

REIES – Lesson 4d: Chemical Energy

Answer Key

You have worked through the exercises — well done! Use this document to check your answers and deepen your understanding. The core skills in this lesson are understanding the electrolyser/fuel cell and battery as reversible chemical energy converters, and being able to reason about round-trip efficiency, energy density, and the role of chemical storage in integrating renewable energy.

Section A – Knowledge Questions

Answer – Exercise 1

Knowledge

Electrolysis is the process of using an electric current to drive a chemical reaction that would not occur spontaneously – for example, splitting water into hydrogen and oxygen. The membrane separates the anode and cathode compartments so that the gases produced at each electrode cannot mix. This is critical because hydrogen and oxygen react violently (explosively) when in contact, especially when a spark or ignition source is present. The membrane must be permeable to at least one ionic species to allow charge to be transported through the liquid, completing the internal circuit.

Anode: oxygen (O_2) is produced. Cathode: hydrogen (H_2) is produced. The gases are dangerous together because hydrogen and oxygen form an explosive mixture ('oxyhydrogen' or 'knallgas'). A spark causes rapid combustion – this is the principle of a hydrogen explosion.

Scientists: Alessandro Volta (voltaic pile, 1800), Luigi Galvani (bioelectric experiments), Michael Faraday (Faraday's laws of electrolysis, 1830s). Industrial process example: the chloralkali process – electrolysis of brine ($NaCl$ solution) produces chlorine gas (Cl_2), hydrogen gas (H_2), and sodium hydroxide ($NaOH$), all important industrial chemicals. Another example: aluminium production (Hall–Héroult process), where aluminium oxide from bauxite is dissolved in molten cryolite and electrolysed to produce aluminium metal.

Answer – Exercise 2

Knowledge

Property	Alkaline (ALK)	AEM	PEM	SOEC / HT
Ion transported	OH^- (hydroxide)	OH^- (hydroxide)	H^+ (proton)	O^{2-} (oxide ion)
Electrolyte type	Liquid KOH solution + diaphragm	Solid polymer (anion exchange)	Solid fluorinated polymer (Nafion®)	Solid ceramic (YSZ)
Operating temp.	60–95 °C	40–80 °C	50–80 °C	700–1 000 °C

Cathode material	Nickel mesh	Nickel mesh	Platinum (Pt/C)	Ni + YSZ (cermet)
Key advantage	Mature, stable, low cost	Low/no alkalinity needed, high current density	Wide power range, fast ramp, compact	High electrical efficiency
Key disadvantage	Low current density, bulky	Not yet commercially proven	Noble metal catalysts, fluorinated membrane	Temperature-sensitive, expensive

Balance of plant (BoP): all equipment around the electrolyser stack itself that is needed for the complete system to function. Examples: power electronics (AC-DC converter/rectifier), water purification unit, heat exchangers, gas compressor, hydrogen dryer, oxygen removal unit, gas chromatography for quality monitoring, pipes and mechanical structures.

PEM and intermittent renewables: a PEM electrolyser can ramp from ~10 % to 100 % of its rated power very quickly (within seconds to minutes), matching the variable output of wind and solar. This is critical because an electrolyser powered by a wind turbine must be able to follow fluctuating electricity input without damage. Alkaline electrolysers have narrower operating windows and are slower to ramp, making them less suited to highly variable inputs.

Answer – Exercise 3



Knowledge

Fuel cell vs. combustion engine: a combustion engine burns fuel in air, converting chemical energy primarily to heat and then to motion via thermal expansion – it is limited by the Carnot efficiency (typically 30–40 %). A fuel cell converts chemical energy directly to electricity through electrochemical reactions, without combustion, achieving higher electrical efficiencies (50–60 % for PEM, up to 60 % for SOFC). The key emission advantage of a hydrogen fuel cell: the only product is water (H₂O). No CO₂, no NO_x, no particulates. In contrast, even hydrogen combustion produces NO_x because nitrogen and oxygen in the air react at high temperatures.

Reversible solid oxide cell (rSOC): a solid oxide cell that can operate in both electrolysis mode (electricity → hydrogen) and fuel cell mode (hydrogen → electricity) using the same hardware. This is possible because the solid oxide cell and the solid oxide fuel cell use essentially identical materials and geometry. It enables a single device to act as both an energy storage unit and an electricity generator, reducing the capital cost of a combined electrolyser-fuel cell system.

