WHITE PAPER · TECHNOLOGY ASSESSMENT · GREEN HYDROGEN

Assessing electrolysers: from kWh/kg to return on investment

A six-step method for comparing electrolyser technologies, with shiptown's H-Lyzer as a worked example

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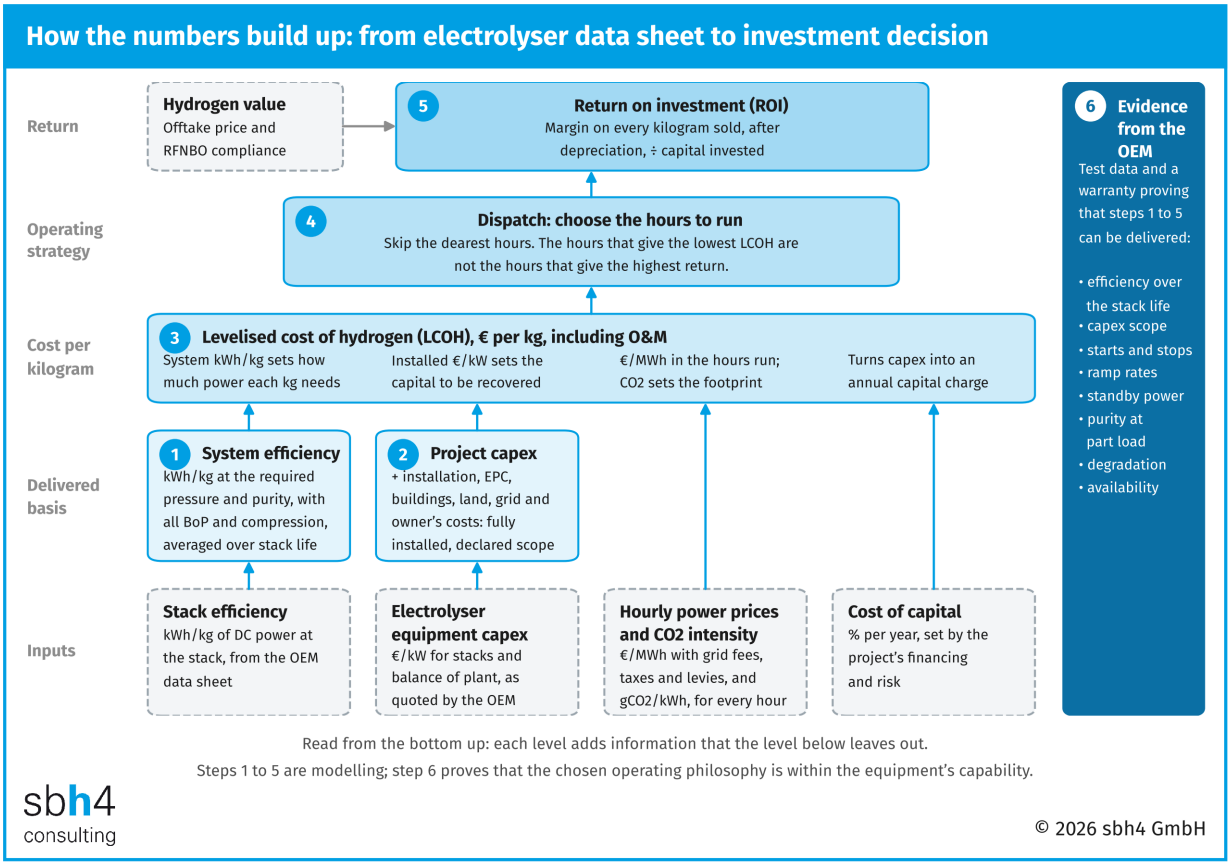
21 November 2026 · Worked example: 100 MW plant in Germany · day-ahead prices October 2023 – September 2026 · 10%/yr capital charge



Methodology note based on public sources and sbh4's techno-economic modelling. Company statements are reported as such. Not investment advice; see the disclosure on page 2.

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WORKED EXAMPLE shiptown

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Disclosure. Stephen B. Harrison of sbh4 consulting is Strategic Advisor to shiptown A/S, as listed in shiptown's investor presentation of October 2026. Readers should take this relationship into account. [To complete before release: nature of any remuneration, options or shareholding.]

This paper sets out a method that applies to any electrolyser technology. shiptown's H-Lyzer is used as a worked example alongside three commercial benchmarks, with all four assessed on identical assumptions. shiptown's technical figures are company statements and targets, reported as such.

Basis of the numbers. Worked-example figures come from sbh4's white paper *Flexible electrolysis for low-cost green hydrogen* (November 2026). Unless stated otherwise: a 100 MW plant (rectifier AC input); hydrogen at 30 bar(g) or more; levelised cost of hydrogen (LCOH) in € per kg at the plant outlet; an annual capital charge of 10% of fully installed capex; power bought in the cheapest hours of each year at day-ahead prices from October 2023 to September 2026, plus 2026 grid fees, taxes and levies. Commercial systems use vendor datasheet efficiencies and sbh4 estimates of fully installed capex. Electrolyser O&M, stack replacement, water, storage, tax and subsidies are excluded.

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SECTION 1

Executive summary

+2 kWh/kg
extra electricity to compress hydrogen from an atmospheric electrolyser to 30 bar [2]

40–50%
of total capex on large projects is installation and EPC, not equipment [9]

€6.01/kg
LCOH of the incumbent with the lowest kWh/kg: the highest of three at 4,000 h in Germany [3]

4,000 vs ≈8,100 h
lowest LCOH versus highest return, 100 MW in Germany at €7/kg [3]

Key findings

- **Measure at the delivery point.** Stack efficiency is not a meaningful benchmark. Compare system kWh/kg at the site boundary, at the pressure and purity the process needs, averaged over the life of the stack. Compression alone is enough to reverse the ranking of two alkaline systems in sbh4's benchmark.
- **Count every layer of capex.** The stack is typically 20 to 45% of project capex and installation and EPC often 40 to 50%. Installed costs range from €550/kW for Chinese electrolysers in China to €2,400/kW for electrolysers made and installed outside China [10].
- **Combine power and capital in the LCOH.** kWh/kg ignores capex and the cost of capital. In the benchmark, the PEM system with the lowest kWh/kg of the three incumbents has the highest LCOH.
- **Optimise the hours.** With volatile power prices, LCOH has a minimum that depends on capex, efficiency and market: 4,000 hours for the H-Lyzer in Germany, 5,500 hours for a pressurised alkaline system and 6,500 to 7,000 hours in the northern Nordic zones.
- **Decide on return on investment (ROI).** The lowest LCOH is not the highest ROI. In Germany at €7/kg, a 100 MW plant earns a pre-tax ROI of 23% at the LCOH optimum and almost 35% at 8,000 hours.
- **Demand evidence.** The original equipment manufacturer (OEM) must show that the electrolyser can operate as the model assumes: cycling, ramping, standby, purity at part load, degradation and a warranty that covers the duty.

> **Implication for developers, lenders and offtakers.** Ask for system efficiency and fully installed capex on a declared scope. Model LCOH against real hourly prices for the site, choose the operating strategy on ROI, and make sure that the OEM's test evidence and warranty match that strategy. A technology that wins on any single metric can still lose the investment case.

