

Electrodialysis-Reverse Electrodialysis (ED-RED) Battery

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This report is framed within the Action 2 of the WP6 in EERES4WATER Interreg Atlantic Area project (EAPA 1058/2018), related to “Advanced Reverse Osmosis (RO) process development and validation” task. Specifically, Point 2/Energy storage by using ElectroDialysis/Reverse ElectroDialysis (ED/RED). The aim of this report is to assess and evaluate the electro dialysis – reverse electro dialysis process (ED-RED) as energy storage system as auxiliary power system for a RO desalination plant. The brine produced in a reverse osmosis plant could be used to store energy in form of salinity gradient (Gibbs free energy) instead of simply being disposed to the sea, which constitutes an environmental problem.

1. Process description

Technologies of electric energy storage (EES) based on batteries can be generally classified as static battery, redox flow cell, and fuel cell, depending on how the energy is stored [1]. Static batteries store the energy by means of redox-active materials within the electrodes, redox flow batteries store it in soluble redox couples (oxidation/reduction reactions), while fuel cells store the energy in reactants outside of the cell. These technologies have several decades of implementation and maturity. Examples of conventional batteries are lead-acid (Pb-A), nickel metal hydride (Ni-MH) and lithium ion (Li-ion), while zinc bromine (ZnBr), vanadium redox (VR) and polysulphide bromide (PSB) are representative of flow batteries. The electro dialysis-reverse electro dialysis (ED-RED) energy storage system is not still included in the mentioned classification due to its early stage of development.

Batteries have several advantages with respect other EES systems, such as efficiency, reliability, fast response, ease of use and low maintenance requirements. However, batteries present also disadvantages: environmental issues associated with the disposal of toxic materials, high cost, need of rare and expensive substances, low energy density and reduced cycle life [2]. The cost of the batteries could be reduced replacing those scarce materials by other common and abundant substances (eg. NaCl), which is one the main features of the ED-RED battery concept.

In a RED-ED battery a salinity gradient is used to promote an ion flux and convert it to electricity by means of reversible redox couples (electrode rinse solution). This system is often named in literature as ‘concentration battery’, ‘electrodialytic battery’ or ‘salinity gradient flow battery’, and consists basically in a closed-loop two-stage process involving two salt solutions of different salinity, a dilute solution and a concentrate solution, separated by alternate ion exchange membranes (IEM). These membranes selectively allow the pass of ions (cations or anions), controlling the mixing of solutions. In the first stage, ED mode, the battery is charged by creating a salinity difference between the salt solutions applying an external electric power. In the second stage, RED mode, the battery is

discharged by converting the ionic difference into electric current when an electrical load is connected (see Fig. 1). Both processes can take place in the same membrane stack as long as reversible electrodes are used.

The reverse electrodialysis technology is a membrane-based process that converts the electrochemical energy directly into electrical energy. The main element of this process is the ion-exchange membrane, which can be cationic (CEM) or anionic (AEM), stacked in series with alternative positions. Cationic and anionic membranes only allow the transport of cations and anions, respectively. The dilute and concentrate solutions are pumped into the corresponding channels formed between the membranes, which are supported by spacers (or with profiled membranes). Cations and anions pass naturally through the membranes generating a differential of electrochemical potential between them. At both extremes of the stack, two inert electrodes are used to close the circuit and generate the electricity by means of a reversible redox reaction and a supporting electrolyte solution. In the ED mode, the process is just the other way round, an external voltage (higher than the membrane voltage) is applied to re-establish the initial concentrations of the solutions by moving the ions in the opposite direction.

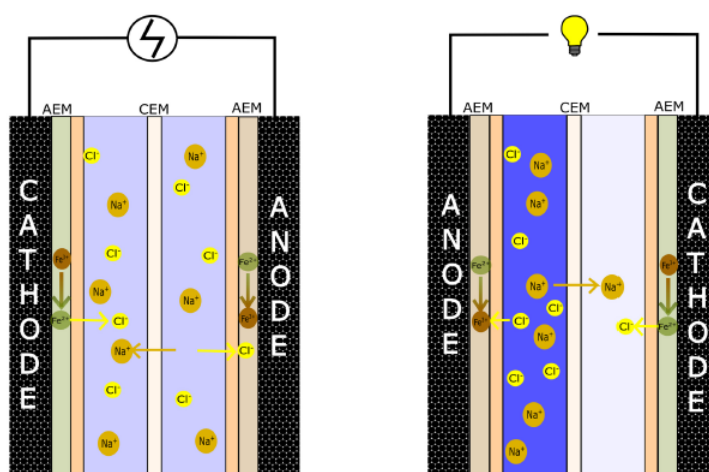


Fig. 1. Scheme of the electrodialysis - reverse electrodialysis energy storage system (charge –left, discharge –right) [3].

