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SALINITY GRADIENT ENERGY

TECHNOLOGY BRIEF

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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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Highlights

» **Process and Technology Status –** Salinity gradient power is the energy created from the difference in salt concentration between two fluids, commonly fresh and salt water, *e.g.,* when a river flows into the sea. There are two technologies for which demonstration projects are running and both use membranes. Pressure Retarded Osmosis (PRO) uses a membrane to separate a concentrated salt solution (like sea water) from freshwater. The freshwater flows through a semipermeable membrane towards the sea water, which increases the pressure within the seawater chamber. A turbine is spun as the pressure is compensated and electricity is generated. Reversed Electro Dialysis (RED) uses the transport of (salt) ions through membranes. RED consists of a stack of alternating cathode and anode exchanging permselective membranes. The compartments between the membranes are alternately filled with sea water and freshwater. The salinity gradient difference is the driving force in transporting ions that results in an electric potential, which is then converted to electricity. Two main applications exist: as standalone plants in estuaries where freshwater rivers run into the sea; and as hybrid energy generation processes recovering energy from high salinity waste streams. This could be for example, brine from desalination or salt mining, as well as waste water treatment plants. A possible third application is salinity gradient technologies applied to land based saltwater lakes or other types of salt water reserves.

In 2013 construction began on a 50 kilowatt (kW) RED plant, based on an existing 5 kW pilot plant. At the same time, the longest running 10 kW pilot project by Statkraft has been stopped, although interested parties are expected to continue. Large-scale production of cheap membranes is one of the key factors for the cost-effective scale-up, and a number of newly created companies are entering this market.

» **Performance and Costs –** An important factor for both the performance and costs of PRO and RED are the membranes. Current net power density (which considers the membrane potential, resistance and the power required to pump the water) of membranes is maximum 2.7 watt per square metre (W/m^2), but the latest laboratory experiments have achieved a net power density of 14.4 W/m^2 (for a PRO process). Higher power densities could be obtained by changing the cell design, in particular the membrane resistance, the cell length and the use of nanotubes. Changing cell designs could increase the calculated net power density close to 20 W/m^2. The power density of membranes is, however, not the only indication of performance. Eventually, it is the design of the entire facility, including the circulation of large quantities of water within the plant, which determines the performance of the plant.

With the exception of the cost estimates for existing projects (which reflect experimental set-ups), there is little hard evidence for the costs of both PRO and RED technologies. Based on feasibility studies, future costs for 2020 are estimated to be around USD 65-125 per Megawatt (/MW) for PRO, and USD 90/MW for RED. Levelised costs of electricity are estimated to be around USD 0.15-0.30 per kilowatt-hour (/kWh) for PRO, and USD 0.11-0.20/kWh for RED in 2020. The lower ranges in cost are for hybrid applications that make use of existing infrastructure. The cost ranges are highly speculative, and are relatively positive compared to cost projections for other ocean energy technologies with a more advanced technological status.

» **Potential and Barriers –** The total technical potential for salinity gradient power is estimated to be around 647 gigawatts (GW) globally, (compared to a global power capacity in 2011 of 5 456 GW), which is equivalent to 5 177 terawatt-hours (TWh), or 23% of electricity consumption in 2011. The technical potential does not consider any ecological and legal constraints to salinity gradient deployment, so the actual potential might be less. There are very few detailed studies that consider the ecological and legal responsibility of water extraction; these are found in Canada, Colombia, Germany, the Netherlands and Norway.

Current estimates exclude the potential of salinity gradient power used in hybrid applications. The technical and economic potential for these kinds of applications could be high, since waste streams from waste water and desalination plants generally have higher salt concentrations than the surrounding sea water. Consequently, the energy produced per cubic metre (m^3) of brine would also be higher and the overall costs lower. More research is required to map the potential for hybrid solutions, as well as land based saltwater lakes or other types of salt water reserves.

