OVERVIEW DEMONSTRATION PROJECTS 2023- ANNEX I

Content

European Demonstration Projects:

The Netherlands - REDstack

REDstack's technology is based on the process of Reverse ElectroDialysis (RED) stacks for Salinity Gradient Energy generation. In addition, REDstack also uses ElectroDialysis (ED) stacks for desalination of brackish water. REDstack is based in Sneek, The Netherlands.

Figure 1: Redstack's prototype and test site on the Afsluitdijk, Netherlands.

REDstack's **Key Market Locations/Aspirations** are in Renewable Energy, CO2 free 365/24/7 energy generation. Water desalination, cooling tower blow-down and regeneration for ZERO Discharge challenges of various types of salt and brackish water streams.

Demonstration Projects and first Results:

At the Afsluitdijk, REDstack tested all process variables and components for a RED power plant and developed the technology to TRL7. REDstack is on the verge of upscaling to a demo-site with TRL8. The location places heavy ecological demands on the design which are met by the actual state of the art of the technology:

The Wadden Sea is an important nature reserve. There are therefore extremely strict environmental requirements. Normal operations (including periodic cleaning) are therefore governed by a strict protocol. The water from the Wadden Sea is very rich in biological terms. In addition, it contains a lot of suspended silt particles. Therefore, the water must be sufficiently purified before it can be led through the stacks. At REDstack, this is done with large drum screens, as well as with fast sand filtration. The filtration process must be (and is) in close harmony with the requirements of the stack. This was concluded in independent research by Deltares, NIOZ and WMR/WUR. REDstack has a lot of expertise in this field.

What was initially described as 'difficult water' also has many benefits. REDstack successfully developed a robust and clean installation. The objective is that the product (the installation, the stacks) can also be used elsewhere in the world without too many major modifications.

The actual, as well as the future demo installation on the Afsluitdijk, consists of the following components:

- The supply of salt and fresh water and the discharge of brackish water, the inlet pumps and filters, the pipes, and the pipe bridge.
- Both the fresh and the salt water are filtered in a drum screen or quicksand filters. Mesh size and rinsing regime are precisely tailored to the requirements of the stacks.
- The stacks. These are designed and patented by REDstack. They work based on flow principles, allowing for optimum use of the membranes.
- The converters. These convert the direct current from the stacks into alternating current and feed it back into the electricity grid. This is the final product of the REDstack pilot project.
- The control unit. The measuring and control system was specially designed for REDstack and is therefore unique in the world.

The next step has been prepared and is about to take place with a scale-up to 12 continuous running industrial size stacks providing 16,5 kW of power 24/7. This is the last step before market entry.

European Co-operation Projects:

HyReward – energy recovery from brine streams. (LIFE20 CCA/ES/001783)

The **LIFE HYREWARD Project** is initiated with the aim of increasing the sustainability of the desalination process by combining a seawater desalination system, for example Reverse Osmosis (RO) process and Reverse Electrodialysis (RED) processes to harvest the energy available in the salinity of the reverse osmosis brine. The integration of the RED process with the conventional desalination process will allow the recovery of the electrical energy contained in the seawater desalination brine before its discharge into the sea through the generation of electrical energy, reducing the global energy consumption and improving the overall efficiency of the desalination process.

Reverse Electrodialysis is a promising technology to generate electrical energy from salinity gradients. The blue energy generated in this process can be considered as a completely renewable and sustainable, CO2-free source of energy that can contribute to the EU climate goals. The technology concept that will be demonstrated within LIFE HYREWARD Project, utilizes the RED technology to harvest the energy available in the salinity gradient between the reject of a seawater desalination and the treated effluent of a Wastewater Treatment Plant.

In this way, the hybrid desalination-RED process suggested in the LIFE HYREWARD process will allow the recovery of up to 20% of the energy consumed in the desalination process, generating clean and renewable energy from the seawater RO brine, reducing CO2 emissions from the desalination process and thereby contribute to the mitigation of the effects of climate change. And moreover, the RED process will reduce the salinity of the SWRO reject, reducing the environmental impact associated with the brine discharge or even allowing to reuse it as feed water again for the SWRO process.

IntelWATT Project (grant agreement No 958454) end date 03/2024.

IntelWATT is a Horizon 2020 funded project which aims to create intelligent Water Treatment Technologies for water preservation combined with simultaneous energy production and material recovery in energy intensive industries. Three TRL7 case studies will be implemented in crucial EU and global industrial applications such as electricity production, mining, and metal plating. REDstack is one of the 20 partners and responsible for developing, manufacturing, and testing RED stacks for the project.

Timing of Market Introduction, and Future Outlook: Various project sites are now under preparation for development in the Netherlands, South Korea, Colombia to enable full-scale implementation of the RED systems. “The Future looks Blue!”, according to REDstack’s business development head, Michael van Oostrum. Link to website: www.redstack.nl.

Costs:

As reference to the market, the CAPEX figures are not used as these specifically relate to the location and infrastructure on site, and as such will vary and do not represent proper comparable figures.

When the Blue Energy generation capacity reaches 100 MW, the Levelized Cost of Energy (LCoE*) will be ca. €0.11 / kWh. This price is more attractive than feeding electricity into the grid by any large-scale power storage system.

According to renown research organization TNO, and the consultants Witteveen & Bos and CE Delft, the LCoE per kWh of Blue Energy will go down to less than €0.05 / kWh before 2050, due to further upscaling and economies of scale.

*) The LCOE "represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle" and is calculated according to the IRENA guidelines.

Furthermore, RED advantages are:

- Robust core-technology, without moving parts
- Generates continuous, stable and predictable power (load factor at least 98%)
- Zero carbon emissions
- Minimum impact on landscape and ecology

Further pictures of site and technology:

Figure 2: Close-up of Redstack site

Figure 3: Redstack's Reverse Electro Dialysis technology.