Ideally, the features that would make this technology competitive are: scalability, fast response time, low capital cost, long operating life (cycling stability), high round-trip energy efficiency and high energy and power densities. However, different applications would require diverse battery characteristics, for instance, batteries for electric cars would need high energy density and efficiency [4]. This kind of batteries have also the advantage of using low-cost and non-hazard work solutions, at the contrary of conventional batteries, and not being geographically constrained, as pumped hydro storage (PHS) or compressed air energy storage systems (CAES).

Redox flow batteries have a similar structure and working principles although the energy storage mechanism is different. A redox flow cell or redox flow battery (RFB) consists basically in two electrolyte compartments separated by an ion exchange membrane, each one connected to a reservoir tank of electrolyte (see Fig. 2). There are two electrolyte tanks containing the catholyte (positive electrolyte) and the anolyte (negative electrolyte). The electrolytes are pumped from the tanks to the respective cell compartment. The energy is stored and delivered in two reversible redox couples by oxidation and reduction of the electroactive species, respectively. In the charge process, external electricity supplied causes a chemical reduction reaction in one electrolyte and oxidation on the other. In the discharge process the reverse reaction induces electricity in the electrodes. The system is comprised also of two electrodes, two bipolar plates and two current collectors connected to a power source or a load (charge or discharge process). Redox-active ions are oxidized or reduced when they are near the current collector while the non-reactive ions pass through the membrane to maintain the electroneutrality and electrolyte balance [5]. In practice, several cells are put together forming a stack of cells (see Fig. 2). The electrodes serve as substrates for the reactions, therefore, there is not material deterioration as in most rechargeable batteries [6]. One interesting advantage of this kind of battery, shared with the ED-RED battery, is the ability of decoupling the energy and power rating, being the former determined by the amount of electrolyte stored in the tanks, and the latter by the active area of the cell stack. As an example of this technology, there is a large-scale storage battery using Vanadium Redox installed in Japan by HEPCO, with rated output of 15 MW and 60 MWh of capacity (4 h) [7].

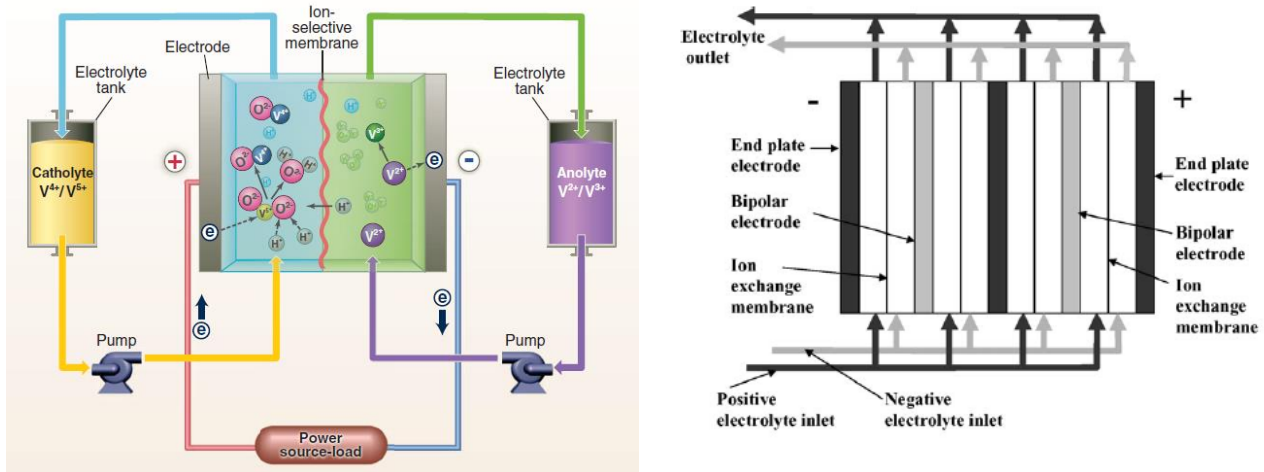


Fig. 2. Scheme of a redox flow cell (left) [5] and a stack of four redox flow cells with bipolar electrodes (right) [1].

The overall performance of batteries is usually expressed by means of the round-trip efficiency [4]:

$$\eta_{RT} = \frac{\text{Energy extracted in the discharging}}{\text{Energy needed to fully charge the battery}} \quad (1)$$

Also, other important parameters are the power density PD (W/m^2), which gives an idea of the total capital costs of the system due to the high cost of IEMs, defined as the power output available during the discharge per total membrane area:

$$PD = \frac{\text{Discharge power}}{\text{Total membrane area}} \quad (2)$$

And the energy density ED (kWh/m^3), which provides information about the size of the system, defined as the total discharge energy per volume of concentrate and dilute solutions.