The main economic barrier are the membrane costs, which account for 50%-80% of total capital costs. Their estimated price ranges from EUR 10-30/m^2 and needs to be reduced to EUR 2–5/m^2 to be competitive with other renewables. Furthermore, improvements in power density, durability and pressure properties are desirable. On a positive note, an increasing number of companies are entering the market to produce these dedicated membranes and other parts of the installations *e.g.*, stacks or modules. Large quantities of dedicated supplies will be necessary for up-scaling, as will sharing documented experiences from pilot projects to help the technology expand across the different regions of the world.

The relatively small experience base with salinity gradient technology also has consequences for policy makers, as technology developers look for support and stability to continue to demonstrate this technology. Unfortunately, due to the lack of reliable financial support mechanisms, the company Statkraft, which is one of Europe's largest generators of renewable energy and a the leading power company in Norway, is going to discontinue its osmotic power efforts this year (2014) and is looking for investors to continue with the research and results attained over the 2006-2014 period.

I. Process and Technology Status

Salinity gradient power is the energy created from the difference in salt concentration between two fluids. Two main applications exist: (1) as a "standalone power plant" located at a site where a river enters the sea, or (2) as a hybrid energy generation process focusing on energy recovery from a production process, for example from desalination or a waste water treatment plant. With respect to stand alone plants, the theoretical amount of energy available from mixing one cubic metre of sea water with one cubic metre of river water is 1.4 megajoules (MJ). For hybrid solutions, which could use saturated brine instead of sea water, the theoretical energy available for mixing with river water is 15 MJ. Salinity gradient power is a renewable energy alternative as it derives its energy from replenishable naturally occurring processes.

The membrane is a critical part of most salinity gradient power technologies. Commercial plants require very large quantities of membranes. For example, for a 2 MW plant at least 2 million m^2 of membrane surface is necessary, and needs replacement and maintenance over time (5 years). Although more efficient membranes are already available on a small scale, up-scaled plants require much larger quantities. Worldwide such large surfaces are not currently available, but a growing number of companies, like Fujifilm, FumaTech, Nitto Denko, Oasys Water, OsmoBlue, Pentair X Flow, Porifera and Toray Industries are actively pursuing the development of more efficient and economic membranes.

Since 2003, the interest in two different technologies has rapidly developed: Pressure Retarded Osmosis (PRO), and Reversed Electro Dialysis (RED).

There are two different membrane variants. For RED, flatsheet membranes are in development (figure 1). The power density for flatsheet membranes is lower, but they hold greater pressure. For PRO, hollow fibre membranes are of interest (figure 2). Hollow fibre membranes are advantageous in that more membrane surfaces can be stacked into one membrane module, thus increasing the power density. Hollow fibre membranes have reached very high power densities in tests from 4.4 W/m^2 to 16 W/m^2 (Kurihara, 2012; Kurihara and Hanakawa, 2013; Han and Chung, 2014). Research is currently underway in Singapore into hollow fibre membranes use for salinity gradient power applications (Fane, *et al.*, 2012) and further research is planned to start in Italy[1]

1 The University of Palermo has started a study to develop a pilot on desalination and PRO.

as well (Cippolina and Micale, 2012). However, a commercially viable hollow fibre membrane able to sustain the high pressure required for power production is not yet readily available. The estimated current price of membranes that can be utilised for salinity gradient power generation ranges between EUR 10/m^2 and EUR 30/m^2. Considering that the membranes are an important cost component for salinity gradient technologies, ideally this needs to be reduced to EUR 2-5/m^2 to be competitive with other renewables (Ecofys, 2007).

Besides membrane companies, a number of other companies like Energy Recovery Inc. and IDE Technologies are exploring the market.

Figure 1: Flatsheet membranes in a stack

Photo: Statkraft

Figure 2: Hollow fibre membranes within a module, in this case the membane is for gas purification

