# RENEWABLE ENERGY WATER DESALINATION PROGRAMME

## The New Frontier of Sustainable Water Desalination

Masdar
A MUBADALA COMPANY

Masdar INSTITUTE  SIDEM VEOLIA  SUEZ  TREVI SYSTEMS  ABENGOA  Mascara  ILF CONSULTING ENGINEERS  pwc

"Today, water can be provided through desalination, but within decades the situation will be different as there are no rivers in the region and no technology at present under our disposal to help meet the region's demand on fresh water. Therefore we have to focus our efforts on conducting relevant studies and researches and on drawing up suitable strategies and solutions to come up with ways to meet future demand and preserve natural resources for the coming generations."

***– His Highness Sheikh Mohamed bin Zayed Al Nahyan,***
*Crown Prince of Abu Dhabi and Deputy Supreme Commander of the UAE Armed Forces,*

We applaud the initiative of Masdar and its partners in producing this impactful report.

Knowledge building that encourages the commercialisation of clean technologies is critical to drive the expansion of the renewable energy industry and to mitigate climate change.

In particular, new solutions are needed to manage the growing water demand of the Arabian Gulf's population and other arid regions sustainably.

Abu Dhabi has been at the forefront of the shift towards renewable energy and advanced desalination technologies.

At ADWEA, we are developing the emirate's first large-scale solar PV power plant. Meanwhile, in January this year, we launched an expression of interest to develop Abu Dhabi's second large-scale reverse osmosis (RO) plant. Other RO systems are under development in the UAE and the region.

The Masdar Renewable Energy Desalination Programme has been instrumental in advancing the application of renewable energy in the desalination sector. In addition, the pilot plants tested in Ghantoot, Abu Dhabi have raised the industry profile of more energy efficient and novel desalination technologies.

They have also built further confidence in their commercial potential.

ADWEA was proud to offer its experience and expertise to the Masdar Renewable Energy Water Desalination Programme in its role as Abu Dhabi's desalinated water provider.

We look forward to collaborating with Masdar and other stakeholders to promote further innovation, commercialisation and deployment of sustainable water solutions.

**H.E. Dr Saif Saleh Al Sayari**
Director General
Abu Dhabi Water and Electricity Authority (ADWEA)

Developing innovative technologies that can sustainably source clean water is vital, not only for the UAE, but for countries throughout the Arabian Gulf and around the world.

The Masdar Renewable Energy Water Desalination Programme sought to address this critical need by investing in advanced technologies aimed at improving both the efficiency and the environmental performance of desalination processes used here in the UAE and internationally.

Five pilot projects were commissioned to explore the feasibility of renewable energy as a power source for seawater desalination. They also tested more energy-efficient alternatives to conventional desalination technology.

Our programme has helped to bridge the gap between research in the laboratory and commercialisation out in the field. Just as importantly, it has shown that multi-stakeholder partnerships, involving government, business and academia, can realise genuine innovation in response to global sustainability challenges.

Reverse osmosis combined with solar power is a commercially viable option to provide for the water needs of the Arabian Gulf over the long term. Energy efficiency improvements of up to 75 per cent, compared with technologies mostly used in the UAE at present, were also demonstrated through the programme.

On behalf of Masdar, I would like to pay tribute to the vision of His Highness Sheikh Mohammed bin Zayed Al Nahyan, Crown Prince of Abu Dhabi and Deputy Supreme Commander of the UAE Armed Forces. His call to action to safeguard the water security of the UAE inspired our programme.

Along with the Masdar Institute, who worked closely with us, Masdar would also like to recognise the commitment of its partners Veolia/SIDEM, SUEZ, Trevi Systems, Abengoa, and Mascara Renewable Water. We are also grateful for the expertise of ILF Consulting Engineers and PwC.

Together, we have produced compelling evidence of the critical role innovative desalination technologies and renewable energy can play in addressing the acute water needs of the UAE and other arid regions.

**Mohamed Jameel Al Ramahi**
Chief Executive Officer
Masdar

# ABOUT THIS REPORT

**Masdar** launched the Renewable Energy Water Desalination Programme in January 2013 responding to a call from Abu Dhabi's leadership. This forward-thinking initiative directed Masdar to develop and demonstrate advanced and innovative technologies in desalination.

Masdar is Abu Dhabi's renewable energy company which works to advance the development, commercialisation and deployment of clean energy technologies and solutions. The company serves as a link between today's fossil fuel economy and the energy economy of the future. Wholly owned by the Mubadala Investment Company, the strategic investment company of the Government of Abu Dhabi, Masdar is dedicated to the United Arab Emirates' long-term vision for the future of energy and water.

**Masdar Institute,** is part of the Khalifa University of Science and Technology and a graduate-level research university in Abu Dhabi. As part of the Programme, the Masdar Institute conducted five R&D projects in collaboration with – and funded by – the participating companies.

**ILF Consulting Engineers** provided support to Masdar throughout the programme with technical advice and engineering support. Their engagement spanned from the initial design of the Programme to analysis of the results.

**PwC** assisted Masdar in defining an action plan on commercialising its renewable energy desalination efforts, and helped outlining the potential future role of the project site.

# WHAT'S INSIDE

# GLOBAL SUSTAINABLE DEVELOPMENT

## Desalination: quenching the global thirst for clean water

There is plenty and not enough water in the world at the same time. While there's more than 1,400 million cubic kilometres of water on our blue planet, there's actually a shortage of clean drinking water. Our oceans cover more than 71% of the Earth's surface and contain 97% of the Earth's water. This means that only a tiny fraction of all water on our planet – 13,500 cubic kilometres or 1/100,000 of the total water – is actually fresh, drinkable and usable [1].

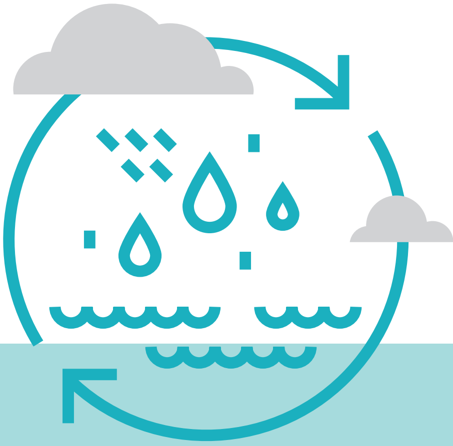
There's a worldwide thirst for clean water – drinking water, water for irrigation, water for industrial use and so on. It's not just a problem for people living in third world countries anymore. With global consumption doubling every 20 years, and at more than twice the rate of the world's population growth, getting clean water is also an issue for the world's major cities. Climate change will also affect water scarcity, where for each degree of global warming, approximately 7% of the global population is projected to be exposed to a decrease of renewable water resources of at least 20% [2].

**"By 2030, global demand for water is expected to grow by 50%" [3]**

Water is the fundamental building block of life, and it's vital for the sustainable development of countries worldwide. That's why the United Nations (UN) has included a specific Sustainable Development Goal to "ensure the availability and sustainable management of water and sanitation for all" as part of the UN's Sustainable Development Agenda. In response to the UN's call to action, countries have attempted to help solve global water shortage through a variety of demand-side and supply-side solutions, the latter including desalination of brackish water and sea water.

While desalination currently provides only around 1% of the world's drinking water, this percentage is increasing year on year. A rising demand for safe water, depleting natural fresh water resources, and the falling costs of desalination technologies – are all contributing to growing investment in desalination plants. Due to the high energy consumption and environmental footprint associated with desalination, however, the pressure is on to develop more sustainable desalination solutions.

The UAE is among other nations initiating dedicated programmes to address these challenges. Among these efforts is the Renewable Energy Water Desalination programme, managed by Masdar. The programme stimulated the development and demonstration of innovative energy efficient desalination technologies that can be cost-effectively powered by renewable energy sources. This effort is complemented by the Global Clean Water Desalination Alliance – "$H_2$0 minus $CO_2$" (Alliance), an international climate initiative launched by Masdar and the French Government and the International Desalination Association in 2015 at COP21 in Paris. The Alliance currently includes more than 150 members worldwide on corporate and governmental levels committing to reduce the carbon dioxide emissions from desalination plants.



# GLOBAL CLEAN WATER DESALINATION ALLIANCE – "$H_2O$ MINUS $CO_2$"

A key milestone in the UAE's journey towards developing sustainable desalination has been Masdar's support of the Global Clean Water Desalination Alliance – "$H_2O$ minus $CO_2$". Masdar has been actively involved with the Alliance, which is working towards reducing $CO_2$ emissions in the desalination industry. The Alliance was launched at the 2015 United Nations Climate Change Conference COP21 as part of the Lima Paris Action Plan.

Working in partnership with industries, the utilities sector, research organisations, universities, NGOs, financial institutions, local authorities and governments, the Alliance's work focuses on four key areas:

## TARGETS FOR CLEAN ENERGY SUPPLY

Mapping and assessing potential markets for clean energy-powered desalination, led by the International Desalination Association. The Alliance has set the following targets for the next 20 years: 10% clean energy supply by 2020 for existing desalination plants; 20% for new plants from 2020-2025; 40% for new plants from 2026-2030, 60% for new plants from 2031-2035; and 80% for new plants after 2035.

## ENERGY EFFICIENCY AND SYSTEM OPTIMISATION

Promoting energy efficiency, system integration and demand response, led by the US National Renewable Energy Laboratory (NREL). NREL is analysing how incentives, such as tax credits, rebates, special tariff structures can help to advance energy efficiency and system integration of desalination facilities.

Global Clean Water Desalination Alliance
$H_2O$ minus $CO_2$

## RESEARCH, DEVELOPMENT & DEMONSTRATION

Research, development and demonstration, led by the Massachusetts Institute of Technology. Members of the Alliance are identifying research gaps in sustainable desalination to help attract additional investment in solution-driven research, development and demonstration.

## CAPACITY BUILDING

Education, training and outreach, led by the Renewables 100 Policy Institute and ENGIE. The Alliance is supporting the dissemination of information on opportunities for reducing $CO_2$ emissions in the desalination sector through a dedicated web-based platform.

# DESALINATION IN THE ARABIAN GULF AND THE UAE

Desalination is critical to the sustainable growth of the United Arab Emirates

**83%**
of the desalination capacity in the UAE consists of thermal plants

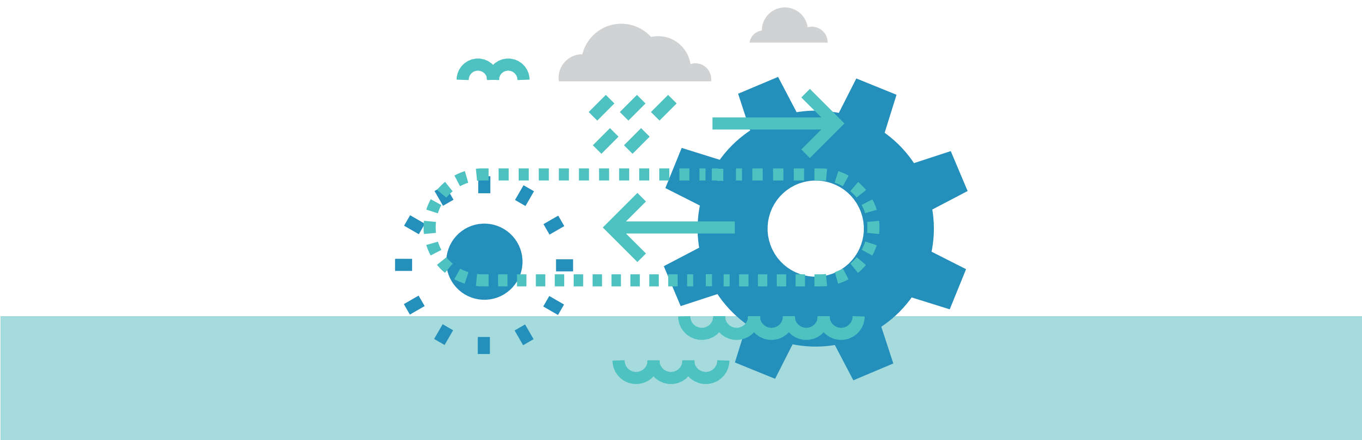
Desalination sector is estimated to contribute over **22%** of the $CO_2$ emissions of the Emirate of Abu Dhabi

The GCC is one of the world's main producers of desalinated water – around 45% of global desalination production is in the GCC countries (as of 2010) [4]. GCC countries increased their capacity to turn seawater into freshwater from 3,000 million cubic metres per year in 2000 to 5,000 million cubic metres per year in 2012; looking ahead, we can expect this figure to rise to around 9,000 million cubic metres per year by 2030 [3].