SECTION 2

Why one number is not enough

Electrolysers are usually marketed and compared on one number: the kilowatt-hours of electricity needed to make a kilogram of hydrogen. It is a necessary number, but it is not a sufficient one. It says nothing about the condition of the hydrogen, the capital needed to build the plant, the cost of that capital, the hours the plant will run or what the hydrogen will earn.

A robust assessment therefore builds up in six steps from four sets of inputs: stack efficiency, electrolyser equipment capex, hourly power prices and CO2 intensity, and the cost of capital (Figure 1). Each step adds information that the one below it leaves out. Stopping early gives a ranking, not a decision.

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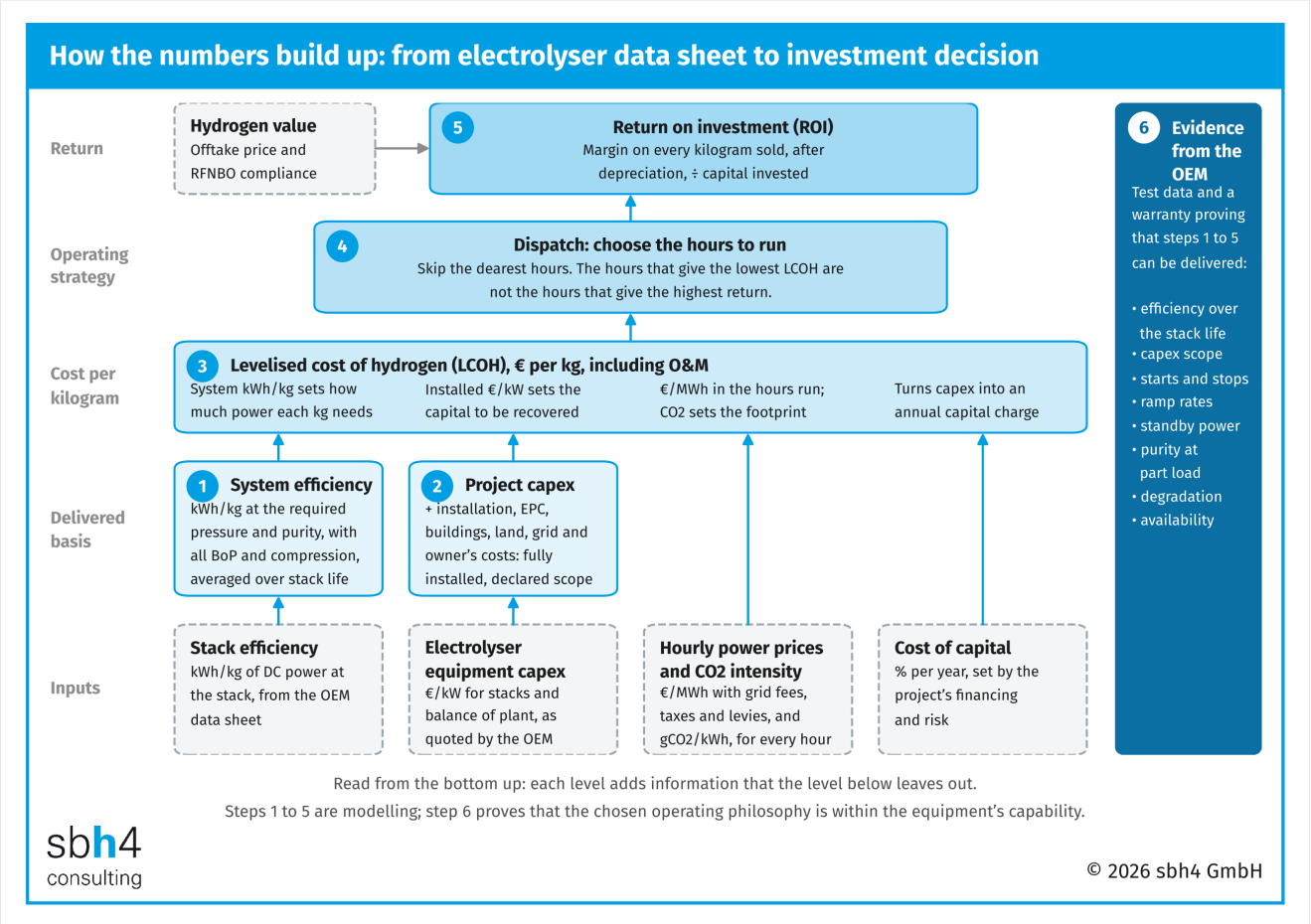

Figure 1. How the numbers build up from electrolyser data sheet to investment decision: four sets of inputs feed six assessment steps. Steps 1 to 5 are modelling; step 6 is evidence that the chosen operating philosophy is within the equipment's capability.

SECTION 3

Step 1: System efficiency at the delivery condition

Efficiency can be quoted at three boundaries. The **stack** takes direct current and delivers wet hydrogen at its own pressure. The **electrolyser system** adds the transformer and rectifier, pumps, cooling, gas/liquid separation and controls, and is fed with alternating current. The **plant**, at the site boundary, also includes purification and compression to the condition that the process needs, standby loads and any hydrogen lost in purging or dryer regeneration. Siemens Energy stresses that the boundary must also define water quality, waste heat, power quality, gas quality and pressure at every interface [1].

Only the last boundary describes hydrogen that a refinery, a biorefinery or an e-fuels plant can use. Electric Hydrogen estimates that efficiency figures which leave out some of the expected losses can be overstated by 10 to 20%, and that an electrolyser producing hydrogen at close to atmospheric pressure needs about 2 kWh/kg more to reach 30 bar [2].

Compression can change the ranking

Table 1 compares four systems for hydrogen delivered at 30 bar(g) or more. The atmospheric alkaline system is rated at 54.5 kWh/kg, better than the 55.6 kWh/kg of the pressurised alkaline system. Once its hydrogen has been compressed, it needs 56.3 kWh/kg and falls behind.

System	Outlet bar(a)	Electrolyser kWh/kg	Compression kWh/kg	At 30 bar(g) kWh/kg	Efficiency % LHV
PEM, atmospheric outlet	1.05	52.2	1.93	54.1	61.6%
Alkaline, atmospheric outlet	1.3	54.5	1.80	56.3	59.2%
Alkaline, pressurised	31	55.6	0.00	55.6	59.9%
H-Lyzer (company statement)	36	44.0	0.00	44.0	75.8%

Table 1. Electricity per kg of hydrogen at 30 bar(g) or more. Vendor datasheets for Siemens Energy Elyzer P-300, thyssenkrupp nucera scalum and John Cockerill DQ1000; shiptown company statement. Purity: vendors quote more than 99.9%, for some systems after their own purification stage (DQ1000: 99.8% before, 99.999% after). Compression: four-stage reciprocating compressor, 75% isentropic and 95% motor efficiency. LHV 33.3 kWh/kg. Source: [3], Table 1.