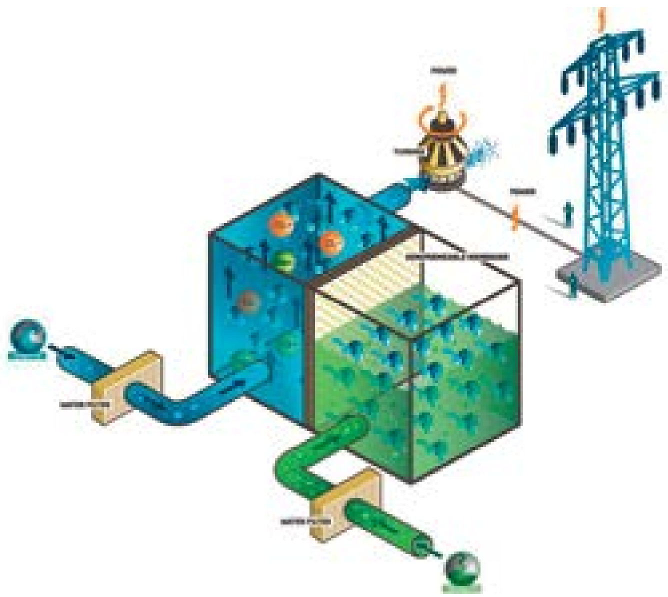
Photo: Evonik

The sections that follow discuss RED and PRO separately as the differences between their technologies has led to divergent trajectories.

1.1 Pressure Retarded Osmosis (PRO) Power Plants

PRO creates power by exploiting the osmotic pressure resulting from mixing seawater and fresh water. Seawater is pumped into a pressure exchanger where the osmotic pressure is less than that of the fresh water. Freshwater flows through a semipermeable membrane towards the sea water, increasing the pressure within the chamber; a turbine is spun as the pressure is compensated and electricity is generated, as illustrated in figure 3. The energy derived from osmotic pressure is comparable to a water potential with a theoretical pressure of 26 bars, or a water column of 270 metre (m) height (Sharif, *et al*., 2011).

Figure 3: Simplified Scheme of PRO Process,



Source: Kleverud, Skilhagen and Brekke, 2012

The potential of osmotic power was first recognised by Pattle (1954) and Loeb (1975), but due to the lack of a suitable quality membrane and the low oil prices no pilot or demonstration plants were set up. The invention was once again picked up when new materials became available and the search for renewable energy innovations intensified. Statkraft, a Norwegian hydropower company, started exploring osmotic power in 1997. In 2003 a dedicated research laboratory was set up. Development of high performance membranes was the focus of a co-operative research project with the Norwegian University of Science and Technology, and the Foundation for Scientific and Industrial Research (SINTEF).

PRO standalone power plants

Statkraft developed the first ever PRO power plant application in 2006. It uses 2000 m^2 of flatsheet membranes. It was officially opened in November 2009 and could technically produce 10 kW, although the actual production was around 5 kW (figure 4). It powered an electric kettle for demonstration purposes (Sandvik, 2011). Since then, Statkraft has been researching the improvement of their flatsheet membranes (in collaboration with Nitto Denko – a Japanese-American membrane company), and has been investigating hollow-fibre membranes. Furthermore, Statkraft also conducts research in the reduction of very high cost of water pre-treatment, as well as in lowering the

energy consumption of the pumps.

Figure 4. Statkraft, pilot plant in Tofte, 2011

Photo: Statkraft/D. Heinisch

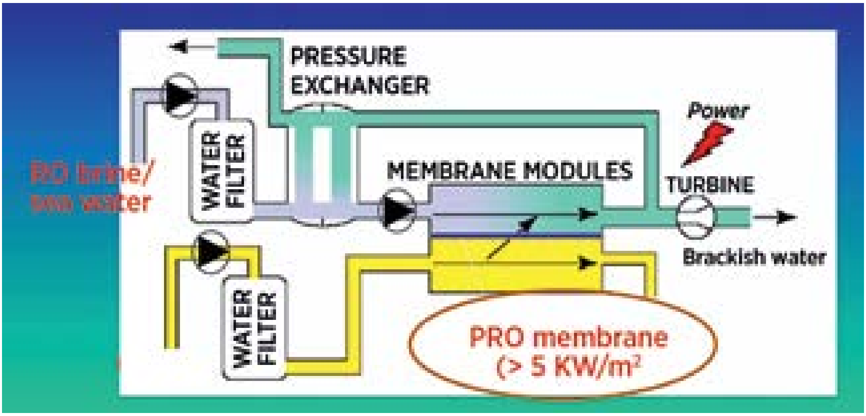
Statkraft has been exploring the construction of a 2 MW power plant, and the design of the 2 MW power plant was finalised and a permit obtained in 2013. However, at the end of 2013 Statkraft decided to discontinue their investment in osmotic power, due to a lack of long-term financial support mechanisms. Besides Statkraft, other initiatives testing PRO stand alone power production are based in Canada (see figure 5), Singapore and South-Korea. Ambitions to increase the scale of such initiatives are in their early stages.

