CITIES IN THE SAND: ADAPTABLE DESALINATION TECHNOLOGY

SUN, WIND AND WAVE POWER: HARVESTING RENEWABLES

GOLD RUSH OF THE OCEAN: THE RISE OF BRINE MINING

DESALINATION IMPACT 2024

AN FII INSTITUTE PUBLICATION

GREEN REVOLUTION

HOW WE CAN BRING FERTILITY TO THE WORLD'S DESERTS

FII INSTITUTE
Future Investment Initiative Institute
Impact on Humanity

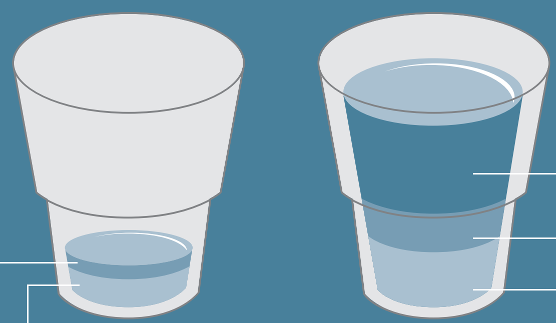
FACTS AND FIGURES

WATER CALCULATOR

There are lots of ways to measure water, but what do they all mean? We explain the most common units used internationally and put them into perspective.

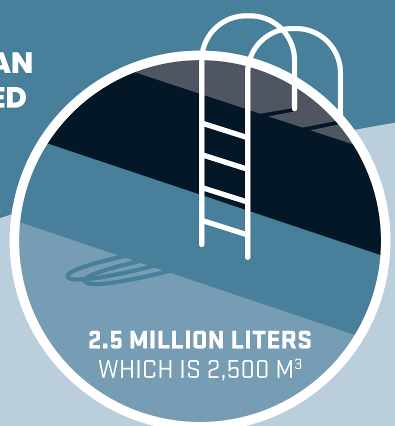
HOW MUCH WATER DO HUMANS NEED?

WHO recommends:



HOW MUCH DO THEY USE?

HOW MUCH WATER DOES AN OLYMPIC-SIZED SWIMMING POOL HOLD?

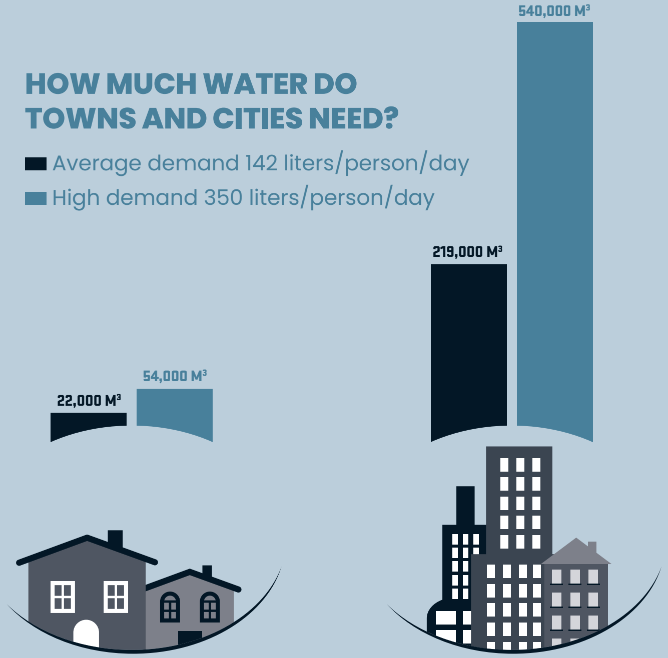


ENERGY USE

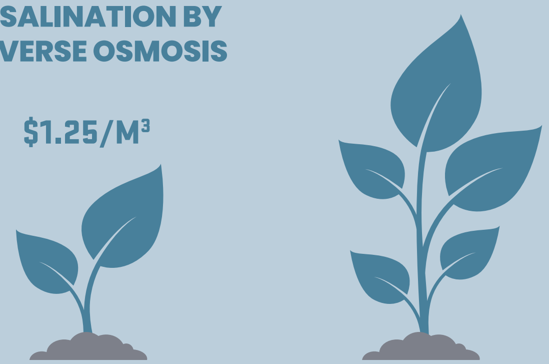
MODERN D.R.O. PLANT
4–6 KWH PER M³ WATER

HOW MUCH WATER DO TOWNS AND CITIES NEED?

■ Average demand 142 liters/person/day
■ High demand 350 liters/person/day



AVERAGE COST OF DESALINATION BY REVERSE OSMOSIS



EDITORIAL

WATER CAN BRING WEALTH AND PEACE

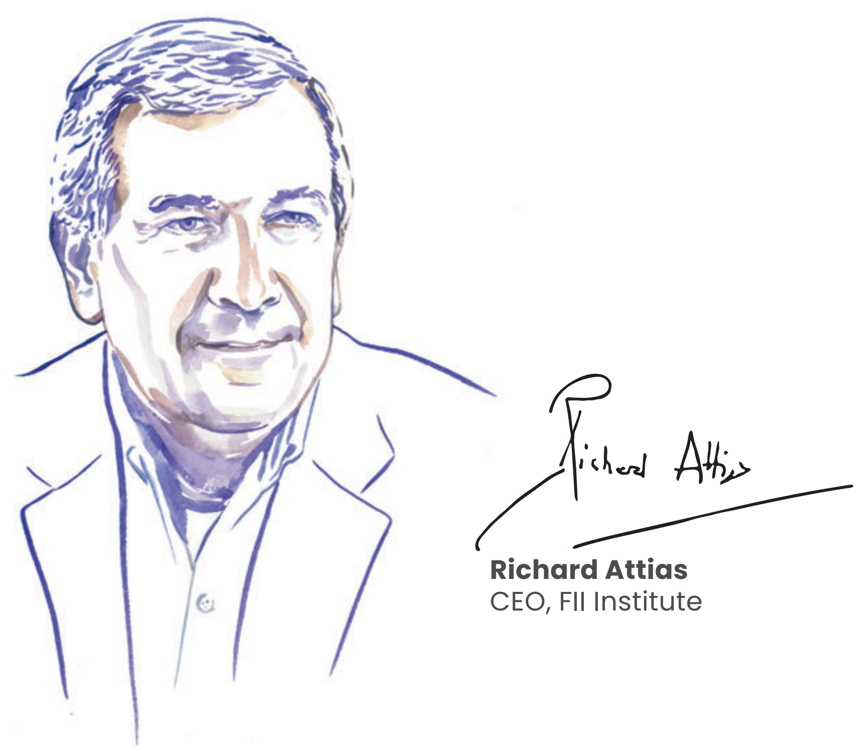
ADDRESSING THE WORLD'S overlooked yet crucial need for fresh water amid climate change and biodiversity loss is imperative. As the global population approaches 10 billion, demand for water intensifies, particularly in rapidly growing, low-GDP regions facing severe water stress.

Solutions include better water management, reuse and replenishing natural water cycles through new methods such as seawater desalination.

This technology, successfully implemented in the Middle East, Australia and the US, offers sustainable, affordable access to fresh water even in the hottest, driest areas without exacerbating CO_2 emissions or harming the environment.

Desalination innovations not only promise to meet global water needs, but also address social and economic disparities, making the greening of deserts feasible.

This revolutionary approach can redefine global access to essential, clean water.



Richard Attias
CEO, FII Institute

COVER: GETTY IMAGES/CAVAN IMAGES; INFOGRAPHICS: CARINA DYLUS; ILLUSTRATION: ANJE JAGER/SOOTHING

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CONTACT US:
info@fii-institute.org
@fiiksa
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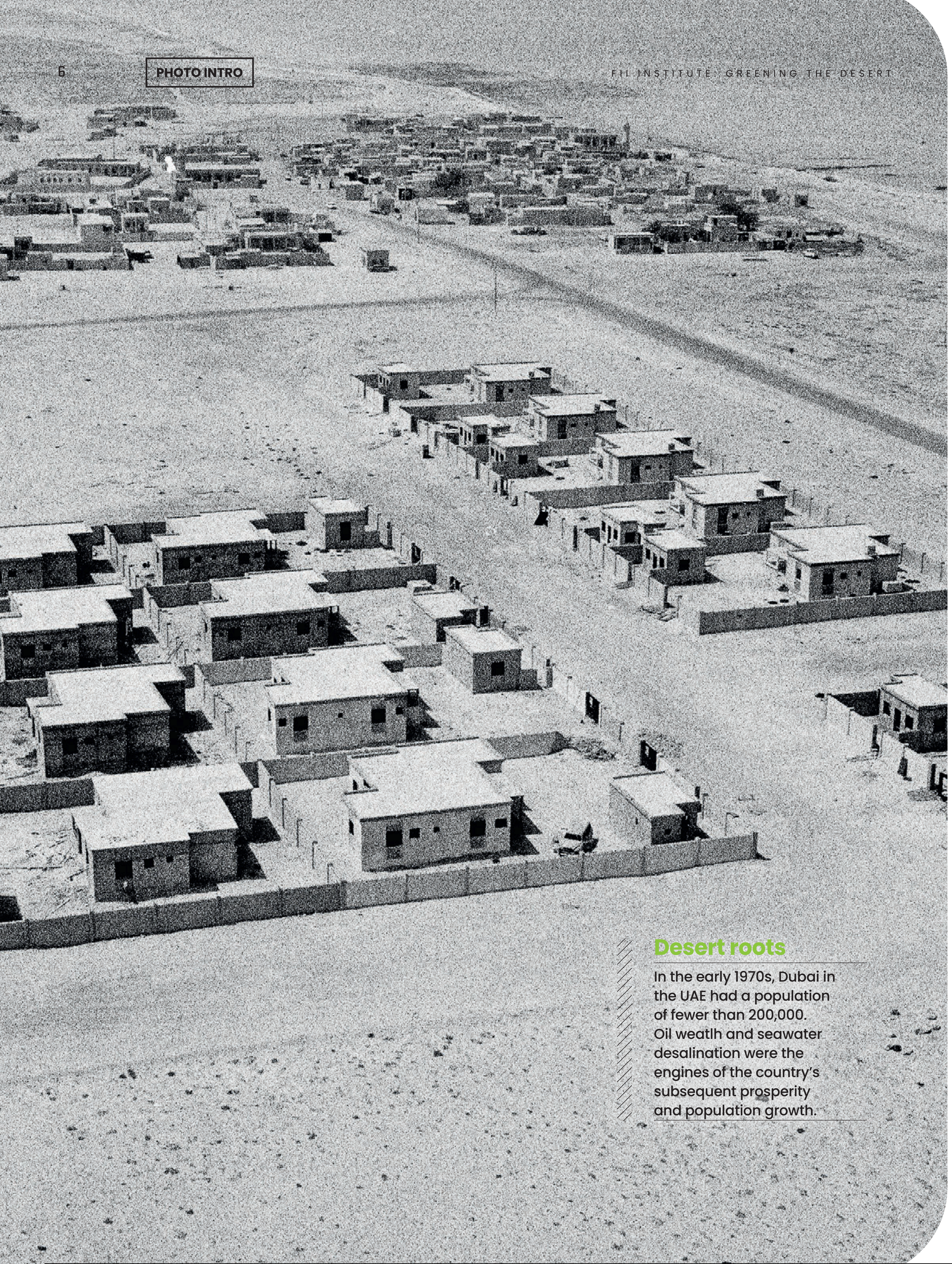
Crop circles

Fields watered by center pivot irrigation at Wadi Al-Dawasir, Saudi Arabia. Alfalfa is the most common crop in the 1km diameter circles, fed by aquifers at depths of 100 to 200 meters.

PHOTOS: GETTY IMAGES/AFP/FRANCK FIFE, GETTY IMAGES/AFP/EDUARDO SOTERAS

Dust storm

Women and children at the village of El Gel, near K'elafo, Ethiopia, where the last five rainy seasons have failed, triggering the worst drought in four decades.



Desert roots

In the early 1970s, Dubai in the UAE had a population of fewer than 200,000. Oil wealth and seawater desalination were the engines of the country's subsequent prosperity and population growth.

Wealth center

Today, Dubai is a city of 3 million people at the center of a range of expanding industries and a globally important finance hub. The UAE is ranked among the world's wealthiest and most advanced economies.

PHOTOS: MAURITIUS IMAGES/ART DIRECTORS & TRIP/ALAMY STOCK PHOTOS, SHUTTERSTOCK/GAGLIARDI PHOTOGRAPHY

An Arabian oryx grazes in the desert of the United Arab Emirates (UAE), against a view of the city of Dubai

PHOTOVOLTAIC REVOLUTION: PRICE PLUMMET EMPOWERS SOLAR DESALINATION

A solar farm the size of four football fields is all that's needed to supply fresh water to a city of 100,000 people. It could cost as little as $10 million to build. This opens up the prospect of bringing substantial, affordable and net-zero water supplies to the world's coastal deserts.

DESALINATION, FOR seawater and other brackish water sources, has come a long way. In the 1950s, state-of-the-art plants heated up water using coal or gas and condensed it. They required lots of energy and discharged hot brine, usually into the sea. Modern reverse osmosis (RO) technology, used in virtually all new plants, is non-thermal. It pumps water at high pressure through specialized membranes.

The spectacular lowering in price of photovoltaic panels in the last decade has contributed to a desalination revolution. It has made possible substantial RO plants, like Al Khafji in Saudi Arabia, powered entirely by solar energy. Al Khafji produces 90,000 m³ (36 Olympic swimming pools) of water a day.

There is no one-size-fits-all solution for RO. The choice of technology and plant size depends on the number of people to be served, the salinity or contamination of the water source, local climate, the availability of grid electricity, and the nature of available renewable sources.

The world's hottest and thirstiest regions, for example in the Middle East, Africa and South America, are becoming hotter and drier because of global warming (see page 12). These locations have lots of sun, and often great wind- and wave-power potential too.

They are ideal for large-scale coastal combined RO and power plants powered by renewable energy. Such plants can already output 500,000 m³ of fresh water a day (or 200 Olympic-sized swimming pools). That's like a large river. But with RO, small is also beautiful. The nature of the technology means that, apart from serving a conurbation, it can produce fresh water renewably from a unit the size of a washing machine or a shipping container, or a large chemical plant, or something in between.

Let's take the case of a desert city in a water-stressed region with low precipitation and depleted aquifers. Let's say it has 100,000 people. Philip Davies, professor of water technology at the UK's University of Birmingham can help us to do the math. How much water does our desert city need? A good base point would be 100 liters a day per person. That gives a total water need of 10,000 m³ a day – or four Olympic-sized swimming pools.

This level of fresh water equates to a solar farm taking up the fairly modest size of four football fields. He notes: "This size of plant would not quite be 'off the shelf,' but it would be a standard system that many companies could supply."