Denmark – SaltPower

SaltPower is based on the on production of osmotic power by use of Pressure Retarded Osmosis (PRO). This process uses the gradient in salinity between 2 streams of high and low salinity. These two streams are mixed via a semi-permeable membrane to produce electricity. SaltPower is based in Sønderborg, Denmark.

The SaltPower PRO technology is most efficient when using saturated brine and freshwater. In SaltPower's own facility there is a test unit for testing of full-scale membranes and the full operational concept.

SaltPower is currently constructing its first commercial scale plant at its facility to be delivered in first half of 2023. The capacity of this unit is 100 kW and the technology can easily be scaled up, only limited by the availability of brine and water. The **key markets** of SaltPower are: Industrial salt producers and consumers, Solution mining for hydrogen and gas storage caverns and Geothermal power plants.

Demonstration Projects and First Results: The SaltPower PRO technology has participated in several projects to scale up the technology. A containerized test unit demonstrated fully stable operation for 2000 hours on full scale membranes, the results of which have been used to further improve the design and scale up the technology.

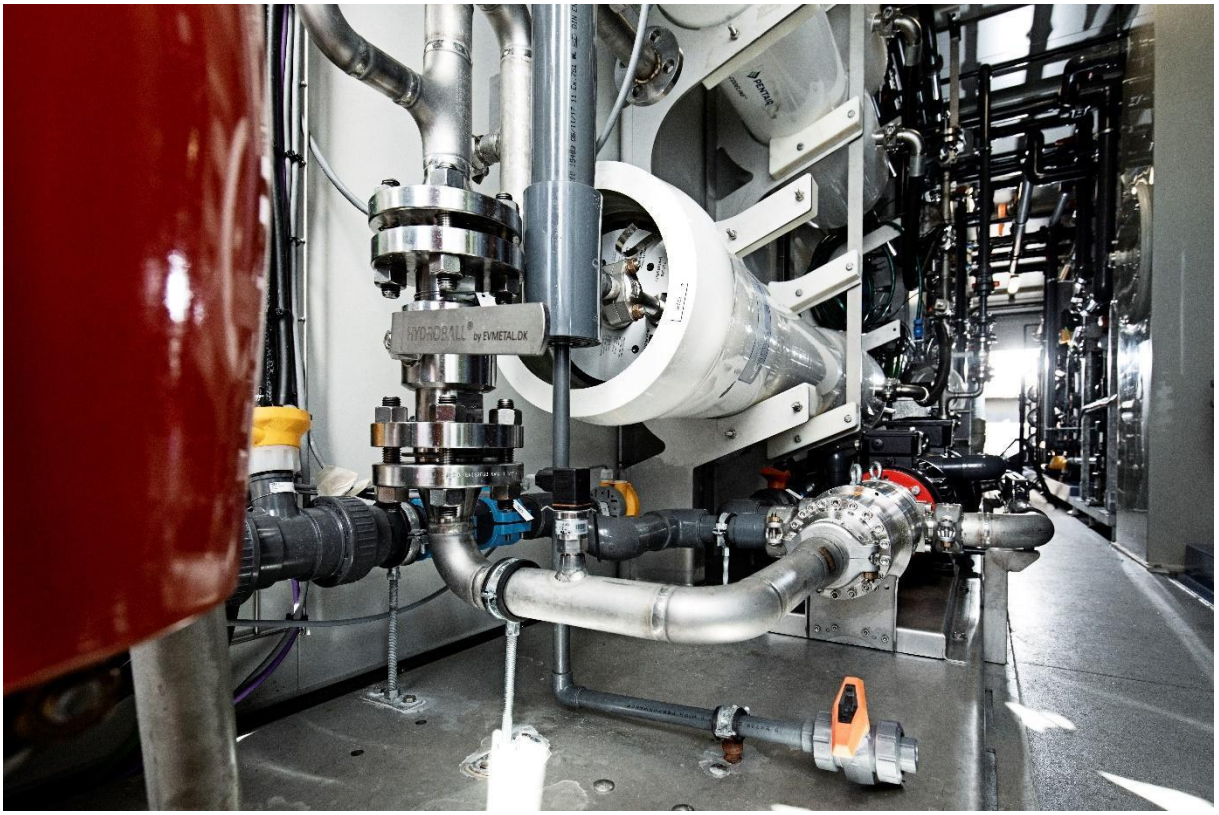

Figure 4: Containerized test unit at SaltPower in Sønderborg, Denmark.

Figure 5: Test unit at SaltPower facility

SaltPower is supported by **Horizon 2020 programme** with a grant to commercialize and scale up the PRO technology. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 954045. The first commercial scale plant is under construction with scheduled delivery and commissioning in the first half of 2023. The technology is being marketed for further sale.

Future Outlook and Special Remarks: The potential for PRO plants is high with many salt producers being able to benefit from the solution. The market for cavern excavation from solution mining is dependent on the development in renewable energy and the Power-to-X. When large amounts of hydrogen are produced there will be a need for storage capacity. This area is expected to accelerate over the coming 5-10 years. Link to Website: www.saltpower.net.

France – Sweetch Energy

- INOD is different from PRO and RED.
- High power system x low cost.
- Osmotic Energy ready for full scale development.
- Competitive alternative in renewables.