$$ED = \frac{\text{Discharge energy}}{\text{Total volume}} \quad (3)$$

2. Literature review

2.1 ED-RED batteries

This energy storage system is fairly recent, hence the number of publications related to this technology is low. In 2015 Kingsbury, Chu, & Coronell [4] evaluated the performance of a ED-RED battery, both experimentally and theoretically, in a laboratory scale prototype (Fig. 3). The main parameters assessed were the round-trip energy efficiency (ratio of the energy delivered in the discharge to the energy required to restore the initial state or charge), power density and energy density. A mathematical model was developed as a function of time to determine the mentioned parameters. Also, a stack of 13 membrane pairs (35 cm^2 per membrane exposed to the solutions) was built using IEMS from FuMA-Tech GmbH (AEM FAS-20 and CEM FKE-20). Concentrations of NaCl 0.5 mol/kg and 0.25 mol/kg were used for the concentrate and dilute solutions, respectively. A round-trip energy efficiency between 21 – 34% was obtained, with power densities of $0.07 - 0.44 \text{ W/m}^2$ and energy densities of $7 - 87 \text{ mWh/L}$, for a charging time of 120 min. It was also reported that lithium ion batteries have much more efficiency for mobile applications, near 99%, however, electric storage solutions for large-scale applications have comparatively lower efficiencies, about 60-75%. A value of 40% could be acceptable if it is combined with other desired features for the specific application. The main drawback highlighted was the non-complete reversibility due to the water transfer by osmosis. Results obtained showed that it was impossible to return the battery to its initial state due to this effect, thus impeding multiple charging-discharging cycles.

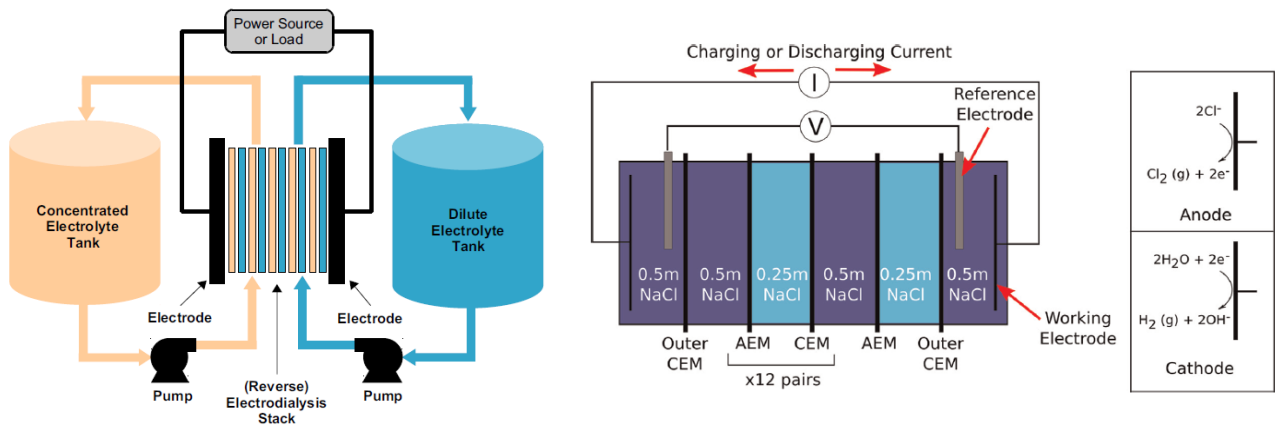


Fig. 3. Scheme of the electrodialysis - reverse electrodialysis energy storage system (left) and detail of the cell stack (right) [4].

In 2016, Van Egmond et al. [8] presented experimental evaluation of the ‘concentration gradient flow battery’ (CGFB) under a wide range of operating conditions (salt concentrations and current densities). Two main performance parameters were defined: the thermodynamic efficiency of the discharging process (ratio of the generated power to the total power contained in the solutions), and the thermodynamic efficiency of the charging process (rate of energy stored to the external power supplied). A stack of four CEMs and three AEMs was used (with CMX and AMX Neosepta IEMs) using sodium chloride concentrations between 0.025 – 3 m and current densities $-49 - 33 \text{ A} \cdot \text{m}^{-2}$. Results obtained showed that the efficiencies of charging and discharging processes were considerably different. The highest efficiencies were obtained for the lowest salinity of the concentrate ($0.5 \text{ mol} \cdot \text{kg}^{-1}$), with values around 50% for the charging and 65-70% for the discharging (see Fig. 4). The increase of the salinity hindered the system performance due to the irreversible effect of water and co-ion transport. It was also observed that the thermodynamic efficiency of the discharging process was higher than the one of the charging process for all the concentration range. It was noted that in order to reduce the size of the system high energy density was desired, which means high salinity gradient between the solutions, however, the lowest efficiency is reached with those conditions. Higher concentration differences led to higher water and co-ion transport due to osmosis and diffusion, main mechanisms of energy dissipation.

