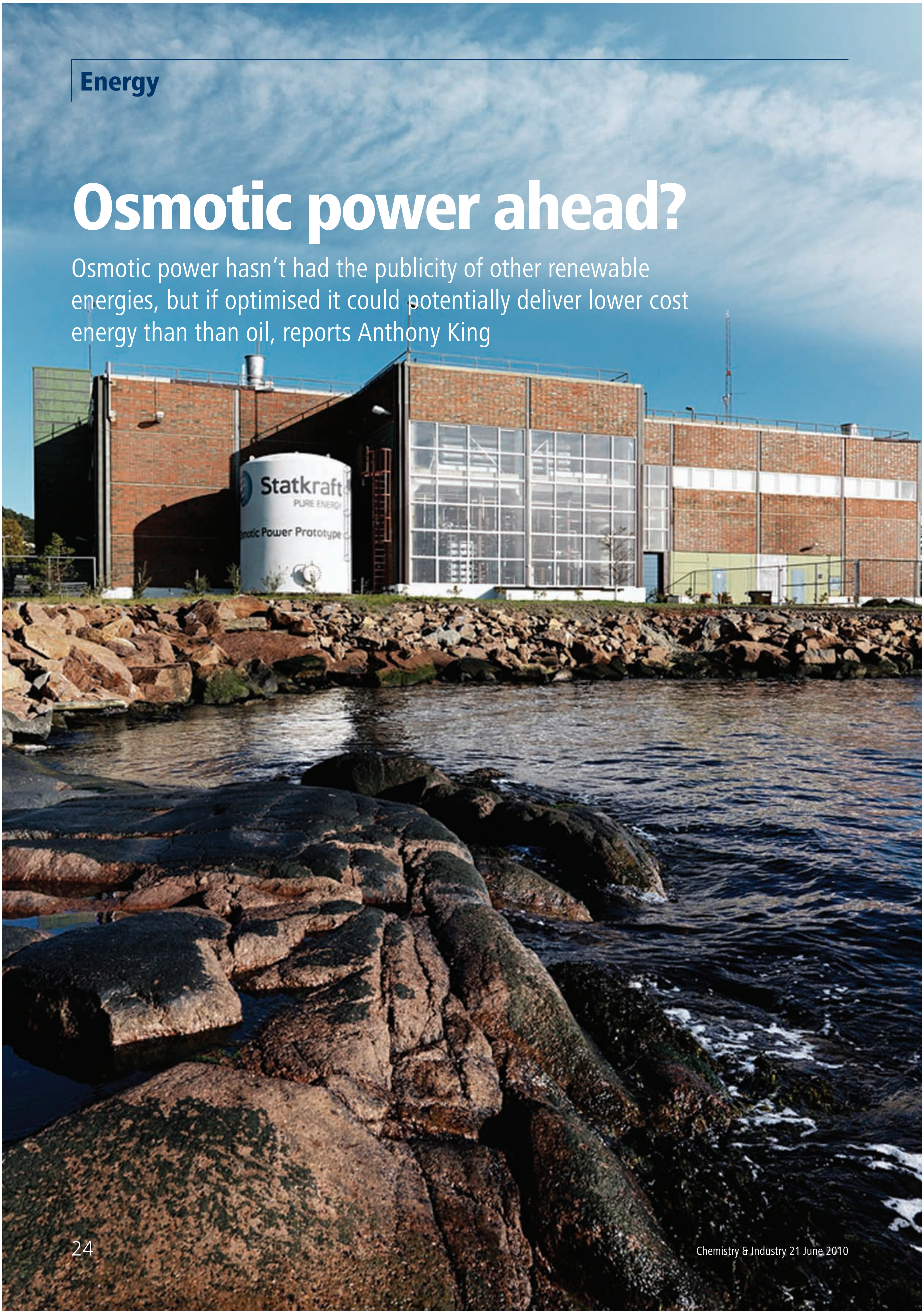
Osmotic power ahead?

Osmotic power hasn't had the publicity of other renewable energies, but if optimised it could potentially deliver lower cost energy than than oil, reports Anthony King



Where will your future electricity come from? Wind, solar and wave energies are all touted as leaders in a greener future, but there is another option to throw into the mix.

Osmotic power came into sharper focus when the world's first osmotic facility (opposite) opened in the village of Tofte in Norway in November 2009. A proof-of-principle facility set up by Norwegian power company Statkraft, the plant takes in freshwater and saltwater and converts it to brackish water and energy as the outputs.

Osmosis occurs when water spontaneously moves across a membrane from a liquid with low solute concentration, like freshwater, to high solute concentration, like saltwater. At Tofte, freshwater crosses a membrane to the seawater side, an influx that builds up pressure and drives turbines. Water begets energy and water. Unlike solar and wind, the energy output is predictable. Such power plants could be situated anywhere there is abundant seawater and freshwater, such as the mouth of a river.

