IEAGHG Information Paper; 2012-IP13: Power Generation from Saline Water

Background: **Article in Nature entitled "Membrane-based processes for sustainable power generation using water"**

IEAGHG maintains a watching brief on technologies that might be capable of generating electricity with low CO_2 emissions. A technology that is attracting increasing interest is the generation of electricity using water with different salt concentrations such as river water and sea water, as described in a recent article in Nature.

http://www.nature.com/nature/journal/v488/n7411/full/nature11477.html?WT.ec_id=NATURE-20120816

In principle, of the order of 1MW of electricity could be generated from 1m^3/s of fresh water but the net generation may be significantly less. The quantity of water that is required per MW is about an order of magnitude greater than the quantity of water needed by a coal fired power plant with a once-through cooling water system. The global potential for electricity generation is reported to be of the order of 1600TWh/y which is equivalent to about half of the current hydroelectricity generation and about 7% of total global electricity generation. However, the proportion of this potential that could be exploited in practice would be limited by site specific features such as the technical feasibility, costs and environmental impacts of redirecting large flows of water at river estuaries and the remoteness of some estuaries from areas of major power demand. One of the more attractive types of site for this type of power generation could be dikes, such as in the Netherlands, where fresh water has to be pumped into the sea from low lying land. An advantage of osmotic power compared to most other types of renewable energy is that electricity would be generated continuously at a high capacity factor, giving good utilisation of the investment.

Several techniques are being developed, the most promising of which are pressure-retarded osmosis (PRO) and reverse electrodialysis (RED), which are shown in Figure 1.

In PRO, low salinity water (such as river water) and high salinity water (such as sea water) are fed to opposite sides of a semi-permeable membrane. Fresh water is drawn by osmosis through the membrane into the high salinity water side, which is at high pressure. A large portion of the high pressure water would be fed to a pressure exchanger to pressurise the high salinity water feed and the remainder would be passed through a hydraulic turbine to generate electricity. PRO is the opposite of reverse osmosis desalination, in which saline water is pressurised and fed to membranes where the pressure energy is used to separate it into fresh water and high salinity waste water. Reverse osmosis desalination is a well-established commercial technology. The main development issues for PRO are the design of the membrane, in particular the achievement of high throughputs, avoidance of fouling and the requirement for pre-treatment, particularly of the fresh water which passes through the membrane.

In reverse electrodialysis (RED) saline water and fresh water flow through channels separated by cat-ion-exchange and an-ion exchange membranes, as shown in Figure 1. The difference in electrochemical potential as a result of the positive ions moving one way and the negative ions moving the other way is turned into an electrical current at the electrodes, which provides electric power.