And the cost of our net-zero, desert city desalination plant? The market price for utility scale panels is $1–$1.50 per W. The PV panels for a 5 MW peak plant serving 100,000 people, he calculates, could cost as little as $5 million. Add another $5 million to build the plant, excluding land costs. Over a 15-year contract period, the cost per person is 56 cents per month. That's cheap. ■

DESERT CITY DESALINATION PLANT
SOLAR PV REVERSE OSMOSIS

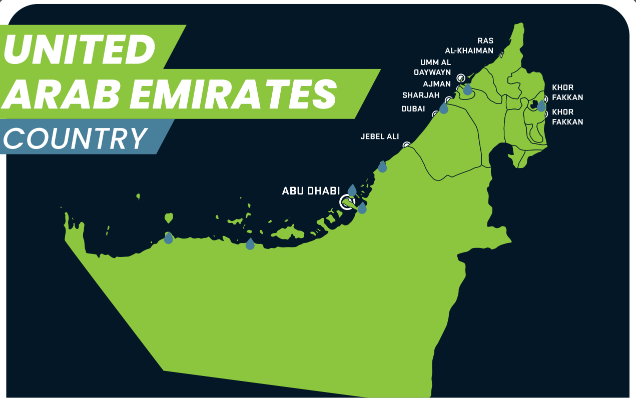
POPULATION SERVED:	100,000 people
EST. WATER NEED:	100 liters per person/day
PLANT OUTPUT:	10,000 m³ water per day (four swimming pools)
ENERGY/DAY & PEAK OUTPUT:	30 mWh & 5 MW
SIZE OF SOLAR ARRAY NEEDED:	30,000 m² (four football fields)
NUMBER OF PV PANELS:	15,000 Estimated cost $5 million
SIZE OF CITY:	5–10 km²

PHOTOS: GETTY IMAGES/AFP/KARIM SAHIN, GETTY IMAGES/AFP/FAYEZ NURELDINE

A TALE OF TWO DESERT COUNTRIES

For the UAE, a rich country, extremely high water stress potentially threatens further population growth and economic expansion. Mauritania, a poor country, requires a huge scale-up of desalination and wind and solar power over the next decade to shift its economy from an agrarian to an industrial base. This and green hydrogen could increase its GDP by more than half.

UNITED ARAB EMIRATES COUNTRY



POPULATION:	9 million, density 114 people/km^2
CAPITAL:	Abu Dhabi, 1.8 million
CLIMATE:	Arid with very dry, hot summers
LABOR FORCE BY OCCUPATION:	Services **78%**, industry **15%**, agriculture **7%**
MAIN INDUSTRIES:	Oil and gas, chemicals, aluminum, cement, fertilizer, ship repair
GDP PER CAPITA	$51,393. 20th/world, IMF
COASTLINE:	1,318 km

UNITED ARAB EMIRATES SITUATION

WATER

Extremely high water stress

Water consumption is high, 500 liters per day

The UAE gets 90% of its drinking water from 70 large desalination plants, producing 7.1 million m^3 of desalinated water per day

In 1968, the UAE had 180,000 inhabitants and a subsistence economy dominated by agriculture, pearl extraction and fishing. Thanks to prudent management of oil and gas resources following independence in 1971, its GDP per capita rose from $4,425 to $51,393 today, nearly 80% higher than the OECD average. The UAE is now on a par with the world's advanced economies according to the World Economic Forum. Lacking freshwater resources, it will need to expand desalination to continue its growth trajectory, and is committed to deploying solar energy and reducing brine discharge into the Arabian Gulf. ▪

ILLUSTRATIONS: FLATICON.COM/YAICON, FLATICON.COM/CREATIVE STALL MEDIUM, CHOKKICX / GETTYIMAGES(2)

MAURITANIA COUNTRY

POPULATION:	5 million, density 5 people/km^2
CAPITAL:	Nouakchott, 1 million
CLIMATE:	Dry, hot and windy, severely exposed to desertification
LABOR FORCE BY OCCUPATION:	Agriculture **50%** services **48%**, industry **2%**
MAIN INDUSTRIES:	Mining (iron ore, gold, copper, gypsum), petroleum, fish processing
GDP PER CAPITA	$2,338. 144th/world, IMF
COASTLINE:	700 km

MAURITANIA SITUATION

WATER

Medium to high stress

Per capita consumption: less than 50 liters per day

Three-quarters of water, mainly extracted from rivers and boreholes, is used for irrigation

Current desalination capacity: 5,000 m^3 per day

Planned desalination capacity of 200,000 m^3 per day for Nouakchott

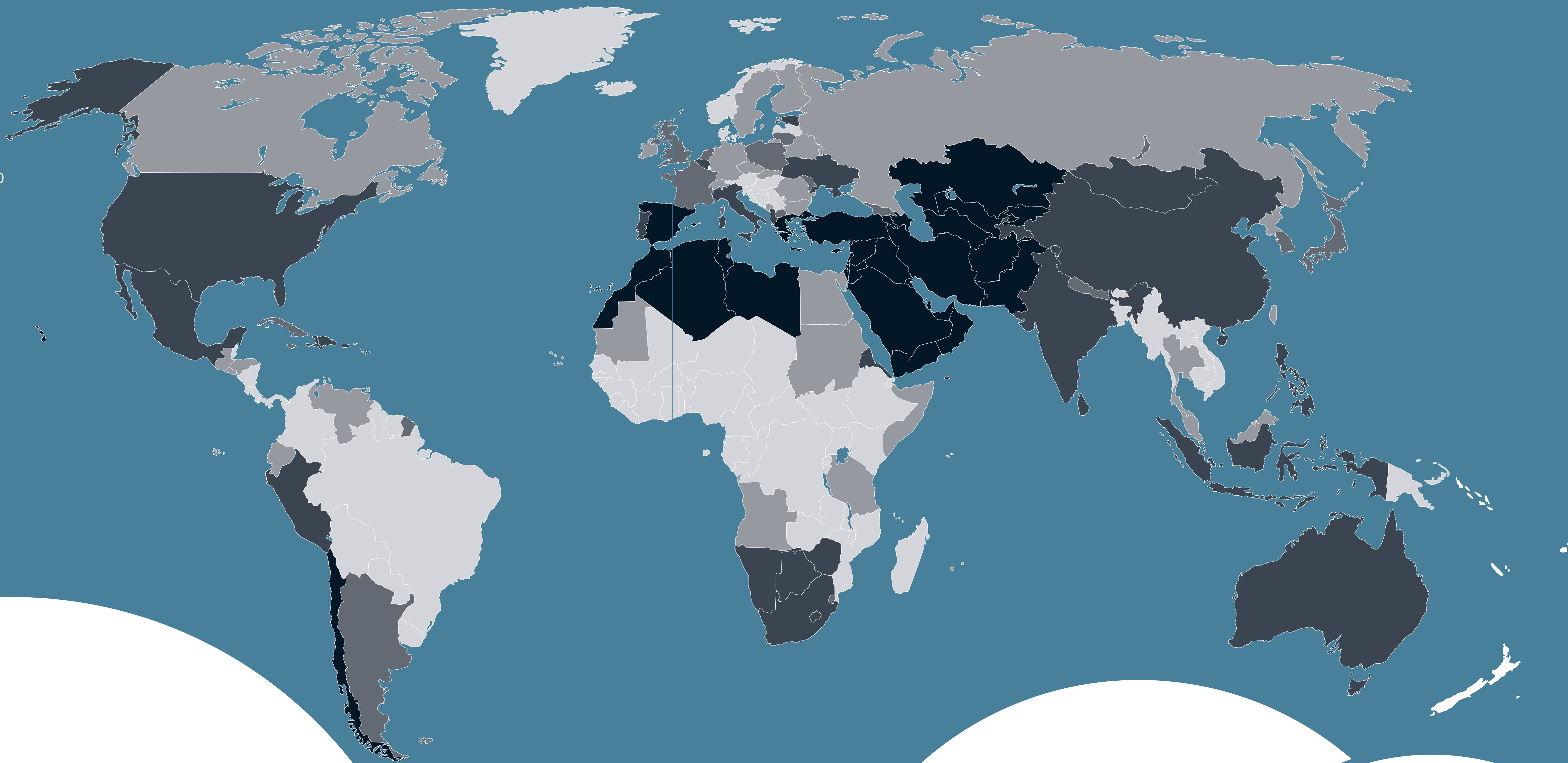
There was rapid economic expansion after independence in 1960, but since severe drought in the early 1970s, Mauritania has depended on imported food. In the early 1980s, fishing became the leading source of foreign exchange as iron ore prices fell, but overfishing has led to severe stock decline. BP is developing offshore liquified natural gas fields and the government has signed substantial MOUs with foreign investors to scale up wind, solar, green hydrogen, green ammonia and green steel infrastructure near the capital, Nouakchott. Within a decade, these developments and large-scale RO desalination could increase the country's GDP by up to 60%. ▪

WHERE WATER STRESS WILL BE HIGHEST BY 2040

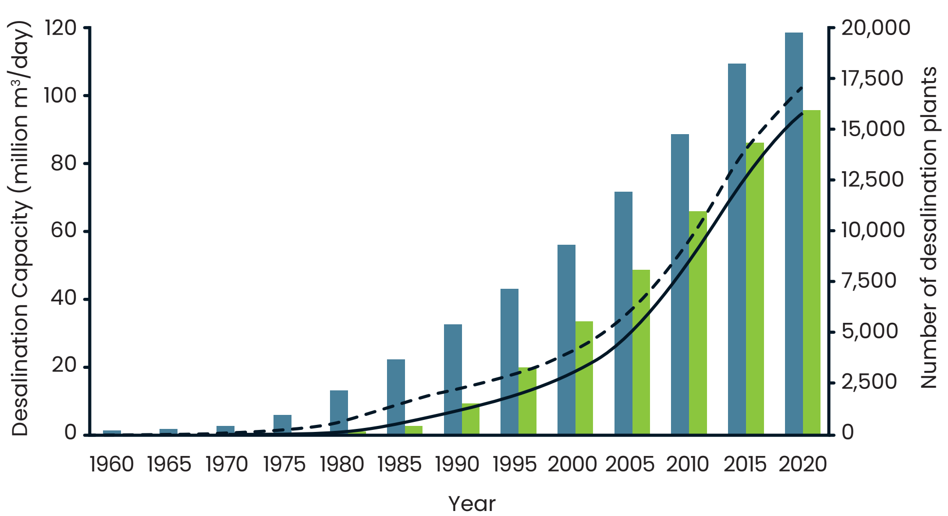
Projected ratio of water withdrawals to water supply (water stress level) in 2040

- EXTREMELY HIGH (>80 %)
- HIGH (40–80 %
- MEDIUM TO HIGH (20–39 %)
- LOW TO MEDIUM (10–19 %)
- LOW (<10%)

SOURCE: WORLD RESOURCES INSTITUTE VIA THE ECONOMIST INTELLIGENCE UNIT



GROWTH OF DESALINATION GLOBALLY, 1960–2020



DESALINATION PLANTS
OPERATIONAL DESALINATION PLANTS
DESALINATION CAPACITY
OPERATIONAL DESALINATION CAPACITY

SHARES OF DESALINATION METHODS IN CAPACITY

- REVERSE OSMOSIS (65%)
- MSF: MULTI-STAGE FLASH (21%)
- MED: MULTI-EFFECT DISTILLATION (7%)
- ED: ELECTRODIALYSIS (3%)
- NF: NANOFILTRATION (2%)
- REST (2%)

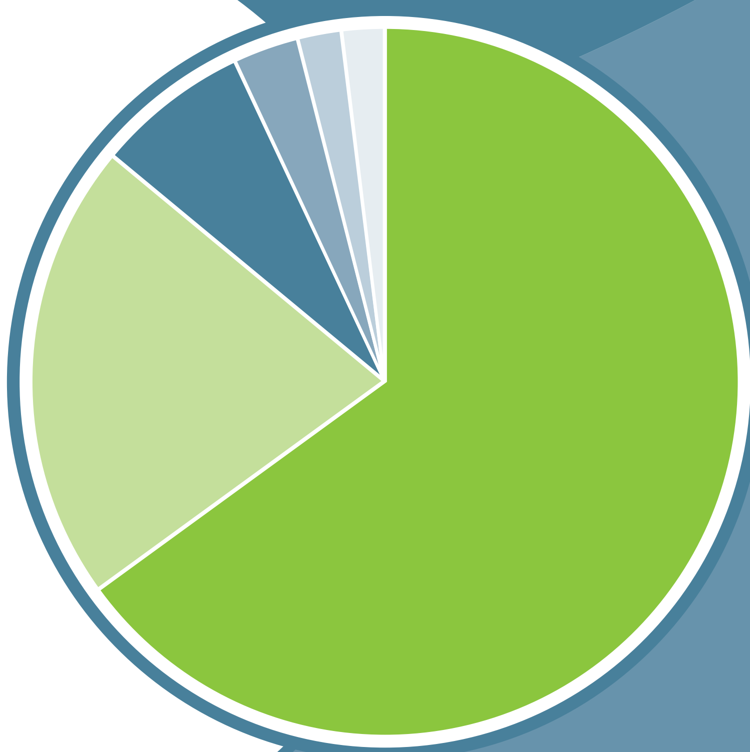


ILLUSTRATION: CHOKKICX / GETTYIMAGES

DIVERSION TACTICS
MOVING WATER INLAND

"Sea to sea" solutions have potential to turn extensive areas green, while meeting power and drinking water needs. The largest projects would require cooperation with neighboring countries.

SALTON SEA

The Salton Sea in Southern California is 70 m below sea level and 100 km from the coast. The hypersaline water body is shrinking, causing the former lakebed to blow away as toxic dust, devastating wildlife. Under a plan being developed by geoengineering firm E2EDEN, a 4 m diameter tunnel would connect the sea to the Pacific.

It would be gravity-fed with seawater. Seawater greenhouses near the lake (see page 24) would create fresh water for irrigation and encourage natural vegetation to grow. One version of the plan would extract lithium salts from saline groundwater.

DEAD SEA

Fed by the Jordan River, the Dead Sea is the lowest-lying and saltiest lake on earth. Some 430 m below sea level, it has shrunk by one-third since the 1960s, and is sinking by more than a meter a year. Neighbouring Jordan has a population of more than 10 million, but only enough water for 2 million.

A plan from Jordan for a canal linking the Dead Sea to the Red Sea dates to 2005. The $10 billion dollar project would have seen a dam and desalination plant built at Aqaba to provide power and 533 million m³ of fresh water annually to irrigate local lands. Saline wastewater would have refilled the Dead Sea. The project was abandoned in 2021.

PHOTOS: GETTY IMAGES/ PHOTODISC/SPOTMATIK; GETTY IMAGES/ANADOLU AGENCY/ALI BALIKCI; GETTY IMAGES/DE AGOSTINI/ DEA/V. GIANNELLA; PICTURE ALLIANCE/DPA/NASA EARTH OBSERVATORY/ LAUREN DAUPHIN

QATTARA DEPRESSION

On an even larger scale, the huge Qattara depression in Egypt's Western Desert, which is the size of Lebanon and, on average, 60 m below sea level, could be filled with water from the Mediterranean, creating an inland hypersaline lake.

Long-standing plans to link the water bodies were revived in the 1960s, now in conjunction with a large hydropower scheme. A canal would deliver water to the depression and provide a shipping route to the Qattara lake, which, it was estimated, would take ten years to fill. Hydropower would be used for desalination.

NEW DELTA PROJECT

Egypt has population of 102 million people. It is classed as suffering from extremely high water stress and must import 40% of its food. In 2022, it began to construct the world's largest human-engineered waterway, the New Delta Project. Its purpose is to redirect water from the Nile, plus groundwater and treated agricultural wastewater, to irrigate a new agricultural region of more than 9,000 km² to the west of Cairo. The project is expected to cost around $5 billion and will be completed in three phases, from developing roads, canals and irrigation systems through cultivating the land to eventually growing crops.

