Danish Energy Agency

Technology Brief

Updated chapter for the production of hydrogen via electrolysis

The Danish Energy Agency published an updated Technology Catalogue chapter for the production of hydrogen through electrolysis in August 2026. The revision updated the expectations surrounding investment costs for electrolysers that have changed significantly since 2023, when this chapter was last updated.

Along with cost updates and clearer system boundaries (components included and excluded in the cost formation), the chapter now differentiates between pre-fabricated and chemical plant archetypes, it includes extended considerations regarding flexible operation, and an updated section on offshore electrolysis along with its own datasheets, as some of the most significant changes.

Major changes in updated Technology Catalogue

Investment costs

Based on detailed project design and in-depth knowledge of concrete projects accumulated through the last couple of years, there is now a more detailed understanding of the technical and economical prerequisites for the development of green hydrogen plants. It became evident that the complexity of establishing green hydrogen plants involves different sub-components, in greenfield projects, with a lower level of standardisation than previously expected, which was likely not fully understood or acknowledged a couple of years ago.

		2025		2030		2040		2050	
		Previous	Current	Previous	Current	Previous	Current	Previous	Current
AEC	Investment	1.022	1.254	642	990	496	806	350	652
	Difference		23%		54%		63%		86%
PEMEC	Investment	1.139	1.765	759	1.250	584	851	409	563
	Difference		55%		65%		46%		38%
SOEC	Investment	1.518	2.024	905	1.358	759	868	584	532
	Difference		33%		50%		14%		-9%

Figure 1: Investment costs (€/kW) comparison for 100MW electrolysis chemical plants in the 2023 update and current chapter[1]

In practice, this translates into generally increased investment costs compared to the previous iteration of the chapter. The differences are not the same across all technologies, as illustrated in Figure 1. Alkaline electrolysis (AEC) costs appear overly optimistic in the old iteration, particularly towards 2050, while proton exchange membrane electrolysis (PEMEC) costs appear underestimated across all projected years. Solid-oxide electrolysis (SOEC) remains an expensive technology

[1] All costs adjusted to 2025€ using the Danish Consumer Price Index

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although the cost differences to the previous chapter are less pronounced notably for 2040 and 2050.

The cost distribution across an electrolysis plant also changed significantly, being the most visible for the cost estimates in this decade. Figure 2 shows an example for a 100 MW PEMEC, where it is primarily the indirect costs that drive the price increase. The indirect costs refer to the EPC (Engineering, Procurement and Construction) costs, and exclude contingency and owner's cost. However, they still show that establishing electrolyser plants is more challenging than anticipated. In 2023, when the chapter was last revised, large projects were at an early stage, so few thorough feasibility studies did exist, which underestimated system complexity and spending cost.

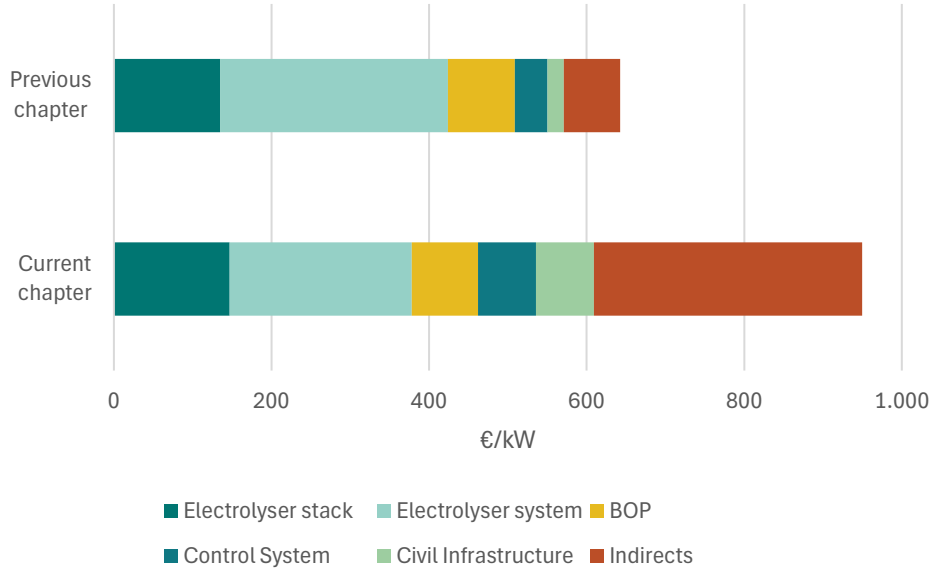

Figure 2: Cost distribution in a 100 MW PEMEC chemical plant for 2030 in the 2023 update and current chapter

The high EPC project costs mainly refer to chemical-plant concepts, where electrolysis plants are built on site as bespoke chemical process facilities and with a limited scope of supply from the Original Equipment Manufacturer (OEM). On the other hand, pre-fabricated plants aim to standardise more of the scope of supply and thus reduce the EPC costs. Elements in the chemical-plant configuration across the balance-of-system and part of balance-of-plant are brought inside the unit and delivered by the unit OEM as part of an integrated product. While the chapter differentiates between the two concepts, it does not include separate data sheets for the pre-fabricated concept due to its novelty and limited suppliers for such integrated units.

