Unleashing renewable energies from the ocean: Statkraft's experience in developing business opportunities in immature technologies and markets

The forces of osmosis and tidal currents

by

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Introduction

During the past decade, global climate change challenges and the world's steadily growing demand for energy have brought the need for more renewable energy to the top of the international community's agenda. Therefore, the United Nations decided at the first World Summit on Sustainable Development (2002, Johannesburg) to create a specific forum dedicated to further advance the deployment of renewable energy sources: the International Conference for Renewable Energies. At the forum's first meeting, all countries reaffirmed their commitment "to substantially increase with a sense of urgency the global share of renewable energy in the total energy supply." During a follow-up meeting in 2008, it was clearly stated that in order to reach this goal, it is imperative to use both existing and new renewable energy sources.

Based on more than a hundred years of experience in developing and operating hydropower, the Norwegian utility Statkraft[1] has set a course for corroborating its leading role in renewable energy generation by investing in the quest of new renewable energy sources in strategic areas. As a result the company has formed an innovation and growth business unit that is spearheading Statkraft's research and development (R&D) efforts.

By focusing on two new renewable technologies – osmotic and tidal power – this article will present two different approaches towards R&D and towards positioning the company's activities within the business value chain.

1. Background

The pressure on the environment caused by human activities and especially the climate change challenges related to continuously increasing greenhouse gas emissions, calls for a thorough research of alternatives. Since the Kyoto Protocol in 1997, efforts to reduce carbon emissions have been intensified. Among others, the EU adopted an integrated energy and climate change policy in December 2008, including ambitious targets for 2020. It aims at bringing Europe onto a more sustainable energy track – towards a low-carbon future with an energy-efficient economy, which will cut greenhouse gases emissions by 20%, reduce energy consumption by 20% through increased energy efficiency and meet 20% of Europe's energy needs from renewable sources.

Despite these globally shared efforts, fossil fuels will continue to remain the most important source of energy in the decades ahead, as they are the world's main source of low-cost and broadly available energy. In addition, the global consumption of energy is growing, so the need for more renewable energy will even be more pressing in addition to the need to reduce our dependency on finite and carbon-intensive fossil fuels as an energy source.

[1] Statkraft develops and generates electricity from water, wind, biomass, sun and natural gas, while also being a major player on the European energy exchanges. In 2008, Statkraft achieved gross operating revenues of EUR 3.1 billion and employed more than 3000 employees in 23 countries. With and average annual electricity production of about 46 000 GWh only from hydropower, it has become one of the most important renewable energy producer in Europe.

In this context of climate and environmental challenges, R&D has a key role to play in finding new solutions. From a company's perspective, R&D is also about safeguarding business survival and shaping growth ambitions, meaning that we need to create a better balance of efficiency by improving existing technologies as well as to gear up for building new renewable solutions.

Statkraft has therefore created a business unit specifically focused on innovation and growth. This division is responsible for making Statkraft a pioneer in the commercialization of new energy technologies and for being in the forefront of developing and deploying existing technologies.

In order to fulfil our vision "as Europe's leader in renewables, we will meet the world's need for pure energy" the Innovation and Growth Division has to be in the vanguard of knowledge, technology and partnerships. Its efforts include the development of technology to harness energy from the ocean such as tidal and osmotic power. The division also focuses on energy efficiency measures for retail customers as well as energy recovery measures for industrial partners.

Statkraft has been engaged in developing new renewable energy technologies since the early 90's. Based on the company's history as a major Norwegian power producer, our focus has been on harvesting the energy that is available along the far-reaching Norwegian coastline. For more than a decade we have been working internally and in close collaboration with R&D parties as well as universities in order to find ways to produce renewable energy from the natural forces of the ocean.

Tidal and osmotic power are two examples of energy sources from the ocean on which Statkraft has been working and for which we see positive prospects of becoming commercially viable. Moreover, both technologies are excellent alternatives for carbon-free energy sources. There are however some major points of distinction between these two developments, especially when it comes to the level of maturity in the development stages. Osmotic power is a combined project involving research, development and innovation in order to utilize non-existing components with well known ones in a new system. Tidal power is a market-driven business development that uses existing technologies developed by the suppliers, so it is closer to commercialization.

Statkraft aims at establishing a track record in both of these positions. For osmotic power, we would like to keep our leading role in the early phase of technology development and transfer results from research and development into manufacturing partners. For tidal power, we intend to keep our comparative advantages gained together with established business partners and to use our market and technology understanding as a key for further business development. Both are part of a corporate responsibility to ensure a portfolio of innovation and growth for renewable energy sources.

