

L'energia pulita e il mare: il ruolo dell'Idrogeno

Integrazione con Impianti di Dissalazione

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Genova – Villa Cambiaso - 1° piano - I.015 - Aula A2

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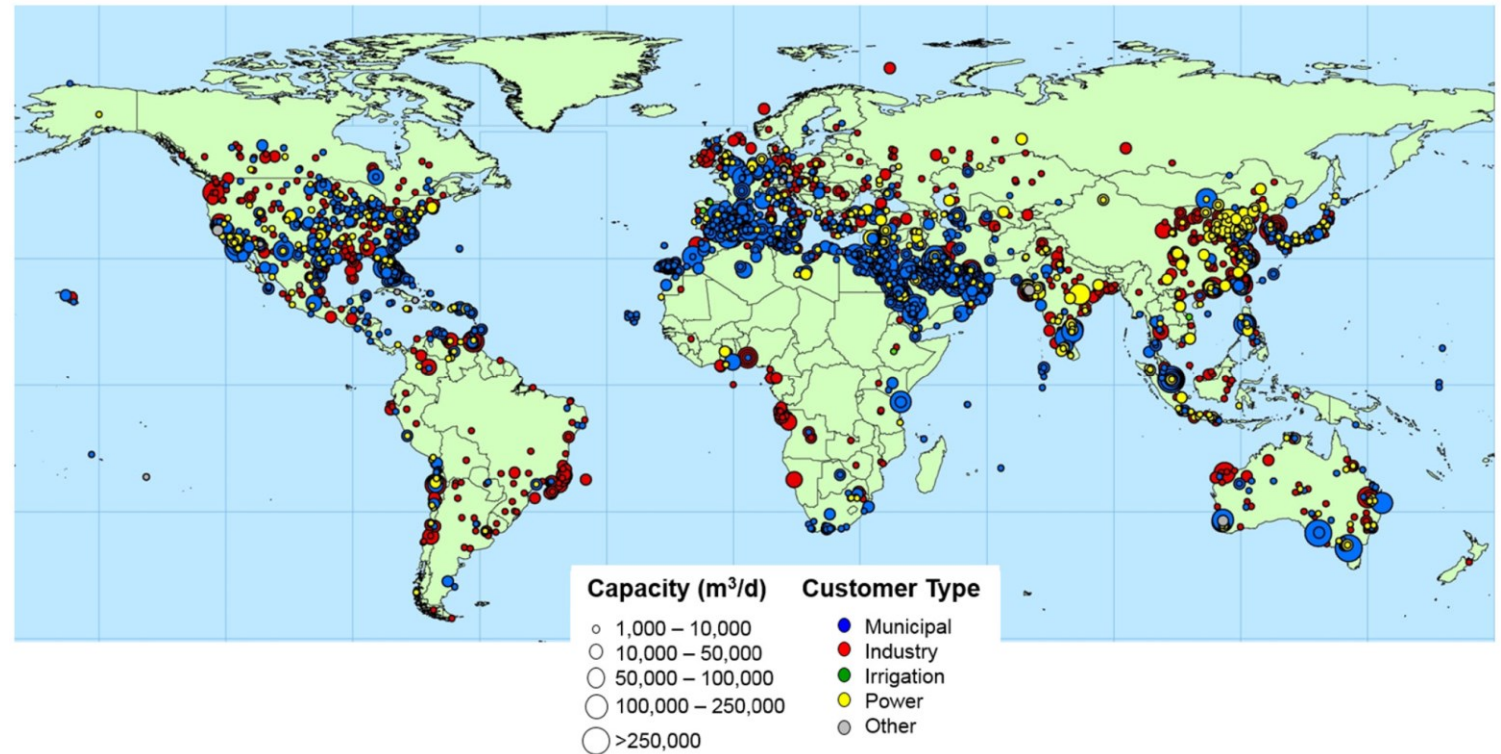
EVENTO in modalità ibrida



DESALINATION OUTLOOK

There are currently around 16,000 desalination plants worldwide, with a total global operating capacity of roughly 95.37 million m³/day.

Currently, desalination is largely used in the **Middle East and North Africa (70% of global capacity / 48% of production)**, in the US, increasingly in Asia, and only to a limited extent in **Europe (about 10% of global capacity)**.



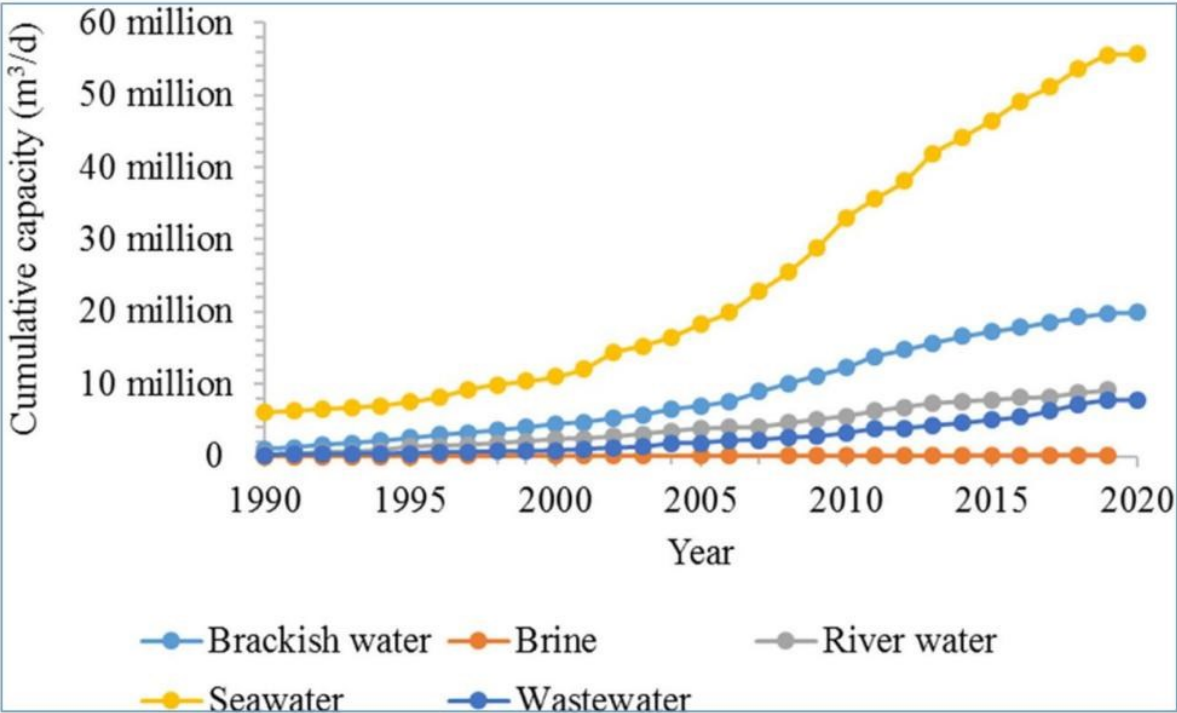
In the EU, a small fraction of freshwater is obtained through seawater desalination. EU facilities can supply up to 2.89 billion m³ of desalted water a year (active capacity).