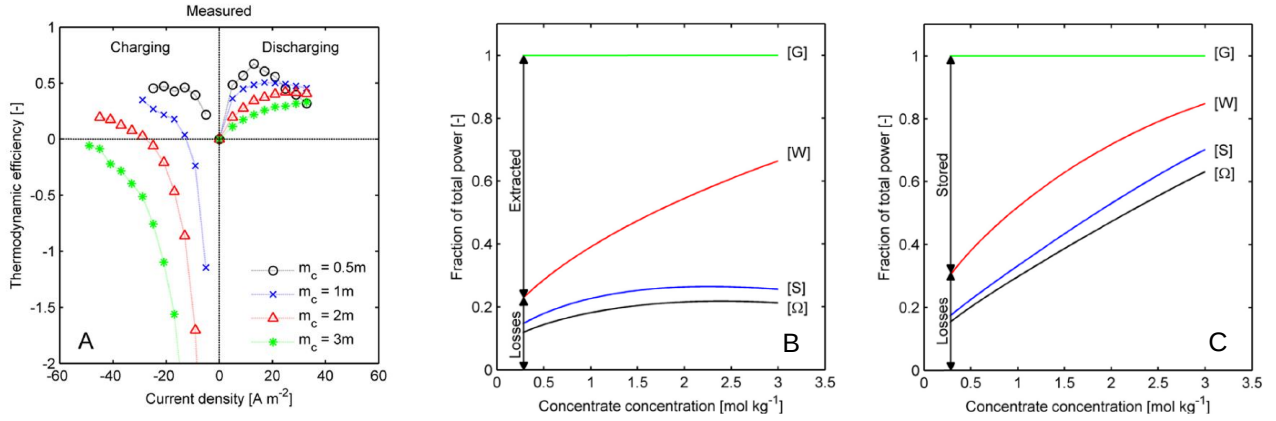


Fig. 4. (A) Measured thermodynamic efficiencies during charge and discharge as a function of the current density for different values of concentrate salinity. (B) Power dissipation for the discharge and (C) charge stages as a function of the concentrate salinity (diluate 0.25 m). [G] represents the total available energy, [W] losses by internal resistance + salt transport + water transport, [S] losses by internal resistance + salt transport, and [Ω] losses by internal resistance. Adapted from [8].

In 2016 Yip et al. [9] performed a review of the actual state of salinity gradient power (SGP) technologies. As an application, grid energy storage systems using SGP were also analyzed. The authors reported that the excess of electric energy produced by renewable energy technologies or in periods of low demand could be used to charge a salinity gradient flow battery (by generating the difference of chemical potential) and then be discharged on demand. Also, it was reported that the energy density of this technology could be theoretically comparable with the other two main grid energy storage solutions: pumped hydroelectric storage and compressed air storage. For instance, with 4 – 0.017 M NaCl solutions, up to 1.9 kWh/m³ of total solution could be stored, energy equivalent to 700 m of hydraulic head or 1 m³ of pressurized air at 22 bar. The size of the battery should cover typical energy surplus rates of 1-10 MW of the electrical grid. Round-trip energy efficiencies of 65 – 80% and 77 – 89% were indicated for the pumped hydroelectric and compressed air storage systems, respectively, which were considerable higher than that of the ED-RED battery reported in Ref. [4]. To reach 60% of efficiency in the concentration battery, the standalone efficiency of the charge and discharge processes would need to be of 77%, which are not normally reached in ED and RED processes. The operating conditions could be changed to enhance the efficiency but at the expense of decreasing the power density (large gradients lead to lower permselectivity [10]), which in turn would rise the capital costs. It was estimated that to be competitive, the capital costs should be around 100 US\$/kWh, despite of the low cost of the solutions and materials needed (water and salts). It was recommended to perform techno-economic analyses of this system to further clarify the battery size that would lead to a competitive kWh cost. Fig. 5 shows the LCOE for the RED and PRO processes as a function of the membrane costs, where it can be seen how for real membrane prices the LCOE is considerable higher than the rest of technologies (solar, wind and conventional). It was highlighted

that aside from the improvement of the power density, a large reduction of membrane and electrode costs would be required in order to make these salinity gradient power technologies competitive.

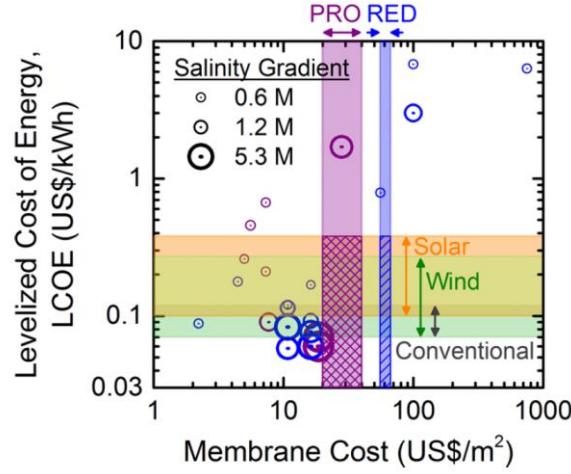


Fig. 5. LCOE of salinity gradient technologies, in blue for RED and in purple for PRO. Vertical bands indicate the 2016-values of membrane modules of PRO and RED. Values collected from techno-economic assessments of salinity gradient energy costs reported in the literature [9].