The new growth targets are based on a strategic rationale to develop new areas into new business units where Statkraft is not yet present. A main part of the new growth areas – building competitive advantages – is expected to be developed in correlation with existing core business.

The paper will elaborate on the past and current challenges in developing new business activities by harvesting new renewable energy sources from the ocean with two different approaches.

2. The power of osmosis

It has been known for centuries that mixing freshwater and seawater releases energy. For example, a river flowing into the salty ocean is releasing large amounts of energy. The challenge is to utilise this energy, since the energy which is released from the mixing of salt and freshwater leads only to a very small increase of the local water temperature. During the last few decades at least two concepts for converting this energy into electricity instead of heat have been identified.

One of these is Pressure Retarded Osmosis (PRO). Thanks to this technology one might be able to utilise the enormous potential of a new, renewable energy source. This potential represents a worldwide electricity production potential of more than 1600 TWh per year – equivalent to China's electricity consumption in 2002.

For Pressure Retarded Osmosis, also known as osmotic power, the released chemical energy is transferred into pressure instead of heat. This was first considered by Prof Sidney Loeb in the early 70's, when he designed the world's first semi-permeable membrane for desalination purposes using reverse osmosis.

Statkraft has been engaged in the research and development of osmotic power and related enabling technologies since 1997. Together with its international membrane R&D partners, Statkraft is the main active technology developer globally and therefore an osmotic power knowledge hub. The team has made state-of-the-art achievements in terms of developing a new energy efficient membrane technology during the past few years.

Osmotic power is in fact based on naturally occurring osmosis, triggered by Nature's drive to establish equilibrium between different concentrations in liquids. Osmosis is a process by which solvent molecules pass through a semi-permeable membrane from a dilute solution into a more concentrated solution. The difference in concentration of salt between seawater and freshwater contains a strong force towards mixing. The effects of this strong force to mix can be intensified through a special membrane which separates salt and freshwater in a finite space and which only lets the water pass, and not the salt molecules. In this way, an osmotic pressure can be achieved by the amount of freshwater moving to the seawater side. This pressure can be in the range of 24 to 26 bars depending on the salt concentration of seawater.

More precisely, in a PRO system filtered freshwater and seawater are led into a closed system as illustrated by Figure 1. Before entering the membrane modules, the seawater is pressurised to about half the osmotic pressure, approximately 12-14 bars. In the module freshwater migrates through the membrane and into pressurised seawater. This results in an excess of diluted and pressurised seawater which is then split into two streams. One third of this pressurised seawater is used for power generation in a hydropower turbine, and the remaining part passes through a pressure exchanger in order to pressurise the incoming seawater. The outlet from such a plant will mainly be diluted seawater that will be led either back to the river mouth or into the sea.

