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Marrying Wind Power To Desalination

Desalination and wind energy technologies have matured to a level at which they can provide plentiful, renewable water and energy at an economical price.

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Many people do not know what it is like to go for even a single day without being able to readily access freshwater. Indeed, in much of the developed world, bottled drinking water is ubiquitous – to be found even at gas stations where, ironically, one can pay more per gallon for some brands of bottled water than for gasoline. But while freshwater is becoming ever more available in the developed world, the opposite is the case in developing nations.

While "boutique" water explodes in the developed world, poorly managed wastewater, highly concentrated populations, increasing urbanization in arid regions, higher per-capita water consumption following Westernization, and the high cost of conventional infrastructure combine to make drinking water access a daily challenge for most people.

Wind power, when sited wisely and employed to offset some very high energy demand, yields an awesome technical solution to this problem. In this light, we explore the marriage of wind power to the increasingly important task of manufacturing drinking water from the sea.

Human water cycle

While about 73% of the earth's surface is water, only a small portion of it consists of liquid water that is fit to drink, grow crops and satisfy other human needs. Of the total volume of water on the planet (an estimated 1.39 billion cubic kilometers), only 2.5% is fresh – and two-thirds of that is locked in glaciers and ice caps. A mere 0.77% of all freshwater is held in lakes, rivers, wetlands, underground aquifers, soil pores, plant life and the atmosphere. Therefore, freshwater is infinitely valuable, since land-based life would entirely disappear without it.

Human demand for freshwater is changing in concert with the shift of human populations from rural to urban. Rural populations typically access decentralized local surface water and shallow aquifers, whereas urban populations often rely on miles of pipe and pumps to bring in large volumes of freshwater from large-volume sources, such as reservoirs, lakes, rivers and deep-well fields. According to a report titled "The State of World Population 2007: Unleashing the Potential of Urban Growth" released by the United Nations:

- the migration of people from rural to urban areas is increasing and not expected to slow or reverse for the next 30 or more years,
- growing urban areas exert tremendous pressure on freshwater supplies,
- as of 2008, more than half the world's current 6.7 billion people live in cities,
- over 30 years, the population of African and Asian cities will double, adding 1.7 billion people – more than the populations of China and the U.S. combined,
- it is estimated that as many as 60% of all urban dwellers will be under the age of 18 by 2030,
- in Africa and Asia, the number of people living in cities increases by approximately 1 million, on average, each week,
- though cities with more than 10 million people will continue to grow, most people will be living in cities of 500,000 or fewer,
- by 2030, the urban population will rise to 5 billion, or 60% of world population, and
- globally, all future population growth will take place in cities – nearly all of which will occur in Asia, Africa and Latin America.

The world's oceans easily are the largest repository of water, but due to a high concentration of dissolved salts, it is toxic to land-based life. Terrestrial life, whether rural or urban, is completely dependent on the hydrological cycle being replenished with rainfall for the water needed to run terrestrial ecosystems. In addition to better water management, wastewater recycling and rainwater capture, developing methods to tap the world's seawater safely and efficiently in order to augment freshwater would go a long way to meet new water demands.

To achieve this goal, the critical task is to remove salt from seawater. However, desalination – also known as desalinization – is an energy-intensive process and therefore, a prohibitively expensive supply option. This is where wind power has the potential to deliver power, zero emissions and freshwater.

Coastal zones

Another significant demographic transition is the increasing concentration of people near or in coastal zones. Indeed, 37% of the world's population is now within 100 kilometers of a coastline (see Table 1), and many of the world's fastest-growing cities are found there.

This trend exacerbates pressure on freshwater supplies. Coastal aquifers are shallower near the continental shelves, and when tapped, they are easily rendered unusable due to the intrusion of salt water. If there is anywhere on earth where industrial-scale desalination would be most desirable, it is in the coastal zone.

Table 1: World Population Proximity To Coastlines

Proximity To Coast (km)	Percent Of World's Population
100	37
150	44
200	49
400	66

Fortunately, coastal zones are also windy zones. So, it may be possible – and desirable – to harness wind to power desalination plants and provide a reliable source of freshwater to growing coastal urban centers with an environmentally friendly production process.

