EMERGING SUSTAINABLE TECHNOLOGIES

EDITION 2024

RESEARCH & INNOVATION

ENGIE

EMERGING SUSTAINABLE TECHNOLOGIES

EDITION 2024

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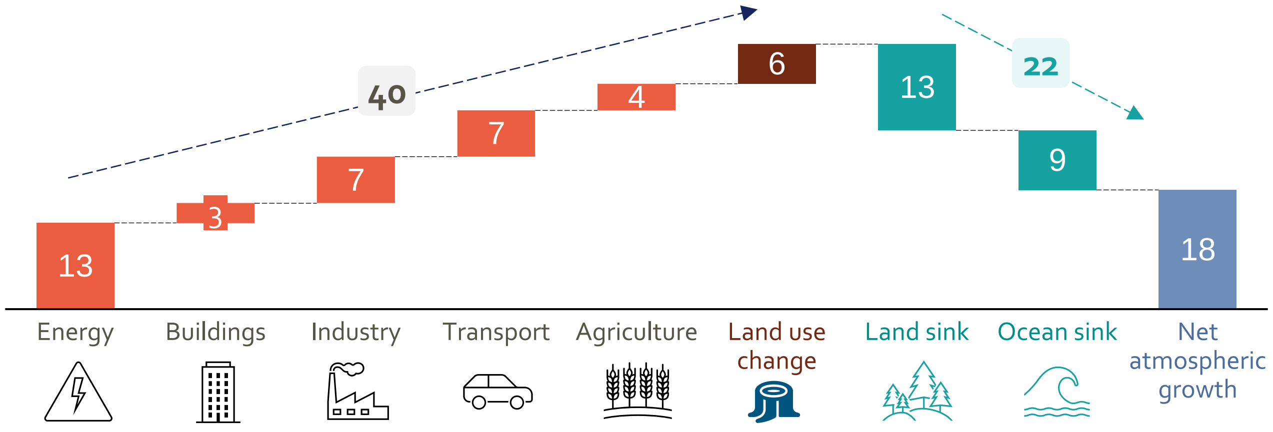
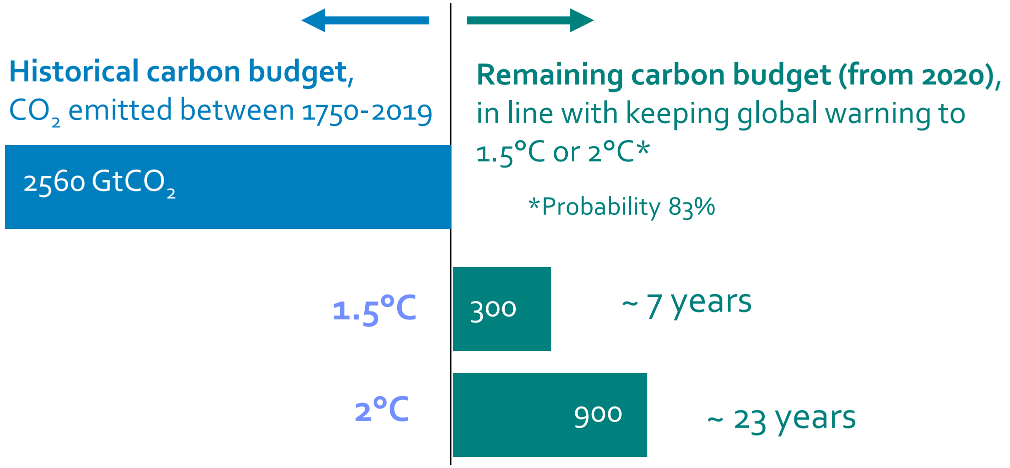
CO_2 stocks and flows are enormous compared to yearly CO_2 emissions from fossil fuels and industries, highlighting a high potential for Carbon Dioxide Removal (CDR) solutions

Key figures:

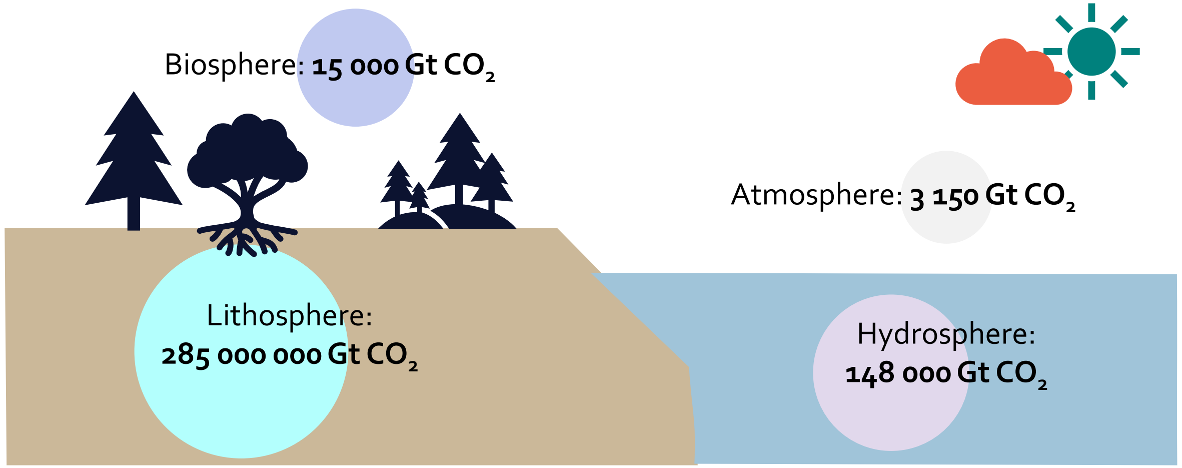
- **~30 $GtCO_2$** yearly were emitted from fossil use on average between 2010 and 2019, rapidly increasing to 38 $GtCO_2$ in 2022
- **18 $GtCO_2$** of which has remained in the atmosphere while 13 $GtCO_2$ was sequestered by the land and 9 $GtCO_2$ absorbed by the ocean on average each year between 2010 and 2019
- Remaining carbon budget amounts to **400 $GtCO_2$**, which corresponds to **~10 years of 2019 emissions**



CO_2 flux (2010-2019 average $GtCO_2$/y)[3]

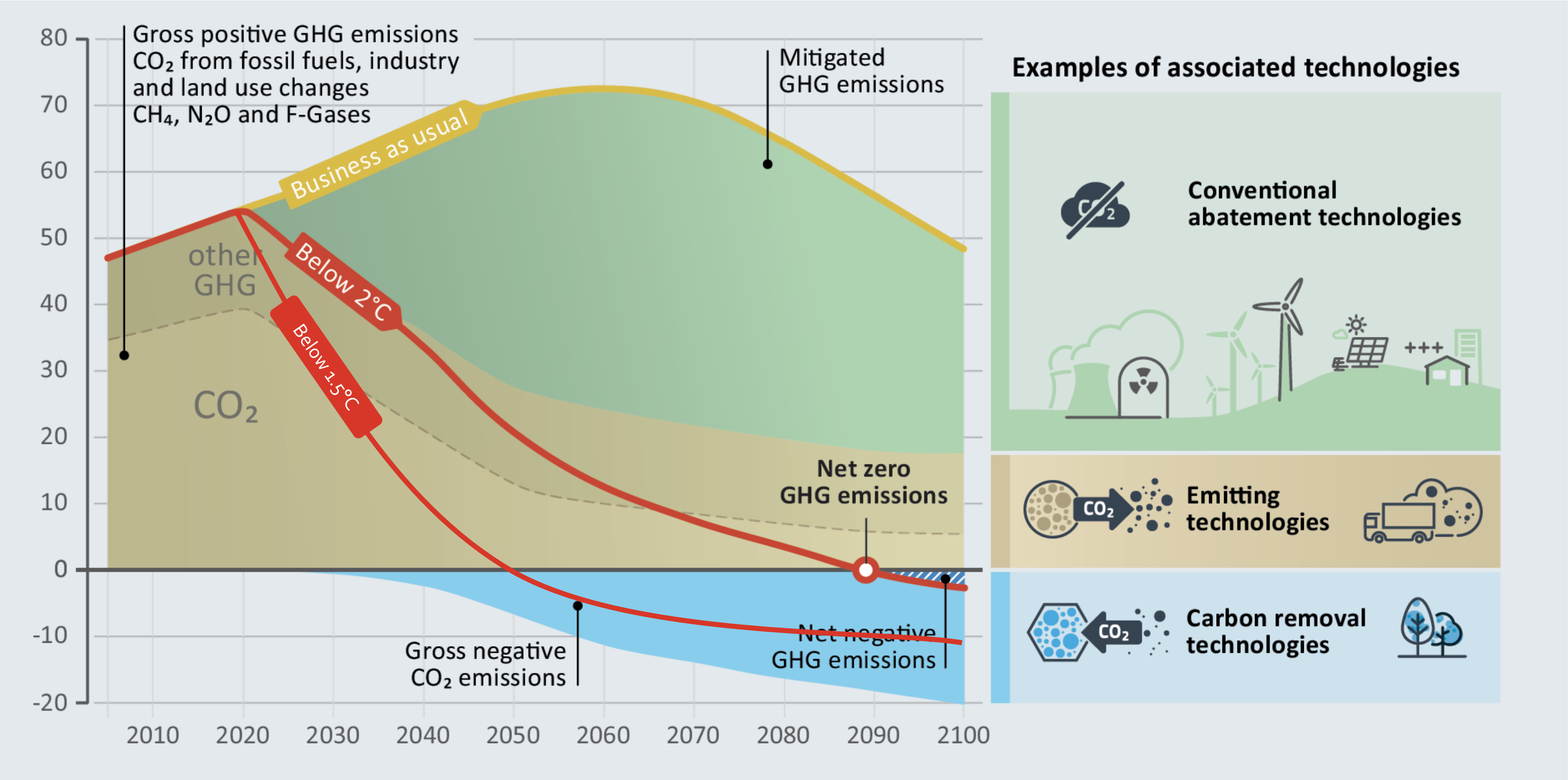


Remaining carbon budget is limited[1]