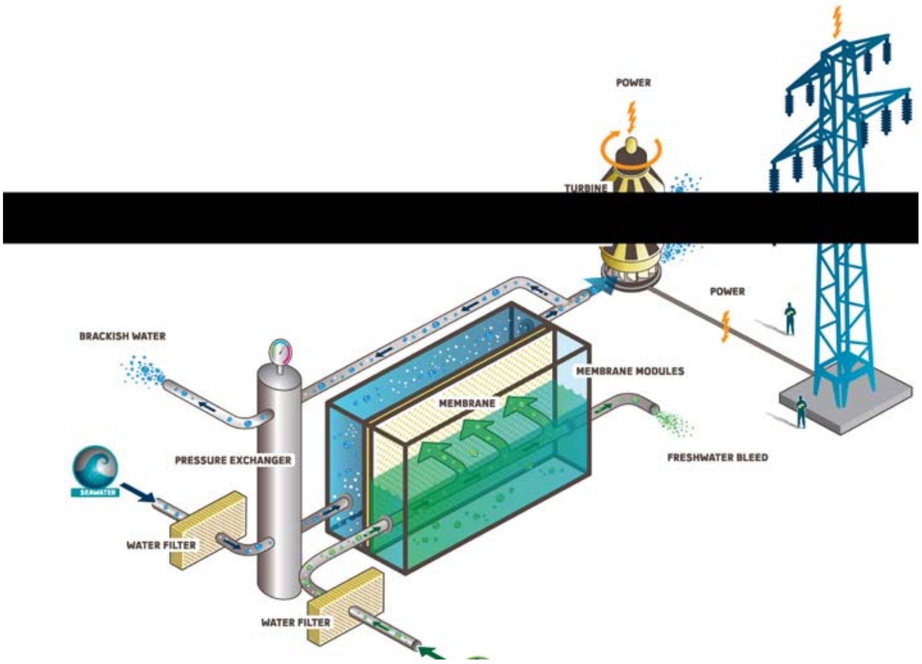

Figure 1: The principle of osmotic power is utilising the energy outcome of mixing water with different salt gradients. In the process the water with low salt gradient moves to the side with the higher salt concentration and creates increased pressure due to osmotic forces. Given the sufficient control of the pressure on the saltwater side, approximately half the theoretical energy can be transformed to electrical power, meaning that the operating pressure is in the range of 11-14 bars enabling the generation of 1MW per m^3/s of freshwater.

Consequently, the higher the salinity gradient between fresh- and saltwater, the more pressure will build up in the system. Similarly, the more water that enters the system, the more power can be produced. At the same time, it is important that the freshwater and seawater be as clean as possible. Substances in the water may get captured within the membrane's support structure or on the membrane surfaces, reducing the flow through the membrane and causing a reduction in power output. This phenomenon, which is called fouling, is linked to the design of the system, to the characteristics of the membrane, and to the membrane element.

An osmotic power plant will to a large degree be designed of existing "off-the-shelf" technology. The two key components in this technology are the membrane and the pressure exchanger. The lion's share of our efforts to commercialize osmotic power is dedicated to improving and scaling up these components.

2.1. Environment and market

The mixing of seawater and freshwater is a process that occurs naturally all over the world. Osmotic power plants will extract the energy from this process without polluting discharges to the atmosphere or water. Moreover, this process produces no other emissions that could have an impact on the global climate. Osmotic power's excellent environmental performance and CO^2-free power production will most likely qualify for green certificates and other supportive policy measures to increase the share of renewable energy.

A possible source of impact could be the effect of brackish water which will be discharged by the osmotic power plant into marine environment. This may alter the local marine environment and result in changes for animals and plants living in the discharge area. However, the osmotic plant will only displace the formation of brackish water in space without modifying the water quality so this will not be a significant environmental impact.

Since most rivers run into the ocean at a place were people have already built cities or industrial areas such as harbours, most of the potential sites for osmotic power generation can be utilized without affecting pristine areas. Moreover, the plants can be constructed partly or completely under ground (e.g. in the basement of an industrial building or under a park) which will make them very discreet. In these areas the environmental impacts on shore are estimated to be minor. These impacts will mainly be related to the building of access roads, channels and connections to the electricity grid.

Careful building of a plant in already-developed areas will cause no negative effects, since its visual impact can easily be minimised through underground locations or mitigated through appropriate landscaping such as tree and bush planting. It might even be possible to improve the present condition of biotopes along the river or in the estuary and the sea.

A power plant the size of a football stadium could supply around 10 000 households with electricity.

The estimated energy cost of osmotic power is comparable and competitive with the other new renewable energy sources, such as wave, tidal and offshore wind being in the range of 50-100 €/MWh.

With a worldwide potential of more than 1 600 TWh per year, whereas 170 TWh per year could be generated in Europe, osmotic power is likely to make a major contribution to the growth of renewable energy. This would also represent a new attractive business potential for both the commercial power companies and technology suppliers.

2.2. Osmotic power project status

The osmotic power research has been focused on designing a suitable and efficient semi-permeable membrane for PRO. At the same time, we have worked with system design, and have done several feasibility studies to scrutinize the concept as a commercial source of energy.

The membranes are fitted into membrane elements containing a specific amount of membrane area. In the desalination industry the so-called spiral-wound-element design and the hollow-fibre design are the most common cost-effective designs. Statkraft is actively developing these designs to fit with the special requirements for PRO. In this respect, the following design criteria have been adopted:

- the elements must be able to have flow on both the freshwater and the seawater side of the membrane,
- the elements must contain a large membrane area,
- fouling must be minimised, and
- the design must be cost-effective.

This research has mainly been done in Germany, Norway and the Netherlands. There are, however, other groups working on elaborative topics both in North America and Asia.

The world's first prototype of osmotic power is under construction in the southeast of Norway, as illustrated by the picture below in Figure 2. This prototype plant will be put into operation in 2009.