Figure 5: Sites for Osmotic Power Production along the Lawrence River based on a preliminary resource assessment.

Source: Laflamme, 2012.

PRO in hybrid applications

A number of product developers, including Statkraft up to 2013, are developing hybrid applications for PRO that use brine from desalination. The largest



pilot currently, is developed by Toray industries (figures 6 & 7).

Figure 6: Simulation of a hybrid plant using PRO to recover energy from brine produced by Reverse Osmosis desalination.

Source: Fane, 2012.

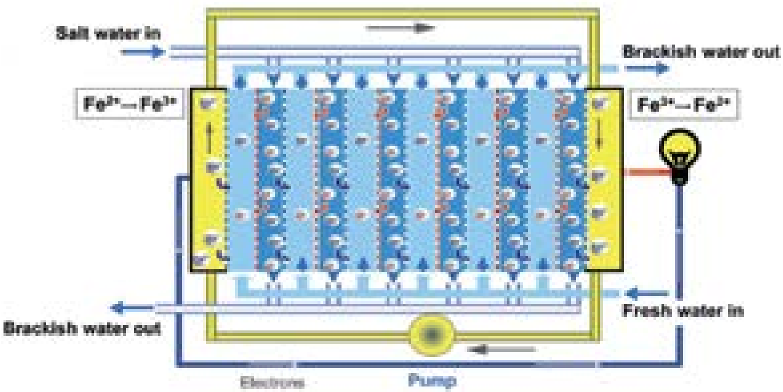
Figure 7: Toray pilot site for hybrid PRO application

Photo: Toray Industries

1.2 Reversed Electro Dialysis (RED) Power Plants

RED works through the transport of (salt) ions through membranes. Two substances with a salinity difference pass through a stack of alternating cathode and anode exchanging permselective membranes. The compartments between the membranes are alternately filled with sea water or a concentrated salt solution and a diluted salt solution (or fresh water). The salinity gradient difference is the driving force for transport of ions that results in an electric potential that is then converted to electricity. The total electricity output is determined by the sum of the potential difference over all the membranes. In the RED process, the two inlet streams (high and low saline) are converted into a single brackish stream. (figure 8).

Figure 8: Flow scheme for RED power generation



Source: REDStack, 2009.

Pattle was the first to describe the RED process in 1954 (Pattle, 1954). RED came back as a research topic in the 1970s, 1980s and as late as 1986. However, at that time the required materials were not available on an industrial scale. In the Netherlands several actors initiated research in 2003 and started exploring RED for power generation. In 2005, a 5 kW RED pilot project was started jointly by REDStack with Frisia, a European Salt company (see figure 9). The main research was published by Post (2009), Veerman (2010) and Vermaas (2014).

Figure 9: 5 kW RED pilot in The Netherlands

Photo: REDStack, 2010

Based on this first 5 kW pilot, REDStack and Fujifilm started a follow-up project for a 50 kW pilot, situated on the sea defense site and major causeway called the 'Afsluitdijk'. This 'Afsluitdijk' separates relatively clean fresh water on the one side from relatively clean seawater present in the Wadden Sea/North Sea. Additional studies investigating locations for a larger plant, found that Afsluitdijk was the most suitable – see figure 10.