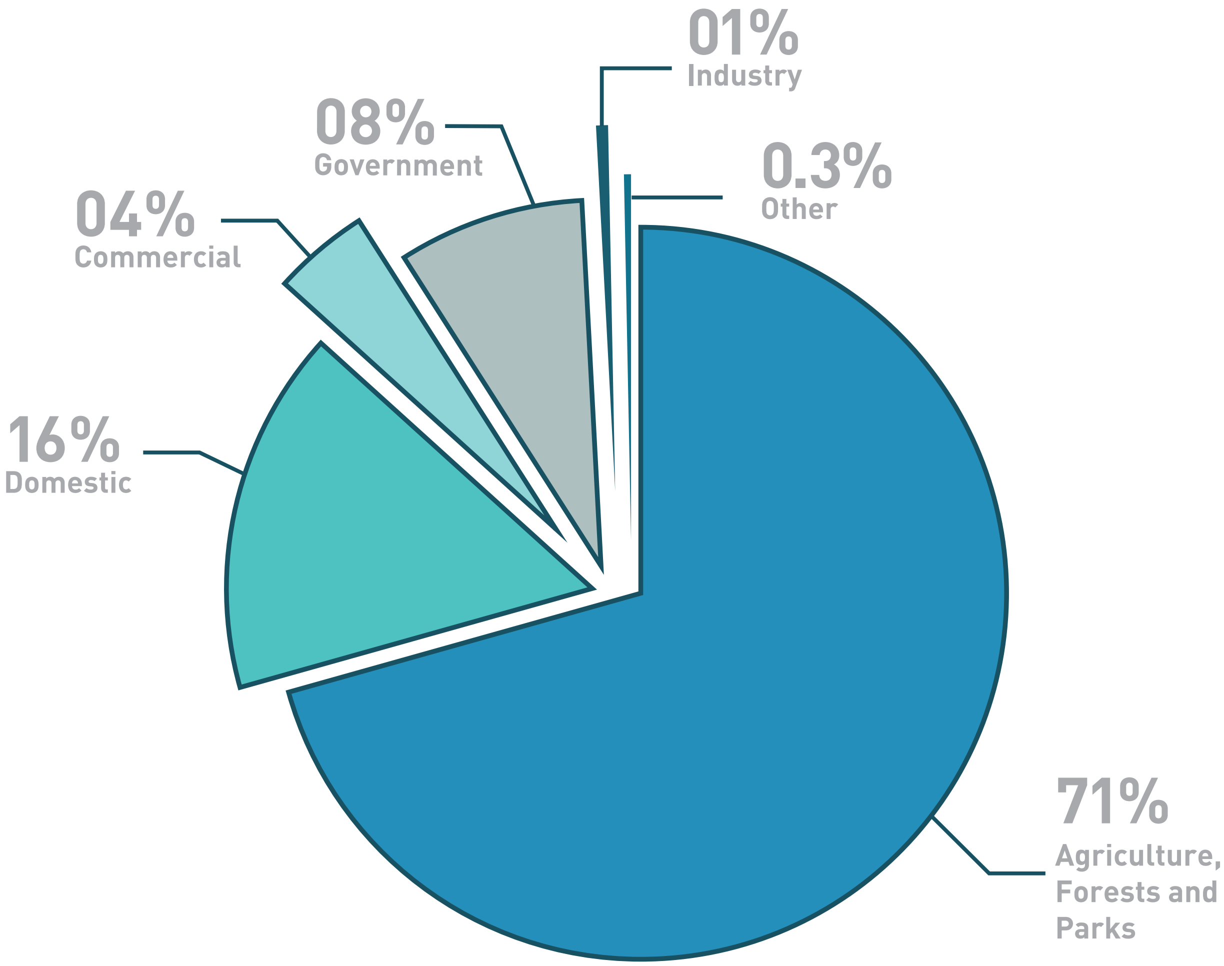
The growth of the UAE depends on producing sufficient water for its growing population – and what it lacks in freshwater, it is accounting for in desalinated water. Desalinated seawater accounts for 31% of the total water supply in Abu Dhabi, and has become the main source of drinking water [5].

There is a considerable environmental downside to the desalination methods used in the UAE. The majority of UAE's desalination plants use thermal desalination processes, which are in most cases considerably more energy intensive compared to reverse osmosis processes. The thermal plants release hot brine, chemicals and other trace elements into coastal waters, which increases seawater temperature and salinity, and harms the marine environment. Climate change is expected to compound such impacts by increasing salinity in certain locations and increasing seawater temperatures in the Arabian Gulf [6]. Any significant changes to the quality of the seawater will also impact the efficiency of desalination plants, furthering the need to find new cleaner and less damaging ways to desalinate water.

- **83% of desalination in the UAE is produced at thermal plants, which consume around 3.5 times more energy for each unit of produced water than modern reverse osmosis plants [7][8]**
- **The widely deployed integration of electricity and water production leads to energetic inefficiencies caused by seasonal variations mainly in electricity demand forcing the integrated water and power plants to operate sub-optimally during winter**
- **The desalination sector is estimated to contribute more than 22% of Abu Dhabi's total $CO_2$ emissions [9]**



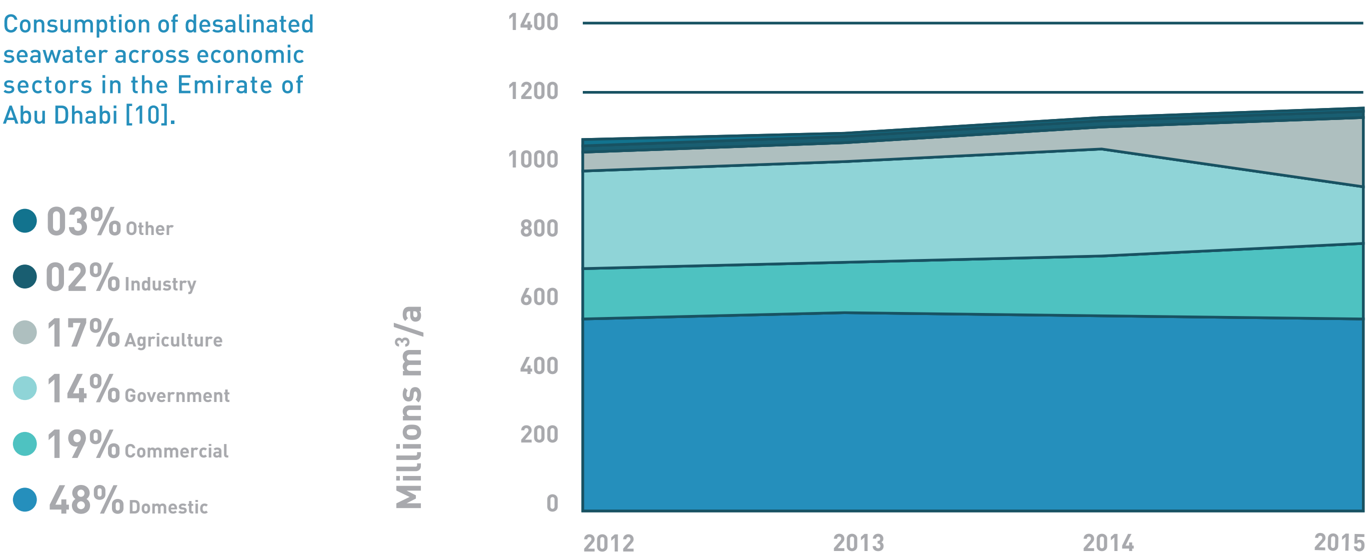
Fresh water demand by economic sector in the Emirate of Abu Dhabi in 2012 [5].



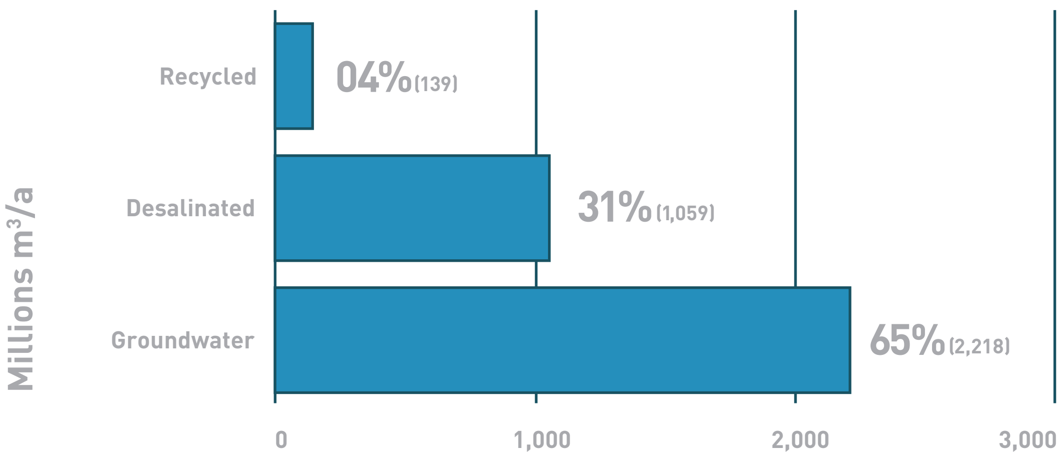
# DESALINATION IN THE ARABIAN GULF AND THE UAE

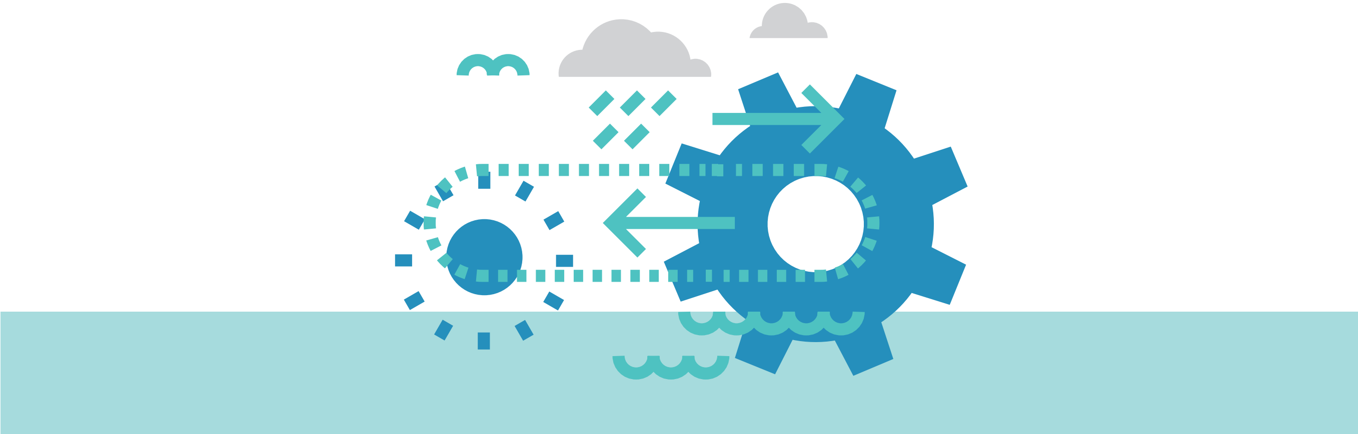
Desalination is critical to the sustainable growth of the United Arab Emirates

Consumption of desalinated seawater across economic sectors in the Emirate of Abu Dhabi [10].




Fresh water demand by source in the Emirate of Abu Dhabi in 2012 [5].



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HIGH PRESSURE

"Water is an essential component for industrial, economic and social development and its demand globally is predicted to increase by %55 by 2050. While the UAE is developing rapidly, it remains one of the most water-scarce countries in the world, and with more than %90 of the UAE's drinking water provided through desalination, we have a duty to pursue and deliver solutions to manage the increasing demand using sustainable, clean technologies. The UAE is committed to this and through programmes like the Ghantoot Renewable Energy Desalination Pilot Programme, we are working towards this objective to achieving our goals set out in the UAE Energy Strategy 2050."

***- His Excellency Suhail Al Mazrouei, UAE Minister of Energy.***

# CREATING OPPORTUNITIES

## Driving innovation for the next generation of desalination technologies

**The key objectives of the programme were to develop and demonstrate seawater desalination technologies that:**

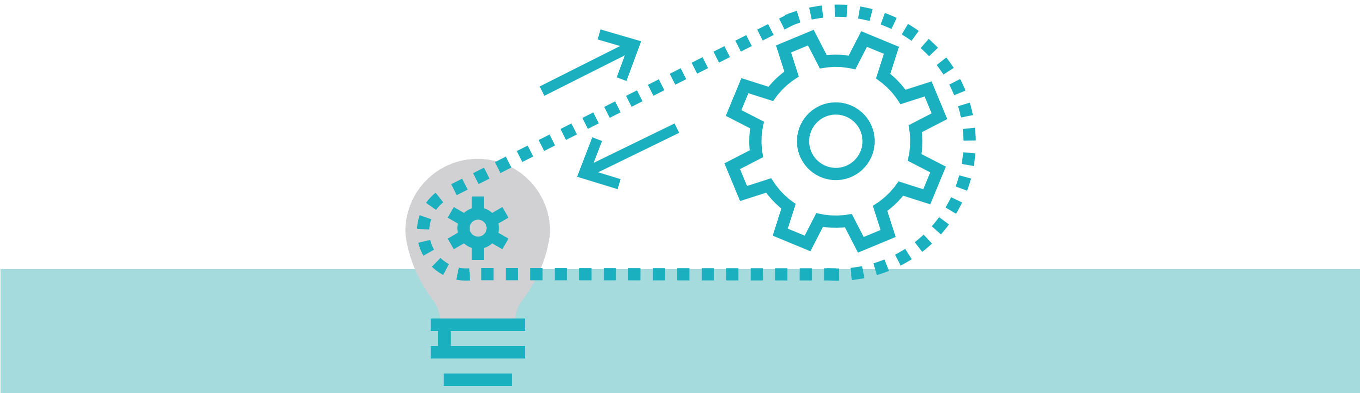
- Are more energy efficient than state-of-the-art systems;
- Are suitable to be powered by renewable energy sources;
- Are cost competitive with non-renewable energy powered seawater desalination;
- Have minimal environmental impact; and
- Are resilient in challenging seawater and environmental conditions.

The UAE is committed to improving existing desalination methods and pioneering new solutions that are more energy-efficient and cost-effective. It is actively working towards powering a more sustainable future by diversifying its energy resources, introducing renewable energy sources, and developing nuclear energy. Coupling energy-efficient reverse osmosis plants with the abundantly available solar resources and capitalizing on low-cost renewable generation technologies will allow the UAE to transition to achieve the country's strategic goals and environmentally benign, cost-effective and secure water supply solution for the future.