TACKLING YEAR ZERO

The world is waking up to some of its largest cities running out of water. Sustainable desalination can provide both short- and long-term solutions.

IN JANUARY 2018, Cape Town officials announced that, following four years of severe drought, with supplies almost exhausted, the city was only three months away from "year zero." In other words, it was about to be the world's first major city to run out of water. If the taps had been turned off, 4 million people would have had to rely on water tankers and communal standpipes. The authorities made contingency plans for social unrest. They also imposed rationing measures.

Water use was restricted to 50 liters per person per day (the average US usage is 373 liters), and residents were asked to take short showers, flush toilets only when necessary and refrain from using drinking water for gardening.

The city also turned to reverse osmosis desalination. Three short-term plants were quickly built: one on the V&A waterfront produced 2 million liters of water per day; others at Strandfontein and Monwabisi produced 7 million liters each.

All three facilities have now been decommissioned. The city has learned lessons and its per capita water use has fallen significantly since the crisis of 2018. But under a new water program, Cape Town plans to produce 300 million liters of new water daily by 2030 to ensure resilience when future droughts occur. It will come from diverse sources, including desalination, groundwater extraction and reuse.

Cape Town is not alone in facing a dire shortage of fresh water. As global temperatures rise and unseasonal storms and typhoons bring floods that destroy crops, other cities are getting closer to their own versions of year zero.

2023 saw heatwaves and droughts in California, Australia, East Africa and India, and flash floods in Zambia and Algeria. In 2022 there was record flooding in Pakistan.

The global average temperature in July 2023 was confirmed by the UN to be the highest ever recorded. Furnace Creek in Death Valley, California clocked a blistering 53.3 °C, while in August torrential rains trapped thousands of attendees at Nevada's Burning Man festival in a sea of mud.

The Christian Aid report "Scorched Earth" spotlights ten cities that are at high risk of year zero: Sydney, Harare, Sao Paulo, Phoenix, Beijing, Kabul, New Delhi, Cape Town, Cairo and London.

In the case of Sydney, a severe drought in 2017–2020 halved the amount of water in the reservoirs ↘

Cape Town faces a dire shortage of fresh water

Residents line up to fill their containers at a public fountain in the Newlands area of Cape Town in early 2018.

PHOTO: VISUM/PANOS PANOS/FOLHAPRESS/PANOS PANOS/LALO DE ALMEIDA

Stop sign at Stove Pipe Dunes, Death Valley, California.

that supply this city of 5 million people. A draft water strategy published by the New South Wales government last year concluded that unless the Australian government invests in rainfall-independent sources of water, such as recycled wastewater and desalination, Sydney could run out of water when the next drought hits.

In China, more than 100 cities face a severe water shortage, including Beijing, whose 21 million residents are running out of water sources. In 2002, the government began three canal systems to transport water from southern rivers to cities in the drier north. The colossal South-North Water Transfer Project aims to carry 45 billion m^3 of water – or 179,200,000 Olympic-sized swimming pools – every year.

WATER CYCLE IS SPEEDING UP

Currently, one-quarter of the global population uses unsafe drinking water and one-half has no safely managed sanitation. In March of 2022 in New York, at the first global water conference it has held for more than 40 years, the UN predicted that global demand for water will outstrip supply by 40% in 2030. One reason for this is population growth. Another is climate change. The Intergovernmental Panel on Climate Change analysis confirms that rising global temperatures are causing the world's water cycle (see box page 19) to speed up.

Via extreme storms and flooding, more and more fresh water is leaving the planet's dry regions and ending up in the wet ones. El Niño and La Niña, extreme weather events related to fluctuations in natural rainfall patterns, are increasing in frequency.

Experts predict that every 1°C increase in the global average temperature will be matched by a 20% drop in renewable water resources.

The world's most water-stressed regions are the Middle East and North Africa, followed by South Asia. The biggest change in water demand between now and 2050 is expected to occur in Africa, home to six out of the ten fastest-growing economies in the world. Here and in many other water-stressed regions, particularly those that have coastal deserts, desalination by reverse osmosis, powered by renewable energy, is well-placed to provide a sustainable solution.

PHOTOS: GETTY IMAGES/IMAGE SOURCE/OWEN SMITH, PICTURE ALLIANCE/NURPHOTO/ COSTFOTO; ILLUSTRATION: GETTY IMAGES/ANILYANIK

The Sihong Station of the South-North Water Diversion Project in Suqian, Jiangsu Province, China.

CALL TO IMPACT

1 Cities and communities in water-stressed areas should plan for future shortage rather than merely reacting to crisis.

2 Eliminating unnecessary uses of fresh water and recycling waste water are just as important as ensuring new supplies in sustainable water management.

2 To solve the world's water crisis, we will need to address global warming by reducing greenhouse gas emissions.

THE WATER CYCLE

Fresh water comes in two forms. "Blue water" is that found in rivers, lakes, groundwater, glaciers and polar ice caps; "green water" is found in plants, the soil and rain. There is no "new water." The water (or hydrological) cycle is a process of constant recycling. The sun causes evaporation from water surfaces, land and plants. Water vapor rises and condenses in the atmosphere, where water droplets merge into clouds that cause precipitation in the form of rain, hail and snow. Most rain falls onto the ocean; on land, it flows over the ground as surface runoff and reenters the ocean. As water evaporates, it absorbs energy and cools the local environment. As water condenses, it releases energy and warms it up.

Ras Al-Khair hybrid water desalination plant on the Arabian Gulf Coast, owned by the Saudi Arabian government.

PHOTOS: GETTY IMAGES/AFP/FAYEZ NURELDINE

A WORLD-CHANGING TECHNOLOGY

Large-scale seawater desalination began in the 1950s. It was viewed as a tool for world peace. We approach its centenary with hugely improved technology and great potential to address the global crisis of water stress.

> "We need a Paris agreement for water globally and national water plans for each country."
>
> **CHARLES ICELAND**
> World Resources Institute

SEAWATER IS all around us, covering 70% of the planet's surface. And desalination in its most basic form, allowing the sun to heat seawater and condensing its vapor to provide fresh water, has been in use for millennia. But scaling up the process for provision of major water supplies on land did not arrive until the twentieth century.

From 1950, a decade of drought began in the southern US states. Fear of a repetition of the 1930s Dust Bowl led President Eisenhower to unleash the full might of American scientific know-how on the problem. Eisenhower – the president who opened America's first nuclear power station – turned to seawater for the solution.

In 1955, he created the Office of Saline Water and, in 1961, the world's first industrial-scale desalination plant, opened in 1961 in Freeport, Texas. The coal-fired plant supplied 4 million liters of water a day to the people of Freeport and a Dow chemical factory.

John F. Kennedy pushed a button in the Oval Office to set the plant in motion. In dedicating it, he said: "No water resources program is of greater long-range importance than our efforts to convert water from the world's greatest and cheapest natural resources – our oceans – into water fit for our homes and industry."

Kuwait, with no natural rivers and low precipitation, had created a successful oil-based economy by the late 1940s. Kuwait's first thermal seawater evaporation plant opened in 1951. It pumped 38,000 liters of purified water from the Persian Gulf to Kuwait City every day. A new plant, built in 1953, reached a capacity of about 9 million liters per day. By the early 1960s, it could deliver 23 million liters (2,300 m³).

RISE OF REVERSE OSMOSIS

Early desalination plants used thermal evaporation and distillation to purify seawater. But in the late 1950s, a technology emerged that was to revolutionize desalination. UCLA researchers Sidney Loeb and Srinivasa Sourirajan produced a membrane from cellulose acetate. It could act as a filter that only water molecules could pass through, leaving behind salt and other impurities.

A commercial desalination by reverse osmosis (DRO) plant was built in Coalinga, California in 1965 for brackish water. In 1975 in Bermuda, the first seawater DRO plant came into operation.

By the 1980s, DRO plants were becoming more efficient in ↘

energy demand than thermal alternatives, such as Multiple Effect Distillation (MED) and Multi-Stage Flash distillation (MSF). "The introduction of membranes in desalination was extremely disruptive," says Paul Bujis, UAE-based water treatment expert and consultant. "It has taken from the 1970s to now to reach a maximum daily capacity of around a million cubic meters per day at the largest plants. That is huge," he adds, "but each step of ten times bigger is roughly taking 15 to 20 years."

There are now about 21,000 desalination plants in 180 countries around the globe, producing more 100 million m^3 of fresh water daily. An estimated 200 million people rely on desalinated water for their daily needs.

The world's largest plants are in the United Arab Emirates, Saudi Arabia and Israel. Globally, 62% of desalinated water is destined for municipal supply, followed by industry (30%) and agriculture (9%).

It estimated that more than 60% of all installed desalination capacity now uses reverse osmosis technology. "Reverse osmosis has proved to be a reliable and more energy-efficient technique than thermal desalination processes," says Arturo Buenaventura, Strategy and Corporate Development Manager of Spanish energy and infrastructure company Abengoa Water.

The average price range of desalinated water is between \$0.5 and \$1.5/m^3. The lower end of this comes from countries with low electricity costs, such as the Middle East. At the upper end are regions with higher electricity costs, such as Australia.

Membrane plants leave a smaller carbon footprint than conventional thermal desalination and, when powered by renewable energy, that footprint is smaller still. With a record low cost for a solar-powered plant, achieved in the UAE, of \$1.4/kWh, renewably desalinated water is now reaching the threshold of affordability for irrigation. Globally, irrigation accounts for 70% of fresh water usage and more than 90% across the Middle East, so this development will represent a step change.

UN SLOW TO ACT ON WATER

Founded in 1945, the UN has been late to acknowledge water scarcity as an international issue. Its first international water conference was not held until 1977 in Argentina, and water and sanitation were not declared to be a human right until 2010.

Although the UN designated 2018–2028 as a "decade of action" on water, it does not acknowledge water as an overarching theme, like food, health or climate change. While UN-Water is a "coordination mechanism" for the organization, there is no UN agency, fund or program dedicated exclusively to water.

Social Development Goal 6 specifically requires achieving clean water and sanitation, but campaigners point out that water and sanitation are essential to the realization of all human rights and are involved in at least 14 of the 17 SDGs. They argue that SDG 6 has a "multiplier effect."

In 2023, the UN's second international water conference produced no formal agreement comparable to the 2015 Paris climate accord or the 2022 Montreal biodiversity pact. Charles Iceland, global director for water at the World Resources Institute, said: "We need a Paris agreement for water globally, national water plans for each country, and regional water plans for each shared basin and aquifer."

Henk Ovink, special envoy for water for the Netherlands, which co-hosted the conference, observed: "We have fragmented water governance across the world, fragmented finance, and not enough science and data." ■

INFOGRAPHIC: CARINA DYLUS; PHOTO: SHUTTERSTOCK/JOSE LUIS STEPHENS

CALL TO IMPACT

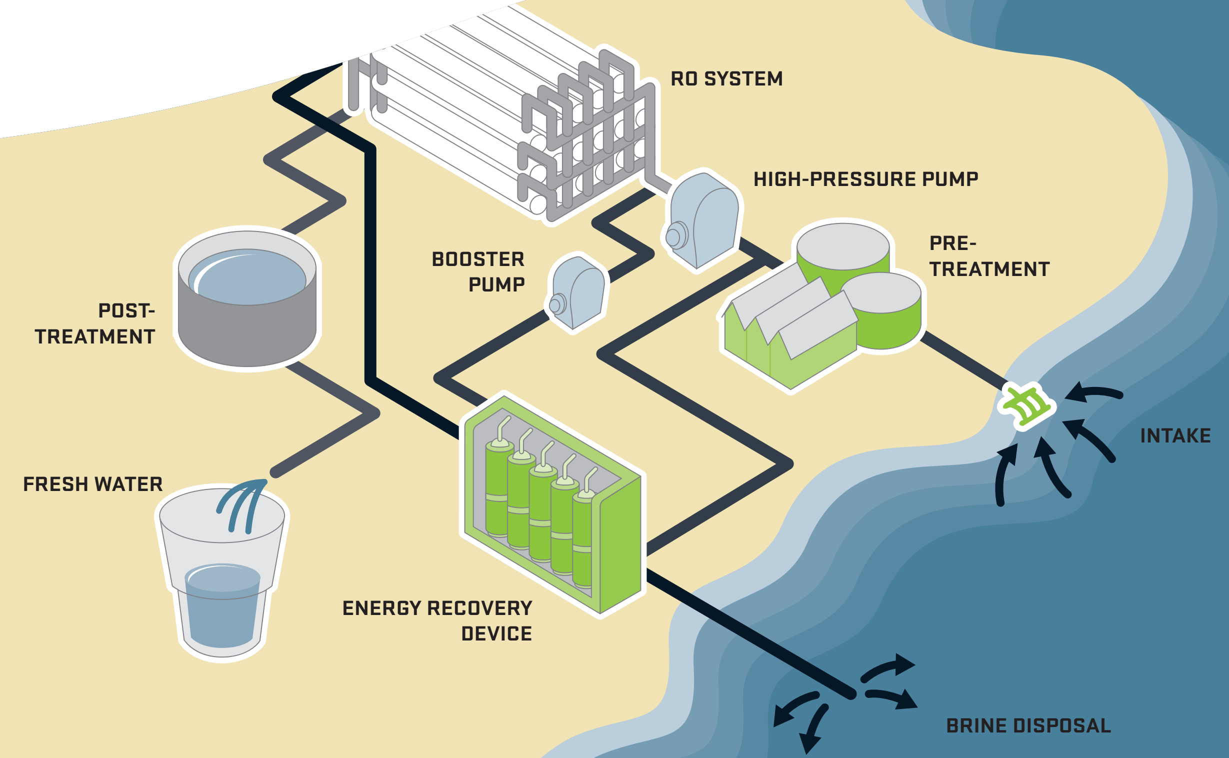
1 Growing water stress, if not addressed, will lead to escalating conflicts in many parts of the world.

2 Improving water and sanitation, SDG 6, is essential to the realization of all human rights.

3 Desalination of seawater by reverse osmosis filtration has a lower energy requirement than thermal methods.

4 Renewable energy reduces the carbon emissions of desalination. Its brine output can be reduced or eliminated.

Reverse osmosis equipment in a desalination plant.



HOW REVERSE OSMOSIS WORKS

Water removed from the sea is filtered and forced, at up to 70 times atmospheric pressure, into steel tubes filled with spiral-wound membranes.

The amount of pressure required is determined by the salt concentration of the feed water. Tiny pores in the membranes permit water molecules to go through, leaving up to 99 % of dissolved salts and other impurities in the waste stream. About 1.5 liters of briny wastewater is produced for each liter of fresh water.

WATER TREATMENTS

Pre-filtration removes suspended solids from seawater, pH lowering is carried out to protect membranes and control the precipitation of salts. Anti-scaling inhibitors are used, as well as disinfectant to control fouling by microorganisms. Post-treatment includes adjusting the water's pH and adding calcium and magnesium.

Modern plants aim to produce zero liquid discharge. Membrane reverse osmosis is used to treat brackish water, wastewater and industrial discharges.

FROM DESERT TO FOREST GARDEN

Charlie Paton has developed a technology he believes could help vegetate the world's driest regions.