Stocks are enormous[4]

First priority remains the 90+% CO_2 emission reduction



GHG emissions (GtCO2/year)[1]

In February 2024, the European Commission presented its assessment for a 2040 climate target for the EU. The Commission recommended **reducing the EU's net greenhouse gas emissions by 90% by 2040 relative to 1990.**

There is no technology without negative impacts (footprint) but these should be compared to the positive value they bring (handprint)

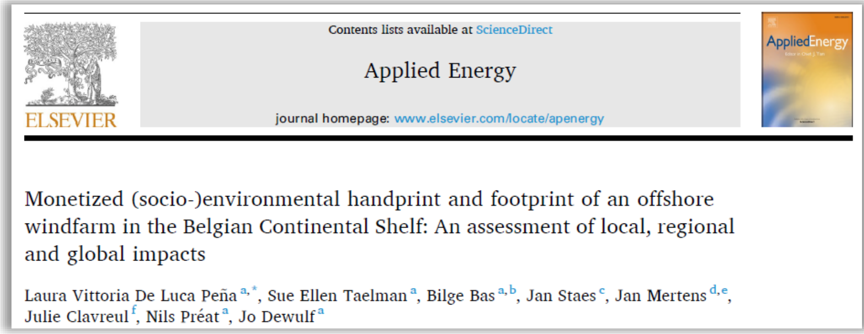
Handprint: positive effects

- Quality of life
- Ecosystems (ES) quality
- Social gains
- …

Footprint: negative effects

- Resource use
- Waste generation
- Emissions
- Social impacts
- …

Handprint versus footprint: example of a Belgian offshore wind farm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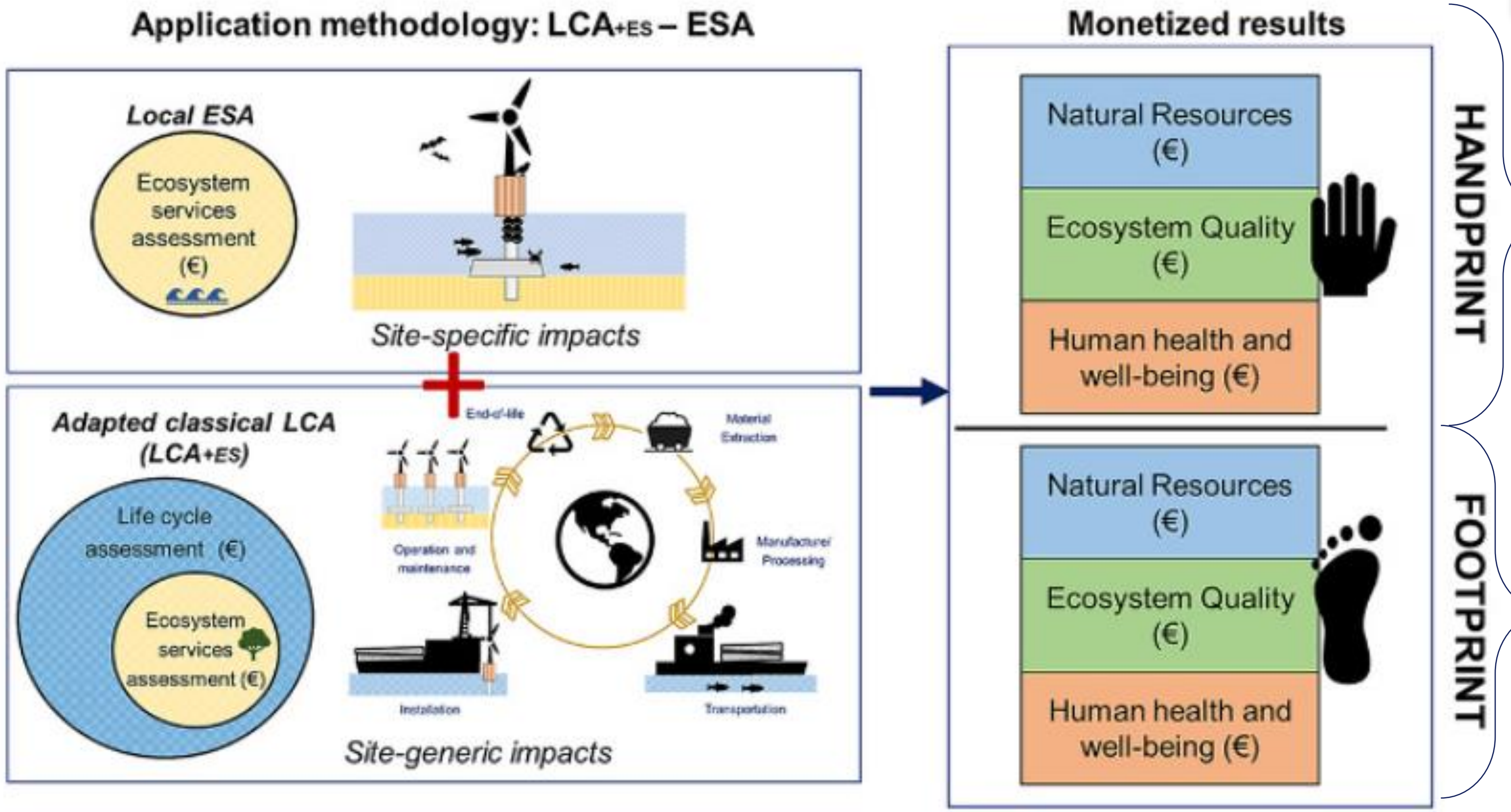
Monetized (socio-)environmental handprint and footprint of an offshore windfarm in the Belgian Continental Shelf: An assessment of local, regional and global impacts

Laura Vittoria De Luca Peña [a,*], Sue Ellen Taelman [a], Bilge Bas [a,b], Jan Staes [c], Jan Mertens [d,e], Julie Clavreul [f], Nils Préat [a], Jo Dewulf [a]



offshore wind farm
net **handprint of +€ 85.196**

absolute footprint (**- € 4039)** mainly due to supply chain of materials to manufacture the offshore windfarm

Agenda

01
Offshore Renewable Energy Production & Storage Technologies

- Osmotic Power
- Tidal & Ocean Currents Energy
- Wave Energy
- Ocean Thermal Energy Conversion
- Marine Floating Solar Power
- Offshore Molecules Production
- Large Energy Storage

02
Resource Recovery Technologies

- Innovative Large-scale Desalination
- Mineral Recovery from Brine
- Mineral Recovery from the Seafloor

03
CO_2 Removal Technologies

- Ocean-based Negative Emission Technologies
- Direct Ocean Capture (DOC)

- Environmental-DNA, as a Biodiversity Monitoring Tool?