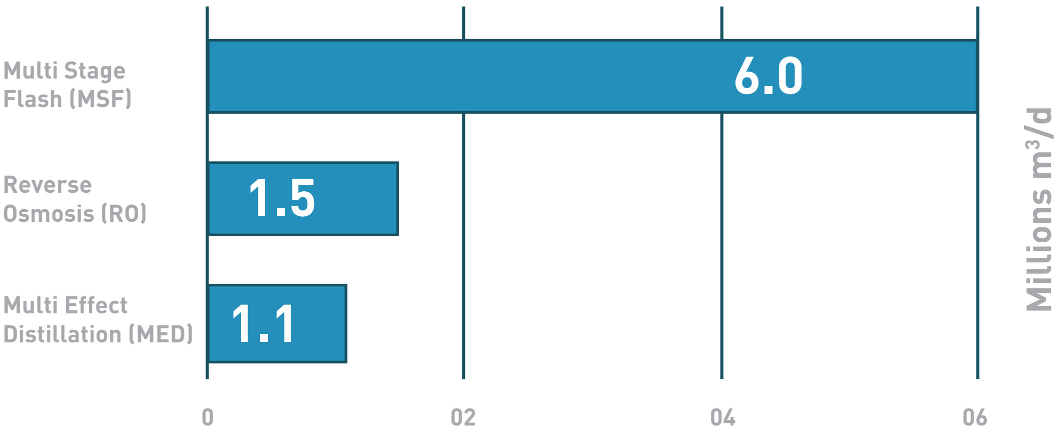
The UAE is a rapidly developing country with one of the fastest population growth rates in the world. As the population grows, so does the demand for safe, easily accessible freshwater for human consumption and for agricultural, commercial and industrial use – and this is the driving force behind the UAE's investment in pioneering, innovative technologies for water desalination.

### HOW IT ALL STARTED

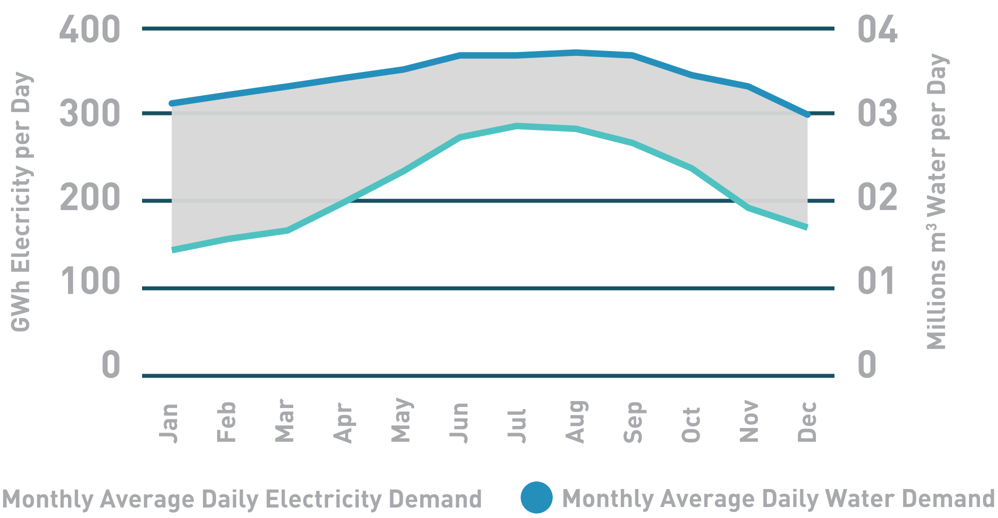
The quest for clean water desalination started in 2013 when Masdar launched the Renewable Energy Water Desalination Programme. The programme was a result of a call to action to improve water security made by His Highness General Sheikh Mohammed bin Zayed Al Nahyan, Crown Prince of Abu Dhabi and Deputy Supreme Commander of the UAE Armed Forces. The programme was established to stimulate growth, promote investment and advance the desalination sector. The key objectives of the Programme were to research and develop energy-efficient, cost-efficient desalination technologies that are powered by renewable energy. The long-term goal was to establish renewable energy-powered desalination plants in the UAE, and across the MENA region. The Programme was sponsored by the Abu Dhabi Government and co-funded by the industry partners participating in the Programme. During the Programme, five different desalination pilot plants were operated at a site in Ghantoot. Each one used innovative technologies to demonstrate different approaches to energy-efficient seawater desalination.



Installed seawater desalination capacity per technology type in the UAE [7].




Electricity demand and water demand throughout 2015 in the Emirate of Abu Dhabi [11].



"Trevi was honored to be selected for the Renewable Energy Desalination Challenge by Masdar. The selection afforded us the opportunity to build a large scale pilot plant and demonstrate the technology under real world conditions. We were able to improve key components of the design and the data gathering proved invaluable. Our partner Masdar provided a facility which would be dearly missed in desalination research, and their financial and technical support during the project was key to our success."

*– John Webley, CEO of Trevi Systems*

# MASDAR'S RENEWABLE ENERGY WATER DESALINATION PROGRAMME

## Transforming the desalination industry into a more sustainable model

Throughout the Programme, Masdar worked with local and international stakeholders in what became a truly global effort to achieve energy-efficient seawater desalination. International technology providers, industry experts and professors from the Masdar Institute of Science and Technology (MI) (a graduate-level research university in Abu Dhabi) have all contributed to the Programme in terms of research, development and monitoring. Rather than operating on typical supplier-customer relationships, the Programme was very much a partnership between all the participating companies who united to address the specific challenge.

The commercialization of new desalination technologies is especially challenging until a first commercial reference plant has been built using the new technology. Expenditures are high during this phase of technology development, and practical implementations may prove difficult to realize outside of the lab. It is therefore difficult to attract funding for this phase. The programme offered infrastructure and funding in one of the prime markets, addressing key pitfalls in the commercialisation of new desalination technologies.

Masdar was responsible for the management of the programme. Masdar's role included the identification, refurbishment and provision of the project site in Ghantoot, including the solicitation of all required permits to perform the pilot projects. Masdar had all needed site infrastructure, including electric power supply, natural gas supply and seawater supply, installed at the site. Masdar selected the participating companies and engaged in detailed technical discussions to make sure that the demonstrated technologies address the Programme objectives. Masdar established key collaborations with multiple relevant stakeholders, both nationally and internationally, to enable stakeholder input and dissemination of the Programme results. The collaborative instruments included the Project Management Office, Steering Committee, and the Independent Advisory Panel. "(See page 17-18 for more details)", Moreover, Masdar has introduced the Programme and shared its results at multiple national and international conferences. MI also contributed to the Programme by conducting five research and development projects in collaboration with the participating companies in the Programme.

**The programme addressed key challenges to the UAE's desalination sector, and built upon the knowledge and experience of local and global stakeholders. Masdar has involved local and global stakeholders throughout the programme to enable a lasting impact of the programme's results.**

# FORGING PARTNERSHIPS FOR A SUSTAINABLE ADVANTAGE

Masdar monitored the performance of the pilot plants on an ongoing basis, and analysed the results in collaboration with the five different technology partners. This process involved regular progress reports, and:

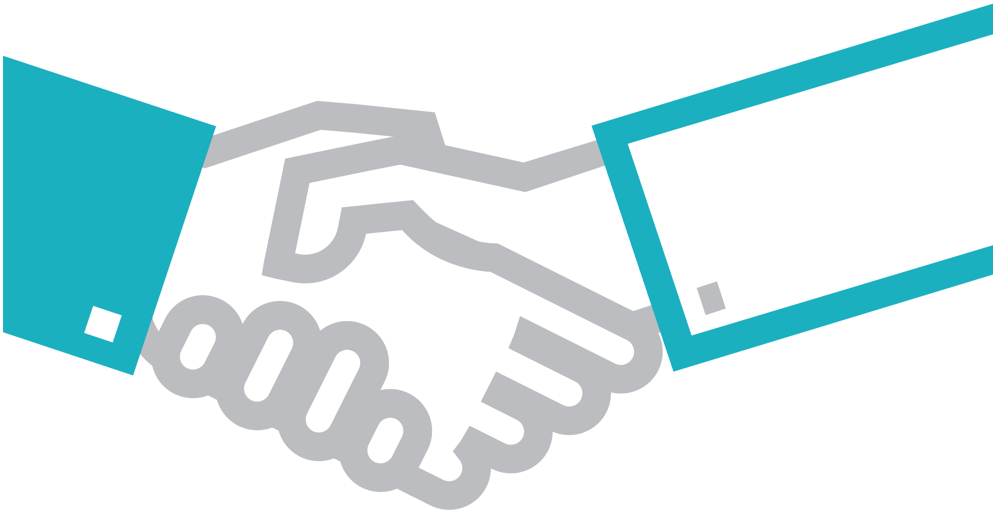
**ON-SITE TESTS**

- Trial run
- Acceptance test
- Availability test
- Performance tests
- Completion test

**MONITORING OF KEY PARAMETERS**

- Energy consumption (electricity and heat)
- Seawater quality
- Potable water quality and quantity
- Brine discharge quality and quantity

There was a rigorous selection process for the technology partners. Masdar invited bids from companies who could develop and demonstrate innovative and advanced desalination technologies that were suitable for the UAE. The mandate was kept relatively open to encourage providers to propose solutions that would meet the Programme's objectives while maximising the company's individual strengths.



## THE FOLLOWING PARTNERS WERE SELECTED BY MASDAR TO PARTICIPATE IN THE PROGRAMME:

**ABENGOA**

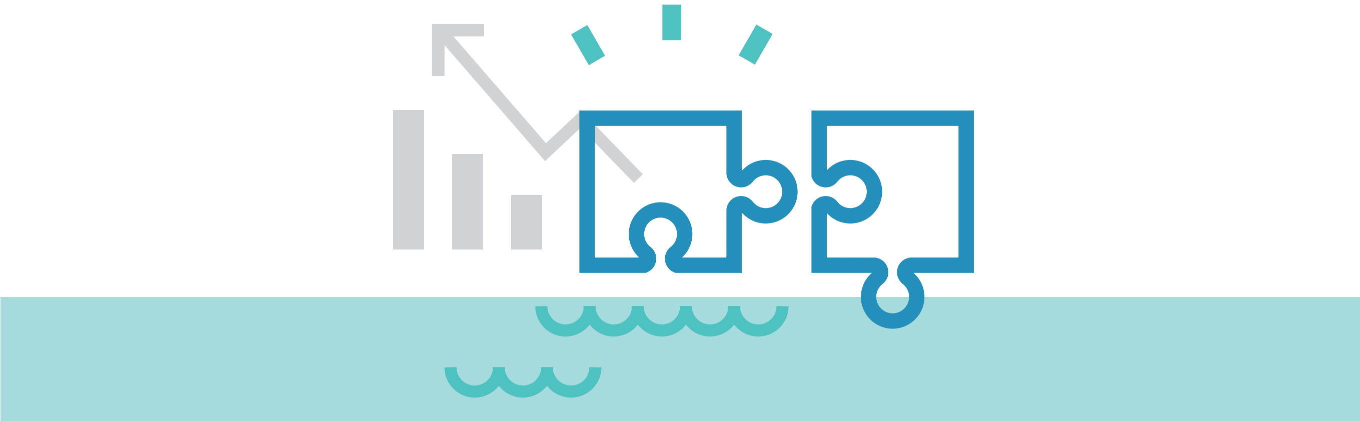
The Spanish company Abengoa is a global leader in energy and desalination. As well as delivering turnkey solutions for solar energy, biofuel plants, conventional energy plants, desalination, and electricity and water infrastructures, Abengoa operates and maintains energy and water plants. It also has a research and development arm.

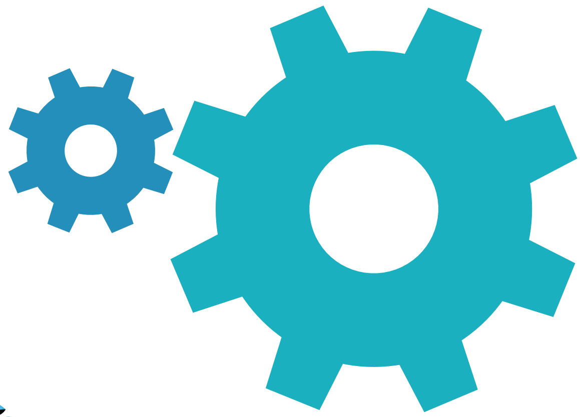
Roughly 1% (400,000 $m^3$/day) of the world's water desalination capacity originates from Abengoa's plants located in North Africa, Latin America, China, and the Middle East [7].

**SUEZ**

A global expert in the water and waste sectors, SUEZ offers services in water treatment, water distribution and management, waste recycling and waste recovery. The company is based in France and designs, builds and operates desalination and other water treatment plants.

SUEZ has plants in Europe, North Africa, the Middle East, Australia and Latin America, and is responsible for roughly 4% (1,700,000 $m^3$/day) of the world's water desalination capacity [7].





Mascara Renewable Water specialises in solar-powered desalination. The French company has developed a technology for PV-powered desalination that can decrease and increase water production according to the available solar energy. This enables off-grid solar powered desalination, as well as demand response functionality for micro-grid systems.

After piloting a 30 m³/day desalination plant in partnership with Masdar, Mascara has installed an off-grid system in Bora Bora that has a capacity of 80 m³/day. The company also plans to install an 80 m³/day plant in Rodrigues, an island of the Republic of Mauritius.

Trevi Systems has developed a Forward Osmosis technology that is used to desalinate seawater, high salinity water, brackish water and industrial wastewater. The California-based start-up company operated the following pilot plants: Orange County Water District (California), Port Huenema Seawater Desalination Test Facility (California), and Romberg Tiburon Centre (California).

It the Middle East, Trevi has installed a 10 m³/day pilot plant in Kuwait while it was operating its 50 m³/day pilot plant in in the UAE. Trial Zero-Liquid Discharge systems have been installed in India, China and the US.

Veolia group is a global leader in optimized resource management. The group designs and provides water, waste and energy management solutions that contribute to the sustainable development of communities and industries.

Roughly 13% (6,200,000 m³/day) of the world's operational seawater desalination capacity originates from Veolia/SIDEM at plants in Africa, Latin America, Australia, China, the Middle East, Europe, East Asia, and North America [7].

# EVALUATING AND VALIDATING

**EVALUATION CRITERIA:**
The programme addressed key challenges to the UAE's desalination sector, and built upon the knowledge and experience of local and global stakeholders. Masdar has involved local and global stakeholders throughout the programme to enable a lasting impact of the Program's results.