IN THE 1970S AND '80S, Charlie Paton ran a successful theater lighting company. It built the rig of motorized lights and cameras for the hit musical "Starlight Express" – a show that has been seen around the world.

But he has also had a lifelong fascination with the way in which nature elegantly performs processes that are essential to life, such as osmosis and photosynthesis, using the natural design of plants and leaves, whose efficiency humans cannot yet equal.

Today, he lives in a wood in Sussex, southern England, for half his time. The other half, he manages his company, Seawater Greenhouse, from an office in north London. The company, he explains, has a simple mission – developing solutions for hot, arid environments that lack fresh water. It came about from his twin passions, nature and light.

The idea of seawater greenhouses came to him when he was on his honeymoon in Morocco in 1984. He was pondering how plants could be encouraged to grow in hot countries with limited water.

His eureka moment came while he was sitting on a bus. "It had been raining. People were getting on with wet, steamy clothes. I understood that, as the water evaporated, the people would become cooler."

Evaporative cooling raises humidity and reduces temperature. In the natural world, those factors slow down a plant's transpiration rate, reducing its need for water. In a country that is dry, with low ambient humidity, he realized, it would be easier to bring about evaporative cooling to allow plants to grow, and a free, unlimited medium could be used – seawater.

PROTOTYPE IN TENERIFE

In the 1990s, he teamed up with Phil Harris, professor of plant science at Coventry University, and engineer and physicist Philip Davies. Assisted by EU funding, they built a prototype seawater greenhouse in Tenerife that was highly successful.

The concept relies on two natural ingredients that are in abundamt supply– sunshine and seawater. Air is pumped or blows naturally through seawater-soaked "pads," layers of corrugated cellulose, creating a cool, humid enclosed environment, ideal for growing plants.

On the same site, seawater is desalinated using reverse osmosis powered by solar energy to provide water for irrigation. Waste brine is evaporated for its mineral content. On the land around the seawater greenhouse, residual water vapor creates an "oasis effect" and plants naturally begin to grow. What was once dust becomes a growing medium. When shrubs and trees appear, shade is created. Newly greened land increases local rainfall and sequesters carbon dioxide through photosynthesis. In effect, seawater greenhouses assist and speed up the natural hydrological cycle (see page 19).

They have now been built and used successfully in Oman, the UAE, Australia and Somaliland. A plant originally developed by Paton's company in Port Augusta, South Australia, the 20-hectare Sundrop Farms, shows the concept can work on a very large scale.

Hydroponically, it grows 17,000 tonnes of tomatoes a year, 15% of the country's annual total. The ↘

> "Only 600 years ago, parts of Saudi Arabia were much greener and wetter than today."
>
> Charlie Paton,
> product developer, maker,
> designer and forester

PHOTOS:CHRISTOPHER ANDREOU

plant turns 1,000 m³ of seawater a day into fresh water.

Sundrop Farms uses concentrated solar power from 23,000 mirrors directed up to a 123-meter-high tower. Its company has expanded operations to Portugal and the US. Launched by Paton in 2017, using a similar technology, the Sahara Forest Project has built hydroponic seawater greenhouses in Qatar, Jordon and Tunisia. Paton believes the most recent version of his company's product, the lowest cost solution to date, is ideally suited to the deserts of the Middle East, North Africa, Australia and southern Europe. "In Somaliland, where we are successfully growing tomatoes, melons and salad crops, we've switched to using the wind instead of fans, which halves the cost, and instead of having polythene or glass we have shade net, which reflects about 40% of the solar radiation."

> "In my ideal world, you would have seawater evaporators in every hot, arid country, from the Sahara down to Australia."

REGIONAL TRANSFORMATION

He notes that many countries with hot, dry desert climates have relied upon irrigation from underground fresh water as if it were an unlimited resource. They have drained their aquifers. Overabstraction and global warming are contributing to an acute water stress crisis, known as desertification, which urgently requires a solution.

"In Saudi Arabia there are now boreholes that are a kilometer deep. Incidentally, the power you need to pump water up a kilometer is greater than what you need to drive an RO plant, by about double."

Only 600 years ago, he notes, parts of Saudi Arabia were much greener and wetter than today. Cooled by seawater and the Khareef wind, the Dhofar region of Oman is still green and fertile to this day.

Paton would like to demonstrate seawater greenhouses on the Red Sea coast, in the Umluj region. The prevailing northwesterly wind, augmented by seawater greenhouses, would blow humid air as far as the cooling Hijaz Mountains, creating an oasis effect he believes could cover as much as 1,000 km² of currently arid land.

Brine would not need to be pumped back into the sea but could be used for mineral and chemical recovery and as a source of fertilizer. Fresh water would be used for drinking and irrigation.

Last year, Seawater Greenhouse was one of the Top 60 submissions for the prestigious $100 million global XPRIZE Award, funded by the Musk Foundation. The competition entry explained the concept brings together a trio of previously separate techniques – agroforestry, evaporative cooling and reverse osmosis desalination – to build "forest gardens" in otherwise barren landscapes. Forest farming means cultivating crops under a diverse forest canopy, which is modified and maintained to provide optimal shade levels and habitat – not only producing food, but also sequestering 3 tonnes of carbon per hectare per year.

Paton says: "In my ideal world, large parts of Saudi Arabia would be turned green, but you would have seawater evaporators in every hot, arid country, from the Sahara down to the deserts of Australia."

He inivites us to picture a vast desert plain, parched by years of drought. "Follow this barren landscape to where it meets the sea, and you'll find a humid oasis of lush farmland that feeds local communities and sequesters CO_2.

The three-for-one solution not only captures CO_2 by unlocking the photosynthetic potential of arid coastal landscapes, but also tackles two of our planet's most urgent problems: water scarcity and food security.

In Somaliland, greenhouses made from low-cost shade nets are already empowering communities with self-sufficient food production. In Australia, the steel-framed, solar-powered greenhouses of Sundrop Farms operate profitably at a commercial scale.

Global problems require creative ideas. It must help that, for half his week, Paton is surrounded by trees, effortlessly converting carbon dioxide to oxygen and nutrients via photosynthesis. We still don't understand exactly how nature does it. No human has made a membrane as efficient as a leaf or a blade of grass, he reflects. Yet. ■

Waterfalls at Wadi Darbat, Dhofar Mountains, Oman.

PHOTOS: SHUTTERSTOCK/HIAMIR, CHRISTOPHER ANDREOU

CHARLIE PATON

A design engineer with a passion for growing things, Charlie Paton owns and manages an ancient woodland and designs greenhouses cooled with seawater for the hottest and most arid deserts.

NEW SOLUTIONS FOR DRY LANDS

Reverse osmosis desalination is constantly being improved and finding new uses, thanks to emerging technologies in energy, water management and membranes.

REVERSE OSMOSIS HAS proved highly adaptable throughout the world in real-life applications. Some of the newest systems, particularly for wastewater treatment, increase efficiency by combining pushing water through membranes with adapted forms of traditional thermal desalination.

In the newest RO systems, energy in the form of pressure and heat is recovered from hot brine discharge and put back into the desalination process, greatly increasing energy efficiency and reducing the final cost of fresh water.

The aim of modern water systems is to use the minimum of fresh water and to recycle as much of it as possible, recovering anything that has value. Human waste, for example, can be used to make energy from anaerobic digestion and to provide fertilizers.

A net zero world dictates that waste is not viewed as waste, but as a resource, providing value for whole countries, municipalities and villages. This approach is dictated by the scarcity and expense of primary materials and also the desire to retain the biodiversity of natural environments.

Engineering solutions that avoid concrete, facilitate natural drainage and runoff and mimic the natural processes of wetlands and catchments are increasingly being adopted.

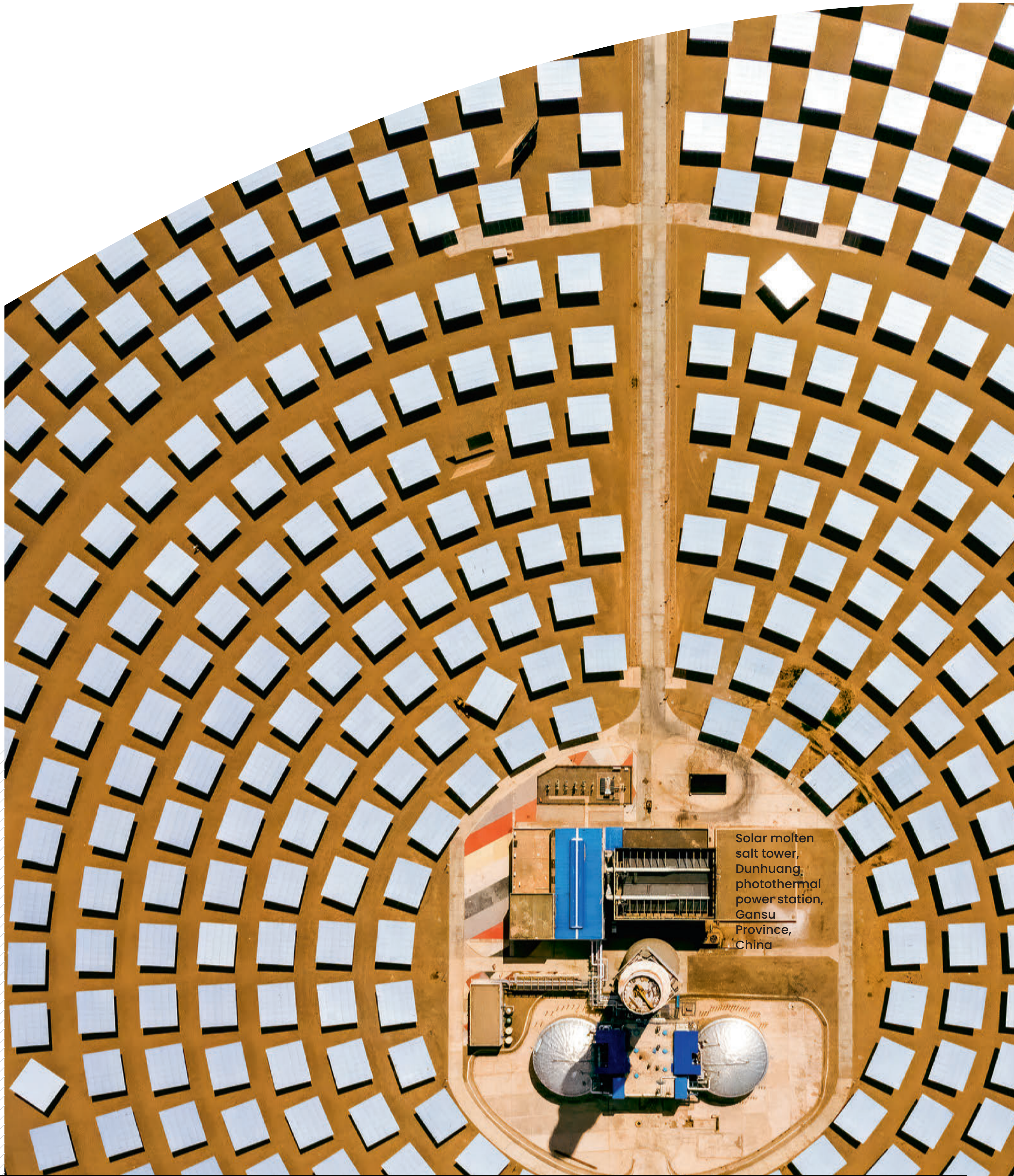
Drawing on chemistry, materials science and thermodynamics, new ways are being found to remove dissolved salts from seawater and brackish water by attracting and repelling their ionic charges (see page 33 Electrodialysis). Very small units can achieve this sophisticated function. So can enormous ones.

Every location imposes its own specifications. Here, we look at existing and emerging options that have the best potential for low-impact or circular desalination.

PHOTOVOLTAIC SOLAR POWER

Photovoltaic solar desalination has emerged as a front-runner because of its low capex costs and scalability. The technology works well on a very large scale but also for districts and villages which may not have a reliable electricity supply. A good ↘

PHOTO: GETTY IMAGES/MOMENT RF/ JIA YU



Solar molten salt tower, Dunhuang, photothermal power station, Gansu Province, China example, on a small scale, is the Likoni desalination plant south of Mombasa, Kenya, built by US non-profit GivePower.

Opened in 2018, it creates 75,000 liters of drinking water a day by reverse osmosis, supporting around 15,000 people. The 50 KW facility cost $500,000 to build and took only one month to construct. It hopes to generate $100,000 per year, providing funding for new plants.

Led by CEO Hayes Barnard, GivePower began in 2013 as a non-profit branch of SolarCity, Elon Musk's solar-panel company. GivePower has deployed more than 2,650 solar-powered energy systems to schools, medical clinics and villages in 17 developing countries.

Barnard says: "Humanity needs to take swift action to address the increasingly severe global water crisis facing the developing world. GivePower can immediately help by deploying solar water farm solutions to save lives in areas suffering from prolonged water scarcity."

German company Boreal Light also provides small-scale solar-powered reverse osmosis units to Kenya and the Philippines through its offshoot, Kiosk. Its units deliver up to 20,000 liters of hygienic drinking water a day, typically with a 10 KW solar array.

CONCENTRATED SOLAR POWER

This technology uses mirrors to focus and concentrate heat. The heat can produce steam to drive turbines to generate electricity. It can also be used to produce molten salt. This can store heat at night when the sun is not shining, acting as a kind of battery.

Configurations include parabolic troughs, solar power towers and dish-shaped reflectors. CSP has great potential as a source of non-intermittent solar energy, but the capital costs are high.

In the 1970s, CSP plants were built in California and southern Spain, and in the mid-2000s it seemed to be the way forward for large-scale renewable energy in the MENA region.

In 1986, German particle physicist Gerhard Knies calculated that concentrated solar power had the potential to provide enough electricity for North Africa and the Middle and one-fifth of Europe, while requiring just 0.3% of the desert area.

The Desertec Industrial Initiative (DII), launched in 2009, attracted large German companies E.ON, Siemens and Deutsche Bank. It had a big idea – a network of CSP plants extending across North Africa to Saudi Arabia. The plants, up to 1 GW, would be linked to each other and to Europe, exporting current across the Mediterranean in a "super grid."

Despite the backing of then German chancellor Angela Merkel, the plan had foundered by 2014. The "Arab Spring" of 2010 led to political instability that discouraged investment, and the plummeting cost of photovoltaic panels meant that this form of solar energy was now by far the cheapest.

WIND POWER

Wind energy is well-suited to coastal and island communities. The world's largest examples are in Australia. Wind-powered plants have also been built in Spain's Canary Islands.

Sydney Desalination Plant is powered entirely by a wind farm, which has also increased the supply of wind energy in New South Wales by over 700%.

Also in Australia, the Perth Seawater Desalination Plant provides 15% of Perth's water supply using electricity generated by the 80 MW Emu Downs Wind Farm. Emu Downs is accredited as a green power generator by the Sustainable Energy Development Authority.

The wind farm contributes 270 GW-hours per year to the grid, exceeding the 180 GW-hour per year requirement from the desalination plant. An adjacent 20 MW solar farm tops up power in the middle of the day, when wind energy decreases.

In the Canary Islands, which have constant, reliable trade winds, wind-powered RO systems have been installed in Gran Canaria and Fuerteventura. Both can provide up to 50 m³ of water a day. Gran Canaria has installed wind power capacity of 100 MW.