But the track to commercial power has a technological hurdle: improving the membrane. The flux rate of water going through the membrane determines the power output. The Totfe facility produces less than 1 watt/m^2, which is well below Statkraft's target of 5W/m^2 for commercialisation. 'We are able to produce membranes in our labs producing 3W/m^2,' says Stein Eric Skilhagen, head of osmotic power at Statkraft, but scaling up is the challenge. The Norwegian facility is a perfect test bed and different membrane options are being put through their paces.

Skilhagen says the next step is to build a pilot plant and they hope to be in this position within two to three years, which would generate 1 or 2MW. Ultimately, a good average size plant would be a 25MW installation, producing about 150 to 200GWh/year of electricity. And you could locate close to a village, town or city, since there are no noise or pollution issues. It could make a big splash on the energy market: Statkraft estimates that there is a potential of producing 180TWh/year in Europe. The company forecasts a price of €50 to €100/MWh in ten years time, which is in the range of wind power, but below the cost of solar.

Statkraft just wants to be a power generator; it wants someone to develop the membranes, says Paul O'Callaghan, water technology analyst with O2 Environmental. 'They are getting people to send material from all over the world and I think it is a question of resources being applied to the problem.' If the technology takes off, it would have a huge impact on the global membrane market. The Tofte facility has 2000m^2 of membrane. A 25MW facility would need 5m m^2 of membrane, Skilhagen says.

The Norwegian trials initially tested spiral wound membranes – flat sheets of membrane wound into a spiral – which are also the membranes of choice for reverse osmosis (RO) in desalination plants. Manufacturers of RO membranes were among the first to recognise the potential demand from osmotic power. However, unlike RO, osmotic power needs no pressure to be applied – it is also called pressure retarded osmosis (PRO) – and chemists suspect a slightly different membrane technology will be needed.

Statkraft

World first: membranes inside pressure vessels are key to the operation of Tofte's facility

One of the few commercially available forward osmosis membranes has been developed by Hydration Technologies (HT), by coating cellulose triacetate on a mesh. HT already profits from making forward osmosis membranes for oil and gas applications, while Statkraft has evaluated HT's membrane and the two companies are working to improve performance.

However, Statkraft is also interested in other membrane configurations like rectangular plates of membrane and hollow fibre membranes. O'Callaghan says O2 Environmental will be involved in bench-scale testing using HTI's membrane but also biomimetic membranes based on aquaporin, the protein that selectively shuttles water across cell membranes. 'The goal is to try out different materials in different configurations and monitor flux rates,' O'Callaghan explains.

'In many ways the large companies are outsourcing their innovation,' he adds. And the Statkraft facility has offered a beacon to research groups and smaller companies to develop forward osmosis membranes with high flux and good solute exclusion. A conference organised by the American Membrane Technology Association in San Diego, US, the 2nd Osmosis Membrane Summit, to be held in July 2010 will be devoted to forward osmosis membrane technology. Ben Mattes, ceo at Santa Fe Science and Technology, will speak about thin film hollow fibre membranes for separation. 'Our company is making hollow fibre ultra filtration membranes and then coating a thin film, about 100 or 150nm on top of this substrate,' he explains. According to Mattes, this membrane shows a higher recovery of the feed-in liquid than flat sheet spiral bound membranes because there is a reduction in the resistance to water flow, technically called 'concentration polarisation'. Basically, freshwater hangs out close to the membrane on the saltwater side and tunes down the osmotic pull.

The hollow fibre membrane has been overlooked for 40 years because it wasn't used for desalinisation, says Mattes. His company has form; it worked with NASA to develop membranes for water purification on board space flight. By the end of summer 2010, Statkraft will be testing Mattes' membranes. 'After 18 months we have a membrane that produces about 1W/m^2 of membrane, and we have good reason to believe we can increase that by at least a factor of three within a reasonable period of time.'

In Brief

- **Osmotic power can be harnessed because water spontaneously moves across a membrane from a liquid with low solute concentration to high solute concentration**
- **The world's first osmotic facility opened in November 2009 in the village of Tofte in Norway**
- **Norweigan power company Statkraft estimates that there is a potential 180TW of osmotic power available in Europe**
- **Statkraft forecasts osmotic power will cost between €50 and €100/MWh by 2020, compared with €160 forecast for solar energy; oil costs €125/MWh today**
- **Power outputs are a function of the flux rate of water and are presently too low, but work to optimise membrane performance is under way**

Most of these membranes are made from synthetic polymers, with the most common based on cellulose acetate, PBI (polybenzimidazole) fibre, polyamide, or polysulfone. For the moment, experts say ceramic membranes are not in the game, being held back by thickness and cost. But there is a third option now being explored by a start-up company in California. The new arrival is Porifera and its *raison d'etre* is carbon nanotube membranes for forward osmosis. The pores are actually the holes of the carbon nanotubes, explains chief technology officer Olgica Bakajin, who says water goes through the nanotubes three orders of magnitude faster than through pores made from regular material. The company founders were motivated by their experiments, which showed high flows through carbon nanotubes and the potential for forward osmosis applications like osmotic power.

