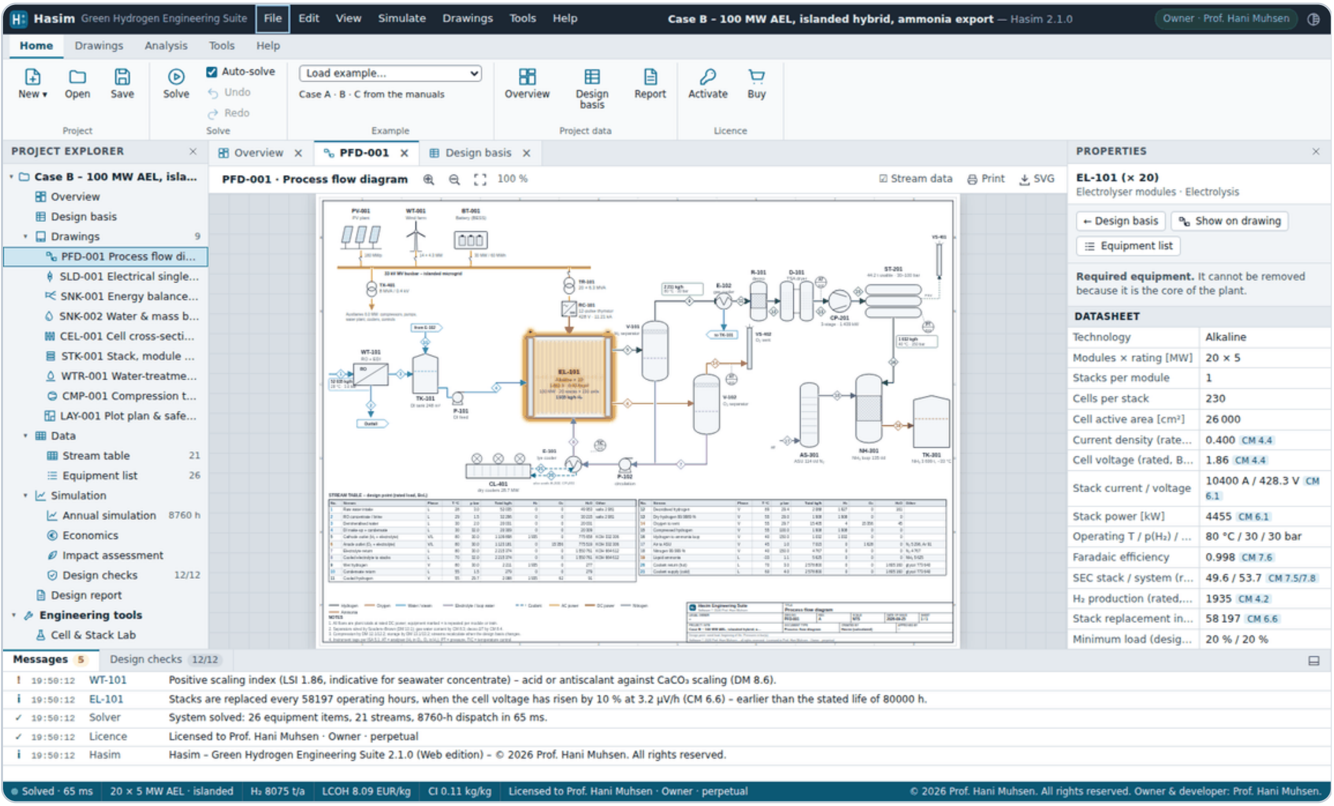
Hasim

Green Hydrogen Engineering Suite · version 2.1.0

User Manual

Engineering workstation for green hydrogen – from the electrochemical cell to the plant fence: drawings, streams, equipment, annual simulation, economics, component library, impact assessment, safety and design reports.



Owner and developer: Prof. Hani Muhsen

Desktop · Portable · Web · Microsoft Store editions · September 2026

137 executable equations · 16 simulation levels · 9 engineering drawings · 35 library components · 318 validation checks

Contents

About this manual

Chapters 1–3 get you started and explain the workstation. Chapters 4–10 follow the engineering workflow: design basis and library components, solver, drawings, data, annual simulation, economics and impact assessment, checks and report. Chapter 11 describes the engineering tools – among them the Component library and the Model builder –, chapters 12–13 the verification and the modelling assumptions. Step-by-step modelling exercises are provided in the companion document *Hasim – Model-Building Examples*.

1 Introduction

Hasim is an engineering workstation for green hydrogen projects. From a compact **design basis** – technology, number of modules, power supply, site, water source, storage, delivery and economics – it builds and solves a consistent engineering model of the complete plant and presents it the way engineers work: as drawings on sheets with title blocks, stream and equipment tables, datasheets, an annual 8760-hour simulation, economics, automatic design checks and a printable design report. Every change of an input re-solves the whole model within a fraction of a second.

The engineering content is taken from two references: the *Green Hydrogen Calculations Manual* (Edition 3, "CM") and the *Green Hydrogen Plant Design Manual* (Edition 1, "DM"). Hasim implements 137 of their numbered equations (90 from CM, 47 from DM) as executable functions; results are traceable to these equation numbers throughout the program and in the reports.

Plants and value chains can also be built from the component level. The **component library** contains 35 generic components – PV plants, wind turbines, batteries, water plants, electrolyser stacks, power electronics, balance of plant, compressors, storage vessels, pipelines, tube trailers, refuelling stations and conversion plants – each with technical, economic, environmental and social data and the sources of its values; you add your own. The **component wizard** chooses the equipment step by step and shows the effect of every choice, and the **impact assessment** reports the technical, economic, environmental and social impacts of the plant or chain.

1.1 What Hasim produces

- **Nine engineering drawings**: process flow diagram with stream table (PFD-001), electrical single-line diagram (SLD-001), energy and mass Sankey diagrams (SNK-001/002), cell cross-section (CEL-001), stack and module arrangement (STK-001), water-treatment train (WTR-001), compression train (CMP-001) and plot plan with safety distances (LAY-001).
- **Stream table** with temperature, pressure, mass and volume flow and composition of every numbered stream, plus the energy streams.
- **Equipment list** with tags following the DM conventions and a datasheet for every item.
- **Annual simulation** of 8760 hours with a live, hour-by-hour power-flow view.
- **Economics**: LCOH, CAPEX build-up and a sensitivity (tornado) analysis that re-solves the whole system.
- **Impact assessment**: technical performance and checks; investment, NPV, IRR and local content; life-cycle carbon intensity, embodied emissions, water and land; construction, manufacturing and permanent jobs, water-stress risk and the safety exposure of neighbours.
- **Design checks** against the limits of both manuals, of the chosen components and of international codes, standards and regulations (IEC/ISO, EU, US), a **codes and standards screening** – RFNBO, hazardous areas, major-accident regulations, pressure equipment, separation distances, power quality – and a complete **design report**.
- **Component library** with 35 generic components and your own, and the **component wizard** for plant projects and Model-builder chains.
- **Engineering tools**: Cell & Stack Lab, Equation library, Experiments, Component library, Model builder, Script console and Validation.

1.2 Simulation levels

The equations are organised in sixteen levels that follow the value chain from the electrochemical cell to the plant, the market and safety:

Level	Name	Equations
1	Properties & units	10
2	Thermodynamics	6
3	Cell	8
4	Stack & power electronics	9
5	System efficiency & balances	10
6	Renewable supply	12
7	Water supply & treatment	12
8	Cooling & heat	5
9	Compression & purification	8
10	Storage	14
11	Transport	5
12	Power-to-X & end use	12
13	Economics	7
14	Environment & certification	3
15	Safety & materials	13
16	Design basis & reliability	3

2 Installation, editions and licensing

Hasim is delivered in four editions built from the same program. All run on the local computer: projects, inputs and results never leave the device. The Desktop, Portable and Web editions need no internet connection after download; the Microsoft Store edition uses it for installation and updates and works offline in between.

Edition	Package	How to start	Best for
Desktop	Hasim_Desktop_v2.1.0.zip	Unzip, double-click **Hasim.vbs** (Windows) or run **hasim.sh** (macOS/Linux). Optional Start-menu shortcuts with **Create_Shortcuts.cmd**.	Daily engineering work in a dedicated window
Portable	Hasim_Portable_v2.1.0.zip	Double-click **Hasim_Portable.html** – one self-contained file.	USB sticks, restricted computers, classrooms
Web / intranet	Hasim_Web_v2.1.0.zip	Copy the folder to a web server; open **index.html**. Installable as an app, works offline after the first visit.	Company intranets, teaching labs
Microsoft Store	Hasim in the Microsoft Store (Windows 10/11)	Buy it in the Microsoft Store (search “Hasim”) – one price, paid once – and start it from the Start menu. It starts as the full version; updates arrive automatically (§2.4).	Individual engineers and researchers on Windows
Online evaluation	hasim website ▸ Try online	Opens in the browser; projects stay in the browser.	A first look without downloading

2.1 First start

On the first start Hasim shows the welcome screen with the licence agreement. After you accept it, the 14-day evaluation starts automatically (Figure 2.1). The example project “Case B – 100 MW AEL, islanded hybrid, ammonia export” is loaded and solved.

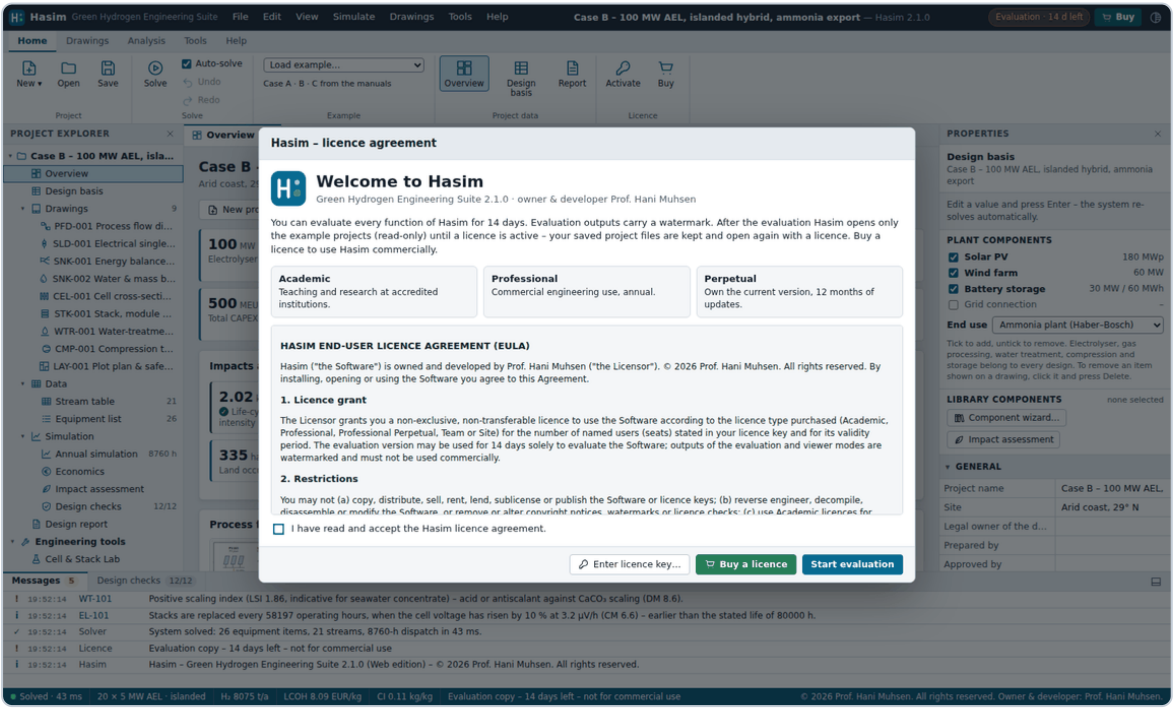


Figure 2.1 – Welcome screen with the licence agreement, shown on first start.

2.2 Evaluation, viewer and licensed modes

Function	Evaluation (14 days)	Viewer (after evaluation)	Licensed
Example projects, drawings, tables, charts	✓	✓ (read-only)	✓
Edit the design basis, solve	✓	–	✓
Save and open projects (.hasim)	✓	–	✓
Export SVG / CSV / HTML, print	✓ watermarked (also on printouts)	–	✓
Engineering tools	✓	Validation only	✓
Drawing title block	“Evaluation copy – not for commercial use”	“Viewer – not licensed”	“Licensed to …”

The licence state is shown by the badge in the title bar and in the status bar. Evaluation outputs carry a diagonal watermark and must not be used commercially (Figure 2.2). Hasim reminds you during the last three days of the evaluation. Your own project files are kept after the evaluation and open again as soon as a licence is active.

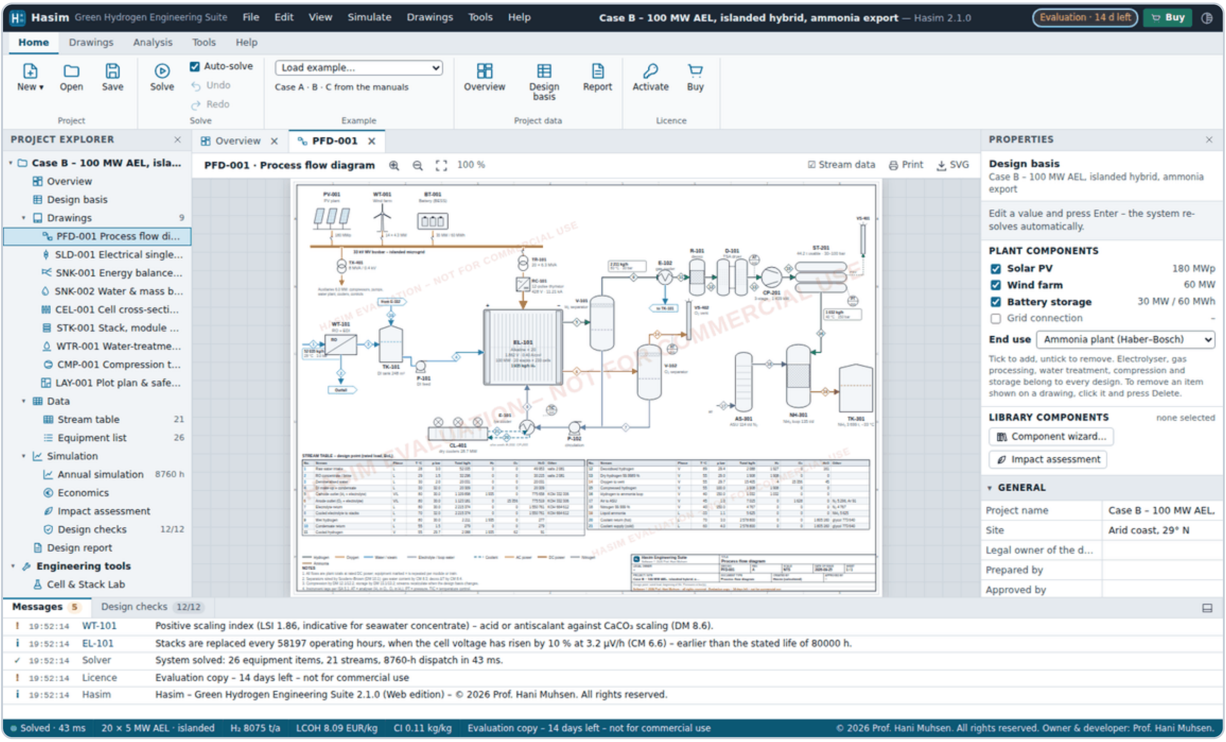


Figure 2.2 – Evaluation mode: the licence badge in the title bar and the watermark on the drawing.

2.3 Activating a licence key

Licence keys are used in every edition; Hasim bought in the Microsoft Store needs no key (§2.4).

1. Buy a licence on the Hasim website. The licence key is shown on the order-confirmation page and sent by e-mail. It starts with `HASIM-`.
2. In Hasim, click the licence badge in the title bar or choose **Help ▸ Activate licence**.
3. Paste the complete key (or load a `.hasimlic` file) and press **Activate** (Figure 2.3).
4. The badge turns green and shows the licensee. Drawings and reports now carry “Licensed to …” in the title block and no watermark.

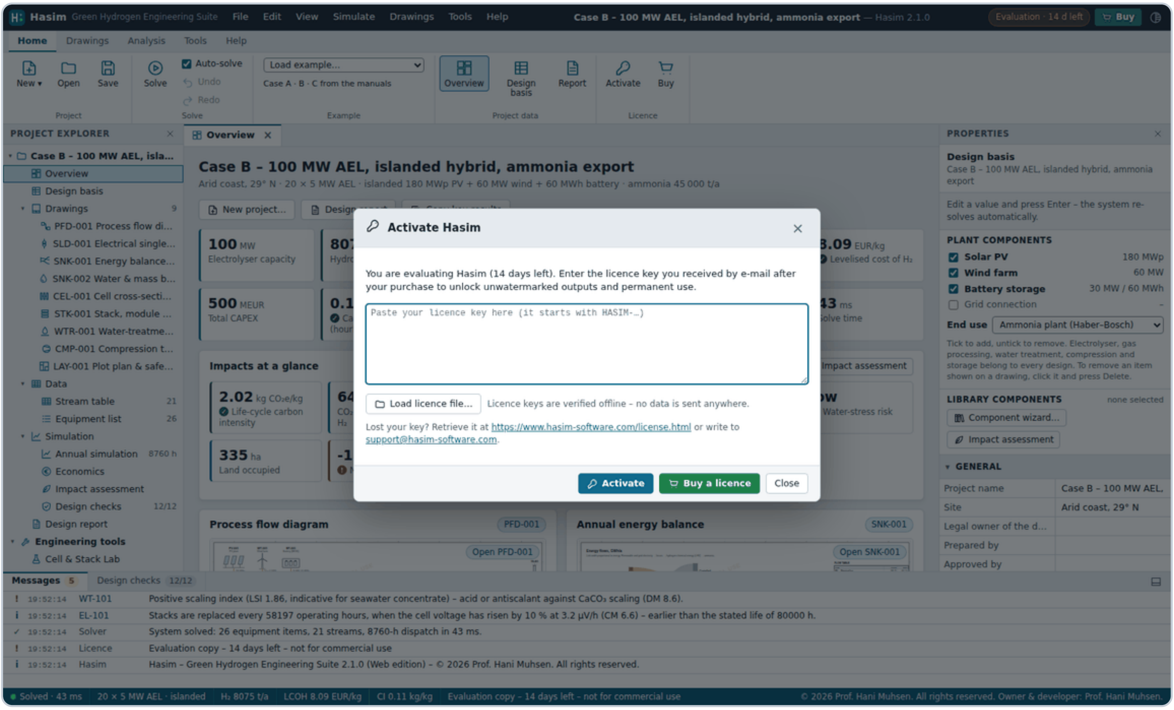


Figure 2.3 – The activation dialog. Keys are digitally signed and verified offline.

Good to know

Licence keys are verified offline with a digital signature (ECDSA P-256); no account or internet connection is needed. A key can be used on up to three computers of the same named user (see the EULA). To move to a new computer, activate the same key there. Lost keys can be retrieved on the website with the e-mail address used for the purchase. Subscriptions renew automatically; after each renewal you receive a new key by e-mail – activate it before the old one expires. A Professional Perpetual licence covers every version released during its update period; earlier versions remain available on the download page. Hasim re-checks the licence whenever its window regains focus. If the browser blocks local storage for Hasim, the activation dialog warns that the licence stays active only for the current session.

2.4 Buying Hasim in the Microsoft Store

In the Microsoft Store Hasim is a one-time purchase: one price, paid once – a lifetime licence for one user with all updates of the Store edition. Microsoft handles payment, receipts, taxes and refunds; there is no licence key to enter and no sign-in.

1. Try Hasim first: its web address in a browser runs as the free 14-day evaluation. **Buy** there explains the purchase and opens the Hasim page in the Microsoft Store (Figure 2.4).
2. Buy Hasim in the Microsoft Store with your Microsoft account and install it – a desktop app of about 100 MB.
3. Start Hasim from the Start menu: it starts as the full version, with the badge “Licensed · Microsoft Store” and no watermark. A click on the badge shows the licence (Figure 2.5).

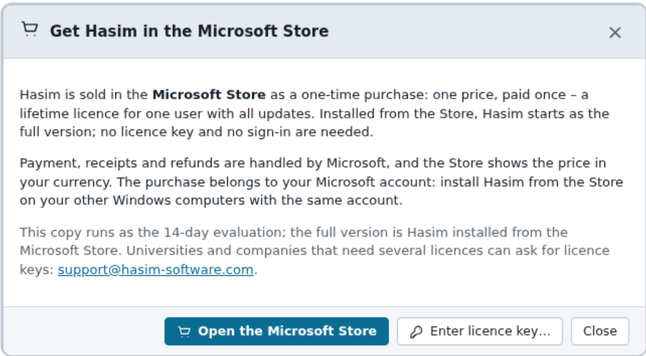


Figure 2.4 – Buy in the free evaluation: the one-time purchase in the Microsoft Store.

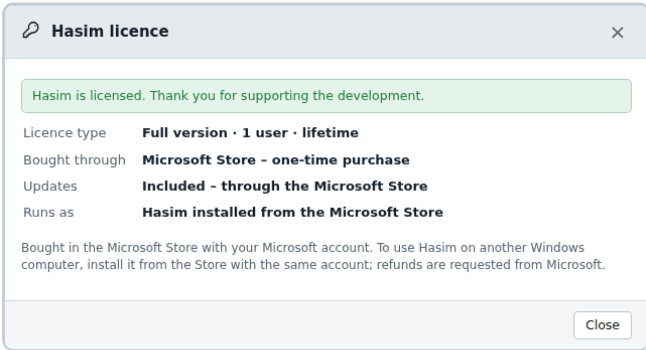


Figure 2.5 – Hasim installed from the Store: full version, lifetime licence, one-time purchase.

Good to know

Hasim from the Microsoft Store is a desktop app that contains the whole program: it works without an internet connection and starts as the full version – no key, no sign-in. On your other Windows computers, install it from the Store with the same Microsoft account. The web address in a browser always runs as the evaluation. **Help ▸ User Manual (PDF)** opens the manuals (a copy is saved in Documents\Hasim). Refunds are requested from Microsoft. Universities and companies that need several licences use licence keys (§2.3), which work in every edition.

2.5 System requirements

- Windows 10/11, macOS 12 or newer, or a current Linux desktop. The Microsoft Store edition needs 64-bit Windows 10 (version 1809 or later) or Windows 11 and about 400 MB of disk space.
- A current browser engine: Microsoft Edge, Google Chrome, Firefox or Safari (the desktop edition uses the Edge engine included in Windows).
- 4 GB RAM; a screen of 1366 × 768 or larger is recommended. Hasim also adapts to tablets and phones (Figure 3.6).

3 The engineering workstation

Hasim uses the layout of engineering workstations such as process simulators: menus and a ribbon at the top, the project explorer on the left, tabbed documents in the centre, the properties panel on the right, the message log at the bottom and a status bar (Figure 3.1).

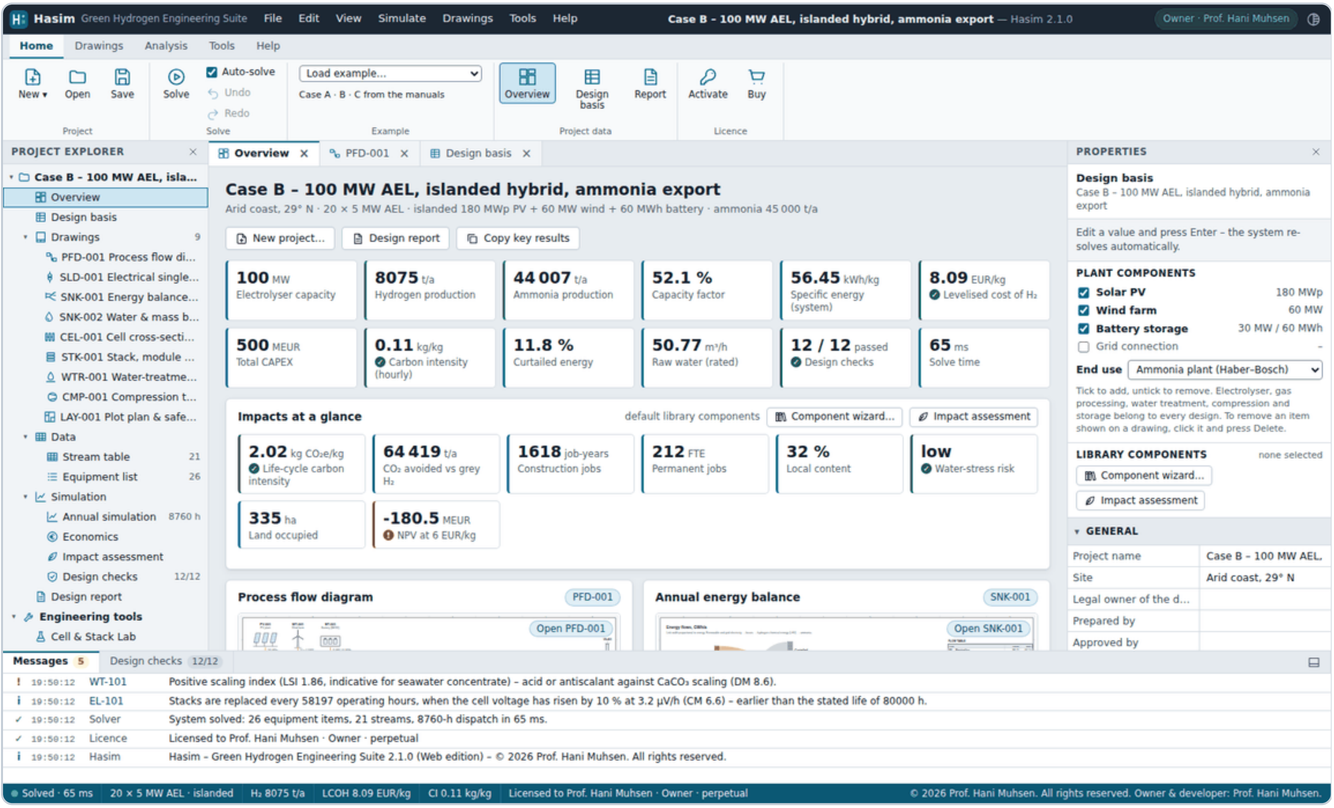


Figure 3.1 – The Hasim workstation with the project overview of Case B.

Area	Purpose
Title bar	Hasim logo, menus (File, Edit, View, Simulate, Drawings, Tools, Help), project name with “●” for unsaved changes, licence badge, Buy button and theme switch.
Ribbon	Tabs Home, Drawings, Analysis, Tools and Help with the most used commands, grouped as in engineering software.
Project explorer	Tree of all project documents – overview, design basis, the nine drawings, stream table, equipment list, annual simulation, economics, impact assessment, design checks, report – and the engineering tools.
Documents	Open documents as tabs. Drawings open in a zoom/pan viewer; tables and charts scroll.
Properties	The design basis as an editable property grid, or the datasheet of the selected equipment or stream.
Messages	Solver messages, warnings and input changes; a second tab lists the design checks.
Status bar	Solver state and time, plant summary, hydrogen production, LCOH, carbon intensity, licence and copyright.

3.1 Menus and ribbon

The **File** menu creates new projects with the **New project (wizard)** or from the examples, opens and saves `.hasim` project files, exports the stream table, equipment datasheets, hourly results and the design report, and prints the active document (Figure 3.2). **Edit** provides undo/redo of input changes; **View** toggles the panels and the theme; **Simulate** solves, controls auto-solve and opens the annual simulation, economics, impact assessment, checks and report; **Drawings** opens the drawings; **Tools** opens the engineering tools, the Component library and the component wizard of the plant; **Help** contains the user guide, licence functions and About.

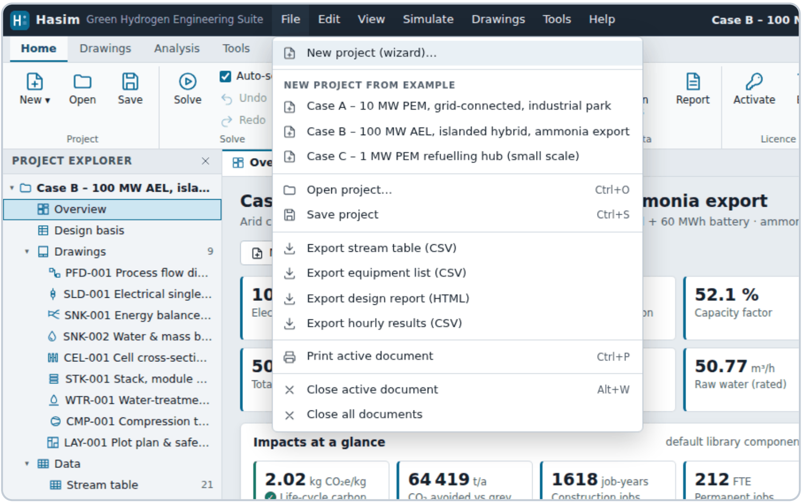


Figure 3.2 – File menu.

3.2 Project explorer and documents

Click an entry of the project explorer to open it as a tab. Tabs keep their state (zoom, scroll position) while you switch between them. Close a tab with its × button, the middle mouse button or **Ctrl+W**. The design-checks entry shows how many checks pass and turns amber when a check needs review.

3.3 Properties panel

Without a selection, the properties panel shows the **Plant components** (section 4.6), the **Library components** (section 4.7) and the design basis grouped into General, Electrolyser, Power supply, Site and weather, Grid connection, Water, Storage and delivery, Economics and Impact assessment. Click a group header to collapse it. Type a value and press **Enter**; values outside the allowed range are marked red and not applied. Inputs that differ from the example are marked with a blue bar. When you click equipment on a drawing or in the equipment list, the panel shows its datasheet with the manual reference of every value (Figure 3.3); a stream shows its conditions and composition.

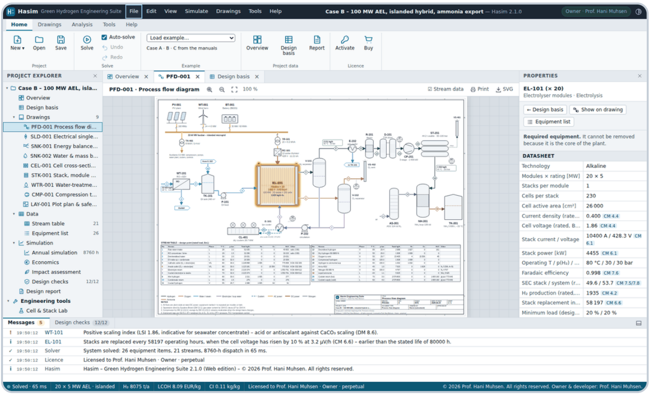


Figure 3.3 – EL-101 selected on the PFD; its datasheet appears in the properties panel.

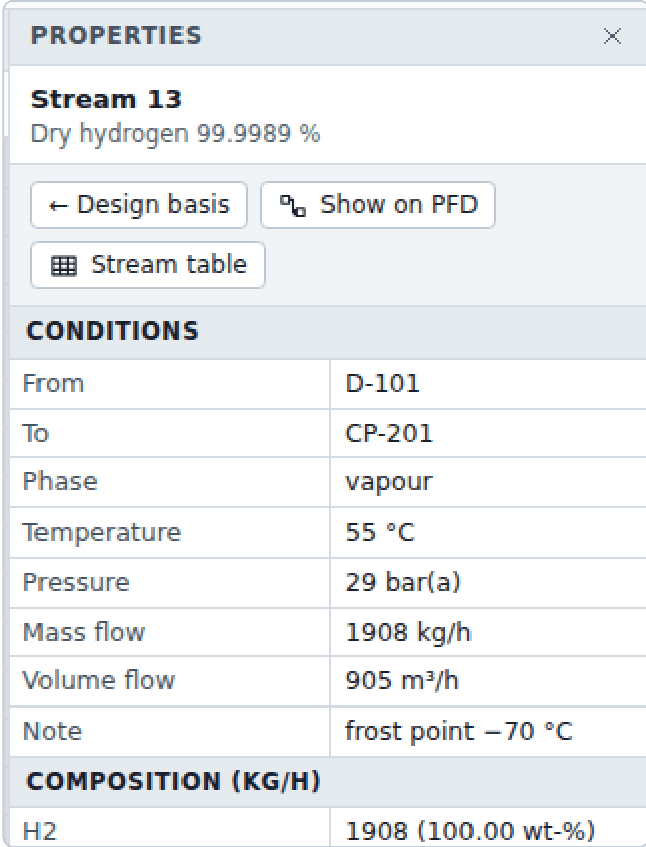


Figure 3.4 – Stream 13 (dry hydrogen) selected: conditions and composition.

3.4 Keyboard shortcuts

Keys	Action
F5	Solve the design basis
Ctrl+S / Ctrl+O	Save / open project
Ctrl+Z / Ctrl+Y	Undo / redo input changes
Ctrl+P	Print the active document
Ctrl+W	Close the active document
Ctrl+PageDown / PageUp	Next / previous document
Alt+1 / Alt+2 / Alt+3	Show or hide explorer / properties / messages
F1	User guide
Drawing viewer	Mouse wheel (hover or Ctrl) zooms, drag pans, double-click fits the sheet, click selects

3.5 Themes and small screens

Hasim follows the light or dark theme of the operating system; the theme button in the title bar switches manually. In the dark theme drawings are shown CAD-style on a dark sheet; exports always use the colours on screen. On narrow screens the explorer and the properties open as drawers from the title bar.

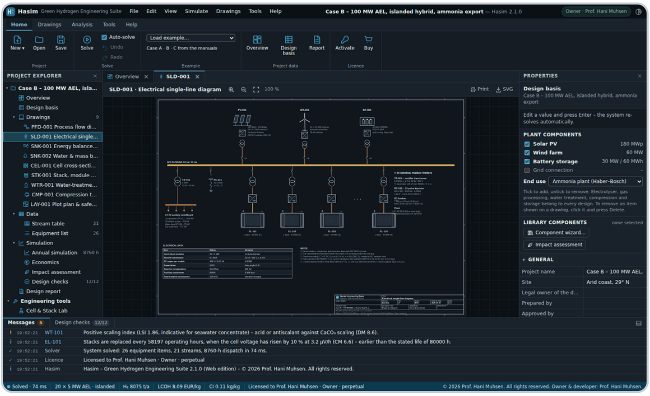


Figure 3.5 – Dark theme with the single-line diagram.