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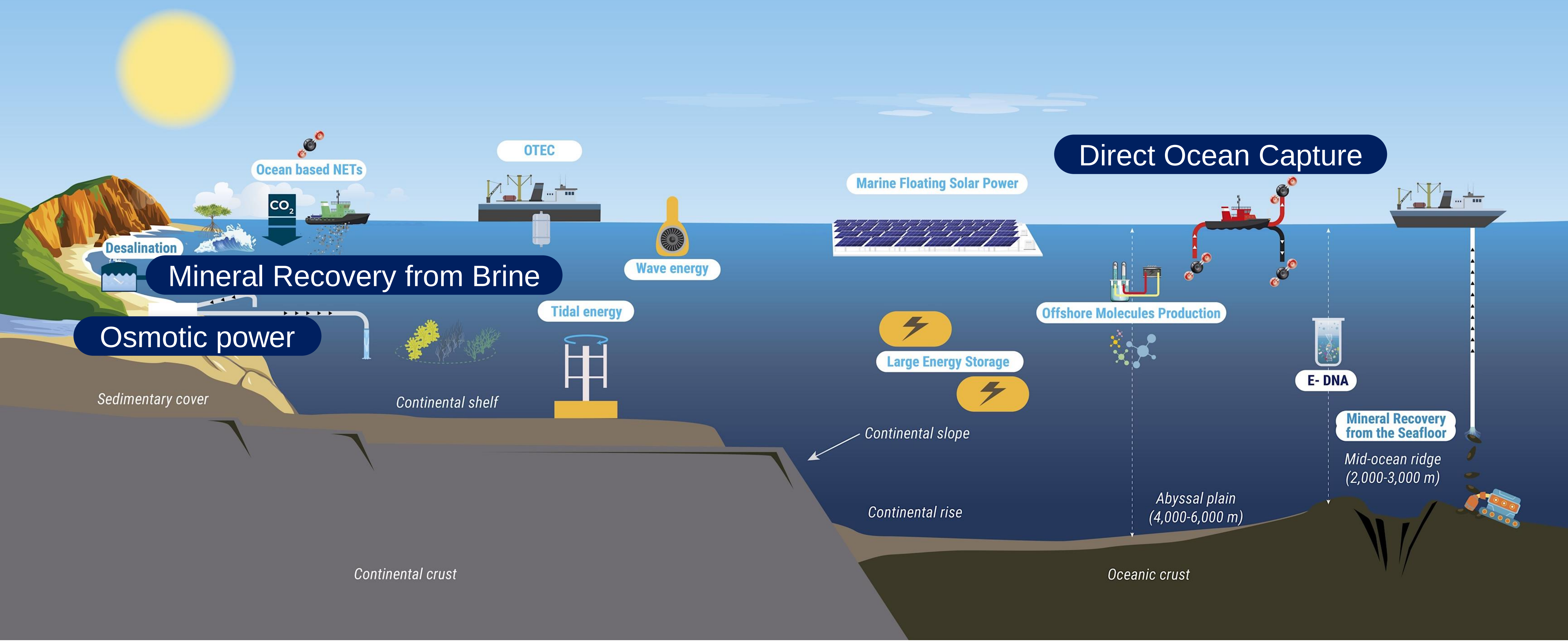
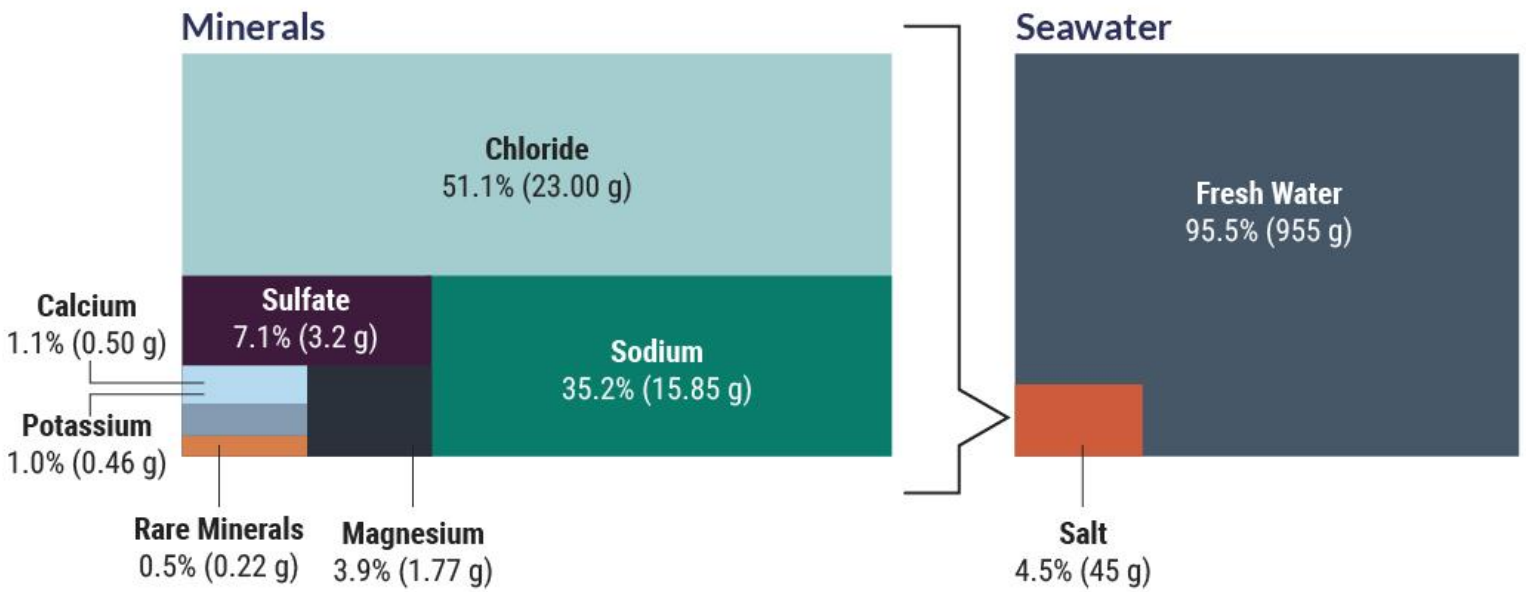
The technologies we looked at



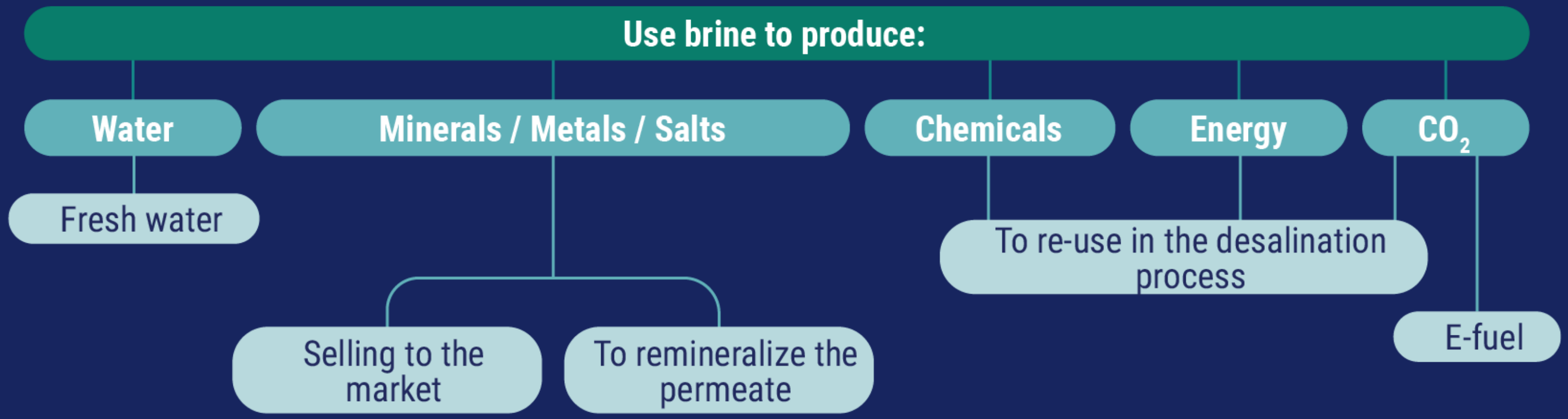
MINERAL RECOVERY FROM BRINE

How to reduce the output from desalination processes towards utilization and resource recovery? From seawater to fresh water and solid products with minimum waste.



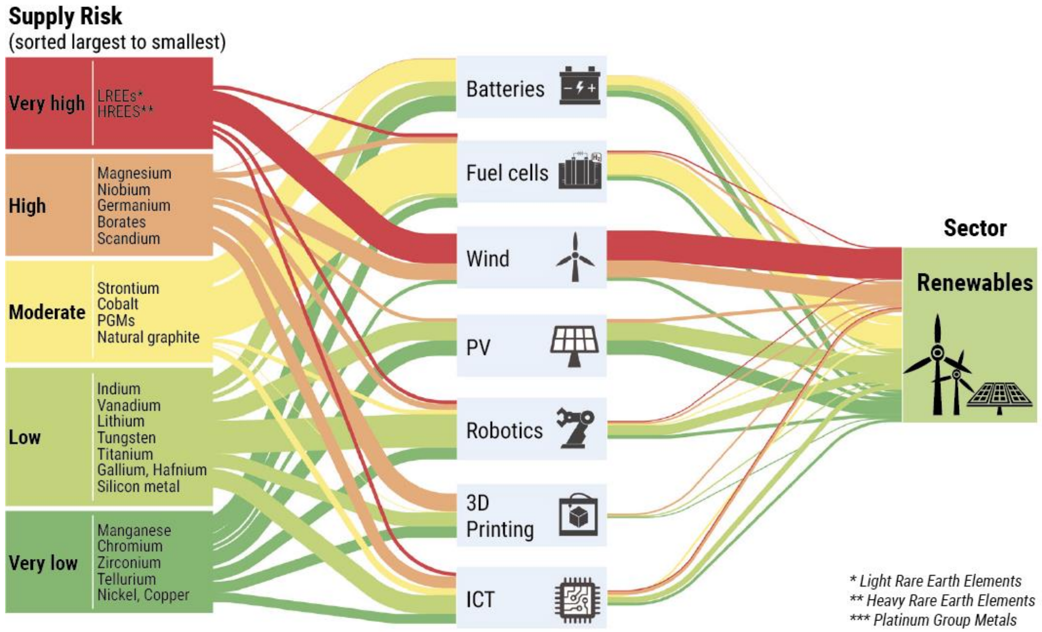
Chemical composition of seawater.

Adapted from © Hannes Grobe, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany; SVG version by Stefan Majewsky.



Reliable and unhindered access to certain raw materials is a growing concern within the EU and across the globe

The European Commission has created a list of Critical Raw Materials (CRMs) in the EU to produce renewable assets.



Materials and technologies relevant to the renewable energy sector

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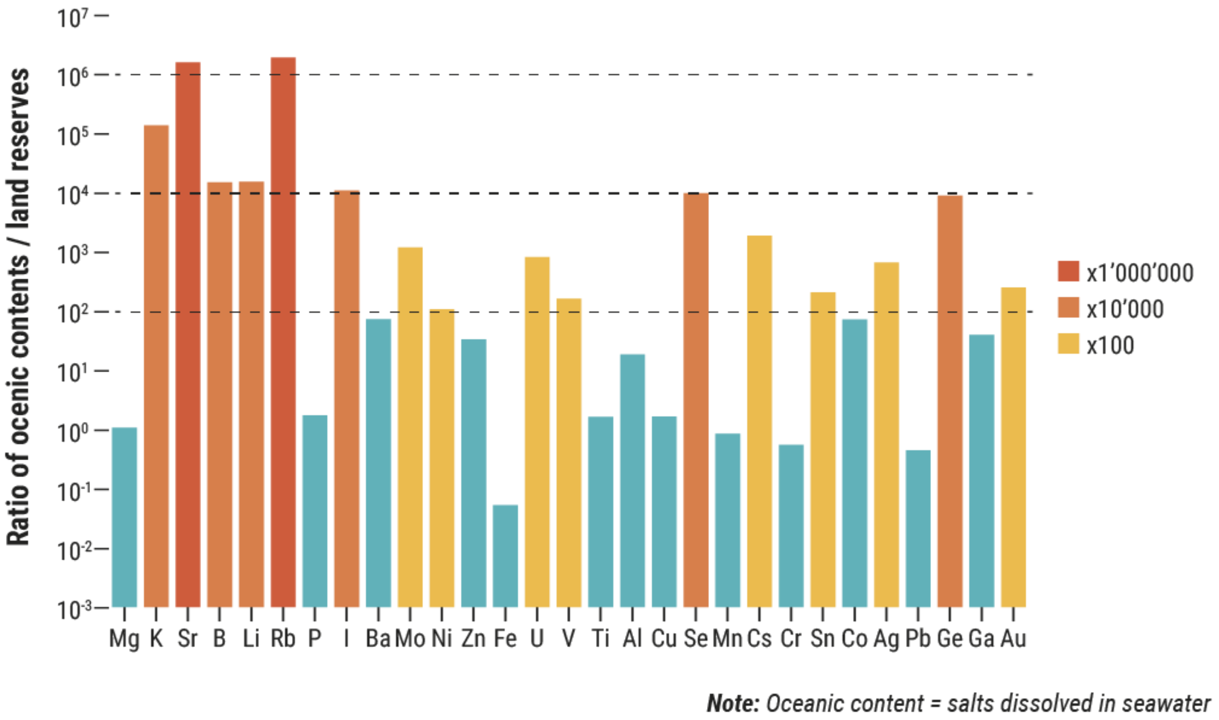