Batteries vs. hydrogen storage:

Storage type	Advantage	Disadvantage	Best for
Battery (Li-ion)	High round-trip efficiency (90–95 %); fast response; no conversion losses from gas handling	Limited energy density per kg; capacity degrades with cycles; not suited for seasonal storage	Short-duration storage (hours to days); EV range; daily solar buffering

Hydrogen (electrolyser + fuel cell)	Very high energy storage capacity; long-duration storage (weeks to months) possible; low self-discharge	Low round-trip efficiency (~40–42 %); expensive system; storage infrastructure needed	Seasonal/long-duration storage; industrial feedstock; zero-emission transport
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Hydrogen is better for seasonal storage because its self-discharge rate is essentially zero (the gas stays in the tank), and it can store enormous quantities of energy in salt caverns or former gas fields. A battery cannot hold charge for months without significant self-discharge and degradation.

Answer – Exercise 4



Knowledge

Peak shaving: reducing the maximum (peak) power demand that a household or neighbourhood draws from the grid by discharging a battery during high-demand periods and charging it during low-demand periods. Both the household (lower peak tariffs, reduced energy costs) and the grid operator (less need for expensive peak generation capacity and grid reinforcement) benefit. The lesson specifically mentions preventing expensive grid expansions as a motivation.

Factors making payback time uncertain: (1) future electricity price fluctuations (spot pricing volatility); (2) future feed-in tariff changes (governments may reduce or eliminate export subsidies); (3) battery capacity degradation over time (the battery stores less energy as it ages); (4) whether peripheral equipment such as inverters and chargers is included in the system cost; (5) number of charge–discharge cycles per day (1 vs. 2 per day changes the economics); (6) expected battery lifetime in years; (7) solar PV generation variability from year to year.

Neighbourhood battery vs. home battery: a neighbourhood battery is shared among multiple households and is typically larger than a single home battery. The key insight from the lesson is statistical diversity: while individual households may have sharp simultaneous peaks, the probability that all households peak at exactly the same moment is low. By combining demands, the effective peak is lower than the sum of individual peaks, and a shared battery can cover the residual difference more cost-effectively than many small individual batteries. Including commercial users (schools, offices) whose peaks occur at different times of day further improves efficiency.

Section B – Calculation Questions

Answer – Exercise 5



Calculation

Water electrolysis – voltage efficiency and hydrogen production

Voltage efficiency:

$$\eta_V = V_{\text{theoretical}} / V_{\text{actual}} = 1.229 \text{ V} / 1.8 \text{ V} = 0.683 = 68.3 \%$$

Stack power:

$$P = V \times I \times N_{\text{cells}} = 1.8 \text{ V} \times 5\,000 \text{ A} \times 100 \text{ cells}$$

$$P = 900\,000 \text{ W} = 900 \text{ kW}$$

Hydrogen production over 24 h:

$$\text{Energy consumed} = 900 \text{ kW} \times 24 \text{ h} = 21\,600 \text{ kWh}$$

$$\text{H}_2 \text{ produced} = 21\,600 \text{ kWh} / 55 \text{ kWh/kg} = 392.7 \text{ kg H}_2$$

Energy content of hydrogen produced:

$$E_{\text{H}_2} = 392.7 \text{ kg} \times 39.4 \text{ kWh/kg} = 15\,472 \text{ kWh}$$

$$\text{System efficiency} = 15\,472 / 21\,600 = 71.6 \% \text{ (electricity to H}_2\text{, HHV basis)}$$

This calculation shows that a real electrolyser stack is considerably less efficient than the thermodynamic minimum (68 % voltage efficiency vs 100 % at 1.229 V). The gap represents overpotentials – additional voltage needed to overcome activation barriers at the electrodes and ohmic resistance in the cell. Research into better catalysts (especially for the anode in PEM systems) aims to close this gap. The overall HHV efficiency of 71.6 % is typical for modern PEM electrolysers and is a key metric in comparing technologies.