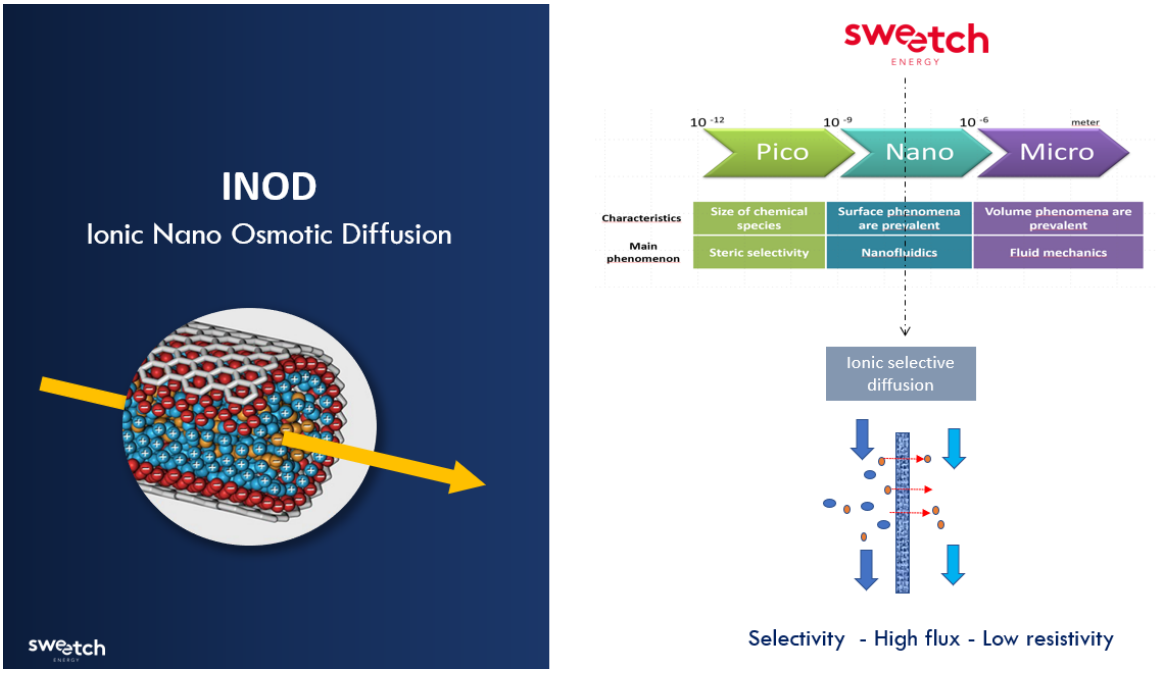

Figure 6: INOD technology illustration from Sweetch, France.

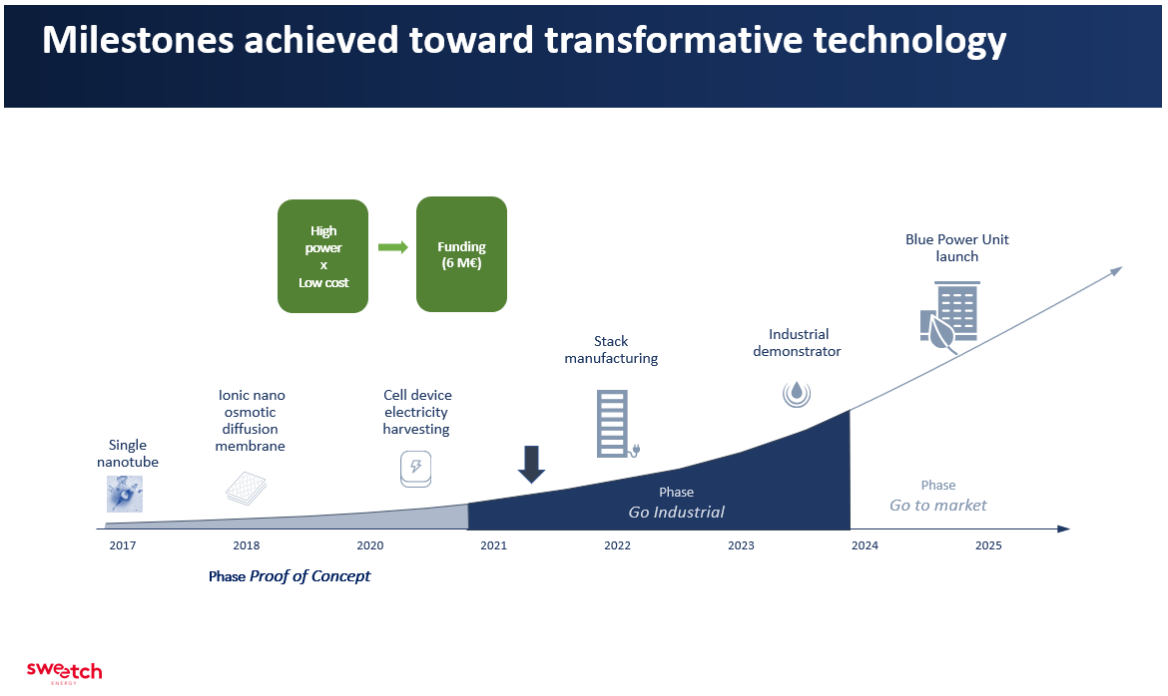

Figure 7: Technology timeline, Sweetch.

Italy – University of Palermo – Department of Engineering

The University of Palermo is one of the largest universities in Italy with more than 40.000 enrolled students. Within the University, the Plant Design research group of the Chemical Engineering Department led by Prof. Giorgio Micale has gained comprehensive experience the last 15 years during which it has greatly benefitted from a number of international research projects and collaborations. The Group has participated in 9 EU-funded projects (MEDIRAS, PRODES, STAGE-STE, REAPower, RED Heat-to-Power, REvivED, ReWaCEM, BAoBaB, ZERO BRINE) on solar-powered desalination and salinity gradient power technologies, novel hybrid technologies for water desalination and energy storage, and valorisation of industrial brines via membrane processes separations and chemical reactions.