Figure 10: Site for RED pilot plant (50 kW) on the Afsluitdijk sea defense in The Netherlands; to the left side, the Ijsselmeer (lake) and to the right the Wadden Sea

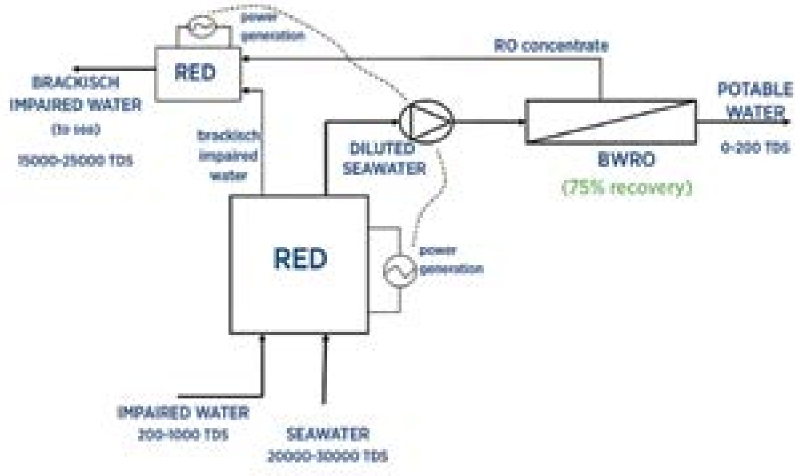
Photo: P. Smith

Work on the 50 kW pilot project has been completed and was officially opened on 11 October 2013. In the longer-term there are plans for an extended installation at the same location; up to 200 MW.[2] An upscaling to commercial stand-alone power plants is estimated to take place around 2020 or later.

2 REDStack webpage see: www.redstack.nl/index.php?option=com_content&view=article&id=13&Itemid=10

RED in hybrid applications

The same actors that are working on RED power plants also took an initiative



to use brine from desalination plants. Within the framework of the European REApower project, an initial experiment that later became a pilot project was developed that generates power using seawater and low salinity waste water, and also potable fresh water (see figure 11).

Figure 11: Simulation of REApower scheme using brine and waste water as inputs[3]

Source: Genné and Brauns, 2011

A small pilot is planned to be in operation in South Italy, connected to an existing desalination plant in Trapani (Tedesco, *et al*., 2012). Additionally, one of the variants of this application is to produce the mineral magnesium from the reverse osmosis concentrate (Cippolina and Micale, 2012).This application has yet to be tested in an experimental setting.

RED without membranes or with carbon membranes

3 TDS stands for Total Dissolved Solids, which is an indication of the salt content of the water. The higher the TDS, the greater the salinity in the water flow.

One application of RED in an early stage of innovation is capacitive mixing. In this process electricity is generated directly from the mixing process, without the need for a membrane or other type of conversion module. This application has been studied within the framework of the Capmix project, financed under the European Seventh Framework Programme.[4]

1.3 Technological challenges

Technological challenges to upscale PRO and RED technologies, include the quality of the membranes, bio-fouling, and the development of the modules containing membranes, the pre-treatment of water, and the technology to produce large amounts of durable and affordable membranes.

These challenges are studied in pilot projects in Norway and the Netherlands, as well as in research projects in Germany, Italy, Canada, Japan, Singapore, South-Korea and the USA. The applications focused on energy recovery from brine, from desalination, and highly saline wastewater streams seem to have greater commercial viability for any upscale application, looking forward to 2017 for PRO and beyond 2020 for RED. Both PRO and RED standalone power production are expected to be at commercial stage application around 2020.

4 See also www.campmix.eu.; an FP 7 research project with Dutch, Polish, Italian, Spanish and UK partners.

II. Costs and performance

The cost perspectives for full-scale PRO and RED systems are still very uncertain (Vermaas, 2014). It is therefore only possible to make projections of costs based on current knowledge and suppositions about the development of the key components of these technologies. Key components affecting the capital, operation, and maintenance costs are the membranes (including replacement over the life-time of the project), and the pre-treating and pumping of water.

Regarding the membranes, it is estimated that membranes account for up to 80% of total capital costs. The main reason for these high costs is that currently available membranes for salinity gradient power are 2-3 times higher than commercially available membranes. Other capital costs (installation, pumping, pressure vessels, and turbines) are available at market rates. Therefore, the main challenge is finding membranes that are efficient and robust enough to boost production, while remaining affordable.