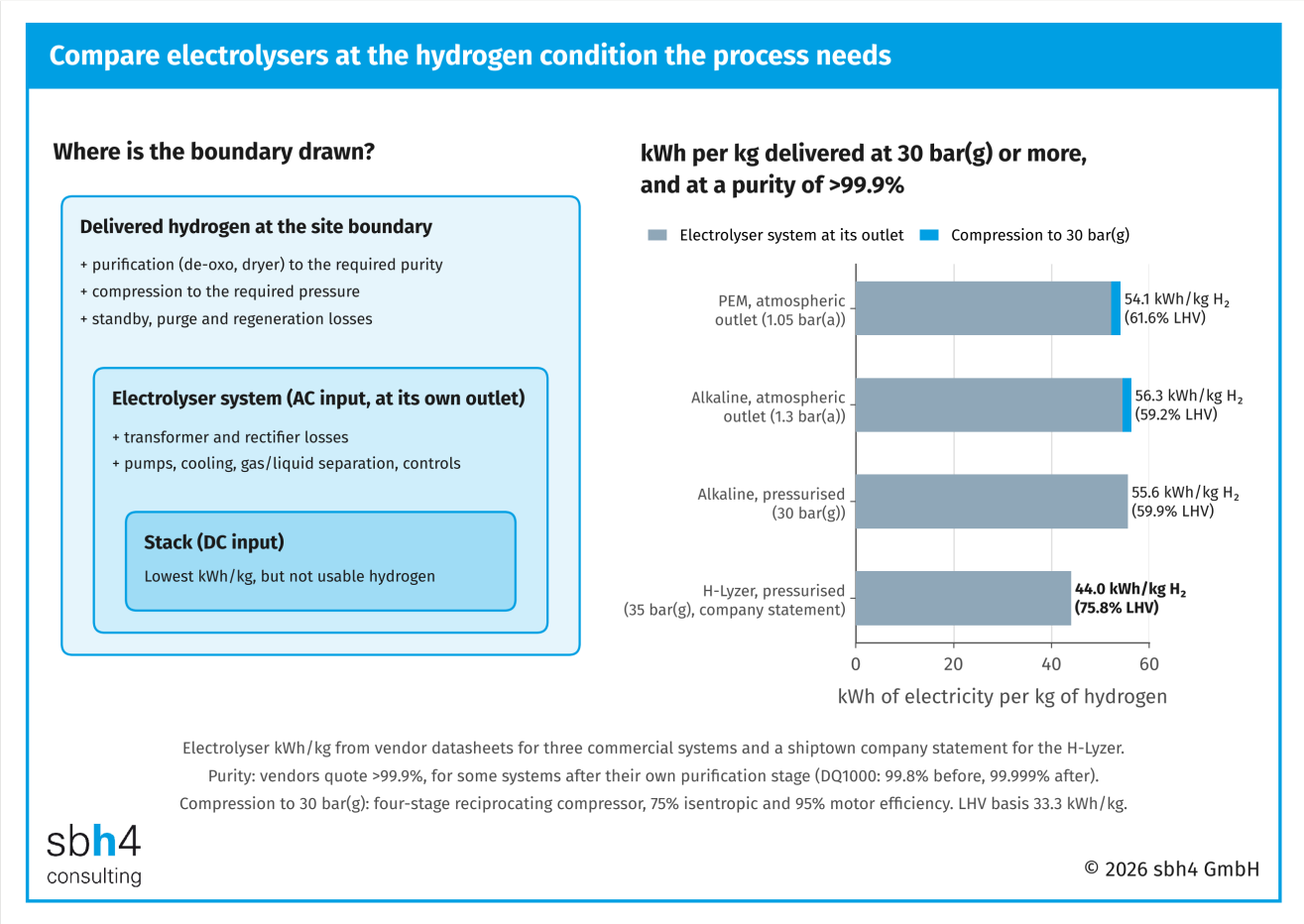

Figure 2. Where the boundary is drawn, and electricity per kg delivered at 30 bar(g) or more and above 99.9% purity for four electrolysers. Source: [3]; purity from vendor literature.

Purity, degradation and the life of the stack

Where the process needs better than 99.9% purity, a catalytic de-oxo unit and a dryer are usually added [4]. Both consume power, and dryers are regenerated with a share of the product hydrogen, so their design decides whether that gas is recovered or lost [5]. Their energy and any losses belong inside the boundary.

Stacks also degrade, and consumption rises over their life. The figure that belongs in a financial model is the average consumption over the stack life, at the delivery condition, under the intended operating profile. The EU Joint Research Centre (JRC) has published harmonised accelerated stress-testing protocols to assess that degradation on a common basis [6].

Worked example: designing out the balance of plant

shiptown states that its H-Lyzer delivers hydrogen at 35 bar(g) and more than 99.9% purity, measured at the site boundary, at 44 kWh/kg, with no compressor and no cooling water [3]. Figure 3 shows the balance-of-plant equipment of a conventional system that the H-Lyzer stack is designed not to need. shiptown reports 90% system efficiency (HHV basis), about 43.8 kWh/kg, on a five-cell stack. The figure must now be demonstrated at module scale, including rectifier and auxiliary loads.