71% of the water produced is used for **public water supply**, (equal to the 4.2% of total).

17% of the desalinated water produced in the EU is used for **industrial applications**, 4% in power plants, and 8% for irrigation.

EU desalination plants are mainly located in **Mediterranean countries**, where they will be mostly needed in the future: about 1,200 plants provide **82% of total EU desalination capacity**

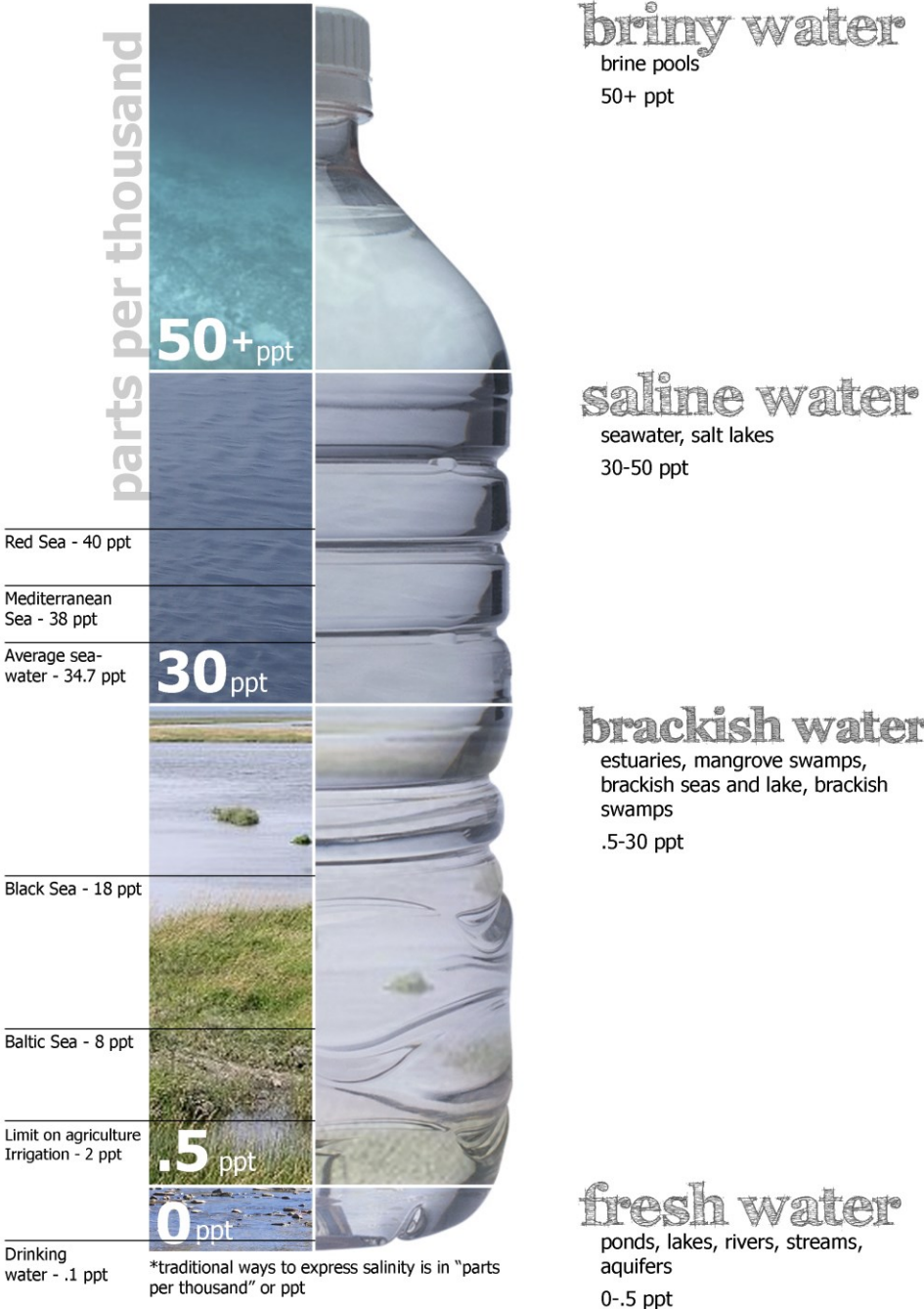
WATER QUALITY (INPUT and OUTPUT)



Source: Eke et al. 2020

Table 1
 Required energy for producing 1 m³ of drinking water from different water sources.
 Reproduced from Ref. [12, 13].

Water source	Energy (kWh/m ³)
Surface water (lake or river)	0.37
Groundwater	0.48
Wastewater treatment	0.62–0.87
Wastewater reuse	1.0–2.5
Seawater	2.58–8.5



DESALINATION TECHNIQUES

Electrically driven technologies

- **Reverse Osmosis (RO)**

Sea Water Reverse Osmosis (SWRO) / Brackish Water Reverse Osmosis (BWRO).

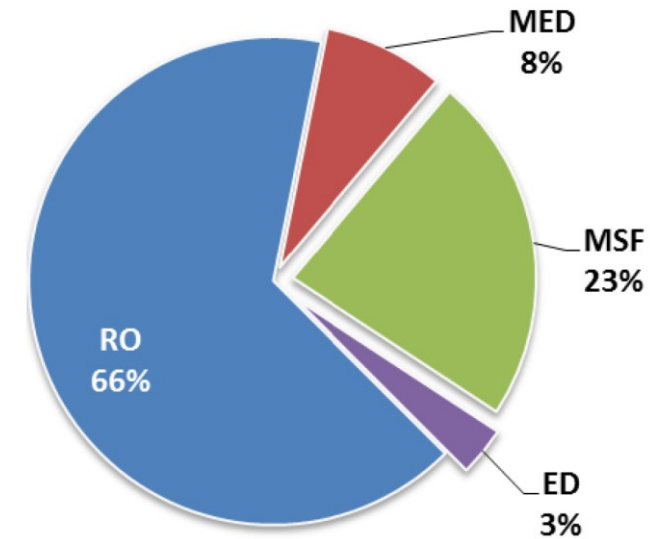
- Mechanical Vapour Compression (MVC)
- Electrical Dialysis (EDR).