For the operation and maintenance costs, the process of pre-treating the water and pumping requires a relatively large amount of energy and has a high cost. These costs need to be brought down to make the installations more efficient. Throughout the operation of the pilot PRO power plant at Statkraft between 2006 and 2013, Hydro Quebec Canada and Statkraft concluded a memorandum of understanding with the purpose to reduce these costs.

Current capital cost for the 50 kW RED pilot plant at the *Afsluitdijk* site in The North Netherlands is estimated to be around EUR 7.33 million. Hack (2011) estimates that it would cost over USD 600 million to construct a 200 MW salinity power plant covering the area of two soccer pitches at the Afsluitdijk dam, and that this plant would produce electricity at a retail cost of USD 90/MWh. Statkraft did not released detailed numbers, but in their projections they were aiming to produce electricity at a retail price of between USD 65-125/MWh by 2015 (Ravillious, 2009).

Besides these actual cost figures, some generic cost estimates were made for standalone installations that would be marketable in 2020. Cost projections for 2020, which were made using the years 2005-2007, varied from EUR 0.09/kWh to EUR 0.27/kWh and from EUR 0.11/kWh to EUR 0.28/kWh, though more recent projections fluctuate between EUR 0.08/kWh and

EUR 0.15/kWh.[4] Costs for hybrid installations would generally be lower and are estimated at EUR 0.11/kWh (Integrated Network for Energy from Salinity Gradient Power (INES), 2011; Stenzel, 2012).

Further price estimations, have been made by Ecofys (2007) and Stenzel (2012). Ecofys (2007) estimates cost per kilowatt-hour ranging from EUR 0.11/kWh to EUR 0.22/kWh, the difference being dependent on the location; and Stenzel arrives at a range of EUR 0.28/kWh for standalone power generation down to EUR 0.11/kWh for an installation that uses the brine from a desalination plant, or other production processes that emit highly saline waters, as listed in Table 1. The more detailed cost calculations of Stenzel (2012), based on simulations of plants near existing installations in Germany, demonstrate that besides the costs of membranes and pre-treatment of water, of particular relevance are the local site conditions, for example to what extent the plant can use the infrastructure already available.

Table 1: Illustrative indicators of PRO and RED based on estimates in 2011-2012.[5]

Indicator	PRO	RED
Tested Production	5 KW	5 KW
Upscale forecasted in	2 MW/ 2017	5 MW/ 2020 50 kW 2017
LCOE*/MWh in 2020	USD 65-125/MWh	USD 90/MWh
LCOE/kWh in 2020	USD 0.15-0.30/kWh	USD 0.11-0.20/kWh

*Levelised Cost Of Energy (LCOE), including capital investment, maintenance and operation

Sources: adapted from Sandvik, 2011; Hack, 2011; Stenzel, 2012.

5 P. Hack, REDStack, personal interview 18 January 2013.

III. Potential

The global amount of salinity gradient energy available from oceans and seas is estimated at 3.1 terawatt (TW) (Stenzel, 2011; 2012). This theoretical amount has to be adjusted for technical feasibility and environmental impacts. Table 2 below compares the theoretical and technical potential for different continents.

Table 2: Theoretical and Technical Potential of Salinity Gradient Energy

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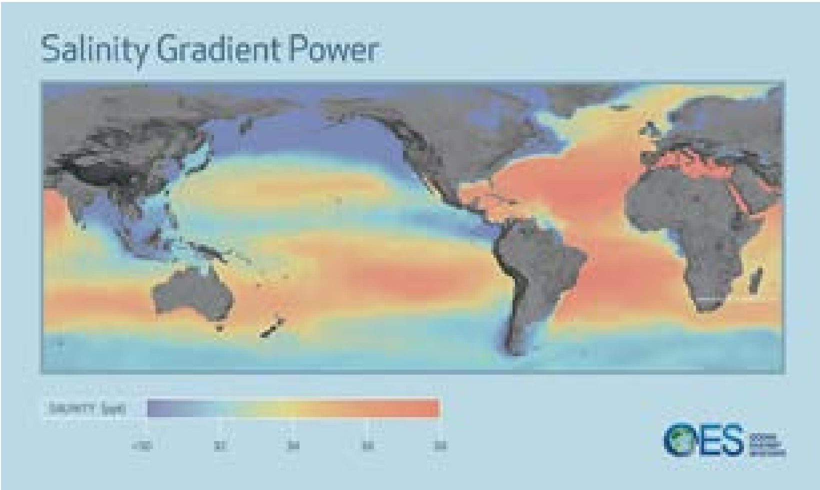
Continent	Theoretical Potential		Technical Potential	
	[GW_{gross}]	[TWh_{gross}/year]	[$GW_{electricity}$]	[$TWh_{electricity}$/year]
Europe	241	2 109	49	395
Africa	307	2 690	63	503
Asia	1 015	8 890	208	1 663
North America	479	4 195	98	785
South America	969	8 492	199	1 589
Australia*	147	1 291	30	242
World	3 158	27 667	647	5 177
*Incl. Oceania				