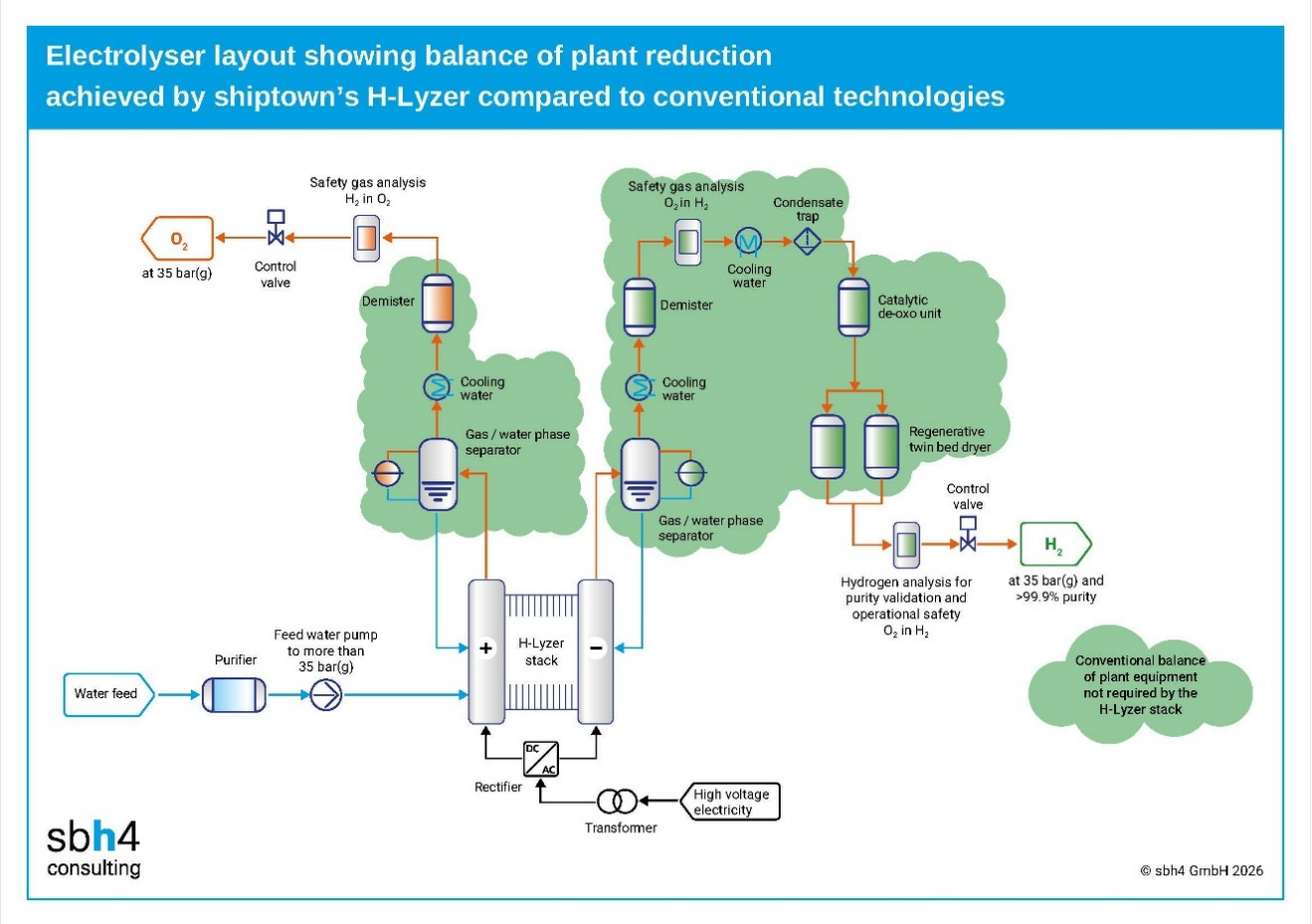

Figure 3. Electrolyser layout showing the conventional balance-of-plant equipment (shaded) that shiptown states is not required by the H-Lyzer stack. Company design information; sbh4 graphic.

> **What to ask the OEM at step 1.** kWh/kg with AC input at the site boundary, at the stated pressure and purity; at nominal and part load; at beginning of life and averaged over the stack life; including standby power and any hydrogen lost in purging or dryer regeneration; and how surplus heat is rejected, with the auxiliary power that this needs.

SECTION 4

Step 2: Fully installed capex

Capex figures suffer from the same boundary problem. A quote for stacks, or for stacks and their balance of plant (BoP), is not the cost of a project. The European Clean Hydrogen Observatory splits electrolyser capex into four layers: the stack; BoP, including the rectifier and its transformer, gas/liquid separation, water or lye feed and gas purification; other utilities, including the high-voltage transformer, water treatment, cooling, compression and the control system; and other capex, including land and grid fees, insurance, permitting, feasibility studies, contingency and engineering, procurement and construction (EPC) management [7].

The layers above the stack dominate. Projects surveyed by TNO and reported by the JRC put the stack at 20 to 45% of capex and BoP at 15 to 40%, with the balance in compressors, contingency and other indirect costs [8]. The World Bank puts installation and EPC at 40 to 50% of total capex on large projects, and warns that cost and price information is of limited value because the scope of what is included varies [9].

The International Energy Agency (IEA) shows how wide the spread can be. In 2024, electrolysers made and installed in China cost €550 to 1,100/kW. Installed outside China, Chinese electrolysers cost €1,400 to 2,200/kW once transport and tariffs are added, against €1,850 to 2,400/kW for electrolysers made and installed outside China [10]. The IEA's USD figures are converted at the ECB 2024 average of USD 1.0824 per euro.

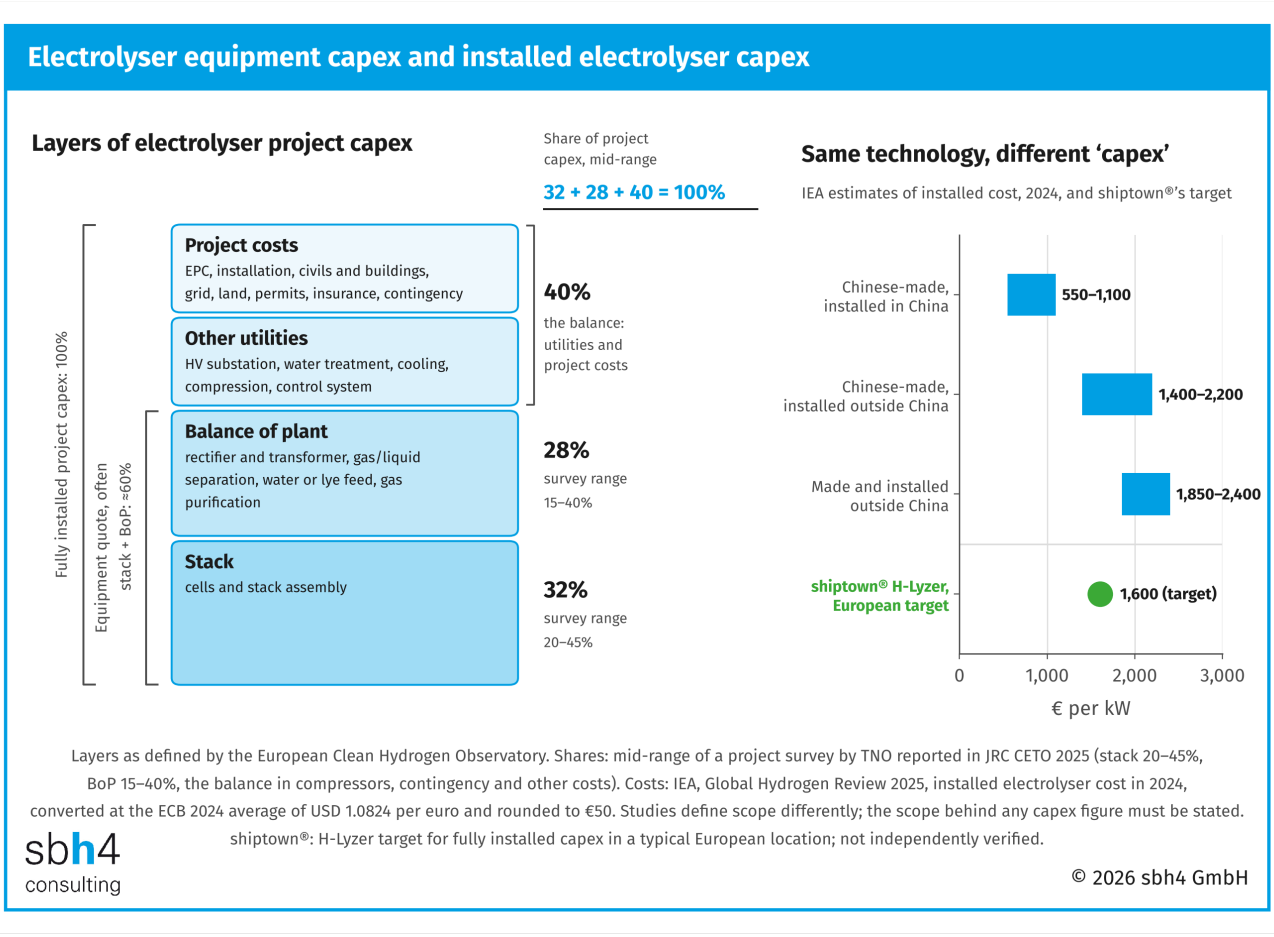

Figure 4. Layers of electrolyser project capex with mid-range shares that add up to 100%, and installed cost by where the electrolyser is made and installed, with shiptown's target for the H-Lyzer (green dot). Sources: [3], [7], [8] and [10].