## TECHNOLOGY
- Technology references
- Quality of proposed technology
- R&D competence
- Energy intensity
- Projected development outlook of the technology
- Potential for industrial applications
- Robustness and reliability
- Innovativeness, potential for technological breakthrough
- Suitability for coupling with renewable energy sources
- Environmental impact of brine discharge

## COST
- Cost of produced potable water
- Projected development outlook in terms of cost
- Cost sharing in project

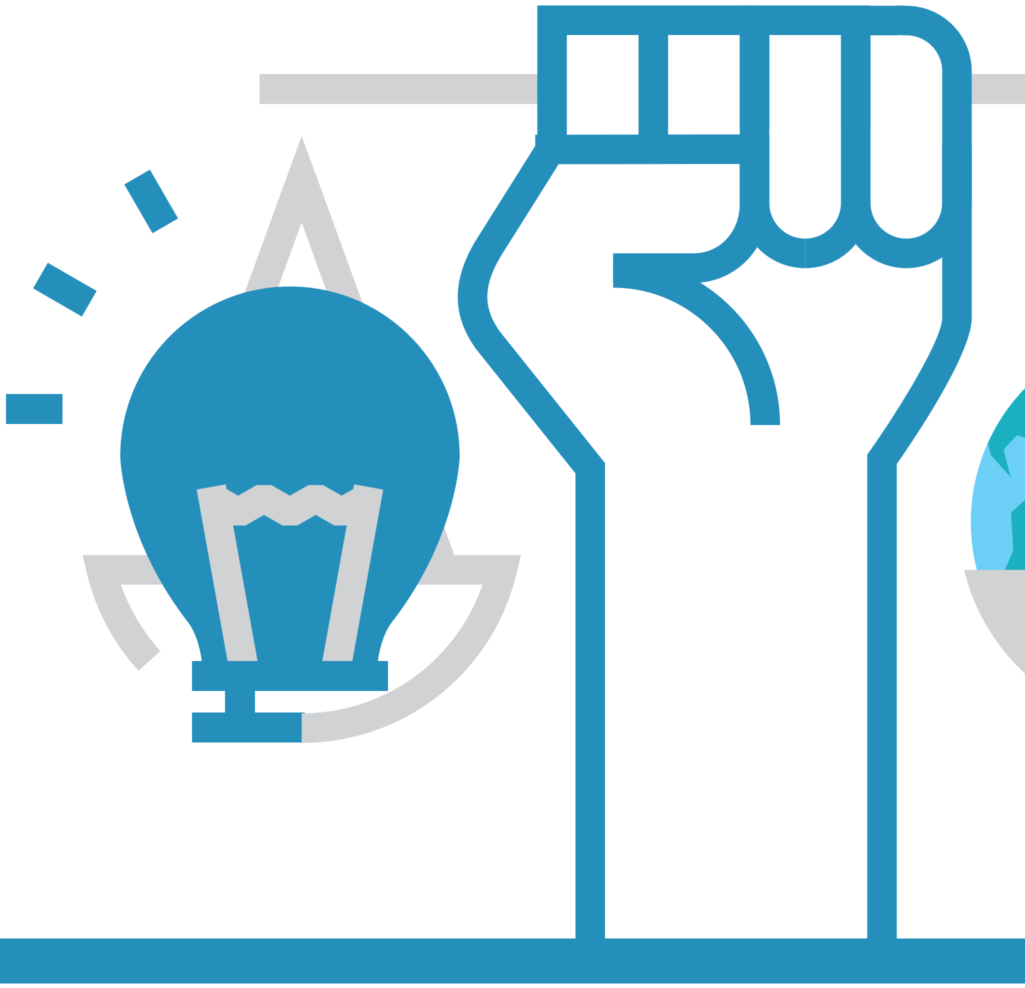
**PROJECT TEAM COMPETENCE**

**EPC COMPETENCE**

**O&M COMPETENCE**

**PROPOSED R&D ENGAGEMENT WITH MI**

## DELIVERY
- Schedule
- Pilot plant production capacity



## PROJECT MANAGEMENT OFFICE

The Project Management Office (PMO) facilitated the involvement of key local stakeholders in the programme:

- **Abu Dhabi Water & Electricity Authority (ADWEA)**
- **Abu Dhabi Regulation and Supervision Bureau (RSB)**
- **Environment Agency - Abu Dhabi (EAD)**
- **Abu Dhabi Sewerage Services Company (ADSSC)**
- **Executive Affairs Authority (EAA)**

Masdar briefed the PMO on the project status and results of the pilot plants in periodic meetings and site visits throughout the programme. Discussions with the PMO centered on the results and potential of the technologies, targeting adoption in the UAE.

## STEERING COMMITTEE

The Steering Committee (SC) was comprised of four senior level representatives of Masdar and the Masdar Institute. The SC provided guidance to Masdar's project managers on achieving the programme's objectives, timeline and budget.

## INDEPENDENT ADVISORY PANEL

The Independent Advisory Panel (IAP) included eight distinguished international desalination and renewable energy experts. Participation of the IAP was on a voluntary and non-commercial basis. The IAP met three times at the project site in Ghantoot during the programme. The IAP's role centered around independent review and feedback on the programme's results and the next steps in developing and commercialising the desalination technologies. Masdar briefed the IAP on the project status and results of the pilot plants to this end. Members to the IAP were:

- **Dr. Corrado Sommariva (Chair), Managing Director, ILF Consulting Engineers;**
- **Ursula Annunziata, President, European Desalination Society;**
- **Leon Awerbuch, Director, International Desalination Association;**
- **Dr. Nobuya Fujiwara, General Manager, Toyobo;**
- **Paul Holthus, Founding President and CEO, World Ocean Council;**
- **Dr. Joachim Koschikowski, Head of Group, Fraunhofer;**
- **Dr. Masaru Kurihara, Advisor, Toray Industries;**
- **Dr. Adam Warren, Group Manager, National Renewable Energy Laboratory, US DOE.**

" Masdar was the first to offer Mascara Renewable Water the chance to test and validate its innovative solar desalination technology through its Renewable Energy Desalination Programme in Ghantoot. This programme fully achieved its initial goal to bridge the gap between R&D and industry : the industrialisation of the world's first solar desalination technology powered by solar energy only and no battery, OSMOSUN®, was accelerated through that programme.

Without Masdar's trust and support, Mascara would have taken many more years to prove and gain credibility for its OSMOSUN® technology. The validation by Masdar of the unique performance of OSMOSUN® enabled Mascara to sign its first orders in 2017. Mascara is now developing projects in Mauritius, Cape Verde, South Africa, Morocco and Vanuatu in the Pacific. Some of these projects are being developed through the strategic development partnership tying the two organisations along with the Ghantoot programme.

Besides supporting the testing and validation of OSMOSUN®, Masdar involved Mascara in other programme of interest : Masdar co-founded during the COP21 in Paris and now holds the secretariat of the climate initiative Global Clean Water Desalination Alliance – "$H^{2}0$ minus CO2", and is offering Mascara an incredible opportunity to lead the change of the sector along with Masdar and the Alliance members.Mascara was also offered to join an R&D programme with Masdar Institute to improve the efficiency of solar panels, which displayed important results for future implementation of solar desalination projects."

*– Marc Vergnet, CEO of Mascara Renewable Water*


Mascara
Renewable water
Masdar
A MUBADALA COMPANY
مصدر

# DESALINATION TECHNOLOGIES

Bridging the gap between research & development and commercialisation

The five pilot plants in the Programme demonstrated different seawater desalination technologies and configurations that aimed to achieve the Programme's objectives.

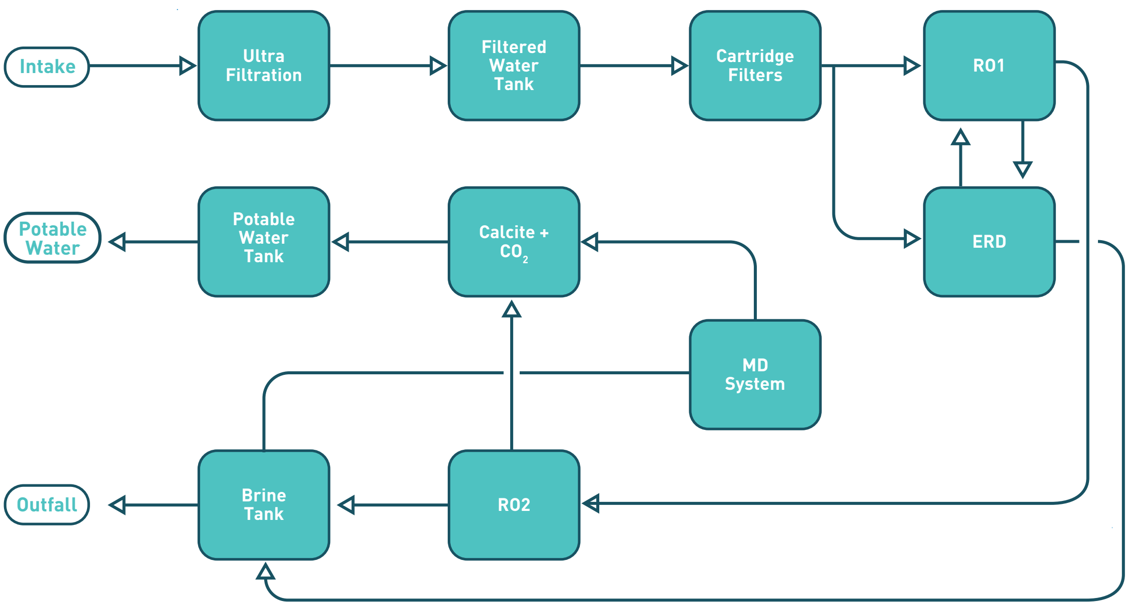
## ONE SITE, FIVE PILOTS

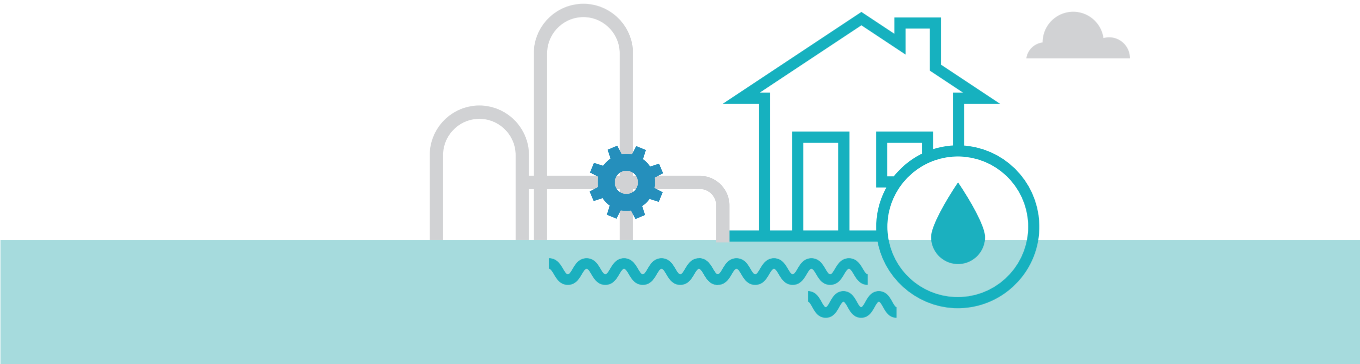
**The Programme's five pilot plants operated from a site in Ghantoot, in the emirate of Abu Dhabi. Located around 65km northeast of the city of Abu Dhabi, this site became a competitive hub where the five pilot plants were in operation side-by-side.**

## ABENGOA

The desalination system piloted by Abengoa used a Reverse Osmosis (RO) system and has a capacity of 1,080 $m^3$/day. This RO system uses an ultra-filtration system and self-cleaning cartridge filters for the pre-treatment of seawater. Then, there's a two-pass RO system with split partial second pass, which sends only the relatively high salinity permeate from the first-pass RO to the second-pass RO. Abengoa used an isobaric Energy Recovery Device (ERD) to recover energy from the high-pressure brine, and remineralization was achieved by calcite and $CO_2$ treatment.

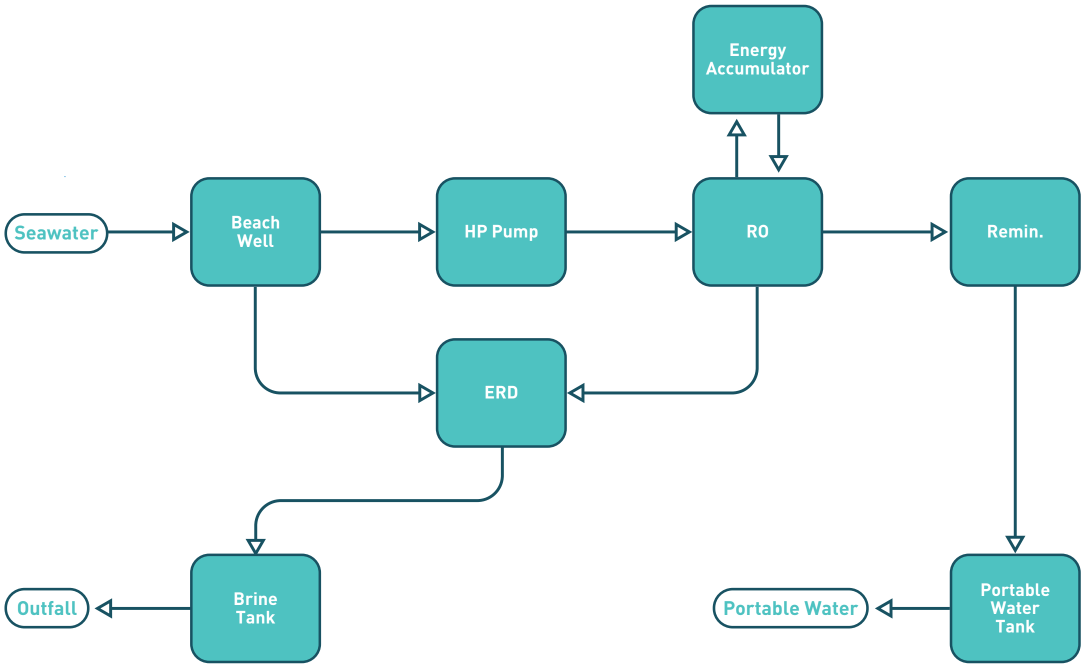
Approximately 10% of the brine from the first pass RO system was treated using a low-grade, heat-driven Membrane Distillation (MD) system. Product water from the MD system was sent for remineralization along with permeate of the second pass RO system. The MD system was of a Vacuum Multi-stage type and consisted of three units treating brine in parallel. Because the MD system is driven by low temperatures, the Abengoa pilot plant required both electric and thermal energy.