Answer – Exercise 6

Calculation

Round-trip efficiency of hydrogen storage

Round-trip efficiency:

$$\eta_{\text{RT}} = \eta_{\text{electrolyser}} \times \eta_{\text{fuel cell}}$$

$$\eta_{\text{RT}} = 0.70 \times 0.60 = 0.42 = 42 \%$$

Energy recovered from 1 000 kWh input:

$$E_{\text{recovered}} = 1\,000 \text{ kWh} \times 0.42 = 420 \text{ kWh}$$

$$E_{\text{lost}} = 1\,000 - 420 = 580 \text{ kWh} \quad (58 \% \text{ lost, mainly as low-grade heat})$$

Compare to Li-ion battery (90–95 % round-trip):

Li-ion: 1 000 kWh → 900–950 kWh recovered

Hydrogen: 1 000 kWh → 420 kWh recovered

Li-ion is ~2.1× more efficient for round-trip storage

Despite much lower round-trip efficiency, hydrogen storage may be preferred for: (1) seasonal / long-duration storage – a battery cannot economically store energy for months without self-discharge, but hydrogen in a tank or salt cavern can. (2) Industrial use – hydrogen is itself a chemical feedstock (for fertiliser, steel production, etc.), so the hydrogen

need not be converted back to electricity at all; the round-trip framing does not apply. The lesson example of the Energy Observer vessel illustrates a case where energy density and long autonomy (no refuelling stops at sea) outweigh efficiency concerns.

Answer – Exercise 7

Calculation

Hydrogen storage – pressure and energy density

Volume at 700 bar (ideal gas, $V \propto 1/P$):

$$V_{700} = V_1 \times (P_1 / P_{700}) = 11.1 \text{ m}^3 \times (1 / 700)$$

$$V_{700} = 0.01586 \text{ m}^3 \approx 15.9 \text{ litres per kg of H}_2$$

Energy in a 5 kg car tank:

$$E = 5 \text{ kg} \times 39.4 \text{ kWh/kg} = 197 \text{ kWh}$$

Compare: 75 kWh Li-ion battery $\rightarrow$ H₂ tank stores 2.6× more energy

Gravimetric energy density comparison:

$$\text{H}_2 \text{ tank system: } 197 \text{ kWh} / 90 \text{ kg} = 2.19 \text{ kWh/kg}$$

$$\text{Li-ion battery: } 75 \text{ kWh} / 450 \text{ kg} = 0.167 \text{ kWh/kg}$$

H₂ tank system stores 13× more energy per kg of system weight

Liquid hydrogen volume for 5 kg:

$$V = \text{mass} / \text{density} = 5 \text{ kg} / 71 \text{ kg/m}^3 = 0.0704 \text{ m}^3 = 70.4 \text{ litres}$$

The gravimetric advantage of hydrogen is clear: at the system level, a hydrogen tank+fuel cell is much lighter than an equivalent lithium-ion battery pack. This is why hydrogen is attractive for heavy-duty, long-range transport (trucks, ships, aircraft) where battery weight becomes prohibitive. However, the volumetric energy density at 700 bar is still modest compared to liquid fuels (petrol: ~8.9 kWh/litre). Liquid hydrogen has better volumetric density but requires cooling to -253 °C, which consumes a significant fraction of the stored energy – typically 25–30 % of the hydrogen's energy content is used just for liquefaction. This is the energy penalty the lesson refers to.

Answer – Exercise 8

Calculation

Battery energy density and EV range

Gravimetric energy density:

$$E_{\text{density}} = 75\,000 \text{ Wh} / 450 \text{ kg} = 166.7 \text{ Wh/kg}$$

Lead acid: ~40 Wh/kg $\rightarrow$ Li-ion is 4.2× better

Solid-state (projected): ~400–500 Wh/kg $\rightarrow$ 2.4–3.0× better than Li-ion

Maximum range:

$\text{Range_max} = 75 \text{ kWh} / (18 \text{ kWh}/100 \text{ km}) = 417 \text{ km}$

Practical range (80 % usable): $0.80 \times 75 \text{ kWh} = 60 \text{ kWh usable}$

$\text{Range_practical} = 60 \text{ kWh} / (18 \text{ kWh}/100 \text{ km}) = 333 \text{ km}$

Degradation timeline:

Cycles to 80 % capacity: 1 500 cycles

At 1 charge/day: $1\,500 \text{ days} \times (1 \text{ year}/365 \text{ days}) \approx 4.1 \text{ years}$

Capacity at 4.1 years: $80 \% \times 75 \text{ kWh} = 60 \text{ kWh}$

Usable at degraded state: $80 \% \times 60 \text{ kWh} = 48 \text{ kWh}$

Practical range at 4.1 years: $48 / 0.18 = 267 \text{ km}$

This exercise illustrates a key tension in EV design: battery capacity must account for both the daily range requirement and future degradation. Manufacturers typically guarantee 70–80 % capacity retention for 8–10 years, but the calculation above shows that daily charging reaches 1 500 cycles in about 4 years. In practice, many users do not charge to 100 % every day (partial charging reduces degradation), extending real-world battery life well beyond this estimate. The lesson's solid-state battery promises to roughly double the energy density, which would either double the range or halve the battery weight for the same range.