In all the mentioned research projects, UNIPA has contributed with modelling activities, laboratory investigations, process & plant design, pilot units design, construction & installation in real environments, and, eventually, long-run monitoring activities.

UNIPA has also created a Brine Excellence Centre, a laboratory specifically designed for research on brine valorisation, circular economy, and resource recovery.

These efforts resulted in a extremely wide scientific literature and three books, regarded as a fundamental reference by the research community:

- Micale, G., Rizzuti, L., Cipollina, A., 2009. Seawater Desalination, Green Energy and Technology, Green Energy and Technology. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-01150-4
- Cipollina, A., Micale, G., 2016. Sustainable Energy from Salinity Gradients, First edit. ed, Sustainable Energy from Salinity Gradients. Woodhead Publishing, Elsevier, Amsterdam. https://doi.org/10.1016/C2014-0-03709-4
- Tamburini, A., Cipollina, A., Micale, G., 2022. Salinity Gradient Heat Engines. Elsevier. https://doi.org/10.1016/C2018-0-01788-0.

Demonstration Projects and Results:

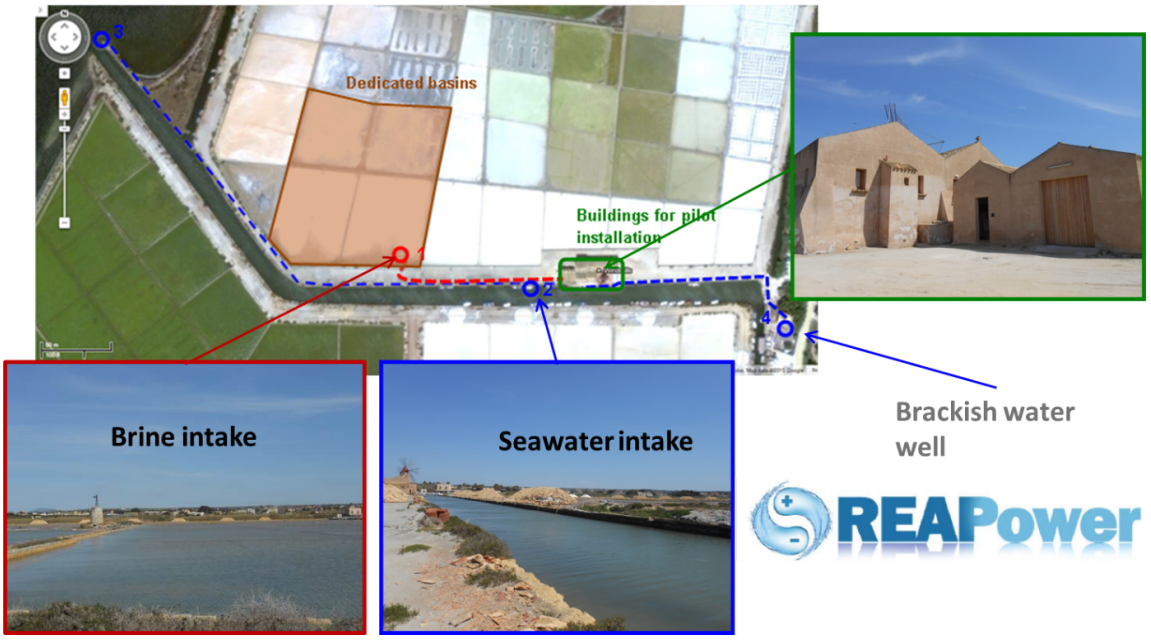

Figure 8: Trapani saltworks, Italy. Installation site of the first 1 kW Reverse Electro-Dialysis prototype.

The research group has a track-record of prototype systems. Noteworthy, the first and unique RED prototype in the world, successfully operating with highly concentrated brines and brackish waters as feed solutions, has been constructed by REDstack b.v. in the framework of the REAPower project led by UNIPA (see Figure 8). The prototype was positioned at the Trapani saltworks site in Italy with an installed power of 1 kW. The plant has been operated for 5 months without substantial efficiency loss (see Figure 9).

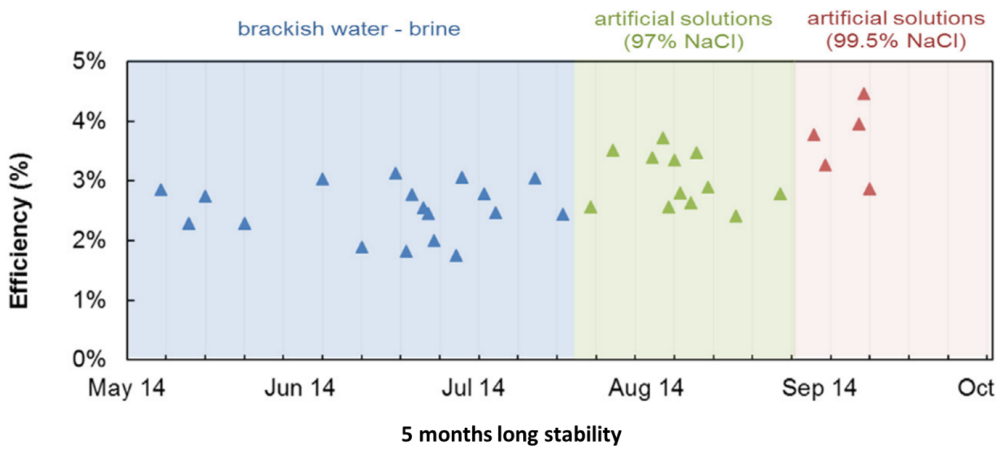

Figure 9: efficiency of the first RED prototype installed by Unipa over the testing period.

