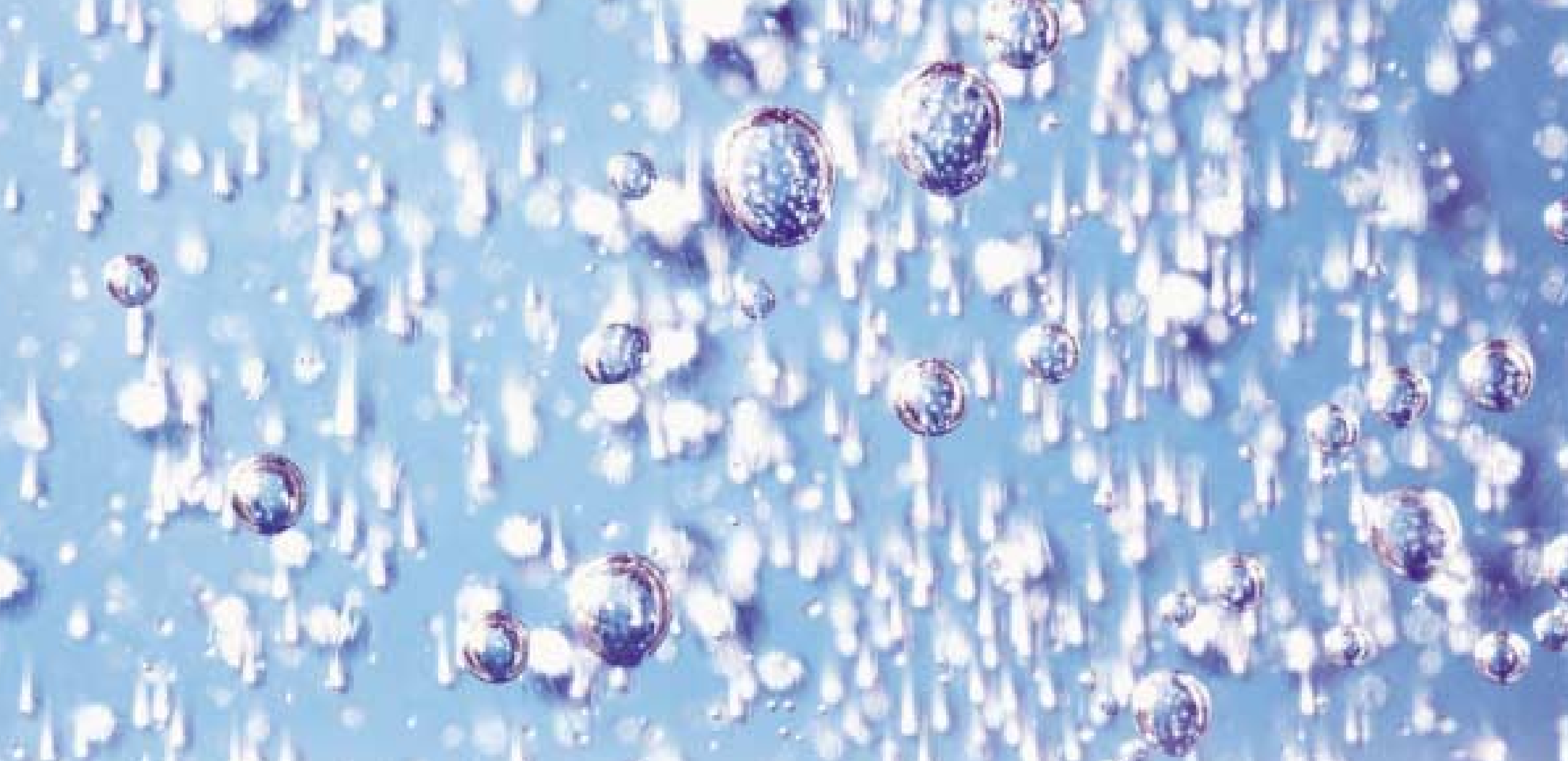
The Salinity Power project

Power production from the osmotic pressure difference between fresh water and sea water.