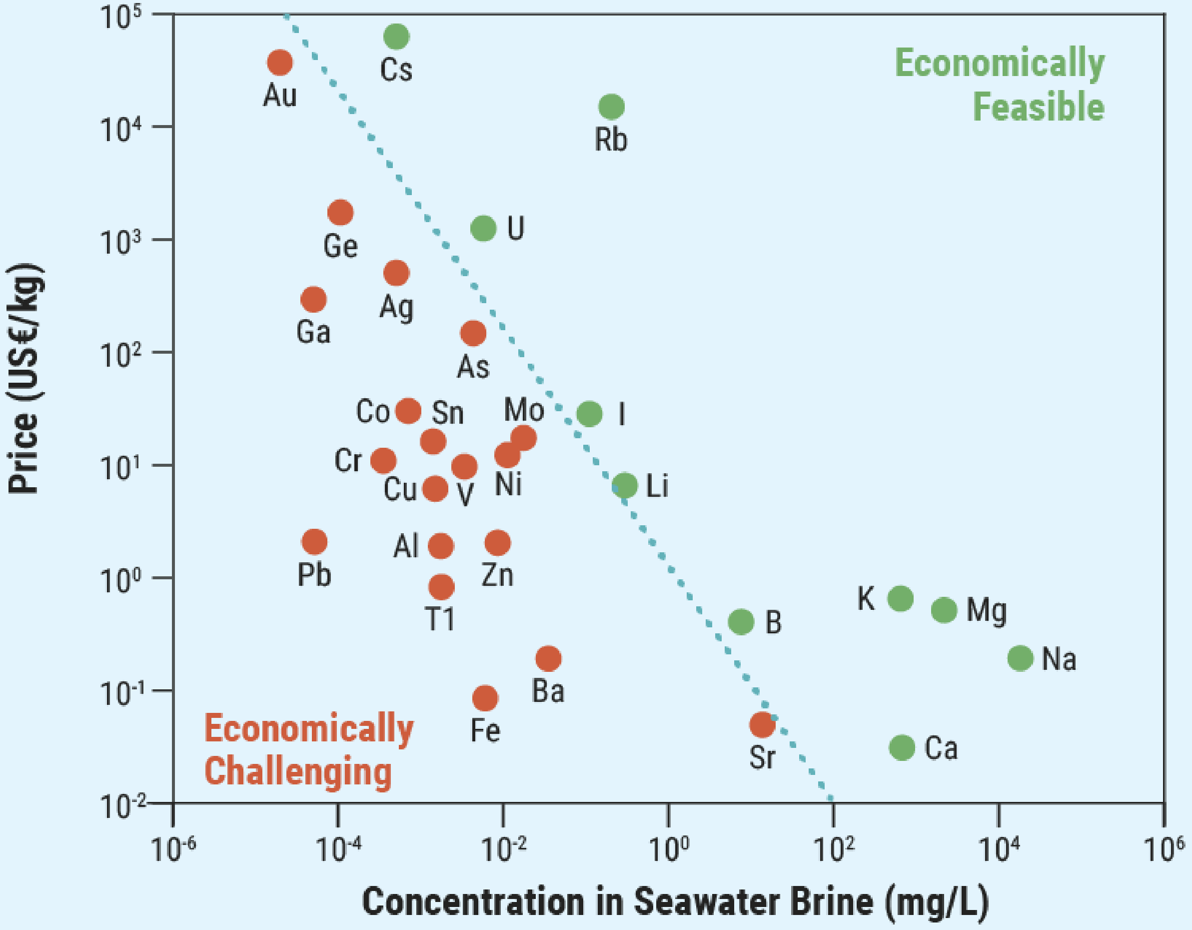
Estimated ratio of the amounts of minerals in oceans to the land reserves of minerals. Oceanic abundance is calculated assuming a total ocean volume of 1.3 × 109 km^3 (1.3 × 1018 tons)

Adapted from © Loganathan et al 2016 [3], based on the data from: U Bardi doi.org/10.3390/su2040980, U.S. Geological Survey 2016 http://minerals.usgs.gov & Seafriends website.

Mineral extraction from brine would support a more sustainable economy, reducing both drinking water production cost & the environmental impact generated by brine disposal

Element concentration and price.

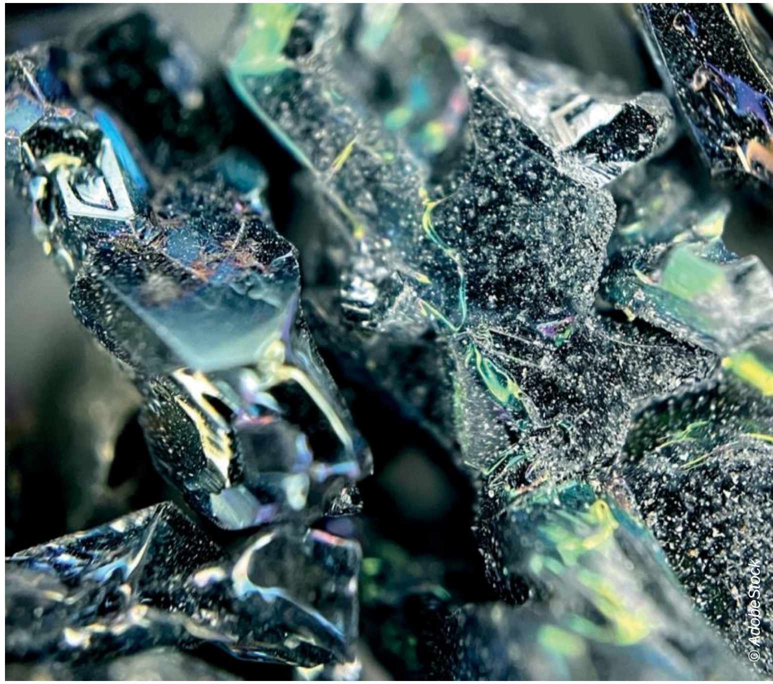
Element concentration in seawater brine is estimated based on an average 40% recovery rate from a desalination plant. Market prices of elements are based on 2018 USGS metal commodities summaries (Kumar et al. (2021)).



Selectivity is key in brine mining. Focusing on the main brine concentration & separation processes towards all-membrane technologies

Concentration technologies	TRL
Membrane-based technologies	
NF: Nanofiltration	High TRL
ED: Electrodialysis	Low TRL / High TRL
MD: Membrane Distillation	Low TRL

Separation technologies	TRL
Crystallization by evaporators	High TRL
Membranes crystallization	Low TRL
Precipitation: well implemented in water treatment / large-scale	Low TRL
A(b)dsorption-desorption processes	High TRL



Why is brine mining attractive?

ADVANTAGES

- Contribution to the security of supply
- Higher desalinated water recovery
- Circularity, on-site chemical production
- Waste minimization

CHALLENGES

- Energy-intensive processes
- Membrane-based technologies performance challenge e.g. fouling, scaling…
- Pretreatments & anticorrosion materials are costly
- Some processes may be chemical-intensive

What impact?