Source: Stenzel, 2012

Figure 12 shows the considerable differences in salinity between the fresh waters and the seas in which they flow. It is interesting to note that areas with higher all-year stable temperatures, located around the equator, are attractive locations for salinity gradient power.

Figure 12. Estimated salinity gradient differences in oceans and seas worldwide (IEA-OES, 2014)



Source: International Energy Agency – Ocean Energy Systems (IEA-OES), 2014)

Saline lakes and other saline water bodies, such as underground reserves/ aquifers, can also be used as sources for the production of energy. However, they have not been taken into account in the estimation of the global salinity gradient power potential.

The theoretical or technical potential must be further revised to assess the actual potential of salinity gradient power generation. This requires an analysis on what constitutes ecological and legally responsible water extraction, composition of water (accounting for pollution and sediments) and the shape, and flows, of the water bodies (Stenzel, 2011; 2012). Inlets, outlets, and actual capacity are limited by environmental and seasonal conditions. As far as this report can ascertain, these analyses have been made or are in the process of being made in Canada, Colombia, Germany, the Netherlands and Norway. This study is planned to be enlarged under the Integrated Network for Energy from Salinity Gradient Power (INES) project.

Applications that focus on the use of brine or saline wastewaters as inputs, in particular those which seem to have a very high potential, have not been mapped or published yet. Although, as a commercial application this could be made available for use within a short time frame.

The worldwide estimate for salinity gradient power excludes brine available from desalination plants as these have not yet been comprehensively mapped, despite having a high potential for commercial applications within a relatively short time period. However, for a selected number of countries some information may be available.[6] For example, there have been a number of feasibility studies in Canada that confirm that salinity gradient potential exists close to urban and industrial centres. The Lawrence River for instance has a very high potential for osmotic power production. Hydro Quebec Canada, which like Statkraft started as a hydropower company, has ambitious plans for osmotic power production (LaFlamme, 2012). They have been conducting research together with Statkraft into improving water pre-treatment.

Hybrid applications can be implemented away from seas or oceans, and show that salinity gradient power generation is not *per se* an ocean or marine energy, but rather a saline variant of hydropower. The hybrid application has a serious commercial interest for desalination stakeholders. Besides a European co-operation project, REApower,[7] which includes Flemish, Dutch, Italian and German partners, another example is the Japanese MegaTon project (Kurihara, 2012). Interests have been expressed by companies and research laboratories ranging from Singapore,[8] Israel,[9] South-Korea[10] and elsewhere. Using saline waste water as input has important ecological benefits as it dilutes saline wastewater streams, whilst generating renewable electricity.

A novel, yet unexplored application, is storing highly saline water in ponds for later use in a RED or PRO power generation process.[11] This may be interesting

6 *E.g.*, for Germany (Stenzel, 2012), Ireland (Murray, Blackledge, and Kearney 2013), Norway (Kleverud, Skilhagen and Brekke, 2012), The Netherlands (Ecofys, 2007; Post, 2009), Canada (Hydro Quebec), more detailed information is available. Additional studies for a larger number of countries are underway in perspective of the INES project.

7 See also *www.reapower.eu*, a project financed under the European FP 7 programmes.

8 At the Singapore Membrane Technology Centre (SMTC) of Nanyang Technological University (NTU), and at the German Institute for Science and Technology (GIST) at the National University of Singapore (NUS).