Thermally driven technologies: thermal desalination process uses energy to evaporate water and subsequently condense it again.

- **Multi Stage Flash (MSF),**
- **Multi Effect Distillation (MED),**
- Thermal Vapour Compression (TVC) ,
- Membrane Distillation (MD).

GOR Gain Output Ratio

$$\text{GOR} = \frac{\text{fresh water latent heat}}{\text{Thermal input}} = \frac{m_{fw} h_{fw}}{Q}$$



Main KPI

RR: Recovery Ratio

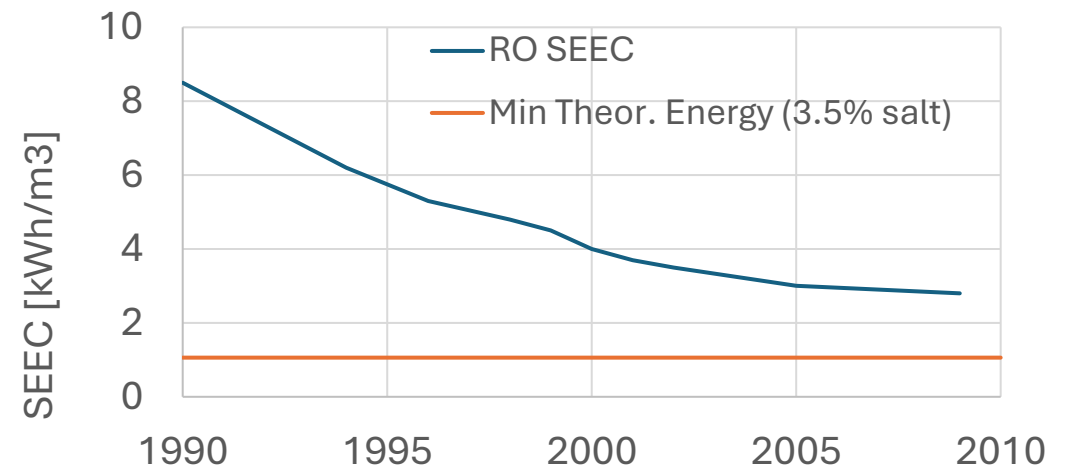
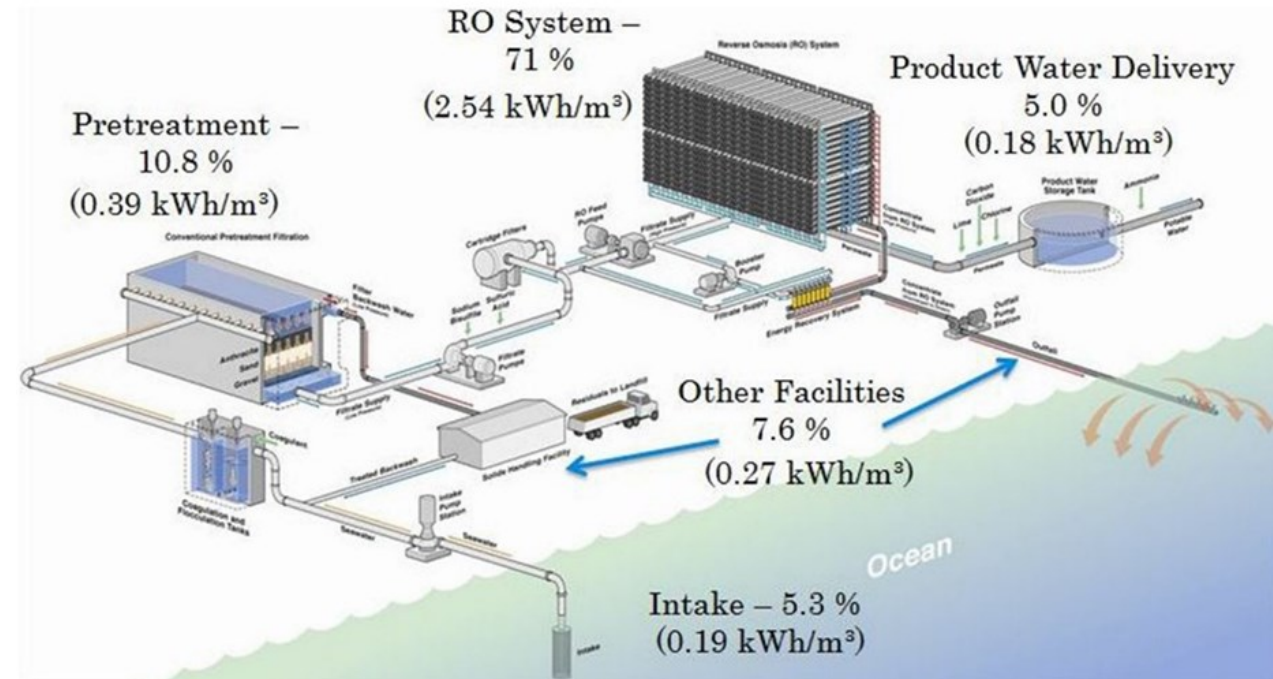
$$RR = \frac{\text{Output}}{\text{Input}} = \frac{m_{fw}}{m_{sw}}$$

SEC_{equiv} : Specific Energy Consumption Equivalente

$$\text{SEC} = \frac{E + Q * (1 - T_0/T_H)}{\text{Output water}} = \text{SEEC} + \text{STEC} * \eta_{th}$$

