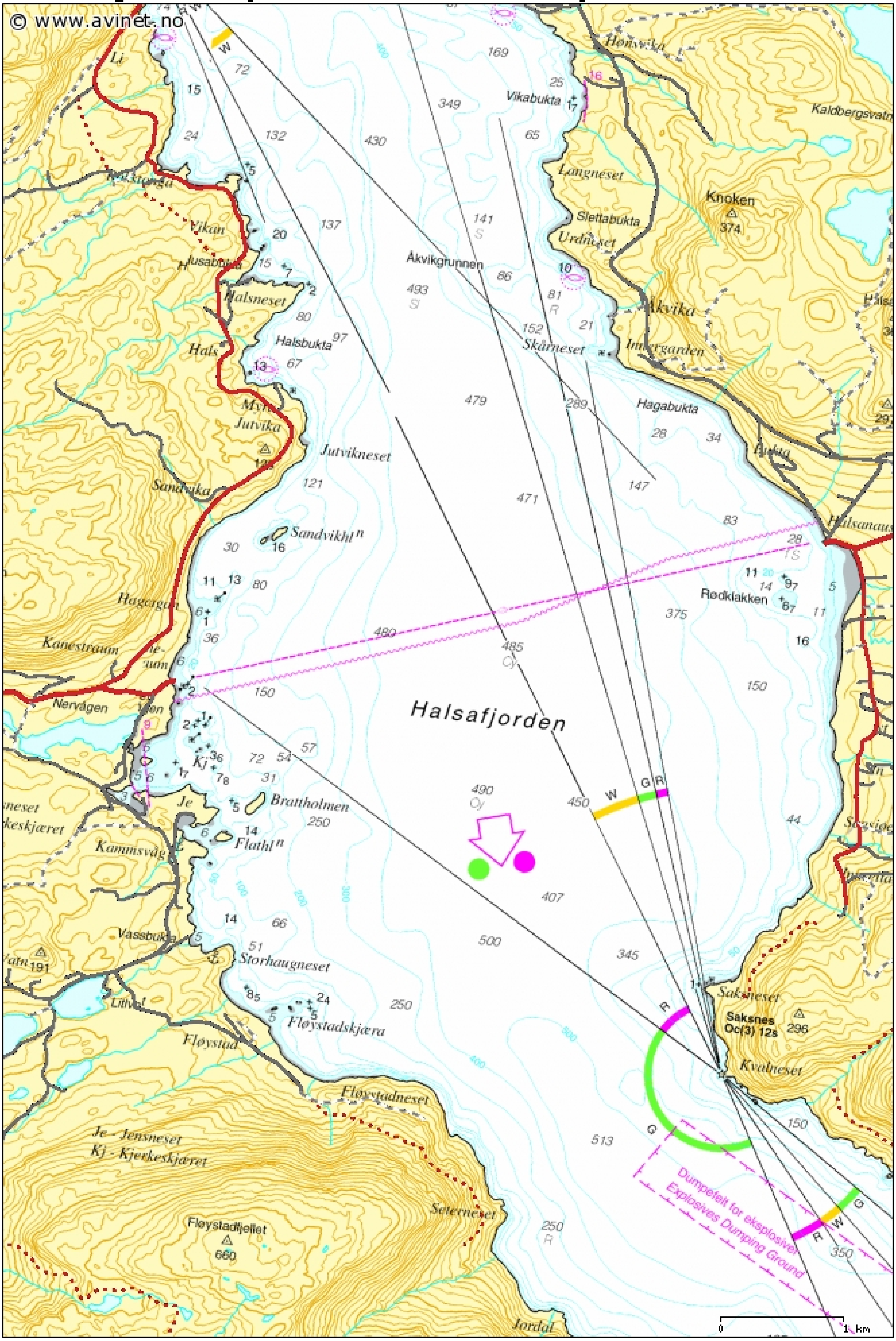


Målestokk: 1:20 148

Boknafjorden (Mortavika-Årsvågen)



Halsafjorden (Kanestraum-Halsa)



ATTACHMENT III – BRIDGE DESIGN VALUES FOR BERGØYSUNDET OG SALHUSFJORDEN

The best data Rambøll currently have for E39 is the measuring results from the planning of floating bridge in Nordhordland and Bergsøysund bridge. This data is the result of a measurement campaign that was ongoing for several years.