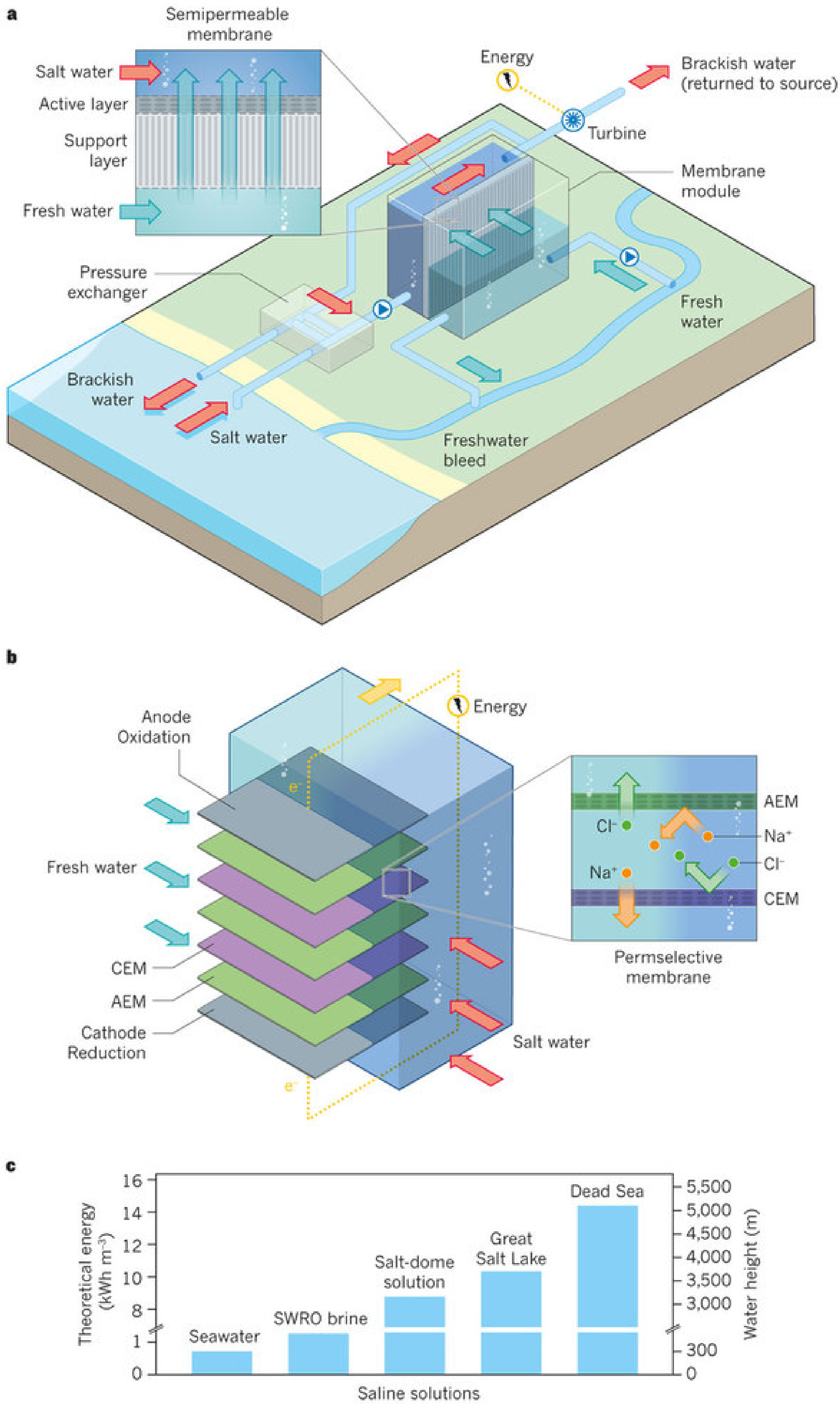

Figure 1: Schematic of PRO and RED power generation systems.

The amount of electricity that could be generated depends on the water salinity. The osmotic pressure of typical sea water is 2.7MPa, which is equivalent to a 270m head of water, but a lower pressure would be achieved in practice in a real power plant. The osmotic pressures of other types of saline water are shown in Figure 1, for example, the highly saline water in the Dead Sea has an osmotic pressure of over 50MPa, which would mean that a much larger amount of power could be generated for a given amount of water. Highly saline water could be produced by solar evaporation. Areas with high solar radiation, low rainfall, suitable land and access to saline water would be required. Some suitable sites with high potential for power generation have been identified, for example a site with a 3GW potential in Tunisia. The high salinity waste water produced by seawater reverse osmosis (SWRO) desalination plants could also be utilised for power generation, thereby reducing the net power required for desalination.

The development of PRO has been hindered for many years by the lack of a membrane capable of allowing an adequate flow but new types of membranes are being developed which are said to achieve higher throughputs. However, membrane throughput and lifetime are still major development issues. The feed streams to PRO, particularly the fresh water that passes through the membrane, need to be pretreated to reduce membrane fouling and deterioration in performance. The amount of energy needed for feed water pretreatment, particularly pressurisation of the high salinity water, could substantially reduce the net electricity generation. Scale-up of equipment is another area where development is required. The need to use multiple items of equipment and to minimise environmental impacts mean that the technology may be best suited to relatively small local power generation schemes.

The main challenges for RED are similar, particularly the cost of ion-exchange membranes. Substantial advances are said to be being made to increase RED power densities and energy efficiencies through improvement of membrane materials, spacing and architecture but further improvements are needed. A global increase in demand could lower membrane costs.

The technology for generation of electricity from saline water is at a relatively early stage of development. The largest plant that has been built is a 2-4kW PRO plant that was built in Norway by Statkraft in 2009. Statkraft is now focussing on development of improved membranes and water treatment in collaboration with Japanese and Canadian industrial companies respectively. A site has been selected for a 2MW pilot plant and an investment decision is expected in late 2013. The next stage after that would be to build a 25MW demonstration plant. Statkraft estimates that the levelised cost of electricity from a 25MW demonstration plant would be €120/MWh and they project that the cost will reduce to €70-80MWh by 2030 due to learning. However, as with any technology at an early stage of development, cost estimates are highly uncertain and some other papers indicate that the substantial improvements in membrane performance, lifetime and costs that would be required are unlikely to be achieved.

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