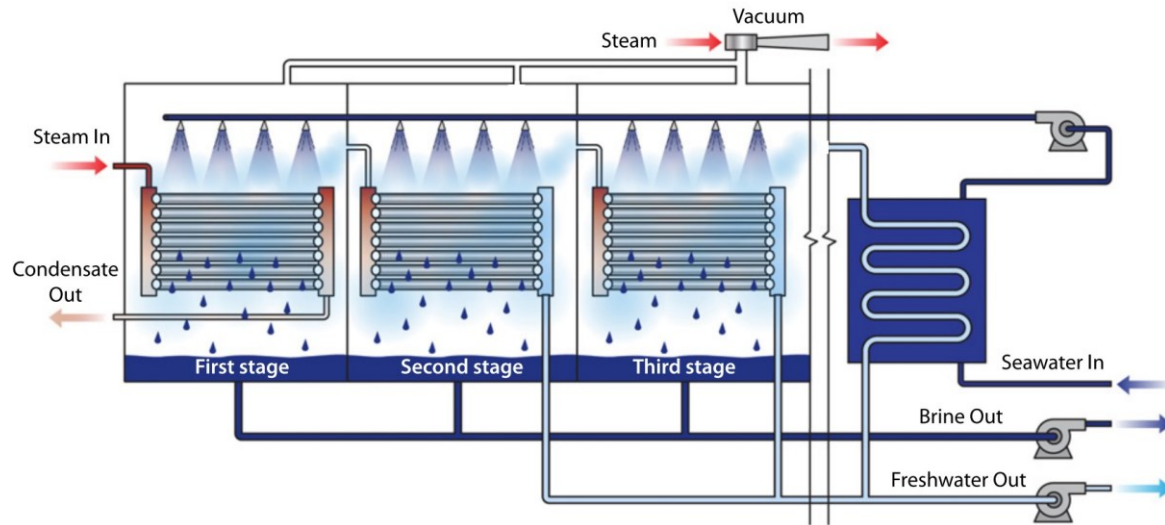
REVERSE OSMOSIS (RO)

- Uses a semi-permeable membrane to remove salt and impurities from seawater, driven by high pressure.
- EDR (Energy Recovery Device) can be used to recover pressure (up to 90%)
- Highly effective in producing potable water from seawater, with recovery rates typically ranging from 30-50%.
- **Maintenance:** Requires regular cleaning and replacement of membranes to maintain performance and prevent fouling.
- **Scalability:** Flexible in design, suitable for both small-scale and large-scale desalination plants.
- **Limitations:** Sensitive to feedwater quality; pretreatment is often necessary to prevent damage to membranes.



MAIN THERMAL DESALINATORS

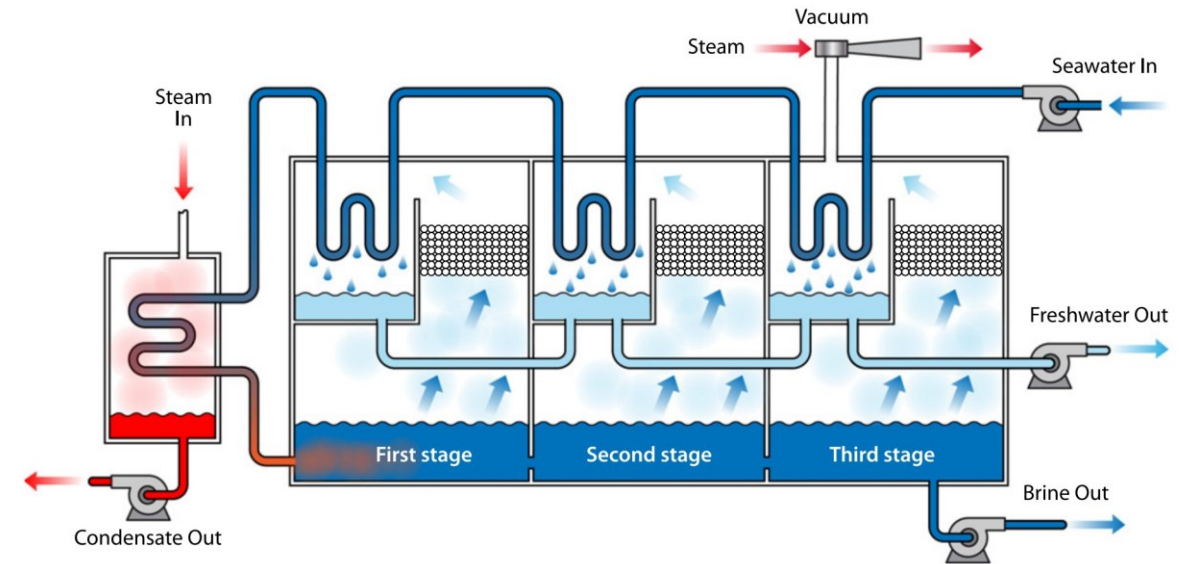
Multi Effect Distillation MED



- Operates in temperatures between 70°C and 90°C
- Requires 145-230 MJ/m³ of thermal energy
- Presents GOR between 10 and 13
- Requires large heat exchange surfaces
- Suffers from severe fouling and corrosion problems