WAVE POWER

The sea contains immense kinetic energy. In wave-powered systems, paddles or submerged devices create electrical energy, which is used for pumping and RO desalination on the shore.

At Garden Island in Western Australia, the Perth Wave Energy Project installed the world's first commercial-scale project to produce power and fresh water from wave energy in 2014.

The plant meets one-third of the water needs of the Royal Australian Navy's largest naval base, HMAS Stirling, using fully submerged, point absorber technology.


GivePower's Likoni Solar Water Farm, Kenya.

PHOTO: KLENSED PHOTOGRAPHY

The sea contains energy which can be used for desalination.

A fully wave-powered desalination system is planned in Cabo Verde, an island country in the Atlantic off the west coast of Africa. The €20 million system is designed to supply more than 48,000 people with fresh water.

Developer Resolute Marine Energy claims that the Wave20 plant will produce drinking water at one-third of the price of conventional systems and save 5,400 tonnes of CO_2 a year. It aligns with the country's goal to achieve 100% renewable energy. The project is funded by the African Development Corporation.

GEOTHERMAL ENERGY

Geothermal desalination means using heat found underground to convert salty water to fresh water. Direct geothermal desalination uses captured heat directly to boil and condense seawater. In contrast, indirect geothermal desalination converts geothermal energy into electricity that is used for membrane desalination.

> "Humanity needs to take swift action to address its severe water crisis."
>
> **HAYES BARNARD**
> CEO GivePower

Geothermal energy is accessible day and night every day of the year, unlike intermittent renewable energy sources. It is affordable. The US Department of Energy has estimated that geothermal desalination can produce desalinated water at a cost of $1.50 per m³. It is estimated that 39 countries in Africa, the Americas and the Pacific could potentially obtain 100% of their electricity geothermally. As yet, this energy is rarely used for seawater or brackish water desalination.

Saudi Arabia has substantial geothermal resources along the Red Sea coast that could be developed to generate power cost-effectively and produce fresh water at scale. California is also well-supplied with geothermal energy.

The small coastal country of Djibouti in the horn of Africa has a geothermal potential estimated at 1,000 MW, enough to meet the country's entire electricity demand. This would provide an ideal energy source for desalination.

FORWARD OSMOSIS

Forward osmosis is used for the treatment of brackish water with a lower saline concentration than seawater, and for wastewater treatment and resource recovery.

A highly concentrated "draw solution" is placed in a tank, separated from a "feed" solution to be purified by a permeable membrane. Because natural osmotic pressure is used, there is no requirement for high-pressure pumping. The process can remove high levels of contaminants, including bacteria, viruses and organic compounds.

The energy requirement is extremely low compared to reverse osmosis and the process can be assisted by waste heat, which is found in most industrial areas. The final product of the FO process is not clean water, but a diluted draw solution. In some cases, this is then filtered by RO, in post-treatment, to produce pure drinking water.

ELECTRODIALYSIS

Electrodialysis, an ion exchange technology, is also used mainly for treating brackish water, with total dissolved solids (TDS) of 2,000 to 15,000 ppm. Seawater contains up to 35,000 ppm. Most salts dissolved in water are negatively or positively charged ions. The technology uses electrodes and specialist membranes to attract and remove them. An ED stack consists of hundreds of cells that the feedwater is pumped through.

This is a chemical-free operation, and doesn't require specialized pipes, valves and pumps. It has a relatively low power requirement and achieves very high purity rates. In some systems, it is applied to "soften" water for post-treatment or drinking by removing the calcium salts that cause scale and make water "hard."

Energy consumption as low as 1.65 kWh/m³ has been demonstrated. This is less than half the energy that is required by conventional seawater reverse osmosis. ED and RO can be used together, with the ED stack treating both the RO feedwater and its brine stream.

CALL TO IMPACT

1 Modern water systems should use as little fresh water as possible.

2 In a net zero world, waste should not be regarded as waste, but as a resource.

4 Wind, wave and geothermal energy offer huge unexploited potential for reverse osmosis desalination.

PHOTO: GETTY IMAGES/E+/SHANNONSTENT

A NEW GOLD RUSH: EXTRACTING VALUE FROM BRINE

Formerly regarded as a waste product of reverse osmosis, liquid brine can be "mined" for valuable resources and used for fish farming and to grow fodder crops.

SEAWATER DESALINATION has been dogged by two main problems – its energy demand on grids and the high salinity of its wastewater discharges, which often contain residues of pre-treatment, such as descaling and cleaning chemicals that can harm marine ecology.

Reverse osmosis desalination significantly reduces energy demand compared to earlier thermal methods, but most of its energy is still coming from fossil fuels, producing 76 million tonnes of Co_2 per year. This issue can be addressed by using renewable energy sources to power desalination (see page 28 New Solutions), but what of brine? Global brine production from desalination stands at 142 million m^3/day. Saudi Arabia alone is reckoned to produce 20% of that brine.

Most large RO plants discharge their briny wastewater back into the ocean, often after diluting it with normal seawater. The effect on marine ecology is disputed. RO desalination has had less impact than thermal MED and MSF methods, which discharged brine at a higher temperature in greater volumes for the fresh water recovered. But it still has the potential to harm aquatic life, particularly given that the brine tolerance of sea grass is low. In the Middle East, the Red Sea and Arabian Gulf are already highly saline.

The best process regulation, as in Western Australia, dictates that ↘

PHOTO: GETTY IMAGES/MOMENT/NUDIBLUE

Salt
Chemical and food industries.

Lithium
Lithium hydroxide is essential for batteries

Magnesium
Pharmaceutical and agricultural industries.

Potassium
Fertilizers, food industry, medicine.

Bromine
Treating water, flame retardants. Chemical and food industries.

Gypsum
Fertilizers, paper filler, textiles, plaster and wall boards.

PHOTO: GETTY IMAGES/MOMENT/NUDIBLUE

↘ water is removed from the sea so as not to scoop in fish and other marine life, and that brine is discharged with harmful chemicals removed, at an appropriate temperature, pH level and salinity, and dispersed. That minimum level of good practice is still not the case in every regulatory system.

Providing these good practices are observed, Philip Davies, professor of water technology at the UK's University of Birmingham, who has worked on desalination projects in the Middle East and India, believes that the impact of RO desalination on marine ecology can be reduced to an acceptable level. "The amount of seawater that we are treating by desalination is very small compared to the natural global water cycle, which is desalinating all the time through rain. If you mix and spread out the outlet water sufficiently, it should be possible to deal with the problem."

Seawater contains every element in the periodic table – even gold, at tiny levels that cannot yet be economically extracted (though researchers are trying). Every liter of seawater contains 35 grams of dissolved salts. Some are valuable and extracting them from highly concentrated brine is less environmentally invasive than digging them out of the earth. While there can still be a saline discharge after "brine mining" has taken place, it is a good example of circular water management and often forms an element of "zero liquid discharge" systems.

The most abundant dissolved compound in the sea, sodium chloride, or salt, has many commercial uses. It is used to produce chlorine, caustic soda, sodium hydroxide and hydrochloric acid; to manufacture plastics, textiles and paper; in the oil and gas industry to extract natural gas and remove impurities; as well in food manufacturing and on our tables.

But salt is only the start. Lithium, sodium and potassium, reactive alkali metals found in seawater, have extensive uses both as pure metals and as compounds. Seawater also contains magnesium, calcium, bromine, chlorine and gypsum (see box on page 36).

Using different pore sizes and materials, reverse osmosis membranes can be "tuned" to remove different permutations of salts and other chemicals from seawater or brackish water, which can come from underground aquifers, and wastewater, as well as bacteria and suspended solids.

Engineers can decide which to extract and which to let through, allowing a finely nuanced system. Specialized membranes, offshoots from reverse osmosis research, used singly and in combination, are pushing forward an exciting new development – extracting valuable resources from water. ↘

Whether it is economic to source chemicals from seawater depends on complex factors – commodity prices, politics (such as the desire for resource self-sufficiency in a given region), the possiblity of the co-location of processes and economics of scale.

Co-locating power generation, seawater desalination and brine processing on one large site optimizes energy and transportation costs and assures product volumes that can supply both domestic and international markets.

This upscaling is already happening in Saudi Arabia. Saline Water Conversion Corporation of Saudi Arabia (SWCC) has embarked on a comprehensive program to develop advanced technologies to extract minerals from brine.

The SWCC has made large offtake agreements with Saudi chlor-alkali producers to supply them with high-purity salt as liquid solution or crystals. A new plant will receive brine from the 1 million m³/day Jubail 2 desalination plant. It is set to produce 2 million tonnes of sodium chloride and 3,600 tonnes of bromine annually. An SWCC statement says: “We consider desalination plant brine to be a valuable resource rather than a waste. At present our focus is extracting sodium chloride and bromine, with plans in a later phase for production of potassium chloride, magnesium salts and rare metals such as rubidium, lithium and caesium. The revenue from selling these commodities can be used to subsidize the cost of water production, with the ultimate vision of ‘zero cost’ water.”

“Brine mining” will be integral to Saudia Arabia’s megaproject, NEOM, explains its head of water Gavin Von Tonder. “We’re not allowed to put the brine back into the sea, so we are using advanced membrane technology to extract valuable minerals. In the early phase, we will focus on four materials. The first is salt – there’s a huge salt market in the world. The second is potassium, which has a very high value, especially as fertilizer. Given that we’re going to be doing a lot of regreening, we’ll use that fertilizer within NEOM. We will also produce gypsum, to make gypsum board for construction. The fourth is magnesium.”

Valuable chemicals can also be extracted from inland water sources, such as brackish aquifers and mine and quarry workings. In Chile and Argentina, lithium hydroxide is produced by surface evaporation. Chile is the world’s largest producer of this valuable resource, which is essential for lithium-ion batteries used in EVs. In the UK, companies in Cornwall hope to extract up to 20,000 tonnes a year of lithium from brine in former china clay mines.

PHOTO: GETTY IMAGES/MOMENT/NUDIBLUE, PRIVATE

> “The amount of seawater that we are treating by desalination is small compared to the natural global water cycle.”

Philip Davies, Professor of water technology, University of Birmingham

FISH, ALGAE AND SALTBUSH

In South America, vast expanses of brackish underground water, often rich in valuable mineral salts, extend across eastern Bolivia, Paraguay, northern Argentina and northeast Brazil. These areas are home to low-income, agricultural communities based on livestock farming and irrigated agriculture.

Highly water-stressed, north-eastern Brazil is one of the largest semi-arid areas of the Americas, with a population of 22 million. Underground brackish groundwater is found throughout the region.

Launched in 2004, a government program named “Agua Doce,” meaning fresh water, has greatly benefited this part of Brazil. Almost 1,000 reverse osmosis plants, serving half a million people, have been built and provide 3.2 million liters of fresh water a day for drinking, washing and irrigation.

Most of the waste brine is used profitably, generating much-needed income for local communities. Some of the brine discharge is allocated to commercial fish farming based on tilapia.

Salty water is also used to irrigate fields of halophytic, or salt-tolerant, plants. An introduced crop, Atriplex nummularia, or oldman saltbush, native to Australia, is used as animal fodder in the commercial farming of goats, sheep and cattle.

Seawater and brackish water desalination combined with fish farming has enormous global potential to produce protein for local consumption or as a high-value export. Saltwater-tolerant species include barramundi, red snapper, black bream, mullet, tilapia and brine shrimp. In Norway, a facility proposed by Eco Seafood for the island of Kråkøy would produce 1,200 liters of desalinated fresh water per minute to farm up to 46,000 tonnes annually of valuable salmon and rainbow trout.

In other emerging systems, saline permaculture could be used grow Spirulina cyanobacteria, an edible algae, which can also be used as a human food supplement or as animal food or to make a biofuel.

BIOLOGY AND CHEMISTRY

Salt-tolerant algae can concentrate multiple times more salt levels than the water they live in. This opens up the prospect of a technology that has not yet been commercially developed: bio-desalination. Seawater would be pumped into vats of algae and fresh water would emerge.

Ocean alkanization has been trialed to enhance the ocean’s function as a carbon sink. In this process, a mineral, such a basalt, or an artificial substance, such as calcium hydroxide, or lime, is added to seawater. In a reverse chemical reaction to cement-making, it is converted by the sea into calcium bicarbonate. This causes the ocean to absorb more CO_2 from the air. In another version of the idea, alkaline magnesium hydroxide, separated from the sea by electrolysis or solar thermal decomposition would be discharged back into it.

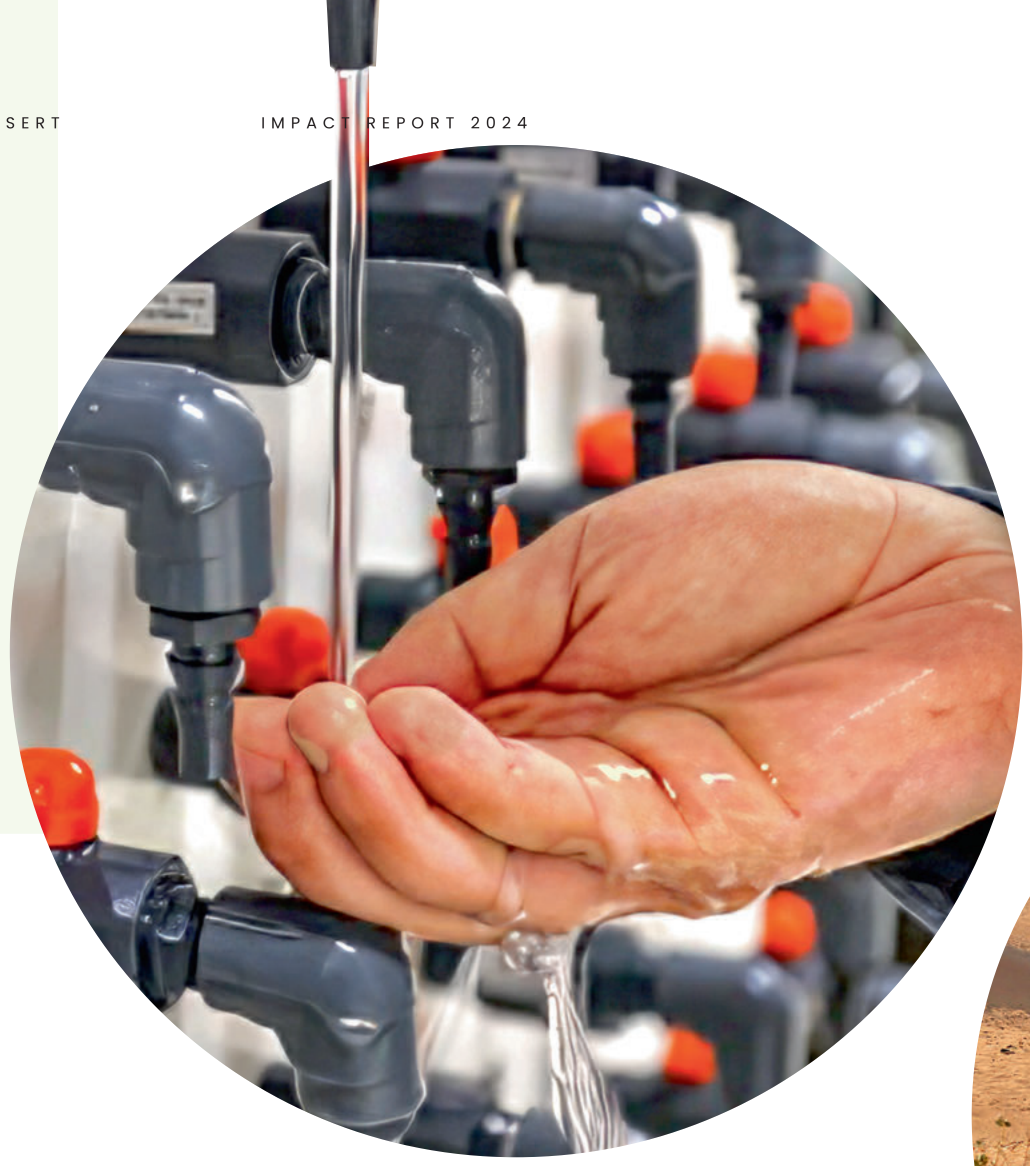
As with other forms of large-scale geoengineering that have been proposed to combat climate change, ocean alkanization is controversial. Critics say that even if it worked in its primary objective, it could have unforeseen and damaging consequences for the sea. ■

CALL TO IMPACT

1. Process regulation should minimize brine discharge.
2. Valuable salts and other chemicals can be extracted from seawater and brine.
3. Reverse osmosis can be tuned to remove different chemicals.
4. Fish farming can generate protein and income from discharged brine.