## MASCARA RENEWABLE WATER

Mascara Renewable Water developed an off-grid, solar powered desalination solution that used a beach well to obtain seawater from a borehole near the sea. The natural sand filtration of the beach well eliminated the need for a dedicated pre-treatment system. A special RO system with a proprietary hydraulic energy accumulator ensured that the RO system could operate under a varying power supply. Also, a special isobaric Energy Recovery Device (ERD) system recovered energy from the high-pressure brine, and was designed to operate at low flow rates. Powered by a 30 $kW_p$ PV plant, this 30 $m^3$/day system operated only during sunlight hours. The membranes were automatically flushed before sunset to avoid biofouling. A control system managed the continuous operation of the pilot plant under the varying sunlight by adjusting the water production and hence the demand for power throughout the day, assisted by the hydraulic energy accumulator to smooth out sharp fluctuations in power supply.



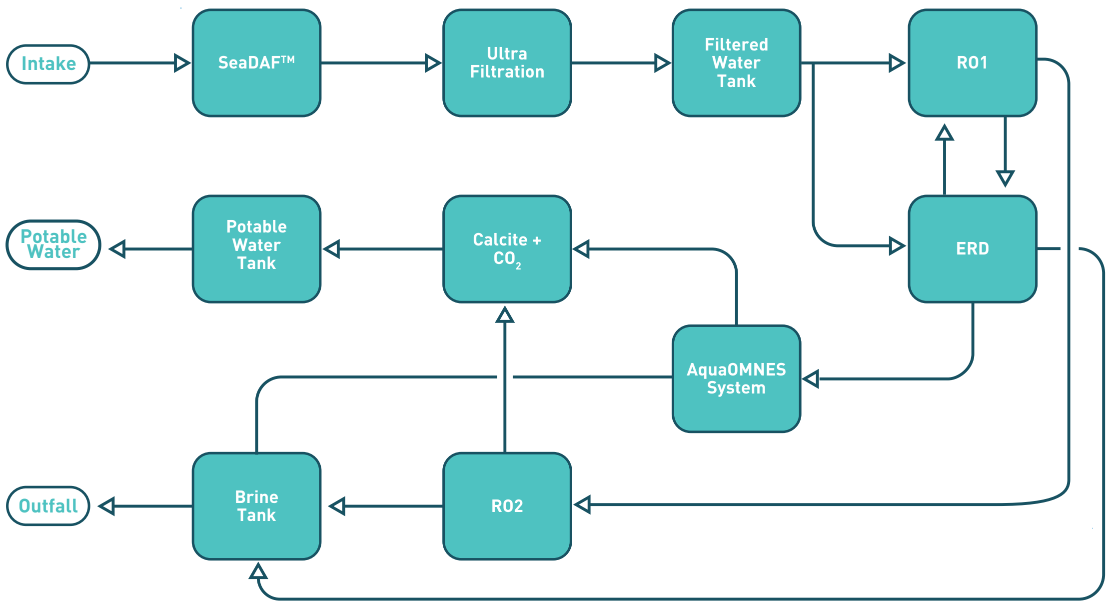
# DESALINATION TECHNOLOGIES

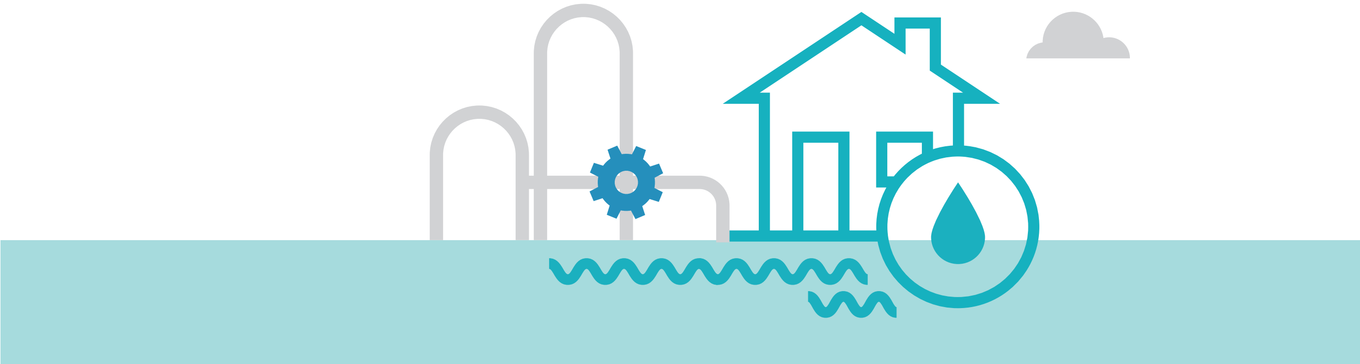
Bridging the gap between research & development and commercialisation

## SUEZ'S

SUEZ's 100 $m^3$/day pilot plant combined an advanced RO system with an innovative brine treatment system The RO system used two pre-treatment systems, Dissolved Air Floatation (DAF) and Ultrafiltration (UF). The RO system consisted of two passes, and there was a partial split-second pass with full regulation of the front and rear permeate flow rates on the first pass. This determined how much permeate from the front or rear of the first pass RO system was sent to the second pass RO.

Brine from the first pass RO was treated by the AquaOmnes® system, an innovative Ionic Liquid Membrane (ILM) technology, which extracted fresh water from the brine stream by capturing it in a special solvent. The fresh water was then stripped from the solvent using low-grade heat. A Brackish Water Reverse Osmosis system was used to polish the fresh water from the ILM system. SUEZ also used an isobaric Energy Recovery Device (ERD) to recover energy from the high-pressure brine, and remineralization was performed by calcite and $CO_2$ treatment.

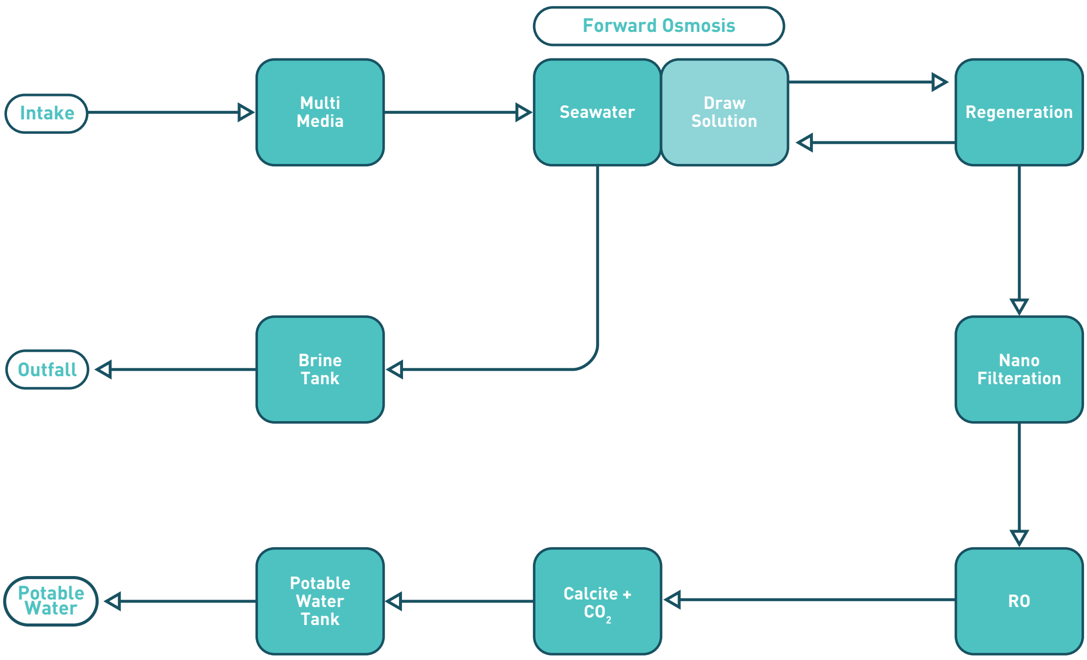




## TREVI SYSTEMS

The Forward Osmosis (FO) desalination system of Trevi Systems' pilot plant had a total capacity of 50 m³/day. A multi-media filtration system was used in the pre-treatment stage. Then, during the FO process, a proprietary draw solution absorbed the freshwater from the seawater and the draw solution was regenerated using low-grade heat; this separated water from the draw solution. A low pressure nano-filtration was then used to recover any infiltration of the draw solution from the permeate stream.

Multiple heat exchangers were used throughout the process to recover heat from the seawater, freshwater, brine and draw solution streams. An RO filtration system was deployed to guarantee sufficient boron removal from the water, before processing the fresh water by conventional remineralization using calcite and $CO_2$ treatment.

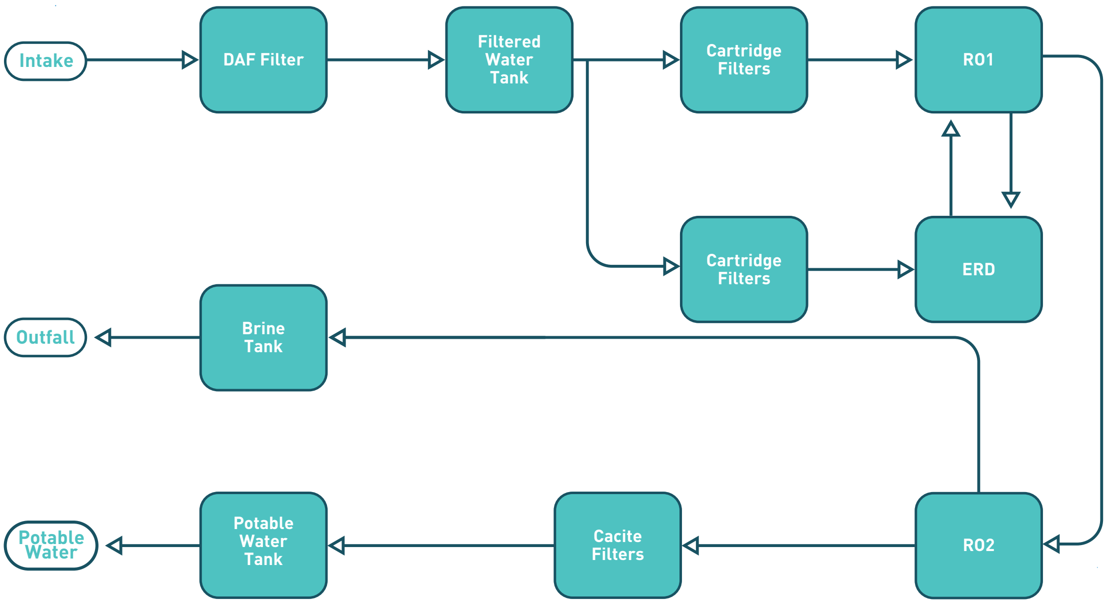


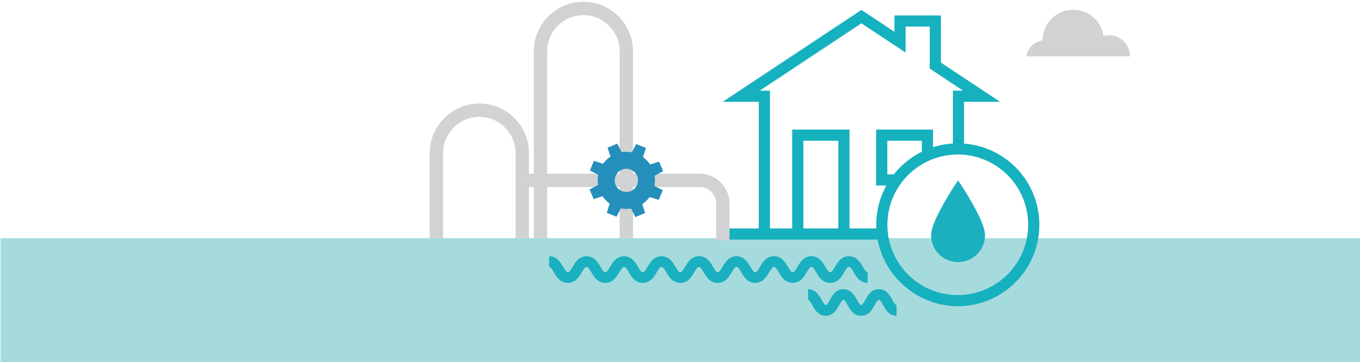
# DESALINATION TECHNOLOGIES

Bridging the gap between research & development and commercialisation

## VEOLIA/ SIDEM

The 300 m$^3$/day pilot plant developed by SIDEM combined Dissolved Air Flotation (DAF) and gravity dual media filtration into one single unit for the pre-treatment of the seawater. SIDEM used a two-pass RO system with a central port configuration, and it deployed an innovative Energy Recovery Device (ERD) that avoided mixing RO feed water with the brine stream and promised a 98% efficiency across its operating range. Calcite filters were then used for remineralisation treatment.





## RESEARCH & DEVELOPMENT

As part of the Programme, the MI conducted five R&D projects in collaboration with – and funded by – the participating companies.