Another potential application of RED is in closed loops, where the total mass within the systems doesn't change in time and the salinity (or pH) gradient between the two fluxes is recovered using waste heat or surplus energy upon depletion.

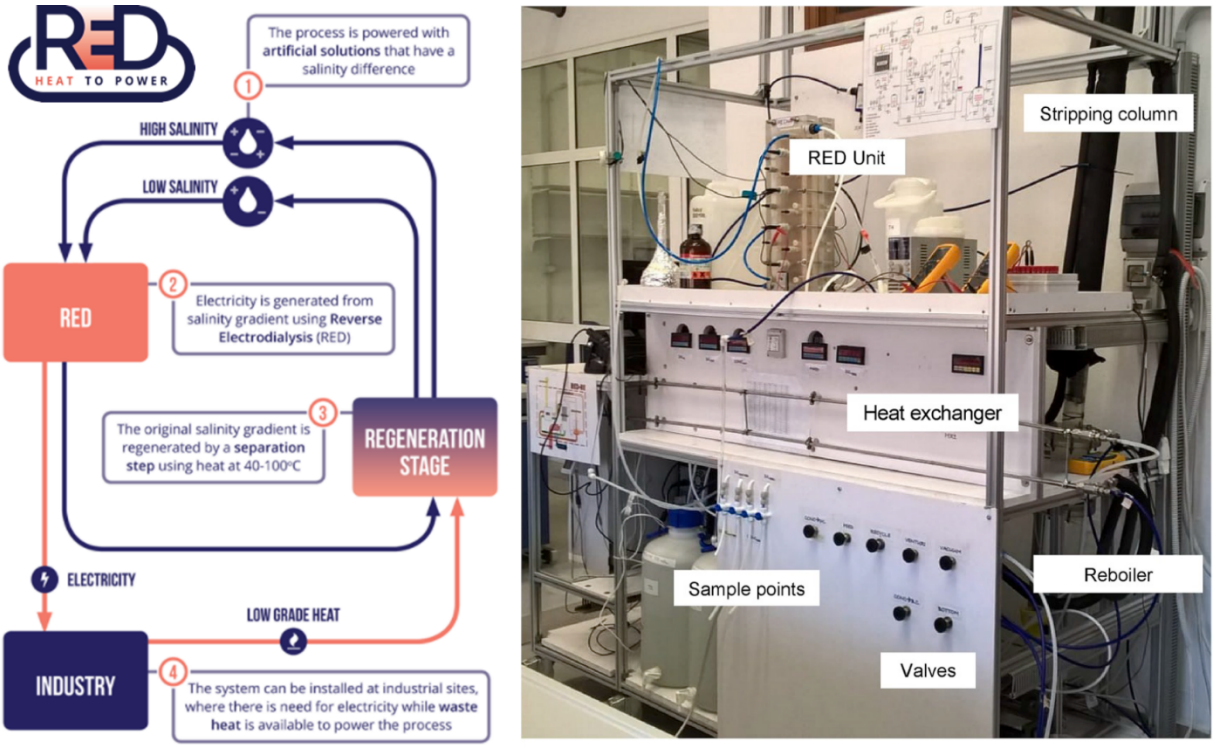

Figure 10: The first RED Heat Engine installation. Left: conceptual scheme of the process. Right: The demonstrator installed at UNIPA premises.

In the first case, the university of Palermo has constructed and operated the first pilot of its kind, for the recovery of waste thermal energy in the framework of the RED heat-to-power project (see Figure 10), while for the second case has collaborated with AquaBattery B.V. for renewable energy sources surplus energy storage in the framework of the BAoBaB project (Figure 11).

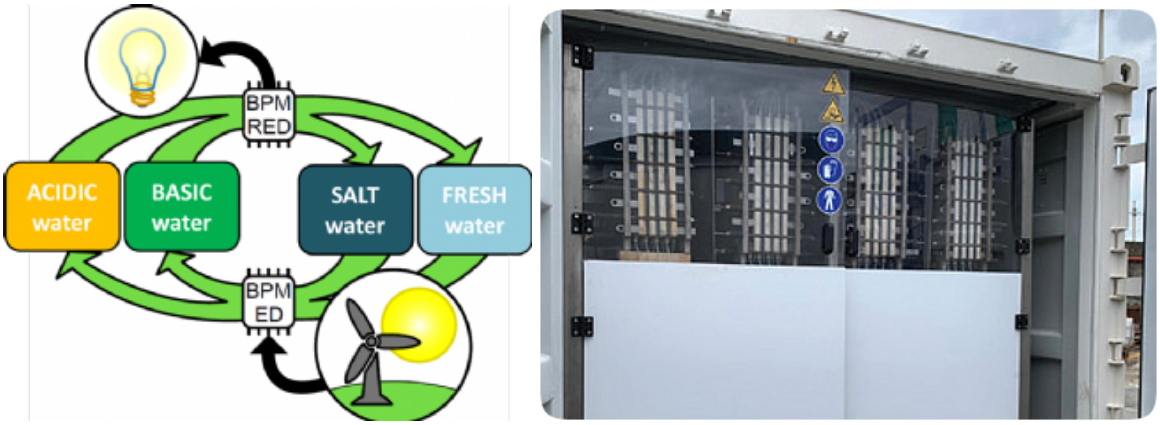

Figure 11: The first bipolar membrane RED flow-battery pilot installation. Left: conceptual scheme of the process. Right: The containerized pilot plant constructed by AquaBattery B.V. in the BAoBaB project. Target capacity of 1 kW/7 kWh, four-stacks hydraulically connected in parallel, each stack contains 56 triplets with a membrane active area of 0.5 × 0.5 m^2 (Pärnamäe, 2020).