The ocean/land boundary is inherently energetic because land and water have different thermal properties (i.e., one or the other mass typically is cooler than the other, and the air over the cooler mass will have a higher density). The resulting coastal winds are very reliable, having powered the coastal schooners that fueled the economies of Africa, Europe, the Americas and Asia for nearly 300 years.

Desalination and the environment

Desalination uses energy (either heat or electricity) to separate salts from freshwater. The heating process, known as thermal distillation, boils the water, captures the steam and collects the freshwater as condensate when it cools. A breakthrough in thermal distillation occurred when scientists learned how to control atmospheric pressure and reduce energy requirements for heating. Just as water boils at a lower temperature on the top of a mountain than it does at sea level, thermal distillation employs distinct vessels, each with a lower atmospheric pressure to maintain steam production without adding heat.

Thermal distillation has not changed much since the 1950s, but efficiencies gained since then have made it more economical. Some of the countries that first constructed desalination plants are dependent on the technology to supply water to urban areas. Nearly 90% of all freshwater produced by countries on the Arabian Peninsula, such as Saudi Arabia, the United Arab Emirates and Kuwait, is supplied by thermal distillation.

The second process uses electricity and membranes to achieve separation. One method, electrodialysis, manipulates the electrical charge of elements to draw them through a membrane and leave the freshwater behind. The positively charged electrodes attract negatively charged ions, such as chloride and carbonate, while the negative electrodes attract the positive ions, such as sodium and calcium.

A second method, reverse osmosis (RO), employs brute force to push the relatively lighter, less dense water through a membrane, leaving the more dense solids in a briny solution. Energy is applied to the salty water to produce a pressure energy gradient across the membrane. The freshwater overcomes the osmotic pressure and passes through the membrane to produce potable drinking water. Membrane plants began commercial development in the late 1960s with RO development entering the market in the 1970s. Currently, there are an equal number of thermal and membrane utility-scale desalination plants. The economics of membrane plants, however, have improved significantly in recent years, and their numbers are expected to eclipse that of thermal plants in the short term.

Table 2: Costs For Reverse Osmosis

Country (Plant)	Year	Price Per Gallon
Bahamas	1995	$0.48
Cyprus (Dheklia)	1997	$0.46
Cyprus (Larnacus)	2001	$0.32
U.S. (Tampa)	2003	$0.21
Singapore	2005	$0.16

Source: Loupasis, 2002

Energy requirements

Desalination does not work without a lot of energy. Ideally, thermal desalination is coupled with traditional fossil fuel power generators. Membrane plants powered by electricity must be supplied by a traditional fossil fuel source connected to the electrical grid or from an on-site renewable source, such as wind or solar.

A comparison of the energy requirements of all of the desalination technologies reveals that RO is the least energy consumptive. This fact has helped increase its share of the desalination market in recent years. Thermal plants that provide 90% of the potable water in Kuwait require an average of 10 kW per meter-cubed. In comparison, units in Spain use approximately 4.4 kWh per meter-cubed.

Energy recovery systems, like turbines and pressure exchangers, have significantly decreased energy demand while dropping the price of water production. A large amount of energy must be applied to the saltwater to establish the pressure gradient at the membrane. While the freshwater exits the membrane, the concentrate that remains under high pressure is circulated to a storage tank for stabilization before being disposed. Because the flow of concentrate is typically 1 bar to 4 bars less than the applied pressure of the system, a significant amount of the energy used to build pressure on the feedwater can be recaptured in the concentrate flow.

Costs for RO continue to decrease as the result of technological advances, automation and operational experiences (see Table 2).

Environmental consequences

No effective technology is completely benign. Environmental impacts can result from the operation of desalination plants if improperly sited and designed. Impacts are associated with three parts of desalination: intake, discharge and energy demand. The intake structure draws in the salty water used to produce freshwater.