The major technical prerequisites of osmotic power plant sites are:

- steady availability of freshwater and seawater, as well as

- available building sites at or beneath the surface.

Statkraft’s prototype is built in such a way that it will also be possible to use it as a laboratory for further development of the technology. In this respect, the prototype will contribute to technology enhancements in order to reach a competitive cost, as well as building knowledge towards further scaling up of its components.

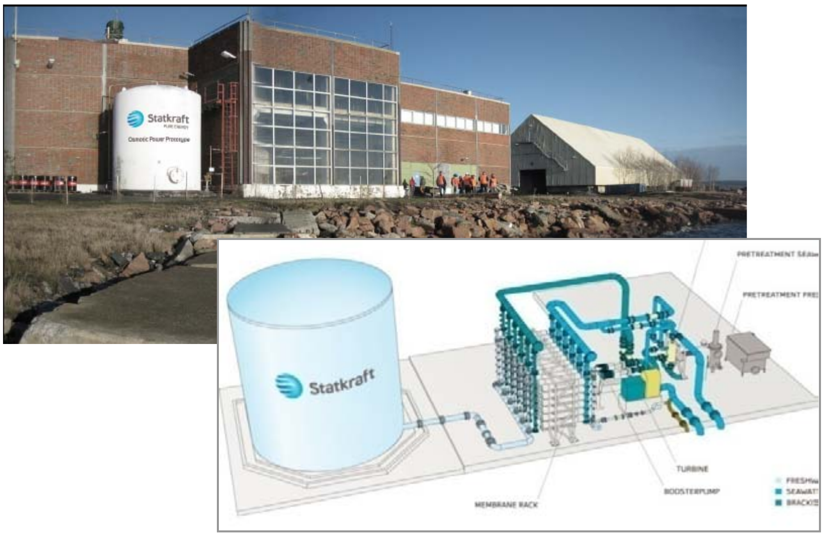

Figure 2: The prototype located at the east coast of Norway.

In addition to further research, with the main focus being the membrane and the membrane module, the prototype serves as a catalyst for developing partnerships and building relationships. The prototype facilitates the creation of partnership for development of osmotic power outside Statkraft’s core geographic area, and it increases awareness of osmotic power among governments and manufacturers that are invited to test the technology. Furthermore, the prototype will be a starting point to test and measure environmental challenges such as measuring potential algae bloom related to the discharge of brackish water.

This project-related work runs in parallel with defining business models in the pre-commercial phase to develop the production technology, and later establish an effective value chain that will be attractive for different parties without one party holding a monopoly.

3. The power of tides

Tidal energy is a renewable, everlasting and carbon-dioxide-free energy source. It is the result of the sun and the moon’s gravitational pull on the tides. When the Earth rotates, the tides move – ebbing and flowing. The change in the water level between high tide and low tide creates tidal currents in coastal areas, which can be forceful enough to drive a turbine, especially if the geomorphology comprises formations like islands and fjords, which can intensify the force of the tidal currents. The high density of water – it is nearly 1,000 times as dense as air – means that there is a lot of energy to harvest from marine currents even if they are moving at a relatively low velocity.

Tidal currents are governed by the movement of the Earth, moon and sun, and are therefore cyclical and completely predictable, which is particularly favourable for production and maintenance planning.

Statkraft has been involved in tidal energy since 2001. During the first years the activity was focused on the development of one specific tidal energy technology – Hydra Tidal, where Statkraft funded part of the development and today holds a 25% share – as well as some R&D activities.

During the last two to three years, we have used our skills and experience from these early-stage-initiatives to develop a strategy focused on evolving business opportunities for tidal energy. Over that period the level of activity has increased significantly, and at present we have several site development projects, a specific ocean energy university program and stakes in several technology developers.

The rationale for being involved in technology development and to make investments in technology companies is that we believe technology knowledge is essential to understand site development and deployment. Technology knowledge and experience is also important to reduce risk and to deliver cost-effective operation and maintenance.

We have an ambition to become a significant player in the tidal energy business when the business is commercialized.

Our strategy is to demonstrate our ability to deploy and deliver large-scale tidal energy projects by

- leveraging Statkraft's existing skills and capabilities in project execution, power production and trading of renewable energy;
- developing specific skills and capabilities related to tidal energy; and
- building up an exclusive pipeline of sites, technologies and business partners

3.1 Technology

The energy in the tides can be harvested either by utilizing the potential energy in the level between high and low tides or by using the kinetic energy in the tidal currents.