Italy – ResourSEAs

Through the many aofrmentioned R&D projects, the Plant Design research group of the University of Palermo has gained a unique and valuable industrial know-how. The natural consequence of the experience gained was the foundation of a company to transform the result of the research into market products: ResourSEAs (www.resourseas.com).

ResourSEAs' key market locations/aspirations:

ResourSEAs is a consultancy company specialized in the circular economy of brines, with every possible related scenario and market exigency. At the core of the company is a circular economy approach to brines management and valorisation.

The assumption is that the most abundant industrial and natural salty solutions can be valorised through a fully integrated approach, where each waste is used as valuable input for the following treatment step. Most representative products of our projects are freshwater, table salt, gypsum, limestone, lime, hydrochloridric acid, magnesium and energy.

This circular economy approach has produced many intellectual property assets, such as the basic scheme of the SEArcularMINE project (www.searcularmine.eu).

Figure 12: The SEArcularMINE project concept (ResourSEAs Patent Granted). An integrated water cycle for the production of water, minerals and energy.

Demonstration Projects and first Results:

In the SEArcularMINE project, divalent ions are extracted from the waste brine of saltworks (the bittern) thus leaving a concentrated solution containing only monovalent ions. Using this solution as RED feed, pushes productivity to its limits. Thus, one of the highest measurements of power density ever recorded with a RED device was obtained by ResourSEAs team in the SEArcularMINE project (in publication).

Timing of Market Introduction:

Being mostly an innovation provider, ResourSEAs portfolio is composed mostly of intangible products, patents on different processes and reactors.

Main players of the water and energy sector, such as SUEZ, ENI and A2A have already used ResourSEAs' consultancy services for bringing their business to the new-generation economy.

Demonstration Projects in Emerging Economies:

Mexico - Institute of Engineering UNAM (National Autonomous University of Mexico)

A laboratory-scale device (TRL 3) has been developed by Institute of Engineering UNAM (National Autonomous University of Mexico) and characterized with the purpose of studying the physical principle of energy generation by salinity gradient. The institute is based in Mexico City, Mexico.

UNAM's key market locations/aspirations: Mexico has an extensive coastline, due to its location with respect to the equator, it presents favourable conditions for the extraction of energy by salinity gradient. In addition, Mexico is the fourth country in the world with the highest production of geothermal energy with an installed capacity of 958 MW, so it also has residual brines derived from industrial processes that could be used with an SGE system. Also, mining and petroleum industries are two of the most important economic activities in the country, therefore it could be of interest to use the effluents of this industry to desalinate water and recover raw materials.

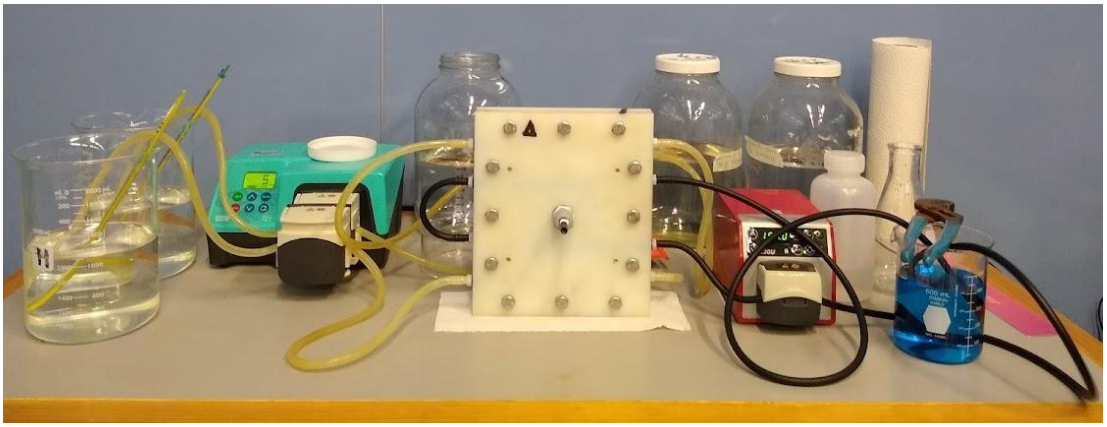

Figure 13: RED unit cell.

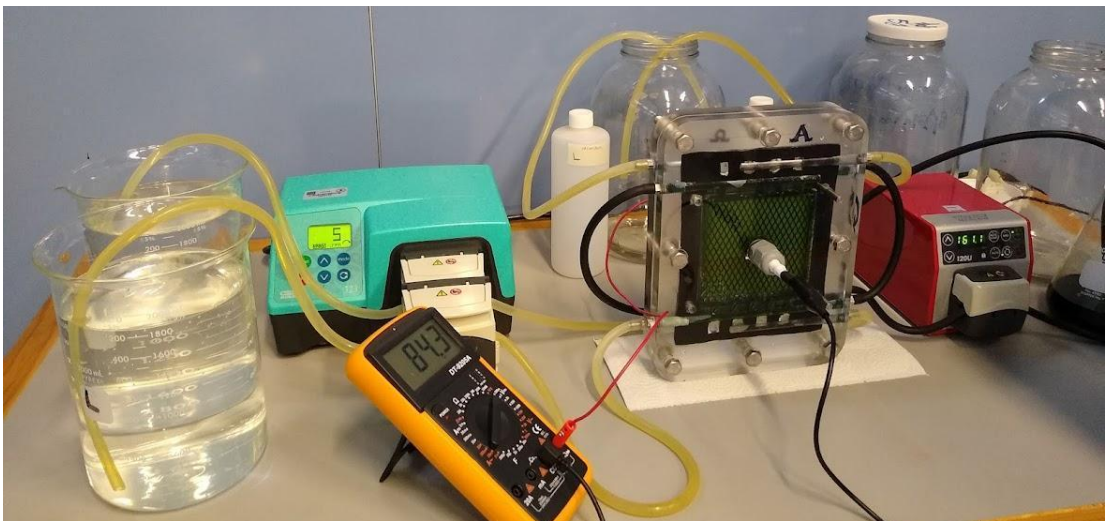

Figure 14: Experimental setup.