RISE OF THE SOLAR GIANTS

The Middle East has fantastic solar resources, plenty of land to build on and long coastlines. It is leading the word in the development of desalination by reverse osmosis using solar power.



PHOTOS: GETTY IMAGES/AFP/FAYEZ NURELDINE; GETTY IMAGES/AFP/KARIM SAHIB

TWO RESOURCES FOUND deep underground have played equally important roles in the economic and social evolution of the Middle East: oil and water. The Hejez, the western part of Saudi Arabi, was a poor, dusty region in the 1920s, home to nomadic tribes, its oil and mineral resources yet to be discovered.

It had, however, a huge and precious asset, the Holy City of Mecca, to which thousands of pilgrims flocked each year. Nearby Jeddah, on the Red Sea coast, was the gateway to Mecca. Historically, Jeddah had struggled to supply enough water to meet the needs of pilgrims. In 1907, a Dutch company provided a partial solution – two coal-fired seawater distillers from ships. These primitive devices were the ancestors of modern seawater desalination in the Middle East.

In 1928, King Abdulaziz Al Saud, who was to found the modern Kingdom of Saudi Arabia four years later, ordered two brand new units. They had a capacity of 135,000 liters a day – enough water for about a thousand people. In 1933, oil was discovered on the island of Bahrain. In 1938, oil was struck in the fabulously rich Dhahran field in Saudi Arabia. Vast reserves were soon also found in Iraq, Kuwait and the UAE.

Oil extraction and its subsidiary industries needed large supplies of water. In the 1950s, Qatar and Kuwait built what were then substantial municipal seawater desalination plants.

GAME CHANGING TECH

By the 1960s, a game-changing technology had arrived. Multistage flash (MSF) technology, invented by Scottish engineer Robert Silver, increased the capacity of thermal saltwater desalination plants by a factor of more than ten. The first MSF plant in the Middle East was installed in Kuwait City in 1960. The largest in the world at the time, it provided 4,546 m³ of water a day.

The growth of oil wealth in the Middle East was matched by a population boom. Between 1960 and 2022, Saudi Arabia's population alone rocketed from 4 to 37 million people. The country relied on water drawn from deep underground aquifers. This supply of "fossil water" is extensive – it still meets 40% of the country's needs – but it is not renewable. Like oil, it will run out.

Saudi Arabia nationalized water, and in 1965 its agriculture ministry set up a department dedicated purely to desalinating saline water. It began to build large desalination plants along coastlines. By now, a new technology had arrived, requiring even less energy than MSF – reverse osmosis. By 2000, 51% of new installed desalination capacity in the Middle East used this method.

Today, Gulf Cooperation Council (GCC) countries account for 60% of global desalination from more than 1,000 plants, with the largest in Saudi Arabia, the UAE, Kuwait, Bahrain and Oman, as well as Israel.

Saudi Arabia is the world's leading desalinator, providing 38% of total world output, with 21 plants on the Red Sea Coast and six along the Persian Gulf using reverse osmosis.

Finance has been as important as technology in advancing progress, according to Paul Buijs, water treatment consultant and formerly water center liaison officer for the King Abdullah University of Science and Technology (KAUST). "There is a very important paragraph in Saudi Arabia's national plan, Vision 2030. It says that providing subsidies with no clear criteria is an obstacle to competitiveness. In the future, subsidies will only go to those who need them."

Buijs argues that the free market has opened the door to unprecedented investment in Saudi Arabia's water infrastructure. Vision 2030, launched by Crown Prince Mohammed bin Salman in 2016, created a new procurement mechanism – public private partnerships (PPPs).

In a bold partial privatization, shares from Saudi Aramco were offered to investors in 2019 in the world's largest IPO, raising $25.6 billion from 3 billion shares, which was 1.5% of the company's value, for state coffers.

Saudi Arabia's National Water Strategy of 2018 specifies that 90% of Saudi Arabia's water demand should be supplied from desalinated sources and 100% of wastewater treated by 2030, by which time the country is projected to have a population of 40 million.

Saudi Arabia is signed up to achieving the UN's Sustainable Development Goal 6, clean water and sanitation for all by 2030. It has a target of supplying 50% of electricity from renewable sources by the same year, with an additional 41 GW of solar capacity by 2032, and to achieve net zero by 2060.

The Saudi Water Partnership Company (SWPC), created as part of Vision 2030, tenders all water supply and treatment projects. It plans to oversee the investment of $80 billion into desalination over the next decade and to reach a ↘

Ahmed Abdulla Alsuqri and his son harvesting roses in Al Jabal, Al Akhdar, Oman.

Reflection of palm trees at Yanbu al-Bahr Tusam, Red Sea coast, Saudi Arabia.

desalination capacity of 8.5 million m³ a day by 2025. It is committed to increase the use of solar energy for new projects, and to make wastewater treatment more efficient. Competing for contracts are companies such as Saudi Arabia's ACWA Power and Mowah, the UAE's Masdar and Tawzea, and international players including French Suez and Veolia, Spanish Acciona and US Aquatech.

Buijs argues that SWPC's build, own, operate and transfer (BOOT) contracts have been central to reducing the energy requirements and cost of desalinated water.

Typically, contracts specify two offtakes – water and electricity – at a guaranteed price for a period of up to 25 years. Buijs says: "The developer provides the investment for the plant in return for a guaranteed, long-term income. They take the risk. It's in their interest to make the plant as energy-efficient as possible."

Reverse osmosis and the ever-decreasing cost of photovoltaic solar energy are driving change. The Middle East is leading the world in showing how these technologies can be scaled up to produce the "mega plants" of the future.

Commissioned in Saudi Arabia in 2017 as a flagship project for Vision 2030, built by Advanced Water Technology (AWT) and completed in 2019, the Al-Khafji plant on the Persian Gulf coast, close to Kuwait, is a way marker.

The first in the Middle East to be powered entirely by solar PV energy, it is a close-to-zero carbon emission desalination facility. Using cutting-edge technology developed by the King Abdulaziz City for Science and Technology (KACST), including concentrated solar power, the plant can produce 90,000 m³ liters of clean water per day, enough to supply a city of 150,000 people. It is reckoned to have produced a 40% reduction in cost per m³ compared to previous plants.

Acciona and a Chinese company, SEPCOIII, have begun work on an even larger RO plan. From 2024, Jubail 3B will filter 570,000 m³ per day, enough to supply 2 million people in Riyadh and the Al Qassim province. It is one of seven desalination and wastewater treatment plants being built by Acciona in the KSA. They will jointly produce 2.4 million m³ per day, enough to supply about 5 million people. Jubail 3B will draw some of its power from a 61 MW photovoltaic facility, the largest solar plant for a desalination facility in the KSA. Another solar giant, being built by ACWA Power in the UAE, is expected to be completed by 2025. The Taweelah desalination plant will produce 909,000 m³/day from RO desalination, sourcing power from a solar park.

Nost desalinated water in the Middle East is used in cities rather than for farming. But that could change. Philip Davies, Professor of water technology at the University of Birmingham says: "Desalinated water is now reaching the threshold of affordability for irrigation."

As oil reserves become more precious, Davies notes, it will be increasingly important to use them for industry and petrochemicals, rather than for producing water – another factor that is driving low-energy forms of desalination.

PHOTOS: GETTY IMAGES/ FRANCOIS NEL; PICTURE ALLIANCE/WESTEND6; ILLUSTRATION: FLATICON.COM/PIKSART

CALL TO IMPACT

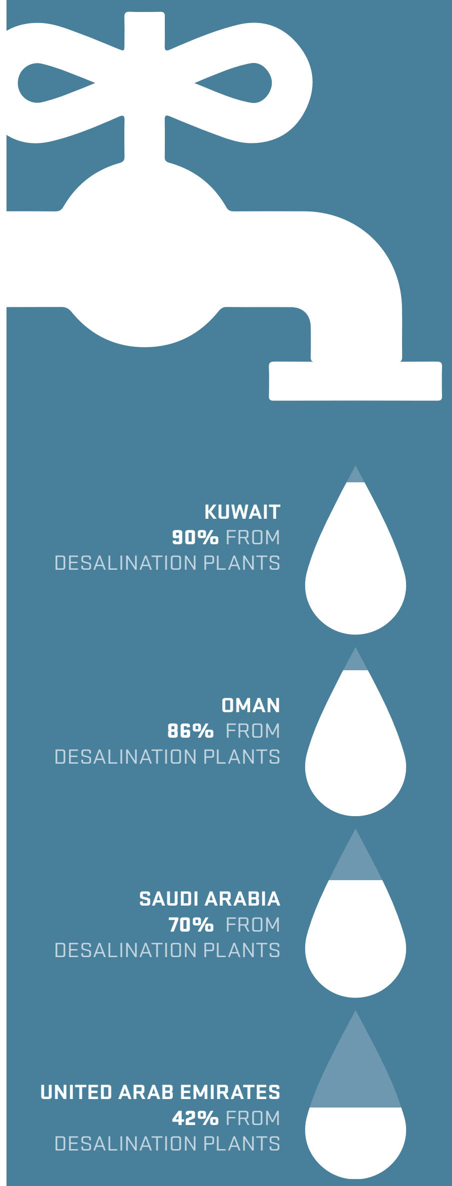
1 In Saudi Arabia, private finance, specified by Vision 2030 in 2016, has driven investment and innovation in desalination.

2 Shifting development costs to the plant operator Build, own, operate and transfer (BOOT) contracts are good for water infrastructure.

3 In the Middle East, the decreasing cost of photovoltaic solar energy and concentrated solar power makes RO "super plants" possible.

4 It will become desirable to use oil for industrial processes and petrochemicals, rather than desalination.

DEPENDENCE OF GCC COUNTRIES ON DESALINATED WATER



Boa Vista, one of the Cabo Verde islands, off the coast of Mauritania.

PHOTO: SHUTTERSTOCK / M.PAKATS

COASTAL POTENTIAL: AFRICA IS WAITING FOR DEVELOPMENT FINANCE AND LARGE-SCALE INVESTMENT

Climate change is having a profound impact on Africa's already fragile water security. With miles of coastline and abundant sun, several African countries are perfect for sustainable desalination, but the continent still has many hurdles to overcome.

THE NUMBER OF PEOPLE who are experiencing water insecurity in Africa is staggering. According to the Global Water Security 2023 assessment from the United Nations University's Institute for Water, Environment and Health, the figure is 1.34 billion: pretty much the continent's entire population.

The Sahel, the Horn of Africa and parts of West Africa are among the least water-secure regions on earth. But desalination by reverse osmosis offers a huge opportunity for coastal African countries and those with access to salt lakes to overcome their water insecurity. The vast amount of potential renewable energy sources across the continent means it should be possible to do this without impact on greenhouse gas emissions.

A wave-powered desalination system using reverse osmosis by tidal energy specialists Resolute Marine planned for Cabo Verde, off Africa's west coast, will supply almost 50,000 people with clean water, while avoiding 5,400 tonnes of CO_2 emissions annually.

The plant is an important indicator of potential, but solar power offers the biggest opportunities for Africa to transform its most water-insecure regions.

According to World Bank data, Africa has the greatest solar energy potential of anywhere on earth, ranking ahead of Central and South America and Asia. A 2022 report from the Energy for Growth Hub states that while the rapid growth of the continent's solar PV market would be "an enabler for renewable energy-powered desalination by driving down energy costs," some significant challenges remain.

The document calls on African governments to formally recognize desalination in their water strategies, in order to spur market growth. "Unfortunately, desalination was not considered in the African Development Bank Water Strategy 2021-2025, nor in the Water Strategy 2018-2030 of the African Ministers' Council on Water," it states.

The report calls for investment in smaller, decentralized modular desalination systems, which don't require the "high capital investments, complex financing requirements and large land utilization" of large-scale plants, and are also able to boost the socioeconomic development of remote rural communities.

The continent's first solar-powered desalination plant, in South Africa's Hesseuqua principality, has now been fully operational since 2018. The OMOSUN plant is currently producing around 150,000 liters of drinking water per day, two-thirds of which is produced exclusively using solar energy.

Commissioned in 2020, GivePower's solar water farm in Likoni, Kenya, is a solar-powered desalination plant able to convert 70,000 liters of seawater or brackish water per day into drinking water for up to 35,000 people. This in a region where almost half the population lives on less than a dollar a day, and many lack access to fresh water.

Three African countries combine access to vast quantities of seawater along lengthy coastlines with abundant solar potential – Mauritania, Morocco and Namibia.

While about 90% of Mauritania's territory is in the Sahara, it also has more than 700 km of coastline. According to the Global Water Security 2023 assessment, it's also among the countries worldwide with the highest modeled drought risk, along with Niger and Sudan.

A reverse osmosis desalination plant in a fishing village south of Mauritania's capital Nouakchott has been fully operational since September 2022. A partnership project between Spanish company SETA and the Canary Islands Technological Institute, the plant, which has a capacity of 80 m^3 per day, is able to use solar panels, SETA tells Impact.

Solar power company ERM Energies has already established three small solar-powered desalination stations elsewhere in Mauritania. Two of the plants, which provide water for coastal villages in the Banc d'Arguin National Park, produce 10 m^3 per day, while the third produces 25 m^3.

On a larger scale, OMOSUN, the company behind Africa's first solar-powered desalination plant in South Africa, announced in March 2023 that it had plans to implement five solar desalination units with a capacity to produce 200 m^3 in the desert region of Tiris-Zemmour.