PROJECT DURATION 1. NOV. 2001 TO: 31. OCT. 2004



Salinity Power was the world's first major research project focusing on the development of salinity (osmotic) power technology.

Salinity power uses membranes to generate power from the entropy difference between seawater and freshwater. This project made significant progress in membrane performance, the key component for competitive renewable energy production by this method.

Based on evaluation of the technical, environmental and economical features of the concept, Salinity Power concludes that a 200 TWh/a power generation potential exist in Europe.

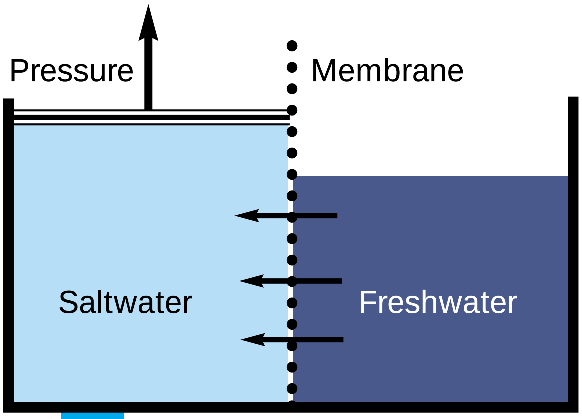
The project have brought great interest around the world in this new, renewable energy source and establish the participants in this project as the world leaders in the development of salinity power.

The aim of the project was to evaluate the feasibility of commercial power production from the entropy change of mixing of fresh water and sea water. This was done through development and optimization of membranes and membrane modules suitable for pressure retarded osmosis.

The project made great progress in developing membranes especially designed for pressure retarded osmosis. Prototype membranes were developed, starting at an energy density of less than 0.1 W/m^2. At the end of the project, an energy density of 1.7 W/m^2 was verified for the best membrane. This represent a significant step toward the required power density for an commercial power plant.

A study of the environmental consequences, as well as the technical and economical potential for salinity power was completed to investigate possible "show stoppers". Today, no technological obstacles are identified that could prevent salinity power to become a huge, new renewable energy source.

The partners in the Salinity Power project were Statkraft (Norway), SINTEF (Norway), Forchungszentrum GKSS (Germany), Helsinki University of Technology (Finland) and ICTPOL Instituto de Ciência e Tecnologia de Polímeros (Portugal).



Pressure retarded osmosis

The power of osmosis

When a river runs into the ocean and the freshwater mixes with the saltwater, huge amounts of energy are unleashed. Unlike violent torrents in a water fall or steaming hot geysers, the energy released when mixing water with different salinity cannot easily be seen from the banks of the estuary. Nevertheless, the energy is there and everyone who has tried to separate salt from seawater knows that large amounts of energy are needed.

When placing a semi-permeable membrane (i.e. a membrane that retains the salt ions but allows water through) between reservoirs containing freshwater and seawater respectively, a net flow of water towards the saltwater side will be observed. If the saltwater compartment has a fixed volume the pressure will increase towards a theoretical maximum of 26 bars. This pressure is equivalent to a column of water 270 meters high.