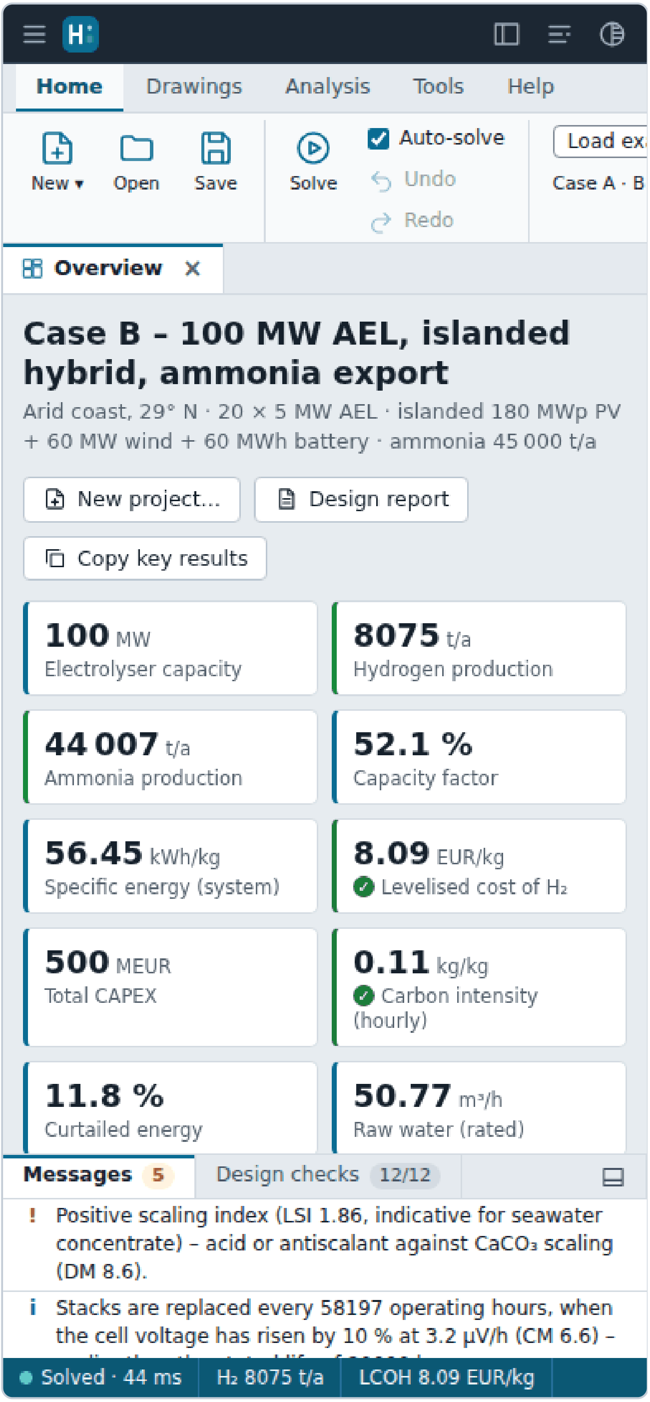


Figure 3.6 – Layout on a phone.

4 Projects and the design basis

4.1 Example projects

Three complete examples from the manuals are built in. Load them from **Home ▶ Example** or **File ▶ New project from example**.

	Case A	Case B	Case C
Plant	10 MW PEM, grid-connected, industrial park	100 MW AEL, islanded hybrid, ammonia export	1 MW PEM refuelling hub (small scale)
Electrolyser	2 × 5 MW PEM	20 × 5 MW AEL	1 × 1.25 MW PEM
Power supply	Grid + PPA (30 MWp PV, 15 MW wind)	Islanded: 180 MWp PV, 60 MW wind, 30 MW/60 MWh battery	Grid + PPA (2 MWp PV)
Hydrogen [t/a]	1 050	8 075	155
Capacity factor	67.7 %	52.1 %	80.1 %
System SEC [kWh/kg]	56.4	56.5	56.6
LCOH [EUR/kg]	10.14	8.09	15.16
CAPEX [MEUR]	35.2	500.0	8.8
Carbon intensity [kg CO_2e/kg]	3.06	0.11	17.81
Equipment items / streams	24 / 19	26 / 21	22 / 18
Design checks passed	15 of 16	12 of 12	15 of 16

4.2 Editing the design basis

Edit values in the properties panel or open the **Design basis** document, which shows all groups side by side (Figure 4.1). With **Auto-solve** on (Home ribbon), every accepted change re-solves the complete system; with auto-solve off, press **F5**. Changing the technology loads its minimum-load preset; switching the product to ammonia selects ammonia delivery. **Undo**/**Redo** (Ctrl+Z/Ctrl+Y) step through up to 100 changes. The message log records every change.

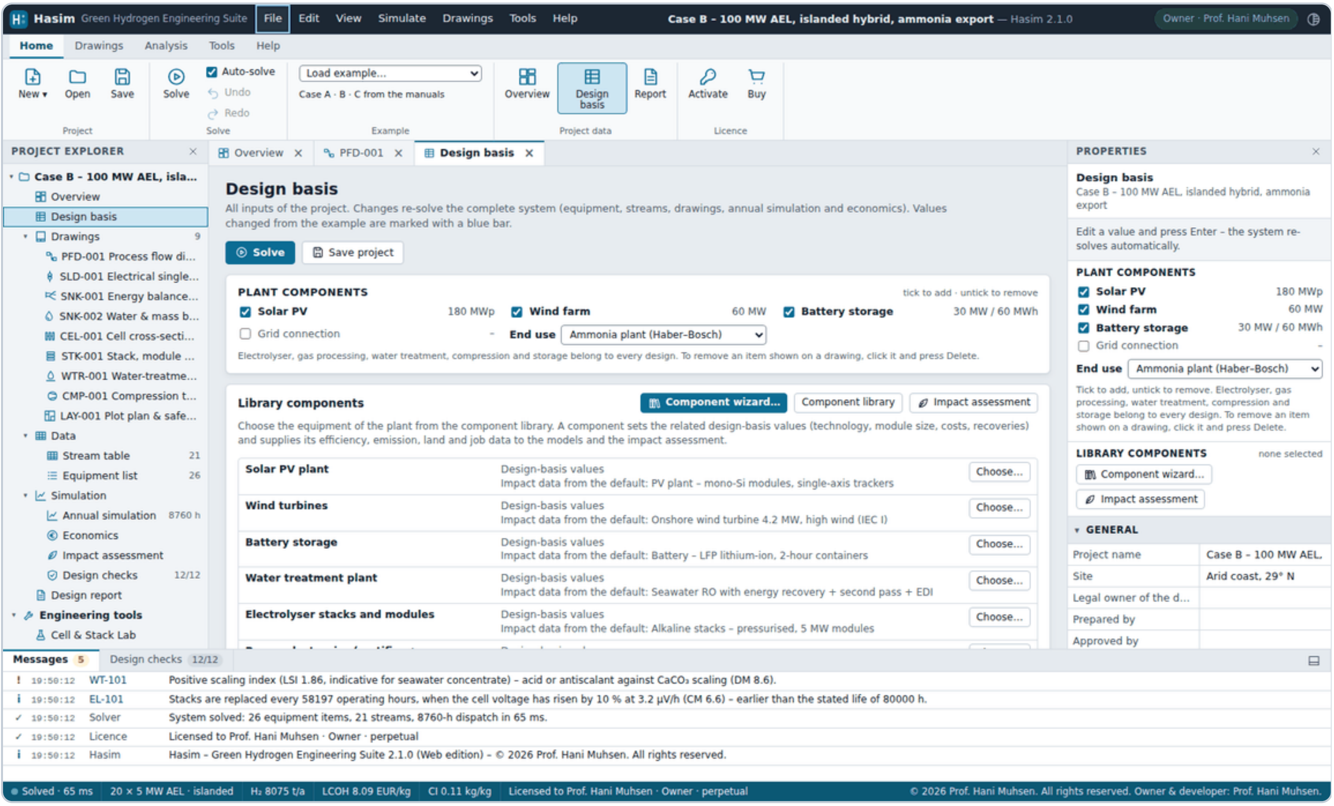


Figure 4.1 – The design-basis document.

4.3 Design-basis reference

The table lists every input with its unit, allowed range and meaning.

Input	Unit	Range / options	Meaning
General			
Project name			Project name shown in the title bar, drawing title blocks and the report.
Site			Site description printed on every drawing.
Legal owner of the documents			Legal owner of the documents – printed in the title block of every drawing (ISO 7200).
Prepared by			Person who prepared the drawings and the report (title block).
Approved by			Person who approved the drawings and the report (title block).
Product		Hydrogen / Ammonia	Hydrogen delivered as gas, or ammonia produced in a Haber–Bosch loop (adds ASU, synthesis loop and NH_3 tank).
Demand	kg/d (H_2) or t/a (NH_3)	1 … 10 000 000	Hydrogen demand in kg/d, or annual ammonia production in t/a; drives the sizing chain and the demand check.
Plant availability	–	0.50 … 1	Fraction of the year the plant is available (DM 1.1). The annual simulation takes the modules out of service for maintenance one at a time, in six blocks per year, so that the time average equals this value.
Electrolyser			
Technology		PEM / Alkaline (AEL) / AEM / Solid oxide (SOEC)	Electrolysis technology; loads the cell, stack and operating-condition presets.

Input	Unit	Range / options	Meaning
Number of modules	–	1 … 200	Number of identical electrolyser modules, each with its own transformer and rectifier.
Module rating	MW	0.10 … 50	Rated DC power of one module.
Minimum load	–	0 … 0.90	Minimum stable load of the dispatch. A lower value than the load at which hydrogen in oxygen reaches the 2 % trip (CM 7.7) is raised to that load; the H_2-in-O_2 check reports the load actually used.
Design full-load hours	h/a	500 … 8 760	Full-load hours of operation used by the sizing chain (DM 1.2), without downtime; the annual simulation gives CF × 8760 ÷ availability.
System CAPEX	EUR/kW	100 … 10 000	Installed electrolyser system cost per kW.
Stack share of CAPEX	–	0 … 0.80	Share of the electrolyser CAPEX spent on each stack replacement.
SOEC heat for steam raising		Electric boiler and heaters / External heat (e.g. waste heat)	SOEC only: heat for raising the steam and for operation below the thermoneutral voltage – electric boiler and heaters (counted in the SEC) or external heat such as waste heat (paid at the heat price).
Price of external heat (SOEC)	EUR/MWh	0 … 500	Price of external heat for an SOEC.
Power supply			
Supply concept		Grid-connected + PPA / Islanded (off-grid)	Grid-connected with a renewable PPA, or an islanded PV–wind–battery microgrid (generation CAPEX then belongs to the project).
PV capacity	MWp	0 … 100 000	PV DC capacity.
Wind capacity	MW	0 … 100 000	Wind-farm capacity.
Battery power	MW	0 … 10 000	Battery inverter power.
Battery energy	MWh	0 … 100 000	Battery usable energy.
Renewable share of supply (sizing chain only)	–	0 … 1	Renewable share of the purchased electricity assumed by the sizing chain; the annual simulation computes the grid share hour by hour.
Electricity price	EUR/MWh	0 … 1 000	Price of purchased grid/PPA electricity.
Curtailment allowance (sizing chain only)	–	0 … 0.90	Curtailment allowance of the sizing chain.
Surplus renewable energy (grid-connected)		Curtailed / not bought / Sold to the grid (pay-as-produced PPA)	Grid-connected plants: PPA electricity the electrolyser cannot use is curtailed (not bought), or sold to the grid at the export price (pay-as-produced PPA). Only a sold surplus can be matched with grid imports in the monthly correlation of the RFNBO rules (until the end of 2029).
Price of sold surplus	EUR/MWh	-100 … 500	Price received for sold surplus electricity.
PV CAPEX (islanded)	EUR/kWp	0 … 5 000	PV cost for islanded plants.
Wind CAPEX (islanded)	EUR/kW	0 … 6 000	Wind cost for islanded plants.
Battery CAPEX	EUR/kWh	0 … 3 000	Battery cost per kWh.
Site and weather			
Latitude	°	-66 … 66	Latitude for the solar geometry of the synthetic year.

Input	Unit	Range / options	Meaning
Annual GHI	kWh/m²	500 … 2 800	Annual global horizontal irradiation – scales the solar year.
Mean wind speed at hub	m/s	2 … 14	Mean wind speed at hub height.
Weibull shape factor k of the wind	–	1.20 … 4	Weibull shape factor of the site wind (2 onshore by default, about 2.1 offshore); the synthetic year reproduces the mean and k exactly.
Mean ambient temperature	°C	-20 … 40	Mean ambient temperature (PV temperature losses).
Cloudiness index	–	0 … 1	Day-to-day variability of the solar resource, 0 clear … 1 overcast.
Weather-year seed	–	1 … 9 999	Random seed of the synthetic weather year – change it to test other years.
Design ambient (cooling)	°C	-10 … 55	Design ambient temperature for the dry coolers.
Grid connection and electrical			
Grid import limit	MW	0 … 10 000	Maximum grid import.
Grid use		Bridge to minimum load / Always full load / Fill to target load	Bridge: the grid keeps the electrolyser at minimum load when renewables are short; target: tops up to the target load; full: always rated load.
Target load (target mode)	–	0 … 1	Target load for the “target” mode.
Grid carbon intensity	g/kWh	0 … 1 200	Carbon intensity of grid electricity.
MV voltage	kV	6 … 132	Medium-voltage level of the plant substation.
Grid fault level	MVA	0 … 100 000	Short-circuit power of the grid (fault levels).
Auxiliary backup supply	MW	0 … 1 000	Backup supply for the auxiliaries (e.g. of an islanded plant).
Auxiliary load (× rating)	–	0 … 0.30	Auxiliary load as a fraction of the electrolyser rating.
Water			
Raw-water source		Municipal / fresh / Seawater	Raw-water source.
Raw-water TDS	g/L	0.01 … 60	Total dissolved solids of the raw water.
RO recovery, pass 1	–	0.20 … 0.95	Recovery of the first RO pass.
Recovery, pass 2 / EDI	–	0.50 … 1	Recovery of the second pass / EDI polishing.
DI water consumption	L/kg	9 … 20	Demineralised water per kg of hydrogen, including losses (DM 6.1).
Calcium	mg/L	0 … 2 000	Calcium in the raw water (scaling).
Sulphate	mg/L	0 … 6 000	Sulphate in the raw water (gypsum).
Alkalinity	mg/L	0 … 2 000	Alkalinity (as $CaCO_3$).
Raw-water pH	–	5 … 10	Raw-water pH.
Water temperature	°C	1 … 40	Raw-water temperature.
Raw-water price	EUR/m³	0 … 20	Price of raw water.
Storage and delivery			

Input	Unit	Range / options	Meaning
Storage pressure	bar	10 … 900	Maximum storage pressure (compressor discharge).
Minimum storage pressure	bar	1 … 500	Minimum storage pressure (usable inventory).
Compressor discharge temperature limit	°C	120 °C – API 618 6th ed., hydrogen, non-lubricated / 135 °C – API 618 6th ed., general / 150 °C – API 618 5th ed.	Highest discharge temperature of a compressor stage; sets the pressure ratio per stage and the number of stages (API 618: 120 °C for hydrogen-rich gas in non-lubricated machines).
Storage sizing		Days of full-load flow / From hourly inventory	Size the buffer as days of full-load flow, or from the 8760-hour inventory.
Buffer	d	0.05 … 30	Buffer in days of full-load flow.
Offtake averaging window	h	0 … 720	Offtake averaging window: 0 = constant offtake, 168 = weekly flexibility.
Offtake turndown	–	0 … 1	Minimum offtake as a fraction of the mean offtake.
Storage CAPEX	EUR/kg	0 … 5 000	Storage cost per kg of usable hydrogen.
Delivery		Pipeline / Ammonia plant / Refuelling station / At plant fence	Delivery route: pipeline, ammonia plant, refuelling station or plant fence.
Pipeline length	km	0 … 2 000	Length of the product pipeline.
Delivery pressure	bar	1 … 200	Delivery pressure at the customer.
Trailer loading	kg/d	0 … 100 000	Hydrogen filled into tube trailers per day.
Economics			
WACC	–	0 … 0.30	Weighted average cost of capital.
Economic life	a	5 … 50	Economic life.
Other direct costs incl. battery and storage (× electrolyser)	–	0 … 5	Other direct costs relative to the electrolyser CAPEX – balance of plant, civil works and EPC; the battery and the hydrogen storage are paid from this budget.
Fixed OPEX (share of CAPEX)	1/a	0 … 0.20	Fixed O&M per year as a share of CAPEX.
Impact assessment			
Labour-productivity region		OECD (jobs × 1) / Middle East (jobs × 2) / Latin America (jobs × 2.3) / China (jobs × 1.3) / India (jobs × 1.4) / Developing Asia (jobs × 1.5) / Africa (jobs × 6.8) / Transition economies (jobs × 1.7)	Labour-productivity region; multiplies all employment factors of the impact assessment (section 9.3).
Local share of equipment supply	–	0 … 1	Share of the equipment supply manufactured in the country (local content, local manufacturing jobs).
Local share of installation & civil works	–	0 … 1	Share of installation and civil works carried out by local companies (local content, local construction jobs).
Local share of engineering & services	–	0 … 1	Share of engineering, services, indirect and owner's costs spent in the country.
Baseline water stress (WRI Aqueduct)		Low (< 10 %) / Low–medium (10–20 %) / Medium–high (20–40 %) / High (40–80 %) / Extremely high (> 80 %)	Baseline water stress of the site (WRI Aqueduct 4.0); with the water source it gives the water-stress risk.
Distance storage – site boundary	m	0 … 100 000	Distance from the storage yard to the site boundary, compared with the hazard distances of a storage leak.

Input	Unit	Range / options	Meaning
Distance to nearest residents	m	0 … 1 000 000	Distance from the storage yard to the nearest residents (exposure of neighbours).
Hydrogen value (for NPV / IRR)	EUR/kg	0 … 50	Value of the hydrogen for the NPV, IRR and payback of the impact assessment.

4.4 Saving and opening projects

File ▸ Save project (Ctrl+S) writes a `.hasim` file (JSON) containing the design basis and project information; **File ▸ Open project** reads it back and solves it. Hasim also keeps the current project in the browser storage of the edition you use, so it reappears at the next start. Design-basis JSON files of Hasim 1.x can be opened as well.

4.5 Creating a project from scratch

File ▸ New project (wizard) (also Home ▸ New ▾ and the **New project** button of the Overview) creates a plant from scratch in six steps: **Product** (hydrogen or ammonia, demand, end use), **Power supply** (grid-connected with PPA, or islanded; solar PV, wind, battery; grid use and prices), **Site & water** (climate preset or own values, municipal water or seawater), **Electrolyser** (technology, minimum load, CAPEX), **Storage & economics** and **Review**. The minimum load is preset to the lowest load, in steps of 5 %, at which hydrogen in oxygen stays below the 2 % trip; a lower value would be raised to the trip limit in the simulation. With **Size the plant for me**, Hasim runs the complete 8760-hour model repeatedly and sizes the electrolyser modules and the power supply so that the yearly production after gas processing meets the demand – whole modules first, then the solar and wind volumes close the remaining gap; alternatively enter the sizes yourself. The review shows the expected production, capacity factor and an indicative LCOH before the project is created.

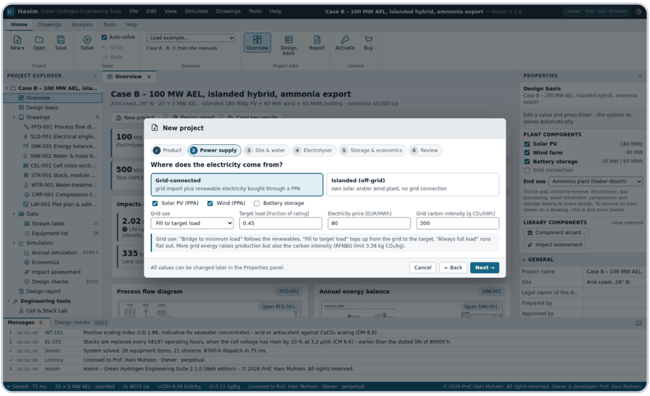


Figure 4.2 – New Project wizard, step 2: power supply.

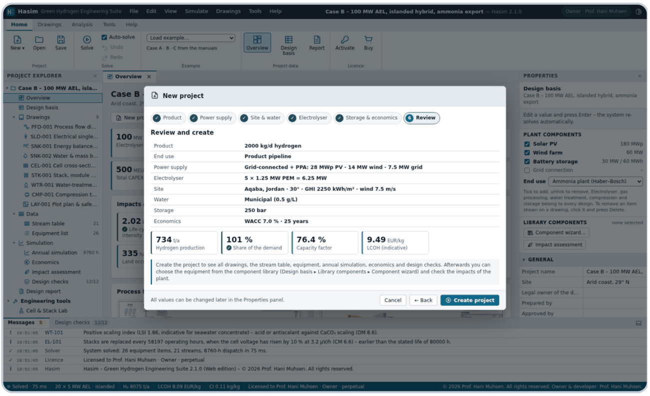


Figure 4.3 – Step 6: the plant sized to meet the demand.

A wizard project is an ordinary project. The blue change markers compare with the values chosen in the wizard, and **Edit ▸ Reset design basis to the wizard values** restores them. The Model-Building Examples document walks through a complete wizard project (“Start here”).

4.6 Adding and removing plant components

The **Plant components** list at the top of the Properties panel and of the Design basis document switches the optional equipment on and off: **Solar PV**, **Wind farm**, **Battery storage**, **Grid connection** and **Tube-trailer loading**, plus the **End use** (plant fence, product pipeline, refuelling station or ammonia plant). A removed component keeps its size, so ticking it again restores it; each change is one step of Undo. At least one power source must remain; removing the grid connection makes the plant islanded.

Equipment can also be removed where you see it: click it on a drawing or in the equipment list – its datasheet shows **Remove from plant** – or press **Delete** (Edit ▸ Remove selected equipment from the plant). Hasim asks for confirmation and re-solves the system. Equipment that every plant needs – electrolyser, gas processing, water treatment, compression and storage, and the electrical equipment that follows from the electrolyser rating – cannot be removed; its datasheet says why.

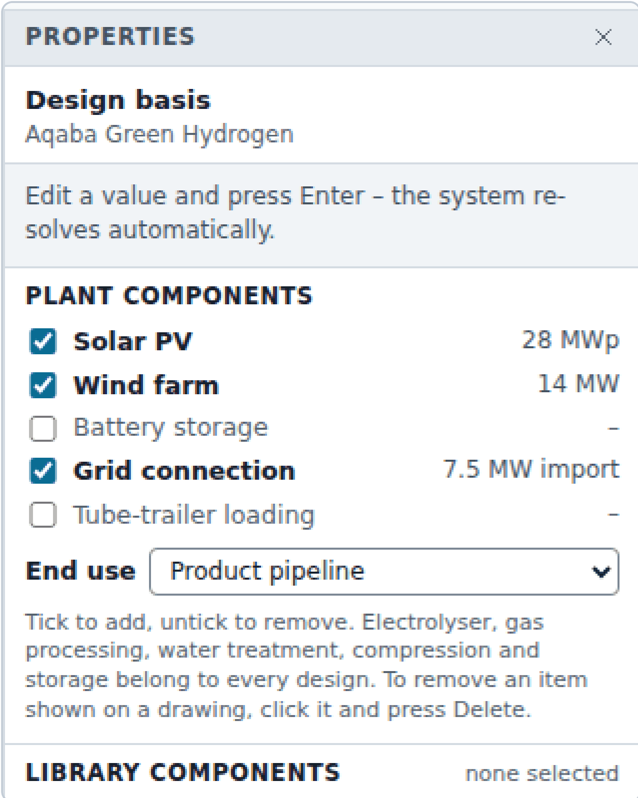


Figure 4.4 – Plant components in the Properties panel.

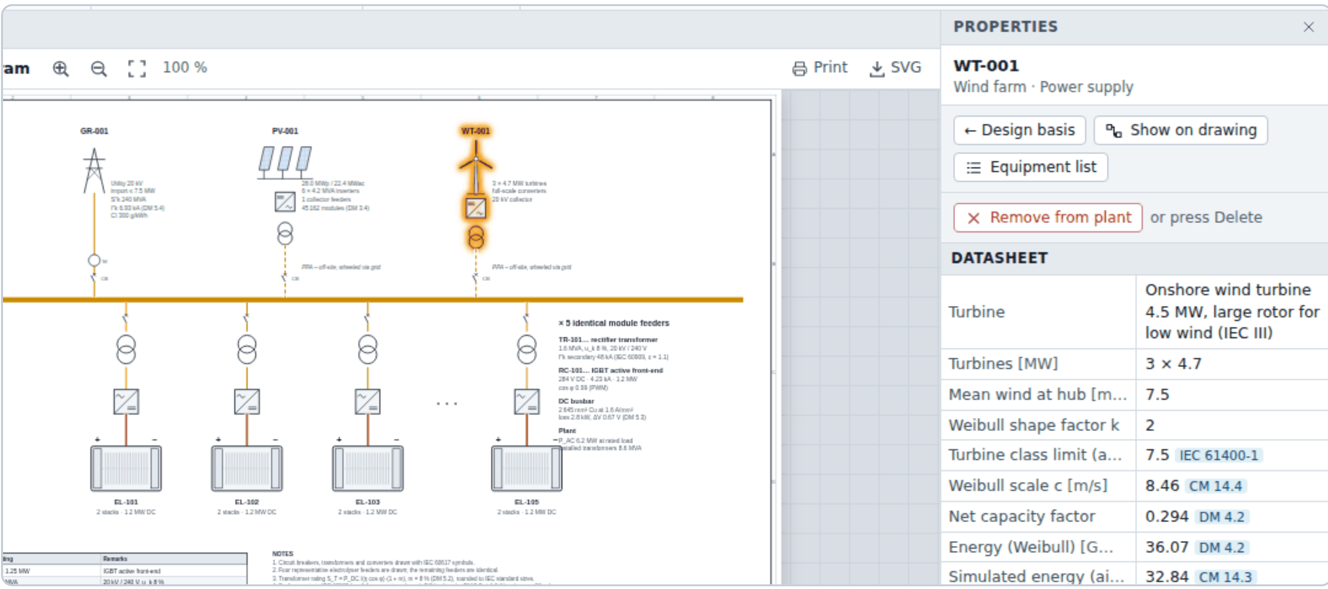


Figure 4.5 – The wind farm WT-001 selected on the single-line diagram: its datasheet offers Remove from plant.

4.7 Library components of a plant

The equipment of a plant can be chosen from the **component library** (section 11.4). The **Library components** card of the Design basis document (Figure 4.6) – and its one-line version in the Properties panel – lists the equipment of the plant: solar PV, wind turbines, battery, water treatment, electrolyser stacks, power electronics, balance of plant, compressor and storage vessels and, depending on the end use, the pipeline, tube trailers, refuelling station or ammonia plant. Without a selection the plant keeps its design-basis values, and the impact assessment uses the **default component** of each type, shown in grey. The default follows the design basis: the stack and balance of plant of the chosen technology, the water plant for the salinity of the raw water, the turbine class for the site wind (IEC 61400-1), the vessel type for the storage pressure.

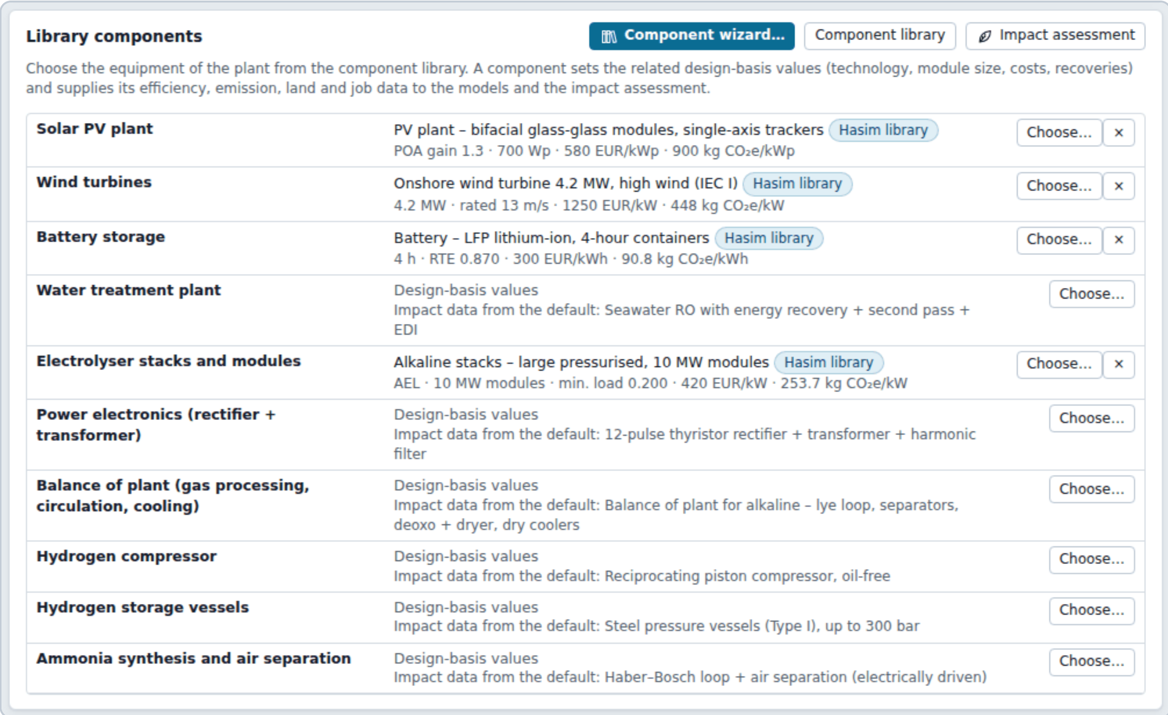


Figure 4.6 – Library components of Case B after choosing stacks, PV, wind turbines and battery; the other items use the defaults.

1. Press **Component wizard...** – on the card, in the Properties panel, in the Impact assessment or with **Tools ▸ Component wizard for the plant**. The wizard shows the equipment of the plant as steps; **Choose...** on the card opens it at one item.
2. Choose a component from the list on the left. **Hasim default – keep the design-basis values** removes a selection.
3. Set its size on the right – for example the number of modules, the PV or wind capacity or the battery power – and change parameters of the component if needed. An edited component is marked **modified**; the library itself stays unchanged. **Save as my component...** adds it to your library, **Reset to library values** undoes the edits.
4. **Effect on the model** at the bottom re-solves the complete plant – 8760-hour simulation included – with the components chosen so far: hydrogen, LCOH, investment, life-cycle carbon intensity, construction and permanent jobs, local content and checks passed (Figure 4.7).
5. **Apply components** applies all selections as one change; **Ctrl+Z** undoes it. The × on the card removes one selection – the design-basis values stay as they are.

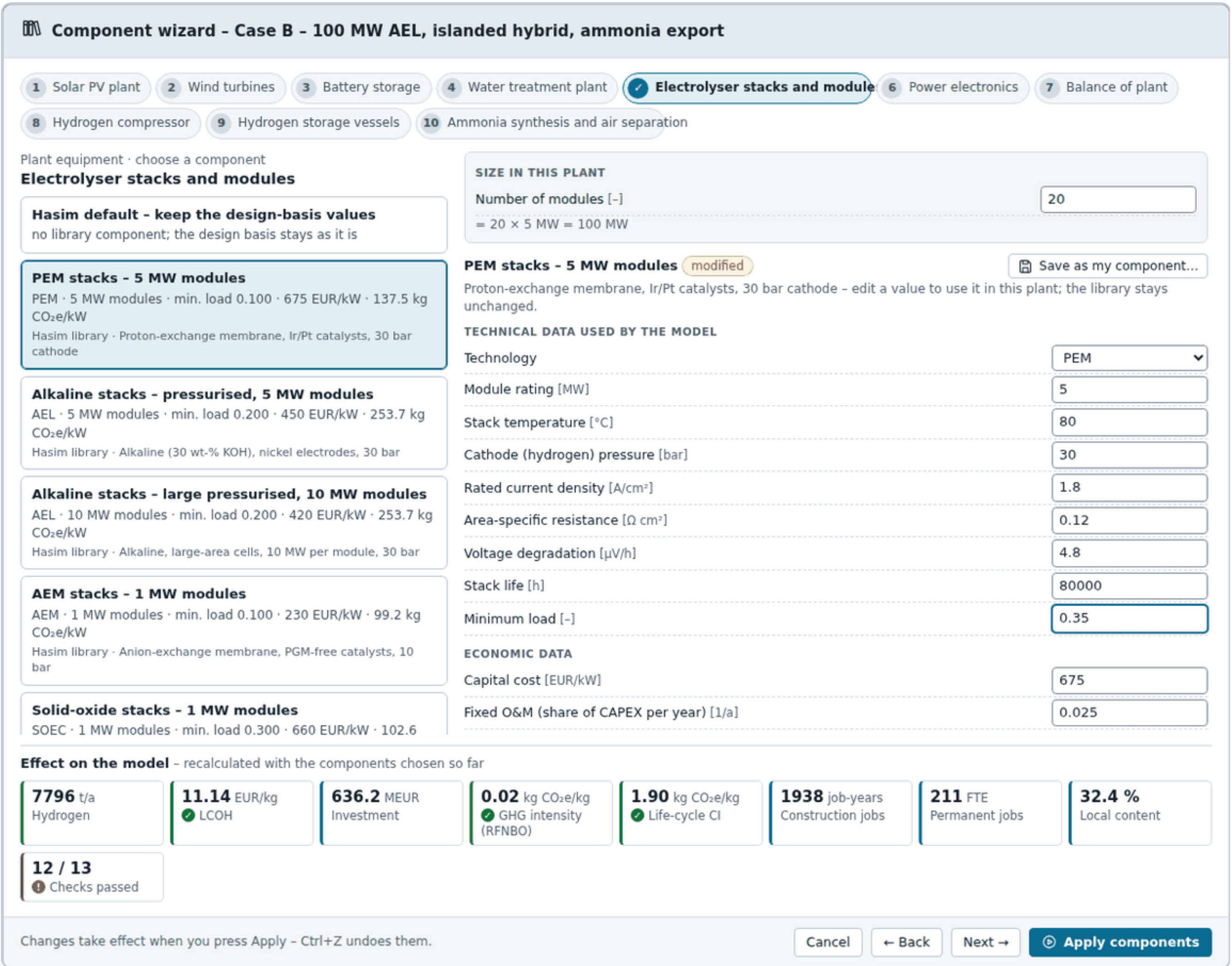


Figure 4.7 – Component wizard of Case B: PEM stacks with the minimum load edited to 0.35 (marked modified) and the effect on the whole plant.