The data is intended for estimation of design values for bridges. The statistical values are determined for the respective return periods of 1, 50, and 100 years.

These include of measurements of:

• Wind speeds, direction (sector)

• Sea states with wave heights, periods and dispersion

• Power Rates

• Tidal Levels

• The density variations in salt water

• Assessment of ising

• Coating thicknesses and weights

In addition to this, the SINTEF report; *Estimate of waves and currents v. Lavik-Oppedal in Sognefjord* will be supplementary to these data.

The results from this are presented in the following pages. The text is presented in Norwegian. Please contact Rambøll for additional information.

Utdrag av målte data fra Bergsøysundet

Designverdiene for naturlaster i Bergsøysundet er registret for følgende sektorer:

I: 345°-75° (hovedretningen normalt på brua, nord-vest, gir trykk i buen)

II: 75°- 165°

III: 165° - 225° (sekundærretningen normalt på brua, syd-øst, gir strekk i buen)

IV: 225° - 345°

Vind

Designverdier for vind er basert på en kombinasjon av målinger og NS-tabellverdier.

Det vises til scatterdiagram med beregnede vindhastigheter registrert på retning og returperioder. Returperioden på 0,1 år er av interesse for energibetraktninger.

De største vindhastigheter (10m høyde) opptrer fra nord (sektor I). Aktuelle utvalgte returperioder er:

0,1 år= 18,78 m/s

1 år= 27,04 "

50 år= 36,30 "

100 år= 37,54 "

Forholdet mellom RP=0,1 år og design RP kan benyttes til å skalere vindbølger og vindstrøm.

Bølger (Sjøtilstander)

Bølgehøyder og perioder framgår av spredningsdiagrammene (scatterdiagram) pr. retningsintervall (sektor). Verdiene her er beregnet (ekstrapolert) for en RP=5 år.

Bølgehøyder og perioder er her parametre i et Jonswap spekter som er funnet representativt for sjøtilstander i norske fjorder.

Aktuelle utvalgte returperioder for kritisk sektor I er:

(Signifikant)Bølgehøyde Hs, Bølgeperiode Tp (maks)

1 år= Hs= 1,0 m/s, Tp=4,6 s

50 år= Hs= 1,23 m/s, Tp=4,9 s

100 år= Hs= 1,41 m/s, Tp=5,2 s

Lavere returperioder kan grovt skaleres fra forholdet mellom tilhørende returperioder for vind. Forekomsten av bølger med varierende høyder finnes fra scatterdiagrammene.

Strøm

Karakteristiske strømhastigheter V_k for jevn strøm over sundet er:

1 år= V_k = 1,12 m/s

50 år= V_k = 1,28 m/s

100 år= V_k = 1,31 m/s

Strømmens hovedretning er 305° (inn og ut sundet).

Lavere returperioder kan (meget) grovt skaleres fra forholdet mellom tilhørende returperioder for vind.

Tidevann

Vannstandsvariasjoner i forhold til NGO's kote null er:

MV=middelvannstand

1 år= MV = ± 1,75 m

100 år= MV = ± 2,00 m

Utdrag av målte data fra Salhusfjorden

Designverdiene for naturlaster i Salhusfjorden er registret for følgende sektorer:

I: 15°-90° (sekundærretningen normalt på brua, nord-øst, gir strekk i buen)

II: 90°- 165°

III: 165° - 240° (hovedretningen normalt på brua, syd-vest, gir trykk i buen)

IV: 240° - 15°

Vind

Designverdier for vind er basert på målinger.