### FOULING IN MEMBRANE DISTILLATION

Abengoa's pilot plant used the emerging desalination technology Membrane Distillation (MD) to enhance the overall water recovery process from the seawater desalination plant. A typical seawater desalination plant produces high-quality freshwater and reject water with a high salinity called brine. There are several brine disposal methods, which all have different costs and environmental impacts.

Using MD technology, the brine can be treated to recover fresh water, increasing the overall water recovery from seawater desalination systems and reducing brine volume. On the downside, membrane systems such as MD are affected by fouling, which occurs when salt or other compounds deposit on the membrane surface. Fouling restricts water flow and ultimately affects the water recovery of the MD system and damages the membranes – but it can be prevented by adding special chemical agents or anti-scalants to the brine.

The collaborative R&D project between Masdar Institute and Abengoa evaluated fouling in the MD process at Abengoa's pilot plant. Their goal was to develop a strategy to prevent or reduce fouling, which would help to improve MD technology. The project tested five different commercially available anti-scalants. Tests were performed on brine from the pilot plant's RO system using MI's Membrane Test Unit; a small lab-scale MD systems was configured to test different types of membranes and feed water (different brine configurations) under the same operating conditions of the pilot plant. Final results of the R&D were used to determine which chemical agent and dosage should be used to operate the MD system at Abengoa's pilot plant.

"The project was led by Dr Hassan Arafat,a Professor in Water and Environmental Engineering at the MI's Department of Chemical and Environmental Engineering."

### PV MODULE COOLING

Mascara Renewable Water used photovoltaic (PV) energy to power its off-grid desalination units. PV energy has become an increasingly popular form of alternative energy in both standalone and grid connected systems. However, PV power output is not constant and depends on the incident solar irradiance as well as the PV cells' operating temperature.

In a PV system, the open-circuit voltage and output power decreases as the operating temperature of the solar cells increases. Any rise in the operating temperature affects the solar cells' electrical conversion efficiency and, thus, reduces the energy output; it can also reduce the PV system's lifespan. Two main types of cooling methods were analysed: An active method which requires an energy input and a passive method which does not.

In a joint R&D project, Masdar Institute and Mascara have tested cooling schemes on three PV modules, identical to the ones used at the pilot plant located in Ghantoot. One module was actively cooled, while another module was passively cooled and the last module was used as a reference. The tests were conducted at Masdar's PV Test Centre in Masdar City. Prior to outdoor testing, the performances under Standard Test Conditions (STC) were verified using Masdar's indoor solar simulator. This STC test allowed to determine the correction factors used to normalise the modules' outdoor performances.

As a result, both tested cooling methods may be implemented on Mascara's off-grid PV-powered desalination systems in order to help increase energy production and reduce the footprint. Any increase in energy production will reduce the desalination plant's footprint, which is particularly valuable in densely populated coastal areas where desalination plants are likely to be located.

The project was led by Dr Mohamed El Moursi, Associate Professor at the Masdar Institute Department of Electrical Engineering and Computer Science.

# DESALINATION TECHNOLOGIES

Bridging the gap between research & development and commercialisation

## DESIGN AND COST OF SOLAR DESALINATION

While there's no shortage of seawater desalination and renewable energy systems in the global market, the challenge is finding the right one. SUEZ collaborated with Masdar and ENGIE Laborelec in an R&D project that focused on the optimisation of renewable energy-driven desalination plants in terms of cost and design.

Solar irradiance data, seawater temperature and salinity profiles, and cost were mapped to identify which type of solar desalination configuration has the greatest potential. Researchers technically-modelled and simulated Seawater Reverse Osmosis (SWRO) desalination systems (with and without thermal energy-driven brine concentration steps), as well as multiple photovoltaic, concentrated solar power, solar thermal, thermal storage and electrical storage systems.

Researchers had the technical data they required to develop a cost model to simulate a commercial solar-powered desalination plant. The results highlighted the strengths and limitations of each solar-powered system, as well as the expected cost of solar-powered water desalination.

The project resulted in the prioritisation of solar desalination configurations for both grid connected and off-grid situations. It provided the participants of this R&D project with a sound technical understanding of the limits and strengths of each solar system, as well as the expected cost of solar powered water desalination. Moreover, the cost model allowed adjustments of key parameters to analyze new scenarios without the need for further detailed technical simulations.

The project was led by Dr Hassan Arafat, a Professor in Water and Environmental Engineering at MI's Department of Chemical and Environmental Engineering.

## CAPACITIVE DEIONIZATION

Masdar Institute and Veolia investigated the feasibility of membrane based Capacitive Deionization (CapDI) for seawater desalination systems. CapDI systems remove salt (e.g. table salt, sodium chloride) by applying an electrical potential difference over two electrodes to saline water; the negatively charged ions (chloride) can be stored by the positive electrode and the positively charged ions (sodium) can be stored by the negative electrode.

The project evaluated the energy consumption, desalting performance, and potential applications of CapDI technology. Research focused on using CapDI technology within an SWRO plant for the post-treatment of first-pass RO. Water produced by a first-pass RO system was treated using CapDI, instead of feeding it to a second-pass RO system that is often applied to meet drinking water standards. Throughout the project, researchers evaluated a range of water qualities produced by a first pass RO system in a small pilot scale CapDI unit. Tests monitored flow rate, operation time, applied electrical current, energy consumption and achieved levels of solids removal. Researchers compared the performance of one-pass and two-pass CapDI systems, as well as water with different concentration levels.

The project was led by Dr. Linda Zou, a professor in chemical and environmental engineering at the Chemical and Environmental Engineering department of MI.

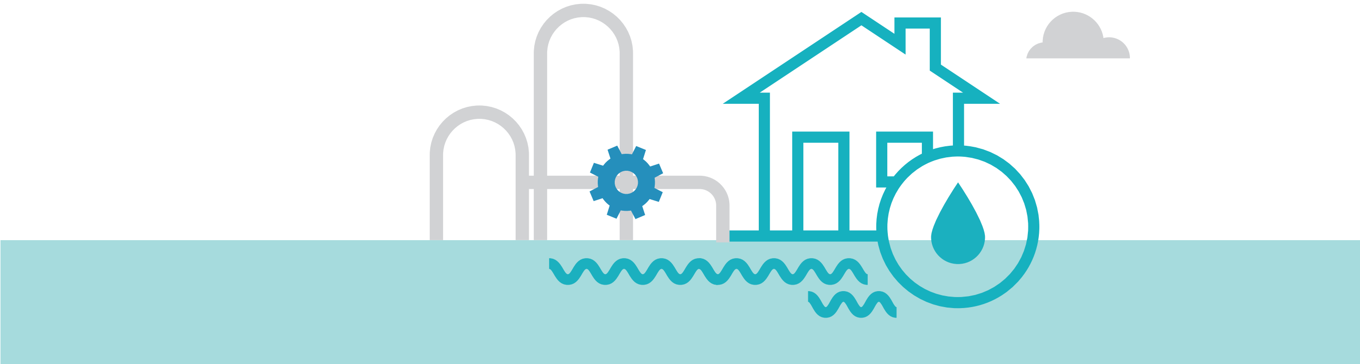
## FORWARD OSMOSIS

Trevi Systems employed Forward Osmosis (FO) at its pilot plant, a technology that has gained attention as an energy efficient technology to desalinate water and treat contaminated industrial water. Forward Osmosis (FO) is a two-stage process where water is extracted from seawater or brackish water (feed solution) with lower osmotic pressure into a more concentrated draw solution with a higher osmotic pressure. This results in concentration of the feed solution and dilution of the draw solution. The second stage is the regeneration step where draw agent is recovered by extracting water from the draw solution.

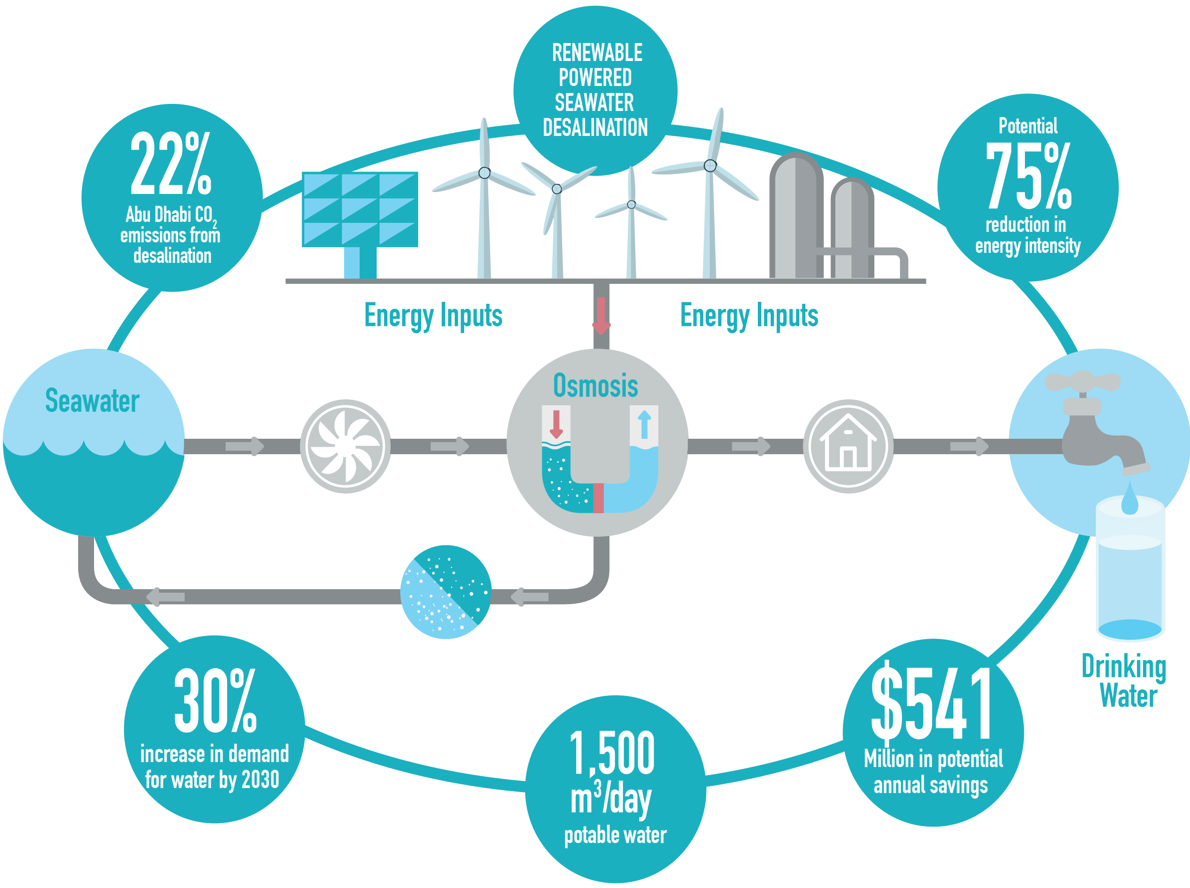
The membranes used for the FO process in the UAE have to be customised for the higher salinity and temperatures of the Arabian Gulf seawater. In light of this, the R&D project by the Masdar Institute and Trevi Systems focused on the development of FO membranes that allow high water flux, high salt rejection, minimise salt flux and can operate at temperatures of 40°C or higher.

Researchers investigated the effect of membrane preparation conditions via a phase inversion technique on the performance of asymmetric polybenzylimide (PBI) flat sheet membranes, and investigated the integration of silica nanoparticles (SNPs) into PBI which was supplied by Trevi Systems to develop a novel mixed membrane matrix for FO applications.

The project was led by Dr Shadi Wajih Hasan, an Assistant Professor in Water and Environmental Engineering at MI's Department of Chemical and Environmental Engineering.



## PIONEERING NEXT GENERATION DESALINATION




1. Increased energy efficiency
2. Reduced cost of desalination
3. Decreased environmental impact
4. Diversification of energy supply

"Abengoa would like to thank Masdar for the opportunity to participate in the Renewable Energy Seawater Desalination Program. Abengoa developed a cutting edge desalination pilot plant with the goal of employing a more sustainable and energy-efficient process that could be powered by renewable energy. Abengoa has learned valuable information throughout the project, that will lead to future sustainable projects."

***– Tyson Doyle, Project Manager at Abengoa***


Abengoa-Masda
Renewable Energy
Desalination facility
Description:
Main data:
Capacity:
1,060 m³/d
Main Process Units:
ABENGOA

# A TIMELINE OF SUCCESS

A key step to achieving water security and reducing energy consumption

Masdar
A MUBADALA COMPANY

## 2013

Masdar launches the Renewable Energy Water Desalination Programme to develop advanced energy-efficient seawater desalination technologies suitable to be powered by renewable energy sources.

## 2014

Masdar partners with four global industry leaders – Abengoa, SUEZ, Veolia/Sidem, and Trevi Systems – to operate four pilot desalination plants in Ghantoot.

ABENGOA

SIDEM VEOLIA

suez

TREVI SYSTEMS

## 2015

- Masdar inaugurates its project site in Ghantoot, Abu Dhabi; the inauguration ceremony is attended by HE Dr Suhail Al Mazroui (UAE Minister of Energy), HE Dr Sultan Al Jaber (UAE Minister of State and Chairman of Masdar), HE Dr Ahmad Belhoul, Minister of State for Higher Education, HE Razan Al Mubarak (Secretary General, Environment Agency - Abu Dhabi), HE Faris Obaid Al Dhaheri (Director General, Abu Dhabi Water & Electricity Authority), HE Michel Miraillet (former Ambassador of France to the UAE).
- Pilot plant comes into operation
- R&D programme started

## 2016

- Masdar partners with Mascara Renewable Water to operate a fifth pilot desalination plant in Ghantoot.
- The pilot plants are visited by a delegation of the International Renewable Energy Agency (IRENA).
- The pilot plants are visited by attendees of Abu Dhabi Sustainability Week 2016.
- The pilot plants are visited by members of the media from the BBC, National Geographic, Russia24, Vietnam Television (VTV), Huffington Post and more.