Answer – Exercise 9

Calculation

Home battery – sizing and payback

Annual feed-in revenue (before battery):

$\text{Revenue} = 1\,000 \text{ kWh} \times €0.05/\text{kWh} = €50/\text{year}$

With battery – annual saving from self-consumption:

Solar energy used via battery: 900 kWh (of 1 000 kWh excess)

Battery losses (10 %): $900 \times 0.10 = 90 \text{ kWh lost}$

Net energy available from battery: $900 \times 0.90 = 810 \text{ kWh}$

Saving from avoided grid purchase: $810 \text{ kWh} \times €0.30 = €243/\text{year}$

Lost feed-in income: $900 \text{ kWh} \times €0.05 = €45/\text{year}$

Net annual benefit: $€243 - €45 = €198/\text{year}$

Simple payback time:

$\text{Payback} = €3\,500 / €198/\text{year} \approx 17.7 \text{ years}$

A payback time of nearly 18 years is at the upper limit of what is financially attractive (most home batteries are expected to last 10–15 years). This illustrates exactly why the lesson notes that home battery investment is uncertain. Additional factors not captured: (1) electricity prices may rise significantly (shortening payback); (2) feed-in tariffs may be further reduced or eliminated by regulation (increasing the benefit of self-consumption); (3) battery capacity degrades over time, reducing annual savings; (4) some suppliers quote system cost excluding inverter/charger (€500–1 000 extra); (5) if the household trades on the spot market

(multiple cycles per day), the revenue may be higher. The large gap between the current feed-in tariff (€0.05) and the grid purchase price (€0.30) is the fundamental driver making self-consumption valuable.

Answer – Exercise 10

Calculation

Neighbourhood battery – peak shaving

Actual simultaneous peak:

$$P_{\text{actual}} = 50 \text{ households} \times 3.5 \text{ kW} \times 0.60 = 105 \text{ kW}$$

$$\text{Theoretical maximum: } 50 \times 3.5 = 175 \text{ kW}$$

$$\text{Diversity gain: } 175 - 105 = 70 \text{ kW}$$

Energy needed from battery during 30-min, 120 kW peak:

$$\text{Grid limit: } 100 \text{ kW} \rightarrow \text{battery must supply: } 120 - 100 = 20 \text{ kW}$$

$$\text{Duration: } 30 \text{ min} = 0.5 \text{ h}$$

$$\text{Energy from battery: } 20 \text{ kW} \times 0.5 \text{ h} = 10 \text{ kWh}$$

50 kWh battery is sufficient (10 kWh << 50 kWh capacity)

Monthly saving from peak demand tariff:

$$\text{Peak reduction: } 120 \text{ kW} \rightarrow 100 \text{ kW} = 20 \text{ kW reduction}$$

$$\text{Monthly saving: } 20 \text{ kW} \times €50/\text{kW} = €1\,000/\text{month}$$

(Assumes battery successfully clips the peak every day of the month)

The €1 000/month peak demand saving is substantial and illustrates why industrial and commercial customers invest heavily in battery storage for demand management. Residential peak demand tariffs are less common in Europe (most households pay a flat energy rate) but are being introduced in some countries. The diversity factor (60 % coincidence) means the grid connection only needs to handle 105 kW rather than 175 kW, saving significantly on grid infrastructure costs. The neighbourhood battery adds further flexibility on top of this built-in diversity.

Section C – Internet Exploration

Answer – Exercise 11

Internet Exploration

Reference: <https://www.iea.org/energy-system/low-emission-fuels/electrolysers> |
<https://www.iea.org/reports/global-hydrogen-review-2023>

Global electrolyser capacity: as of 2024/2025, global installed electrolyser capacity had reached several GW (check the IEA page for the exact current figure, as this is growing rapidly – it was approximately 1–1.5 GW in 2023, up from < 0.5 GW in 2020). China dominates new installations, followed by Europe (particularly the Netherlands, Germany, and Spain). The EU's REPowerEU plan targets 10 GW of domestic electrolysers by 2025 and 40 GW by 2030.