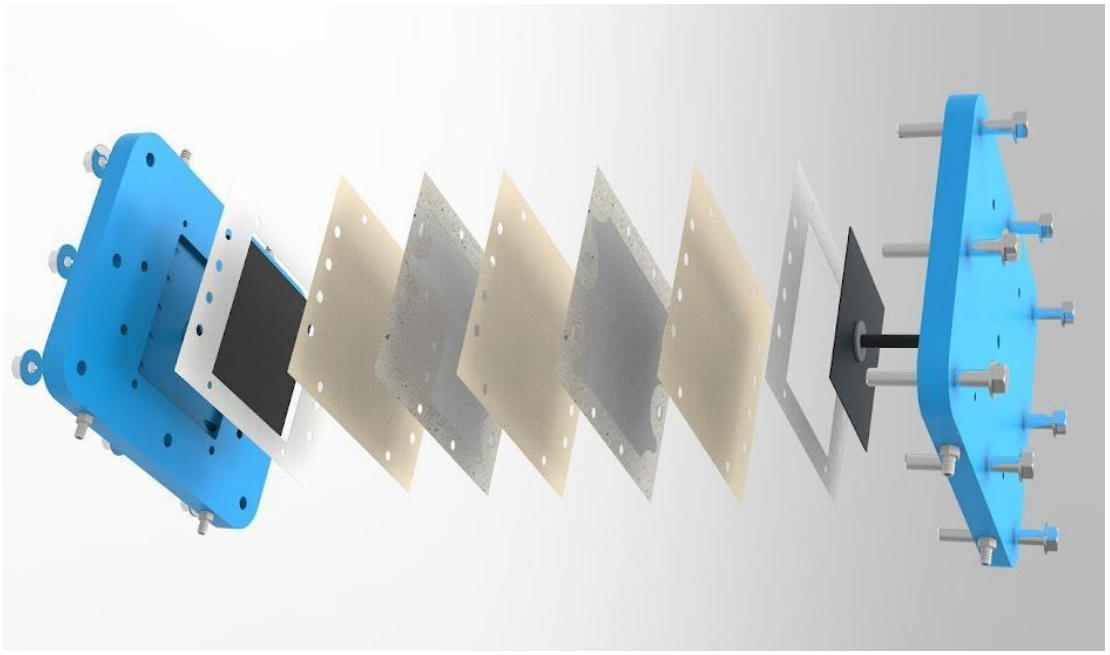

Figure 15: RED unit cell scheme.

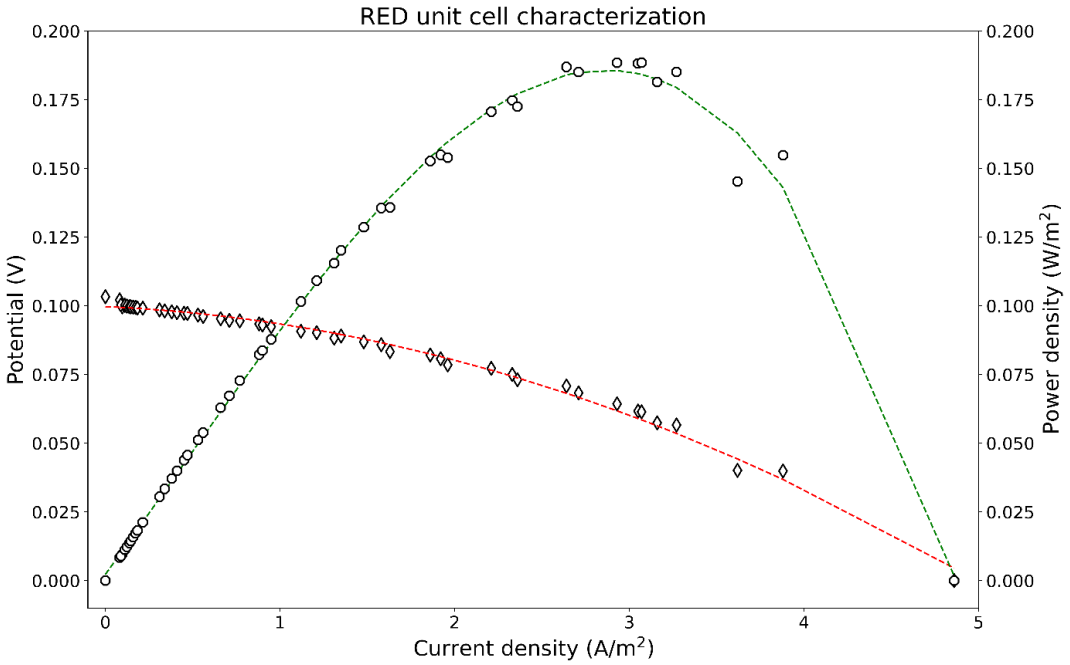

Figure 16: Characterization of a RED unit cell.

Demonstration Projects and first Results:

The salinity gradient power principle has been demonstrated with a RED device with a gross power density of 0.19 W/m2 per unit cell under laboratory conditions.

Mexican CEMIE-O is involved in several international networks. The international advisory panel of CEMIE-O includes European institutions such as EMEC. CEMIE-O is working in projects with European partners, including: University of Strathclyde, Fraunhofer-Gesellschaft, PLOCAN and University of Cantabria.

Timing of Market Introduction:

Before introducing the technology to the market, it is first necessary to integrate a system that complies with component validation and can complete long-run tests in a laboratory environment, as well as showing feasibility of upscaling and reproducibility. The estimated time to reach TRL 4 is December 2023.