Mascara Renewable water

## 2017

- The pilot plants are visited by a delegation of the Saline Water Conversion Corporation (SWCC) from the Kingdom of Saudi Arabia, led by Eng. Ali Abdulrahman Al-Hazmi (Governor, SWCC).
- The pilot plants are visited by a delegation of the Dubai Electricity and Water Authority (DEWA).
- Final results collected and synthesised

"Our partnership with Masdar during the Ghantoot Renewable Energy Desalination Pilot Programme provided us with a unique opportunity to assess the development of our desalination technologies. The cooperation between all parties has allowed us to gain valuable data and insight to move forward with implementing these solutions in a large-scale commercial setting and we are looking forward to further progressing the technologies piloted."

***– Vincent Baujat, Veolia Water Technologies Executive Vice-President for the Middle East.***


SIDEM VEOLIA
Masdar
مصدر
ILF

# IT'S JUST THE BEGINNING...

Reverse osmosis and solar power are the future

The Programme showed that reverse osmosis seawater desalination technologies are able to achieve an energy consumption of below 3.6 kWh per cubic meter of produced water

## PROGRAMME OUTCOMES

The programme outcomes have defined that reverse osmosis and solar power are commercially attractive, sustainable long-term mainstream solutions to water and energy security in the Gulf region.

Multiple technologies were tested to provide reliable results: The desalination pilot plants have successfully established a reference for multiple advanced desalination technologies and configurations.

Solutions were proven in the Gulf's specific local conditions: The Programme demonstrated that the advanced technologies are capable of handling one of the world's most challenging seawaters, fulfilling a key requirement for commercial adoption.

Reverse osmosis was confirmed to be the most energy efficient desalination technology with 75% gains over the current status-quo in the UAE: The Programme showed that reverse osmosis seawater desalination technologies are able to achieve an energy consumption of below 3.6 kWh per cubic meter of produced water treating highly saline seawater of the UAE's Arabian Gulf coast, if applied in a large-scale setting.

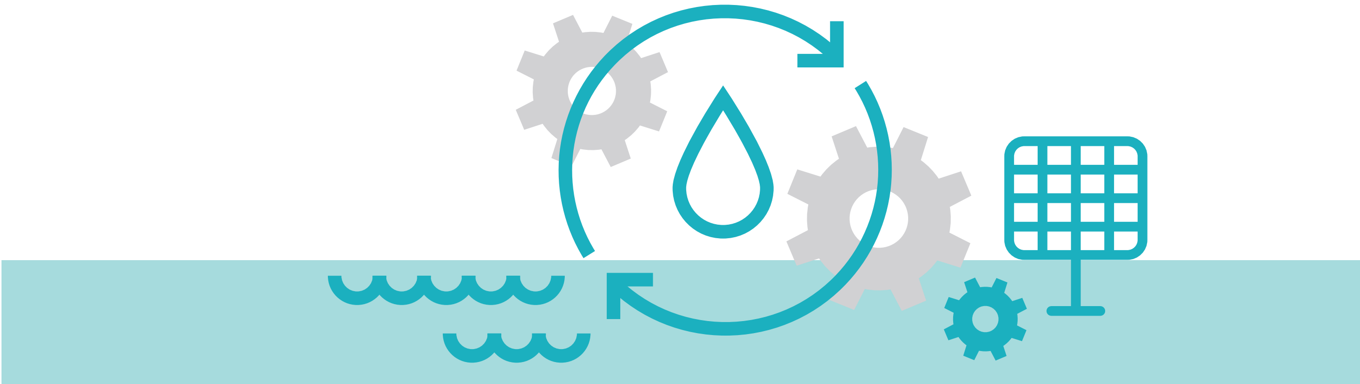
Renewable energy powered reverse osmosis has been proven commercially viable with drastic reduction in production cost: Levelized costs of below AED 3.3/$m^3$ can be realized if applied at a scale of 100,000 $m^3$/day or higher, compared to current average water production cost of 5.16 AED/$m^3$ in the UAE [10].

## LOOKING AHEAD

The demand for desalinated water across the UAE is expected to rise, and more than 800 million imperial gallons per day (MIGD) of additional seawater reverse osmosis capacity is expected to be installed by 2030 [11]. Based on this estimate, the implementation of renewable energy powered advanced seawater reverse osmosis desalination would reduce natural gas consumption by up to 235 million MMBtu per annum; this is worth more than USD 1.4 billion [12] per annum and is equivalent to 47% of present-day net natural gas imports. If 100% of this new capacity is powered by renewable energy reverse osmosis desalination, it would save more than 14 million tonnes of $CO^2$ per annum.

The UAE has already taken proactive steps to implement reverse osmosis desalination technology. This could potentially be accompanied by other supporting measures to save energy, reduce $CO_2$ emissions and add more value:

- Desalination plants could be subjected to the true cost of energy supply. Charging pre-determined cost of energy for desalination plants limits the development of more energy efficient plants to achieve a lower lifecycle cost.
- Water and power production could be separated allowing more efficient and seasonally adequate water and power production.
- The energy supply for desalination plants could be preferably sourced from renewable energy plants via a grid connection.



- $CO_2$ accounting could be introduced to benchmark and optimize the desalination plants.
- Environmental key performance targets could be established for desalination plants to mitigate the impact of chemical usage and brine discharge on the marine environment.
- Desalination plants could offer demand response capabilities to be able to reduce electricity peak demand when needed and to create value outside of the water sector.

## INNOVATION BEYOND THE PROGRAMME

Further research and development on seawater desalination could focus on new solutions that utilise optimised pre-treatment technologies to achieve energy savings and additional value creation by demand response.

The infrastructure at the pilot facility in Ghantoot can be used to innovate, develop and create a new wave of solutions for the UAE's future, especially within the water-energy-food nexus. The facility could be kept in operation as a Water Innovation Park ('the Park'), an idea that has received a lot of support from project partners, the independent advisory panel and other stakeholders from the pilot phase. By operating the Park at the heart of the region with the world's largest desalination industry and growing demand, it would lend itself well to ensuring the UAE and Masdar are competitively positioned to develop and commercially deploy novel water technology in the region and beyond for the next 30 years. The Park could be operated as a Public-Private-Partnership model in order to become a world-leading, cross-disciplinary hub where partners from technology companies, universities, government entities and international organisations work together to foster holistic innovation in water across the following multiple themes:

- Innovative technological advancements across the water sector value chain.
- Addressing environmental impact of desalination and climate change.
- Studying social attitudes towards water and influencing behaviour.
- Policy research for commercialization and application of novel water technologies.
- Education, awareness and training that inform, educate and inspire water industry professionals, utilities, policy makers and schools.

SUEZ is proud to have played an active role in the Masdar Renewable Energy Water Desalination Programme and to have partnered with Masdar by contributing to their ambitious initiatives for renewable energy. Masdar and SUEZ reached the objective to test new desalination technologies and process optimization to reduce the energy consumption that will address sustainable access to potable water. Masdar Renewable Energy Water Desalination Programme was a unique opportunity to test out bench scale to relevant scale innovative process with the challenging seawater quality of the Arabian Gulf. The project provided Masdar and SUEZ with valuable information about the performance of Masdar Renewable Energy Water Desalination Programme components to ensure water security and reduce energy consumption in order to meet the United Arab Emirates' energy reduction target:

- An innovative brine treatment solution has been implemented, based on a counter-current liquid/liquid deionisation technology with thermal energy: the reactor shape could be tested and evaluated and the resin formula confirmed.
- The pretreatment solutions have been operated out of their design range to challenge their capacity and robustness.
- The research project with Masdar Institute and ENGIE provided valuable insights about new configurations of solar powered reverse osmosis seawater Desalination plant.

This project would not have been possible without the support and trust from Masdar. The collaboration was deeply enriched by the expertise of Masdar Institute, Masdar, and ILF, its consulting partner. The forward-looking vision of the involved stakeholders enabled the development of innovative solutions for desalination.

– ***Gregory Tesse, Project Director, SUEZ***


suez

# EVALUATION BY THE INDEPENDENT ADVISORY PANEL

Final report
October 2017

## MEMBERS OF THE INDEPENDENT ADVISORY PANEL:

**Dr. Corrado Sommariva (Chair)**
ILF Consulting Engineers

**Ursula Annunziata**
Genesys International

**Leon Awerbuch**
International Desalination Association

**Dr. Nobuya Fujiwara**
Toyobo

**Paul Holthus**
World Ocean Council

**Dr. Joachim Koschikowski**
Fraunhofer

**Dr. Masaru Kurihara**
Toray Industries

**Dr. Adam Warren**
National Renewable Energy Laboratory

## PREMISE

In 2013, Masdar launched the Renewable Energy Water Desalination Programme (the Programme). The Programme is based in Ghantoot, UAE. Its goal was to develop and demonstrate advanced and innovative seawater desalination technologies that are highly energy efficient and cost-competitive and can be powered by renewable energy coupled to utility-scale desalination plants in the near future.

Five different desalination pilot plants have been operated at the project site in Ghantoot in the course of the Programme. The pilot plants demonstrated different advanced and innovative approaches to energy-efficient seawater desalination. The technologies have been selected by Masdar on a competitive basis after a comprehensive technical due diligence process.

**The following technologies have been developed and demonstrated:**

| Technology Provider | Desalination Technology | Capacity of Pilot Plant [m³/d] |
|---|---|---|
| Abengoa | Reverse Osmosis and Membrane Distillation | 1,000 |
| Suez | Reverse Osmosis and Liquid Ionic Membrane | 100 |
| Trevi Systems | Forward Osmosis | 50 |
| Veolia | Reverse Osmosis | 300 |
| Mascara | PV Powered Reverse Osmosis | 30 |

## PANEL

Masdar invited the Independent Advisory Panel (the Panel) to review the Programme and to provide independent expert opinion and guidance on the implementation of the Programme. The panelists are internationally well recognized industry experts in areas relevant to seawater desalination and have been appointed by Masdar. Dr. Corrado Sommariva, Managing Director of ILF Consulting Engineers Middle East, has been appointed by Masdar as Chair of the Panel.

Masdar paid attention that the appointed panelists represent different areas of expertise complementing each other to guarantee that all aspects relevant to seawater desalination are covered. The panelists were also selected to have a good geographical and institutional diversity among the Panel.

The mandate of the Panel was to provide independent expert opinion and guidance on the implementation of the Programme. Participation of the panelists was in an honorary capacity. The Panel met once a year at the project site in Ghantoot for a full day workshop. Masdar and the participating companies in the Programme provided the Panel with detailed information about the demonstrated technologies and shared with them the performances of the pilot plants. Each workshop included a site tour guided by Masdar and the participating companies. At the end of each workshop a discussion was arranged between the panelists, the programme managers of Masdar and faculty of Masdar Institute of Science and Technology allowing immediate feedback and guidance.

## CONTEXT

Currently operating desalination plants generate 90-billion liters of water per day. Population growth and climate change is expected to increase this demand by 12% over the next five years. Energy consumption represents over 1/3 of the cost of desalinated water in current systems. From these and subsequent discussions in the Panel several themes emerged:

- **There is a need to test technologies at scales not possible in a typical research laboratory. We need a bridge between bench-scale and full-scale testing.**

- **Research on integrated energy-water systems is needed, particularly on systems powered by renewable energy or sources of 'waste' heat.**

- **Further research is needed into the ability of desalinization systems to provide grid services, such as significant flexible load or demand response.**

- **Demonstration and testing of small-scale, integrated desalination and energy systems is needed. Such systems are needed in areas of water scarcity with limited, weak, or non-existent grids.**

- **Collaboration between academia, industry, and government is needed to address future R&D needs.**

## FEEDBACK OF THE PANEL ON THE PROGRAMME

Masdar has done an excellent job of overviewing the projects and summarizing the critical information for the Panel.

The Panel confirmed that it has been a very interesting experience to observe the Ghantoot piloting facility evolving from concept to pilot and on to fully operational plants, and additionally being able to be involved in the developmental progress of these technologies.

One of the first observations by the Panel was that while the original focus of the Programme was mainly to test innovations in desalination technologies, it was satisfying to see that as a response to initial panel feedback the Mascara renewable solar energy project was added during the latter part of the Programme to demonstrate that coupling with renewable energy supply is feasible. The fact that forward osmosis and membrane distillation were included right from the start was considered also interesting as well as that the Programme distinguished between advanced and innovative so that companies both large and small were involved. The panel also appreciated the fact that Masdar installed three different solar thermal collector systems at the project site to evaluate the most suitable way of providing low temperature heat for thermal desalination processes.

Reducing energy consumption, as well as increasing the proportion of renewable energy consumed, was a key factor in monitoring success, and these measurements have been made. The Panel commends Masdar for carrying out this important initiative in a very organized, collaborative and transparent way. The Programme stimulated the development and commercialization of new technologies that are needed to reduce the economic and environmental footprint of desalination. The Programme also enabled the participating companies to improve and optimize their technologies and adapt them to the seawater conditions of the Arabian Gulf. This is a very important aspect that will ultimately benefit all countries that operate desalination plants as newly constructed plants may now be better designed and operated taking into account the findings of the Programme.

## FUTURE R&D DEVELOPMENTS

The panel recommends an extension of the Programme. Further development of the Programme could include the following RD&D elements:

- **Optimization of recovery ratio. Increased percentage recovery may reduce chemical consumption as well as affecting the energy consumption, pumping costs, volume of water required etc. – mostly this is accounted for in the overall energy consumption, but probably not in all cases.**

- **Brine recovery / Zero-liquid-discharge. Depending on the location, this may or may not be currently an issue, but this topic is definitely becoming one to be solved as completely as possible.**

- **Chemicals. Although the objective is to have the plants as self-sufficient as possible, there will be a necessity for some chemical additions, both continuously and occasionally off-line for cleaning events. They are used for pretreatment, post-treatment, antiscalants, cleaning etc. The objectives would be to reduce chemicals consumption as much as possible, and to ensure that the most effective products are used in order to reduce downtime. In addition, it would be necessary to ensure that non-hazardous products are used as far as possible in order to reduce transport and storage hazards.**

# EVALUATION BY THE INDEPENDENT ADVISORY PANEL

Final report
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- Development of membrane cleaning procedures, perhaps using different temperatures, or testing novel products. This topic is part of, or related to the point mentioned above; by use of membrane autopsies where relevant (or trial and error), frequency of cleaning could be minimized by using the most effective products identified during flat sheet cleaning protocol comparisons.