It can, at the same time, draw in marine life, particularly fish eggs and larvae that cannot swim. Similarly, the discharge of the concentrated brine waste produced by desalination can be toxic to marine life. Impacts from the intake and discharge structures can be avoided by understanding the marine life that lives in the source waters and its potential to be drawn into the intake or affected by higher brine concentrations. This understanding will help in the design and operation of a facility with an appropriate intake velocity and discharge concentration that minimizes environmental impact.

Because energy is a significant part of the desalination process, its environmental impacts cannot be ignored. Where desalination is powered by fossil fuel energy, either by thermal heating or from electricity, it will cause air pollution with negative impacts on public health. Impacts from fuel extraction, particularly from coal, also are a factor in environmental and habitat degradation. Desalination powered by renewable energy sources would have comparatively less environmental impacts. Furthermore, renewable energy can supply remote areas without the need to develop an electrical grid network.

Desalination in itself offers not only solutions to water supply needs, but also relief of environmental stresses associated with existing freshwater scarcity. Some rivers are drying up due to overuse, which is degrading river and wetland habitats. Groundwater withdrawal can create sink holes that pose public safety and environmental consequences. If properly designed, desalination can produce an unlimited water supply without causing environmental impacts.

Feasibility

Solar/photovoltaics are most often used at renewable energy-powered desalination plants. Wind power is used at 24% of the existing plants, with wind-powered RO at 19% of the total. Because the capacity factor of solar is one-third that of wind – making it more expensive and more area intensive – the feasibility of solar energy to power utility-scale desalination plants is limited given current technology.

In comparison, wind resources in coastal areas where desalination plants predominate are very productive. Their success makes wind-powered utility-scale desalination possible with some capacity for energy backup or storage during low-wind periods. However, desalination plants powered by wind must accommodate the variability of wind resources. This compensation can be accomplished by:

- providing a back-up source of power either through connection to the electrical grid or on-site generation,
- incorporating a large battery storage component to the wind system, or
- utilizing water storage to maximize water production when the wind is blowing, and continue to supply that stored water to customers even when the plant is not running.

The feasibility of these options will depend on plant capacity, patterns of water use and the nature of the wind resource.

Case studies

Governments and private companies see the advantages of further reducing the energy demand of desalination and the potential of unlocking vast amounts of potable water. A number of ongoing studies and test programs are being advanced throughout the world, and a few "real" projects have recently been built.

In the Canary Islands, the Spanish government has a water and energy research institute with eight wind turbines connected to separate RO, electrodialysis and vapor compression desalination systems. Research is supported by Spanish, German and English companies interested in the results for the business sector. The RO portion can produce 200 meters-cubed per day. The energy system is isolated from the grid to allow for wind-powered desalination when the wind is blowing and grid-powered desalination when it is not.

In part as a result of this research, one wind turbine manufacturer recently developed a desalination business line for its wind turbines. In this way, the manufacturer can apply its understanding of the intermittent power associated with wind to design the electrical interconnections to export excess wind power off-site and import energy from the grid to power desalination when the wind is not blowing.

In Australia, Perth constructed the first commercial-scale desalination project powered by wind energy. The Kwinana Plant's 24 MW demand is supplied by the 80 MW, 48-turbine Emu Downs Wind Farm located 160 miles from the city. The water plant generates 40 million gallons of water per day, which is about 17% of Perth's water demand. A smaller example of wind-powered desalination can be found in the United Arab Emirates where an 850 kW wind turbine powers a desalination plant. With half of the world's installed desalination capacity and decreasing fossil fuel reserves, the Middle Eastern countries may look to wind power to sustain their long-term water needs.

In the U.S., researchers are looking at opportunities to pilot wind-powered desalination. Wind energy growth has been greatest in non-coastal areas of Texas and Iowa. Meanwhile, desalination plants have come online in Florida and New Jersey and are planned in Massachusetts and California. Hull, Mass., which has two municipally owned wind turbines and a high cost of potable water, is working with the University of Massachusetts (UMass) to study the potential of wind-powered desalination. With a grant from the Bureau of Reclamation, UMass is assessing the economic feasibility of producing drinking water from the sea with wind energy. NWP

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