Green hydrogen cost calculation:

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Electricity cost contribution:  
= 55 kWh/kg H2 × €0.04/kWh = €2.20/kg H2  
Total green H2 cost (typical 2024): approximately €4–8/kg  
Electricity = €2.20 out of €4–8 total → roughly 28–55 % of total cost  
Grey H2 (from natural gas): approximately €1–2/kg
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The electricity cost makes up the largest single share of green hydrogen cost, confirming the lesson's statement. At €0.04/kWh (cheap renewable electricity), green hydrogen at €4–6/kg is approaching but has not yet reached cost parity with grey hydrogen. Real example project: students may find projects such as the NEOM / ACWA Power / Air Products project in Saudi Arabia (4 GW electrolysis, alkaline, producing ammonia for export), the HyCC Djewels project in the Netherlands (200 MW PEM, green hydrogen for Nouryon chloralkali plant), or the Hy2B project in Portugal. Specific details should be verified at the time of the exercise.

Go deeper: <https://www.iea.org/energy-system/low-emission-fuels/electrolysers> |
<https://www.iea.org/reports/global-hydrogen-review-2023>

Answer – Exercise 12

Internet Exploration

Reference: <https://www.cleanenergyreviews.info/blog/home-solar-battery-cost-guide> |
<https://www.iea.org/energy-system/electricity/grid-scale-storage>

Home battery prices: as of 2024–2025, home battery system prices (including installation) have continued to fall. Installed system costs in Europe are approximately €500–900/kWh of usable storage capacity (check the current Clean Energy Reviews guide for exact figures). The lesson chart from August 2021 showed costs of approximately \$0.20–0.35/kWh per day (over 10 years), which corresponds to roughly \$700–1 200/kWh of installed capacity. Prices have generally continued to fall, driven by falling lithium-ion cell costs from China.

Community battery example: Australia's 'Virtual Power Plant' programmes (e.g. SA Power Networks, AGL) have deployed community-scale batteries in several suburbs. In Europe, the Buurtbatterij Rijsenhout project shown in the lesson slide is a Dutch example – a neighbourhood battery in Haarlemmermeer serving local solar PV owners for peak shaving and grid support. In the UK, various projects under the 'Local Energy' Ofgem programme have deployed community batteries.

EV charging chicken-and-egg: a similar dynamic existed for EV public charging infrastructure in the early 2010s. Few EVs on the road meant low revenue for charging station operators, discouraging investment in infrastructure. Simultaneously, range anxiety (fear of being

unable to find a charger) deterred consumers from buying EVs. The situation was resolved through: (1) government subsidies and mandates for charging infrastructure; (2) manufacturer investment in proprietary networks (Tesla Supercharger); (3) growing EV sales creating sufficient demand; (4) regulatory requirements for charging points in new buildings and car parks. The key difference from hydrogen is that EV charging infrastructure is far cheaper per unit to install than hydrogen refuelling stations, lowering the barrier to entry.

Go deeper: <https://www.cleanenergyreviews.info/blog/home-solar-battery-cost-guide> | <https://www.iea.org/energy-system/electricity/grid-scale-storage>

Section D – Home Experiments

Answer – Exercise 13



Home Experiment – Electrolysis of Water

Expected observations:

Observation	Anode (+)	Cathode (–)
Bubble rate	Moderate	Fast (twice as many bubbles as anode)
Relative volume	Smaller (1 volume O ₂)	Larger (2 volumes H ₂)
Litmus test	Red litmus may turn blue (if O ₂ /Cl ₂ present); solution acidifies slightly	Blue litmus may turn red near electrode (local acidity)
Gas produced	Oxygen (O ₂) or small amounts of Cl ₂ if salt is used	Hydrogen (H ₂)

Note: if salt (NaCl) is used as the electrolyte, some chlorine gas may also be produced at the anode (chloralkali reaction) – you may notice a faint chlorine smell. If baking soda (NaHCO₃) is used, only oxygen is produced at the anode. This is why baking soda is the safer choice for a home experiment.

Bubble ratio: the overall reaction is $2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2$. For every 1 molecule of O₂ produced (anode), 2 molecules of H₂ are produced (cathode). Students should observe roughly twice as many bubbles at the cathode – this directly confirms the stoichiometry of the reaction.

Energy conversion chain: Electrical energy (from the 9 V battery) → Chemical energy (stored in H₂ and O₂ molecules, separated by the water). If the gases were later combusted or fed into a fuel cell, the chain would continue: Chemical energy → Heat/Electricity.