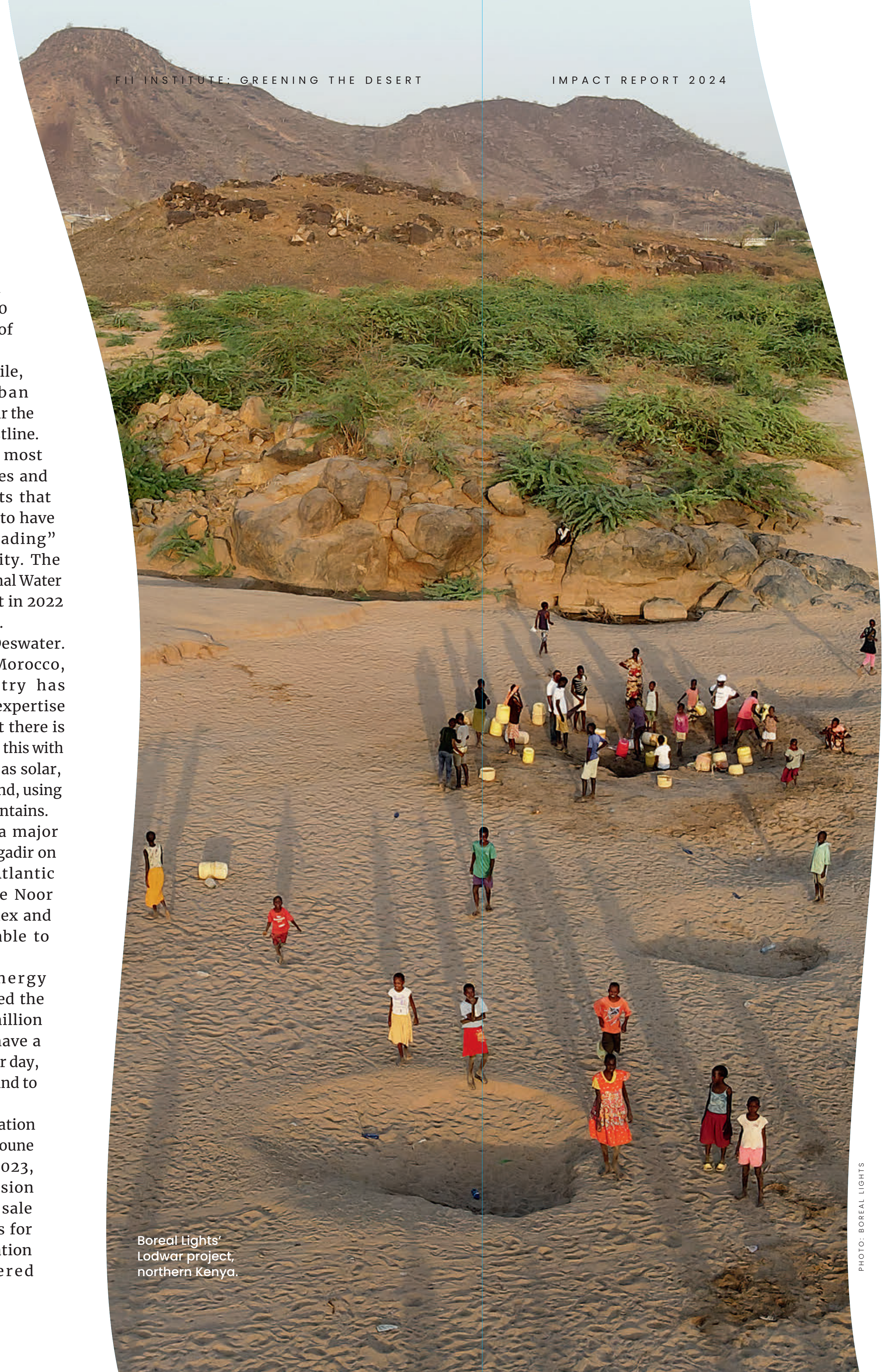
In Morocco, meanwhile, almost half the urban population lives on or near the country's 3,500 km coastline. It is one of the world's most water-stressed countries and the World Bank predicts that climate change is likely to have "cumulative and cascading" effects on water security. The country launched a National Water Plan in 2020. Its drought in 2022 was the worst in 40 years.

A 2021 report from Deswater.com, Desalination in Morocco, notes that the country has acquired considerable expertise in desalination, and that there is great potential to combine this with renewable energies such as solar, mainly in the south, or wind, using turbines in the Atlas mountains.

There are plans for a major desalination facility at Agadir on Morocco's southern Atlantic coast, connected to the Noor Ouarzazate solar complex and where it will also be able to harness wind energy.

Spanish green energy company Abengoa signed the contract for the €300 million project in 2017. It will have a capacity of 275,000 m^3 per day, with the potential to expand to 400,000 m^3.

There are also desalination projects in El Jadida, Laâyoune and Tan Tan. In May 2023, Chinese company Envision Energy announced the sale of 60 MW wind turbines for Morocco's first desalination project to be powered



Boreal Lights' Lodwar project, northern Kenya.

PHOTO: BOREAL LIGHTS

With world-class solar and wind energy, Nambia is well-positioned for renewable desalination.

completely by wind energy, in Dakhla, with a capacity of 113,000 M^3 a day.

Namibia, meanwhile, with its 1,500 km coastline, is home to what was for a long time the largest reverse osmosis desalination plant in southern Africa.

The Orano plant was constructed between 2008 and 2010 by a uranium mining company, with the water produced primarily for an uranium mine near Arandis. In August 2023, a subsidiary of the French company InnoVent began work on a 9.8 MW solar farm to supply the plant.

The country's first fully solar-powered desalination plant – one of the first desalination systems in the world to be 100% powered by renewable energy – was commissioned in 2021 as a joint project between the University of Namibia and Finland's University of Turku.

A modular system, it produces 3,500 liters of water per hour from the sea "with zero energy costs," says Solar Water Solutions, which designed and delivered it. "The life cycle costs of this solar-powered desalination solution are more than 70% lower than conventional systems, as there are no energy costs," explains the company's CEO, Antti Pohjola.

The Namibia Water Corporation has embarked on desalination plant projects in Grünau and Bethanie, to be powered by renewable energy.

"With world-class solar and wind energy, Namibia is well-positioned for renewably powered desalination and is also poised to become one of the world's largest green hydrogen producers," says a 2022 report from development finance body British International Investment.

However, unlike Morocco, Namibia doesn't include desalination in its national water strategy, and the country's aging and incomplete water infrastructure remains a significant challenge. ■

CALL TO IMPACT

1. Desalination by reverse osmosis offers a huge opportunity in Africa, especially for coastal countries.
2. African governments should formally recognise desalination in their water strategies.
3. Both community-based and large-scale national projects will help the continent to meet its water needs.

COULD THE PACIFIC OCEAN QUENCH SOUTH AMERICA'S THIRST?

A farmer waters inside a greenhouse in the Atacama desert, Antofagasta, Chile.

PHOTO: GETTY IMAGES/AFP/MARTIN BERNETTI

Seawater desalination might be the only viable solution to South America's increasingly pressing need to supply its populations and economies with a sustainable source of fresh water.

WATER SCARCITY IS A growing problem in South America, with climate change and unpredictable weather patterns combining with population growth and greater competition among agriculture, industry, and cities for fresh water to pile pressure on supply.

Even in non-arid parts of the continent, supply is a growing issue. Environmentally friendly solutions are needed. While Latin America enjoys roughly 30% of the world's fresh water resources, 16 of its biggest cities are facing water-related stress.

Peru, Chile and Mexico have more than 40 desalination plants between them, supplying mainly coastal regions to remove stress from inland areas. Until recently, the largest desalination plant providing water for human consumption in Mexico is in Ensenada in the Baja California area of the country. Powered from the grid, the comparatively small plant produces 20,000 m³ of fresh water a day.

Chile is a particular focus for the desalination industry, because of its long coastline, dry climate and an economy led by the thirsty mining sector, which accounts for roughly 15% of the country's GDP .

In 2019, showing the way ahead, infrastructure and energy company ACCIONA was awarded a contract to supply renewable electricity to ECONSSA's Caldera desalination plant in Atacama, Chile.

The plant has a capacity of 1,200 liters per second, serves four municipalities in the area and operates 100% on solar renewable energy. "The desalination plant for the Atacama region will provide Chileans with the latest and most efficient technology," says ECONSSA Chile General Manager Patricio Herrera .

But while clean desalination technology is gaining traction, more needs to be done. Former Chilean president Sebastian Piñer said, addressing the 2023 Water and Climate Change Summit hosted by NGO IDA: "The Pacific Ocean can quench thirst, alleviate serious drought and promote great progress for our lives. I'm fully convinced that the alliance between technology, nature and the entrepreneurial spirit can transform millions of liters of salty water into drinkable water."

Neal Aronson, president of Oceanus Power & Water LLC, runs a company that integrates RO desalination with pumped hydro electricity, and is investigating developments in the Americas. He says: "Desalination, both brackish and seawater, is the only true, resilient new supply of water."

Aronson's aim is to decarbonize the water industry, which is a major energy user, by powering plants and conveyance systems directly with green energy, including wind, solar and hydro.

"Part of the solution is designing a desalination system in such a way that it can utilize renewables, ideally for 100% of the power supply, rather than relying on a grid connection."

He says that problems relating to innovative installations come with longer project timeframes, making them a harder sell to private investors. There is also opposition from some environmental groups.

Copiapó desalination plant, Atacama, Chile, built by ACCIONA.

PHOTO: ACCIONA

> **"The science I've seen is that you can have rich marine environments around desalination plants."**
>
> **NEAL ARONSON**
>
> President, Oceanus Power & Water LLC

Aronson argues that these concerns can be avoided with careful planning and proper execution: "The science I've seen, and particularly this comes out of Australia, is that the impact is minimal. You can have rich marine environments around desalination plants." If all the energy consumed is renewable, the environmental case is further strengthened, especially if the byproduct is recycled.

Financial and regulatory barriers are harder to overcome. Aronson calls for more support from national governments, as well as grants, incentives and subsidies for investing in solutions that balance green credentials with problem-solving prowess.

Opponents of seawater desalination, he says, must be ready with viable alternatives. As he asks: if not desalination, then what? In his view, desalination doesn't just solve problems, it presents opportunities. With further advances and better infrastructure, greening coastal deserts could become viable, creating new spaces for farming and human communities in areas that were previously barren, taking stress off the land elsewhere.

"I think we're at an inflection point in society, civilization, where we have to solve resiliency questions. Are we going to decarbonize energy and all the other economic sectors? Are we going to create the resiliency that we need as a species to survive?

"I do believe that we have the tools, that we can do it. The technologies exist. It comes down to our abilities as humans and societal systems. Then it's just a question of whether these things are a priority for us. Or are we going to wait until the last possible minute and then scramble? I'm an optimist. I believe we can accomplish these things."

Seawater desalination via reverse osmosis and powered by green energy is a clear candidate for future provision of water to communities and economies across South America. Companies and regulators need to come together to build solutions that do the job without impacting ecological systems.

California's $1 billion Carlsbad plant in San Diego is the largest desalination facility in the US.

PHOTO: GETTY IMAGES/BLOOMBERG/PATRICK T. FALLON

DESERTS LOOKING FOR PEOPLE: GROWING CRISIS OF U.S. WATER STRESS

In the 1930s, the US built the vast Hoover Dam on the Colorado River and the world's largest aqueduct. Could engineering projects centred on low-low-energy RO desalination solve the dire shortage of fresh water in southern states?

THE UNITED STATES IS NOT famous globally for its drought conditions compared to parts of the Middle East and Africa. But the southern states in particular regularly come under severe water stress, thanks to unpredictable rainfall and tight reserves of fresh water.

Texas has suffered 18 drought events with a negative economic impact of at least $1 billion since 1980, including a water shortage that has endured since 2021, with several of the state's counties in a near perpetual status of "exceptional drought."

This is not a new phenomenon. Texas' worst and most enduring drought took place between 1950 and 1957, while the Dust Bowl period in the 1930s caused ecological disaster here and in neighbouring states all the way up to Canada.

Nor are water shortages limited to one or two rain-starved areas. The southwest, incorporating Arizona, New Mexico and parts of California, has experienced widespread dry spells since the turn of the century. In 2023, Florida faced an unusually dry year, with rainfall levels down significantly on annual averages, resulting in damaging wildfires.

As well as rainwater capture and restrictions on use, the US has embraced desalination technologies to convert both seawater and brackish agricultural wastewater into a product that can be used for industry, agriculture and human consumption.

Affected by the drying-up of the Colorado River, California has ↘

The Central Arizona Project canal runs past new homes under construction.

↘ led on installing desalination facilities. It currently has 12 desalination plants. In service since 2015, built by Poseidon Water, California's $1 billion Claude "Bud" Lewis RO desalination plant in Carlsbad produces some 190,000 m³ of water per day, supplying San Diego County with up to 10% of its needs.

But RO desalination in California has faced stiff opposition from environmentalists. In May 2022, following years of hearings, California's Coastal Commission voted to deny a permit for Poseidon to build a $1.4 billion plant to produce a similar volume of water in Huntington Beach, southeast of Los Angeles.

Despite these developments, at a national level, in September 2019, the US Department of Energy unveiled the Solar Desalination Prize to "accelerate the development of low-cost desalination systems that use solar-thermal power to produce clean water from salt water."

By 2021, the DoE had invested $15 million in the first two rounds. Competitors have access to industry expertise, venture capital and mentorship. Separately, in July 2023, the National Renewable Energy Laboratory (NREL) announced funding to improve energy efficiency in desalination and water recycling, part of a $9 million pilot program called the National Alliance for Water Innovation.

The funding will help NREL researchers work on new ways to treat desalination byproducts, particularly by capturing and reusing useful minerals and chemicals, and ensuring that plants can run on clean power.

Many of those concerned by water shortage fear that the move to new forms of desalination is proceeding far too slowly.

It's possible that the presence of the once mighty Colorado River and existing groundwater reserves have detracted from the very real crisis building up across the country, argues Aaron Mandell, a California-based tech entrepreneur and water expert.

His first desalination business spun out of Yale University and he has been working on new processes ever since, spending time in California's Central Valley, which is awash with brackish wastewater from agricultural irrigation.

With funding from the State of California, Mandell founded the company WaterFX. He argues that making start-ups in water is extremely difficult – water subsidies warp innovation, because prices do not rise in times of short supply, unlike in energy markets.

"At the time, there was no way to build a desal project that would last 20 years, without some type of long-term commitment. Something was broken in the market."

Mandell devised a hybrid plant in which solar electricity is used for reverse osmosis to treat a portion of the water. Once the water has been concentrated to brine, it switches to thermal energy to produce salt.

However, WaterFX's pilot plant is currently offline, caught in a legal dispute between the California Water District and the Bureau of Reclamation. That's 700 liters per minute of fresh water not being pumped that could be being derived from agricultural wastewater.

It's indicative of a country that arguably sits just behind the curve in terms of the potential of desalination technology to increase both productivity and the amount of liveable land in the US.

"The largest city in California by land area is not Los Angeles or San Francisco, it's California City, an enormous settlement with a tiny population right in the middle of the desert," says Mandell. "Not many people live there, because there's no water. You can't develop anything, you can't build anything. If we can master desalination, I think we could build a whole new generation of cities, many of them in places with water scarcity.

"We literally built hundreds of dams, including the Hoover Dam and the largest aqueduct system in the world to redistribute the Colorado River. It completely changed the course of the country in terms of agriculture, literally building California.

"It's not black magic, it's just a matter of actually developing a plan to build a decentralized network of smaller desalination plants, not on the coast but inland, powered by renewable energy."