Outlook into the Future and special remarks:

So far, CEMIE-O has demonstrated the principle of power generation using a RED unit cell under laboratory conditions. Their short- and medium-term goal is to reach a TRL 4 for a power generation system with RED. In addition, they seek to use this in other applications such as hybrid systems focused on water desalination in places with high water stress in the country. In the long term, the focus will be on the development of a system for the recovery of raw materials from industrial effluents.

Links to Company Website:

http://www.iingen.unam.mx/es-mx/Paginas/Splash/Default.aspx,
https://cemieoceano.mx/index.html, https://cemieoceano.mx/CEMIEOAC/index.html

India - Indian Institute of Technology Madras

Professor Nayak's research group introduces an alternate renewable energy source i.e., osmotic power generation using salt/sea water. They create salinity gradients by having salt/sea water and fresh/river water separated by a Nanomembrane to generate electricity/power. The group is based in the IIT Madras Research Park, Chennai, Southern India.

As the primary source of the energy is sea water, intermittency in efficiency will not be an issue as it is in solar power or wind power, which make the technology unique amongst other low (or zero) carbon energy sources. Rapid and scalable synthesis/growth of state of art membrane and fabrication of pores are the first key activities, followed by assembling them in larger customised diffusion cell system (termed by them as "blue energy generator") for producing electricity.

Professor Nayak's research group's **key market** locations/aspirations include the problem of intermittency in the renewable energy (as in solar and wind), which the group states to be the main problematic factor for the renewable energy generation sector. This technology is trying to address this intermittency issue with a non-intermittent and renewable energy source.

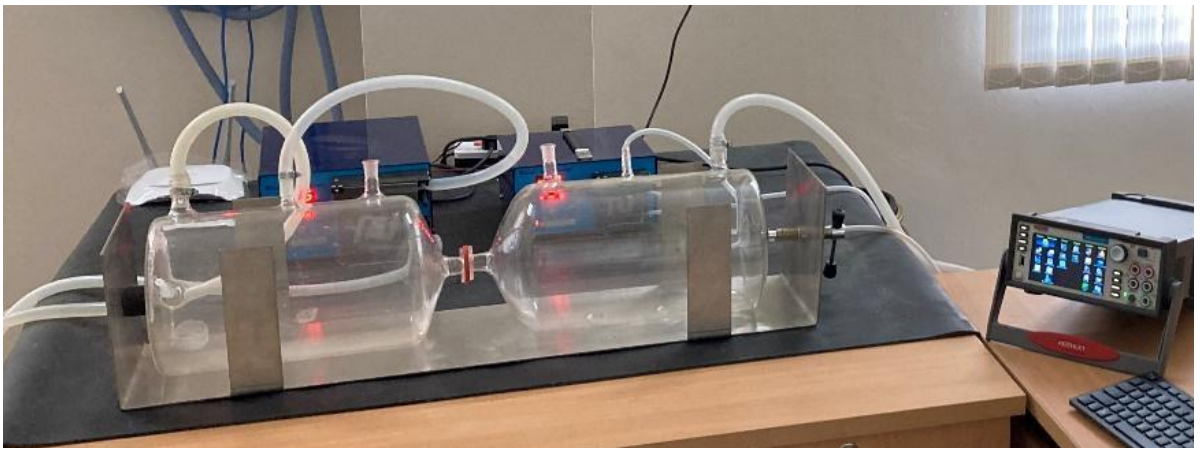

Figure 17: Blue energy generator, IIT Madras, India.

Demonstration Projects and first Results:

The electricity generation using salinity gradients and nanochannels would act as renewable source of power generator, which can produce about six orders of magnitude higher than other power generators currently available in commercial market. The maximum power we generated using single pore is 7.8 µW compared to the reported till date power is few pW to nW range for the same dimension.

Timing of Market Introduction:

Figure 18: Technology timeline, IIT Madras.

Outlook into the Future and special remarks:

As the world is switching from fossils fuel to renewable energy, the salinity gradient energy will help diversify this energy source with an added benefit of non-intermittency. The total addressable market in India is:

Total Addressable Market	• Overall power sector in India (356 GW) • Total power generation 1547 billion units (kWh). • 110 billion USD approx.
Served Available Market	• Renewable power sector in India (77.64 GW) • Total power generation 278 billion units (kWh). • 20 billion USD approx.
Target Market	• 1 GW capacity generating approx. 4.5 billion unit (kWh). • 0.3 billion USD approx.

Figure 18: Market prospects for Salinity gradient energy in India.

Link to website: https://connect2india.com/BLUE-FMA-PRIVATE-LIMITED/5763438/contact-details

Colombia - Universidad del Norte, Barranquilla

The Colombian universities Universidad del Norte (Laboratory of Prof. Oscar Alvarez Silva) and Universidad Nacional de Colombia, are currently being funded by the MINCIENCIAS (Ministry of Science, Technology, and Innovation of Colombia) for the construction of the first proof-of-concept field pilot in Colombia (and Latin America). The capacity will be 0.5 kW using RED technology (their own designed reactors) and is expected to be operational in 2024.

The location of the pilot is shown below. It is the mouth of the Magdalena River in the Caribbean Sea, near the city of Barranquilla. As can be seen in the picture, in this location, a jetty sharply separates the Magdalena River from the Caribbean Sea, becoming an ideal location for SGE generation.

Figure 19: Prospected pilot location for RED plant near Barranquilla, Colombia.

In early 2023, the universities presented a request to the environmental authorities to use this space and are currently waiting for approval. The project is still far from the market, as the time frame sits now, the plan if to have a plant producing multiple MW's in this location by 2030.

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