In 2017, Kingsbury and Coronell [11] proposed a modified ED-RED energy storage system where “osmotic ballasts” (non-charged solute) were added to the dilute solution to balance the difference of osmotic pressure with the concentrate solution. This is the main cause of the unwanted osmotic water transport through the membranes and therefore the reduction in the energy efficiency. Experiments carried out reported an increase of the round-trip energy efficiency from 7% (without ballast) to approx. 15% (with ballast). Even though this efficiency is low, authors stated that the system was not optimized for maximizing the efficiency and there was high room for improvement. In a previous work, a round-trip efficiency of 34% was reached for an optimized system, therefore, they predicted reaching efficiencies greater than 60%.

Also in the same year, Van Egmond et al. [12] investigated, both experimentally and theoretically, the performance of the ED-RED battery as energy storage system at different temperatures. In particular, the charge and discharge efficiencies, energy density and power density were assessed at 10, 25 and 40 °C. The main energy dissipation mechanisms, internal resistance, water transport and co-ion transport, were also analyzed. Results obtained showed that the increase of the temperature caused a reduction of the internal resistance but also an increase of the osmotic water transport, which is a detrimental effect. Maximum charge and discharge efficiencies of 58% and 72% were reported at 40 °C, respectively, leading to a round trip efficiency of about 42% (see Fig. 6).

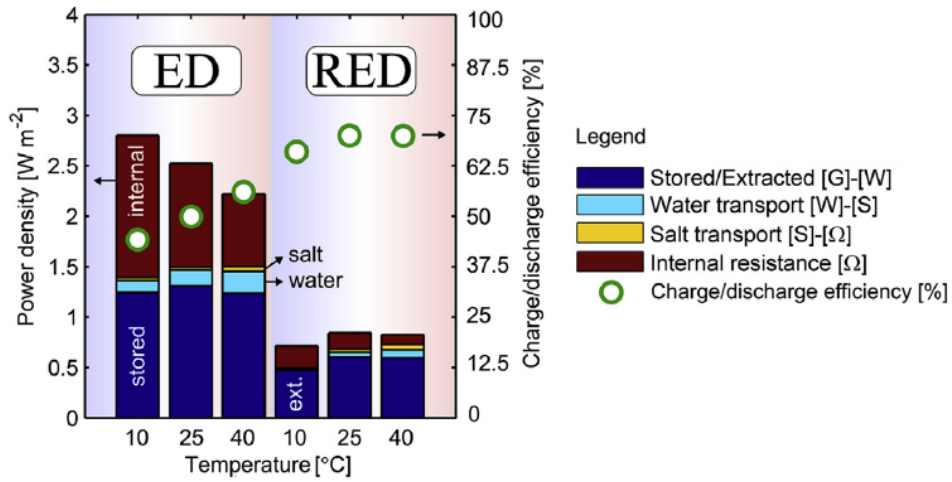


Fig. 6. Experimental results of power dissipation and charge/discharge efficiency as a function of temperature [12].

In 2019, Jalili et al. [3] theoretically evaluated the performance of three different salinity gradient energy storage systems: electrodialysis - reverse electrodialysis, reverse osmosis - pressure retarded osmosis (RO-PRO) and membrane capacity deionization - capacitive Donnan potential (MCDI-CDP). Results showed that the power density of the ED-RED system was higher than the one of RO-PRO for temperatures above 40 °C, and tenth times higher than the capacitive energy storage system. The power density increased with the temperature, as the pumping power consumption decreased. It was found however that the efficiency of the three systems were similar, so other factors such as power density or operating conditions could determine the technology to be used for the specific application. In particular, for the ED-RED system, efficiencies around 40% were calculated with a mathematical model, neglecting polarization phenomena and water transport through the membranes (determined at the beginning of the charge/discharge processes). An economic analysis showed that the systems were feasible below 5.2, 3.7 and 0.43 \$/m² of membrane cost, for ED-RED, RO-PRO and MCDI-CDP, respectively.

In the same year, Papapetrou et al. [13] presented an economic analysis of a closed-loop RED SGP system with regenerative stage driven by multi-effect distillation (MED). The authors also evaluated the energy storage applications of this system and its associated costs. Two reservoir tanks are used to store the concentrated and dilute solutions at the exit of the MED, and other two tanks for collecting the mixed solutions exiting the RED system. Six MED effects, KAc solutions, waste heat at 100 °C and operation temperature of 50 °C were considered. The levelised cost of electricity (LCOE) was estimated for medium and large-scale systems. Results indicated that for 12 h/d operation, LCOE between 0.09-0.16 €/kWh and 0.03-0.09 €/kWh, with peak power outputs of 0.5 MW and 5 MW, could be reached for medium and large-scale systems, respectively. Up to 11 MW could be supplied with a

25% of operation time per day in large scale systems. Those results are very interesting and promising in order to be competitive with current peak power generation technologies.

A summary of the experimental works of ED-RED batteries found in the literature is presented in Table 1, showing the experimental conditions used and performances obtained.