- Development of new membranes, primarily being developed for forward osmosis, but perhaps exhibiting other interesting characteristics.

- Development of different geometric membrane spacers.

- Training local engineers! And thereby increasing the technical labor pool.

- Developing monitoring/specific measuring techniques.

- Simplifying procedures such as shut-down so that automation is increased, for remote situations.

- Evaluating new(ish) standards such as MFI instead of SDI in order to improve automatic control of pretreatment.

- Promoting awareness of the need for energy footprint limitation.

- Improvement of partial load capabilities or RO plants.

- Development and optimization of advanced pressure recovery devices.

- Development of advanced energy supply concept particular to small to medium scale systems.

- Development of water storage concepts as as artificial groundwater recharge.

## EXTENSION OF PROJECT SITE

There was a general consensus among the Panel on the fact that the site potential to develop into a permanent testing facility continuing a program of seawater desalination sustainable development should be pursued considering various factors such as:

**1. The site is available with seawater abstraction facilities that are already installed and easy to operate and maintain.**

**2. In particular this offers a new company who wish to test an innovative product to leverage on**

- **Existing infrastructure**
- **Existing skilled and trained personnel**
- **Permits available**
- **And independent source of evaluation and possibly certification of the performance of the pilot plant.**

Therefore there was a general consensus over that fact that the investment in the existing facility should be leveraged to develop a research 'user-facility' where R&D is conducted through cost-sharing partnerships. Users of the facility would pay for access to the facilities equipment, infrastructure, laboratories, and related support. This would allow partners to test and optimize individual technologies or integrated energy-water systems at scale in a real-world environment.

**Research, development, and demonstration opportunities include:**

- Integrated testing and field validation of components in a controlled environment;
- Simulation and development of new plant configurations and controls;
- Hardware-in-the-Loop (HIL) testing with access to remote simulators;
- Development of codes and standards for energy-water systems;
- Improve investor (equipment supplier, utility, contractors, user, financier) understanding and confidence in new technologies and processes.
- Utilizing three different solar thermal collector systems at the project site would allow to evaluate the most suitable way of providing low temperature heat for thermal and hybrid desalination processes and zero liquid discharge (ZLD).

This user-facility would provide companies, academia, and research institutes a test bed to reduce technology and market risk and to accelerate the development of energy-efficiency, renewable energy powered desalinization at a scale not possible today.

The site would also offer good opportunities to use the plant for public demonstration, for visitors (like a technology museum) or possible use for trainee course on desalination technologies and renewable energy.

Several options were suggested to provide the required funding for the site including:

1. Longer term evaluation of the full scale plant by any of the 5 existing projects – for an agreed rental, any of the companies could stay and continue evaluation and development of their processes.

2. Offer of rental space for product/process development to various companies that initially presented interest for the site.

3. Reconversion of the area into two sectors – one for R&D, as above, while the other could be used for companies to showcase their technologies, so that these could be viewed by interested parties.

4. Concepts such as water for irrigation could be showcased, with small areas given over to demonstrations of fast-growing agricultural products.

5. Water technology centers such as Wetsus in the Netherlands, PUB in Singapore, GIST from Korea, could be interested in co-operating and using/building the facilities for development of projects for their industry and university partners/PhD students – perhaps as a follow-up to laboratory pilot scale projects.

## INDEPENDENT ADVISORY PANEL MEMBERS

### DR. CORRADO SOMMARIVA (CHAIR)

Dr. Sommariva is managing director of ILF Consulting Engineers Middle East and the head of the company's worldwide desalination practice. He has experience in thermal, reverse osmosis and wastewater systems and has served in various roles in all the major desalination developments in the Middle East.

Dr. Sommariva was president of the International Desalination Association (IDA) for the term 2011-2013, served as co-chairman of the technical program for the 2009 IDA World Congress in Dubai and chairman of IDA's recently held conference "Desalination Industry Action for Good," a landmark event held in Portofino, Italy that focused on desalination and social responsibility.

Dr. Sommariva has a PhD in Chemical Engineering from Genoa University and a diploma in Management from Leicester University. He is an honorary professor at Genoa and L'Aquila universities where he holds regular courses on desalination and economics. He has published over 50 papers on desalination leading edge research and economics and published two books on desalination management and economics.

He has been president of the European Desalination Society (EDS) and chairman of the World Health Organization's committee for the establishment of safe drinking water from desalination.

### URSULA ANNUNZIATA

Mrs. Annunziata is an international authority on desalination. She is president of the European Desalination Society and also a board member of the International Desalination Association.
Her qualifications include a BSc Hons in chemistry and Marine Biology and an MSc in Applied Hydrobiology. Over the last 25 years her focus has been on membrane technology, specializing in antiscalants and membrane cleaning chemicals.

# EVALUATION BY THE INDEPENDENT ADVISORY PANEL

Final report
October 2017

### LEON AWERBUCH

Mr. Awerbuch began his desalination involvement over 40 years ago. He joined Bechtel Group in 1972 in R&D followed by increased responsibilities for power and water programs as Bechtel vice president and senior regional representative for the Middle East and Africa. During his 35-year career with Bechtel, he was in charge of desalination programs and involved in R&D, design and engineering as well as EPC of desalination and power projects.

As president & chief technology officer, Leading Edge Technologies Ltd., Mr. Awerbuch is currently involved in providing technical and commercial consulting to a number of leading suppliers and utilities involved in reverse osmosis and thermal desalination and power projects as well as the assessment of new desalination technologies.

Mr. Awerbuch is a past president of IDA and was chairman of six IDA World Congresses. Currently he serves as a director of the association and has been a chairman and co-chair of IDA's Technical Programs for the past 25 years. As such, he has organized and chaired over 40 conferences, forums, seminars and workshops around the world. In addition, he was first vice president and director of the National Water Supply Improvement Association (NWSIA) and the American Desalination Association (ADA).

Mr. Awerbuch holds 28 patents and has published more than 90 technical papers. He received a Lifetime Achievement Award from IDA at the 2007 World Congress in Grand Canarias and a Life Achievement Award at the Inaugural Power Generation and Water Solutions Middle East Awards October 2009. In January 2015, he was voted one of Water & Wastewater International's top 25 industry leaders.

### DR. NOBUYA FUJIWARA

Dr. Fujiwara is deputy director and senior general manager of the Desalination Membrane Department of TOYOBO Co., Ltd. and director of the Arabian Japanese Membrane Company (AJMC) in the Kingdom of Saudi Arabia.

Dr. Fujiwara has been in charge of seawater desalination reverse osmosis plants with a combined capacity of around 2 million m3/d. He currently leads research and development efforts on forward osmosis membrane development. Dr. Fujiwara is a director of the International Desalination Association (IDA) and a vice president of the Japan Desalination Association (JDA).

Dr. Fujiwara graduated from Kyoto University in the department of Chemical Engineering in 1983. He received a PhD from Kobe University in Japan.

### PAUL HOLTHUS

Mr. Holthus is founding president and chief executive officer of the World Ocean Council. He works with the private sector and market forces to develop practical solutions for achieving sustainable development and addressing environmental concerns, especially for marine areas and resources. Mr. Holthus has been involved in coastal and marine resource sustainable development and conservation work in over 30 countries in Europe, Asia, the Pacific, Central America and Africa. As a consultant on sustainable development and environmental management, he has worked with companies, industry associations, UN agencies, international NGOs and foundations on sustainability, especially in the areas of oil/gas, fisheries, aquaculture, standards and certification. Mr. Holthus is a graduate of the University of California and the University of Hawaii, with advanced degrees in coastal/marine resources and international business.

### DR. JOACHIM KOSCHIKOWSKI

Dr. Koschikowski studied mechanical engineering at University Duisburg with a focus on construction and renewable energies. He has been working with the Fraunhofer Institute for Solar Energy Systems ISE, the largest solar research center in Europe, since 1996.

Since 1999, Dr. Koschikowski has been working in the field of solar desalination with a focus on the development, design and simulation of membrane distillation processes and systems. This topic was also the subject of his PhD thesis. He is currently involved in several national and international research projects on solar driven desalination and is coordinator of EU FP7 and H2020 projects.

Since 2014, Dr. Koschikowski is head of the R&D group "Water Treatment and Separation." The group works on the development, construction and testing of solar thermally and PV driven desalination technologies as well as the development of technologies for industrial waste water treatment.

### DR. MASARU KURIHARA

Dr. Masaru Kurihara is senior scientific director of the "Mega-ton Water System," a funding program for world leading innovation, science and technology in Japan, and fellow of Toray Industries, Inc. He graduated from Gunma University in Applied Chemistry in 1963 and completed his doctoral dissertation at the University of Tokyo in 1970. He joined Toray Industries, Inc. in 1963, working on polymers research. Since then, he has held several positions in research and water treatment technology within the company.

Dr. Kurihara is a member of numerous organizations, including the American Chemical Society, Japan Chemical Society, Japan Polymers Society and Japan Membrane Society. He is president of the Asia Pacific Desalination Association (APDA) and vice president of the Japanese Desalination Association (JDA). He has received numerous awards in recognition of his work including a Lifetime Achievement Award from IDA, presented in 2011.

### DR. ADAM WARREN

Dr. Adam Warren is the Director of the Integrated Applications Center at the US Department of Energy's National Renewable Energy Laboratory (NREL). His Center addresses the technical, policy, and financial hurdles to developing resiliency, efficiency, and renewable-energy technologies at scale. Lessons from today's marketplace inform the direction of future technology and policy research at NREL. Prior to joining NREL, Dr. Warren supported PepsiCo's corporate sustainability efforts. Dr. Warren holds PhD and B.S. degrees in Chemical Engineering and is an adjunct professor at Colorado School of Mines.

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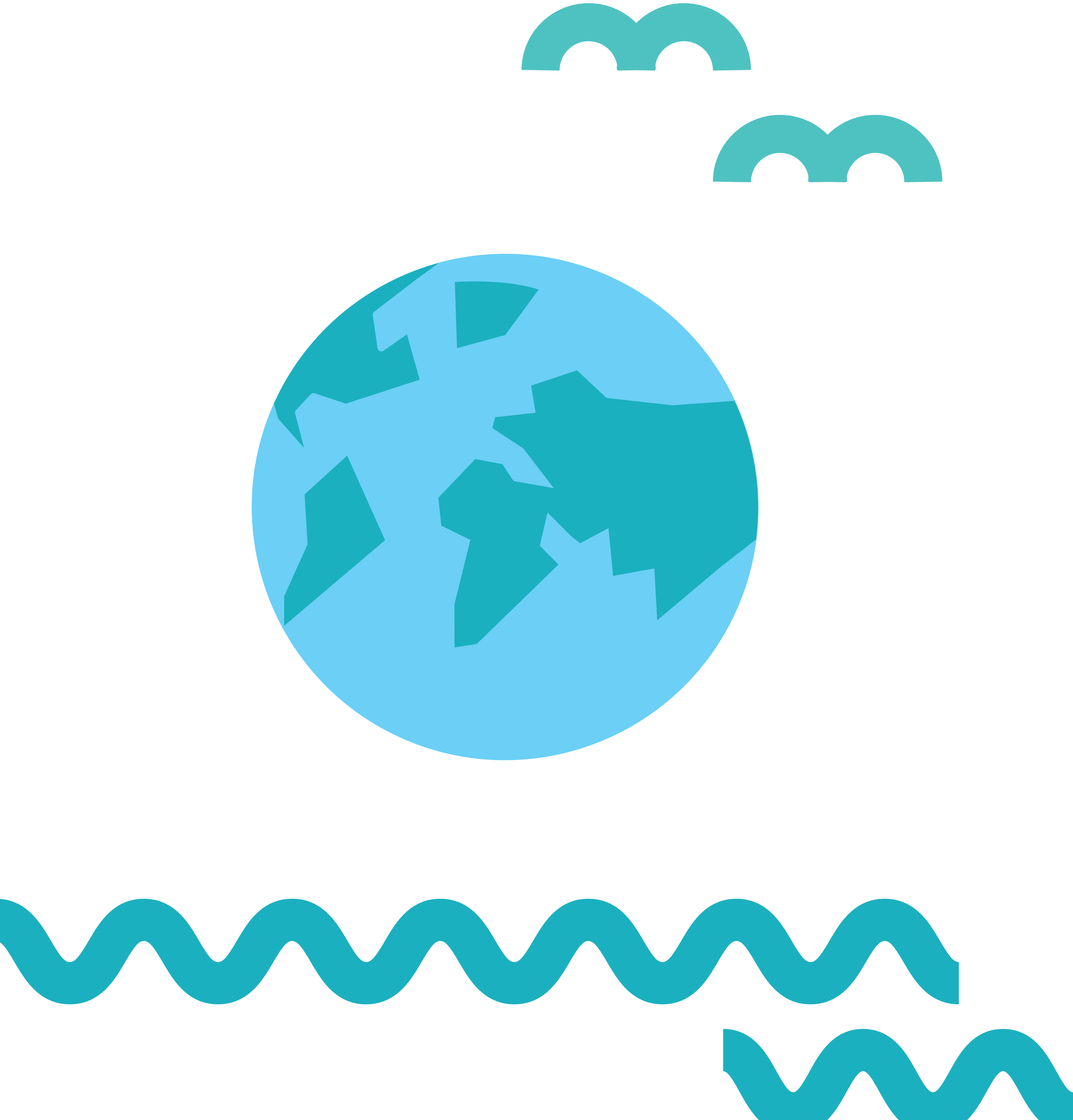

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