Designs that remove a layer, such as the compressor or the cooling-water system, therefore save more than the equipment price. In the worked example, the commercial systems are assessed at sbh4 estimates of €2,300 to €2,500/kW fully installed in typical European locations. shiptown targets €1,600/kW on the same basis, derived from its costed bill of materials; that figure has not been independently verified [3].

> **What to ask at step 2.** Fully installed €/kW on a declared scope, split into stack, BoP, utilities, EPC and owner's costs; what is excluded (grid connection, buildings, water treatment, compression, land); the location and year of the estimate; the contingency included; and the delivery condition to which the scope applies.

SECTION 5

Step 3: From kWh/kg to the levelised cost of hydrogen

Electricity and capital are traded against each other. A design that saves kilowatt-hours may cost more to build, and every euro of capex carries a cost of capital. kWh/kg sees only the first of these. The levelised cost of hydrogen (LCOH) brings them together. In its simplest form, with the plant running for N full-load hours per year:

LCOH = capex × capital charge × kWh/kg ÷ N + average power price × kWh/kg ÷ 1,000

with capex in €/kW, the capital charge as an annual fraction, kWh/kg at the delivery condition and the power price in €/MWh. A complete LCOH also adds fixed and variable O&M, stack replacement and water.

Efficiency counts twice in this equation. A lower kWh/kg cuts the electricity bill per kilogram. Because capex is paid per kW of input, it also spreads the capital over more kilograms: a 100 MW plant at 44 kWh/kg produces about 2,273 kg/h, against 1,799 kg/h at 55.6 kWh/kg [3].

The lowest kWh/kg is not the lowest cost

At 4,000 hours per year in Germany, with power at an average of €46.7/MWh, the PEM system uses the least electricity of the three commercial systems: 54.1 kWh/kg at 30 bar(g). However, its fully installed capex of €2,500/kW gives it the highest LCOH of the three, at €6.01/kg. The pressurised alkaline system uses more electricity but costs €2,300/kW, and produces at €5.79/kg (Figure 5) [3].

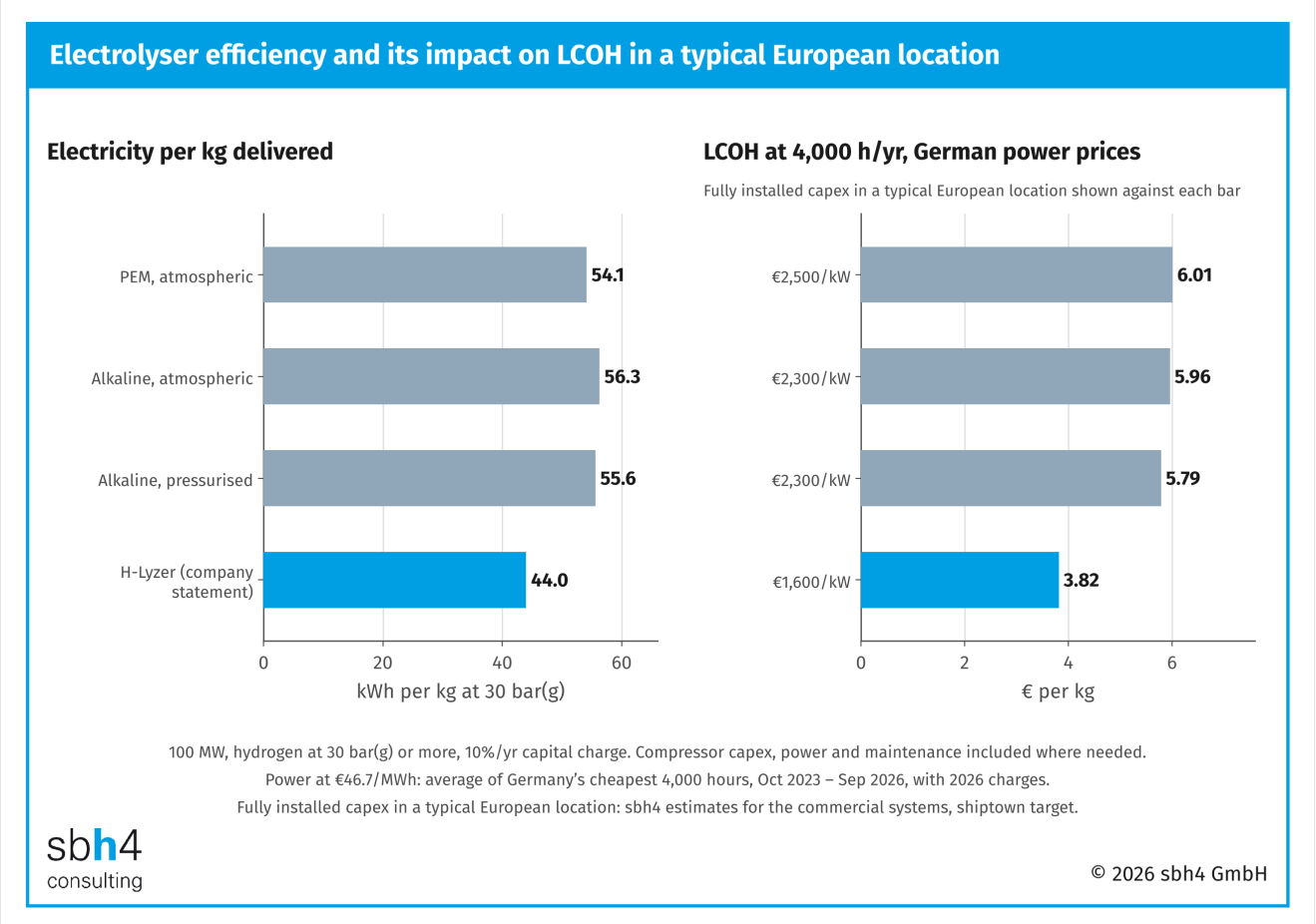

Figure 5. Electrolyser efficiency and its impact on LCOH: electricity per kg at 30 bar(g), and LCOH at 4,000 h/yr with German power prices and fully installed capex for a typical European location. The ranking by kWh/kg and the ranking by LCOH differ. Source: [3], Tables 1 and 3.

The cost of capital matters as much as the capex. Halving the annual capital charge from 10% to 5%, as might apply with public co-financing or low-cost debt, cuts the H-Lyzer's lowest LCOH in Germany from €3.82/kg to €2.53/kg and moves its optimum from 4,000 to 2,000 hours [3].

SECTION 6

Step 4: Dispatch, or choosing the hours to run

An LCOH quoted at a single average power price, or at a fixed 8,000 hours, hides a choice. A flexible electrolyser does not need to buy every MWh on offer. Running only in the cheapest hours lowers the average power price but spreads the capital charge over fewer kilograms. The LCOH therefore has a minimum. At that minimum, the power for the next kilogram costs about the same as the average kilogram, capital charge included.