$$\text{Definendo GOR} = \frac{m_{fw} h_{fg}}{Q_{desal,in}} .$$

Multi Stage Flash MSF



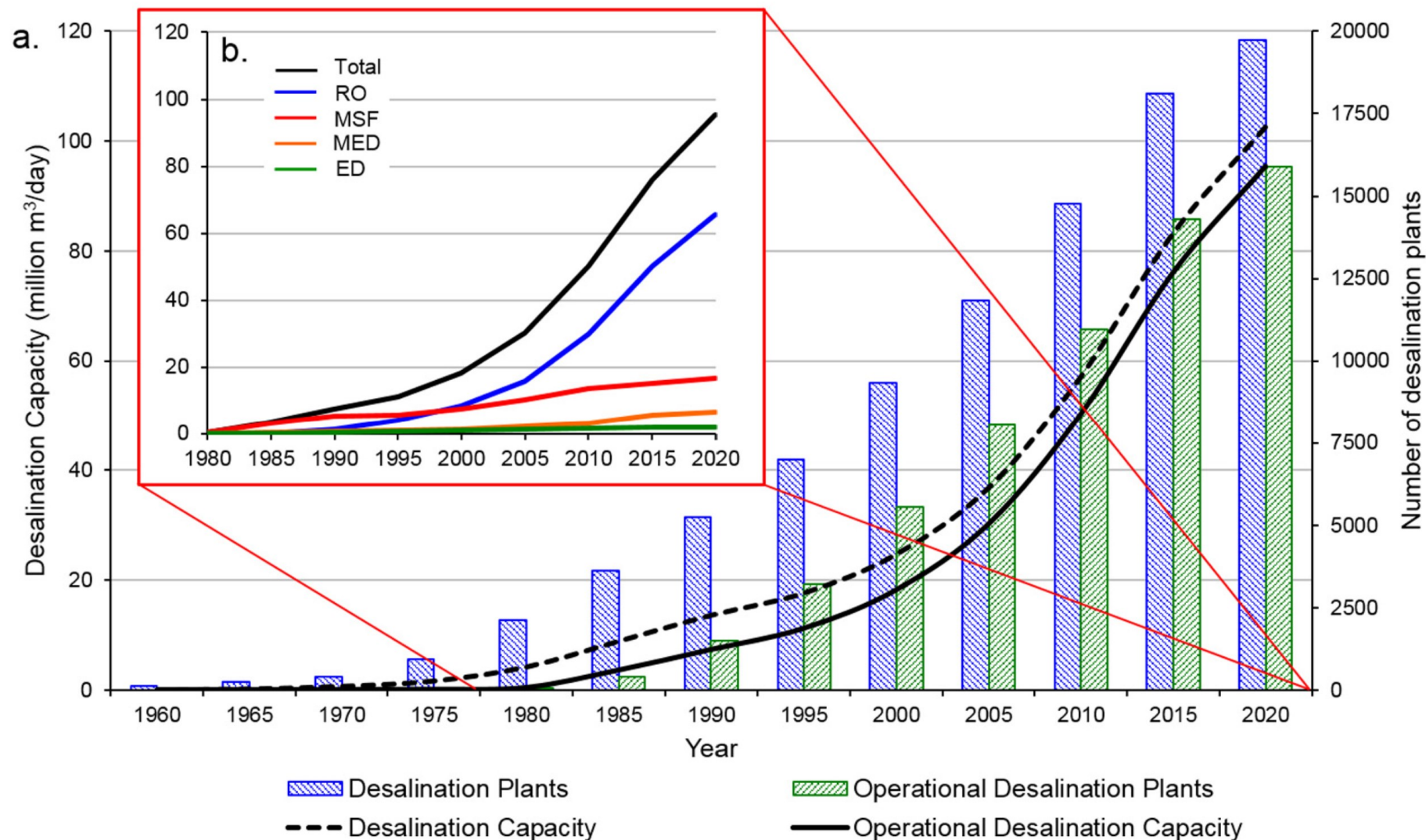
- It operates at temperatures with a TBT of 90°C and 120°C;
- Requires 190-282 MJ/m³ of thermal energy;
- It has GOR between 6 and 9;
- No large heat exchange surfaces required (MED/2)
- Less prone to fouling and corrosion problems;

DESALINATION TECHNIQUES

Comparison between thermal and membrane-based processes.
Reproduced from [7,9,16,81,93,99–101].

Properties	MSF	MED	SWRO	BWRO	ED
Typical plant size ($\times 1000 \text{ m}^3/\text{day}$)	50–70	5–15	Up to 624	Up to 98	2–145
Recovery ratio (%) RR	30–45	30–45	35–50	50–90	50–90
Tolerated feed salinity (ppm)	No restrictions	No restrictions	30,000–60,000	500–10,000	< 5000
Brine temperature ($^{\circ}\text{C}$)	90–120	50–90	Same as inlet	Same as inlet	< 45
Electrical energy ($\text{kW}\cdot\text{h}/\text{m}^3$) SEEC	2.5–5	2–2.5	4–6 with ERD 7–13 without ERD	0.5–2.5	0.7–5.5
Thermal energy (MJ/m^3) STEC	190–282	145–230	None	None	None
Equivalent electrical to thermal energy at heat conversion efficiency of 30% ($\text{kW}\cdot\text{h}/\text{m}^3$)	15.8–23.5	12.2–19.1	None	None	None
Total energy ($\text{kW}\cdot\text{h}/\text{m}^3$) SEC_{equiv}	18.3–28.5	14.2–21.6	4–6	1.5–2.5	2.64–5.5, 0.7–2.5 at low TDS
Product water quality (ppm)	2–10	< 10	300–500 for single pass	200–500	150–500

DESALINATION TECHNIQUES



RO is the most adopted technology due to its higher efficiency / lower specific energy requirement

The most widely used thermal desalination technology is MSF. It replaced MED within a few years of its introduction due to size/maintenance => cost consideration. The return of MED in recent years is due to coupling with low temperature waste heat recovery / solar in small applications and better Efficiency / GOR

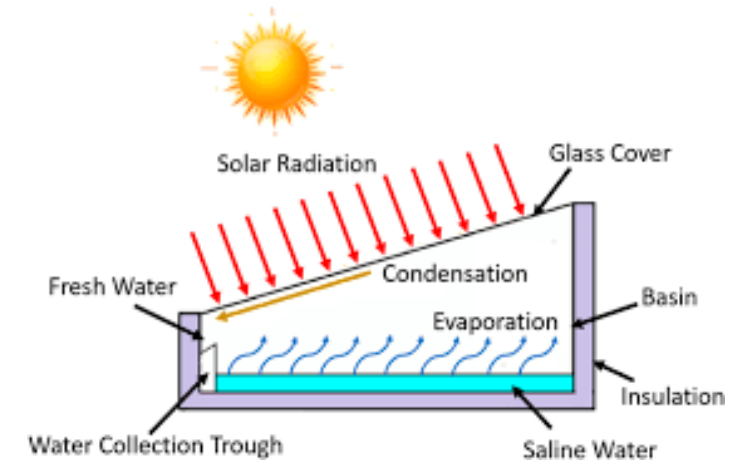
RES HYBRID DESALINATION TECHNIQUES

Electrically driven technologies Reverse Osmosis (RO)