Environmental analysis

Energy-intensive processes

- Need for abundant renewable energy

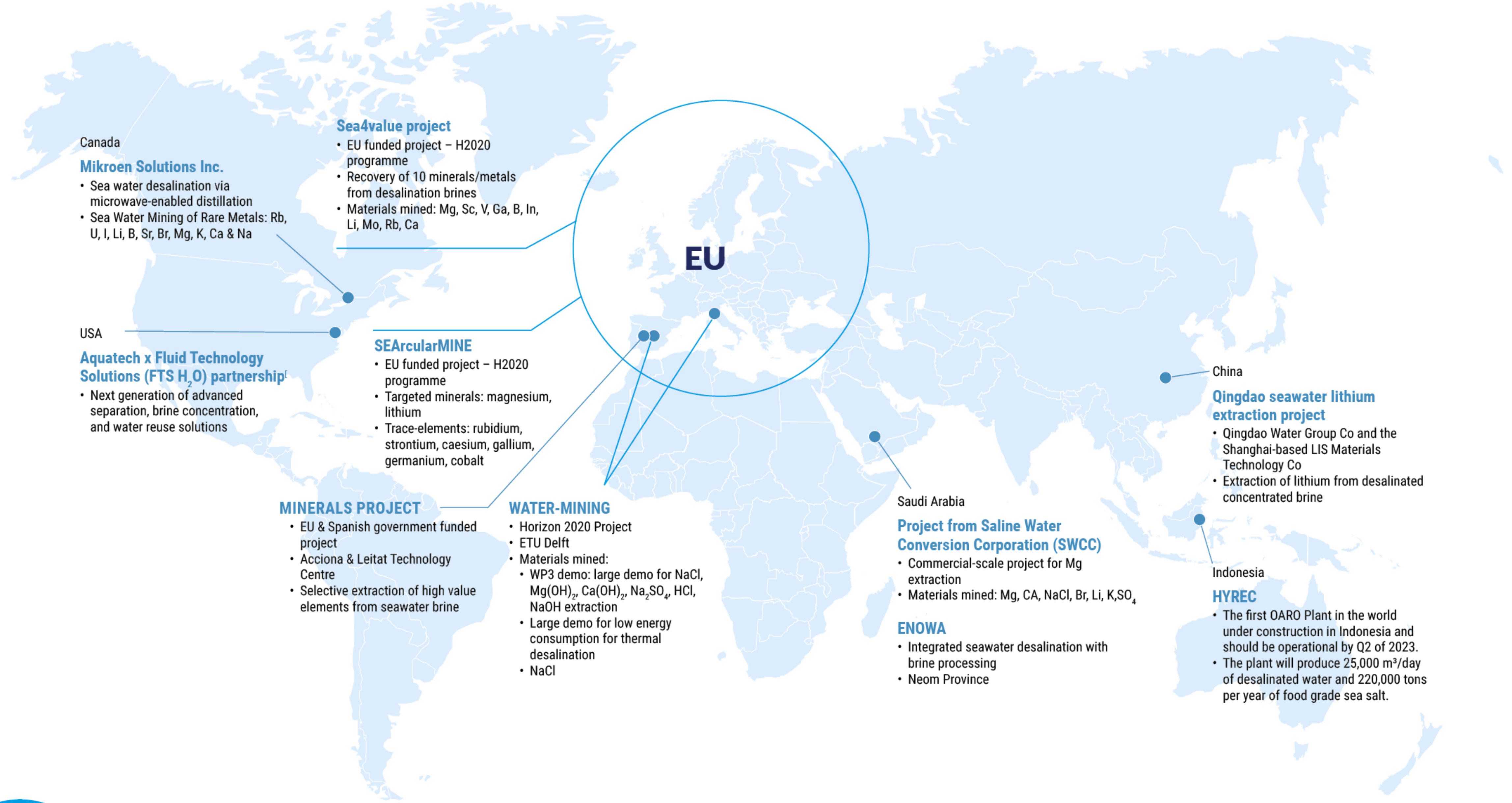
- Reduced salinity in wastewater going back into the ocean
- Latest research points towards zero brine discharge

Social acceptability

- Energy cost
- Land usage competition
- Regulatory uncertainty on the status of brine (wastewater or mineral resource)

- Reducing brine discharge mitigates its environmental impact
- More affordable drinking water

Much attention for brine worldwide



OSMOTIC POWER

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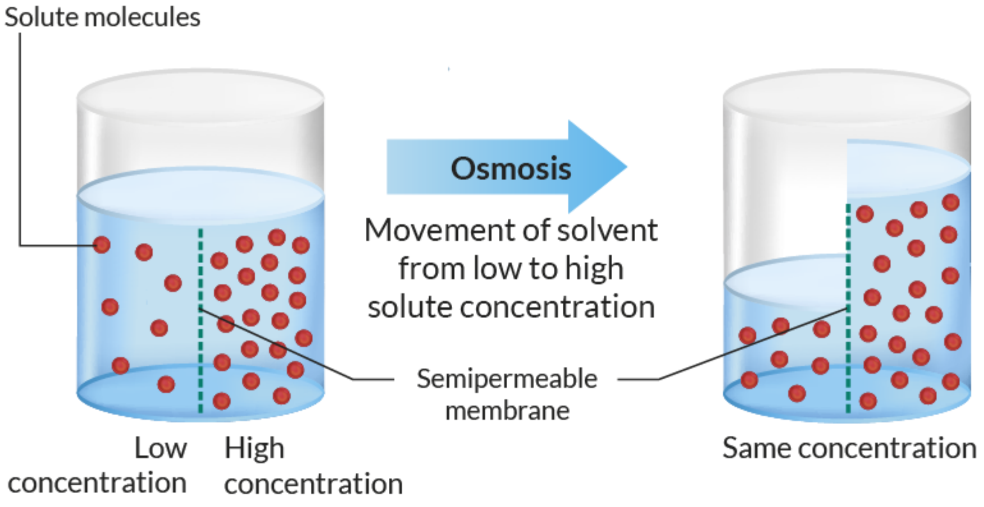
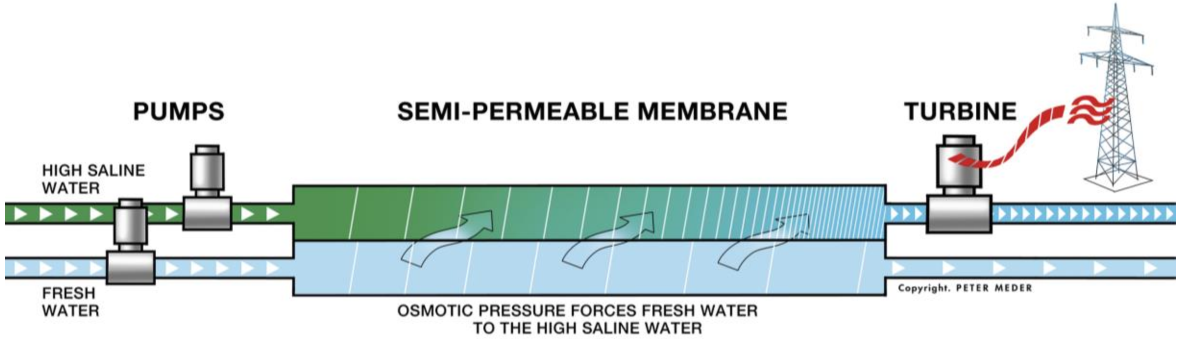
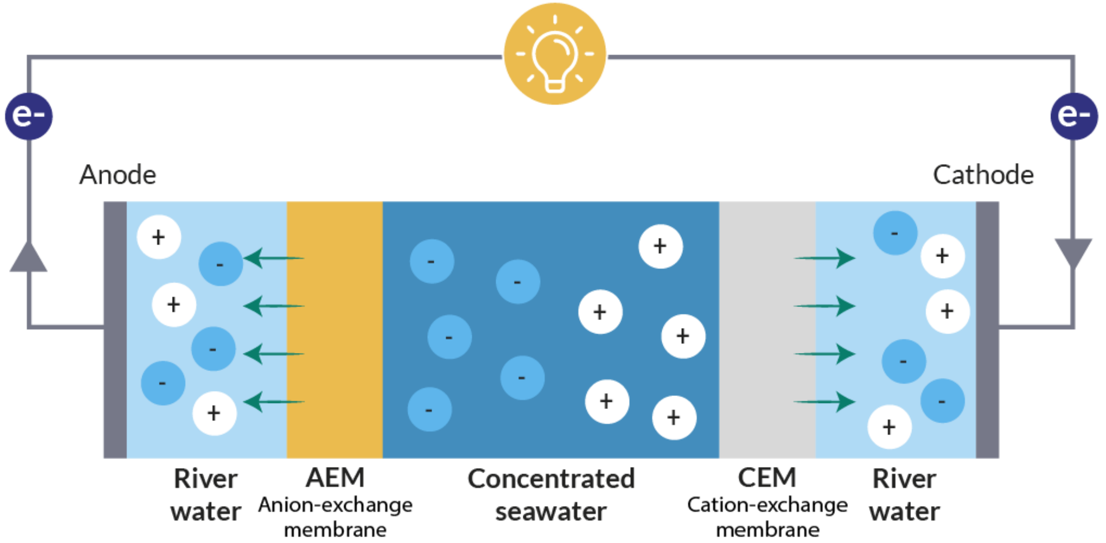
Using the salinity of the oceans to produce sustainable & clean electricity



Osmosis Principle



Pressure Retarded Osmosis (PRO)



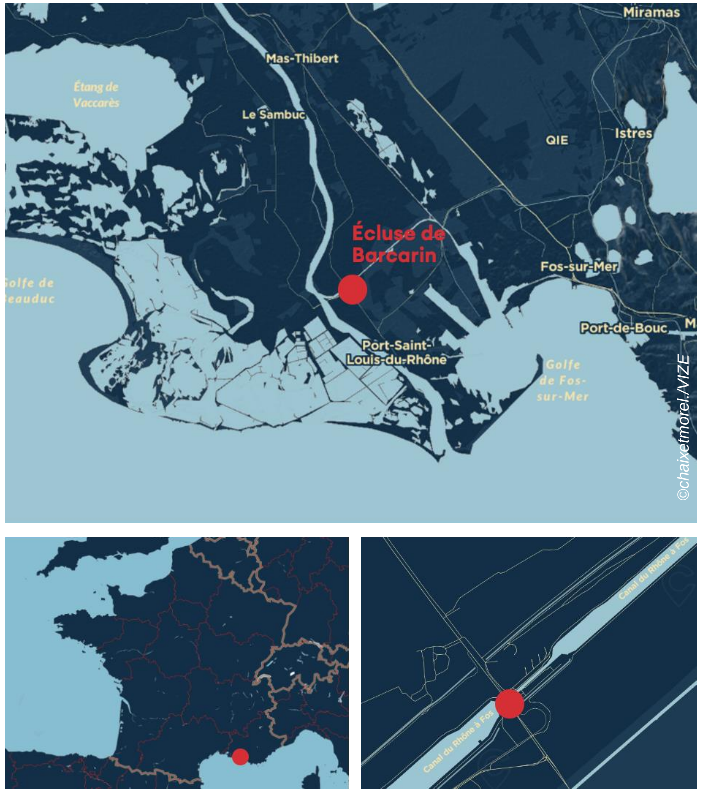
Reverse Electrodialysis (RED)

Emerging technologies rely on nanopore-based membranes. Nanofluidics to improve performance in harvesting renewable osmotic energy

Ionic Nano Osmotic Diffusion® Membrane TRL 6

Sweetch Energy Technology

Relies on nano-scale membranes coupled with electrode systems. These membranes combine high ionic selectivity with high ionic transport to improve performance.