Det vises til scatterdiagram med beregnede vindhastigheter registrert på retning og returperioder. Returperioden på 0,1år er av interesse for energibetraktninger.

De største vindhastigheter (10m høyde) opptrer fra sør (sektor III).
Aktuelle utvalgte returperioder er:

1 år, V_{10}= 20,50 m/s

10 år, V_{10}= 23,80 "

100 år, V_{10}= 26,90 ".

Bølger (Sjøtilstander)

Bølgehøyder og perioder framgår av spredningsdiagrammene (scatterdiagram) pr. retningsintervall (sektor). Verdiene her er beregnet (ekstrapolert) for en RP=5 år.

Bølgehøyder og perioder er her parametre i et Jonswap spekter som er funnet representativt for sjøtilstander i norske fjorder.

Aktuelle utvalgte returperioder for kritisk sektor III er:

(Signifikant)Bølgehøyde Hs, Bølgeperiode Tp (maks)

1 år= Hs= 1,2 m/s, Tp=4,5 s

10 år= Hs= 1,39 m/s, Tp=4,7 s

100 år= Hs= 1,69 m/s, Tp=5,1 s

Forekomsten av bølger med varierende høyder finnes fra scatterdiagrammene.

Herfra sees det at det er bølger med signifikant høyde Hs= 0,0 – 0,1, 0,1 – 0,2 og 0,2 – 0,3 m som dominerer. Disse verdier er ekstrapolert til RP=5år. og må derfor nedskaleres til RP=0,1år for energiformålet her.

Strøm

Karakteristiske strømhastigheter V_k for jevn strøm over sundet er:

1 år= V_k = 1,30 m/s

10 år= V_k = 1,50 m/s

100 år= V_k = 1,75 m/s

Strømmens hovedretning er 240° ± 30°(inn fjorden) og 30°± 30°(ut fjorden)

Tidevann

Vannstandsvariasjoner i forhold til NGO's kote null er:

MV=middelvannstand

1 år = MV = ± 1,25 m

10 år = MV = + 1,45 m/ - 1,35 m

100 år= MV = + 1,60 m/ - 1,40 m

(antall vekslinger på 100 år = 73000)

Islaster

Brua er utsatt for islaster, se vedlegg 2 for lastene

Felles for Bergsøysundet og Salhusfjorden

Vanntettheter

Vannets tetthet= 1005 – 1025 kg/m^3

Marin begroing

Horisontale og vertikale plater med mye lys: vekt= 42 kg/m^2, lagtykkelse= 150 mm

Undersider og flater med lite lys= 14 kg/m^2, lagtykkelse= 50 mm

Utdrag av estimerte data for Sognefjorden

Vind

Retning 210°

RP=100 år: V_{10} = 34 m/s

RP=1 år: V_{10} =13 m/s

Bølger

Dønning Hs = 0,1 m, Tp= 13 -14 s

RP=100 år: midtfjords, Hs = 2,34 Tp = 4,8 s, Tp= 13 -14 s

Vindbølger Retning 210°
RP=100 år: Hs = 2,3 m

RP=1 år: Hs = 0,6 m

Returperioder 0,1 år.

Hs= 0,76 m og 0,65 m for retning hhv. 60° og 240°

Strøm

Ferskvannsstrøm i overflatelaget: 0,2 m/s

RP:100år i 0-10m dybde, v = innover fjorden 0,77 m/s, utover v=0,56 m/s

(usikkerhetsmargin for design= 0,5 m/s)

Dvs. maks hastighet ca. v=1,3 m/s

Tillegsvurderinger fra statens vegvesen:

- ”middelverdi er” langt lavere ca. 0,03 m/s
- midlere brakkvannstrøm = 0,05 m/s
- Midlere tidevannsstrøm = 0,06 m/s

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