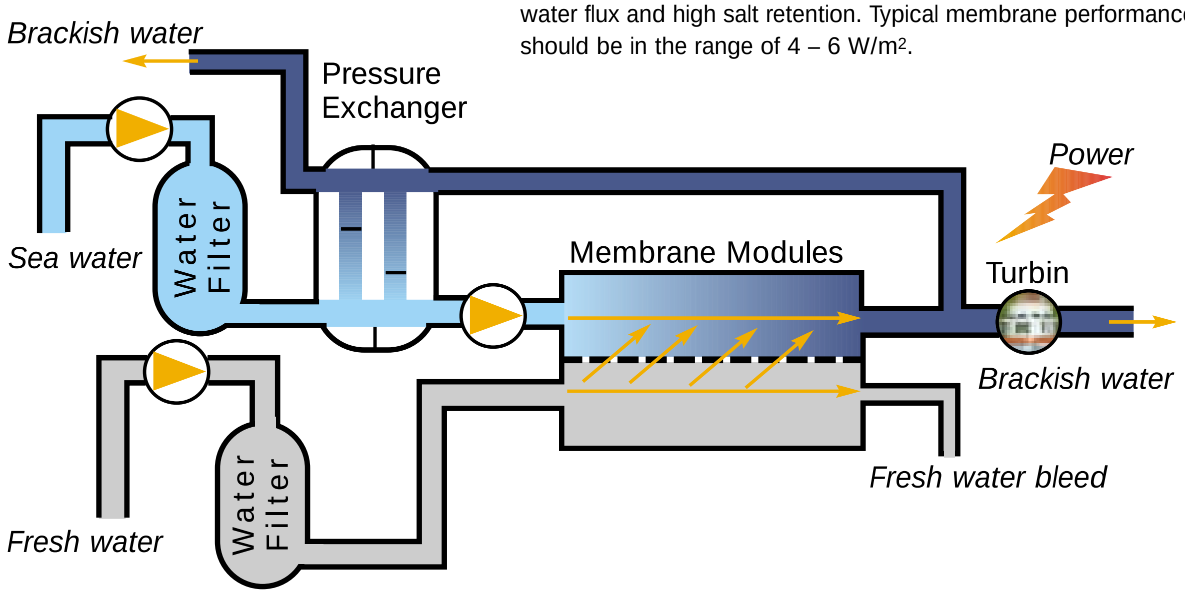
This energy can be used to generate environmentally friendly renewable energy if the mixing can be carried out by controlling the pressure on the saltwater side. The process is called pressure retarded osmosis (PRO) and in a technically feasible process approximately half the theoretical energy can be transformed to electrical power, making osmotic power a significant new source of renewable energy.

Statkraft and research partners have developed pressure retarded osmosis from an academic idea to a new environmentally friendly power technology concept.

The PRO concept

The pressure retarded osmosis power plant is similar to a reverse osmosis desalination plant running backwards. However, the PRO plant generates power from freshwater in stead of consuming power. A simplified PRO process diagram is shown below.

Freshwater is fed into the plant (greyish) and filtered before entering the membrane modules containing spiral wound or hollow fiber membranes. In the membrane module, 80 – 90 % of the fresh water is transferred by osmosis across the membrane into the pressurized seawater (bluish). The osmotic process increases the volumetric flow of high pressure water and is the key energy transfer in the plant. This requires a membrane that has a high water flux and high salt retention. Typical membrane performance should be in the range of 4 – 6 W/m^2.



The osmotic power process

Saltwater is pumped from the sea and filtered before it is pressurized and fed into the membrane module where it is diluted by the freshwater coming through the membrane. The volumetric feed of seawater is about twice that of the freshwater.

The brackish water (dark blue) from the membrane module is split in two flows. About 1/3 of the water goes to the turbine to generate power. 2/3 return to the pressure exchanger to pressurize the feed of seawater. To optimize the power plant the typical operating pressure is in the range of 11 – 15 bars. This is equivalent to a water head of 100 – 145 meters in a hydropower plant, generating about 1 MW/m^{3}s freshwater. The freshwater feed operates at ambient pressure.