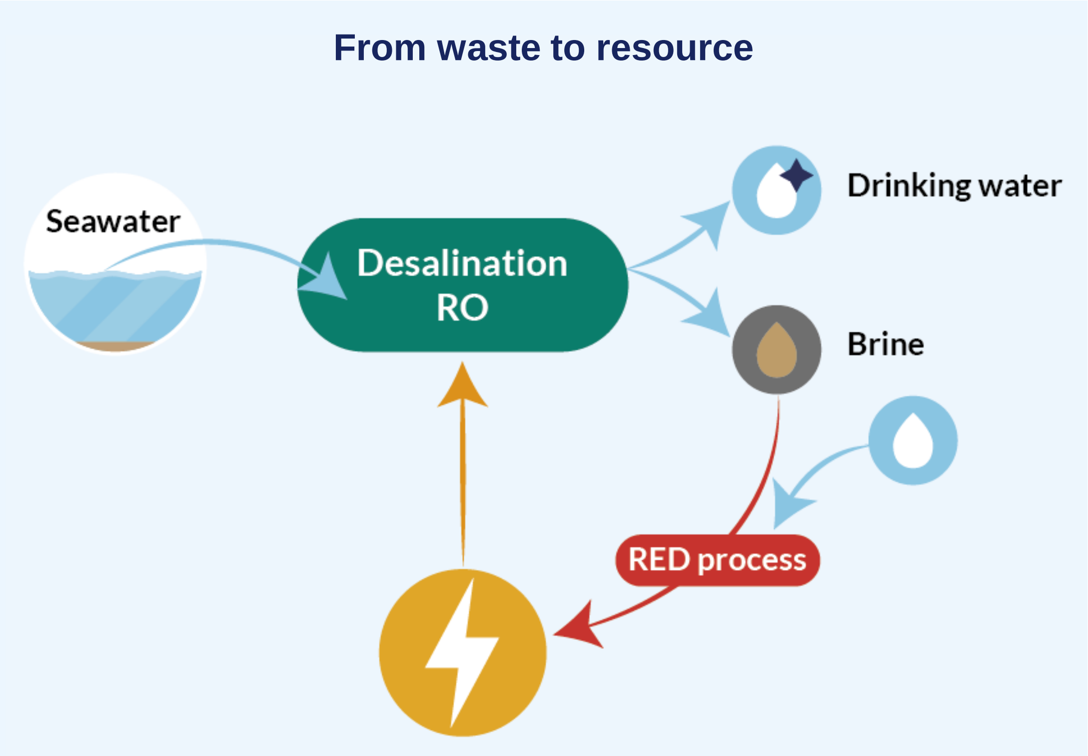


OsmoRhone 1, up to 500 MW of power will be gradually installed and distributed along the Rhône over the next decade.

Industrial Partners: CNR & EDF

Coupling osmotic power & desalination towards a circular solution

There are currently around 16,000 desalination plants worldwide, with a total global operating capacity of roughly 95.37 million m³/day and brine production of 141.5 million m3/day. *(Source: Climate Adapt 2023)*



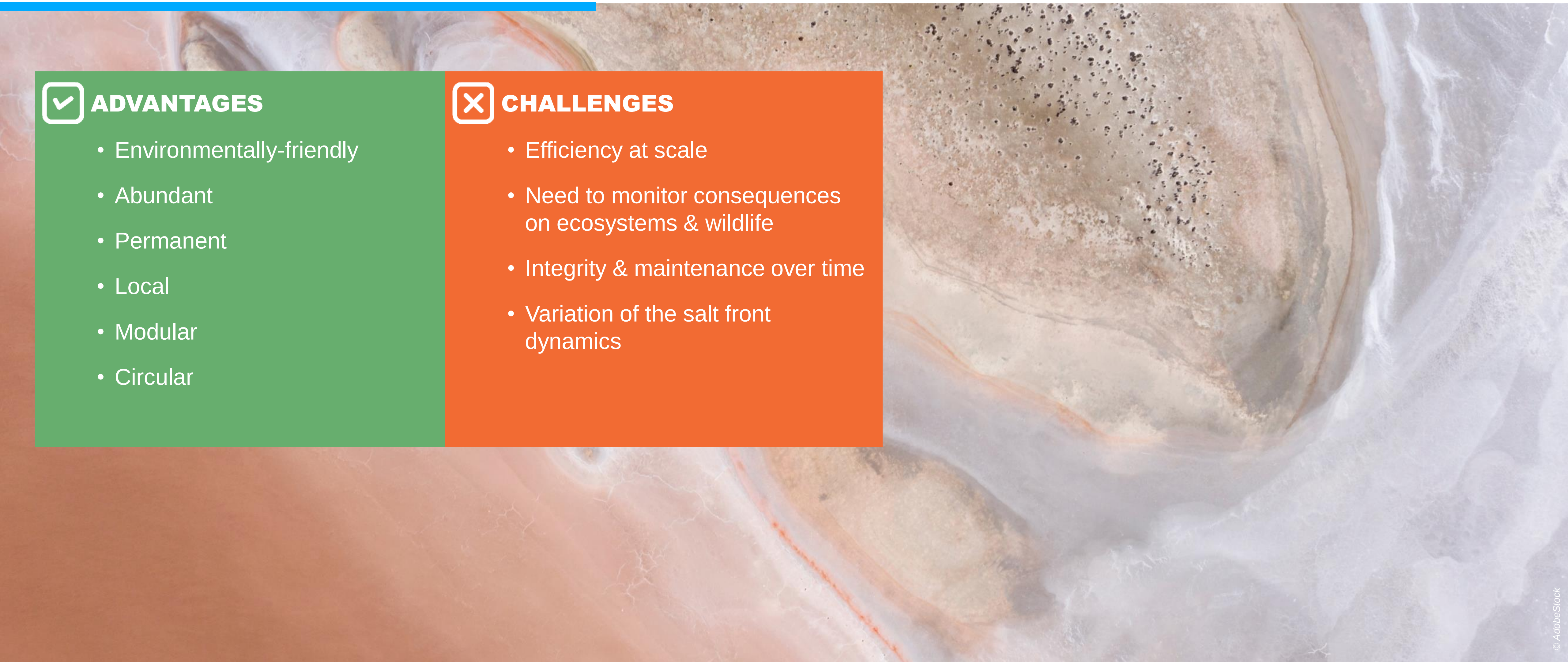
Life Indesal Pilot Unit TRL 6

Desalination plant facilities of San Pedro del Pinatar-II (Murcia, Spain)

Life Hyreward Pilot TRL 6

Desalination plant in Alicante run by Sacyr

What makes Osmotic Power attractive?



ADVANTAGES

- Environmentally-friendly
- Abundant
- Permanent
- Local
- Modular
- Circular

CHALLENGES

- Efficiency at scale
- Need to monitor consequences on ecosystems & wildlife
- Integrity & maintenance over time
- Variation of the salt front dynamics

What impact?

Environmental analysis

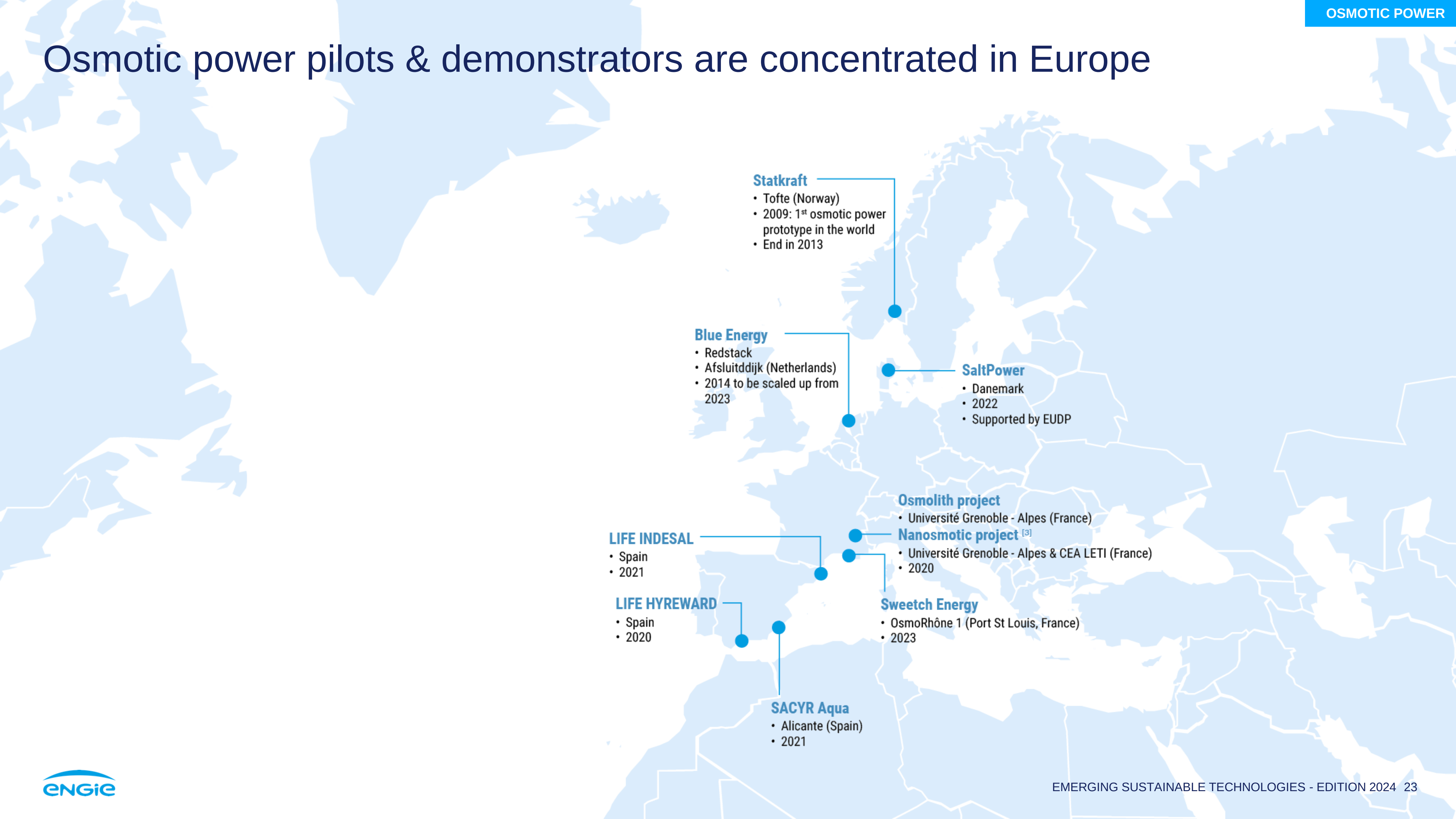
- Habitat reduction
- Change in salinity
- Potential impact of cleaning products
- Production of wet waste
- Infrastructures may alter local hydrodynamics & become colonized by local biodiversity (biofouling)
- Impact on the host environment if a basin must be built to optimize a site's potential