9 Negev University

10 At the Korean Institute of Energy Research (KIER) and Gwangju University.

11 Saline ponds meant here are then used as a reservoir/back up for a process of salinity gradient power generation with a membrane, this is different to the already established 'solar ponds' that can store heat –which in the end can also be used for power generation.

for flatland locations with little viable prospects for basins at different heights. This application was described extensively by Stenzel (2012), including simulations (and cost estimations) to connect storage ponds to installations in Germany.

This last application seems to have a high potential, as the capacity of forecasted desalination is planned to increase exponentially and in the current capacity situation – as illustrated in figure 13 in the Middle East – so far energy recovery by salinity gradient power has not been explored. Salinity gradient technologies could be applied to all of the different desalination technologies: multi-stage flash (MSF), multi-effect distillation (MED), and seawater reverse osmosis (SWRO). This is also the case in other parts of the world, such as South East Asia, Australia and USA, where desalination is expected to increase.

Figure 13. Desalination capacity in the Middle East

Source: Lattemann, 2010

If resources are properly mapped, including salt lakes and other saline water bodies, the true potential for stand-alone power plants might be much higher than the current global 3.4 TW estimate. More analysis needs to be done to identify the potential.

IV. Drivers and barriers

In order to realise the potential from an inventory of developments and efforts for up scaling the following impediments and barriers for the accelerated development and further development of salinity gradient energy include:

1. Bio-fouling

Due to the properties of intakes of sea-water and freshwater with organic matter, biofouling is a major issue in both PRO and RED. This is one of the main items in membrane science. To date, a low cost satisfactory solution has not yet been found, but many research projects have been started, focusing on this issue in relation to technologies for salinity gradient energy.

Particularly for hollow fibre membranes the modules in which they are fitted are not fully developed yet. Research for this module development is underway, particularly in Asia, Singapore and the USA.

2. Environmental and ecological aspects

The environmental impact of such plants can be minimised, thereby respecting the ecological conditions of estuaries and rivers. Neither water nor salt is consumed in the process, and the installations can be located underground or in low buildings. Mono nitrogen oxides (NO_X), carbon monoxide (CO) or carbon dioxide (CO_2) emissions are absent, and the installations are not important sources of noise.

For stand-alone salinity gradient power plants considerable amounts of fresh water run through the system and brackish water exits the process. To mitigate the eco-footprint further, producers, expert organisations and governmental parties joined forces in 2010.[12] Essentially, the ecological aspects are comparable to that from a hydropower system. For ecological conditions, only a limited amount of water can run through a plant. In addition, experience needs to be developed for stand-alone salinity gradient power plants on how to mitigate both the intake points and the brackish water exiting point. Studies related to this are currently being undertaken by REDStack in the Netherlands for RED and by Hydro Quebec for PRO. One of the effects is related to the configuration of the plant. For example, in the direct surroundings of the power plants, turbulence or recirculation zones could occur, which would increase

12 INES, 2011, see *www.salinitygradientpower.eu*

the risk to organisms. To avoid this, as well as the possibility of this risk at the inlets, the plant design should be tailored hydro-dynamically.

It is likely that the power plant will attract fish resulting from the redistribution of nutrients. The net balance of this impact needs to be evaluated and, where possible, mitigation measures need to be designed. Inspiration for this could be experiences from hydropower that has comparable effects.

3. Sector development and supply systems

One of the main challenges of the sector –that is comparable to offshore wind in the earlier stages- is the timely development of a specific and dedicated infrastructure. Currently there are only a limited number of companies producing dedicated membranes and other parts of the installations *e.g.*, stacks or modules. Large quantities of dedicated supplies will be necessary for up scaling. In the last two years more water technology companies and membrane developers have become interested in developing better membranes and other technology essential for salinity gradient power and for energy recovery related to desalination. In terms of the overall commercialisation, the technology would greatly benefit from an increase in the number of industrial parties and companies with expertise in efficiently up scaling the latest developments. First steps to such an increased involvement are already being made in a number of the pilot projects in Europe, Asia and in North America/Canada. This of course is in addition to a more active facilitation with the public, because this technology is not very well known.

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