North America is at a crossroads. The paths ahead are either making a definitive plan to source new freshwater or responding with emergency measures on a case-by-case basis. One thing's for certain: without concrete progress in the near future, states like California, Texas and Florida will go on facing water stress for years to come. ■

"It's not black magic. It's just a matter of developing a plan."

Aaron Mandell, tech entrepreneur and water expert

Worker adjusts RO desalination equipment at Poseidon Water's Carlsbad plant, San Diego.

PHOTOS: GETTY IMAGES/MARIO TAMA, PICTURE ALLIANCE/AP PHOTO/GREGORY BULL

Turbine at Capital Wind Farm in Bungendore, serving Sydney's Kurnel desalinatiion plant.

PHOTO: GETTY IMAGES/ BLOOMBERG/IAN WALDIE

DECARBONIZING DESALINATION

Spurred by drought, Australia has become one of the world's leading providers of seawater desalination. It has the means, through renewable energy, to move the technology from emergency recovery to being a staple of national supply.

AUSTRALIA FORMS the bulk of the driest habitable continent on earth, governed by the warm, sinking air of the subtropical high-pressure belt. It is mostly desert, with only the far east and southwest of the country enjoying more temperate weather systems and, by extension, croppable soil.

Rainfall patterns vary wildly from state to state, ranging from an annual 800 cm in North Queensland to a mere 12 mm at Lake Eyre in the country's south.

Partly due to the unreliability of rain, until the twenty-first century, cities, industry and agriculture drew fresh water from natural catchments and a network of dams. But this all changed with a brutal 12-year drought, which caused severe water shortages until it broke in 2009.

Those living in the country's most populous city, Sydney, will remember 2007 as a particularly bad year. The water level of Warragamba dam – constructed right after World War II due to a water shortage – dropped to less than one-third of its normal capacity.

This stark emergency and others led to a quick policy change, with state authorities diverting funds into large-scale desalination projects, mostly to purify seawater, with some employing renewable energy resources such as wind, solar and hydro to partially mitigate reliance on the local grid.

ADOPTION OF DESALINATION

In just a couple of decades, desalination has gone from being a nascent technology to a key supplier of supplemental fresh water for Australia's people, agriculture and industry. The country's first seawater desalination plant to use reverse osmosis technology, at Kwinana near Perth, was the largest RO plant in the southern hemisphere at the time it was built. The plant opened at the height of the drought in 2006. Built in just 18 months, it can pump 143,000 m^3 liters of ↘

water per day and is capable of fulfilling 17% of the city's fresh water needs.

The Gold Coast Desalination Plant, also using revere osmosis, was completed next in 2009 and, although it is operating at minimum production levels, can supply 27% of southeast Queensland if needed.

In 2012, a four more major RO plants began operating in Sydney, Adelaide, Perth and Dalyston in Victoria. The last is the largest in operation with a capacity of 410,000 m^3 liters per day, enough for about one-third of Melbourne.

Large companies active in the country's desalination sector include Veolia, responsible for long-term operations of the Gold Coast and Sydney plants, and Du Pont, which supplies reverse osmosis elements to Perth and Sydney.

CHALLENGE OF SCALING UP

So far, the exclusive use of renewable power for reverse osmosis desalination has been restricted to relatively small units. These range from emergency drought relief in the southwestern port city of Albany to a naval base at nearby Garden Island, a steelworks in Whyalla, South Australia, and a water sports resort on Long Island in Queensland. In the Northern Territory, an off-grid water-purifying system serves indigenous populations located around Gillen Bore.

The challenge is to scale up such schemes to serve city populations. Several large projects using reverse osmosis and renewable energy have failed to get off the ground. The ambitious Point Paterson project is a good example. The plan was to build a municipal-scale plant incorporating natural evaporation of brine at Winninowie in South Australia, south of Port Augusta.

It would have produced 6 million m^3 of water per year, with additional capacity for many times that amount, generating significantly more than 100% of the area's residential supply of water. Reverse osmosis and solar thermal generation would have produced fresh water and salt that could be sold, offsetting cost and preventing brine being pumped back into the Spencer Gulf.

Despite these strong on-paper numbers, the plant did not achieve the A$370 million funding it needed and was abandoned in 2014, with the insolvency of the parent company. Other projects to be voided or lengthily postponed include the 280,000 m^3 a day Point Lowly plant at Port Spencer in South Australia, designed to attract mining companies; one in Toukley New South Wales, which may now be built in 2039; and an Anketell Point plant, approved in 2013 then cancelled.

LEAD ON RENEWABLES

The state of Western Australia, 32% of whose energy is renewable, is taking a national lead on sustainable desalination, with all new plants in the state legally required to use renewable energy. In a scheme that could set a pattern for future developments in the country, the Water Corporation, which serves 2 million people in the state, has proposed a 270,000 m^3 a day reverse osmosis desalination plant at Akimos Beach, 40 km north of Perth.

In an Integrated Water Supply Scheme (IWSS) including wastewater treatment, the corporation is to secure up to 400 MW of wind energy to power Akimos Beach and its two existing RO seawater desalination plants serving Perth, at Kwinana and Binningup. Subject to environmental approval, the plan is to be delivered in two stages, with the first stage expected by 2028.

In an arid country like Australia, seawater desalination is the most environmentally friendly solution for water security, as long as it's supported by renewable energy, says Gary Crisp, member of the Australian Water Association's Desalination Specialist Network.

"It doesn't damage the environment, it doesn't affect the water table, and it doesn't put dams on rivers. A lot of people are wondering about renewable desalination, where it's going and how it's going to work, particularly in light of the need to switch to carbon-free energy sources. The main thing that makes it difficult is that renewable energy sources are intermittent. The biggest challenge is figuring out ways to go with the flow of renewable energy."

SCOPE OF CENTRAL DESERT

Could Australia terraform parts of its vast central desert, potentially locating new settlements there? Neal Aronson, president of Oceanus Power & Water LLC, argues that, while Australia is up with the front-runners in desalination technology, it and other countries need to make a step change in energy-sourcing, if they are to move the technology, on a large scale, inland.

Aronson says: "In water-stressed regions of the world, like Australia, South America, Africa and even the US, the bulk of the population tends to live in coastal regions, so those are the areas that need to access desalination and to do it cost-effectively. But in the future, internal regions could do so too."

Throughout history, people have followed the discovery of natural resources. The unlocking of new fresh water sources could have massive consequences for land settlement in Australia. The country is a test case for what can be achieved when government, finance and the will to make things happen combine. But after solving the immediate problem of drought with a burst of construction, only time will tell if these factors can also spur a new generation of cleaner plants with a new set of objectives.

PHOTO: GETTY IMAGES/CASSANDRA HANNAGAN/PHOTODISC

Eastern Gray Kangaroo at Pebbly Beach in New South Wales.

THE MULTIPLIER EFFECT

By creating sustainable sources of fresh water, we can reduce carbon emissions, rebalance global food supplies, repair damaged ecosystems and build local and national economies, while addressing all 17 UN SDGs.

EXCEPT IN COUNTRIES AND regions on the front line of the problem, the escalating crisis of water scarcity is being overlooked by most policymakers or, at best, addressed as a silo issue. It is certainly lower in the hierarchy of attention and concern than climate change, yet water lies at the heart of most of the earth's problems. They are present in our concrete-encased, water-repelling cities, drainage systems that simply flush contaminated water into the nearest river and irrigation systems that confer fertility upon parched soil ruined by over-intensive farming.

Ever-deepening boreholes, dwindling aquifers, expanding desertification and shrinking, poisoned lakes provide ample evidence of this malaise. But water is not just another overstressed system. The hydrological cycle is the basic, underlying system that makes all life possible. Ironically in this context, that much-demonized element carbon is our friend not our enemy. Without carbon dioxide, converted by plants into oxygen and energy, life on earth would die.

Yes, there is too much free man-made carbon dioxide in the atmosphere, but a problem of equal magnitude is that, because of historic land-use change, the world is not green enough to allow us to photosynthesize out of danger. We don't just need to green the desert. We need to green the planet.

The water crisis is urgent. According to the World Resources Institute (WRI), global water demand will increase by 25% by 2050. If nothing is done, another billion people will be affected by extremely high water stress, including 100% of people in the Middle East and Africa. This will jeopardize sanitation and healthcare, make regional conflicts more likely and threaten the production of staple crops like wheat, rice and maize. To provide enough food for 10 billion people by 2050, according to the WRI, the world will need to produce 56% more calories than it did in 2010.

Reverse osmosis desalination and smart, circular water management provide partial solutions. They are being applied, but many factors stand in their way. On the facing page, we make some practical recommendations covering policymaking, planning, technology and finance.

TEN WAYS TO REDUCE WATER STRESS

A charter for consumers, policy shapers, scientists and government

1

THE U.N. DOES NOT HAVE A FUND OR PROGRAM DEDICATED EXCLUSIVELY TO WATER. IT HELD ITS FIRST INTERNATIONAL WATER CONFERENCE IN HALF A CENTURY IN NEW YORK IN 2023. THERE IS NEED FOR A "PARIS MOMENT" TO INCREASE INTERNATIONAL AWARENESS OF WATER ISSUES.

2

DEVELOPMENT NGOS AND BANKS HAVE BEEN SLOW TO FINANCE DESALINATION. THE SECTOR NEEDS TO EXPLAIN THAT IT IS NOT MERELY AN "ADAPTION MECHANISM" FOR CLIMATE CHANGE BUT, AT SCALE, CAN PLAY A PROACTIVE ROLE IN REDUCING IT.

3

WATER MANAGEMENT AND PLANNING, AT A NATIONAL AND LOCAL LEVEL, INCLUDING INSTALLING DESALINATION INFRASTRUCTURE WHERE APPROPRIATE, SHOULD BE INTEGRATED, IN EVERY COUNTY, WITH PLANS AND TARGETS FOR ACHIEVING NET ZERO AND INCREASING BIODIVERSITY.

4

IN INFRASTRUCTURE PLANNING, POWER, WATER SUPPLY, SANITATION AND WASTE MANAGEMENT SHOULD ALWAYS BE CONSIDERED TOGETHER, NOT IN SEPARATE SILOS. IN WATER-STRESSED COUNTRIES, CO-LOCATION OF POWER GENERATION AND DESALINATION IS OPTIMAL.

5

TRADITIONALLY, WATER AND WASTEWATER INFRASTRUCTURE HAS BEEN COMMISSIONED BY PUBLIC AUTHORITIES WITH LITTLE INTEREST IN SUSTAINABILITY. PUBLIC PRIVATE PARTNERSHIP BUILD, OWN, OPERATE AND TRANSFER (BOOT) CONTRACTS INCENTIVIZE PLANT OPERATORS TO LOWER ENERGY COSTS AND INCREASE EFFICIENCY.

6

VILLAGE-SCALE DESALINATION UNITS, RUN BY LOCAL ENTERPRISES, WITH PROFITS FROM WATER AND ELECTRICITY SALE FUNNELED INTO NEW UNITS, PROVIDE A "CASCADE MODEL" FOR SUPPLYING SAFE WATER AND POWER TO REMOTE COMMUNITIES.

7

GOOD WATER MANAGEMENT MEANS REDUCING FRESH WATER USAGE, EXTRACTING RESOURCES FROM WASTEWATER AND RECYCLING IT FOR RE-USE. CITIES LIKE AMSTERDAM AND SINGAPORE ARE IMPLEMENTING SMART WATER MANAGEMENT RETROSPECTIVELY, BUT IT SHOULD ALWAYS BE PLANNED INTO NEW SETTLEMENTS.

8

STRINGENT REGULATORY FRAMEWORKS FOR DESALINATION ARE ESSENTIAL. THEY SHOULD SPECIFY ENERGY BALANCE (100% RENEWABLE IS OPTIMAL), WATER INTAKE REQUIREMENTS, AND THE SUSPENDED SOLID AND CHEMICAL CONTENT, SALINITY AND TEMPERATURE OF BRINE OUTFLOW, SO AS TO REDUCE IMPACT.

9

MORE RESEARCH AND DEMONSTRATION IS NEEDED FOR DESALINATION POWERED BY A FULL RANGE OF RENEWABLE ENERGY SOURCES, INCLUDING GEOTHERMAL, CONCENTRATED SOLAR, WAVE, WIND AND HYDROELECTRIC POWER. FUNDING AND COMPETITIONS SHOULD INCENTIVIZE INNOVATION.

10

GOVERNMENTS SHOULD SUBSIDIZE THE USE OF MINERALS AND METALS RECOVERED FROM WASTEWATER AND BRINE IN THEIR INDUSTRIAL, CHEMICALS, FOOD AND CONSTRUCTION SECTORS. AN INTERNATIONAL CREDIT SCHEME COULD INCENTIVIZE BRINE-PROCESSING AND INNOVATIVE END-USES LIKE FISH FARMING AND GROWING SALT-TOLERANT FODDER CROPS.

DESALINATION OFFERS HOPE BUT MUST NOT MEAN 'BUSINESS AS USUAL'

FII-I has three pillars to deliver its mission: THINK, ACT and XCHANGE

1 FII-I THINK
Identify societal challenges and current inhibitors. Curate the brightest ideas to address societal issues

2 FII-I ACT
Catalyze innovation and initiatives by mobilizing partners and resources

3 FII-I XCHANGE
Create platforms for live discussions on the future of humanity. Share knowledge, stories and publications with different stakeholders

IN MANY COUNTRIES, THE availability of fresh water is scarcely thought about. For many decades, water has been an abundant and relatively cheap resource. But that is changing. The incidence of water scarcity is steadily increasing.

Parts of Australia were devasted by the millennium drought from 2001 to 2009. In other regions, drought episodes lengthened in the second half of the twentieth century as once reliable aquifers, lakes and reservoirs shrank under the twin assaults of increased extraction and global warming.

Desalination by reverse osmosis offers a partial solution to growing water stress. But it should not be regarded as a technological fix, supporting "business as usual."

Countries in which fresh water is plentiful should prioritize circular wastewater management systems and share their technologies. Those already reliant on seawater desalination need to reduce its environmental impact if they are to achieve net zero targets, shifting from fossil fuels and minimizing the effects of discharged brine.

This report describes practical, emerging solutions that, we believe, can be exported across a water-stressed world.

ABOUT THE FII INSTITUTE

THE FUTURE INVESTMENT INITIATIVE (FII) INSTITUTE is a global nonprofit foundation with an investment arm and one agenda: Impact on Humanity. Global, inclusive and committed to Environmental, Social and Governance (ESG) principles, we foster great minds from around the world and turn ideas into real-world solutions in four key areas: Artificial Intelligence and Robotics, Education, Healthcare and Sustainability. We are in the right place at the right time: when decision-makers, investors and an engaged generation of youth come together in aspiration, energized and ready for change.

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"Enabling a brighter future for humanity"

VISION
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MISSION
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PUBLISHER
Future Investment Initiative Institute
3884 Alakheel
District Unit 9
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Kingdom of Saudi Arabia

CONTACT
For clarifications and inquiries, kindly email:
info@fii-institute.org

EDITOR
William Hatchett

“NO WATER RESOURCES PROGRAM IS OF GREATER LONG-RANGE IMPORTANCE THAN OUR EFFORTS TO CONVERT WATER FROM THE WORLD’S GREATEST AND CHEAPEST NATURAL RESOURCES – OUR OCEANS.”

JOHN F. KENNEDY,
US PRESIDENT, 1961

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