A component sets the related design-basis values and supplies its data to the plant models:

Equipment	Design-basis values set	Model data used
Solar PV plant	PV CAPEX	Tracking gain, system losses, DC/AC ratio, temperature coefficient, module power, O&M
Wind turbines	Wind CAPEX	Power curve (cut-in, rated, cut-out wind speed), losses, turbine rating (number of turbines), O&M
Battery storage	Battery CAPEX; battery energy = power × storage duration	Round-trip efficiency, state-of-charge limits, O&M
Water treatment plant	Recoveries of both passes, water source; for a source of another kind also its typical salinity, composition and price	Maximum feed salinity (check)
Electrolyser stacks	Technology, minimum load, module rating and number of modules (same total rating), electrolyser CAPEX and stack share	Stack temperature and pressure, rated current density, ASR, voltage degradation, stack life
Power electronics	Electrolyser CAPEX and stack share	Rectifier efficiency and type (single-line diagram)
Balance of plant	Electrolyser CAPEX and stack share	Variable and fixed BoP consumption; technology (check)

Equipment	Design-basis values set	Model data used
Compressor	–	Isentropic efficiency, pressure ratio per stage, capacity per machine (number of machines), pressure rating (check)
Storage vessels	Storage CAPEX per kg	Pressure rating (check)
Pipeline, tube trailers, refuelling station, ammonia plant	–	Impact data; pipeline design pressure (check)

The electrolyser CAPEX of the design basis becomes the sum of stack, power electronics and balance of plant (EUR/kW), and the stack share the part of the stacks. When stacks of another technology are chosen, a balance of plant of the old technology is replaced by the matching one. The component checks of Chapter 10 verify the selection against the design, and the design report lists the components (section 8.4 of the report).

5 The system solver

Solving a design basis runs one deterministic sequence; typical solve times are 20–60 ms, including the 8760-hour simulation.

1. **Sizing chain** of the Design Manual: cell (CM 3–4), stack and module (CM 5–6), system efficiency (CM 7), renewables (DM 3–4), water (DM 6, 8), heat (DM 9), compression (DM 12), storage (DM 13), transport (DM 14), end use (DM 15–16), economics (DM 20), environment (CM 18) and safety (CM 19).
2. **Equipment**: every item receives a tag, quantity and datasheet – separators by Souders–Brown, coolers from duty and LMTD, deoxo and TSA dryers, compressors per stage, storage vessels, water plant, dry coolers, vents, end-use units and all electrical equipment.
3. **Streams**: the design-point mass and energy balance with numbered streams from raw water to product, including electrolyte loops, condensate, oxygen and coolant.
4. **Electrical one-line data**: rectifier type (12-pulse thyristor for AEL, IGBT active front-end otherwise), transformer ratings, DC bus, harmonics at the point of common coupling (IEEE 519-2022) and reactive power, short-circuit currents (IEC 60909), auxiliary transformer, PV/wind/battery/grid feeders.
5. **Annual simulation** of 8760 hours (Chapter 8) and the **annual energy and mass balances** that feed the Sankey diagrams; the energy balance closes to better than 10^{-6} GWh.
6. **Plot plan** with areas from the sizing chain, consequence distances of a storage leak (CM 19.1–19.8) and the separation distances of NFPA 2.
7. **Design checks**, messages and the **codes and standards screening** (Chapter 10).

> **Consistency**
>
> All documents of a project show the same solved state. When you change an input, every open document is marked as outdated and refreshed when you view it; the active document is refreshed immediately.

6 Engineering drawings

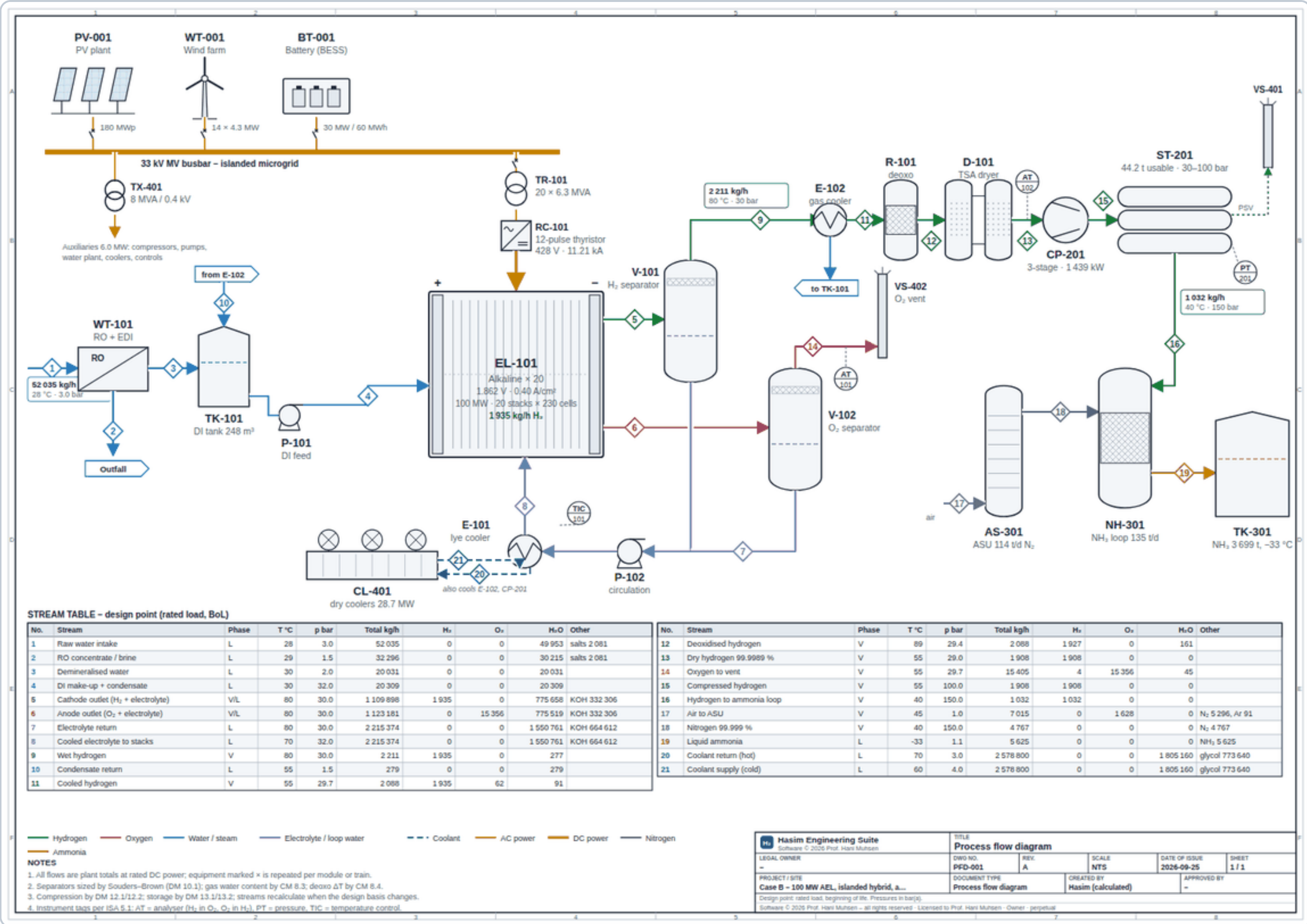
Drawings are generated on A3-proportion sheets with frame, zone markers and a title block with the data fields of ISO 7200: legal owner, identification number (drawing number), revision, date of issue, sheet, title, document type, creator and approver – the owner, creator and approver are taken from the design basis (group General) – plus scale, the basis of the drawing, the copyright line and the licence line. Electrical symbols follow IEC 60617. Line types and colours follow a consistent legend: hydrogen green, oxygen red, water blue, electrolyte violet, coolant teal, AC power amber, DC power brown.

6.1 Drawing viewer

Zoom with the mouse wheel while hovering (or with Ctrl), with the toolbar buttons or by double-clicking to fit. Drag to pan. Hover equipment or streams for a tooltip; click to show the datasheet in the properties panel. **SVG** exports the sheet as a vector drawing for CAD, reports and presentations; **Print** prints it. On the PFD, **Stream data** switches the stream call-outs on and off.

6.2 PFD-001 – Process flow diagram

Power supply and MV bus, transformers and rectifiers, electrolyser modules with separators and electrolyte loop, gas processing (cooler, deoxo, TSA dryer), compression and storage, end use, water treatment and cooling, with numbered stream diamonds, instrument bubbles, stream call-outs and the stream table on the sheet.



STREAM TABLE – design point (rated load, BoL)

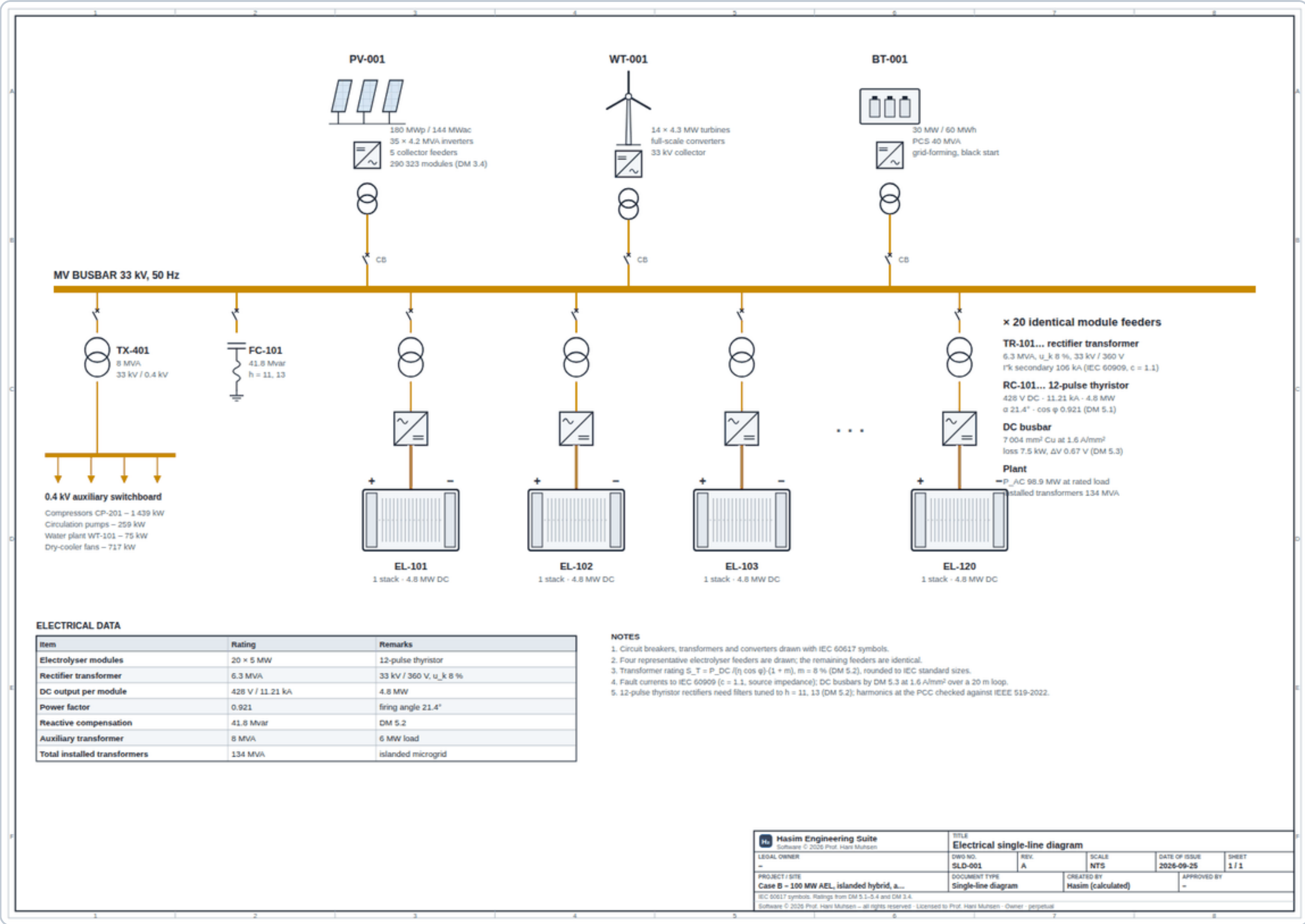
No.	Stream	Phase	T °C	p bar	Total kg/h	H_2	O_2	H_2O	Other
1	Raw water intake	L	28	3.0	52 035	0	0	49 953	salts 2 081
2	RO concentrate / brine	L	29	1.5	32 296	0	0	30 215	salts 2 081
3	Demineralised water	L	30	2.0	20 031	0	0	20 031	
4	DI make-up + condensate	L	30	32.0	20 309	0	0	20 309	
5	Cathode outlet (H_2 + electrolyte)	V/L	80	30.0	1 109 898	1 935	0	775 658	KOH 332 306
6	Anode outlet (O_2 + electrolyte)	V/L	80	30.0	1 123 181	0	15 356	775 519	KOH 332 306
7	Electrolyte return	L	80	30.0	2 215 374	0	0	1 550 761	KOH 664 612
8	Cooled electrolyte to stacks	L	70	32.0	2 215 374	0	0	1 550 761	KOH 664 612
9	Wet hydrogen	V	80	30.0	2 211	1 935	0	277	
10	Condensate return	L	55	1.5	279	0	0	279	
11	Cooled hydrogen	V	55	29.7	2 088	1 935	62	91	
12	Deoxidised hydrogen	V	89	29.4	2 088	1 927	0	161	
13	Dry hydrogen 99.9989 %	V	55	29.0	1 908	1 908	0	0	
14	Oxygen to vent	V	55	29.7	15 405	4	15 356	45	
15	Compressed hydrogen	V	55	100.0	1 908	1 908	0	0	
16	Hydrogen to ammonia loop	V	40	150.0	1 032	1 032	0	0	
17	Air to ASU	V	45	1.0	7 015	0	1 628	0	N_2 5 296, Ar 91
18	Nitrogen 99.999 %	V	40	150.0	4 767	0	0	0	N_2 4 767
19	Liquid ammonia	L	-33	1.1	5 625	0	0	0	NH_3 5 625
20	Coolant return (hot)	L	70	3.0	2 578 800	0	0	1 805 160	glycol 773 640
21	Coolant supply (cold)	L	60	4.0	2 578 800	0	0	1 805 160	glycol 773 640

NOTES
1. All flows are plant totals at rated DC power; equipment marked × is repeated per module or train.
2. Separators sized by Souders–Brown (DM 10.1); gas water content by CM 8.3; deoxo ΔT by CM 8.4.
3. Compression by DM 12.1/12.2; storage by DM 13.1/13.2; streams recalculate when the design basis changes.
4. Instrument tags per ISA 5.1: AT = analyser (H_2 in O_2, O_2 in H_2), PT = pressure, TIC = temperature control.

PFD-001 for Case B.

6.3 SLD-001 – Electrical single-line diagram

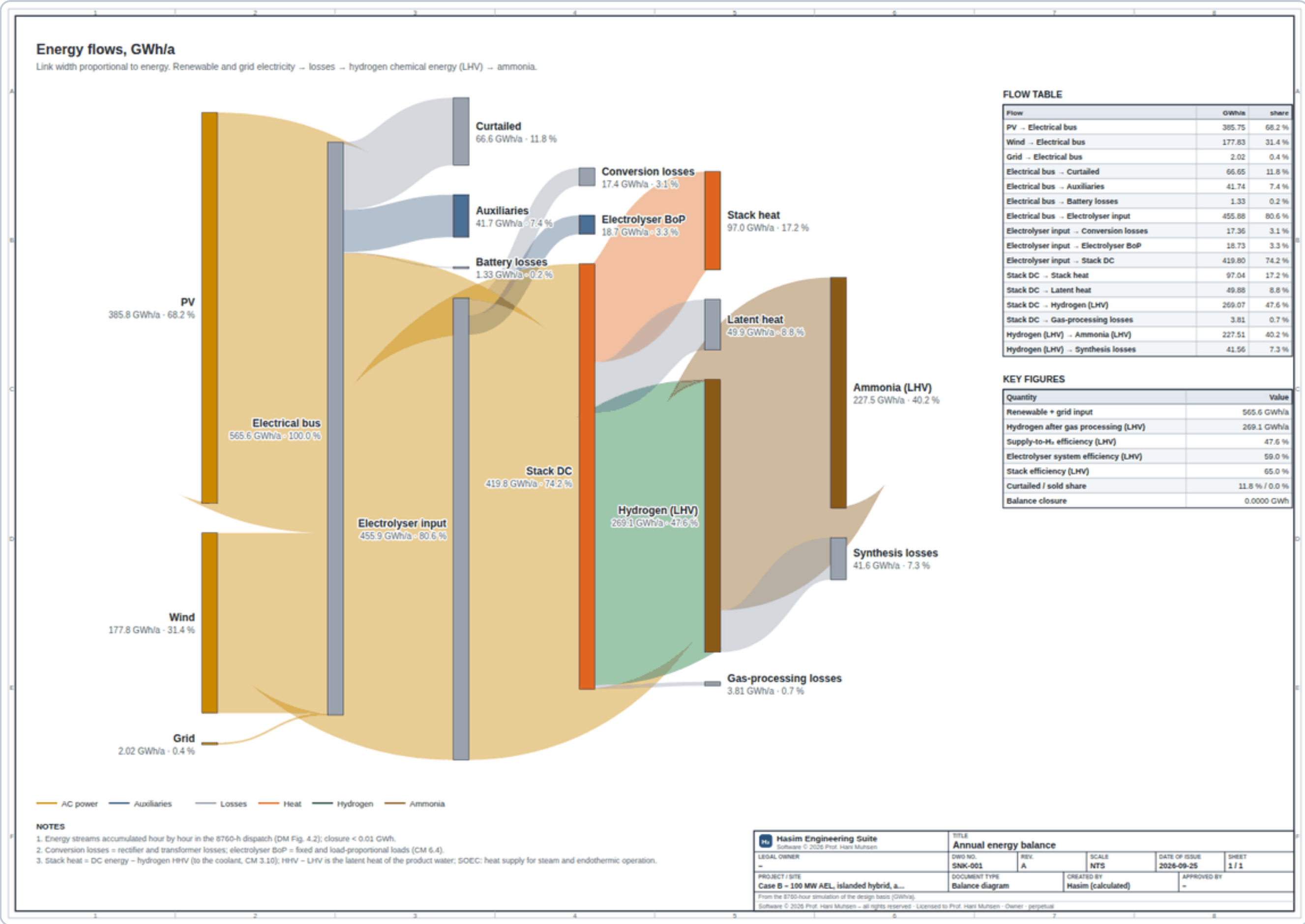
MV busbar with feeders for PV (inverter stations), wind turbines, battery PCS and grid; rectifier transformers with ratings and impedance; thyristor or IGBT rectifiers with DC data; harmonic filter/STATCOM for thyristor plants; auxiliary transformer and loads; ratings table.



SLD-001 for Case B.

6.4 SNK-001 – Annual energy balance (Sankey)

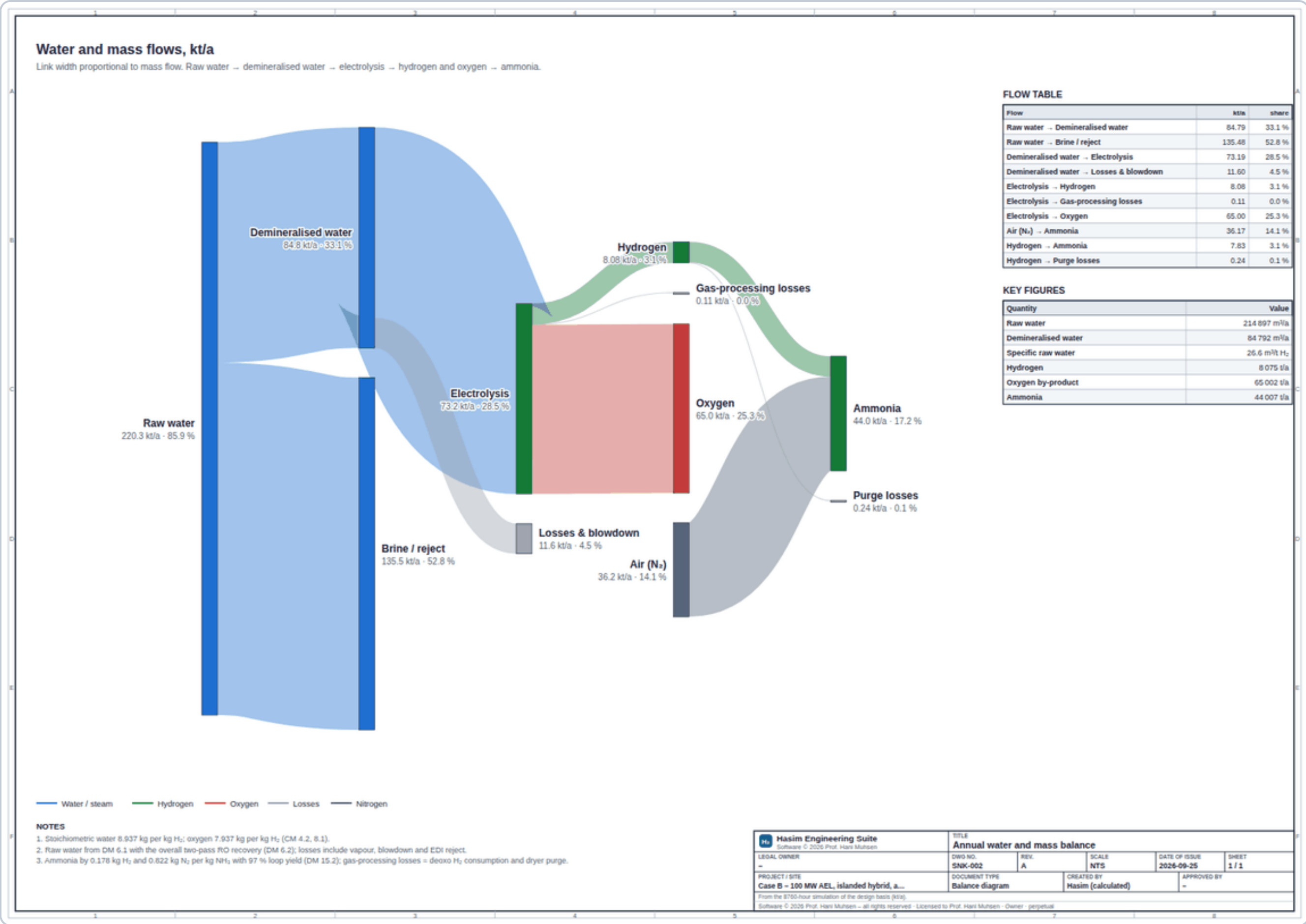
From PV, wind and grid electricity through curtailment, auxiliaries, battery and conversion losses to the stack DC power, stack heat and the chemical energy (LHV) of hydrogen – and ammonia for Power-to-X cases. Flow table and key figures on the sheet.



SNK-001 for Case B.

6.5 SNK-002 – Water and mass balance (Sankey)

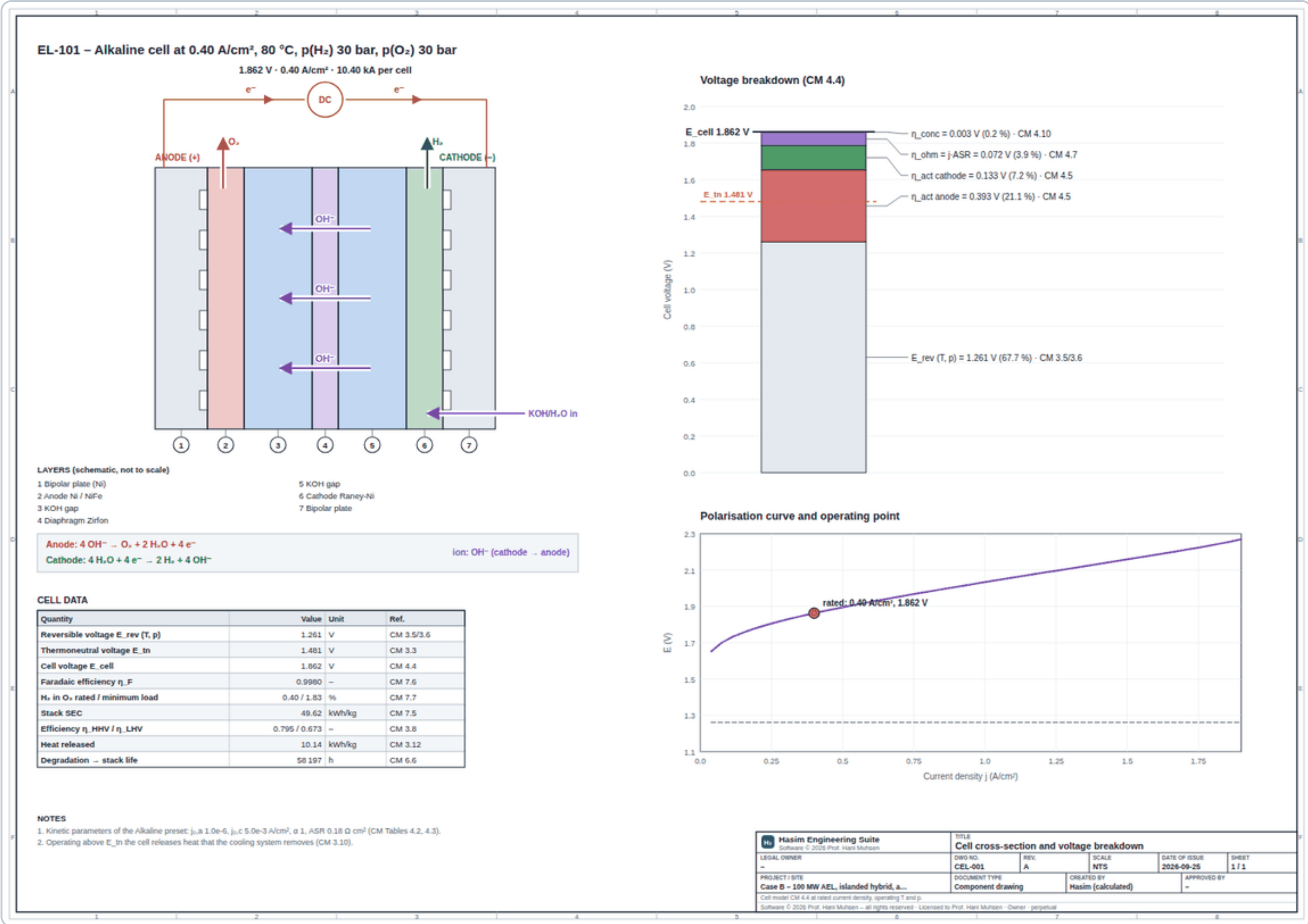
Raw water to demineralised water and brine, electrolysis to hydrogen and oxygen, losses and blowdown, and nitrogen/ammonia for ammonia plants.



SNK-002 for Case B.

6.6 CEL-001 – Cell cross-section and voltage breakdown

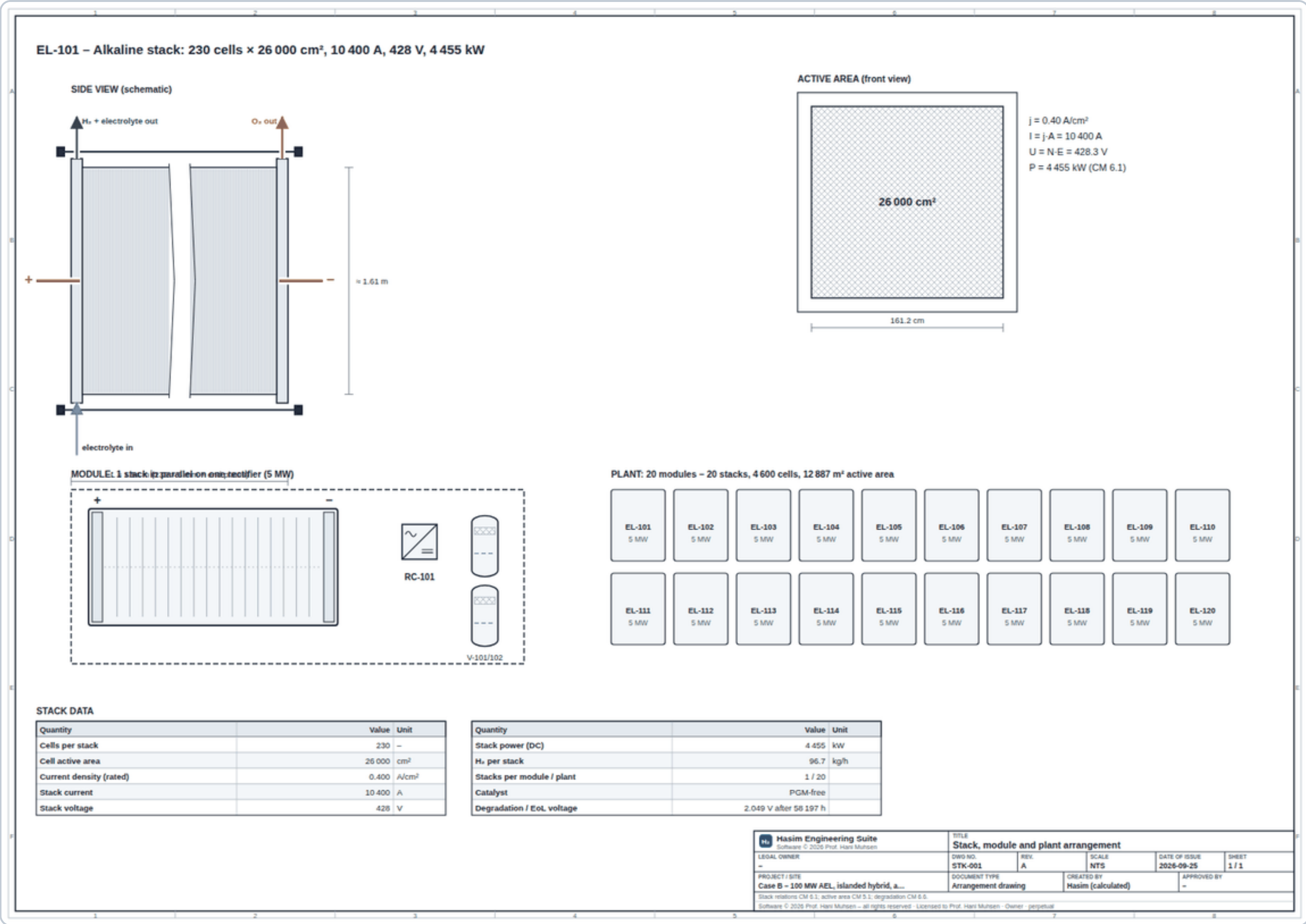
Cross-section of the technology's cell (electrodes, membrane or diaphragm, flows), the voltage breakdown at the operating point and the polarisation curve with the operating point.



CEL-001 for Case B.

6.7 STK-001 – Stack, module and plant arrangement

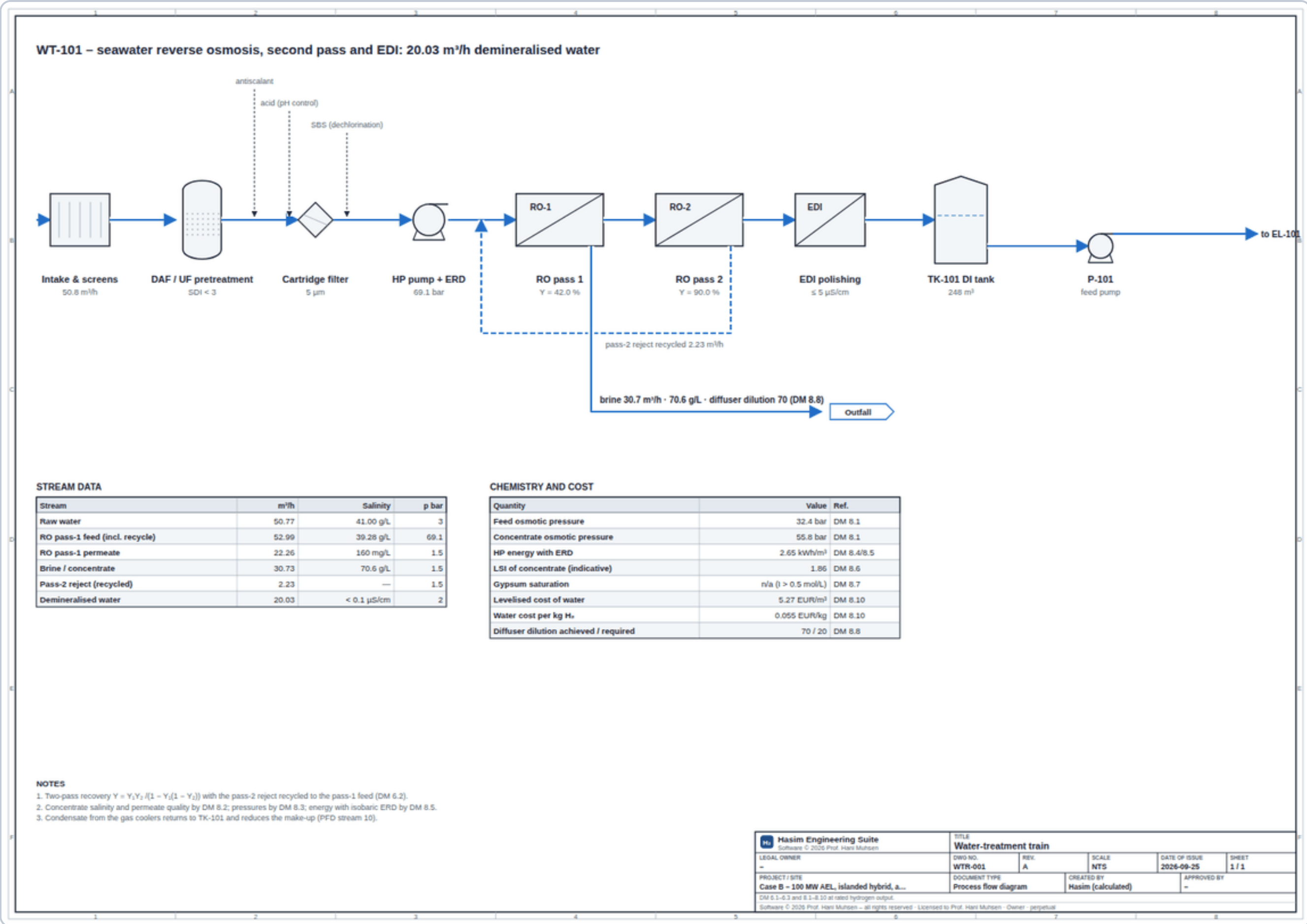
Cell stack with end plates and tie rods, module arrangement on the DC bus and the plant hierarchy from cell to plant with the relations of CM 6.1.