Using the potential energy requires a reservoir to store the water between high and low tide. The technology for converting the water in the reservoir to electricity is similar to conventional hydropower technology. MW-size plants exist in several places worldwide. The largest by far is La Rance in France, a 240-MW tidal power plant.

Using the kinetic energy in the tidal currents requires technologies that are similar to those used for capturing the kinetic energy in the wind. There is a large diversity in the technologies that have been so far. They can be divided into separate groups according to specific characteristics:

- How does the technology translate kinetic energy into electric power? The most obvious solution is the use of horizontal-axis-turbines, which are based on the same technology as is dominant in the wind energy industry. Another alternative is employing vertical-axis-turbines, which are also used on some wind turbines. Besides these, there are devices that use other ways of converting an energetic flow to mechanical movement, for example, moving flaps or large underwater sails.

- How are the devices kept in position? In general, there are two options: Devices can be floating on the surface and kept in position by anchors or they can be fixed to the seabed either by using a gravity-based foundation or a monopole.

- How is the power take-off system configured? Like wind turbines, there are several solutions and the most prominent ones are using a standard gear with fixed speed generator or a direct-driven variable speed generator. Furthermore, there are devices that explore the possibility of using a hydraulic system with a hydraulic pump on the main shaft and a hydraulic turbine connected directly to a high-speed generator.

Figure 3: Atlantis' technology Solon ©. Example of horizontal axis energy translation and device fixed to the seabed.

Currently, there are a lot of tidal technologies under development and the vast majority is focused on utilizing the tidal currents. A few are tested in full scale, which is typically 1 MW+ size, and some are grid connected. Still, all technologies are at a pre-commercial phase and at present there is no commercially available technology to be deployed in multi-MW arrays.

Technologies that have been tested in large/full-scale are Atlantis Resources Ltd, Marine Current Turbines Ltd, Hammerfest Strøm AS and Open Hydro Ltd. The business is spread worldwide and these demonstration projects have been done in Australia, Norway and UK. The United Kingdom has set up a government funded marine energy test facility that is situated in the Orkney Islands called European Marine Energy Centre (EMEC). Several technologies have ambitions to test their device there in the near future.

3.2 Energy and market potential

The energy potential for tidal energy in the world is not calculated in detail and the spread of the estimates is large. The IEA/OES estimates the theoretical power potential from tidal and ocean currents to be 5 TW, which equals an annual energy production of about 20 000 TWh. Other sources estimate the economically exploitable potential to be only a fraction of this ~200 TWh/year. Nevertheless, it represents a vast potential that would make supplying tidal energy a large and viable business. The potential is very site specific, but those sites are situated worldwide. In Europe, the majority of the potential is in the UK, Ireland and France.

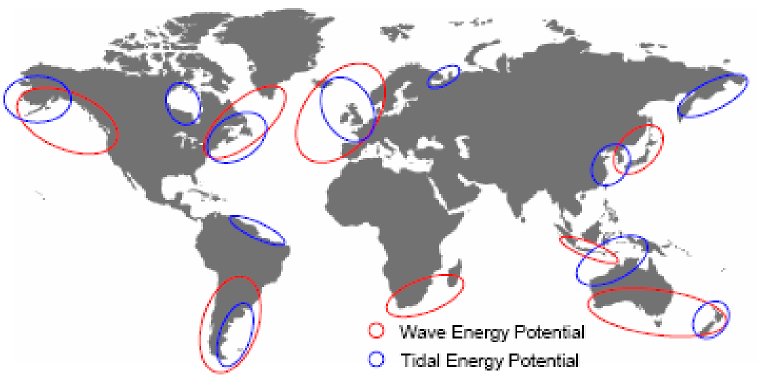

Figure 4: Map of areas with energy potential.

Tidal energy development is still in its early stages, but there is a clear movement in the right direction. We observe that technologies are becoming more mature, the companies developing technologies are becoming more professional and the technologies have started to converge towards some generic solutions.

Several countries have initiated exclusive incentives for tidal energy power production, which will pull the development even more. In addition, the framework for site application is being developed in some countries and there are international collaborations on important issues such as studies of environmental effects and how to get tidal energy grid connected, as well as the development of standards and guidelines.

One piece of evidence that the tidal energy business is about to take off is that the competition has begun for the best sites for deployment of large-scale tidal energy farms. The UK is in the forefront of site development with the ongoing Marine Round 1 on Pentland Firth – the tidal energy equivalent to offshore wind Round 3 in UK.