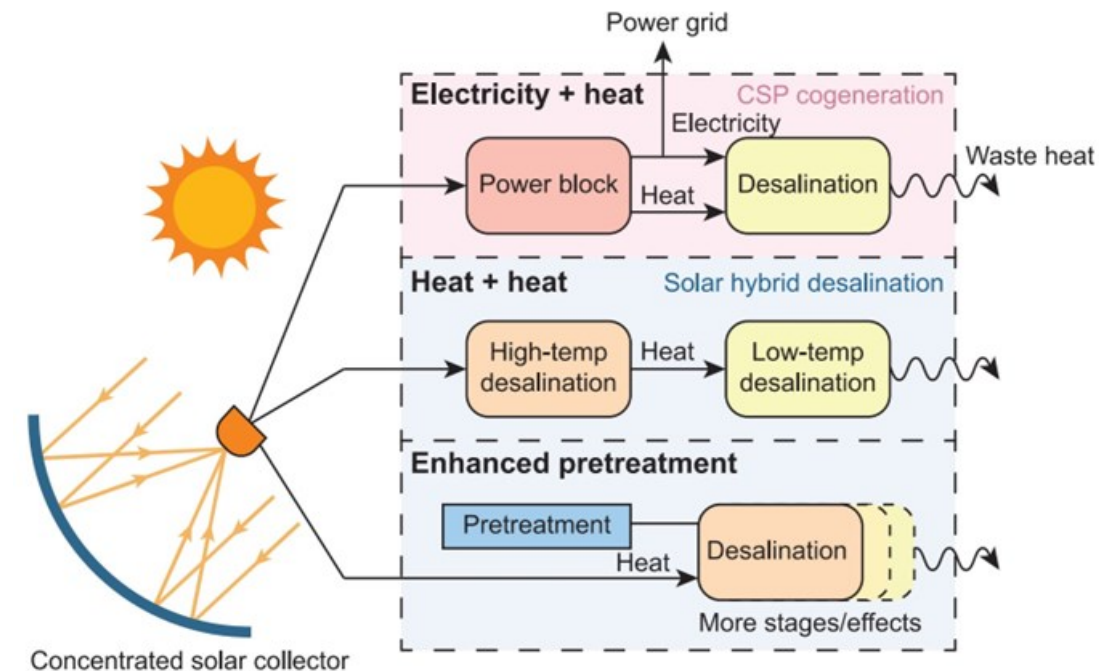
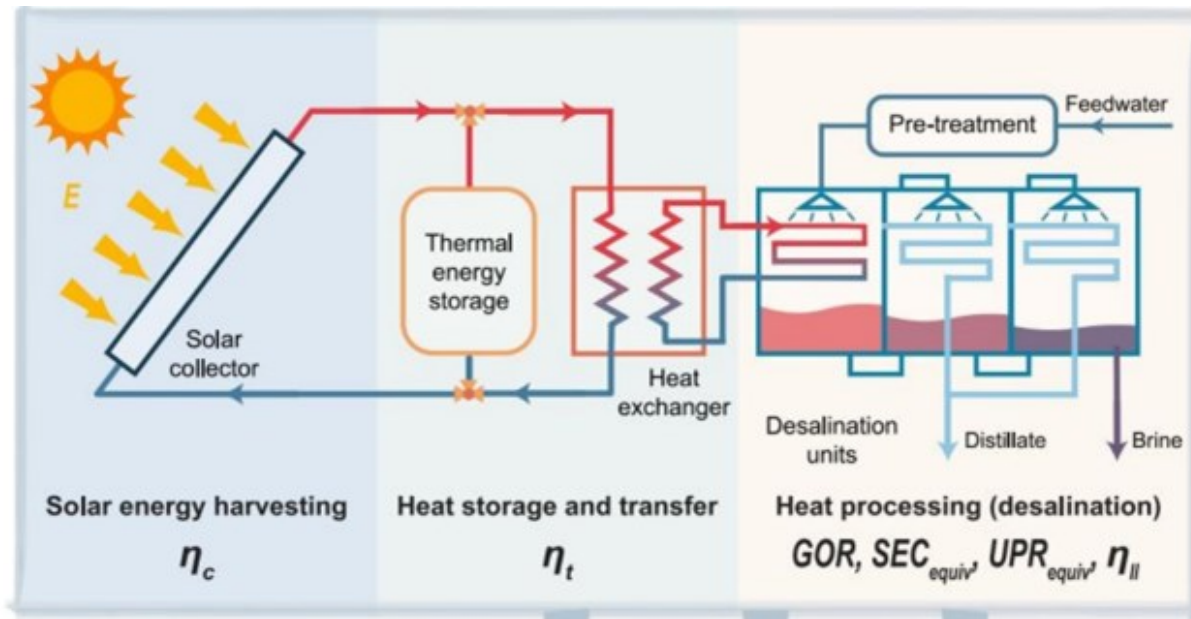
- Exploiting RES produced electricity: PV + WIND (+ Electrical Storages)

Thermally driven technologies: Multi Stage Flash (MSF), Multi Effect Distillation (MED),

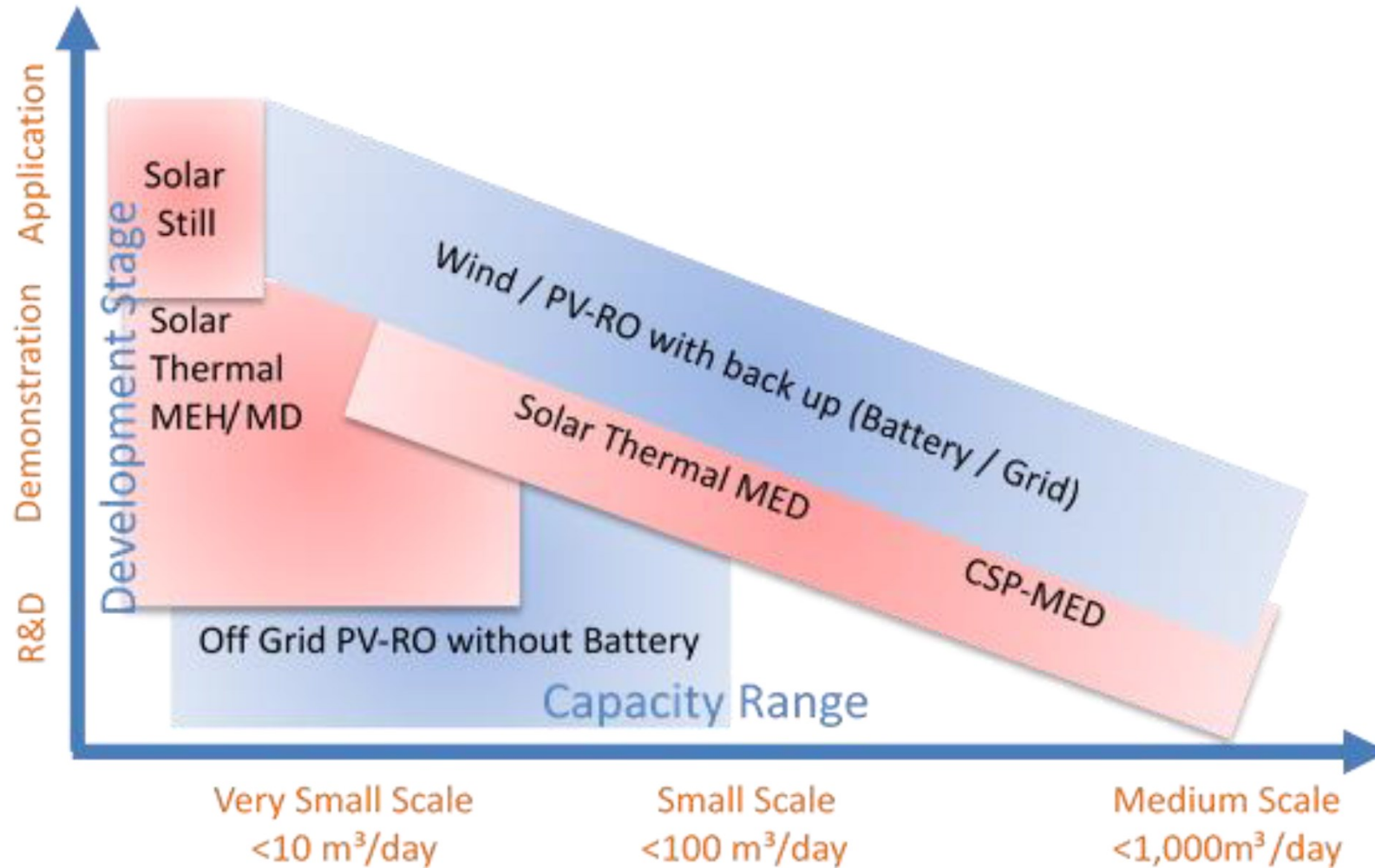
- Solar Still
- Solar Thermal: Solar Thermal Panel or CSP (+ Thermal Energy Storage)