Where the minimum lies depends on the technology (Figure 6). With German day-ahead prices from October 2023 to September 2026, the H-Lyzer's LCOH is lowest at 4,000 hours, at €3.82/kg. The pressurised alkaline benchmark, with higher capex and higher consumption, reaches its lowest LCOH of €5.66/kg at 5,500 hours [3]. Higher capex pushes the optimum towards more hours; lower capex and higher efficiency make it affordable to skip the dearest ones.

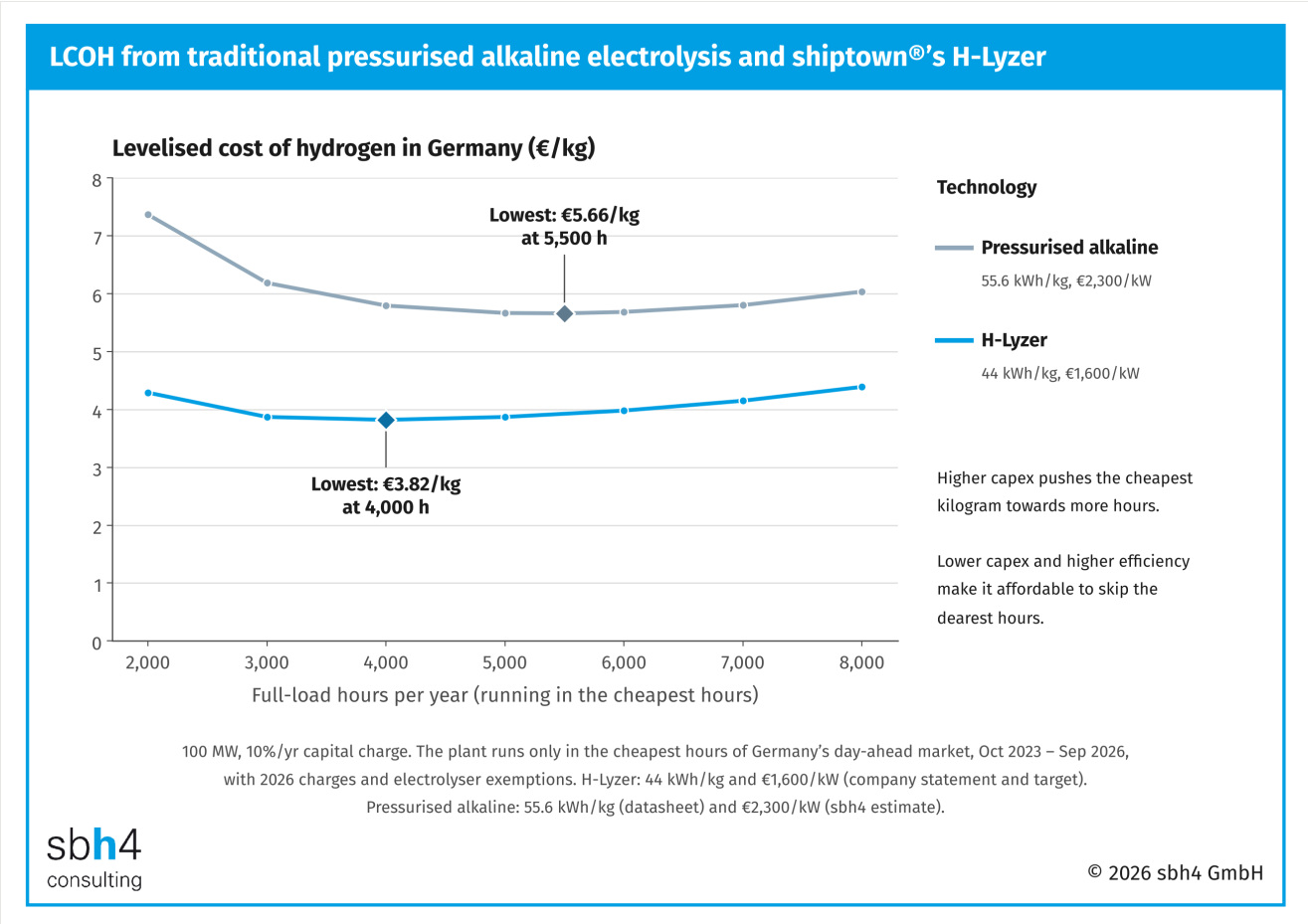

Figure 6. LCOH against annual operating hours in Germany for the H-Lyzer and a pressurised alkaline benchmark. Source: [3], Tables 3, 4 and 6.

It also depends on the market (Figure 7). In Germany and western Denmark, LCOH bottoms out at around 4,000 hours. In northern Sweden and northern Norway, where even the dearer hours are cheap, the H-Lyzer's lowest LCOH is €1.60/kg and €1.54/kg, at 6,500 to 7,000 hours. In Germany the curve is also flat: LCOH stays within 15% of its minimum between 2,000 and 8,000 hours [3].