STK-001 for Case B.

6.8 WTR-001 – Water-treatment train

Intake, pre-treatment, one or two RO passes (with energy recovery for seawater), EDI polishing, DI tank, brine outfall with diffuser, flows and qualities; scaling indices and cost of water.



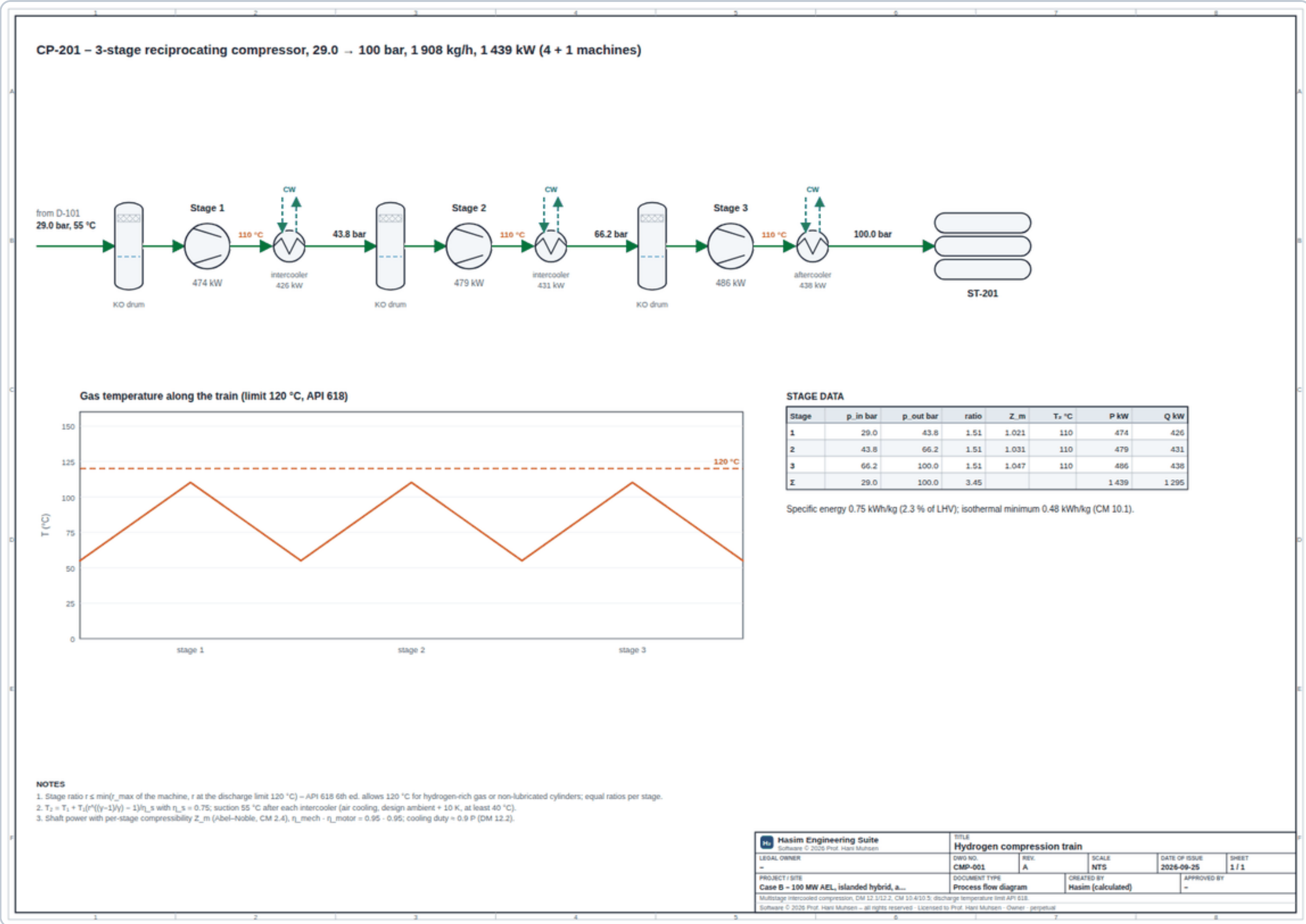
Stream	m³/h	Salinity	p bar
Raw water	50.77	41.00 g/L	3
RO pass-1 feed (incl. recycle)	52.99	39.28 g/L	69.1
RO pass-1 permeate	22.26	160 mg/L	1.5
Brine / concentrate	30.73	70.6 g/L	1.5
Pass-2 reject (recycled)	2.23	—	1.5
Demineralised water	20.03	< 0.1 µS/cm	2

Quantity	Value	Ref.
Feed osmotic pressure	32.4 bar	DM 8.1
Concentrate osmotic pressure	55.8 bar	DM 8.1
HP energy with ERD	2.65 kWh/m³	DM 8.4/8.5
LSI of concentrate (indicative)	1.86	DM 8.6
Gypsum saturation	n/a (I > 0.5 mol/L)	DM 8.7
Levelised cost of water	5.27 EUR/m³	DM 8.10
Water cost per kg H_2	0.055 EUR/kg	DM 8.10
Diffuser dilution achieved / required	70 / 20	DM 8.8

WTR-001 for Case B.

6.9 CMP-001 – Compression train

Multistage intercooled compression with stage pressures, temperatures and power, the p–h path and the specific compression energy.



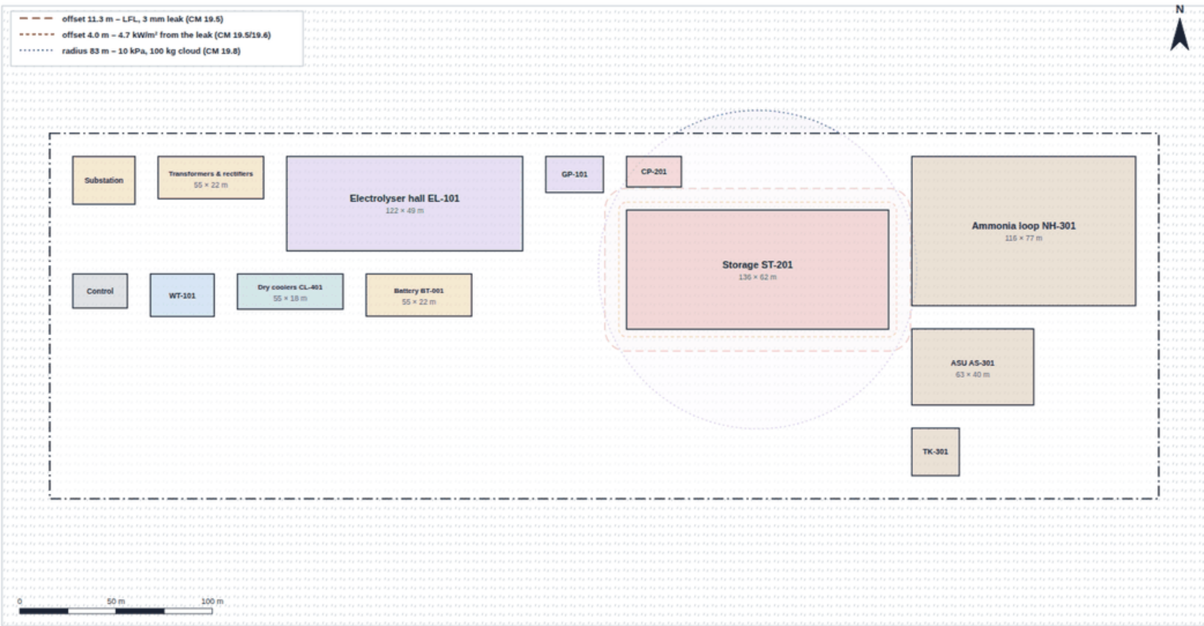
CMP-001 for Case B.

6.10 LAY-001 – Plot plan with safety distances

Areas of substation, rectifiers, electrolyser hall, gas processing, water plant, coolers, control building, compressor and storage yard and end use, placed to scale with roads; zones for the LFL distance, the 4.7 kW/m² radiation distance and the 10 kPa overpressure radius of a storage leak; the storage yard is placed beyond the largest of these distances and of the NFPA 2 separation distance, and a battery keeps the NFPA 855 clearance.

Hydrogen island – site 576 m × 190 m (10.91 ha inside the fence)

Blocks drawn to scale from the sizing of each system; storage yard placed beyond the LFL distance, the 4.7 kW/m² distance and the NFPA 2 group 1 distance.



SAFETY DISTANCES

Quantity	Value	Ref.
3 mm leak release at 100 bar	36.3 g/s	CM 19.1
Distance to LFL (4 vol-%)	11.3 m	CM 19.5
Jet-flame length	3.2 m	CM 19.5
Distance to 4.7 kW/m² (from the leak)	4.0 m	CM 19.6
Distance to 10 kPa (TNT, 10 % yield)	83 m	CM 19.8
NFPA 2 distance, group 1 / 2 / 3	7.5 / 6.8 / 6.2 m	NFPA 2
Separation applied to the storage yard	11.3 m	DM 18.3

NOTES

1. Off this sheet: PV-001 180 MWp (267 ha), WT-001 14 turbines.
2. Zones around ST-201: LFL of a 3 mm leak and 4.7 kW/m² jet-fire radiation (point source at the flame centre) as offsets from the yard boundary; 10 kPa blast as a radius.
3. Screening values – confirm with the code tables in force (NFPA 2 table 7.3.2.3.1.1(a), EIGA Doc 15) and a QRA (DM 18).
4. Oxygen vent VS-402 and hydrogen vent VS-401 on opposite sides, downwind of air intakes (DM 10.3, 18.4).
5. Battery BT-001: ≥ 3 m clearance to buildings, lot lines and combustibles, UL 9540A-tested units (NFPA 855).

Hasim Engineering Suite Software © 2026 Prof. Hani Muhsen	TITLE Plot plan with safety distances				
LEGAL OWNER –	DWG NO. LAY-001	REV. A	SCALE NTS	DATE OF ISSUE 2026-09-25	SHEET 1 / 1
PROJECT / SITE Case B – 100 MW AEL, islanded hybrid, a...	DOCUMENT TYPE Plot plan	CREATED BY Hasim (calculated)	APPROVED BY –		

Areas from DM 1.5 and chapter sizing; consequence distances CM 19.1–19.8.

LAY-001 for Case B.

7 Stream table and equipment list

7.1 Stream table

The stream table lists all numbered streams of the design point: from/to, phase, temperature, pressure, mass and volume flow, and the mass flow of each component (Figure 7.1). The coloured square shows the stream type. Click a row to inspect the stream, double-click to locate it on the PFD. **Export CSV** writes the complete table. The energy streams (AC input, DC power, stack heat, compressor power, heat rejection, hydrogen LHV) are listed below.

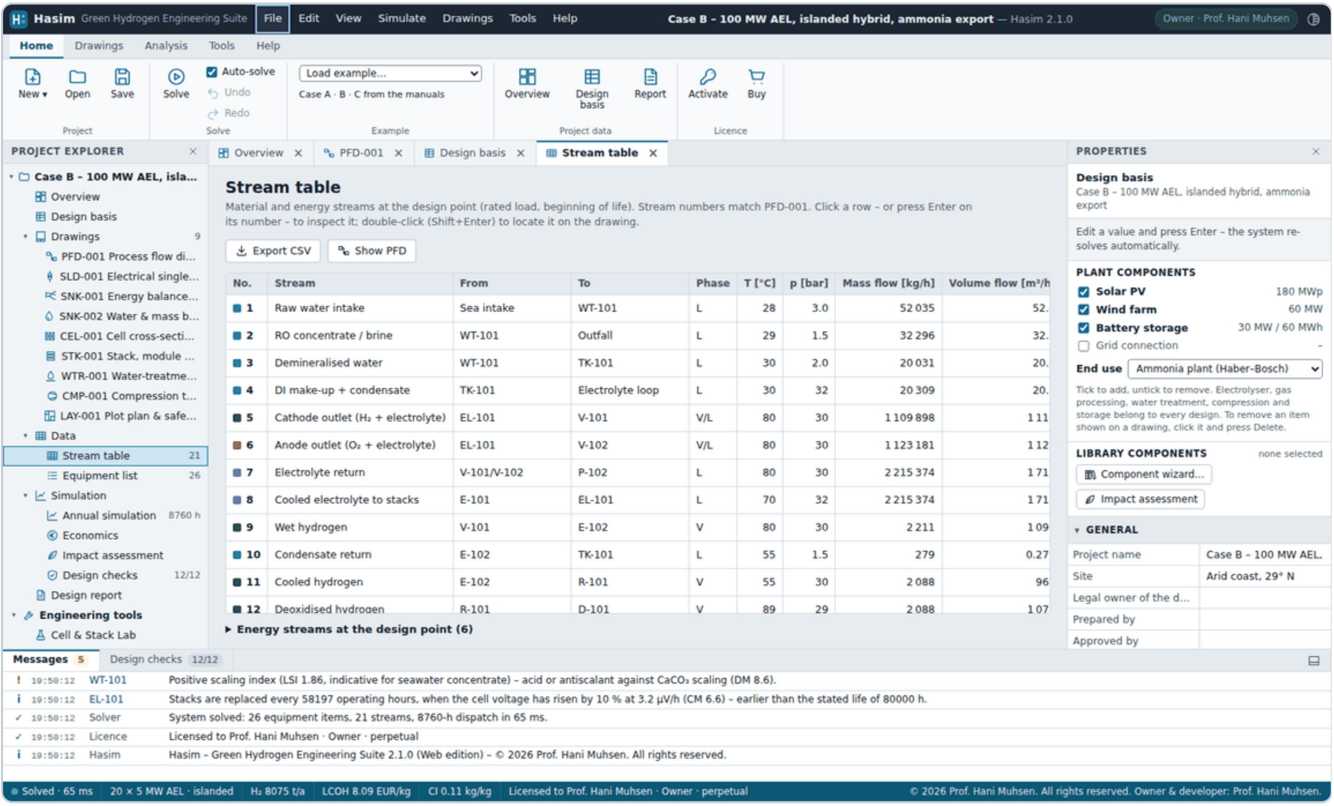


Figure 7.1 – Stream table of Case B.

No.	Stream	From → to	T [°C]	p [bar]	$\dot{m}$ [kg/h]
1	Raw water intake	Sea intake → WT-101	28	3	52 035
2	RO concentrate / brine	WT-101 → Outfall	29	1.50	32 296
3	Demineralised water	WT-101 → TK-101	30	2	20 031
5	Cathode outlet (H_2 + electrolyte)	EL-101 → V-101	80	30	1 109 898
9	Wet hydrogen	V-101 → E-102	80	30	2 212
13	Dry hydrogen 99.9989 %	D-101 → CP-201	55	29	1 908
14	Oxygen to vent	V-102 → VS-402	55	29.70	15 405
15	Compressed hydrogen	CP-201 → ST-201	55	100	1 908
16	Hydrogen to ammonia loop	ST-201 → NH-301	40	150	1 032
18	Nitrogen 99.999 %	AS-301 → NH-301	40	150	4 767
19	Liquid ammonia	NH-301 → TK-301	-33	1.10	5 625

7.2 Equipment list and datasheets

The equipment list groups the equipment by function – electrolysis, gas processing, compression, storage, water, utilities, safety, end use, power supply and electrical – with tag, description, quantity, key data and status. A warning chip indicates items with design warnings, for example scaling of the RO concentrate. Click an item to open its datasheet in the properties panel (Figure 3.3); **Export CSV** writes all datasheets.

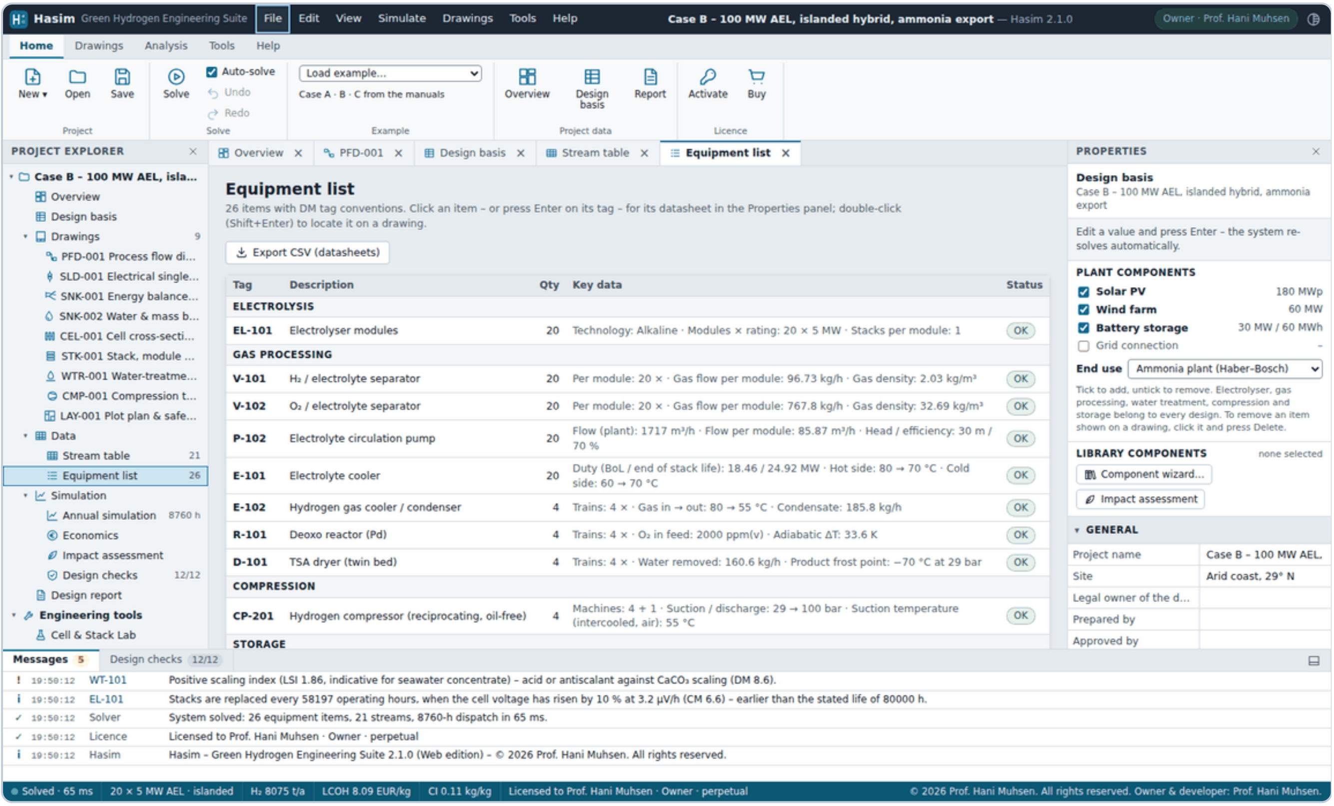


Figure 7.2 – Equipment list of Case B.

8 Annual simulation

The annual simulation dispatches the plant hour by hour over a synthetic typical year: solar geometry with a Markov clearness model scaled to the annual GHI, and an autoregressive wind series with the site's Weibull distribution (mean wind speed and shape factor k). The dispatch follows DM Fig. 4.2: renewable power first supplies the auxiliaries, then the electrolyser between minimum and rated load, then charges the battery; the remainder is curtailed. The battery bridges shortfalls to keep the electrolyser at minimum load; the grid tops up according to the grid mode. The storage inventory balances production against the offtake profile.

Result	Case A	Case B	Case C
Hydrogen [t/a]	1 050	8 075	155
Capacity factor	67.7 %	52.1 %	80.1 %
Full-load hours [h]	5 927	4 566	7 018
PV / wind / grid energy [GWh]	32.8 / 34.5 / 10.73	385.8 / 177.8 / 2.02	3.6 / 0 / 6.12
Curtailed share	20.4 %	11.8 %	4.3 %
Starts per year	1	219	7
Battery cycles [1/a]	0	170	0
Unserved auxiliary energy [MWh]	0	0.40	0

8.1 Models of the dispatch

The hourly dispatch contains the following models. They make the annual production the hydrogen that actually leaves the plant after gas processing, maintenance and ageing – the value compared with the demand by the design checks.

Model	What Hasim does	Reference
Solar resource	Hourly GHI → plane-of-array irradiance with the Erbs diffuse fraction, isotropic sky and ground reflection (albedo 0.2) for a fixed tilt or a single-axis tracker (tracking gain ≥ 1.18); the annual sum is scaled to gain × GHI. Cell temperature from the NOCT model and power with the temperature coefficient of the modules; DC/AC clipping at the inverters.	DM 3.2; Erbs et al. (1982)
Wind resource	Autoregressive series with daily and seasonal variation, mapped by rank onto the Weibull distribution of the site: mean wind at hub height and shape factor k (default 2) are reproduced exactly. The generic power curve (cut-in, rated, cut-out speed of the turbine) uses the wind speed corrected to the air density of the hour (ρ/1.225)^⅓; a loss allowance covers wakes, availability, electrical and other losses (18.8 % onshore and 15.5 % offshore by default, NREL Cost of Wind Energy Review 2024).	DM 3.3, IEC 61400-12-1; Stehly et al. (2024)
Availability	Every module is out of service for maintenance in six blocks per year, the modules staggered in time, so that the time-average equals the plant availability; one module means whole-plant outages, many modules a small derating.	DM 2.3
Minimum load	The minimum load of the design basis, raised if necessary to the load at which hydrogen in oxygen reaches the 2 % trip (crossover by Fick permeation, CM 7.6/7.7). A PEM stack lowers its cathode pressure below this load in proportion to the load, down to 10 bar, so that hydrogen in oxygen stays at the trip; the minimum load is then the one at 10 bar (about 10 %), and the hydrogen produced at part load is compressed from the lower pressure.	CM 7.7, ISO 22734-1; Scheepers et al. (2020)

Model	What Hasim does	Reference
Stack ageing	Stacks are replaced at their stated life or when the cell voltage has risen by 10 %, whichever comes first; the specific energy uses the life-average voltage rise (half of the rise at replacement). The replacements within the economic life enter the LCOH and the impact assessment.	CM 6.6, DM 9.1
Gas processing	Oxygen in the raw hydrogen is converted in the deoxo with twice its amount of hydrogen, and the TSA dryer loses 1 % as regeneration purge; the product is the stack output less these losses.	CM 8.4, DM 10
SOEC heat	Below the thermoneutral voltage the stack needs $k_{SEC} \cdot (E_{tn} - E)$ of heat per kg, and raising the steam about 6.6 kWh per kg of hydrogen – from electric heaters (in the SEC) or from external heat at the heat price.	CM 3.12
Grid and surplus	Grid use: bridge to the minimum load, fill to a target load or always full load. PPA electricity the electrolyser cannot use is curtailed or sold at the export price; only sold surplus supports the monthly RFNBO correlation.	DM 4.2, 4.6
Compression	Number of stages from the discharge-temperature limit (API 618: 120 °C for hydrogen), suction at 40 °C or 10 K above the ambient after the intercoolers.	CM 10.4, DM 12.1

8.2 Live power flow

The power-flow view shows any hour of the year: arrow widths scale with power, the battery shows its state of charge and the storage its inventory. Drag the slider, use the quick buttons (summer noon, winter night, windy day) or press **Play** to animate the year at 1 hour, 3 hours or 1 day per step (Figure 8.1).

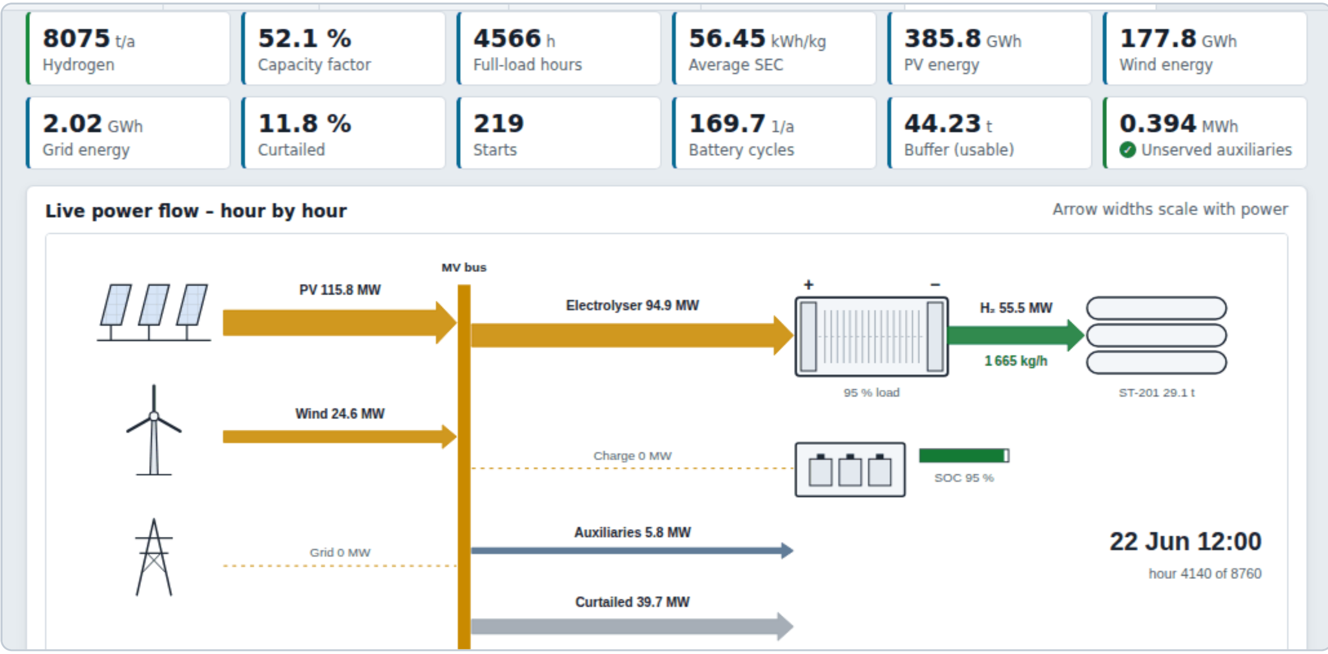


Figure 8.1 – Live power flow of Case B at noon on 22 June.

8.3 Charts

The document continues with the one-week power balance (choose the week with the slider), battery state of charge and hydrogen production, monthly energy, the electrolyser load-duration curve, the storage inventory and a heat map of the electrolyser load by hour of day and day of year (Figure 8.2). Every chart offers **Table**, **CSV** and **SVG**; **Export hourly CSV** writes all 8760 hours.

Figure 8.2 – Monthly energy, load-duration curve, storage inventory and load heat map.

9 Economics, sensitivity and impact assessment

The levelised cost of hydrogen follows DM 20.2 / CM 17.3: annualised CAPEX (capital recovery factor from WACC and life) plus the present value of the stack replacements of the annual simulation (CM 6.6) and of other replacements within the economic life (power electronics and battery, at the life of their components), fixed O&M, electricity – including a sold PPA surplus at the difference between the PPA and the export price –, external heat of an SOEC, water and by-product credits, divided by the simulated annual production after gas processing. The economics document shows the LCOH from the 8760-hour simulation and from the design chain, the CAPEX build-up and the LCOH breakdown. The stacks of Case A are replaced 5 times in 25 years (PEM, limited by the voltage degradation), those of Case B three times (alkaline, stack life 58 197 h).

LCOH component [EUR/kg]	Case A	Case B	Case C
capital	2.88	5.80	5.78
stacks	0.81	0.33	0.96
other replacements	0.05	0.13	0.00
O&M	1.48	1.81	2.84
electricity	4.90	0.02	5.55
water	0.03	0.00	0.03
by-products	0.00	0.00	0.00
Total	**10.14**	**8.09**	**15.16**

9.1 Sensitivity analysis

Run sensitivity varies the key parameters one at a time – electrolyser CAPEX, WACC, other direct costs, fixed OPEX, stack share and, depending on the supply concept, electricity price and PPA share or PV/wind/battery CAPEX and the solar and wind resource – and re-solves the complete system for each case. The tornado chart ranks the parameters by their LCOH swing (Figure 9.1).

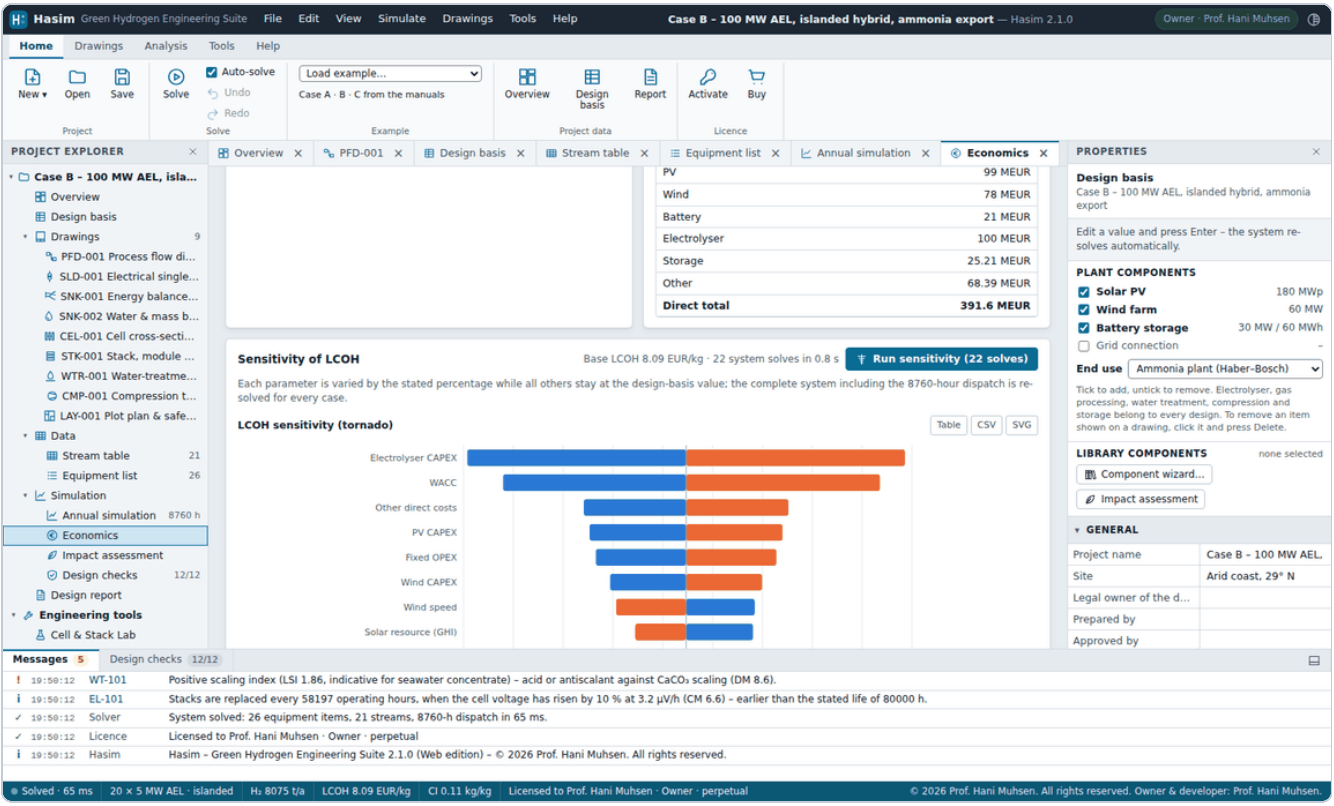


Figure 9.1 – LCOH sensitivity of Case B.

9.2 Impact assessment

Simulate ▸ Impact assessment (also Analysis ▸ Impacts, the project explorer and the Overview card *Impacts at a glance*, Figure 9.3) evaluates the solved plant together with its components (Figure 9.2). The buttons at the top show all sections or one of them:

- **Performance** – production, capacity factor, full-load hours, specific energy, plant electricity per kg and plant efficiency, renewable share, curtailment, starts, and every design and component check.
- **Economic** – investment and specific investment, a conversion plant that is levelised separately, LCOH, running cost, net present value (NPV), internal rate of return (IRR) and payback at the hydrogen value of the settings, local content and local spending; the investment by component and the component inventory (Figure 9.4).
- **Environmental** – life-cycle carbon intensity with its parts, the carbon intensity of the RFNBO design check, CO_2 avoided against grey hydrogen, embodied emissions, water withdrawal, water intensity and brine, land occupied and total project area, platinum-group metals; embodied emissions and land by component (Figure 9.5).
- **Social** – construction and manufacturing jobs (job-years) and their local part, permanent operation and maintenance jobs (full-time equivalents, FTE), jobs per MW, local content, the water-stress risk with the fresh water expressed as the domestic use of a number of people, land, the largest hazard distance of a storage leak, the Seveso III tiers of the hydrogen and ammonia inventories and the exposure of the site boundary and of the nearest residents (Figure 9.6).
- **Method** – the settings, notes on the inventory, the method and the sources used.

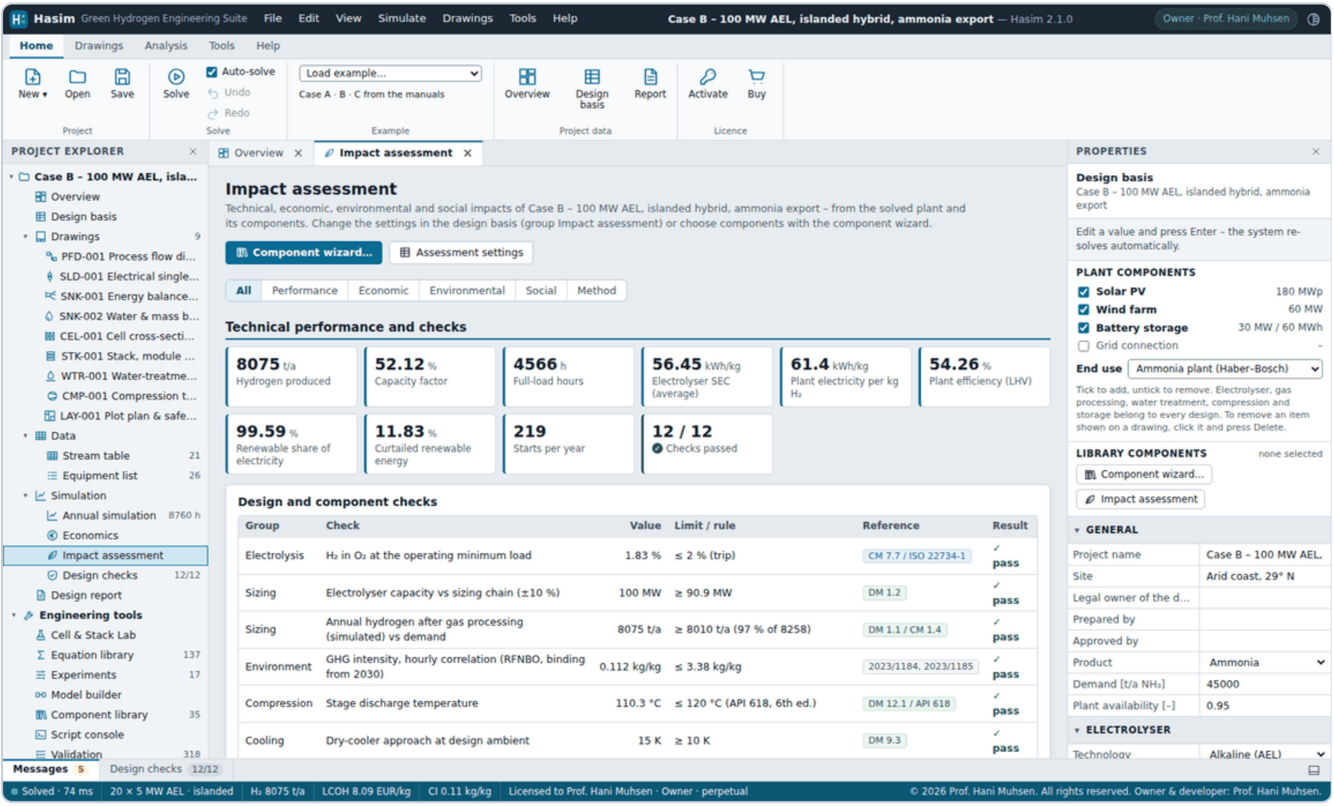


Figure 9.2 – The impact assessment of Case B: technical performance and the design checks.