Solar Still



RES HYBRID DESALINATION TECHNIQUES



CSP-MED-RO is a possible solution to increase production flexibility

RES HYBRID DESALINATION TECHNIQUES (PV+RO)

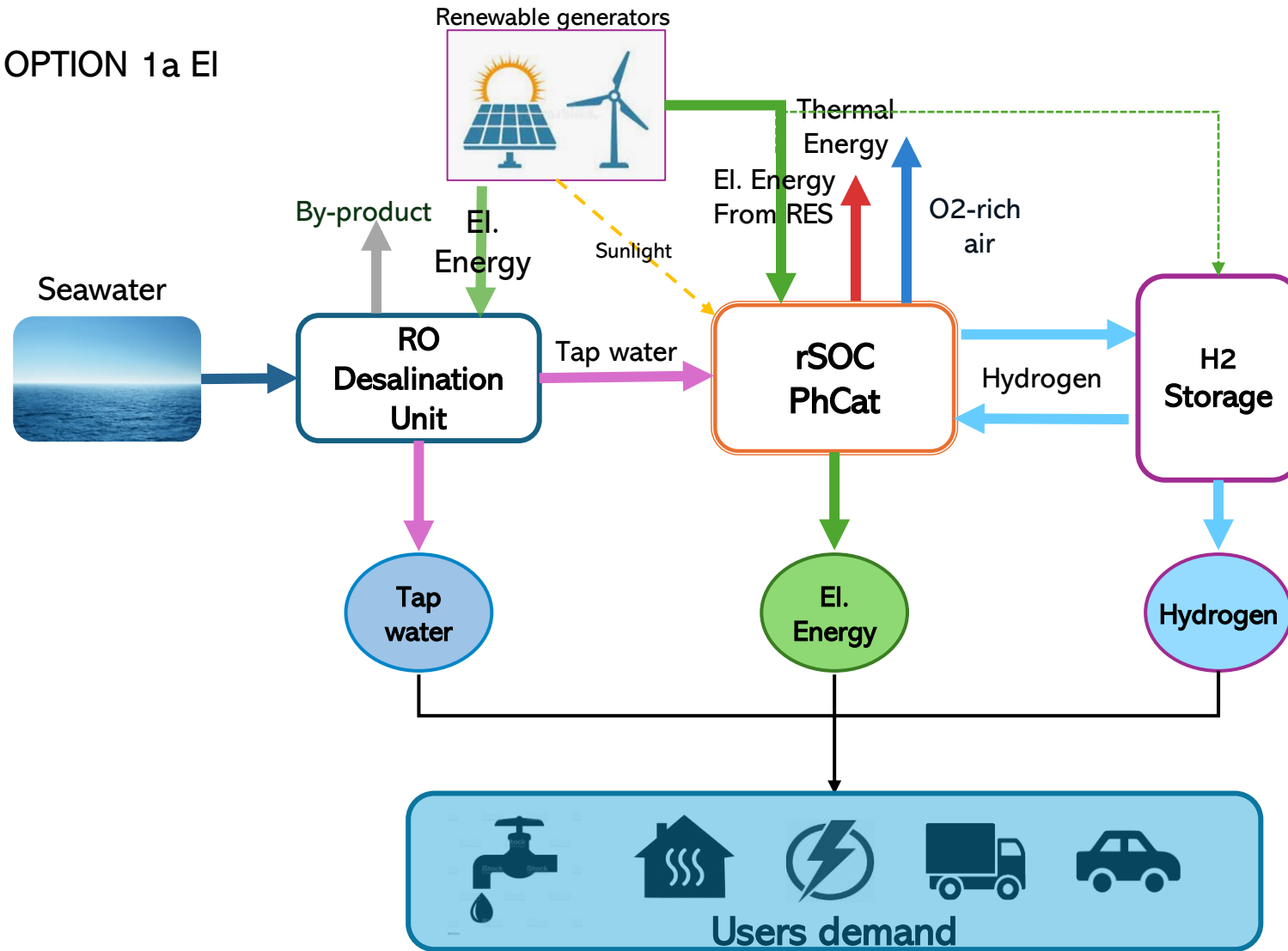
Table20: PV-RO Systems Installed with Support from the Pacific Environment Community Fund

Location	Technology	Application	Total capacity	System capacity	Status	System provider
Marshall Islands	PV-RO	15 plants for fresh water supply to schools in outer islands	9-18 m ³ /day	600-1,200 litres/day	In use since 2014	Toyota Tsusho Corporation, Toray
Nauru	PV-RO & power	Fresh water supply to community	100 m ³ /day	100 m ³ /day	In use since end 2013	Hitachi Plant Technologies Japan
Palau (Peleliu)	PV-RO & power	Fresh water supply to community	100 m ³ /day	150 litres per person/day	In use since March 2014	Hitachi Plant Technologies Japan
Tuvalu (Funafuti)	PV-RO	Fresh water supply to community	120 m ³ /day	1x100 m ³ /day - 2x10 m ³ /day	in use since September 2013	Hitachi Plant Technologies Japan
Vanuatu (Ambae, Aniwa)	PV-RO	Fresh water supply to hospital/ population	110 m ³ /day	1x100 m ³ /day - 1x10 m ³ /day	In use since 2014	Hitachi Plant Technologies Japan
Fiji (Kia, Viwa, Vanuavatu, Kavewa)	PV-RO	Fresh water supply on four islands (174 households) seven plants	136 m ³ /day	7x20 m ³ /day	In operation since 2014	NBK Corporation Japan