'The nanotubes are super smooth. You can imagine them as really slippery straws through which water moves,' explains Bakajin, who was leading a research group in this area at Livermore Laboratory National Laboratory before helping set up the company. The tubes are also atomically smooth with even energy levels on their surface, so that trains of water molecules do not stick to the surface, she says. And during synthesis, pore size can be tightly controlled in the nanotubes. The major challenge now is to fine tune the membrane film material and scale up the manufacture of aligned carbon nanotube (CNT) mats. 'Scalable nanotube manufacturing has not been done on a commercial scale. I don't think there are products that require large sheets of nanotubes at this point,' says Bakajin. 'We either have to figure out how to make efficient membranes with bulk tubes or develop manufacturing process for aligned mats and for membranes that use aligned mats.'

Along with private enterprise, university researchers have been buoyed by the membrane challenge. Recently, researchers led by Neal Tai-Shung Chung at the National University of Singapore sought to produce a membrane with high water flux and high solute rejection. Their prototype cellulose acetate membrane consisted of two thin selective layers and a highly porous sublayer with minimal resistance to water transport and less concentration polarisation. They also worked on single and dual-layer hollow fibre membranes. Skilhagen says both flat sheet and hollow fibre might work, depending on the location.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Prime location: for an osmotic power facility?

Apart from completing some technical magic with membranes, there is another hurdle facing the osmotic power plant. Water must be pre-treated. In Tofte, seawater gets minimally treated, since it does not have to go through the membrane, but the freshwater is going through an ultra-filtration pre-treatment step to take out any 'nasties' that might damage the membrane. This consumes too much energy and is not a sustainable solution, so a way of filtering freshwater fed from a river or lake is necessary. This will be even more of an issue if the water quality is poor. Some work is also being done on making membranes more resistant to fouling and organic growth, for example, by nanoengineering the surface properties could be one way.

A bright spot on the horizon for osmotic power is desalination. These plants consume a lot of energy and produce strong brine as waste. At the back end of a desalination plant, osmotic power could reduce the concentration of the brine, while generating energy through forward osmosis. Indeed, the process would work even if the brine was placed opposite seawater.

Overall, Statkraft's strategy of 'build it and they will come' seems to be paying off. Policymakers and engineers have visited, membrane manufactures have taken notice and power companies have watched with interest. Europe has something of a lead, as the US seems not as aware of osmotic power at a policy level. Mattes says he has spoken to various programme managers at the US Department of Energy, but they said they were not interested in osmotic power at this time. But the call for membrane technology has certainly been heard in Europe, the US and Asia. There is growing awareness that the low environmental impact of a power station, without emissions stacks, that releases only brine into the marine environment has enormous advantages if it can be made economical.

That a Norwegian village holds the promise of renewable energy that is safe, environmentally benign and predictable is something of a surprise. But as Skilhagen says: 'When you see something like this, then you start to believe'. He calls for more funding for research in this area, but also for more competitors to Statkraft. 'We want to increase the momentum,' he says. One of the prizes on offer is a huge, new market for advanced membranes. The pilot phase facility is the next step; all going well, commercialisation will follow.

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Blue energy in Holland

A Dutch company called Redstack is working on a mysterious 'blue energy'. This also uses seawater and freshwater in a membrane-based process to generate energy, but in this case, ions from the saltwater pass through an anion and a cation selective membrane. As Pieter Hack, ceo of the Redstack, explains: 'You put freshwater and seawater between the membranes, and the salt gradient caused by the transport of ions will create an 8-millivolt potential charge.' When you make a stack of 1000 membranes, this creates an 8V potential at the end of the stack, which can be converted into power using electrodes and electrochemical reactions.

Blue energy aims to take advantage of the proximity of fresh and saltwater in Holland's extensive system of dykes. Hack says people laughed at them when five years ago they said they needed membranes costing between €2 and €5/m². However, the membrane can be made out of low cost plastic, it can be very thin and it doesn't need to have especially high selectivity. The cost has now come down to the required level and Redstack has partnered with Fuji to manufacture the membrane. 'It's up to Fuji to work on scaling production of the membrane and Redstack to prove it [blue energy] works in a real live stack.'


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Dutch dykes: tipped for blue energy generation

One pilot is already operating in a salt mine with the aim of harvesting energy as an in-process industrial flow. The firm is applying for permits to build a pilot plant on a dyke in Holland; Redstack is working on the finance side of this project, but Hack believes the pilot plant, with up to 50kW capacity using two stacks will be in operation next year. The next step is to go to an industrial application of between 1 and 5MW at the salt mine, then a surface demo plant at 1MW. The first full-scale plant could be 200MW, according to Hack.