The maximum work extractable from the battery is determined by the exergy analysis. This assessment also allows to identify the irreversibility sources and the energy dissipated. In this sense, Giacalone et al. [14] assessed the exergetic efficiency of the RED process and its main irreversibility sources. Fig. 7 shows the exergy efficiency (a) and the power density (b) as a function of the resistance ratio (external to internal), for different scenarios. In scenario A, only the effect of the internal resistance is considered. In scenario B, the effect of internal resistance and the permselectivity are accounted. Scenarios C and D add the effect of diffusive salt flux and osmotic water flux, respectively. The most detrimental effect on the exergy efficiency is the osmotic water flux, as it can be seen in the figure, followed by the salt flux. Note that with real properties, the value of the external resistance that maximizes the exergy efficiency is approximately equal to the internal resistance.

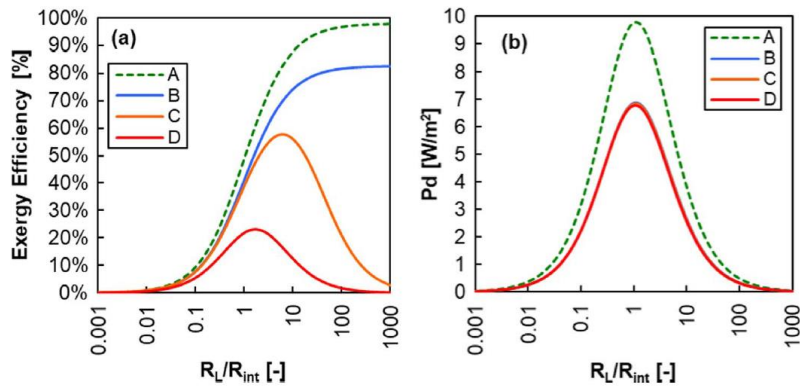


Fig. 7. Exergy efficiency (left) and power density (right) as a function of the external to internal RED stack resistance ratio. Line A represents ideal membranes, only the internal resistance is considered; B adds non-ideal permselectivity, C adds the effect of diffusive salt flux, and D adds the effect of osmotic water flux. Conditions: stack $0.1 \text{ m} \times 0.1 \text{ m}$, $C_{conc}=3.6 \text{ M}$, $C_{dil}=0.05 \text{ M}$, $v_{conc}=v_{dil}=1 \text{ cm/s}$.

Table 1. Summary of experimental results for the ED-RED battery.

	R.S. Kingsbury et al. [4]	W.J. van Egmond et al. [8]	R.S. Kingsbury et al. [11]	W.J. van Egmond et al. [12]
Stack configuration	12 CEM (FKE-20 FuMA-Tech GmbH) 13 AEM (FAS-20 FuMA-Tech GmbH) 2 CEM (Neosepta CMX) end rinse chambers	4 CEM (CMX Neosepta) 3 AEM (AMX Neosepta)	11 CEM 10 AEM	4 CEM (CMX Neosepta) 3 AEM (AMX Neosepta)
Total effective area	0.0019 m ² /IEM	0.01 m ² /IEM	N.A.	0.01 m ² /IEM
Thickness of membranes	20 µm	155 µm	N.A.	155 µm
Spacers	Woven mesh Nitex 03/200-54 (Sefar Inc.). 54% open area	210 µm (SEFAR AG) 50% open area	N.A.	210 µm (SEFAR AG) 50% open area
Electrodes	Graphite (GraphiteStore.com #BL001245)	Titanium coated with Ir/Ru (Magnetospecial Anodes, B.V.)	Mixed metal-oxid coated titanium	Titanium coated with Ir/Ru (Magnetospecial Anodes, B.V.)
Rinse solution	0.5 m NaCl (only for experimental convenience) + sodium formate to stabilize the pH	0.5 M Na ₂ SO ₄	N.A.	Na ₂ SO ₄
Electrolyte	NaCl	NaCl, 25.2 mL/min	NaCl	NaCl
Concentrations tested	Diluate: 0.25 m Concentrate: 0.5 m	Diluate: 0.025, 0.05, 0.1, 0.25 m Concentrate: 0.5, 1, 2, 3 m	Diluate: 0.257 M Concentrate: 0.513 M Ballast added to the diluate solution: ethylene glycol oligomers	Charging: starting LC & HC of 0.5 molal NaCl Discharging: starting LC and HC of 0.02 and 0.85 molal NaCl
Currents tested, A/m ²	5.7, 11.4, 17.1, 22.8	Charging: 12 points between -5 and -49. Discharging: 12 points between 5 and 33.	Optimal: 7	Charging: 6 ED experiments at 40°C ranging from -10 to -47.5 Discharging: 5 RED experiments at 40°C from 7.5 to 37.5
Round-trip efficiency (or charge/discharge eff)	35.1%	50% charging, ~70% discharge (HC 0.5 m)	With ballasts: 15%. Without: 7% System not optimized	Charge eff.: 58% Discharge eff.: 72% Round-trip eff.: 42%
Power density, W/m ²	0.08 – 0.52	~ 4 (simulated)	N.A.	~ 1
Energy density, kWh/m ³	0.007 – 0.095	N.A.	N.A.	~ 0.29
Number of cycles tested (or time)	Charging: 120 min Discharge: 35 – 72 min	N.A.	Charging: 120 min Discharge: 35 – 100 min	6 ED discharges, 5 RED discharges