POSEIDON

Photo-driven Optima Seawater Elecrolysis for energy-IslandDs OperationN

OPTION 1a EI

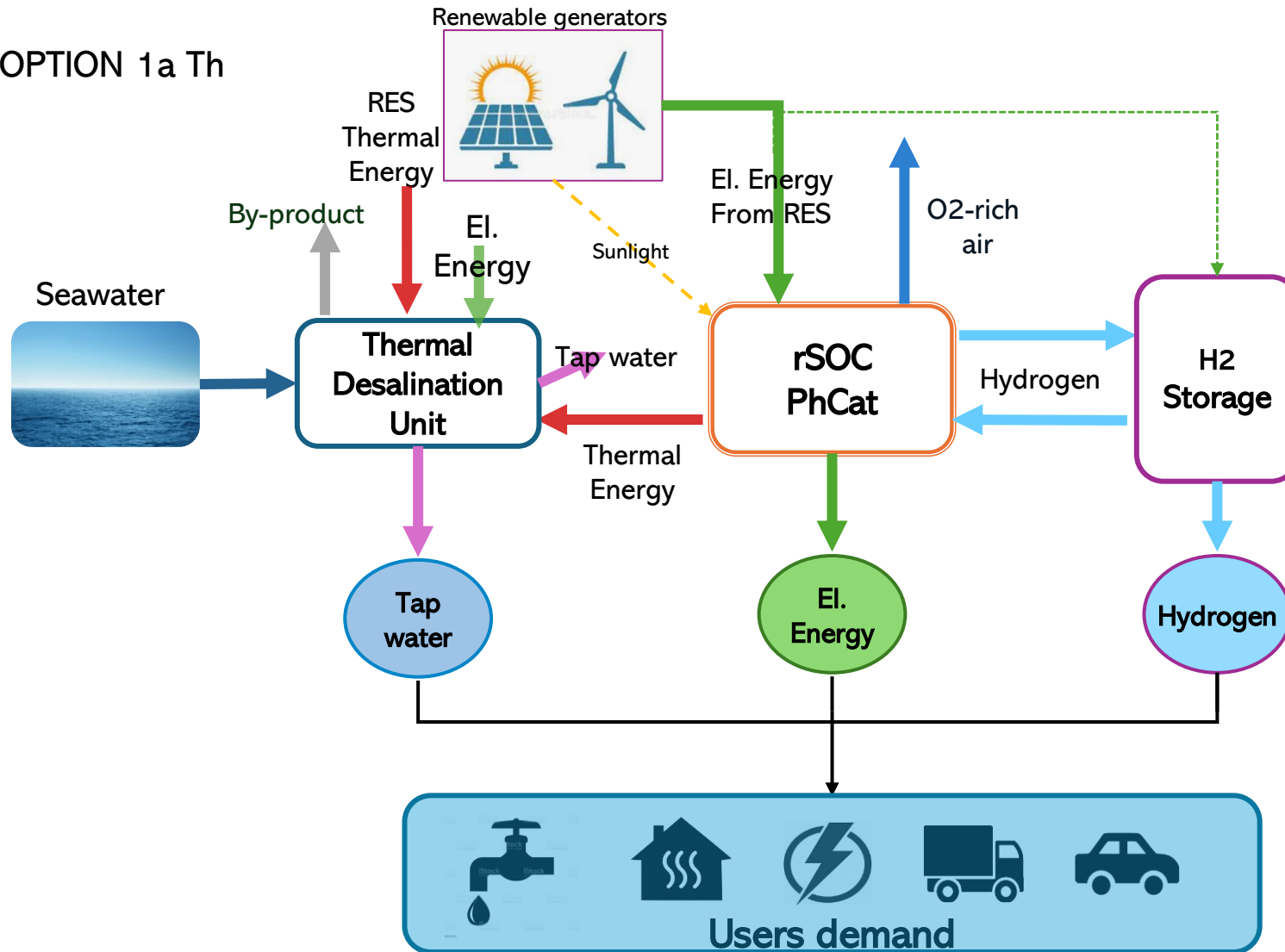


The integration of rSOC, variable RES generation with RO desalination allows the maximum degree of flexibility in managing Electrical, Hydrogen and Tap Water Demand

POSEIDON

Photo-driven Optima Seawater Elecrolysis for energy-IslandDs OperationN

OPTION 1a Th



The integration of rSOC Waste Heat with solar thermal power is used to reduce in variability of the heat available for desalination.

Desalination plant sized on the night/ SOFC use, when the waste heat is maximum.

During the daily RES production phase, both SOEC and Solar Thermal Panel contribute to water production

CONCLUSION

- **The use of desalination plant is expected to grow in the next decades**

Efficiency

- Thermal-based solutions, are energy-intensive due to the need for phase change (evaporation and condensation). Hybrid designs with solar thermal or Waste Heat recovery can improve efficiency.
- Electricity-Based solutions are more energy-efficient overall, especially when paired with energy recovery devices (ERDs). Can achieve lower Primary Energy Consumption with renewable electricity inputs.

Environmental Impact

- Both produces brine as a byproduct, requiring proper disposal to minimize ecological impact. For Thermal solution Brine discharge has thermal pollution effects. Moreover higher greenhouse gas emissions if powered by fossil fuels.

Scalability and Suitability:

- Thermal: Suitable for large-scale applications, particularly in areas with access to cheap waste heat or co-generation plants.
- Electricity-Based: More versatile and scalable for both small and large operations; renewable hybrids are especially advantageous in remote or off-grid areas.

Cost Considerations:

- Thermal: High operational costs due to fuel dependency but may benefit from co-generation setups (e.g., using excess heat from power plants).
- Electricity-Based: Lower operational costs with renewables, but upfront costs for renewable hybrid setups (e.g., solar panels, wind turbines) can be significant.

Grazie per l'Attenzione

Evento di disseminazione del progetto POSEIDON - Piano Nazionale di Ripresa e Resilienza Missione 4 Componente 2, Investimento 1.1 Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN) - Avviso MUR pubblicato con Decreto Direttoriale n. 1409 del 14 settembre 2022 (PRIN 2022 PNRR) - "POSEIDON - *Photo-driven Optimal Seawater Electrolysis for energy-Islands Operation*" – Settore PE8, Codice progetto P2022ER7KM CUP I53D23006440001



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