Levelised cost of hydrogen

The updated knowledge shows that previous techno-economic plant assumptions were too optimistic in the short-term, among which overall plant efficiency. On the other hand, the updated lifetime of the plants is assumed longer and the O&M is expected reduced in the long-term. Figure 3 shows an example of how cost estimates (LCoH) for producing green hydrogen in a 100 MW AEC chemical plant have changed since the 2021 and 2023 updates. While efficiency, lifetime and O&M costs have their share of influence on the increase, the general increase is primarily determined by the overnight costs, that became higher due to increased project complexity, inflation, material costs and not the least, by a more moderate market deployment than previously expected.

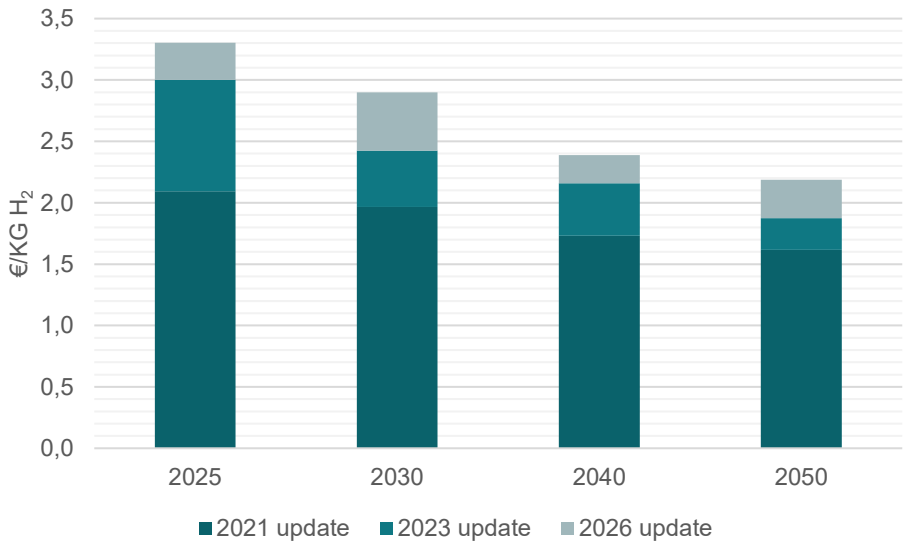

Figure 3: LCOH cost increase in a 100 MW AEC plant [2]

The new chapter has also been strengthened regarding system boundaries, i.e. what is assumed to be included in an electrolysis plant and what is not. Therefore, it should be noted that the costs in this chapter do not include HV/MV transformers, rectifiers or hydrogen storage. Nor, as previously mentioned, include contingency and owner costs, which are expected to increase the costs significantly and especially for projects within this decade.

Flexibility

A more detailed description of electrolyser flexibility is added to the chapter. The ramp up and ramp down rates are now quantified for each electrolyser technology together with degradation rates. In general, all technologies can operate dynamically, but the flexible operation shortens the stack's lifetime. Frequent load

[2] Interest rate 3,5%, Inflation from 2020€ to 2025€: 16,8%, Electricity price is based on the average cheapest 5000 hours in DK1 and DK2 (242 DKK/MWh) in year 2035 based on Klimastatus og fremskrivning 2026.

changes and start-stop cycles accelerate degradation, as do operating temperature and water quality. A stack is generally considered to have reached end-of-life once its performance has fallen by about 10%, at which point refurbishment or replacement is required. This matters most for systems coupled to variable renewable generation, where the fluctuating supply forces dynamic operation and repeated cycling. Some of electrolysers' degradation mechanisms can be reversible, while other degradation phenomena are irreversible.

Flexible operation can improve electrolyser efficiency at partial load. Stacks are generally more efficient at lower current densities**.** The highest system efficiency is typically reached around 50% load. Oversizing plant capacity relative to upstream substation power could therefore provide efficiency gains, although these are partly offset by higher CAPEX and are typically modest, around 5% compared with nominal operation.

Offshore electrolysis

As novelty, the section on offshore electrolysis is now expanded with new datasheets for producing hydrogen at the sea. Two concepts are included (shown in Figure 4):

- 100 MW PEMEC with offshore centralised configuration: electrolysis is performed at large scale on a central offshore platform that aggregates the electricity from several wind farms.

- 10 MW PEMEC with offshore decentralised configuration: electrolysis is placed at or integrated with individual wind turbines, so that hydrogen production is distributed across many installations.