Figure 9.3 – Impacts at a glance on the Overview of Case B.

Indicator	Case A	Case B	Case C
Labour-productivity region	OECD (× 1)	Middle East (× 2)	Middle East (× 2)
Water source · baseline water stress	fresh · low–medium	seawater · extremely high	fresh · high
Investment [MEUR]	35.2	500 + 74.2 ammonia plant	8.8
LCOH [EUR/kg]	10.14	8.09	15.16
NPV at 6 EUR/kg [MEUR] · IRR	-50.7 · –	-180.5 · 3.8 %	-13.9 · –
Local content of the investment	27.5 %	31.5 %	34.4 %
Life-cycle carbon intensity [kg CO_2e/kg] (electricity + equipment)	5.03 (3.06 + 1.97)	2.02 (0.11 + 1.91)	19.21 (17.81 + 1.40)
Carbon intensity of the RFNBO check [kg CO_2e/kg]	3.06	0.11	17.81
Embodied emissions of the equipment [kt CO_2e]	51.7	385.7	4.3
Water withdrawal [m^3/a] · water-stress risk	13 126 · low	214 897 · low	2 269 · high
Land occupied · total project area [ha]	44.6 · 562	334.8 · 2 405	3.8 · 4
Construction · manufacturing jobs [job-years]	116 · 134	1 618 · 1 767	26 · 26
Permanent O&M jobs [FTE]	11.6	212.3	2.9
Seveso III (hydrogen · ammonia)	lower tier	upper tier · upper tier	below threshold

The table compares the three examples with the default components. At a hydrogen value of 6 EUR/kg only Case B earns back part of its investment (IRR 3.8 %, below its WACC of 8 %); at a hydrogen value equal to the LCOH the NPV is exactly zero, so the levelised cost and the cash-flow view are consistent. Case B, with its own PV and wind plants in the Middle East region, creates about 1 600 construction job-years and 212 permanent jobs. Per MW of electrolyser, construction needs 11.6 (A), 16.2 (B) and 20.6 (C) job-years – small plants carry more fixed equipment per MW. Case C draws fresh water in a region of high water stress: the risk is flagged *high*.

Life-cycle carbon intensity and the RFNBO check

The **life-cycle carbon intensity** adds the embodied emissions of all equipment – including PV and wind plants bought through a PPA – to the emissions of the electricity and of transport. It is a screening life-cycle value for comparing designs and components. The **design check** of the carbon intensity (CM 18.1, DM 4.6) follows the RFNBO methodology of Delegated Regulation (EU) 2023/1185: grid electricity at the emission factor of the grid, renewable electricity at zero, plus transport and conversion – the emissions of manufacturing the equipment are not counted. It decides whether the hydrogen qualifies as renewable. For Case A the two values are 5.03 and 3.06 kg CO_2e/kg.

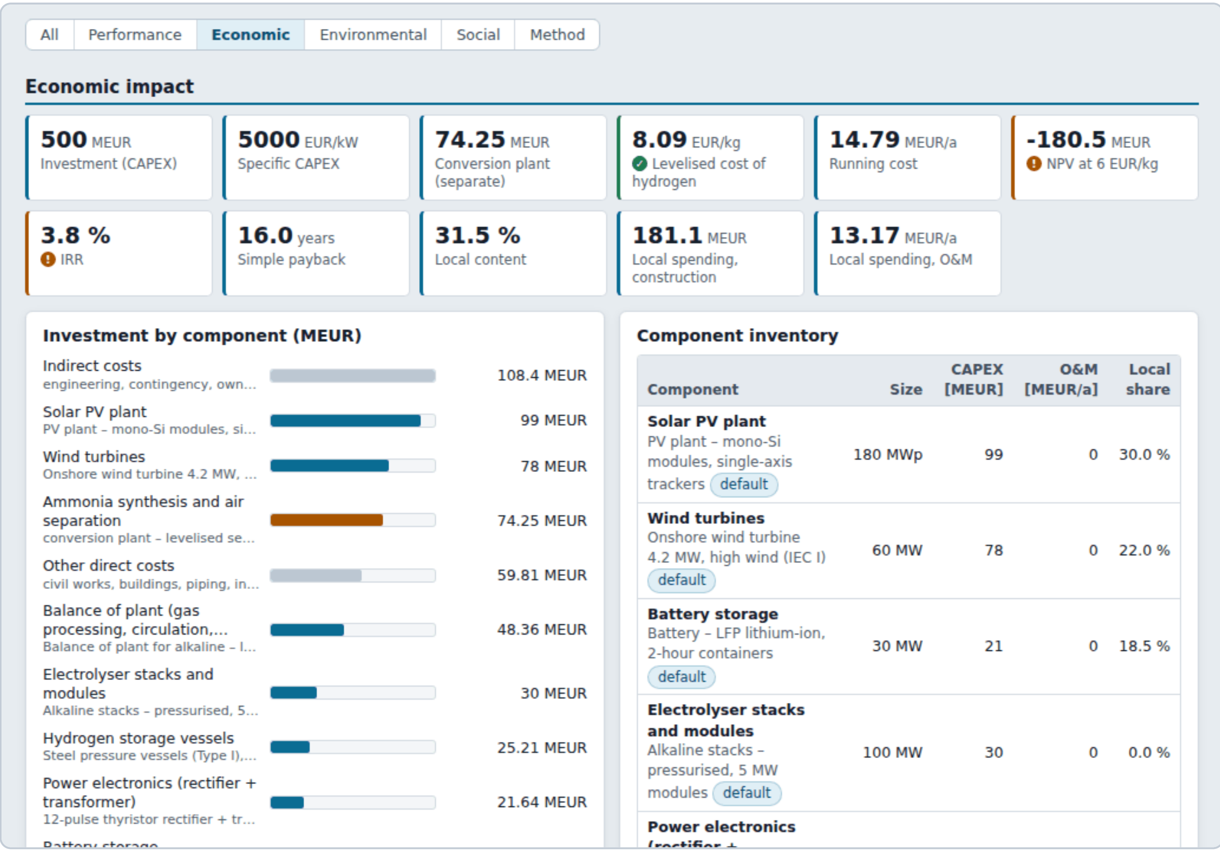


Figure 9.4 – Economic impact of Case B: investment by component and the component inventory.

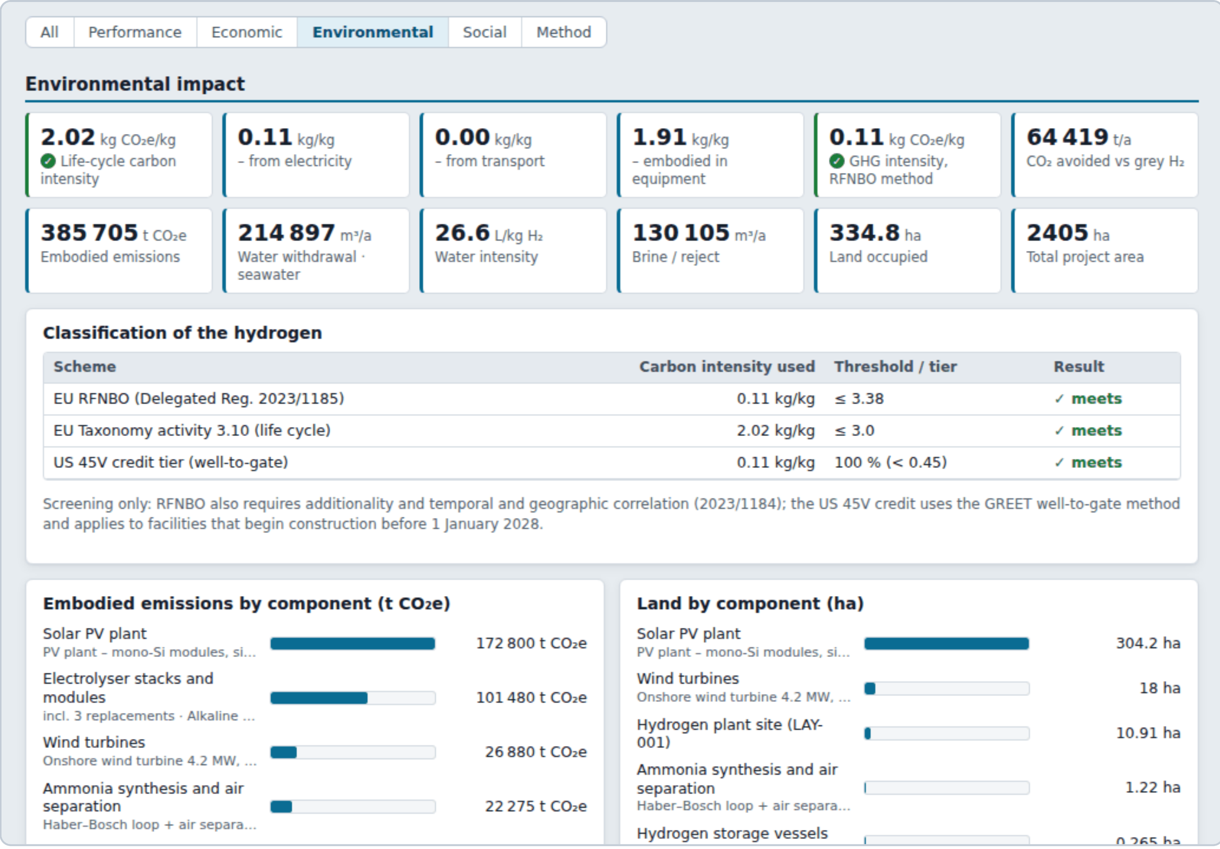


Figure 9.5 – Environmental impact of Case B: carbon intensity, embodied emissions, water and land.

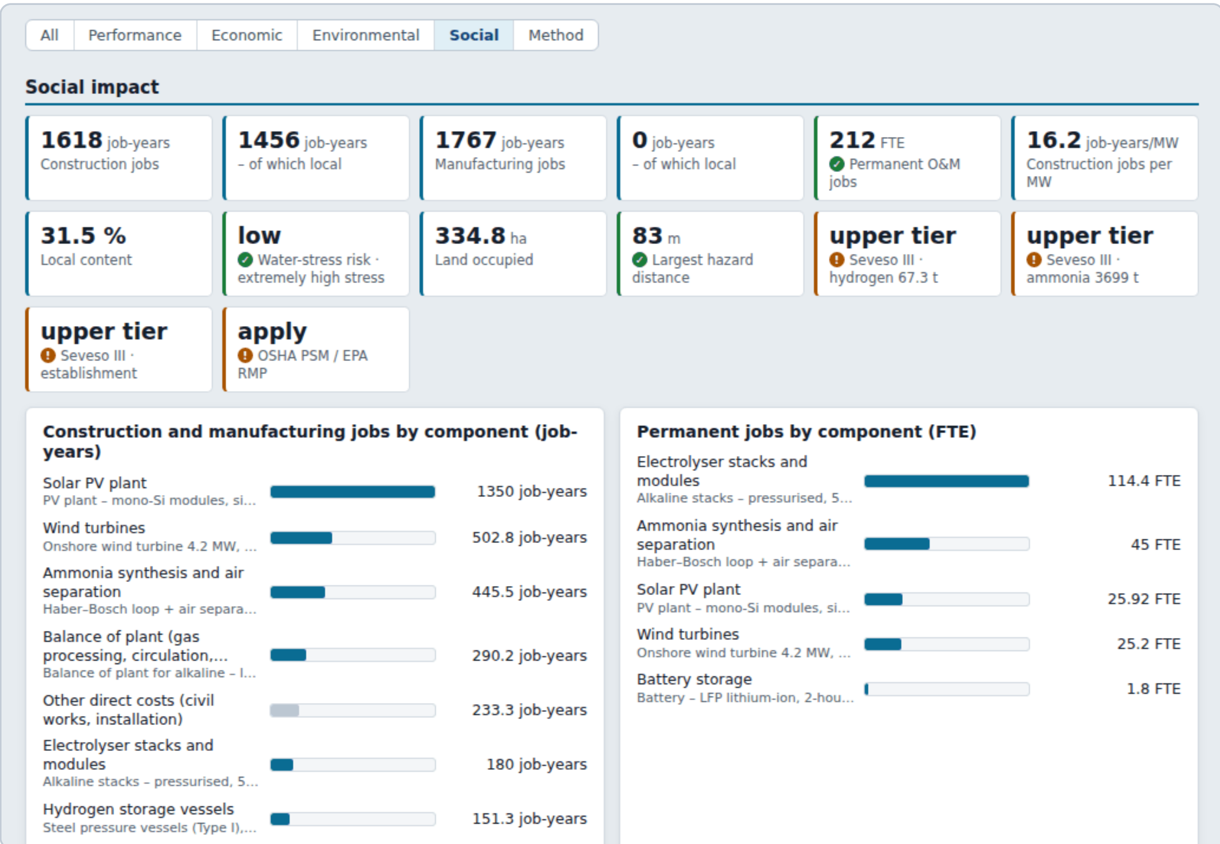


Figure 9.6 – Social impact of Case B: jobs by component, local content, water-stress risk and safety.

Assessment settings opens the design basis at the group **Impact assessment**: labour-productivity region, local shares of equipment supply, installation and services, baseline water stress, the distances from the storage yard to the site boundary and to the nearest residents, and the hydrogen value for NPV and IRR. The New Project wizard presets the region and the water stress from the climate of the site. The **design report** contains the assessment as section 8 (economic, environmental, social, equipment and components).

9.3 Method of the impact assessment

The assessment combines the solved model with an **inventory**: every equipment item with its size, investment, fixed O&M and component. In a plant project, PV, wind, battery, electrolyser and storage carry the costs of the design basis – the electrolyser is split into stacks, power electronics and balance of plant with the cost shares of their components. The water plant, compressor, pipeline, trailers and refuelling station are priced with the unit costs of their components inside the other direct costs of the design basis; if they exceed them, they are scaled down and a note shows the value of “Other direct costs (× electrolyser)” that includes them in full. An ammonia plant is an item outside the hydrogen plant: it is levelised separately as the cost of ammonia (CM 17.6) but counted in local content, jobs, emissions and land. In a Model-builder chain every block adds its equipment and costs.

Indicator	Calculation
Jobs	J = f × Q × m. The employment factor f of the component refers to its size Q (per MWp, MW, MWh, m^3/d, kg …), to its investment in MEUR, to the hydrogen output in MW (LHV) or to the number of drivers; m is the multiplier of the labour-productivity region. Construction and installation and manufacturing in job-years, operation and maintenance in full-time equivalents (FTE). Other direct costs add 1.5 job-years per MEUR for construction and, on their 30 % equipment share, 1.5 job-years per MEUR for manufacturing.
Local content	Share of the investment (incl. a conversion plant) spent in the country: Σ CAPEX × (equipment share × local equipment supply + installation share × local installation + services share × local services); other direct costs split 30/60/10 %, indirect and owner’s costs at the local share of services. Local construction jobs = construction jobs × local installation share; local manufacturing jobs = manufacturing jobs × local equipment share; local O&M spending = fixed O&M × local installation share.
Embodied emissions	E = e × Q × (1 + n) with n replacements over the economic life (stacks: replacements of the annual simulation). Other direct costs are counted with 0.3 kg CO_2e per EUR (spend-based).
Carbon intensity	$CI_{life} = CI_{electricity} + CI_{transport} + E \div$ (hydrogen per year × economic life). CO_2 avoided = $(10 - CI_{life})$ × hydrogen per year, against steam methane reforming at about 10 kg CO_2e/kg (CM 18.2).
Water	Raw-water withdrawal of the annual simulation, water intensity in litres per kg of hydrogen, brine = raw water − demineralised water. Fresh water is also expressed as the domestic use of people at 100 litres per person and day (UN/WHO: 50–100 L).
Water-stress risk	Seawater → low. Brackish water → medium in high or extremely high baseline water stress, otherwise low. Fresh water → high in high or extremely high stress, medium in medium–high stress, otherwise low.
Land	Land factor × size of every component plus, for a plant, the site of the plot plan (LAY-001), which contains the electrolyser area. The total project area adds the spacing area of the wind farm, which remains usable for other purposes.
Safety exposure	Distances of a 3 mm leak from the storage at its maximum pressure: lower flammability limit (CM 19.5), thermal radiation of 4.7 kW/m² (CM 19.6) and 10 kPa overpressure of a cloud of up to 100 kg (CM 19.8), compared with the distances to the site boundary and to the residents. Seveso III (2012/18/EU): hydrogen against 5 t / 50 t and ammonia in the product tank (30 days of production) against 50 t / 200 t, combined with the summation rule of Annex I note 4 (lower / upper tier); OSHA PSM and EPA RMP apply above 10 000 lb (4.5 t).
NPV, IRR, payback	NPV = −(CAPEX + present value of stack replacements) + (revenue − running cost) × annuity factor (WACC, life); revenue = hydrogen × hydrogen value; running cost = fixed O&M + electricity + water − by-product credits. IRR: discount rate at which NPV = 0; payback = investment ÷ annual net cash flow.

Setting (design basis ▸ Impact assessment)	Default	Options
Labour-productivity region	OECD (× 1)	OECD × 1, Middle East × 2, Latin America × 2.3, China × 1.3, India × 1.4, Developing Asia × 1.5, Africa × 6.8, Transition economies × 1.7
Local share of equipment supply	0 %	0 … 100 %
Local share of installation, civil works	90 %	0 … 100 %
Local share of engineering, services	50 %	0 … 100 %
Baseline water stress	Medium–high (20–40 %)	Low (< 10 %), Low–medium (10–20 %), Medium–high (20–40 %), High (40–80 %), Extremely high (> 80 %)
Distance storage – site boundary	100 m	0 … 100 km
Distance to the nearest residents	1000 m	0 … 1 000 km
Hydrogen value for NPV and IRR	6 EUR/kg	0 … 50 EUR/kg

The regional multipliers express the lower labour productivity outside the OECD (more workers for the same equipment) after Rutovitz & Usher (2010), interpolated to 2026 [4]; the employment factors themselves are OECD values [3]. The water-stress classes are those of WRI Aqueduct 4.0 [16]. Choose the region and the stress class of your site – the wizard does it from the climate preset.

9.4 Default values and sources

The library values are **screening values** for concept studies – typical published figures of 2022–2025 or documented Hasim assumptions. Every component lists its sources (Component library ▸ *Sources of the default values*). Replace the values with vendor quotations, environmental product declarations (EPDs) and local labour studies for your project: duplicate a component to your library and edit it (section 11.4). The table lists all components with the units of their category line; the shares split the investment into equipment / installation and civil works / engineering and services for the local content. Numbers refer to the list of sources below.

Component	CAPEX	O&M [1/a] · life [a]	Embodied	Land	Jobs C&I	Jobs mfg.	Jobs O&M	Shares [%]	Sources
Solar PV plant – size in MWp · CAPEX EUR/kWp · embodied kg CO_2e/kWp · land ha/MWp · jobs per MWp									
PV plant – mono-Si modules, fixed tilt	500	0.015 · 30	960	1.15	1.29	2.46	0.072	60 / 25 / 15	2, 3, 7, 9, 10, 20
PV plant – mono-Si modules, single-axis trackers	550	0.015 · 30	960	1.69	1.29	2.46	0.072	60 / 25 / 15	2, 3, 7, 9, 10, 20
PV plant – bifacial glass-glass modules, single-axis trackers	580	0.015 · 30	900	1.69	1.29	2.46	0.072	60 / 25 / 15	3, 7, 9, 20
Wind turbines – size in MW · CAPEX EUR/kW · embodied kg CO_2e/kW · land ha/MW (direct) · jobs per MW									
Onshore wind turbine 5 MW class, medium wind (IEC II)	1300	0.025 · 25	448	0.3	2.65	1.54	0.21	72 / 20 / 8	2, 3, 8, 11, 19, 20
Onshore wind turbine 4.5 MW, large rotor for low wind (IEC III)	1400	0.025 · 25	448	0.3	2.65	1.54	0.21	72 / 20 / 8	3, 8, 11, 19, 20
Onshore wind turbine 4.2 MW, high wind (IEC I)	1250	0.025 · 25	448	0.3	2.65	1.54	0.21	72 / 20 / 8	3, 8, 11, 19, 20

Component	CAPEX	O&M [1/a] · life [a]	Embodied	Land	Jobs C&I	Jobs mfg.	Jobs O&M	Shares [%]	Sources
Offshore wind turbine 15 MW, fixed-bottom (IEC I)	2650	0.025 · 25	887	0	1.5	13.68	0.28	60 / 30 / 10	3, 19, 20
Battery storage – size in MW · CAPEX EUR/kWh · embodied kg CO_2e/kWh · land m^2/MWh · jobs per MW									
Battery – LFP lithium-ion, 2-hour containers	350	0.02 · 15	90.8	20	0.53	0.31	0.03	75 / 15 / 10	2, 3, 12, 20
Battery – LFP lithium-ion, 4-hour containers	300	0.02 · 15	90.8	15	0.53	0.31	0.03	75 / 15 / 10	3, 12, 20
Water treatment plant – size in m^3/d · CAPEX EUR per m^3/d · embodied kg CO_2e per m^3/d · land m^2 per m^3/d · jobs per m^3/d									
Seawater RO with energy recovery + second pass + EDI	3500	0.05 · 25	1050	0.8	1.5/MEUR	1.5/MEUR	0	60 / 30 / 10	2, 20
Brackish-water RO + EDI polishing	2000	0.05 · 25	600	0.5	1.5/MEUR	1.5/MEUR	0	60 / 30 / 10	20
Municipal water: RO + EDI polishing	1500	0.05 · 25	450	0.4	1.5/MEUR	1.5/MEUR	0	60 / 30 / 10	2, 20
Electrolyser stacks and modules – size in MW · CAPEX EUR/kW · embodied kg CO_2e/kW · land m^2/MW (plant incl. BoP) · jobs per MW									
PEM stacks – 5 MW modules	675	0.025 · 25	137.5	250	1.5/MEUR	1.5/MEUR	0.9/MW H_2	100 / 0 / 0	1, 6, 13, 14, 15, 20
Alkaline stacks – pressurised, 5 MW modules	450	0.025 · 25	253.7	350	1.5/MEUR	1.5/MEUR	0.9/MW H_2	100 / 0 / 0	1, 6, 13, 15, 20
Alkaline stacks – large pressurised, 10 MW modules	420	0.025 · 25	253.7	330	1.5/MEUR	1.5/MEUR	0.9/MW H_2	100 / 0 / 0	1, 6, 13, 20
AEM stacks – 1 MW modules	230	0.025 · 25	99.2	300	1.5/MEUR	1.5/MEUR	0.9/MW H_2	100 / 0 / 0	1, 6, 13, 15, 20
Solid-oxide stacks – 1 MW modules	660	0.025 · 25	102.6	400	1.5/MEUR	1.5/MEUR	0.9/MW H_2	100 / 0 / 0	1, 6, 13, 15, 20
Power electronics (rectifier + transformer) – size in MW · CAPEX EUR/kW · embodied kg CO_2e/kW · land m^2/MW · jobs per MW									
IGBT active front-end rectifier + transformer	200	0.01 · 20	60	0	1.5/MEUR	1.5/MEUR	0	100 / 0 / 0	1, 20
12-pulse thyristor rectifier + transformer + harmonic filter	170	0.01 · 20	51	0	1.5/MEUR	1.5/MEUR	0	100 / 0 / 0	2, 20
Balance of plant (gas processing, circulation, cooling) – size in MW · CAPEX EUR/kW · embodied kg CO_2e/kW · land m^2/MW · jobs per MW									
Balance of plant for PEM – water loop, separators, deoxo + dryer, dry coolers	625	0.025 · 25	187.5	0	1.5/MEUR	1.5/MEUR	0	80 / 20 / 0	1, 20
Balance of plant for alkaline – lye loop, separators, deoxo + dryer, dry coolers	380	0.025 · 25	114	0	1.5/MEUR	1.5/MEUR	0	80 / 20 / 0	1, 20
Balance of plant for AEM	720	0.025 · 25	216	0	1.5/MEUR	1.5/MEUR	0	80 / 20 / 0	1, 20
Balance of plant for SOEC – steam generator, recuperators, hot box	1340	0.025 · 25	402	0	1.5/MEUR	1.5/MEUR	0	80 / 20 / 0	1, 20
Hydrogen compressor – size in kW · CAPEX EUR/kW · embodied kg CO_2e/kW · land m^2/kW · jobs per kW									
Reciprocating piston compressor, oil-free	3000	0.04 · 20	900	0	1.5/MEUR	1.5/MEUR	0	80 / 15 / 5	2, 20
Diaphragm compressor for small flows and high pressure	4500	0.05 · 20	1350	0	1.5/MEUR	1.5/MEUR	0	80 / 15 / 5	20
Hydrogen storage vessels – size in kg · CAPEX EUR/kg usable · embodied kg CO_2e/kg usable · land m^2/kg usable · jobs per kg									
Steel pressure vessels (Type I), up to 300 bar	600	0.02 · 30	180	0.06	1.5/MEUR	1.5/MEUR	0	70 / 25 / 5	2, 20

Component	CAPEX	O&M [1/a] · life [a]	Embodied	Land	Jobs C&I	Jobs mfg.	Jobs O&M	Shares [%]	Sources
Composite vessels (Type III/IV), 350–500 bar	900	0.02 · 25	270	0.025	1.5/MEUR	1.5/MEUR	0	70 / 25 / 5	2, 20
Hydrogen pipeline – size in km · CAPEX MEUR/km · embodied t CO_2e/km · land ha/km (right of way) · jobs per km									
Steel pipeline DN300 (L360 / X52), buried	1.2	0.01 · 40	360	2	1.5/MEUR	1.5/MEUR	0.05	40 / 50 / 10	2, 20
Steel pipeline DN100, short connection	0.65	0.01 · 40	195	1.5	1.5/MEUR	1.5/MEUR	0.05	40 / 50 / 10	2, 20
Tube trailers – size in trailers · CAPEX MEUR per trailer · embodied t CO_2e per trailer · land m² per trailer · jobs per trailer									
Tube trailer – steel tubes, 200 bar	0.35	0.03 · 20	105	0	0	1.5/MEUR	1 × drivers	100 / 0 / 0	1, 20
Tube trailer – composite tubes, 500 bar	0.9	0.03 · 20	270	0	0	1.5/MEUR	1 × drivers	100 / 0 / 0	1, 20
Refuelling station – size in t/d · CAPEX MEUR per t/d · embodied t CO_2e per t/d · land m² per t/d · jobs per t/d									
Refuelling station 70 MPa – booster, 900 bar cascade, pre-cooling	3	0.05 · 20	900	1200	1.5/MEUR	1.5/MEUR	1.5	70 / 25 / 5	2, 20
Ammonia synthesis and air separation – size in t/a · CAPEX EUR per t/a · embodied kg CO_2e per t/a · land m² per t/a · jobs per t/a									
Haber–Bosch loop + air separation (electrically driven)	1650	0.03 · 25	495	0.27	1.5/MEUR	1.5/MEUR	0.0005	60 / 30 / 10	1, 2, 20
Methanol synthesis – size in t/a · CAPEX EUR per t/a · embodied kg CO_2e per t/a · land m² per t/a · jobs per t/a									
Methanol synthesis from captured CO_2	900	0.03 · 25	270	0.2	1.5/MEUR	1.5/MEUR	0.0005	60 / 30 / 10	1, 20
Fuel-cell power system – size in kW · CAPEX EUR/kW · embodied kg CO_2e/kW · land m²/kW · jobs per kW									
PEM fuel-cell power system	2000	0.03 · 10	600	0.05	1.5/MEUR	1.5/MEUR	0	85 / 10 / 5	1, 20

Jobs: construction and installation (C&I) and manufacturing in job-years, operation and maintenance in FTE – per size unit of the category line, per MEUR of investment (/MEUR), per MW of hydrogen output (/MW H_2) or per driver of the trailer trips (× drivers), for OECD labour productivity. Shares: equipment / installation and civil works / engineering and services of the investment.

Sources

1. Green Hydrogen Calculations Manual, Ed. 3 (CM) – cell, stack, system and cost equations used by Hasim.
2. Green Hydrogen Plant Design Manual, Ed. 1 (DM) – plant design values used by Hasim (e.g. water-plant and storage costs, example cases).
3. Rutovitz J., Langdon R., Briggs C., Mey F., Dominish E., Nagrath K. (2025). Updated employment factors and occupational shares for the energy transition. Renewable and Sustainable Energy Reviews 212, 115339.
4. Rutovitz J., Usher J. (2010). Methodology for calculating energy sector jobs. Institute for Sustainable Futures, University of Technology Sydney – regional job multipliers (Table 5), interpolated to 2026.
5. IRENA (2017). Renewable energy benefits: leveraging local capacity for solar PV / for onshore wind. International Renewable Energy Agency, Abu Dhabi.
6. Ganter A., Lonergan K.E., Büchi H.M., Sansavini G. (2024). Shifting to low-carbon hydrogen production supports job creation but does not guarantee a just transition. One Earth 7(11), 1981–1993.
7. Bolinger M., Bolinger G. (2022). Land requirements for utility-scale PV: an empirical update on power and energy density. Lawrence Berkeley National Laboratory / IEEE Journal of Photovoltaics.
8. Denholm P., Hand M., Jackson M., Ong S. (2009). Land-use requirements of modern wind power plants in the United States. NREL/TP-6A2-45834.
9. Reichel C. et al. (2022). CO_2 emissions of silicon photovoltaic modules – impact of module design and production location. Fraunhofer ISE, 8th World Conference on Photovoltaic Energy Conversion (WCPEC-8).
10. IEA PVPS Task 12 (2024). Fact sheet: environmental life cycle assessment of electricity from PV systems (2023 update).
11. Vestas Wind Systems (2025). Life cycle assessment of electricity production from an onshore V163-4.5 MW wind plant.

12. Lin X. et al. (2024). Environmental impact analysis of lithium iron phosphate batteries for energy storage in China. Frontiers in Energy Research 12, 1361720.
13. Wei et al. (2024). Comparative life cycle analysis of electrolyzer technologies for hydrogen production: manufacturing and operations. Joule 8(12).
14. U.S. Department of Energy (status 2022). Technical targets for proton exchange membrane electrolysis – PGM loading 0.8 g/kW, stack 450 of 1 000 USD/kW system cost, degradation 4.8 mV/1000 h, stack life 40 000 h (+10 % voltage).
15. Corbeau A.-S., Merz A.-K. (2023). Demystifying electrolyzer production costs. Center on Global Energy Policy, Columbia University – stacks are 19–60 % of electrolyser system cost.
16. Kuzma S. et al. (2023). Aqueduct 4.0: updated decision-relevant global water risk indicators. World Resources Institute – baseline water stress classes.
17. Directive 2012/18/EU (Seveso III), Annex I Part 2 – qualifying quantities: hydrogen 5 t / 50 t, ammonia (anhydrous) 50 t / 200 t (lower / upper tier).
18. UN General Assembly resolution 64/292 and WHO guidance: 50–100 litres of water per person per day meet most basic needs.
19. IEC 61400-1: wind-turbine classes I / II / III for annual mean wind speeds at hub height of 10 / 8.5 / 7.5 m/s.
20. Hasim assumption – a documented screening value (User Manual, section 9.4); replace it with project or vendor data.

Documented Hasim assumptions [20]

- Process equipment without a published factor (water plant, power electronics, balance of plant, compressors, vessels, pipelines, trailers, refuelling stations, conversion plants) and the other direct costs: embodied emissions of 0.3 kg CO_2e per EUR of investment (spend-based), 1.5 construction and 1.5 manufacturing job-years per MEUR.
- Costs of components that the manuals do not give (bifacial PV, the low-wind and high-wind turbines, 4-hour batteries, brackish-water RO, diaphragm compressors, large alkaline modules) are typical 2025 market values; the balance of plant is the technology cost of CM minus stacks and power electronics.
- Seveso III and OSHA PSM / EPA RMP: the hydrogen inventory is the storage at maximum pressure and at the lowest site temperature, plus tube trailers, the refuelling cascade and the process hold-up; the ammonia tank holds 30 days of production. Grey hydrogen for the avoided CO_2: 10 kg CO_2e/kg. Domestic water use: 100 L per person and day.

10 Design checks and the design report

After each solve Hasim checks the design against the rules of both manuals and against the codes, standards and regulations named in each check (section 10.1). Failed checks appear in the design-checks document, in the bottom panel and as warnings in the message log. The limit column states the acceptance criterion – the production check, for example, accepts 97 % of the demand.