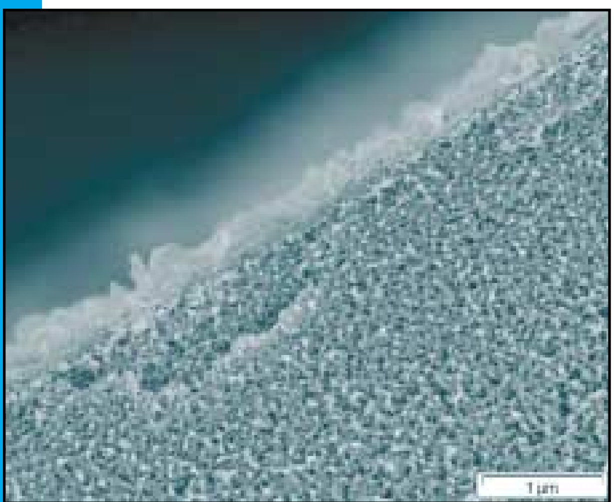
Some pre-treatment of the water is necessary. Experience from Norwegian water treatment plants shows that mechanical filtration down to 50 mm in combination with a standard cleaning and maintenance cycle is enough to sustain the membrane performance for 7 – 10 years. Similar lifetime data are assumed for osmotic power plants.

Today’s status on membrane technology*

A membrane can be described as a permeable barrier characterized by properties of selectivity and flux that provide functional transport across the barrier. Alternatively, it can be described as a thin film barrier that allows preferential passage of certain substances. For years, membranes existed as solutions in search of problems, i.e., products seeking markets. Now, the membrane industry is crucial to the 21st century. Markets exist in potable water, pollution management, power generation, and commercial production of medical devices, biotech products, electronics, pharmaceuticals, foods and beverages, chemicals and cosmetics.

In recent years, membranes and membrane processes have become industrial products of substantial technical and commercial importance. The worldwide sales of synthetic membranes in 1990 were in excess of Euro 1500 million. Today the market is close to 8 billion Euro per year, so the membranes have become an large and still increasing industrial activity.

Membranes and membrane processes have found a very broad range of applications, but, in spite of impressive sales and a growth rate of the industry of about 12 to 15 percent each year, the use of membranes in industrial-scale separation processes is not without technical and economic problems. Technical problems are related to insufficient membrane selectivity, relatively poor trans-membrane fluxes (fouling problems), general process operating problems, and lack of application know-how. Economic problems originate from the multitude of different membrane products and processes with very different price structures in a wide range of applications which are distributed by a great number of sales companies, very often as individual products. This has led to relatively large production volumes for some products such as hemodialyzers, disposable items used only once for a few hours and sold in relatively large and uniform market segments. Other membranes used in special applications in the food or pharmaceutical industry are expected to last for several years in operation and can be sold only in relatively small quantities to small market segments. Consequently, production volumes tend to be low and prices are comparable high.



SEM of PRO membrane

*References:

"RC-201R Membrane Technology: A New Era" (April 19, 2001) BUSINESS COMMUNICATIONS COMPANY, INC

"Water treatment membrane processes"(1996), Mallevialle,J., Odendaal, P.E. and Wiesner, M.R. (ed.), McGraw-Hill, New York. ISBN 0-07-001559-7

Membrane development in Salinity Power

Membrane production at GKSS

A spiral module design for pilot testing has been developed and three modules with 4 m² of membrane each have been produced. One of these has been in successful operation for several weeks and the power yield was as expected.

The main objective of the Salinity Power project was to develop membranes suitable for competitive power production by mixing of fresh water and sea water in pressure retarded osmosis (PRO), and further to develop membrane modules that can facilitate the mixing process with an acceptable hydraulic pressure loss.

Several approaches to the membrane development process have been followed, which involved both asymmetric membranes made of cellulose acetate (CA), and thin film composite (TFC) membranes CA membranes both based on conventional casting technology and development membranes have been produced. For the TFC membranes the main effort has been to enhance the diffusion rate of water through the membranes. The membranes were made as flat sheets of various formats. Innovative production technology has been taken into use for this purpose, and the effects of surface treatments have been studied.

Measurements of CA membranes have proved that many of these membranes behave as, or close to, ideal osmotic behavior. Some of the prototype membranes exhibit very high water permeabilities, but the corresponding salt permeabilities are yet too high, which restricts the power production in pressure retarded osmosis.