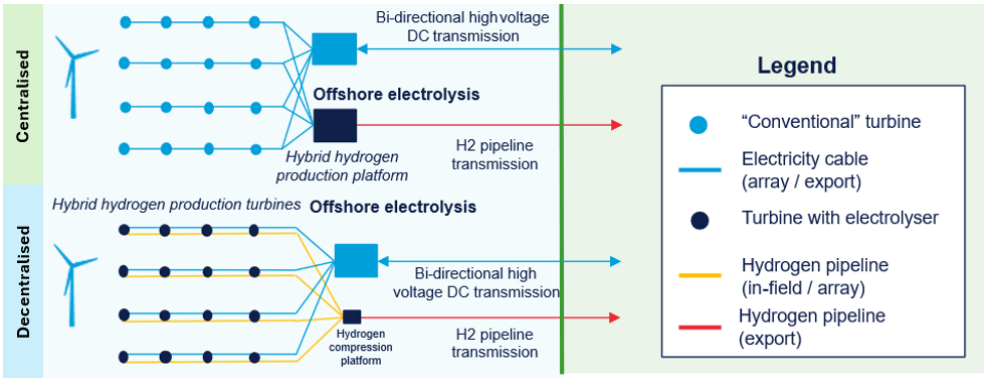

Figure 4: Two offshore hydrogen production concepts. Centralised production is illustrated at the top and decentralised production is illustrated at the bottom.

The technology data is derived from a study done for the Danish Energy Agency that quantified technical and economic prerequisites for the production and transport of hydrogen at sea in 2040 and 2050. In the analysed cases, both configurations include pipeline and electricity connection to land, but the datasheets

refer only to the electrolysis plants and exclude the energy transport and offshore wind costs.

In general, the CAPEX for production of hydrogen at sea is higher than the onshore equivalent, mainly due to the marinization against corrosion, platforms, foundations, and other marine installations. The offshore electrical equipment is also driven by stricter design standards, redundancy requirements, and environmental exposure. The technology data is based on a capacity assumed to be located within the Danish Exclusive Economic Zone (EEZ), at a distance of 300 km from shore and at a water depth of approximately 45 m. The distance from the shore and location limits the access for maintenance, which is then reflected in the higher CAPEX, as there are stricter requirements on reliability and availability, which can influence technology selection and system redundancy.

Based on the datasheets, Figure 5 shows how much more expensive such configurations are compared to the onshore electrolysis equivalent, due to the reasons explained above. The costs can decrease significantly over time, but the balance lies in the cost of offshore electricity and the affordability of transporting energy to land, hydrogen pipelines can unlock cheaper energy transport than HVDC cables can.

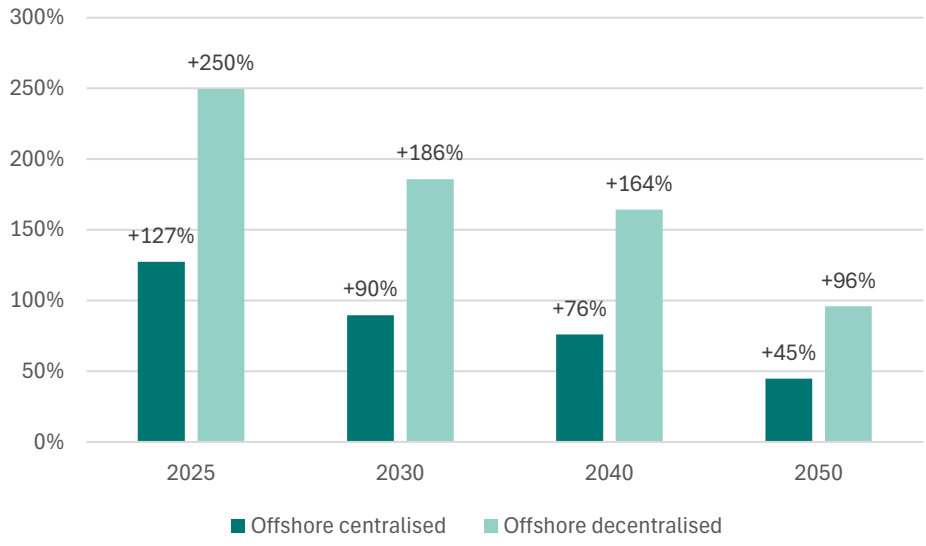

Figure 5: Annualised CAPEX and OPEX for centralised (100MW) and decentralised (10MW) PEMEC offshore configurations compared to an onshore 100 MW PEMEC plant[3]

[3] Interest rate 3,5%, Electricity costs are not included in the calculation.

Perspectives for Denmark

The updated chapter for electrolysis shows higher CAPEX and LCOH compared to the previous iterations of this chapter, both for the price estimates in this decade and towards 2050. This can have lasting effects on the deployment potential in Denmark, which has been apparent in the last 2-3 years through project cancellations, delays or downscaling. Offshore electrolysis can give access to large amounts of wind capacity for hydrogen production, but such offshore infrastructures are and will be affected by high CAPEX, OPEX and other engineering challenges when located so far at sea.

The roll-out of electrolysis capacity is also affected by the increasing potential for electrification in parts of the energy system that were previously ruled out to be electrified, which in the Danish case, could affect the future magnitude of hydrogen export possibilities.