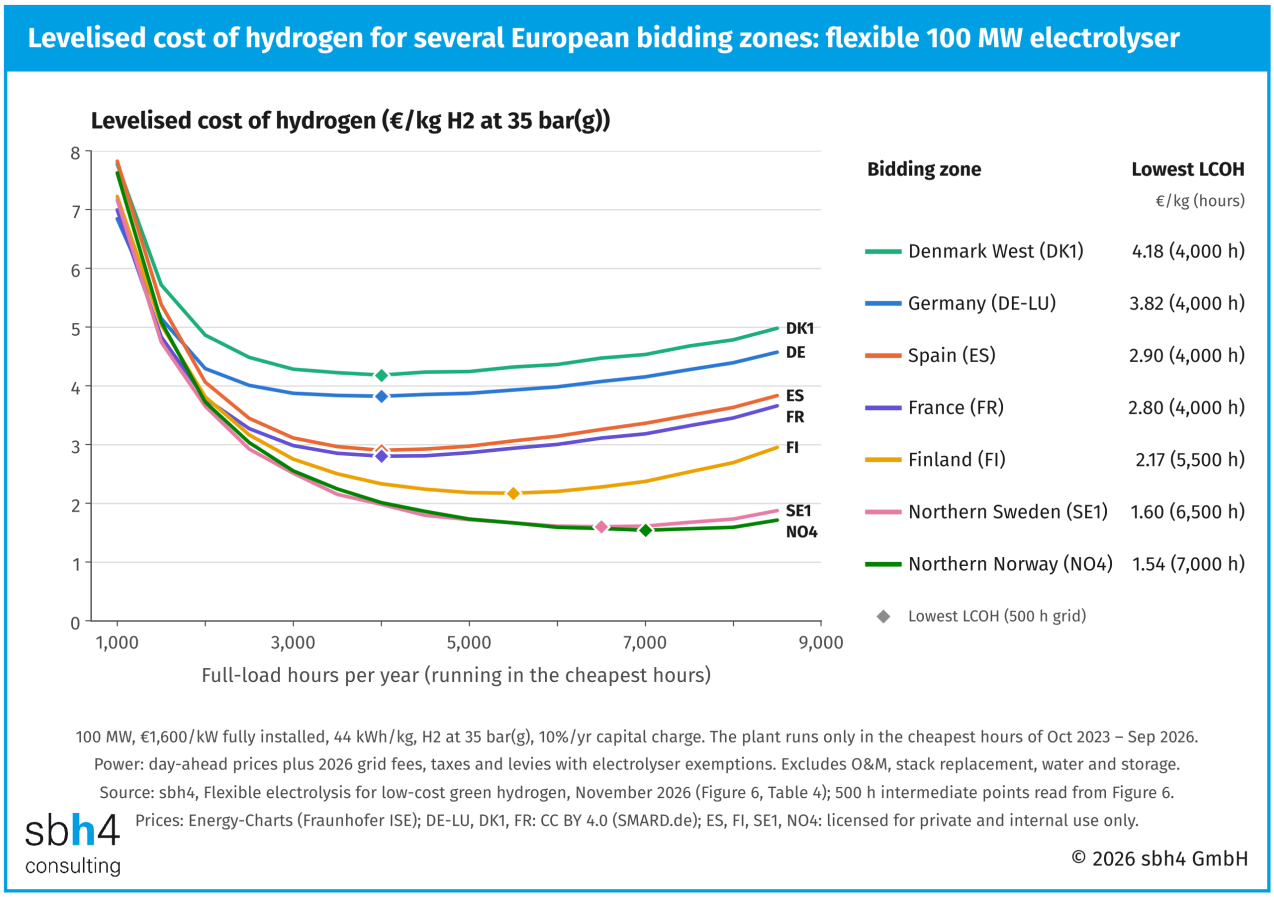

Figure 7. H-Lyzer LCOH by bidding zone when the plant runs only in the cheapest hours of each year. Source: [3], Figure 6 and Table 4.

> **What the model needs at step 4.** Hourly (or 15-minute) prices for the actual bidding zone, with grid fees, taxes and levies, including capacity-based charges that penalise low running hours; the hourly CO2 intensity of the power, which sets the carbon footprint of the hydrogen and must meet EU thresholds for it to count as renewable or low-carbon; the renewable fuel (RFNBO) rules on temporal correlation that apply to the project; and a realistic allowance for imperfect foresight, since a real plant captures somewhat less of the price spread than a model that knows prices in advance.

SECTION 7

Step 5: Return on investment

LCOH is a good yardstick for comparing technologies on identical assumptions. However, it never asks what the hydrogen is worth. Return on investment does, and it gives a different answer.

Table 2 shows a 100 MW H-Lyzer plant in Germany, costing €160 million fully installed and selling hydrogen at an illustrative €7/kg. At 4,000 hours, the point of lowest LCOH, it makes 9,091 tonnes of hydrogen and earns a pre-tax ROI of 23%. At 8,000 hours, LCOH is about 15% higher, but output doubles, profit rises by more than 60% and ROI reaches almost 35%. ROI peaks at about 8,100 hours and then dips (Figure 8).

Annual operating hours	4,000	8,000	8,500
LCOH (€/kg)	3.82	4.39	4.57
Hydrogen output (t/yr)	9,091	18,182	19,318
Profit after 10% capital charge (€m/yr)	29.0	47.4	47.0
Pre-tax ROI	23.1%	34.6%	34.4%
Simple payback (years)	3.6	2.5	2.5

Table 2. 100 MW H-Lyzer plant in Germany at €7/kg. ROI = (revenue − power cost − 20-year straight-line depreciation) ÷ capex. Excludes O&M, stack replacement and tax. Source: [3], Tables 6 and 7 and Figure 7.

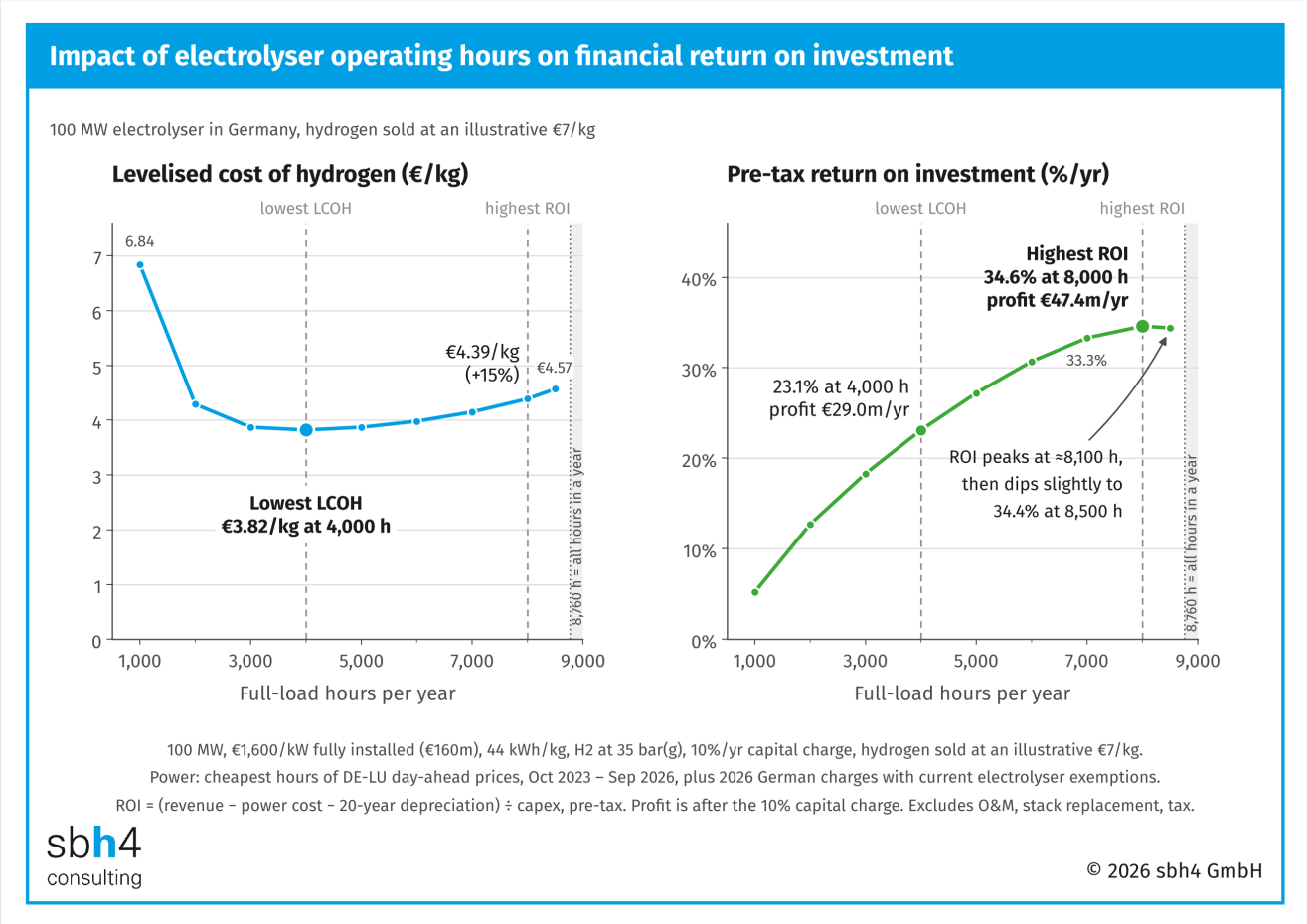

Figure 8. The lowest LCOH and the highest ROI occur at different operating hours. Source: [3].