Calculations using a membrane performance simulator show that the membranes with the best combination of water and salt permeabilities and structure parameter potentially yields a gross specific power close to 3 W/m². This is close to the necessary efficiency for competitive energy production.

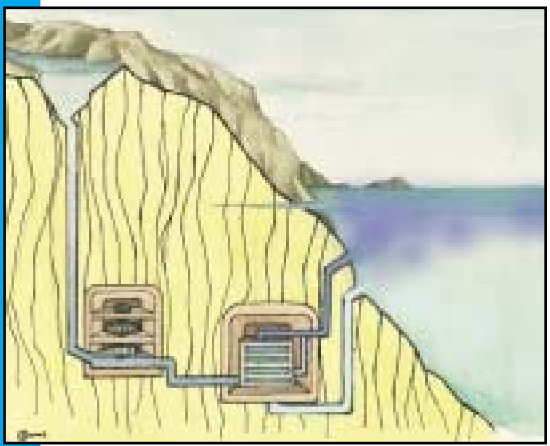
The prototype membranes that were developed in this project show the great progress in the project. In the beginning the membranes had a verified energy density of less than 0.1 W/m². At the end of the project, an energy density of 1.7 W/m² was verified for the best membrane developed.

Models describing spiral and fiber membrane modules operating in PRO has been developed. The models include concentration polarization, basic membrane parameters, module design and dimensions, as well as the hydraulic pressure loss. By using these models spiral and fiber modules could be optimized in a comparable manner

An extensive series of experiments have been performed in a crossflow apparatus that simulate the actual operation of full-scale spiral modules. In this apparatus the theoretical model that describes the operation of spiral module operation has been partly verified in that the energy losses to crossflow and the total concentration polarization is in agreement with calculations.

Plant design evaluation

Sea level PRO power plant



Sub-sea PRO power plant

Power and pumping station

Several plant designs have been developed during the project for PRO power generation. The diagram shown in previous chapter is typical for a plant which is placed at sea level. A power plant based on this concept can look as illustrated below.

Freshwater is taken from a river close to its outlet. Seawater is fed into the plant by underground pipes. The brackish water is let out to the natural brackish water zone of the estuary thus maintaining the flow of water in the river. In many respects this PRO process can be designed as a run-of-river hydropower plant.

Another major concept utilizes the gravity in stead of the pressure exchanger to pressurize the incoming seawater. By placing the whole plant 100 to 130 meters below sea level the efficiency of the process can be increased significantly. The concept comprises a normal hydropower plant running on water from a river or a lake utilizing the extra water head. A membrane plant pumps the water out of the sub-sea cavern.

Osmotic power can also be used for pumping of water across dikes, for example from IJsselmeer in the Netherlands to the North Sea. The flexible design of the PRO plant allows the combined power and pumping station (yellow) to be fitted between existing infrastructures as the illustration to the left suggests.

The membrane section can be located below ground. Filtration units for saltwater and freshwater as well as turbine halls can be placed on appropriate locations in the area.

This concept produces power at the same time as it drains the dike. An additional advantage is that the water going into the ocean will be cleaner than the unprocessed freshwater.

Environmental aspects

Osmotic power is a renewable energy source without any emissions of CO_2. The mixing of seawater and freshwater is a process that occurs in nature all over the world. Osmotic power plants are designed to extract the energy from this process without interfering with the environmental qualities of the site.

Interestingly, most rivers around the globe run into the ocean in a city or an industrial area. This means that most of the osmotic power potential can be utilized without constructing power plants in natural areas. As discussed previously, the power plants can be constructed partly or completely under ground and would thus fit very well into the local environment.

An environmental optimization and pre-environmental impact assessment of an osmotic power plant located at an river outlet has been conducted. As a conclusion; the environmental impacts can be compensated by a combination of environmental flow requirements for the river and the osmotic power plant and environmental engineering of intake and outlet of brackish water.

The water management associated with the operation of the plant is designed so that the biotopes of the river, estuary and sea are maintained in a healthy state. In some cases, particularly in heavily industrialized areas, it is possible that an osmotic power plant can improve the environmental conditions.