Group	Check	Value	Limit	Reference	Case B
Electrolysis	H_2 in O_2 at the operating minimum load	1.83 %	≤ 2 % (trip)	CM 7.7 / ISO 22734-1	pass
Sizing	Electrolyser capacity vs sizing chain (±10 %)	100 MW	≥ 90.9 MW	DM 1.2	pass
Sizing	Annual hydrogen after gas processing (simulated) vs demand	8 075 t/a	≥ 8010 t/a (97 % of 8258)	DM 1.1 / CM 1.4	pass
Environment	GHG intensity, hourly correlation (RFNBO, binding from 2030)	0.11 kg/kg	≤ 3.38 kg/kg	2023/1184, 2023/1185	pass
Compression	Stage discharge temperature	110.3 °C	≤ 120 °C (API 618, 6th ed.)	DM 12.1 / API 618	pass
Cooling	Dry-cooler approach at design ambient	15 K	≥ 10 K	DM 9.3	pass
Water	Brine diffuser dilution (≤ +1.5 g/L at the edge of the mixing zone)	69.62 –	≥ 20	DM 8.8	pass
Power	Unserved auxiliary energy	0.39 MWh/a	= 0 MWh	DM 4.3	pass
Power	Energy balance closure	0 GWh	< 0.01 GWh	solver	pass
Power	Site wind within the turbine class (IEC I)	8.60 m/s	≤ 10 m/s	IEC 61400-1	pass
Safety	Storage separation to the process area	12 m	≥ 11.3 m (LFL, 4.7 kW/m², NFPA 2 group 1)	CM 19 / NFPA 2	pass
Safety	Storage distance to the site boundary	39.81 m	≥ 7.5 m (NFPA 2 group 1, lot line)	NFPA 2 (2026)	pass

The site wind is always checked against the class of the wind turbine – the chosen one or the default for the site (IEC 61400-1). When library components are chosen (section 4.7), **component checks** are added in the group *Components*: the feed salinity within the design of the water plant, balance of plant and stacks of the design-basis technology, the storage pressure within the rating of the vessels and of the compressor, the delivery pressure within the design pressure of the pipeline, and the battery cycles over its life within its cycle life (Figure 10.2).

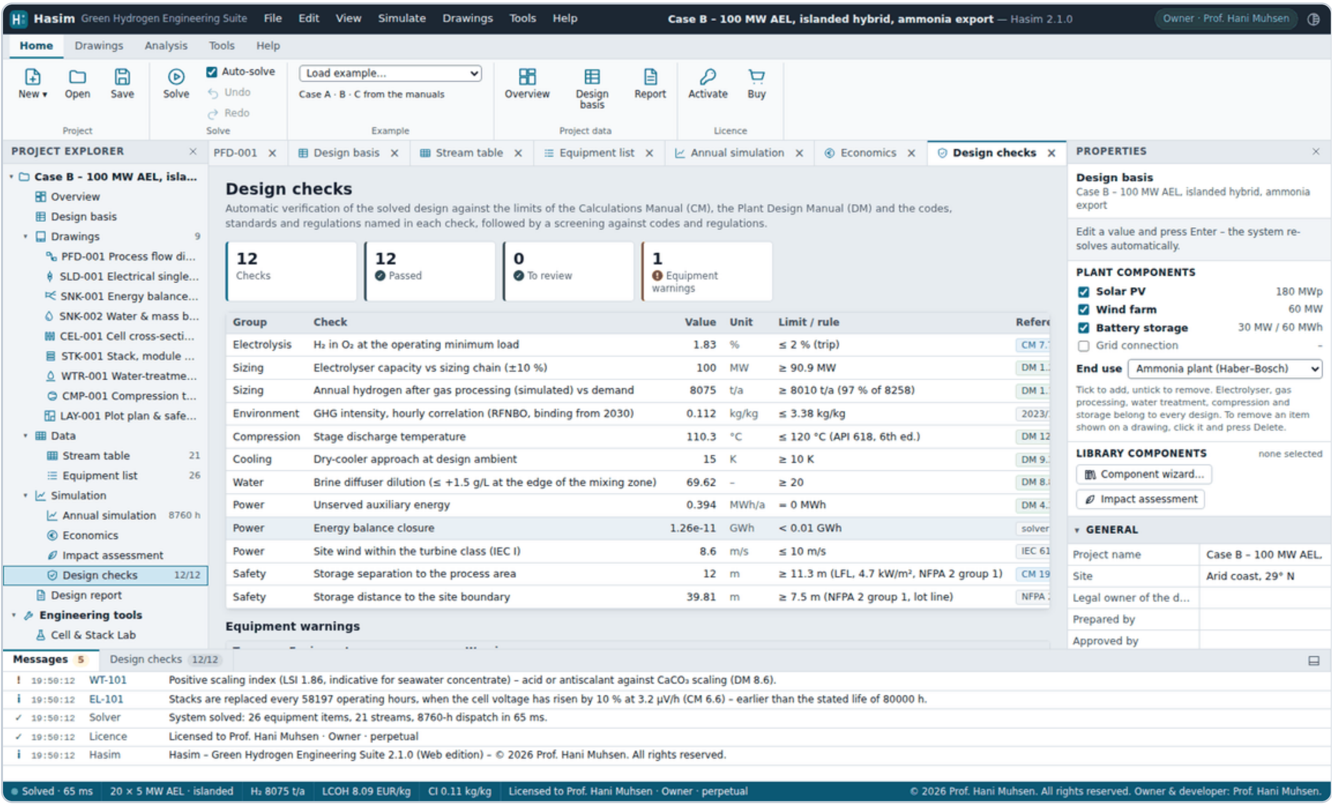
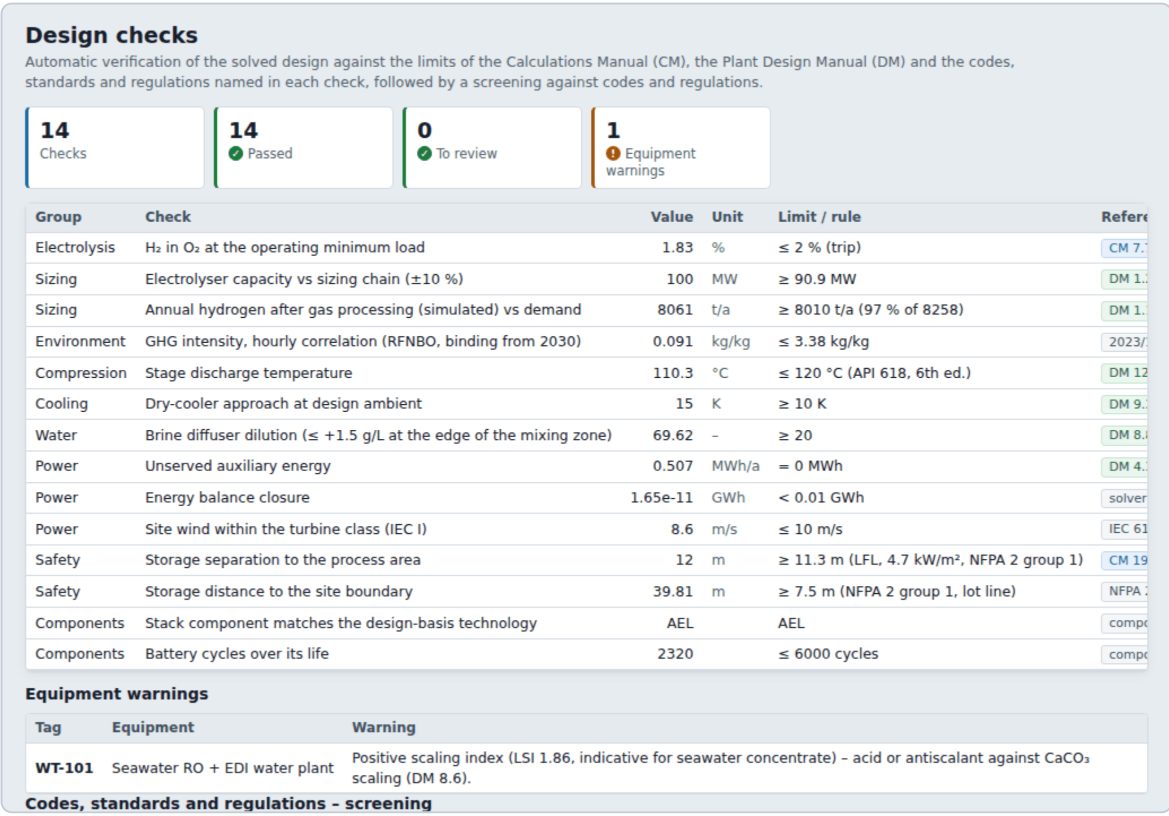


Figure 10.1 – Design checks and equipment warnings.



Design checks

Automatic verification of the solved design against the limits of the Calculations Manual (CM), the Plant Design Manual (DM) and the codes, standards and regulations named in each check, followed by a screening against codes and regulations.

14 Checks | 14 Passed | 0 To review | 1 Equipment warnings

Group	Check	Value	Unit	Limit / rule	Refere
Electrolysis	H_2 in O_2 at the operating minimum load	1.83	%	≤ 2 % (trip)	CM 7.
Sizing	Electrolyser capacity vs sizing chain (±10 %)	100	MW	≥ 90.9 MW	DM 1.
Sizing	Annual hydrogen after gas processing (simulated) vs demand	8061	t/a	≥ 8010 t/a (97 % of 8258)	DM 1.
Environment	GHG intensity, hourly correlation (RFNBO, binding from 2030)	0.091	kg/kg	≤ 3.38 kg/kg	2023/
Compression	Stage discharge temperature	110.3	°C	≤ 120 °C (API 618, 6th ed.)	DM 12
Cooling	Dry-cooler approach at design ambient	15	K	≥ 10 K	DM 9.
Water	Brine diffuser dilution (≤ +1.5 g/L at the edge of the mixing zone)	69.62	–	≥ 20	DM 8.
Power	Unserved auxiliary energy	0.507	MWh/a	= 0 MWh	DM 4.
Power	Energy balance closure	1.65e-11	GWh	< 0.01 GWh	solver
Power	Site wind within the turbine class (IEC I)	8.6	m/s	≤ 10 m/s	IEC 61
Safety	Storage separation to the process area	12	m	≥ 11.3 m (LFL, 4.7 kW/m², NFPA 2 group 1)	CM 19
Safety	Storage distance to the site boundary	39.81	m	≥ 7.5 m (NFPA 2 group 1, lot line)	NFPA
Components	Stack component matches the design-basis technology	AEL		AEL	compo
Components	Battery cycles over its life	2320		≤ 6000 cycles	compo

Equipment warnings

Tag	Equipment	Warning
WT-101	Seawater RO + EDI water plant	Positive scaling index (LSI 1.86, indicative for seawater concentrate) – acid or antiscalant against $CaCO_3$ scaling (DM 8.6).

Codes, standards and regulations – screening

Figure 10.2 – Design checks of Case B with library components: the component checks are added in the group Components.

10.1 Codes, standards and regulations

The checks and the **screening** below them in the design-checks document (Figure 10.3) apply the following international, European and US rules at concept level. The screening tables list the RFNBO criteria, the hazardous areas, the major-accident regulations, the pressure equipment, the separation distances and the power-quality and electrical items of the solved plant; the design report contains them as section 7.1.

Framework	Standard or regulation	Applied by Hasim
ISO	ISO 22734-1 – hydrogen generators using water electrolysis	H_2 in O_2 at the operating minimum load: alarm 1 %, trip 2 % (CM 7.7); the dispatch raises the minimum load to the trip limit (PEM: at the lowered part-load pressure)
ISO / SAE	ISO 14687:2025 grade D, ISO 19880-1, SAE J2601	Refuelling stations: fuel quality after deoxo and dryer (total impurities ≤ 300 µmol/mol, H_2O and O_2 ≤ 5 µmol/mol), cascade pressure above the vehicle MOP, fuel temperature window T40, hot-fill end pressure
IEC	IEC 60079-10-1:2020 with ATEX 1999/92/EC	Hazardous areas: source of release, grade, zone, extent (LFL distance of a secondary release), gas group IIC / IIA, temperature class T1, equipment protection level
IEC / IEEE	IEC 60909-0, IEEE 519-2022, IEC 61400-1, IEC 60617	Short-circuit currents with c = 1.1 and the source impedance of the grid; current TDD and voltage THD at the point of common coupling; turbine class for the site wind; drawing symbols
ISO	ISO 7200	Title block of the drawings: legal owner, identification, revision, date of issue, document type, creator, approver
EU	Delegated Regulations (EU) 2023/1184 and 2023/1185 (RFNBO)	GHG intensity ≤ 3.38 kg CO_2e/kg with hourly correlation (binding from 2030) and, with a sold PPA surplus, monthly correlation (until the end of 2029); additionality, geographic correlation and grid-electricity rules listed for review
EU	EU Taxonomy, activity 3.10	Life-cycle GHG intensity ≤ 3.0 kg CO_2e/kg in the impact assessment (section 9.2)
EU	Seveso III Directive 2012/18/EU, PED 2014/68/EU	Lower and upper tier of the establishment with the summation rule; category of the storage vessels (group 1 gas)
US	ASME B31.12 (option A) with EIGA Doc 121, ASME BPVC VIII-1	Pipeline wall with the hydrogen performance factor, corrosion allowance 1 mm and at least 6.4 mm, hoop stress ≤ 30 % SMYS; vessel shell by UG-27, thick wall by Appendix 1-2
US	API 618 (6th edition)	Discharge temperature of every compressor stage ≤ 120 °C for hydrogen-rich gas (selectable 135 °C or 150 °C)
US	NFPA 2 (2026), NFPA 855 / UL 9540A	Separation distances of bulk gaseous hydrogen for the exposure groups 1–3 against the plot plan; clearance of the battery
US	OSHA PSM (29 CFR 1910.119), EPA RMP (40 CFR 68), IRA § 45V	Threshold quantity 10 000 lb for hydrogen and ammonia; 45V credit tier from the well-to-gate GHG intensity (impact assessment)

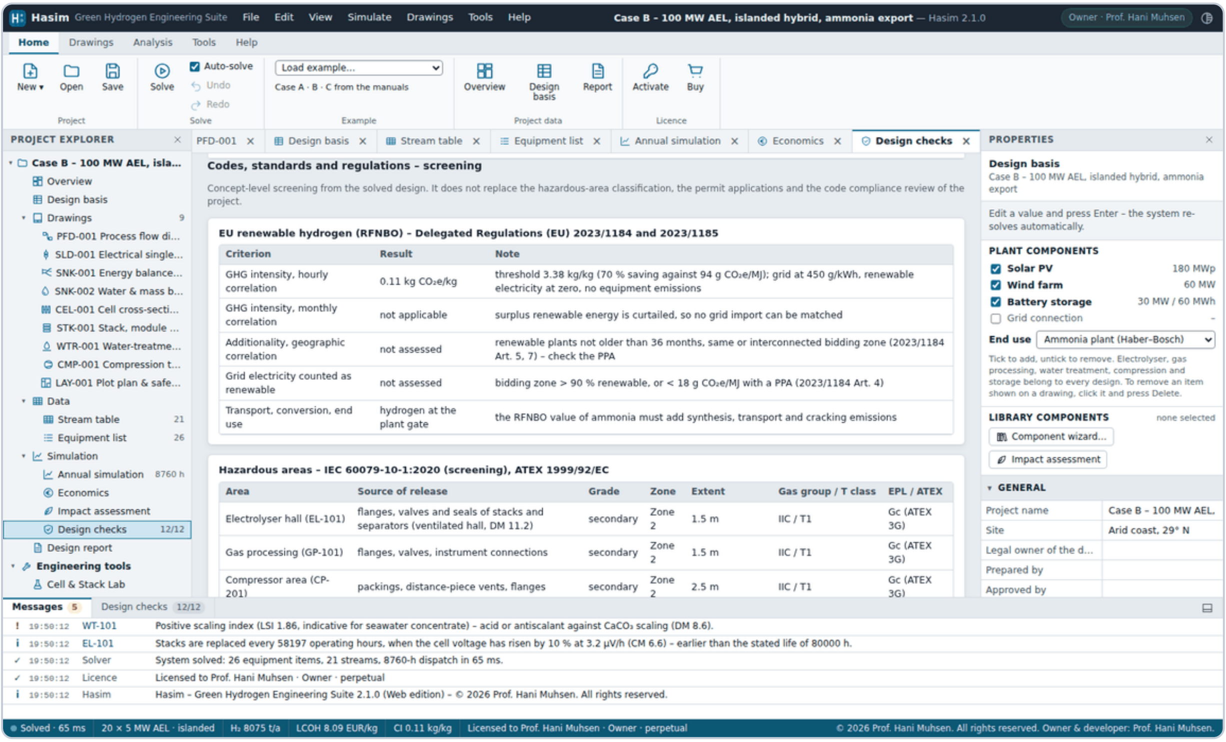


Figure 10.3 – Codes, standards and regulations: the screening of Case B.

Screening, not certification

The checks and tables are concept-level screening values from the solved design. They do not replace the hazardous-area classification and the dilution assessment of the project, the QRA, the design codes of the equipment suppliers, the permit applications or the certification of the hydrogen by an accredited scheme. Verify every code against the edition in force at the site.

10.2 Design report

The design report assembles the cover information with licence line, a summary, the complete design basis, all sizing sections with their equation references, the equipment list, the stream table, the monthly performance, the design checks, the impact assessment with the equipment and its components, all nine drawings and a disclaimer. Print it to paper or PDF with **Print / save as PDF**, or export a self-contained HTML file.

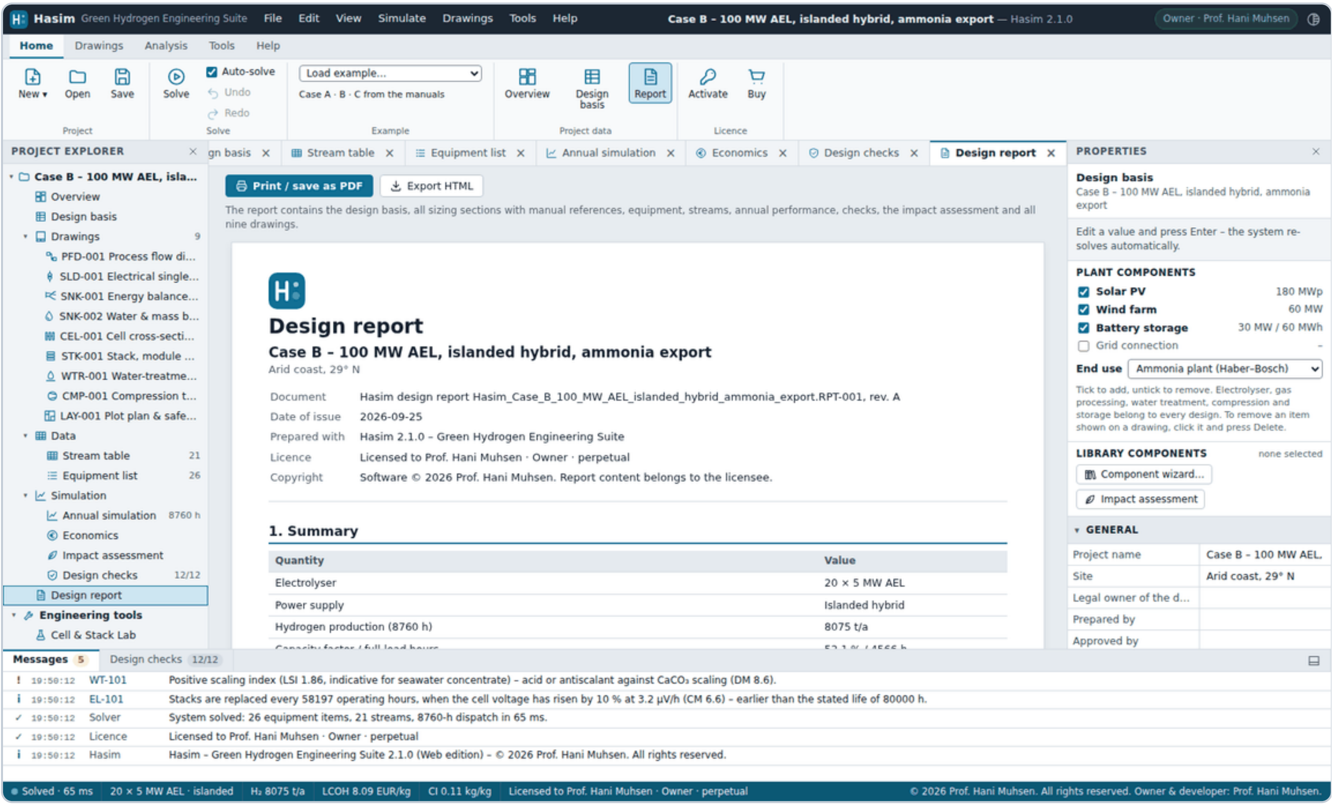


Figure 10.4 – The design report.

11 Engineering tools

11.1 Cell & Stack Lab

Explores the electrochemistry of each technology: reversible voltage $E_{rev}(T, p)$ (CM 3.5–3.6), activation, ohmic and concentration losses (CM 4.4–4.10), Faradaic efficiency and gas crossover (CM 7.6–7.7), stack and system specific energy (CM 7.5, 7.8). Edit any parameter; the polarisation curve, loss breakdown, SEC, part-load efficiency, H_2-in-O_2 and a table of operating points update immediately.

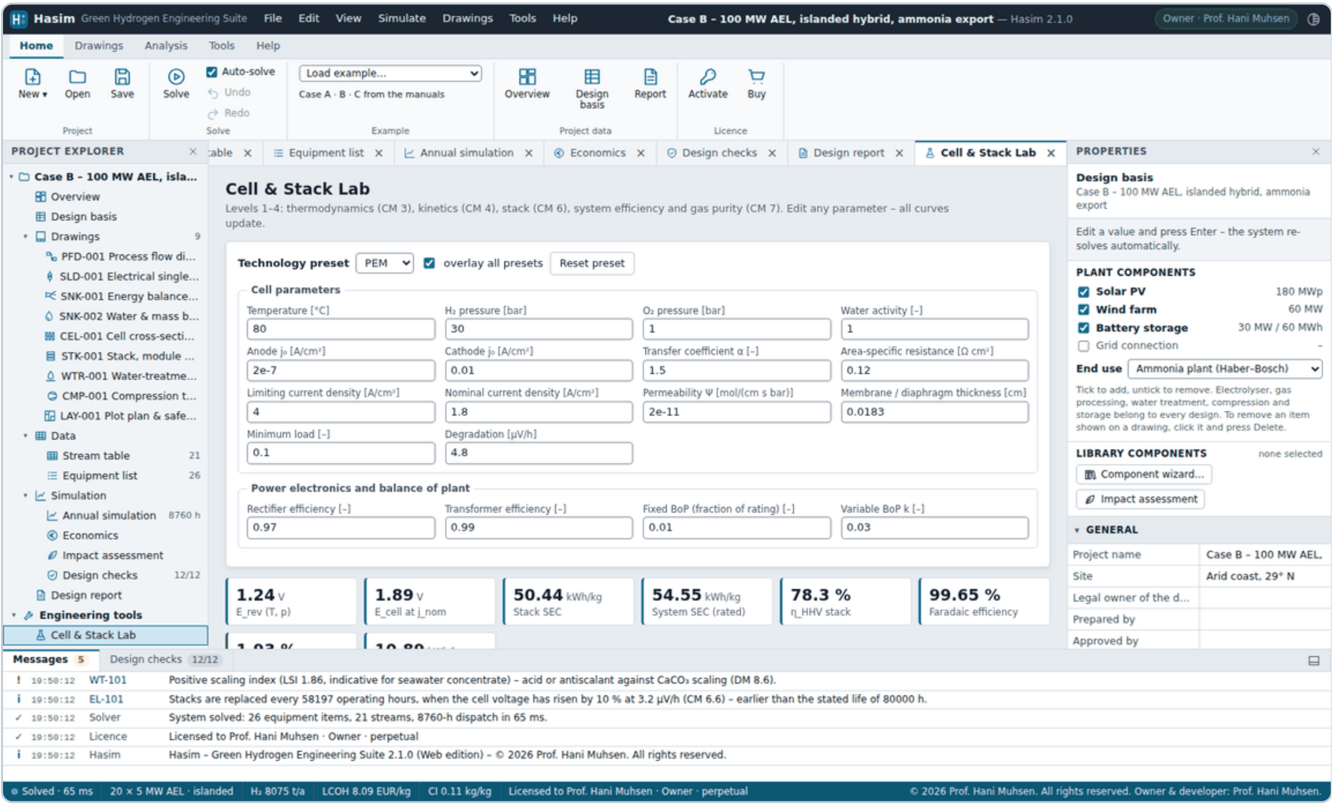


Figure 11.1 – Cell & Stack Lab.

j [A/cm²]	E_rev [V]	η_a [V]	η_c [V]	η_ohm [V]	E_cell [V]	SEC stack [kWh/kg]
0.25	1.235	0.285	0.065	0.030	1.616	44.1
0.50	1.235	0.299	0.079	0.060	1.675	45.1
1	1.235	0.313	0.093	0.120	1.766	47.3
1.50	1.235	0.321	0.102	0.180	1.845	49.3
2	1.235	0.327	0.107	0.240	1.920	51.2
2.50	1.235	0.332	0.112	0.300	1.994	53.1
3	1.235	0.335	0.116	0.360	2.067	55.1

Table 11.1 – Polarisation of the PEM preset (80 °C) computed by the cell model of CM 4.4.

11.2 Equation library

All 137 equations as live calculators, filterable by level and manual and searchable by title, symbol or number. Each equation shows its formula, inputs, outputs and the equivalent script call; the parametric sweep varies one input and plots any outputs.

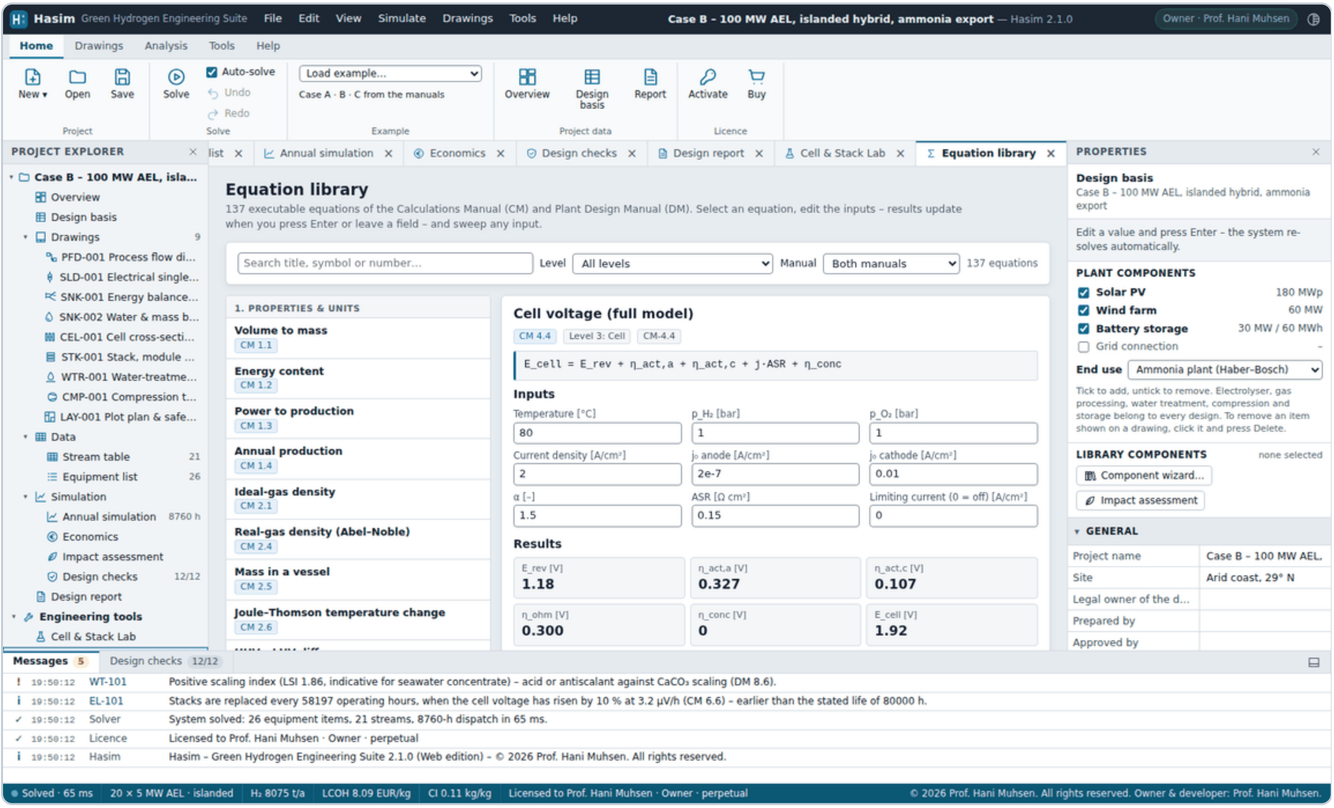


Figure 11.2 – Equation library.

11.3 Experiments

17 ready-made numerical experiments combine many equations; each has parameters, charts and result tables.

Experiment	Level	References
Polarisation curves of the four technologies	3	CM 3.5, 3.6, 4.4–4.10, 7.5
Temperature and pressure effects on the PEM cell	2	CM 3.5, 3.6, 4.5, 4.8
Part-load efficiency, Faradaic losses and gas purity	5	CM 6.4, 7.6, 7.7, 7.8, DM 10.2
Degradation over the stack life	4	CM 6.6, DM 9.1
Hybrid PV–wind sizing sweep (DM Table 4.1 replica)	6	DM Fig. 4.2, 4.3; CM 14.5; DM 20.2
Battery sizing for an islanded plant	6	DM 4.4, Fig. 4.2
LCOH sensitivity (tornado)	13	CM 17.1, 17.3
LCOH map: capacity factor × electricity price	13	CM 17.3
Compression energy vs pressure and stages	9	CM 10.1, 10.2, 10.4, 10.6
Real vs ideal gas: storage density	10	CM 2.1, 2.4, 2.5, 9.1
Weather-year Monte Carlo: P50 / P90 production	6	DM 3.1, 4.3
Transport: pipeline vs tube trailers	11	CM 13.1, 13.3, 20.1
GHG intensity vs grid share (RFNBO / Taxonomy / 45V)	14	CM 18.1, 18.3; Del. Reg. (EU) 2023/1185

Experiment	Level	References
Consequences of leaks: hole size and pressure	15	CM 19.1, 19.5, 19.6, 19.8
Cost outlook with learning curves	13	CM 17.8, 17.3
Desalination: RO energy vs recovery	7	DM 8.1, 8.2, 8.4, 8.5
Storage need vs offtake flexibility	10	CM 14.7, DM 13.1, 13.2

11.4 Component library

Tools ▸ Component library (Tools ribbon ▸ Components) holds 35 generic components in 15 categories, grouped like a plant – power supply (solar PV, wind turbines, battery storage), water treatment, electrolyser (stacks and modules, power electronics, balance of plant), compression and storage, delivery (pipeline, tube trailers, refuelling station) and conversion and end use (ammonia, methanol, fuel cells) – together with your own components. Choose a category on the left: the table compares all its components side by side (Figure 11.3); click a column to select one. The data of a component are grouped as follows:

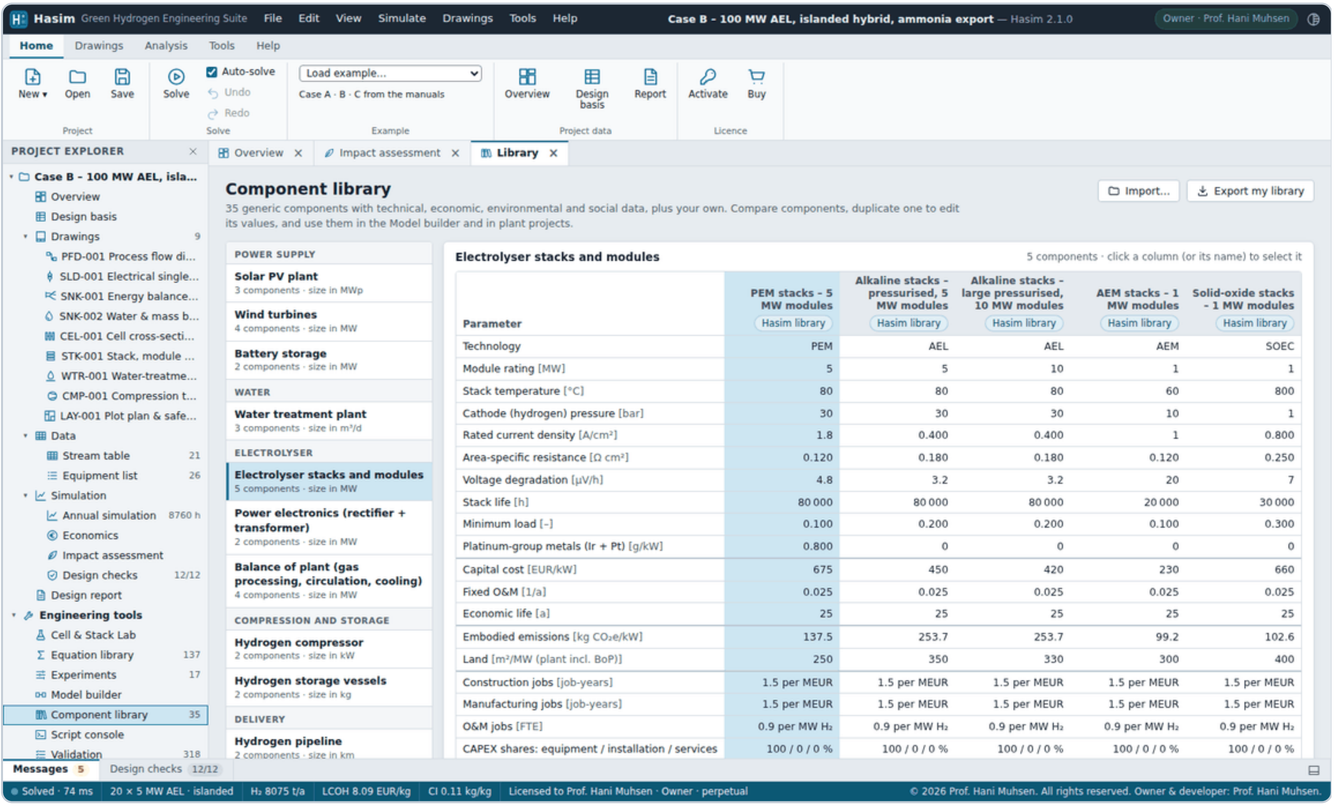


Figure 11.3 – The component library with the five electrolyser stacks side by side (Properties panel hidden with Alt+2).