The reason is simple. Once the electrolyser is built, the capital charge is paid whether it runs or not, so each extra hour costs only the power it consumes. The operator should run whenever the all-in power price is below the hydrogen price divided by the specific consumption: €7/kg ÷ 44 kWh/kg, or circa €159/MWh. At 52 kWh/kg, that threshold falls to around €135/MWh, so efficiency also sets how many hours are worth running.

The ROI optimum also moves with the hydrogen price: 6,500 hours at €5/kg and 8,500 hours at €8/kg, whilst the lowest LCOH stays at 4,000 hours whatever the hydrogen is worth [3]. Whenever hydrogen sells for more than its minimum LCOH, the most profitable operating point lies at more hours than the cheapest kilogram.

These figures exclude O&M, stack replacement and tax. They assume perfect foresight of power prices and today's German grid-fee and levy exemptions, which apply only to plants commissioned by 2029. Stack

replacement intervals are usually set by operating hours, which will trim the advantage of long running times.

SECTION 8

Step 6: Evidence from the OEM

A model is only as good as the equipment's ability to follow it. If the best ROI comes from stopping in the dearest few hundred hours of the year, or from following prices every day, the OEM must show that the electrolyser can do so without harm, and the warranty must cover that duty. Table 3 lists the evidence that turns a modelling assumption into a bankable one. The JRC's harmonised testing protocols, which include dynamic grid-balancing profiles, provide a common framework for these tests [11].

Topic	Why it matters to the model	Evidence to request
Starts and stops	The chosen dispatch may stop and restart the plant daily	Permitted starts per day and per year; logged cycling tests; effect on warranty
Ramp rate and minimum load	Following prices, or providing grid services	Time from standby to full load; minimum stable load; behaviour on sudden loss of power
Standby	Energy used in standby hours, and restart time	Warm and cold standby power; time to hydrogen on specification
Degradation	Consumption rises over life; stack replacement interval	Degradation rate under the proposed duty cycle (µV/h or %/1,000 h); accelerated stress-test results
Purity and pressure	The delivery condition must hold at part load	O2 in H2 and H2 in O2 across the load range; outlet pressure stability; need for a dryer
Warranty and availability	Lenders and insurers need guarantees	Performance, degradation and availability guarantees tied to the operating profile

Table 3. OEM evidence needed to support a flexible operating strategy.

In the worked example, shiptown states that the H-Lyzer tolerates unlimited starts and stops, ramps its electrical input fully in less than 10 seconds and holds warm standby at less than 5% of nominal power, with no noticeable degradation from load-following in laboratory testing so far [3]. Standby energy still belongs in the model: holding a 100 MW plant warm at 5% of rated power uses up to 5 MWh in every standby hour. shiptown reports technology readiness level (TRL) 4 completed, targets TRL 6 in mid-2028 and bankable equipment for 100 MW projects from 2030. Those statements must be proven at scale before lenders will rely on them.

SECTION 9

Putting it together

Each step uses the output of the one before it, so the boundaries must be consistent throughout: the same delivery condition for efficiency and capex, the same scope for every technology, the same price data and the same financing assumptions. A model fit for technology selection should include, as a minimum:

1. system kWh/kg at the site boundary and delivery condition, at beginning of life and averaged over the stack life;
2. fully installed capex on a declared and common scope;
3. LCOH including O&M, stack replacement and water, at a cost of capital that reflects the project's financing;
4. dispatch against hourly prices and CO2 intensity for the site, with all grid fees, taxes and levies;

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5. revenue assumptions, including the offtake price and RFNBO compliance, and ROI or net present value with sensitivities to hydrogen price, power prices, capex and cost of capital;
6. OEM evidence that the dispatch strategy is within the equipment's capability and warranty.

> **The bottom line.** kWh/kg can rank electrolysers; it cannot choose one. Lowest kWh/kg, lowest capex and lowest LCOH each point to a different answer, and none of them alone maximises the return on capital. Climb all six steps, and technology selection becomes an investment decision.

Limitations

The worked example uses the assumptions of sbh4's November 2026 white paper: a flat 10%/yr capital charge in place of a full financial model; perfect foresight of historic day-ahead prices from October 2023 to September 2026; 2026 grid charges and current exemptions; vendor datasheet efficiencies at beginning of life; and sbh4 estimates of fully installed capex, which vary widely between projects. shiptown's efficiency, capex, flexibility and durability figures are company statements and targets that sbh4 has not verified independently. Capex shares and ranges from other sources use different scopes and are indicative.

REFERENCES AND DISCLAIMER

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Disclaimer. This white paper sets out a method for assessing electrolysers, compiled from public sources and sbh4's techno-economic modelling under the assumptions stated. It is not investment, legal or tax advice, an offer of securities or a recommendation to invest in shiptown A/S or any other company or project. Company statements have not been independently verified. Readers should carry out their own due diligence before any investment decision.

Disclosure. Stephen B. Harrison of sbh4 consulting is Strategic Advisor to shiptown A/S. [To complete before release: nature of any remuneration, options or shareholding.]

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Stephen B. Harrison is the founder and managing director of sbh4 GmbH in Germany. His work focuses on decarbonisation and the reduction of greenhouse-gas (GHG) emissions. E-fuels, bio-fuels, hydrogen, ammonia, long-duration energy storage (LDES) and CCU/S are the fundamental pillars of his consulting.

Stephen has extensive investment due-diligence advisory experience in the energy and clean-tech sectors. Private equity firms, investment fund managers and green-tech start-ups are regular clients. He also supports operating companies in their mission to decarbonise their scope 1, 2 and 3 GHG emissions, and helps start-ups scale up successfully through development plans aligned to market needs.

In 2023, Stephen evaluated seven CCTUS, hydrogen and e-fuels submissions to the European Commission's Third Innovation Fund. In 2025 he assessed seven Innovation Fund applications for e- and bio-methanol production and, in 2026, six large-scale bio-SAF and e-SAF projects. In each of these years the fund allocated more than €2 billion to large-scale decarbonisation projects in Europe. In 2024, 2025 and 2026 he also supported the European Commission with venture-capital investment due diligence, and assessed 15 Horizon grant applications and more than 30 Marie Curie Post Doctoral Network and Doctoral Fellowship applications.

Stephen has served as international expert and team leader for three Asian Development Bank (ADB) projects related to CCU/S and renewable hydrogen deployment in Pakistan, Palau and Viet Nam. He has also supported the IFC and the World Bank on e-fuels and green hydrogen strategy development projects in Namibia and Pakistan, and on project evaluations in Paraguay and India.

With a background in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of e-fuels, hydrogen, ammonia and carbon dioxide from commercial, technical and operational perspectives. For 14 years he was a global business leader in these FTSE 100 and DAX 30 companies.

As a member of the H2 View (2020–26) and gasworld (2018 to present) editorial advisory boards, Stephen has advised the direction of leading hydrogen-focused international publications for more than six years. Through H2 View, World Hydrogen Leaders and Sustainable Aviation Futures he has led masterclasses on hydrogen, SAF and hydrogen derivatives in virtual and live sessions. He chaired the e-fuels and hydrogen propulsion track at the Hydrogen Technology Exhibition in 2023 and 2024, and has supported the event as an Advisory Board member since early 2025.

sbh4 consulting

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