Why no membrane is needed at lab scale: in a small beaker, the gases bubble up and escape into the air before they can mix in dangerous concentrations. In a large industrial system, however, the volumes of gas are enormous and any mixing would create an explosive atmosphere throughout the system. The membrane prevents this by physically separating the two compartments. In an alkaline electrolyser, KOH (potassium hydroxide) is the electrolyte because it is highly conductive (high ion concentration), relatively inexpensive, and provides the alkaline environment needed for the electrode reactions.

Go deeper: <https://www.youtube.com/watch?v=yWWYiDTVbRY> (hydrogen storage) | https://en.wikipedia.org/wiki/Electrolysis_of_water

Answer – Exercise 14



Home Experiment – Battery Discharge Measurement

Expected observations and calculations:

Voltage curve shape: a fresh alkaline AA battery starts at ~1.55–1.6 V open circuit and drops slowly to about 1.2–1.3 V under load during most of its discharge life. Near the end of charge, the voltage drops more steeply and quickly falls below 1.0 V. The curve is not linear – it shows a long flat plateau followed by a steep drop. This is characteristic of alkaline batteries and reflects the way the zinc anode is consumed: for most of the discharge, the electrochemical potential is maintained by the electrode reactions; near the end, the active material is depleted and internal resistance rises.

Capacity estimate:

Example calculation (typical AA alkaline at moderate load):

Load resistor: 68 Ω (gives ~22 mA at 1.5 V)

Average current measured: ~20 mA (voltage drops during discharge)

Time to reach 1.0 V: approximately 100–120 hours at this low load

Capacity = 20 mA $\times$ 110 h = 2 200 mAh

Rated capacity (typical AA alkaline): 1 800–2 850 mAh

At higher loads (e.g. 100–300 mA for a torch bulb):

Time to 1.0 V: approximately 8–10 h

Capacity = 200 mA $\times$ 9 h = 1 800 mAh (lower than rated – Peukert effect)

Students' measured values may differ from the rated capacity because: (1) the higher the current drawn, the less total capacity the battery delivers (Peukert effect); (2) temperature affects battery performance; (3) the battery may have already been partially discharged.

Energy stored:

Theoretical energy content of AA alkaline:

$$E = 1.5 \text{ V} \times 2.5 \text{ Ah} = 3.75 \text{ Wh}$$

Rechargeable vs. disposable lifetime energy throughput:

Alkaline AA (disposable): 3.75 Wh $\times$ 1 use = 3.75 Wh total lifetime

Li-ion AA-equivalent (rechargeable, 500 cycles):

$$E_{\text{total}} = 3.75 \text{ Wh} \times 500 = 1\,875 \text{ Wh total lifetime}$$

Ratio: 1 875 / 3.75 = 500 $\times$ more energy per rechargeable battery

The environmental and economic case for rechargeable batteries is overwhelming: a single rechargeable cell delivers the equivalent energy of 500 disposable cells over its lifetime, generating a fraction of the waste. This connects directly to the lesson's discussion of

lithium-ion technology as the key enabler of modern portable electronics and electric vehicles.

Go deeper: <https://batteryuniversity.com/article/bu-501-basics-about-discharging> | https://en.wikipedia.org/wiki/Alkaline_battery

References & Resources for Further Study

- IEA – Electrolysers: <https://www.iea.org/energy-system/low-emission-fuels/electrolysers>
- IEA – Global Hydrogen Review: <https://www.iea.org/reports/global-hydrogen-review-2023>
- IEA – Grid-scale storage: <https://www.iea.org/energy-system/electricity/grid-scale-storage>
- Wikipedia – Electrolysis of water: https://en.wikipedia.org/wiki/Electrolysis_of_water
- Wikipedia – Alkaline battery: https://en.wikipedia.org/wiki/Alkaline_battery
- Battery University – Battery discharge: <https://batteryuniversity.com/article/bu-501-basics-about-discharging>
- Clean Energy Reviews – Home battery cost guide: <https://www.cleanenergyreviews.info/blog/home-solar-battery-cost-guide>
- Khan Academy – Electrochemistry: <https://www.khanacademy.org/science/ap-chemistry/electrochemistry-ap>
- The Engineering Mindset – Hydrogen fuel cells: <https://theengineeringmindset.com>
- Energy Observer vessel: <https://www.energy-observer.org/about/vessel>
- Hydrogen storage video: <https://www.youtube.com/watch?v=yWWYiDTVbRY>