Financial Evaluation

The availability of sustainable energy sources is necessary for any modern society, hence European governments and the EU has very ambitious targets for their energy policy focusing on security of supply and sustainability. Developing technologies for efficient exploitation of the available renewable energy sources is one of the policy instruments. In this respect Salinity Power project has contributed significantly to the development and evaluation of a “new” RE source. Salinity Power estimated a potential of 200 TWh/year of osmotic power in Europe.

The osmotic power plant is very area efficient. A 25 MW plant would only require some 40 000 m^2 of land even if it is located above the ground. Compared to a wind farm or the area required to harvest biomass to produce the same amount of energy, the osmotic power plant is very compact.

The investment cost for an osmotic power plant is relatively high per installed power compared with other renewable energy sources as for example wind or solar power. The main difference is that osmotic power plants will be designed for base load operation and are thus qualitatively different from most other new RE. This means that although a high investment per installed MW, the annual energy cost per kWh are comparable and competitive with the other RES. Although osmotic power development needs long term commitment the Salinity Power project represented a leap in the development of a potentially important future energy technology.

The development of osmotic power has a long term perspective before one can expect entering into a commercialization phase. The potential for job creation in case of successful commercialization will at least be of the same order of magnitude as the current European wind power industry. The necessary incentives for the commercial success and hence the job creation will rely on a proactive renewable energy policy in the European Union and its member states. These incentives are already outlined in several white papers and directives related to renewable energy promotion and CO_2 abatement.

The forecast price level one can expect to achieve, included the green premium, will be 40-50 Euro/MWh in 2015. The higher end of the price range reflecting the FP6 Sustainable Energy Systems, Work Program's indication of 50 Euro/MWh as a threshold for competitiveness in year 2020. The low end representing a level that has to be reached if significant new renewable generation capacity shall be profitable.

Present cost estimates made by the project show that osmotic power generation can be developed to be cost competitive with renewable power sources such as bio power and tidal power when commercialized around 2010 to 2015.

Business potential

Renewable energy sources such as hydropower, wind power and bio-energy are limited compared to the ever growing demand for electric power. As this development continues new alternatives must be found for the future. In this picture, osmotic power represents one of the most significant future renewable energy sources.

As a commercial power company Statkraft is focused on the future income potential of its technology development projects. Major requirements for Statkraft's involvement are a significant energy generation potential and competitiveness in the relevant markets. Furthermore, the technology must be environmentally friendly.

Osmotic power fulfils all these requirements. The power generation potential is huge compared to most other renewable energy sources. In Norway the potential is estimated up to 12 TWh per year, equivalent to 10 % of current power consumption in the country. In Europe the similar potential is estimated at 200 TWh/a while the global potential is in the order of 2000 TWh/a.

Capital cost for an osmotic power plant is relatively high even compared to wind power. However, the osmotic power plant will be designed to operate at full capacity more than 7000 hours a year yielding a power generation capacity which is very high for each MW installed. This reduces the PRO energy cost to an attractive level.

Being a renewable energy source with a high environmental performance of the osmotic power technology will be subject to subsidy programs and green certificate schemes similar to those seen for wind power and solar power today.