Social acceptability

- Social awareness: compact & silent facilities using non-toxic & bio-based materials
- Reassuring continuous energy supply

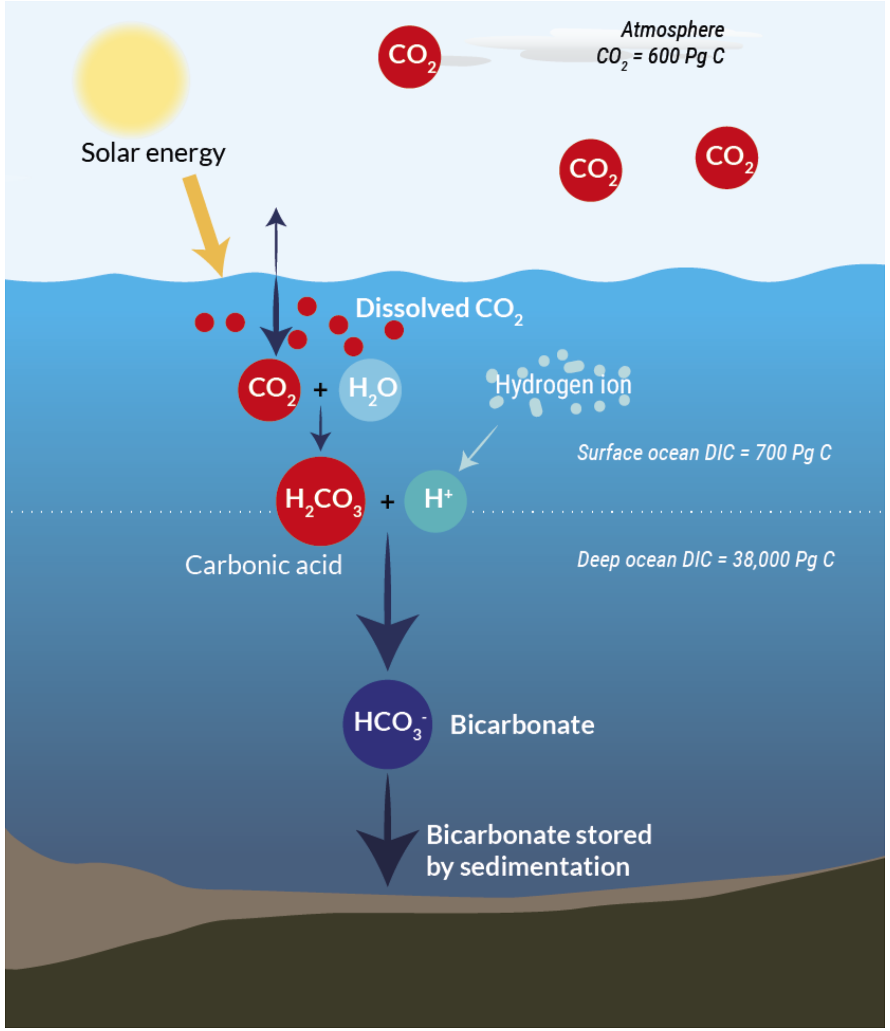
- Competition with other activities
- Visual impact
- Artificialization of land

Osmotic power pilots & demonstrators are concentrated in Europe

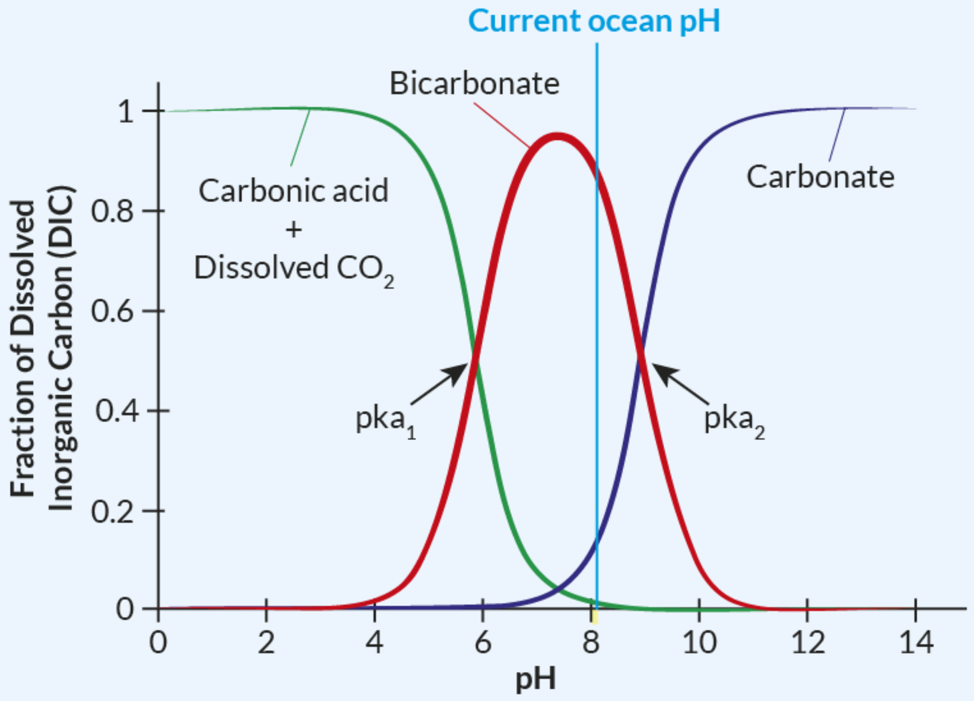


DIRECT OCEAN CAPTURE (DOC)

The CO_2 concentration in the oceans is in equilibrium with the atmospheric CO_2 concentration, leading to an acidification of the oceans over the last decades



Applying a pH swing to capture CO_2 from seawater



Effect of pH on the CO_2 equilibrium (for a closed system at temperature of 25°C and salinity of 35 ppt). The solution is buffered around two pKa values.

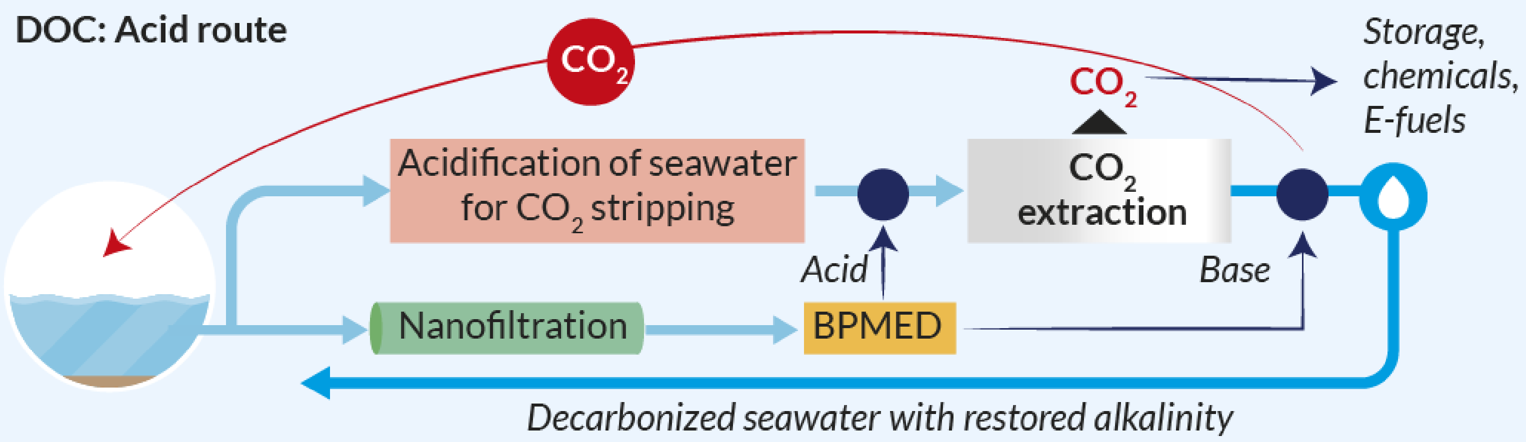
Membrane-based and membrane-free electrochemical technologies are today's main technologies under development for CO_2 capture from seawater