2.2 Other configurations and RFB

Zhu et al. [15] presented in 2016 a modified version of the ED-RED system, using an integrated RED stack with a flow battery, able to capture, store and supply salinity gradient energy. In this system, instead of producing electricity in the RED stack, the redox solutions are not recycled but stored in tanks and later sent to a flow battery to generate power (see Fig. 8). In flow batteries, the electro-active species are pumped from storage tanks to a flow cell composed of two electrodes and an ion-permeable membrane. In this way, the energy produced by the intermittent operation of renewable energy sources can be stored in liquid electrolyte solutions and be dispatched when needed. 2,6-dihydroxyanthraquinone and ferrocyanide were tested as redox couples, which are composed of abundant, non-toxic and safe materials. Experimental tests with three charging times, 4, 8 and 12 h were run at two different salinity gradient ratios, 100 and 330. The energy efficiency obtained, defined as the ratio between discharging energy and charging energy, was of about 30% and the energy density of 2.4 kWh/m³-anolyte. A maximum power density of 3 kW/m²-anode was reached for 12 h charging time, which is considerably higher than that obtained in RED systems (1.6 W/m² of cell pair with brackish water – brine using RED prototype [16] or 6.7 W/m² using river water and 5 M brine at 60 °C in lab [10]). Low energy recovery (ratio between total recovered electrical energy and total energy input to the system) was obtained, 0.55% for a salinity gradient ratio of 100 (HC: 0.6M NaCl; LC: 0.006M NaCl, seawater – river water). However, the authors claimed that an optimization of the operating conditions could led to a 25% of energy recovery with 30% of energy efficiency.

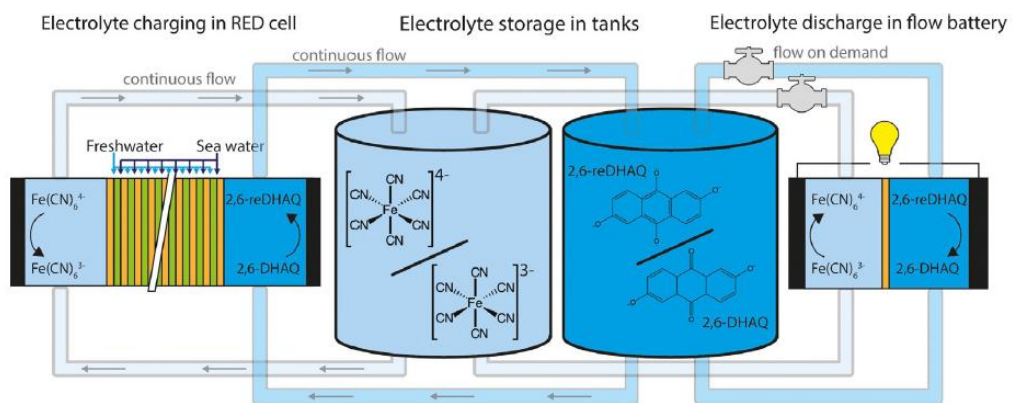


Fig. 8. Scheme of the RED-FB system [15].

In 2019, Akbari et al. [17] reviewed the integration of photovoltaic (PV) systems with the available energy storage technologies. In particular, different PV-battery systems were assessed, including redox flow batteries (zinc-bromide Zn-Br, vanadium V, and polysulfide bromide PSB), sodium-sulfur (NaS), lithium-ion (Li-ion), nickel-cadmium (Ni-Cd), lead-acid and metal-air batteries (Table 2).

Table 2. Comparison of different electric energy storage systems [17].

Storage technology	Power rating (MW)	Discharge time	Capital cost (USD/KW)	Efficiency (%)
SMES	0.1–10	ms to 8 s	200–500	80–90
Flywheels	0–10	ms to 40 s	250–450	90–95
Capacitor	0–0.05	ms to 60 s	200–500	60–75
Supercapacitor	0–0.3	ms to 60 s	100–500	90–100
Batt-ZEBRA	0–0.3	Seconds to hours	150–300	85–90
Batt-NaS	0.05–50	Seconds to hours	600–3000	75–90
Batt-Lead acid	0–20	Seconds to hours	300–800	70–80
Batt-NiCd	0–40	Seconds to hours	500–1500	60–70
Flow-ZnBr	0.05–2	Seconds to 10 h	600–2500	65–75
Flow-VRB	0.03–7	Seconds to 10 h	600–2500	75–90
Flow-PSB	1.0–15	Seconds to 10 h	600–2500	60–70
Metal-air	0–0.01	Seconds to 24 h and more	100–250	30–50
Fuel cells	0–50	Seconds to 24 h and more		20–50
Batt-Li-ion	0–0.1	Minutes to hours	1200–4000	85–100
AL-TES	0–5	1–8 h		40–60
CES	0.1–300	1–8 h	200–300	40–50
Solar fuel	0–10	1–24 h and more		20–30
HT-TES	0–60	1–24 h and more		30–60
CAES	5–300	1–24 h and more	400–1350	70–80
PHS	100–5000	1–24 h and more	600–2000	70–85

Fig. 9 shows the discharge time vs rated power (left) and specific power vs specific energy, for different EES systems. As it can be seen, flow batteries could be applied for load shifting (grid support), however their specific power and densities are comparatively low with respect other batteries. ED-RED batteries could improve the performance and costs of existing flow batteries by using cheaper, safer and environmentally friendly materials.