Technology suppliers market

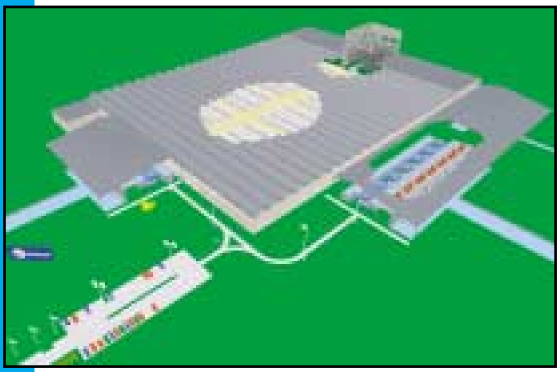
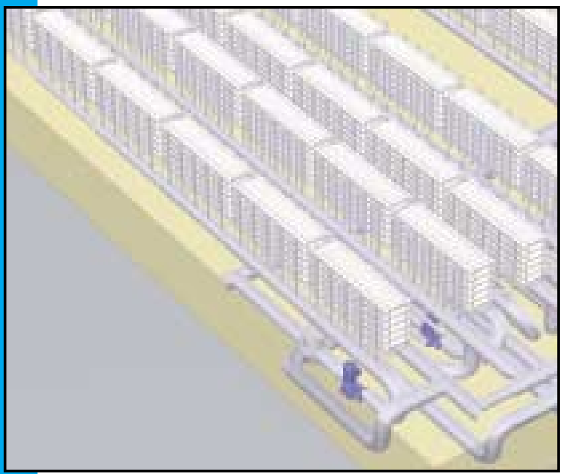


Illustration of MW PRO power plant



Parts of membrane section

The late years of developing the wind power have produced an extensive, new market for deliverance of services and installations. Today the main producers of wind mills and the knowledge related to it are located in Europe. A similar market will evolve as the osmotic power is developed into a commercial concept and the potential is exploited.

The increasingly competitive global water treatment industry is assumed to drive down the cost of all relevant process and auxiliary equipment. Innovative companies will be able to take strong positions in the osmotic power market. Much of the technology known by the water industry today can be transferred to osmotic power plants with only minor modifications, for example membranes, pressure exchangers, pressure vessels, filters, pumps and pipes. This will mean great possibilities for suppliers of these components as a part of a total plant. For the European water treatment industry this could mean a large and welcome new business potential.

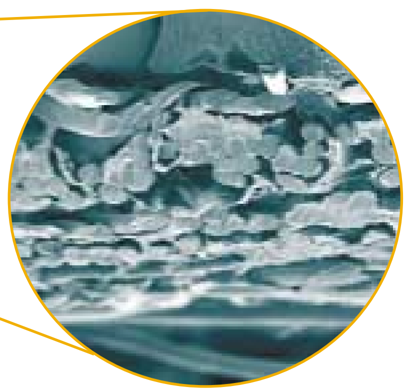
An example of the extensive demand for new supplies is the use of membrane in a power plant. Each MW of osmotic power requires in the order of 200 000 m^2 of membrane. The replacement market for the same power plant would be up to four times this amount over the lifetime of the power plant. Compared to the total world production of membranes today, the exploitation of the potential both in Europe and in the world as a whole will give a major increase in the demand for membranes. In order to exploit 10 % of the estimated European potential about 700 million m2 of membrane would be in operation at any time.

Current progress and future development

The PRO osmotic power process was invented in 1973 by Professor Sidney Loeb, also known for his development of sea-water reverse osmosis. Some research was done in the 70'ies and 80'ies but no particular progress was made due to inefficient membranes.

Statkraft initiated PRO development in 1997. From 2001 Statkraft coordinated Salinity Power, a major research project with the objective to develop osmotic power technology.

Before the Salinity Power project started there was hardly any interest and knowledge in the field of osmotic power in Europe. The project brought together scientific experts and industry that together was able to draw significant attention to the technology and its commercial potential. The consortium represented European world leading experts in membrane development, applied membrane technology and renewable power that together provided the necessary strength to complete the ambitions of the project. The project has contributed strongly to the growing interest in osmotic power and new membrane technology applications in the European scientific community and the relevant industries.



Membrane and module development

The results achieved in Salinity Power are very encouraging. Progress in membrane performance has been accompanied by process optimization and cost reduction studies. The results verify the strength of the concept.

The Parties will continue their efforts to commercialize osmotic power in cooperation with strong industrial and scientific partners. Improving the membrane performance to about 5 W/m^2 and up-scaling the membrane units will be at focus over the next years.

If current progress continues osmotic power can be a competitive renewable energy source in about 10 years.

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