Group	Content	Used by
Technical data used by the model	e.g. module rating, current density, ASR, degradation, stack life and minimum load of stacks; tracking gain, losses and DC/AC ratio of PV; power curve of wind turbines; round-trip efficiency of batteries; recoveries of water plants; isentropic efficiency and pressure ratio of compressors	Plant models and block models
Limits used by the component checks	Turbine class limit, maximum feed salinity, pressure ratings, capacity per machine, cycle life, technology of the balance of plant	Component checks
Datasheet	Hub height and rotor diameter, vessel and compressor type, power factor	Information
Economic data	Capital cost in the unit of the category, fixed O&M as a share of CAPEX, economic life	Costs of blocks and plants, NPV
Environmental data	Embodied GHG emissions of manufacture, transport and installation, land occupied, platinum-group metals, total area of wind farms	Environmental impact
Social data	Employment factors for construction and installation, manufacturing and operation and maintenance with their basis; CAPEX shares of equipment, installation and services	Jobs and local content

Your own components

1. Select a component and press **Duplicate to edit**; give the copy a name. It appears in the same category marked *my library* (Figure 11.4).
2. Change its values, name and technology and press **Save changes**. **Delete** removes it from your library – projects and models that use it keep their own copy.
3. **Apply to the plant project** uses the component in the current plant; **Use in the Model builder** puts it into the selected block of the Model builder (or the first block with this kind of equipment).
4. **Export my library** writes your components to a JSON file, **Import...** reads one – for example vendor data shared in your team. Imported components are checked: unknown fields are ignored and every value is limited to its allowed range.

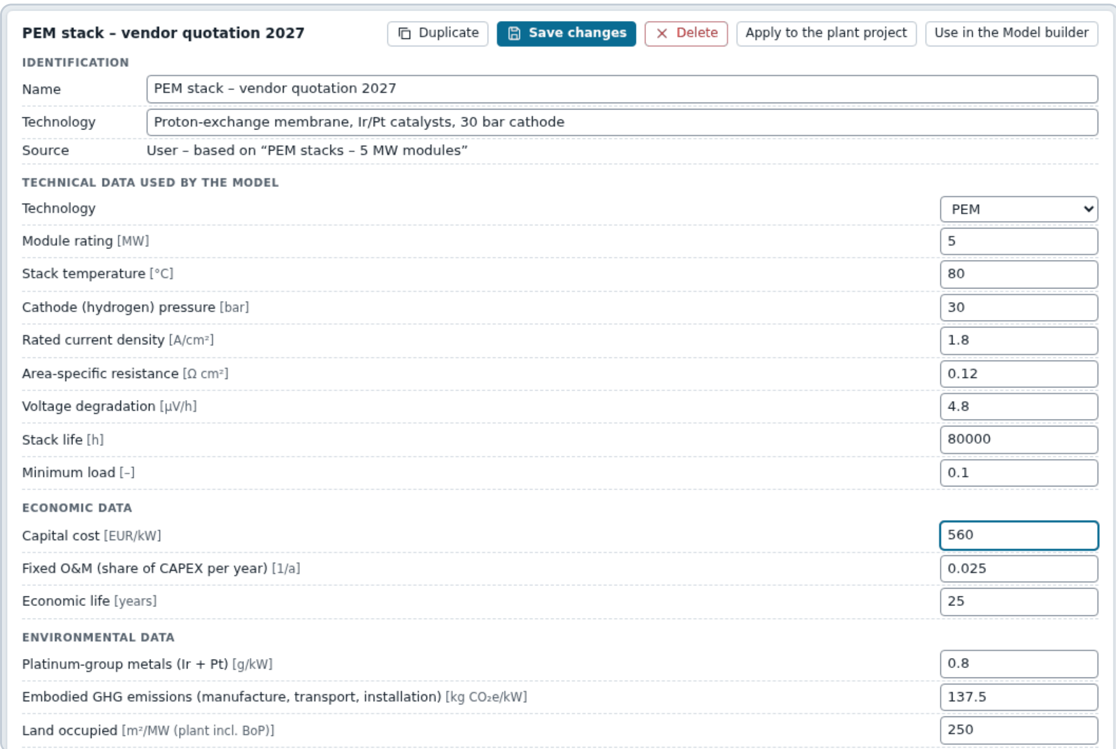


Figure 11.4 – A component of your library, duplicated from the PEM stack and edited with a vendor price.

Components of the Hasim library are read-only. A value changed in the component wizard changes only the copy used by that project or model. Your library is kept in the browser storage of the edition you use – export it to keep a backup or to take it to another computer.

11.5 Model builder

Builds value chains from blocks – Power supply (PV / wind / grid), Water treatment (RO + polishing), Electrolyser plant, Compressor, Compressed storage buffer, Pipeline, Tube-trailer delivery, Ammonia synthesis (Haber–Bosch), Methanol synthesis, Fuel cell (power-to-power), Refuelling station 700 bar, Gas-grid blending, Economics & carbon (LCOH, CI). The stream (hydrogen, pressure, energy, cost, carbon) passes from block to block; the electrolyser block runs the 8760-hour model with the power supply before it. The builder opens with the chain of Case B (islanded ammonia export); **Load example model...** offers further chains.

1. **New empty model**, then **start with a standard chain** or add blocks from the palette. The palette is grouped by stage (power and water, hydrogen production, compression and storage, delivery and end use, evaluation) and every block is inserted at its place in the chain.
2. Click a block to edit its parameters and components in the editor below the palette. **← Move** / **Move →** change its position.
3. Delete a block with its **×**, with **Delete block** or with the Delete key; **Undo** (Ctrl+Z while the builder is active) restores the chain.
4. The order checks under the chain explain problems – a missing electrolyser, water treatment after the electrolyser, blocks that receive no hydrogen, Economics not at the end – and **Fix order** sorts the blocks into flow order.
5. With **Live results** the results update half a second after every change; **Run model** recalculates and scrolls to them. **Save model** / **Open model** store the chain with its components and settings as a JSON file.

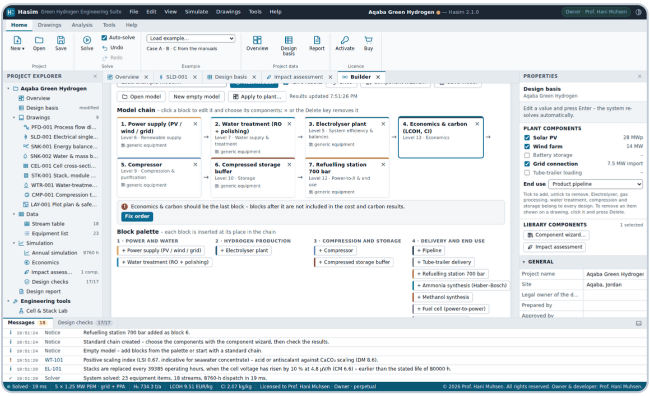


Figure 11.5 – Model builder: chain, order checks and palette.

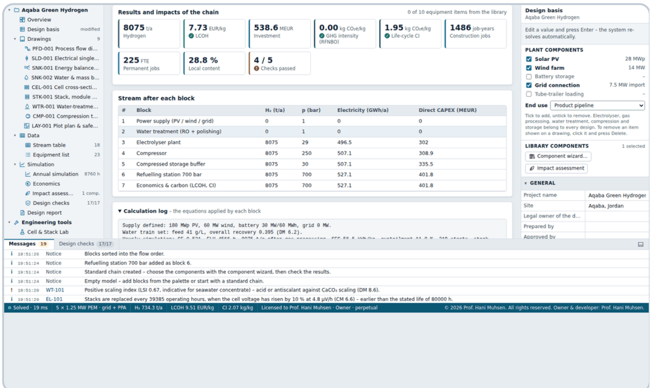


Figure 11.6 – Results of a chain.

Components of the blocks

Blocks with equipment – power supply, water treatment, electrolyser, compressor, storage, pipeline, trailers, refuelling station, ammonia, methanol and fuel cell – list their equipment under **Components of this block** (Figure 11.7). Without a component a block uses its own parameters (*Generic – block values*) and the assessment uses the Hasim default. **Component wizard...** in the block editor or the toolbar walks through the equipment of all blocks of the chain (Figure 11.8): choose a component, set its size in the model – for example the PV capacity, the mean wind speed of the site or the electrolyser rating – edit its parameters and watch the effect on the whole chain. **Apply components** stores the selection in the blocks as one step of Undo. Block parameters defined by a component are shown grey and locked; their tooltip names the component. Change them in the wizard, or return to the generic block with ×.

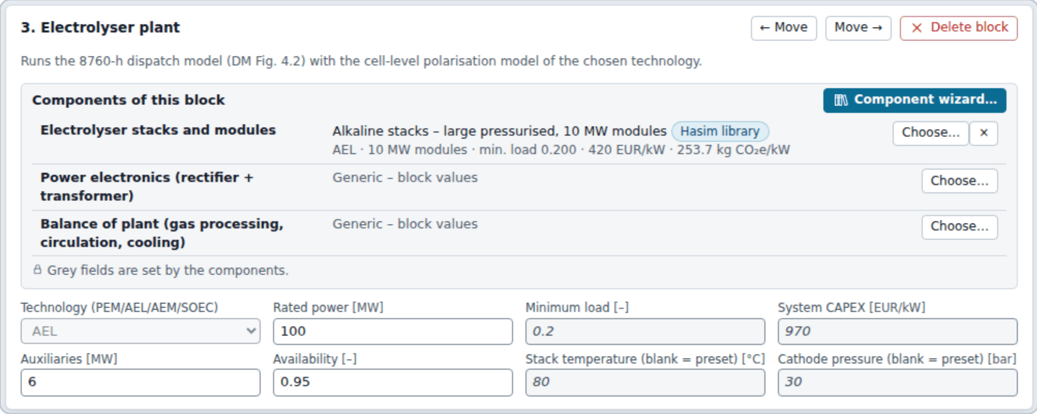


Figure 11.7 – The electrolyser block with a library stack: technology, minimum load, temperature, pressure and CAPEX are set by the components (grey).

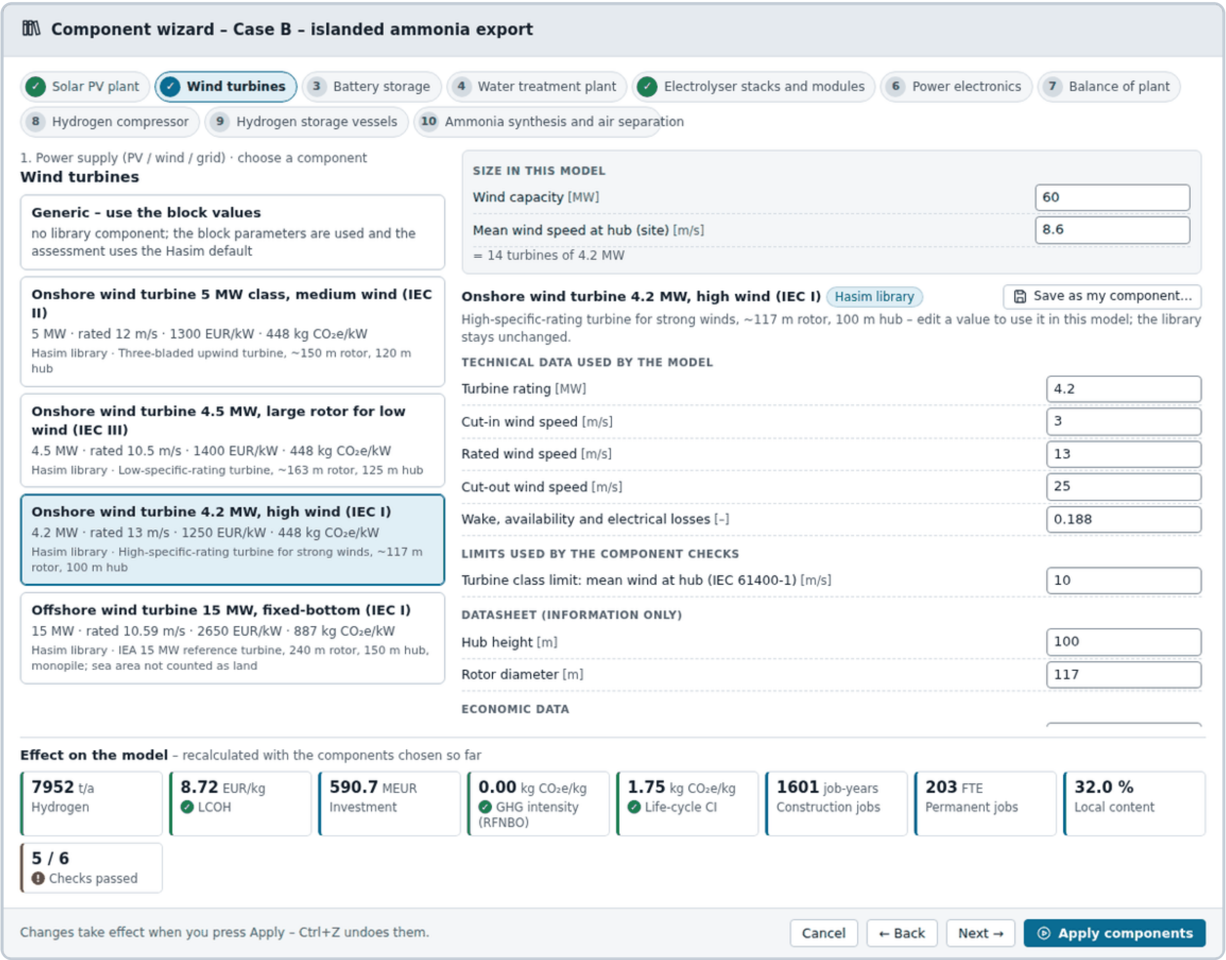


Figure 11.8 – The component wizard of the Model builder at the wind turbines of the power-supply block.

The results start with **Results and impacts of the chain** – hydrogen, LCOH, investment, life-cycle carbon intensity, construction and permanent jobs, local content and checks – followed by the stream after each block, the calculation log, the monthly production and the complete impact assessment of section 9.2 (Figure 11.9). The chain checks cover the gas purity at the minimum load (CM 7.7, DM 10.2), unserved auxiliary energy (DM 4.3), compressor discharge temperature (DM 12.1), storage and pipeline capacity, the carbon intensity (CM 18.1) and the component checks – module rating, balance-of-plant technology, turbine class, battery cycles, feed salinity, pressure ratings, number of compressors and trailer pressure. **Assessment settings** above the results hold the settings of section 9.3 and an optional production target. **Apply to plant...** transfers the library components of the model to the plant project – the plant keeps its sizes – and opens its impact assessment.

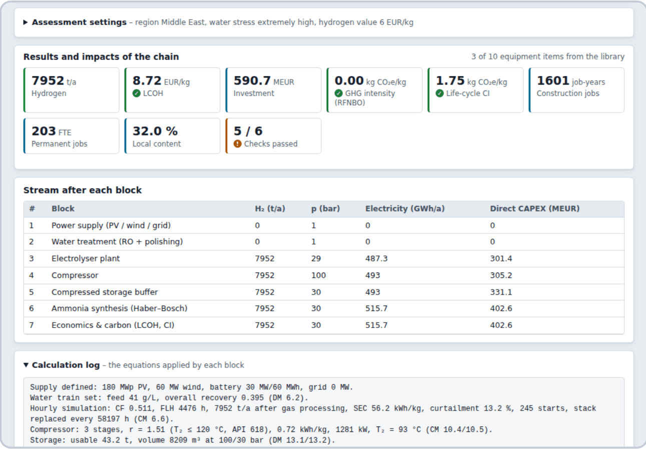


Figure 11.9 – Results and impacts of the chain with three library components.

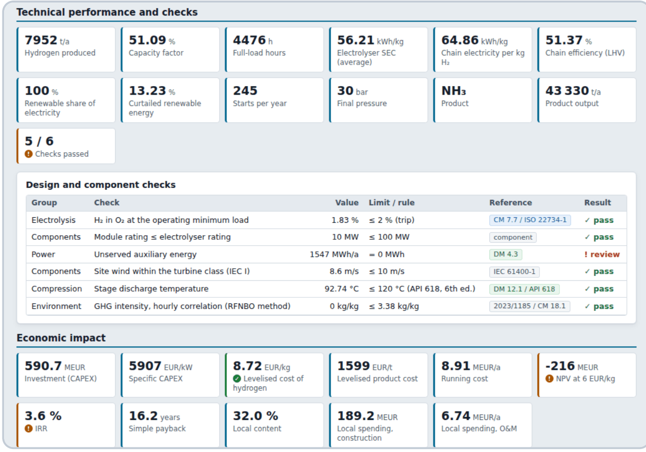


Figure 11.10 – Technical performance and the chain checks: the auxiliaries of the islanded chain are not supplied at night.

11.6 Script console and API

Automates studies in JavaScript. The console provides `H2` (engine), `H2F` (drawings), `print()`, `table()` and `plot()`. Scripts run in strict mode and have no access to the application window, its storage or the licence; results are exported with the Table/CSV/SVG buttons of the charts and tables they create. The example *Impacts of a design with library components* applies components to Case B and tabulates its impacts.

Call	Returns
`H2.solveSystem(basis)`	Complete system: equipment, streams, electrical data, annual simulation, balances, layout, checks, codes and standards screening (`compliance`, `hazAreas`, `seveso`) and KPIs
`H2.CASES.A | B | C`	Example design bases
`H2.run(id, inputs)`, `H2.sweep(id, key, a, b, n, fixed)`	One equation, or a sweep of one input
`H2.cell(tech, j)`, `H2.system(tech, P_kW, opts).atLoad(L)`	Cell model and system operating points
`H2.hourly(cfg)`, `H2.designPlant(basis)`, `H2.runFlowsheet(blocks)`	Annual simulation, design chain, block model
`H2F.pfd(sys)`, `H2F.sld(sys)`, `H2F.DRAWINGS`	Drawing generators (SVG)
`H2.LIB`, `H2.libGet(id)`, `H2.libList(cat)`	Components of the library (copies)
`H2.basisFromComponent(basis, slot, comp)`	Design-basis values set by a component – merge them into the basis with `Object.assign`
`H2.assessPlant(sys)`, `H2.assessChain(result, blocks, settings)`	Impact assessment of a plant or of a Model-builder chain

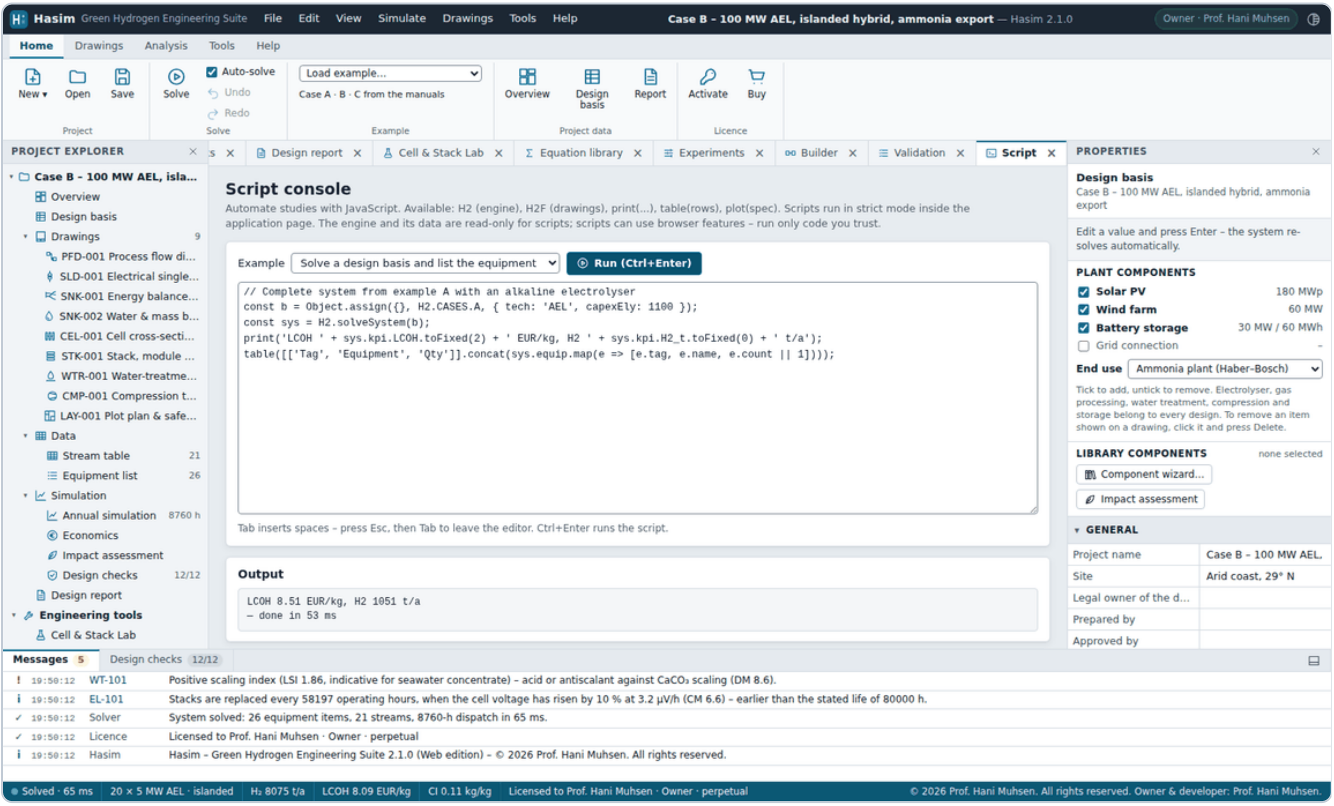


Figure 11.11 – Script console.

11.7 Validation

Runs the verification suite described in Chapter 12 and lists every check with manual value, Hasim value and deviation.

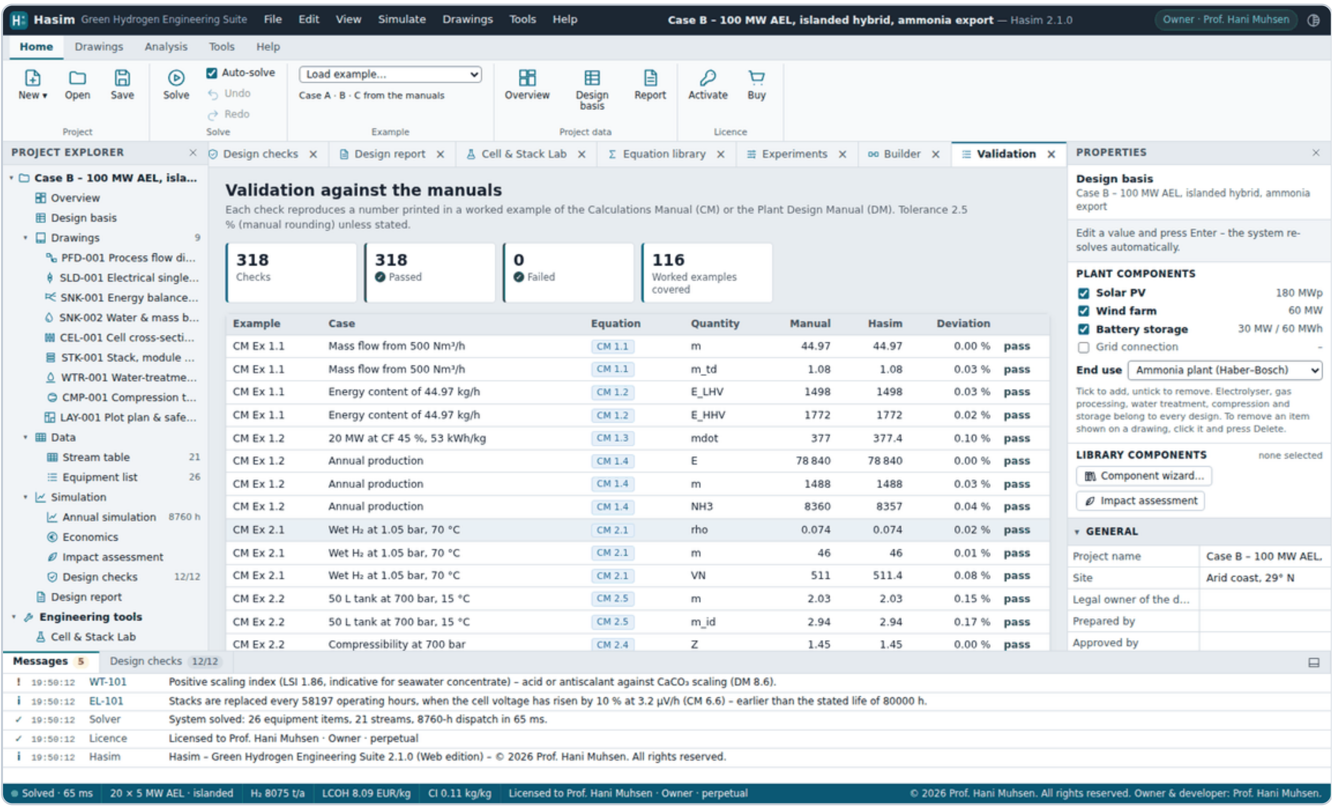


Figure 11.12 – Validation.

12 Verification and validation

12.1 Worked examples of the manuals

Hasim is verified against the worked examples of both manuals: 318 numerical checks from 116 worked examples reproduce the printed results. All 318 checks pass; the largest deviation is 2.4 %, within the rounding of the printed values (tolerance 2.5 %).

- The annual **energy balance** closes to better than 10^{-6} GWh for all examples (reported as a design check).
- The **mass balance** of every stream node is conserved by construction; the water balance matches the DI-water demand of DM 6.1.
- Real-gas densities use the Abel–Noble equation, accurate to about 1 % up to 700 bar at ambient temperature.
- Drawings are checked for consistency with the solved data (equipment tags, stream numbers and values).
- A regression suite of the development checks the models introduced by the 2026 expert review – stack life and degradation, gas-processing losses, the RFNBO method, the compressor temperature limit, the major-accident summation, the SOEC energy balance – and the input guards of the solver.

12.2 External benchmarks

Hasim's models were also compared with independent data: measured operation of real plants, the results of established tools – US DOE H2A and HDSAM, NREL SAM and HOMER Pro – and the reference values of the Clean Hydrogen Partnership, the US DOE, IRENA and the IEA (September 2026). Every comparison uses the default technology presets and library components. **65 of the 86 comparisons agree within 5 %** and 12 more within 10 %; of the 9 larger deviations 6 are conservative and 3 optimistic. Hasim 2.1.0 changed the model elements behind most deviations of the first benchmark (Hasim 2.0: 55 of 84 agreed, 17 deviated). The comparison runs with the regression suite of the development, so every new version is checked against the same references. The *Hasim Validation Note* describes the method in detail.

Domain	Comparisons	Agree (≤ 5 %)	Close (≤ 10 %)	Deviate (> 10 %)
PEM electrolysers: measured plants and DOE H2A	11	8	2	1
Technology presets: Clean Hydrogen Partnership, DOE, IRENA	19	17	0	2
Alkaline, solid-oxide and AEM electrolysers: measured and rated	13	8	5	0
Photovoltaics: measured fleets, SAM and HOMER	12	10	2	0
Wind: measured farms	4	2	1	1
Compression: DOE, HDSAM and measured	8	4	1	3
Water: Hasim defaults and references	5	2	1	2
Levelised cost of hydrogen: US DOE H2A-Lite and IEA	14	14	0	0
Total	**86**	**65**	**12**	**9**

A comparison **agrees** within 5 % (or inside the published range), is **close** within 10 % and **deviates** beyond; a deviation is **conservative** when Hasim's value is less favourable for the plant than the reference. Types: measured, tool result, model assumption, reference value, vendor rating.

Changes in Hasim 2.1.0

Model element	Hasim 2.0	Hasim 2.1.0
Wind: shape of the wind-speed distribution [1, 2]	Weibull k = 2 of the generator; the daily and seasonal variation lowered it to about 1.8 in the series	shape factor k of the site as a design-basis input (default 2); the series is mapped by rank onto the site's Weibull distribution, so mean and k are exact
Wind: loss allowance (wakes, availability, electrical, other) [1]	12 %	18.8 % onshore, 15.5 % offshore (NREL reference projects)
Wind: offshore turbine class [3]	–	15 MW fixed-bottom turbine after the IEA 15 MW reference turbine (240 m rotor, rated 10.59 m/s) with offshore cost, life-cycle emissions and jobs
PEM: minimum load [4, 5, 6, 7]	31 % – the 2 % H_2-in-O_2 trip at 30 bar	10 % – the cathode pressure is lowered in proportion to the load, down to 10 bar; the part-load hydrogen is compressed from the lower pressure
PEM: degradation and stack life [8, 9]	5.0 mV/1000 h, 37 809 h	4.8 mV/1000 h, 39 385 h (US DOE status)
Alkaline: degradation and stack life [10]	0.11 %/1000 h, 90 000 h (stated life)	0.17 %/1000 h (3.2 mV/1000 h), 58 197 h; stated life 80 000 h (US DOE status and 2026 target)
SOEC: degradation and stack life [11, 12]	0.75 %/1000 h, 13 354 h	0.52 %/1000 h (7 mV/1000 h), 19 078 h – between the US DOE status and the 20 000 h stack tests
SOEC: minimum load [5, 13]	20 %	30 % – the drop in efficiency at low load (INL) is not modelled
AEM: cell resistance [14, 15]	0.25 Ω cm²: 57.6 kWh/kg, 2.003 V at 1 A/cm²	0.12 Ω cm²: 53.9 kWh/kg, 1.873 V at 1 A/cm² (current commercial units)

Effect on the example plants (design-basis defaults, annual simulation):

Example plant	Hydrogen, t/a	LCOH, EUR/kg	Wind energy, GWh/a	Minimum load, % of rated input
Case A – 10 MW PEM, grid-connected, industrial park	1 059 → 1 050	10.13 → 10.14	36.9 → 34.5	31.6 → 10.6
Case B – 100 MW AEL, islanded hybrid, ammonia export	8 339 → 8 075	7.66 → 8.09	200.4 → 177.8	20.0 → 20.0
Case C – 1 MW PEM refuelling hub (small scale)	155 → 155	15.19 → 15.16	–	31.6 → 10.6

PEM electrolysers: measured plants and US DOE H2A

Reference	Basis	Published	Hasim	Deviation	Result
Energiepark Mainz, 6 MW PEM (Siemens SILYZER 200), rated 4 MW [16] measured	whole plant incl. transformers, rectifiers, pumps, cooling and compression to 225 bar (64 % HHV) *first-generation stacks (2015)*	61.7 kWh/kg	58.6 kWh/kg	−5.0 %	agrees
Energiepark Mainz, rise of the specific consumption from 4 to 6 MW (150 % load) [16] measured	whole plant	7.9 %	5.0 %	−2.9 pp	close, optimistic

Reference	Basis	Published	Hasim	Deviation	Result
HyBalance, 1.2 MW PEM (Hydrogenics), nominal flow [17] measured	system incl. auxiliaries	56.5 kWh/kg	57.4 kWh/kg	+1.6 %	agrees
REFHYNE, 10 MW PEM (ITM Power), average load [18] measured	stack *Hasim at 60–80 % load*	< 49 kWh/kg	47.8–49.2 kWh/kg	within	agrees
NREL Flatirons, 1.25 MW PEM stack (Nel), PV and wind profiles [19] measured	stack, DC, mean of the runs *Hasim at 60–80 % load*	51.4 kWh/kg	47.8–49.2 kWh/kg	−7.0 to −4.3 %	close, optimistic
DOE H2A: PEM stack at 2.0 A/cm² and 1.9 V [8, 20] model assumption	stack	50.4–51.0 kWh/kg	51.2 kWh/kg	+0.4 %	agrees
DOE H2A: PEM system, beginning of life [8] model assumption	system (stack + balance of plant)	55.2 kWh/kg	54.5 kWh/kg	−1.3 %	agrees
DOE H2A: PEM system, life average [8] model assumption	system, average over the stack life	57.5 kWh/kg	57.0 kWh/kg	−0.9 %	agrees
DOE H2A 2019: PEM system, life average implied by the cost record [20] model assumption	4.18 $/kg electricity cost ÷ 7.35 ¢/kWh	56.9 kWh/kg	57.0 kWh/kg	+0.2 %	agrees
DOE H2A: PEM stack degradation [8] model assumption	cell-voltage rise; replacement after 40 000 h *Hasim replaces the stack after 39 385 h*	4.8 mV/1000 h	4.8 mV/1000 h	±0.0 %	agrees
REFHYNE: PEM stack degradation in the field (2024–2025) [18] measured	at full utilisation	0.09 %/1000 h	0.25 %/1000 h	2.8 ×	deviates, conservative

Technology presets: Clean Hydrogen Partnership, US DOE, IRENA

Reference	Basis	Published	Hasim	Deviation	Result
PEM: system consumption, state of the art (SRIA 2020; DOE status) [9, 21] reference value	system, AC	55.0 kWh/kg	54.5 kWh/kg	−0.9 %	agrees
PEM: stack degradation, state of the art (SRIA 2020) [21] reference value	efficiency loss at nominal capacity	0.19 %/1000 h	0.25 %/1000 h	+31.6 %	deviates, conservative
PEM: stack life, DOE status [9] reference value	end of life at +10 % voltage	40 000 h	39 385 h	−1.5 %	agrees
PEM: lower end of the load range (expert elicitation) [4, 5] reference value	system *Hasim lowers the cathode pressure at part load, down to 10 bar (at 30 bar the 2 % H_2-in-O_2 trip would limit the load to 31 %)*	0–10 % of rated	10 % of rated	within	agrees

Reference	Basis	Published	Hasim	Deviation	Result
PEM: operating range of commercial systems (Cummins HyLYZER-1000, Nel M Series) [6, 7] vendor rating	system, lower end *rated 5–125 % and 10–100 %*	5–10 % of rated	10 % of rated	within	agrees
AEL: system consumption, state of the art (SRIA 2020 – DOE status) [10, 21] reference value	system, AC	50.0–55.0 kWh/kg	53.7 kWh/kg	within	agrees
AEL: cell voltage at 0.5 A/cm² (DOE status) [10] reference value	cell	1.90 V	1.895 V	−0.3 %	agrees
AEL: stack degradation (SRIA 2020 – DOE status) [10, 21] reference value	efficiency or voltage loss	0.12–0.17 %/1000 h	0.17 %/1000 h	within	agrees
AEL: stack life, DOE status and IRENA 2020 [5, 10, 22] reference value	end of life *the expert elicitation gives 60 000–90 000 h*	60 000 h	58 197 h	−3.0 %	agrees
AEL: lower end of the load range (expert elicitation) [5] reference value	system	10–40 % of rated	20 % of rated	within	agrees
AEM: system consumption, state of the art (SRIA 2020) [21, 22] reference value	system, AC *IRENA 2020: 57–69 kWh/kg*	55.0 kWh/kg	53.9 kWh/kg	−2.0 %	agrees
AEM: cell voltage at 0.2–1.0 A/cm² (review) [23] reference value	cell *Hasim at 1 A/cm²*	1.80–2.20 V	1.873 V	within	agrees
AEM: stack degradation, state of the art (SRIA 2020: above 1.0) [21] reference value	efficiency loss	> 1.0 %/1000 h	1.07 %/1000 h	within	agrees
SOEC: electricity, state of the art (DOE status – SRIA 2020) [11, 21] reference value	system, steam from outside	38.0–40.0 kWh/kg	38.4 kWh/kg	within	agrees
SOEC: heat for the steam (DOE status – SRIA 2020) [11, 21] reference value	thermal energy per kg *measured at INL: 6.4 kWh of heat per kg*	9.0–9.9 kWh_{th}/kg	6.6 kWh_{th}/kg	−26.7 %	deviates, optimistic
SOEC: cell voltage at 0.6 A/cm² (DOE status) [11] reference value	cell	1.28 V	1.248 V	−2.5 %	agrees
SOEC: stack degradation, DOE status (6.4 mV/1000 h) [11] reference value	voltage rise	0.50 %/1000 h	0.52 %/1000 h	+4.0 %	agrees
SOEC: stack life, DOE status [11] reference value	end of life	20 000 h	19 078 h	−4.6 %	agrees