As well several big players in the energy business are taking positions. Some 50 per cent of the top 20 utilities in Europe are involved in ocean energy (including wave and tidal).

Based on the current technology status and cost, and the expected learning curves to be followed for the business, we expect tidal energy to be cost competitive with other renewable energy sources within the next decade.

3.3. Ongoing tidal energy activities at Statkraft

Due to the fact that the majority of activities in the tidal energy business are happening in UK and Ireland, Statkraft's tidal energy team is situated in London.

We have active on-site development for large-scale deployment of tidal energy. The ongoing projects are situated in Northern Ireland and in Scotland. Both projects are executed in partnership with local expertise and experience.

In the process of building skills and capabilities, we have invested in Atlantis Resources Corporation Ltd. in addition to the position we are holding in Hydra Tidal Energy Technology AS.

In 2008, Statkraft initiated an Ocean Energy Research Program, in cooperation with the Norwegian University of Science and Technology in Trondheim, The University of Uppsala in Sweden and Danish Technical University in Copenhagen. The objective of the program is to build a world leading competence network within ocean energy – offshore wind, tidal and wave energy. Statkraft funds 2,5 million Euros each year and the universities are matching the funding with their own activities so that the actual activity is equivalent in value to almost double our funding. The program in total funds 30 scientific positions (PhDs, Post-Docs, and professors) at these universities. Our ambition is to extend the program by involving more universities and other industrial partners.

Statkraft's current position in tidal energy is very good. Our pipeline of sites, technologies, projects and partners definitely qualifies us as a leading European player in the tidal energy business.

4. Different approaches to the same value chain

From the description of both technologies provided in the two preceding chapters, is clear that Statkraft's efforts in the field of osmotic and tidal power are focusing on different links of the same value chain as illustrated by Figure 5.

To develop the world's first osmotic power plant prototype, Statkraft has invested intensively in the early stages of research and technology development to create a new concept and the related generating capacity. This investment is now culminating after more than a decade of work in the construction of a prototype. Osmotic power technology development is therefore heading into a promising final stage of the pre-commercial phase, whereas tidal power development has chosen a rationale that puts an emphasis on technology understanding and market-driven business development without being directly involved in technology development. The tidal power R & D project is based on a more mature technology and is therefore closer to commercialization.

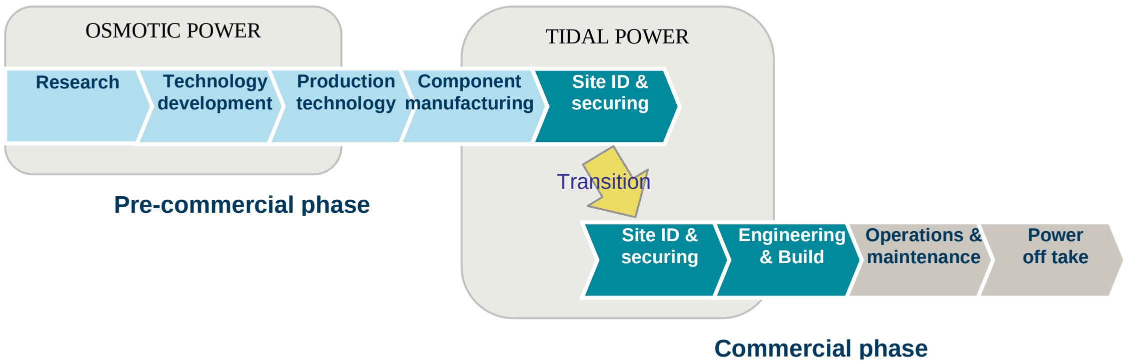

Figure 5: The points of distinction between the different development phases of osmotic and tidal power.

Although Statkraft's focal point in the fields of R&D for osmotic and tidal power are different, both initiatives are part of a corporate strategy to ensure a portfolio of innovation and growth for renewable energy sources in a long-term business development perspective including partnership building with potential associates for further business development.

In order to reach EU goals regarding energy supply from renewable sources and to meet the growing demand for electricity, a variety of new renewable sources is needed. Against this background, marine energy represents a significant future source of renewable energy supply.
At the moment the cost of the technologies makes governmental incentives a premise for profitability. For a successful increased deployment of new renewable energy technologies, it will be important that governments create a facilitating regulatory framework to make our future energy supply more sustainable.

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