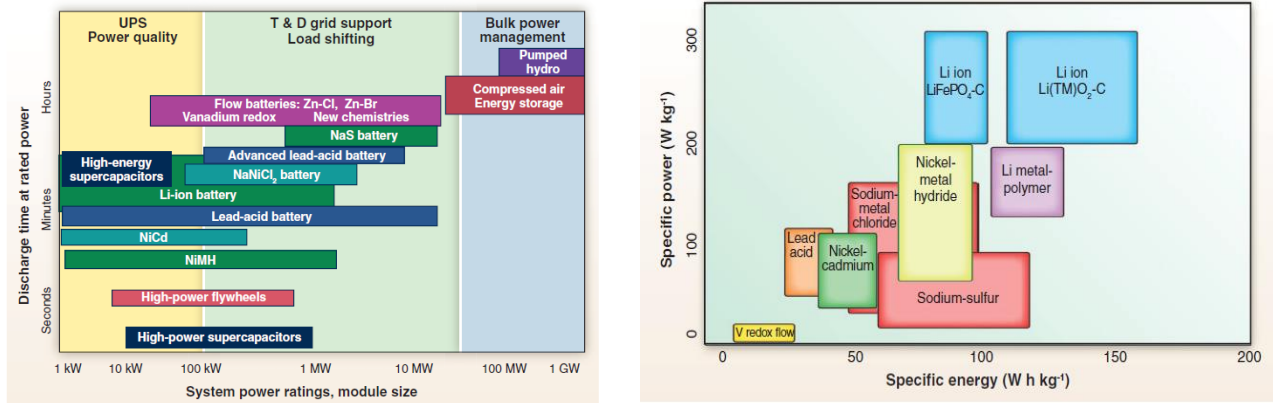


Fig. 9. EES technologies comparison [5]. Note that ED-RED batteries are not included.

3. Conclusions

When comparing ED-RED system with the main large-scale electric energy storage technologies, pumped hydro energy storage and compressed air energy storage, the results show that ED-RED process is still in an early stage and more research is needed to overcome the low performance obtained with this system. Very low efficiencies and technical issues are found, therefore, currently it is not available as energy storage for RO desalination plants. Further investigation is needed

for the increase of the efficiency, improvement of the membranes features and decrease of the associated costs.

Table 3 shows a comparison of the efficiency, rated power, energy density, discharge time, capital costs and cycling times between ED-RED battery and other EES systems: Flow Batteries, PHS, and CAES. The data associated with the ED-RED battery is scarce, therefore only the round-trip efficiency and energy density values are referenced. However, it can be seen that the efficiency of this system, obtained in experiments at laboratory scale, is quite low compared with other available energy storage solutions. Due to the scalability of this system, the rated power could be comparable to that of flow batteries, and also costs could be comparable (although it is expected to be cheaper due to the use of cheap salt solutions).

Table 3. Comparison of ED-RED battery with other electric energy storage systems[17].

	ED-RED	Flow Batteries	PHS	CAES
RT Efficiency (%)	42 [12]	65-85 [2], 90 [17]	70-87 [2], 70-85 [17]	42-70 [2], 70-80 [17]
Rated power (MW)	N.A.	0.03-15 [17]	100-5000 [17]	5-300 [17]
Energy density (kWh/m ³)	0.007 – 0.095 [4], 0.29 [12]	16-65 [2]	0.5-2 [2]	2-6 [2]
Discharge time	N.A.	s-10h [17]	1-24h [17]	1-24h [17]
Capital costs (USD/kW)	N.A.	600-2500 [17]	600-2000 [17]	400-1350 [17]
Cycling times	N.A.	2000-13,000 [2]	10,000-30,000 [2]	8000-12,000 [2]

The market of EES systems for the electric grid is dominated by the PHS technology. Up to 99% of the global large scale energy storage systems are PHS, with total production of 127 GW in 2016 [8]. However, although the ED-RED battery is not currently competitive with other energy storage technologies, it has interesting inherent features (low material costs, abundant salt solutions, scalability, power-energy decoupling, etc.). It could be used for medium scale or peak power supply for the electric grid, or for auxiliary energy source in other applications such as RO desalination plants, once all the technical issues have been solved.

The ED-RED battery uses a sub-product of the RO desalination process as the energy source (concentrated solution), which otherwise would be simply rejected to the sea. Therefore, the efficiency could not be crucial in the decision-making process, as the RO brine have no cost associated. Techno-economic analyses are needed to further investigate the viability of the process.

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