Reference	Basis	Published	Hasim	Deviation	Result
SOEC: lower end of the load range (expert elicitation) [5] reference value	system	> 30 % of rated	30 % of rated	within	agrees

Alkaline, solid-oxide and AEM electrolysers: measured and rated

Reference	Basis	Published	Hasim	Deviation	Result
AEL 1 MW atmospheric (Nel), full load [24] measured	stack, DC; model fitted to plant data *Hasim AEL preset at atmospheric pressure*	52.0 kWh/kg	47.5 kWh/kg	−8.7 %	close, optimistic
AEL 1 MW atmospheric (Nel), 20 % load [24] measured	stack, DC; model fitted to plant data	47.0 kWh/kg	43.4 kWh/kg	−7.7 %	close, optimistic
AEL LONGi ALK Hi1 / Hi1 Plus, full load (factory test witnessed by DNV) [25] vendor rating	stack, DC	45.6–47.8 kWh/kg	49.6 kWh/kg	+3.8 %	agrees
SOEC GrInHy2.0, 720 kW (Sunfire), best measured [26] measured	electrical, steam from waste heat (84.6 % LHV)	39.4 kWh/kg	38.4 kWh/kg	−2.5 %	agrees
SOEC MultiPLHY, 2.6 MW (Sunfire), full load [27] measured	module, factory acceptance test (86 % LHV)	38.8 kWh/kg	38.4 kWh/kg	−1.0 %	agrees
SOEC MultiPLHY, part load [27] measured	module, factory acceptance test (89 % LHV) *Hasim at 74 % load*	37.4 kWh/kg	37.1 kWh/kg	−0.8 %	agrees
SOEC 2 × 100 kW (Bloom Energy) at INL, 97 % load [13] measured	DC incl. blowers, heaters, controls; excl. AC/DC and steam	36.7 kWh/kg	36.7 kWh/kg	±0.0 %	agrees
SOEC at INL, 74 % load [13] measured	as above	37.7 kWh/kg	35.7 kWh/kg	−5.3 %	close, optimistic
SOEC at INL, heat for the steam [13] measured	external electric boiler	6.4 kWh_{th}/kg	6.6 kWh_{th}/kg	+3.1 %	agrees
SOEC stack degradation in 18 000–23 000 h tests (Jülich, EIFER) [12, 13, 28] measured	cell or stack voltage *INL systems: below 0.2 %/1000 h*	0.57–0.60 %/1000 h	0.52 %/1000 h	−8.8 %	close, optimistic
AEM Enapter EL 4.1, beginning of life [14] vendor rating	system (4.8 kWh/Nm^3)	53.4 kWh/kg	53.9 kWh/kg	+0.9 %	agrees
AEM Enapter Nexus 1000, beginning of life [14] vendor rating	system incl. utilities	51.3 kWh/kg	53.9 kWh/kg	+5.1 %	close, conservative
AEM 2 kW stack (ANIONE), 1 A/cm^2, 2 000 h [15] measured	cell voltage	1.80 V	1.873 V	+4.1 %	agrees

Photovoltaics: measured fleets, SAM and HOMER

Reference	Basis	Published	Hasim	Deviation	Result
NREL ATB (SAM), single-axis, GHI > 5.75 kWh/m²/d [29] tool result	AC capacity factor, ILR 1.34 *Hasim at 6 kWh/m²/d*	34.0 %	33.6 %	−1.2 %	agrees
NREL ATB (SAM), single-axis, GHI 5.00–5.25 kWh/m²/d [29] tool result	AC capacity factor, ILR 1.34 *Hasim at 5.125 kWh/m²/d*	29.8 %	29.1 %	−2.3 %	agrees
NREL ATB (SAM), single-axis, GHI 4.00–4.25 kWh/m²/d [29] tool result	AC capacity factor, ILR 1.34 *Hasim at 4.125 kWh/m²/d*	24.5 %	23.7 %	−3.3 %	agrees
NREL ATB (SAM), single-axis, GHI < 3.75 kWh/m²/d [29] tool result	AC capacity factor, ILR 1.34 *Hasim at 3.5 kWh/m²/d*	21.4 %	20.2 %	−5.6 %	close, conservative
LBNL US fleet: gain of single-axis tracking over fixed tilt [30] measured	AC capacity factor *Hasim at 5.3 kWh/m²/d*	3.0–5.0 pp	3.2 pp	within	agrees
Chile, 109 tracking plants, fleet average (GHI about 2 500 kWh/m²/yr) [31] measured	specific yield *grid data may mix AC and DC ratings*	2 388 kWh/kWp	2 450 kWh/kWp	+2.6 %	agrees
India, 10 MWp at 18.75° N (GHI 1 814 kWh/m²/yr) [32] measured	specific yield, fixed	1 580 kWh/kWp	1 591 kWh/kWp	+0.7 %	agrees
Alice Springs (DKASC), p-Si, fixed 20° (GHI about 2 245 kWh/m²/yr) [33] measured	performance ratio	0.81	0.782	−3.5 %	agrees
Germany, new systems (GHI 1 102 kWh/m²/yr) [34] measured	performance ratio	0.80–0.90	0.855	within	agrees
HOMER Pro study, Ayvalık, Turkey (GHI 4.62 kWh/m²/d, derating 88 %) [35] tool result	specific yield, fixed	1 645 kWh/kWp	1 544 kWh/kWp	−6.1 %	close, conservative
HOMER Pro study, Naogaon, Bangladesh (GHI about 5.0 kWh/m²/d) [36] tool result	specific yield	1 594 kWh/kWp	1 610 kWh/kWp	+1.0 %	agrees
HOMER Pro study, Ostrava, Czechia (GHI 2.89 kWh/m²/d) [37] tool result	specific yield	1 008 kWh/kWp	1 016 kWh/kWp	+0.8 %	agrees

Wind: measured farms

Reference	Basis	Published	Hasim	Deviation	Result
US wind farms installed 2022 (233 W/m², 8.3 m/s at 100 m), 2023 [38] measured	capacity factor, curtailment (4.6 %) added back *wind index of the year 0.95; Hasim low-wind turbine (216 W/m²)*	40.0 %	39.6 %	−1.0 %	agrees

Reference	Basis	Published	Hasim	Deviation	Result
US wind farms installed 2021 (231 W/m², 8.0 m/s at 100 m), 2022 [38] measured	capacity factor, curtailment (5.3 %) added back *wind index of the year 1.06*	39.1 %	37.7 %	−3.6 %	agrees
alpha ventus offshore, 12 × 5 MW, 10 m/s at hub, 2011–2013 [2, 39, 40] measured	capacity factor *Hasim with the turbine data of the farm, the FINO1 shape factor k 2.1 and the offshore loss allowance (15.5 %)*	48.2 %	41.2 %	−14.5 %	deviates, conservative
NREL Cost of Wind Energy Review 2024: fixed-bottom offshore reference project, 9.05 m/s at hub, k 2.1 [1, 3] tool result	net capacity factor, losses 15.5 % *Hasim offshore turbine class (IEA 15 MW reference turbine)*	49.0 %	46.1 %	−5.9 %	close, conservative

Compression

Reference	Basis	Published	Hasim	Deviation	Result
Isothermal minimum 20 → 350 bar at 300 K (DOE) [41] reference value	thermodynamic minimum	1.05 kWh/kg	1.10 kWh/kg	+4.8 %	agrees
Isothermal minimum 20 → 700 bar at 300 K (DOE) [41] reference value	thermodynamic minimum *Hasim averages Z over the pressure range*	1.35 kWh/kg	1.50 kWh/kg	+11.1 %	deviates, conservative
HDSAM station compression 20 → 440 bar (isentropic 56 %, motor 92 %) [41] tool result	electricity, same efficiencies in Hasim	2.23 kWh/kg	2.41 kWh/kg	+8.1 %	close, conservative
HDSAM station compression 20 → 880 bar [41] tool result	electricity, same efficiencies in Hasim	3.0 kWh/kg	3.13 kWh/kg	+4.3 %	agrees
Pipeline compressor 20 → 100 bar (DOE status 2015) [42] reference value	electricity *Hasim default efficiencies*	0.82 kWh/kg	0.95 kWh/kg	+15.9 %	deviates, conservative
Terminal compressor 100 → 550 bar (DOE status 2015) [42] reference value	electricity	1.1 kWh/kg	1.14 kWh/kg	+3.6 %	agrees
Compression at US refuelling stations, 350 bar (DOE technology validation) [41] measured	measured range *Hasim 20 → 440 bar, default efficiencies*	2.0–4.0 kWh/kg	1.91 kWh/kg	−4.5 %	agrees
Diaphragm compressor 10 → 420 bar, Cal State LA station [43] measured	measured over several quarters	1.5 kWh/kg	2.28 kWh/kg	+52.0 %	deviates, conservative

Water

Reference	Basis	Published	Hasim	Deviation	Result
Demineralised water consumed per kg (Arup) [44] reference value	process water *Hasim default of the design basis*	9.0–11.0 L/kg	10.0 L/kg	within	agrees
Raw water, surface or municipal supply (Arup, PEM, dry zone) [44] reference value	process water, air cooling *Hasim case A: RO recovery 0.8*	15.0 L/kg	12.5 L/kg	−16.7 %	deviates, optimistic

Reference	Basis	Published	Hasim	Deviation	Result
Raw water, seawater (Arup, PEM, dry zone) [44] reference value	process water, air cooling *Hasim case B: SWRO + second pass*	25.1 L/kg	26.6 L/kg	+6.0 %	close, conservative
Hydrogen Park South Australia, 1.25 MW PEM [45] measured	ultrapure water per kg (operator)	15.0 L/kg	10.0 L/kg	−33.3 %	deviates, optimistic
Practical range, stoichiometric to deionisation losses (JRC) [46] reference value	fresh water per kg *Hasim case A: municipal water, RO recovery 0.8*	9.0–22.0 L/kg	12.5 L/kg	within	agrees

Levelised cost of hydrogen: US DOE H2A-Lite and IEA

The DOE record gives the LCOH of a 50 t/d PEM plant for four power supplies at three installed costs, all with 57.5 kWh/kg (life average), fixed O&M of 5 % of the capital per year, a stack replacement costing 11 % of the capital every 40 000 operating hours and a 30-year life [8]. H2A-Lite finances the plant with equity, debt and income tax; Hasim's LCOH (equation CM 17.3) uses one discount rate. With a single rate of **11.6 %** – the pre-tax equivalent of the H2A financing – Hasim reproduces all twelve DOE values within **1.9 %** (mean 0.7 %). One rate fits all cases, so Hasim treats capacity factor, electricity price, capital cost and stack replacement the same way as the DOE tool.

Power supply	Capacity factor	Electricity, ¢/kWh	1 500 $/kW: DOE / Hasim	2 000 $/kW: DOE / Hasim	2 500 $/kW: DOE / Hasim
Grid average	97 %	8.3	6.80 / 6.74	7.50 / 7.39	8.20 / 8.04
Hydropower	50 %	3.4	5.50 / 5.54	6.70 / 6.74	7.90 / 7.93
Land-based wind (class 1)	51 %	2.9	5.20 / 5.19	6.40 / 6.36	7.50 / 7.53
Hybrid wind–PV	74 %	3.3	4.40 / 4.40	5.20 / 5.23	6.00 / 6.06

The IEA gives the LCOH of PV-based hydrogen in Oman in 2030 for an electrolyser of 320 $/kW, 69 % efficiency (LHV), fixed O&M of 3 % per year, a PV capacity factor of 29 % and a 25-year life, with a WACC of 3.5–5 % [47]. Hasim's range covers these discount rates without and with one stack replacement after 50 000 h:

Electricity price	IEA	Hasim (WACC 3.5–5 %, without / with one stack replacement)
35 $/MWh	2.4 $/kg	2.24–2.40 $/kg
25 $/MWh	1.9 $/kg	1.76–1.91 $/kg

HOMER Pro and the accuracy of established tools

The three HOMER Pro studies that publish complete inputs and results [35, 36, 37] all ran the electrolyser at a constant 46.4 kWh/kg (85 % HHV at every load). Hasim's PEM system needs 54.5 kWh/kg at the beginning of life and 57.0 kWh/kg over the stack life, in line with the measured plants and the DOE values. With the same electricity HOMER therefore reports about 23 % more hydrogen than Hasim. An independent study found that constant-efficiency models overestimate the hydrogen from wind and PV by 5–24 % [48]. The PV yields of the same HOMER studies agree with Hasim.

Tool	Compared with	Deviation from the measurement
HOMER Pro [49]	PV energy, 4.2 kWp rooftop, Valencia	+5.3 %
SAM [49]	same system	+7.6 %
HOMER Pro / SAM / PVsyst / RETScreen [50]	PV energy, 177.8 kW plant, Sacramento	+5.5 / +3.6 / +6.9 / −3.9 %
HOMER Pro [50]	wind energy, 1.25 MW turbine, 5.8 m/s	+15.7 %
PV models, blind test [51]	six systems with measured weather	median −3.3 % (annual energy)
Fixed-efficiency electrolyser models [48]	hydrogen from wind and PV	+5 to +24 %

Deviations above 10 % and how to handle them

Conservative (6)

- **REFHYNE: PEM stack degradation in the field (2024–2025)** (2.8 ×): Hasim uses the US DOE status of 4.8 mV per 1000 h, on which H2A and the DOE stack life of 40 000 h are based. The rates measured in the field at REFHYNE and given by the Clean Hydrogen Partnership are lower, so stack replacements are costed on the safe side. Enter the vendor rate in the Component library for a specific stack.
- **PEM: stack degradation, state of the art (SRIA 2020)** (+31.6 %): See above – the same rate compared with the Clean Hydrogen Partnership state of the art.
- **alpha ventus offshore, 12 × 5 MW, 10 m/s at hub, 2011–2013** (−14.5 %): Hasim's generic power curve rises with the cube of the wind speed from the cut-in to the rated wind speed. The 5 MW turbines of alpha ventus reach rated power only at 12.5–13 m/s but deliver much more below it than such a curve. With the site's shape factor and the offshore loss allowance Hasim is therefore 14.5 % low; for the modern offshore class the gap to the NREL reference project is 5.9 % (section 5). Wind yields of turbines with a high rated wind speed are conservative.
- **Isothermal minimum 20 → 700 bar at 300 K (DOE)** (+11.1 %): The isothermal minimum shown in the compression results averages the compressibility over the whole pressure range; at 700 bar this overstates it by about 11 %. The compressor energy itself is computed stage by stage and agrees with HDSAM within +4 to +8 %.
- **Pipeline compressor 20 → 100 bar (DOE status 2015)** (+15.9 %): Hasim applies one compressor efficiency set (isentropic 75 %, mechanical 95 %, motor 95 %) with the API 618 discharge-temperature limit; large pipeline compressors reach higher efficiencies. Enter the vendor efficiency in the Component library.
- **Diaphragm compressor 10 → 420 bar, Cal State LA station** (+52.0 %): The measured 1.5 kWh/kg of this diaphragm compressor implies an isothermal efficiency of about 90 % – far above typical values; at the US refuelling stations the DOE measured 2–4 kWh/kg, and Hasim's 1.91 kWh/kg lies at the lower end of that range.

Optimistic (3)

- **SOEC: heat for the steam (DOE status – SRIA 2020)** (−26.7 %): Hasim needs 6.6 kWh of heat per kg to raise the steam – close to the 6.4 kWh/kg measured at INL. The DOE and Clean Hydrogen Partnership values (9–9.9 kWh/kg) include further heat demands at their system boundary.
- **Raw water, surface or municipal supply (Arup, PEM, dry zone)** (−16.7 %): Water use depends on the inputs of the design basis. Hasim's defaults (10 L of demineralised water per kg, 80 % RO recovery for municipal water) lie at the lean end; enter the supplier's values.
- **Hydrogen Park South Australia, 1.25 MW PEM** (−33.3 %): The small Australian plant reports 15 L of ultrapure water per kg; Hasim's default of 10 L/kg can be raised to the plant value (the design basis accepts 9–20 L/kg).

Planned model improvements

Tabulated power curves for vendor turbines in the Component library, so that turbines whose power rises faster than the generic cubic curve – such as those of alpha ventus – are modelled with their own curve; and stack-specific durability data from the vendors.

Not yet compared

- **HOMER Pro run on identical inputs.** HOMER is commercial software; this benchmark compares Hasim with published HOMER results, whose weather data and some inputs are not fully published. *Next step:* Run two or three reference cases in HOMER Pro with the hourly PV and wind profiles exported from Hasim, so that both tools see the same weather.
- **Plant data of alkaline and PEM plants at 10 MW and above.** Large plants (Kuqa, Baofeng, FH2R, Puertollano) publish production but not their specific consumption. *Next step:* Add the data when operators or projects publish them.

Sources of the benchmark

1. Stehly T, Duffy P, Mulas Hernando D. Cost of Wind Energy Review: 2024 Edition. NREL/PR-5000-91775, November 2024 (reference projects: land-based 8.01 m/s, k 2.0, total losses 18.8 %; fixed-bottom offshore 9.05 m/s, k 2.1, gross capacity factor 58.0 %, losses 15.5 %, net 49.0 %). https://docs.nlr.gov/docs/fy25osti/91775.pdf
2. Pettas V, Kretschmer M, Clifton A, Cheng PW. On the effects of inter-farm interactions at the offshore wind farm Alpha Ventus. Wind Energ Sci 6 (2021) 1455–1472 (Table 2: Weibull k at FINO1, 101.5 m), doi:10.5194/wes-6-1455-2021. https://doi.org/10.5194/wes-6-1455-2021
3. Gaertner E, Rinker J, Sethuraman L et al. Definition of the IEA 15-Megawatt Offshore Reference Wind Turbine. NREL/TP-5000-75698, 2020 (Table 1-1). https://docs.nlr.gov/docs/fy20osti/75698.pdf
4. Scheepers F, Stähler M, Stähler A, Rauls E, Müller M, Carmo M, Lehnert W. Improving the efficiency of PEM electrolyzers through membrane-specific pressure optimization. Energies 13 (2020) 612, doi:10.3390/en13030612. https://doi.org/10.3390/en13030612
5. Schmidt O, Gambhir A, Staffell I, Hawkes A, Nelson J, Few S. Future cost and performance of water electrolysis: An expert elicitation study. Int J Hydrogen Energy 42 (2017) 30470–30492, doi:10.1016/j.ijhydene.2017.10.045 (Table 1). https://doi.org/10.1016/j.ijhydene.2017.10.045
6. Cummins Inc. HyLYZER-1000 PEM electrolyser, specification sheet 5676518 (2021): operating range 5–125 %. https://www.cummins.com/sites/default/files/2021-08/cummins-hylyzer-1000-specsheet.pdf
7. Nel Hydrogen. M Series containerised PEM electrolyser MC250/MC500, product data PD-0600-0136 Rev J: turndown range 10–100 %. https://nelhydrogen.com/wp-content/uploads/2021/01/MC-Series_PD-0600-0136-Rev-J.pdf
8. Hubert M, Peterson D, Miller E, Vickers J, Mow R, Howe C. Clean Hydrogen Production Cost Scenarios with PEM Electrolyzer Technology. US DOE Hydrogen Program Record 24005 (H2A-Lite, 2022 dollars), 2024. https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/24005-clean-hydrogen-production-cost-pem-electrolyzer.pdf
9. US DOE Hydrogen and Fuel Cell Technologies Office. Hydrogen Shot: Water Electrolysis Technology Assessment, December 2024 (Table 2). https://www.energy.gov/sites/default/files/2024-12/hydrogen-shot-water-electrolysis-technology-assessment.pdf
10. US DOE Hydrogen and Fuel Cell Technologies Office. Technical Targets for Liquid Alkaline Electrolysis (2023, updated 2026). https://www.energy.gov/eere/fuelcells/technical-targets-liquid-alkaline-electrolysis
11. US DOE Hydrogen and Fuel Cell Technologies Office. Technical Targets for High Temperature Electrolysis (2023, updated 2026). https://www.energy.gov/cmei/fuels/technical-targets-high-temperature-electrolysis
12. Schefold J, Brisse A, Poepke H. 23,000 h steam electrolysis with an electrolyte supported solid oxide cell. Int J Hydrogen Energy 42 (2017) 13415, doi:10.1016/j.ijhydene.2017.01.072. https://doi.org/10.1016/j.ijhydene.2017.01.072
13. Casteel M et al. Performance of two 100 kW solid-oxide electrolysis systems over 7,140 h at Idaho National Laboratory. Int J Hydrogen Energy 157 (2025) 150283, doi:10.1016/j.ijhydene.2025.150283. https://doi.org/10.1016/j.ijhydene.2025.150283
14. Enapter AG. AEM Electrolyser EL 4.1 and AEM Nexus 1000 data sheets (beginning-of-life ratings). https://www.enapter.com

15. ANIONE – Anion exchange membrane electrolysis (GA 875024), results. CORDIS, European Commission. https://cordis.europa.eu/project/id/875024
16. Kopp M, Coleman D, Stiller C, Scheffer K, Aichinger J, Scheppat B. Energiepark Mainz: Technical and economic analysis of the worldwide largest Power-to-Gas plant with PEM electrolysis. Int J Hydrogen Energy 42 (2017) 13311–13320, doi:10.1016/j.ijhydene.2016.12.145. https://doi.org/10.1016/j.ijhydene.2016.12.145
17. HyBalance (GA 671384), periodic report 2019-04 to 2020-09. CORDIS, European Commission. https://cordis.europa.eu/project/id/671384/reporting
18. Ødegård A (SINTEF). REFHYNE – 10 MW PEM electrolyser. Clean Hydrogen Partnership, Hydrogen Research & Innovation Days, 24–25 Nov 2025. https://www.clean-hydrogen.europa.eu/document/download/4d0c2927-da90-43ce-bba0-c528c0f474b0_en?filename=05_Day1_Session_1_H2Production_AndersOdegard_public.pdf
19. Sprik S et al. MW-scale electrolysis testing at the Flatirons campus. US DOE Annual Merit Review 2024, NREL/PR-5700-89514; Leighton D, DOE H2IQ Hour, 25 Jul 2024. https://docs.nlr.gov/docs/fy24osti/89514.pdf
20. Peterson D, Vickers J, DeSantis D. Hydrogen Production Cost From PEM Electrolysis – 2019. US DOE Hydrogen and Fuel Cells Program Record 19009 (H2A v3.2018, 2016 dollars). https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/19009_h2_production_cost_pem_electrolysis_2019.pdf
21. Clean Hydrogen Partnership. Strategic Research and Innovation Agenda 2021–2027, Annex 2: state of the art and targets for AEL, PEMEL, SOEL and AEMEL (Tables 2–5), 2022. https://www.clean-hydrogen.europa.eu/knowledge-management/strategy-map-and-key-performance-indicators/clean-hydrogen-ju-sria-key-performance-indicators-kpis_en
22. IRENA. Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5 °C Climate Goal. Abu Dhabi, 2020 (Table ES1). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf
23. Miller HA et al. Green hydrogen from anion exchange membrane water electrolysis: a review of recent developments in critical materials and operating conditions. Sustainable Energy Fuels 4 (2020) 2114, doi:10.1039/C9SE01240K (Table 1). https://doi.org/10.1039/C9SE01240K
24. Pöyhönen S et al. Energy 322 (2025) 135602 – model of a 1 MW atmospheric alkaline electrolysis plant fitted to plant data, doi:10.1016/j.energy.2025.135602. https://doi.org/10.1016/j.energy.2025.135602
25. LONGi Hydrogen. ALK Hi1 and Hi1 Plus product launch – stack DC consumption in a factory test witnessed by DNV (GB/T 32311-2015). https://www.longi.com/us/news/hydrogen-alk-hi1-product-launch/
26. GrInHy2.0 – Green Industrial Hydrogen (GA 826350), periodic reports. CORDIS, European Commission. https://cordis.europa.eu/project/id/826350
27. Mougin J et al. MultiPLHY: 2.6 MW solid-oxide electrolyser – factory acceptance tests and stack durability. Int J Hydrogen Energy 141 (2025) 1165, doi:10.1016/j.ijhydene.2025.02.070. https://doi.org/10.1016/j.ijhydene.2025.02.070
28. Fang Q, Frey CE, Menzler NH, Blum L. Electrochemical performance and preliminary post-mortem analysis of a solid oxide cell stack with 20,000 h of operation. J Electrochem Soc 165 (2018) F38, doi:10.1149/2.0541802jes. https://doi.org/10.1149/2.0541802jes
29. NREL. Annual Technology Baseline 2024 – Utility-scale PV (reV/SAM, single-axis tracking, inverter loading ratio 1.34). https://atb.nrel.gov/electricity/2024/utility-scale_pv
30. Bolinger M, Seel J, Robson D. Utility-Scale Solar, 2018 Edition. Lawrence Berkeley National Laboratory (Section 2.4). https://eta-publications.lbl.gov/sites/default/files/lbnl_utility_scale_solar_2018_edition_report.pdf
31. Ascencio-Vásquez J et al. Performance of 168 utility-scale PV plants in Chile, 2014–2019. Solar Energy (2021), doi:10.1016/j.solener.2021.07.007. https://doi.org/10.1016/j.solener.2021.07.007
32. Kumar BS, Sudhakar K. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. Energy Reports 1 (2015) 184–192, doi:10.1016/j.egyr.2015.10.001. https://doi.org/10.1016/j.egyr.2015.10.001
33. Kunaifi K, Veldhuis AJ, Reinders AHME. The electricity grid in Indonesia … performance ratios of PV systems in the tropics and at DKASC Alice Springs. Appl Sci 10 (2020) 5412, doi:10.3390/app10165412. https://doi.org/10.3390/app10165412
34. Fraunhofer ISE. Recent Facts about Photovoltaics in Germany (2026), Section 16. https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/recent-facts-about-photovoltaics-in-germany.pdf
35. Turkdogan S. Design and optimization of a solely renewable based hybrid energy system for residential electrical load and fuel cell electric vehicle. Eng Sci Technol Int J 24 (2021) 397–404, doi:10.1016/j.jestch.2020.08.017. https://doi.org/10.1016/j.jestch.2020.08.017
36. Ali MF, Azam ME, Shezan SA et al. Techno-economic feasibility study of hydrogen storage in enhancing the reliability of a renewable-based microgrid. Sci Rep 15 (2025) 43473, doi:10.1038/s41598-025-28383-x. https://doi.org/10.1038/s41598-025-28383-x
37. Rizk-Allah RM, Hassan IA, Snasel V, Hassanien AE. An optimal standalone wind-photovoltaic power plant system for green hydrogen generation. Results Eng 22 (2024) 102234, doi:10.1016/j.rineng.2024.102234. https://doi.org/10.1016/j.rineng.2024.102234

38. Wiser R, Bolinger M et al. Land-Based Wind Market Report, 2022, 2023 and 2024 editions (executive summaries). US DOE / Lawrence Berkeley National Laboratory. https://emp.lbl.gov/wind-technologies-market-report
39. Stiftung OFFSHORE-WINDENERGIE. alpha ventus – operating results. https://www.offshore-stiftung.de/en/alpha-ventus.php
40. alpha ventus – Technik: Senvion 5M (126 m rotor, cut-in / rated / cut-out 3.5 / 13 / 30 m/s) and Adwen AD 5-116 (116 m rotor, 3.5 / 12.5 / 25 m/s). https://www.alpha-ventus.de/technik
41. Gardiner M. Energy requirements for hydrogen gas compression and liquefaction as related to vehicle storage needs. US DOE Hydrogen Program Record 9013, 2009. https://www.hydrogen.energy.gov/pdfs/9013_energy_requirements_for_hydrogen_gas_compression.pdf
42. US DOE Fuel Cell Technologies Office. Multi-Year Research, Development and Demonstration Plan – Hydrogen Delivery, 2015 (Table 3.2.4). https://www.energy.gov/sites/prod/files/2015/08/f25/fcto_myrdd_delivery.pdf
43. Genovese M, Blekhman D, Dray M, Fragiacomo P. Hydrogen station in situ back-to-back fueling data for design and modeling. Int J Hydrogen Energy 52 (2024) 688–704, doi:10.1016/j.ijhydene.2023.04.084. https://doi.org/10.1016/j.ijhydene.2023.04.084
44. Arup. Water for Hydrogen – technical paper for DCCEEW and the Australian Hydrogen Council, November 2022 (Table E-3). https://aidc.org.au/wp-content/uploads/2023/02/221114-Arup-Technical-paper-Water-for-Hydrogen-report-FINAL.pdf
45. Australian Gas Infrastructure Group. Hydrogen Park South Australia – plant metrics (September 2024). https://www.agig.com.au/hydrogen-park-south-australia
46. Bolard J et al. Clean Energy Technology Observatory: Water Electrolysis and Hydrogen in the European Union – 2024 Status Report. JRC, EUR 40075. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC139364/JRC139364_01.pdf
47. IEA. Renewable Hydrogen from Oman. Paris, 2023 (Figures 2.4 and 2.5). https://www.iea.org/reports/renewable-hydrogen-from-oman
48. Virah-Sawmy D, Beck FJ, Sturmberg B. Ignore variability, overestimate hydrogen production – quantifying the effects of electrolyzer efficiency curves. Int J Hydrogen Energy 72 (2024) 49–59, doi:10.1016/j.ijhydene.2024.05.360. https://doi.org/10.1016/j.ijhydene.2024.05.360
49. Vargas-Salgado C et al. Validation of HOMER and SAM against a monitored rooftop PV system in Valencia. Sustainable Energy Technol Assess 69 (2024) 103896, doi:10.1016/j.seta.2024.103896. https://doi.org/10.1016/j.seta.2024.103896
50. Komrit S, Zabihian F. Comparison of HOMER, SAM, PVsyst and RETScreen with measured PV and wind output. Energy Convers Manage 293 (2023) 117479, doi:10.1016/j.enconman.2023.117479. https://doi.org/10.1016/j.enconman.2023.117479
51. Theristis M et al. Blind photovoltaic modeling intercomparison. Prog Photovolt 31 (2023) 1144–1157, doi:10.1002/pip.3729. https://doi.org/10.1002/pip.3729
52. Abuyahya A, Feilat EA, Abuzayed A. Optimal Hybrid Energy System Sizing for Green Hydrogen Production: Scenario-Based Techno-Economic Approach. Hydrogen 7 (2026) 12, doi:10.3390/hydrogen7010012. https://www.mdpi.com/2673-4141/7/1/12

13 Modelling assumptions and limitations

- Hasim provides **concept and pre-FEED level** engineering. Results must be reviewed by qualified engineers; applicable codes, standards and certified tools take precedence.
- The weather is a **synthetic typical year** scaled to the site's annual GHI, mean wind speed and Weibull shape factor. Bankable energy yields require measured multi-year data.
- Wind turbines use a **generic power curve** between the cut-in and the rated wind speed. For turbines whose measured power curve rises faster below rated than the generic curve – typically older turbines with a high rated wind speed – the yield is underestimated (section 12.2); the loss allowance of the library turbines is the NREL reference value.
- Technology presets reflect published **status values** (US DOE technical targets, Clean Hydrogen Partnership); the durability of a specific stack – degradation rate and stack life – should be taken from the vendor and entered in the Component library.
- Costs are **indicative values** from the manuals and the component library; replace them with project quotations.
- The **impact assessment** is a screening assessment for comparing designs and components. Employment factors, embodied emissions and land use are typical published values (section 9.4) scaled with the size or cost of the equipment; they do not replace a life-cycle assessment to ISO 14040/14044, a socio-economic study or the environmental and safety permitting of the project. Seveso III tiers use the summation rule of Annex I for hydrogen and ammonia; other dangerous substances on the site and national implementations must be added.
- Cell model: LeRoy reversible voltage with Nernst term, symmetric Butler–Volmer kinetics, ohmic ASR and a limiting-current term; crossover by Fick permeation. SOEC: the heat for raising the steam and for operation below the thermoneutral voltage is supplied electrically or as external heat (section 8.1).
- Stack ageing accrues per operating hour at any load, which is conservative for plants that run long at part load; the replacement criterion is a 10 % voltage rise or the stated stack life (CM 6.6).
- Equipment sizing uses the simplified relations of the manuals (Souders–Brown separators, LMTD heat exchangers, Weibull wind, etc.). Vessel walls use ASME VIII-1 with the allowable stress of SA-516 Gr 70 (138 MPa) – conservative for the Cr-Mo steels of high-pressure tubes; pipelines use ASME B31.12 option A.
- Safety distances are consequence estimates for a reference leak (CM 19) and screening values of the NFPA 2 table; hazardous-area extents are screening values after IEC 60079-10-1. They do not replace a quantitative risk assessment, the hazardous-area classification or the separation-distance codes in force at the site.
- The RFNBO check covers the GHG intensity with hourly and monthly correlation. Additionality, geographic correlation and the rules for grid electricity counted as renewable (Delegated Regulation (EU) 2023/1184) must be verified with the PPA and the certification scheme.
- Scaling indices: the gypsum saturation uses the Davies activity model, valid to an ionic strength of about 0.5 mol/L; for seawater concentrates it is reported as "n/a". The Langelier index is indicative above about 10 g/L, where the Stiff & Davis index applies.

14 Copyright, licence and support

Licensed drawings and reports carry the licensee name in the title block. Evaluation and viewer outputs carry a watermark and may not be used commercially.

Support

Help ▸ User guide in the program · this manual and the Model-Building Examples · technical support: support@hasim-software.com · quotations and licences for organisations: sales@hasim-software.com (Help ▸ About shows both) · licence keys can be retrieved on the Hasim website · Hasim bought in the Microsoft Store belongs to your Microsoft account (account.microsoft.com).