ELECTROCHEMICAL TECHNOLOGIES

Using electricity to accelerate chemical reactions that store carbon

- **Membrane-based Electrochemical DOC**
  - Acid route
    e.g. Captura, SeaO2 technologies
  - Alkaline route
    e.g. Ebb Carbon, Heimdal technologies
- **Membrane-free Electrochemical DOC**
  - Electrolysis-like technology
    e.g. Equatic technology
  - Battery-like Technology
    e.g. MIT technology

Electrochemical DOC uses electricity to rearrange water & salt molecules from seawater into acid & base solutions to capture & convert CO_2



Electrochemical Membrane Based CO_2 capture & conversion from seawater via acid route

ADVANTAGES

- CO_2 concentration in the ocean is 125 times higher than in the air
- Availability of atmospheric CO_2 for usage or storage
- Counters ocean acidification

CHALLENGES

- Requires processing large amounts of seawater
- Impact on seawater chemistry

DOC has several advantages over Direct Air Capture (DAC) although the impact of the water discharge on the local environment needs to be better understood

Environmental analysis

- No land usage competition
- If there is alkalinization, co-benefit of local reversal of ocean acidification, probably benefit marine species
- Can be part of a seawater desalination process

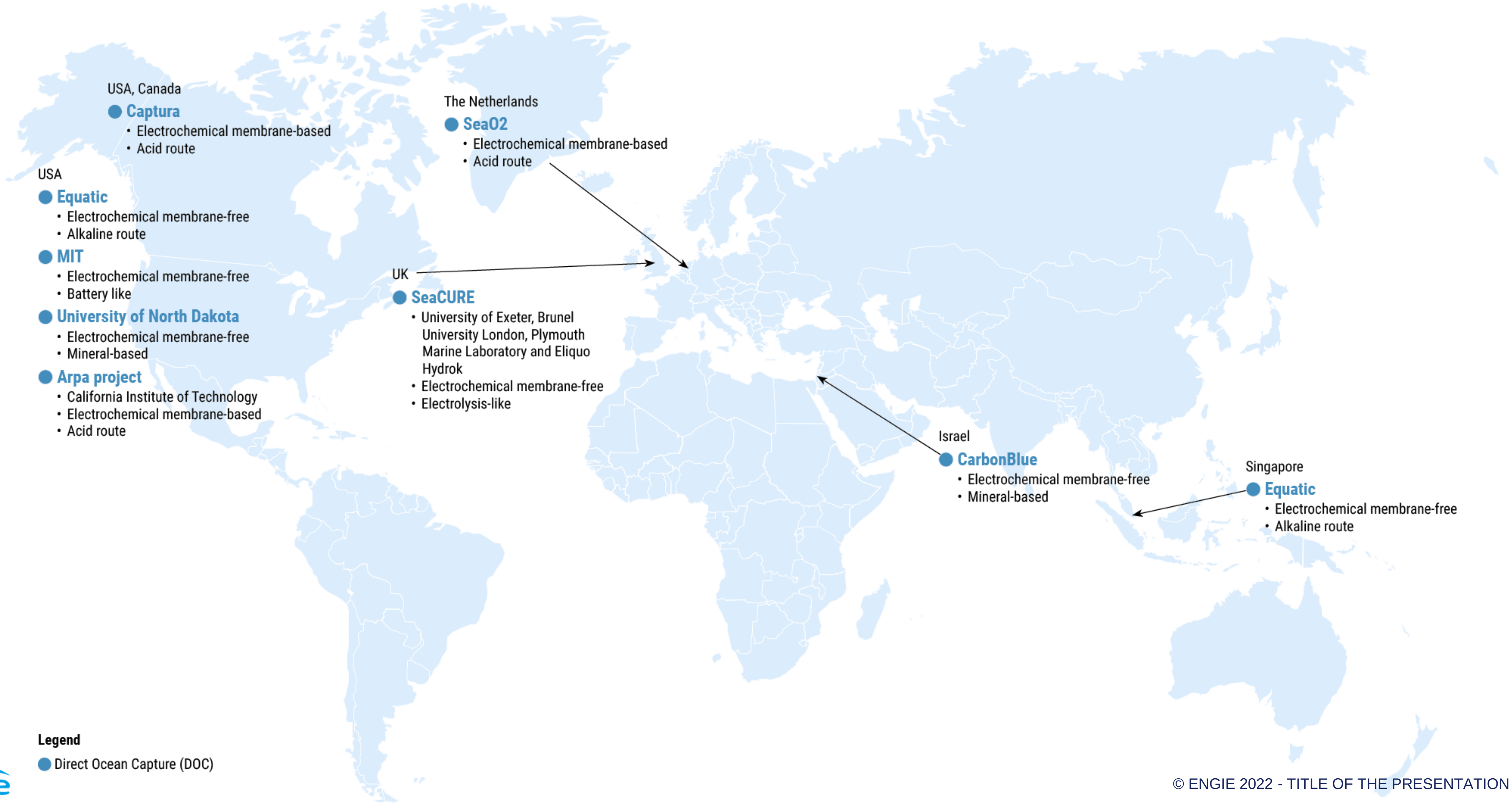
- Energy consumption of the process (from 0.8 to 2MWh/ton CO_2)
- Entrapment of species (marine fauna and flora) with the suction
- Possible water chemistry changes requiring seawater chemistry restoration
- Expensive catalyst for BPMED use

Social acceptability

The main controversies are:

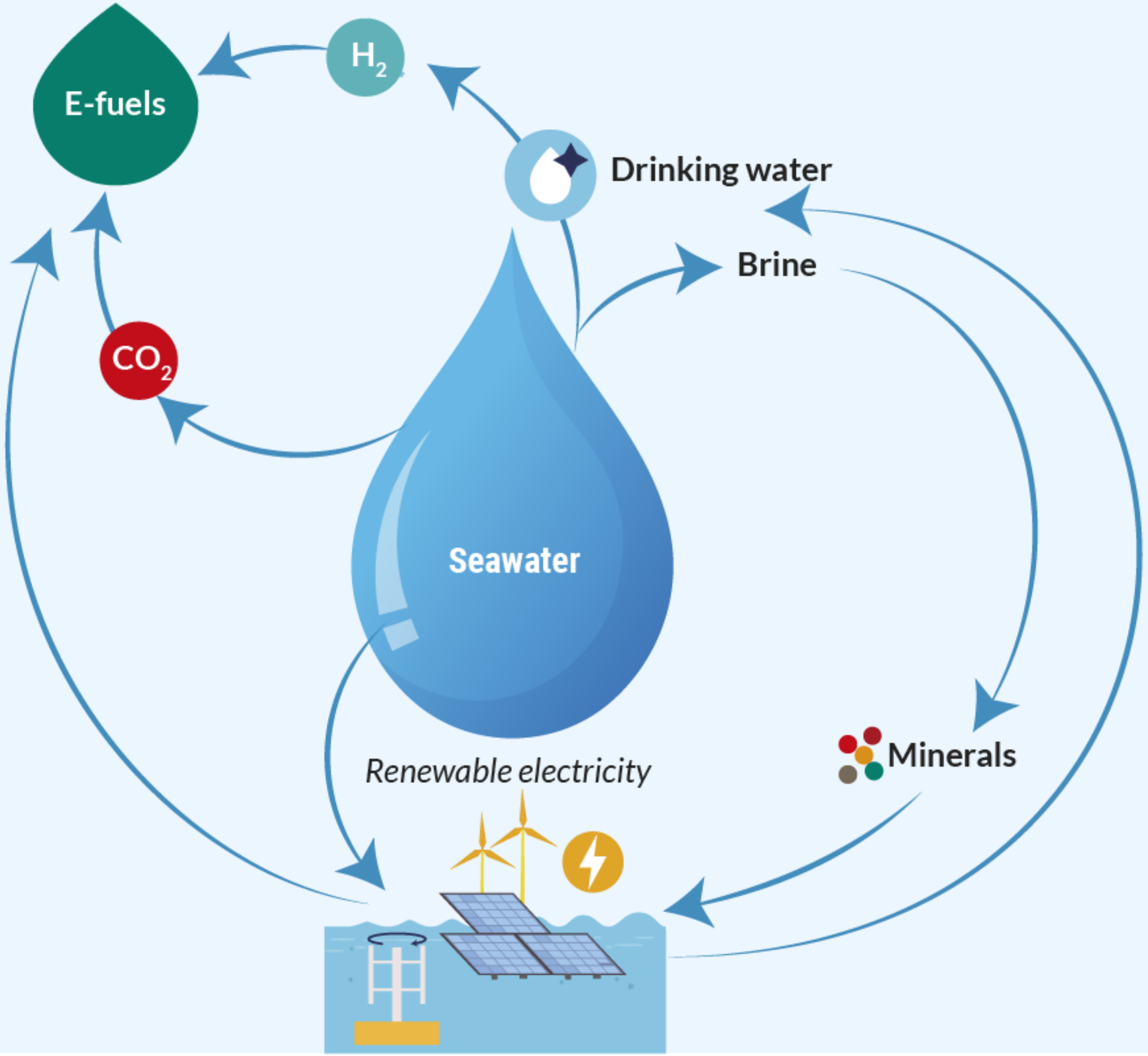
- Potential disturbance of local ecosystems
- Negative perception as this could be seen as an attempt to tamper with nature
- Adaptation of the various regulations & the need to designate liable entities in case of impacts

Main DOC pilot & demonstrator projects are located in the USA, northern Europe, Israel & Singapore



SEArcularity: an integrated marine system of sustainable technologies

> **“Emerging technologies… converging on the oceans”**
> Geoffrey O’Sullivan



THANK FOR YOUR ATTENTION !

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