Hydrogen's Dark Horse Is Turquoise

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Clean hydrogen and solid carbon instead of carbon dioxide. Two prices and one leak rate decide whether it wins.

SERINYX · QUORUM SHOWCASE SERIES Energy and Deep Tech

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Methane pyrolysis makes clean hydrogen and solid carbon instead of CO2, for less than a quarter of the electricity electrolysis needs; two prices and one leak rate decide whether it wins.

12 kWh of electricity per kilogram, against 52.4-55 for electrolysis	**€2.44 / €5.24** a kilogram with the carbon sold, and without a buyer	**0.63%** the methane leak gate that both published figures fail

CAPABILITY DEMONSTRATED
Techno-economic modelling and patent landscaping

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A showcase of the Quorum evidence pipeline. This report summarises a small part of a much larger body of research; the scale of that work, and how to commission it, are set out on the closing page.

Prepared by Serinyx GmbH. Every factual statement carries a superscript reference to a verified source list. AI disclosure: researched, drafted and checked by Serinyx's Quorum evidence pipeline under named human sign-off; it should empower human judgement, not replace it.

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Every section header states the number of separately sourced claims that section rests on. Superscript numerals throughout resolve to the reference list; each figure and table carries the claim ids behind every value it prints.

EXECUTIVE SUMMARY

There is a third way to make clean hydrogen, and it is not a compromise between the other two. Methane pyrolysis (splitting natural gas with heat, no oxygen) breaks methane into hydrogen and solid carbon: no CO2 at the point of production, and roughly 12 kWh of electricity per kilogram against the 52.4-55 kWh the two mainstream electrolyser routes need[1–6,13]. That is an electricity saving, not an energy saving: the methane feed carries about 59 kWh per kilogram, so on total energy pyrolysis is the hungrier route[1–8].

The economics come from an adjudicated European financial model of a first-of-a-kind modular ~25 t/day plant, on verified February 2026 inputs. Its base case lands at €2.44 a kilogram with the solid carbon sold at €700 a tonne, €5.24 if the carbon earns nothing, €5.39 if you pay to bury it[7–10]. Across scenarios the span is €1.47-4.07 with carbon sold[7]. One lever dominates: swung €0 to €1,500 a tonne, the powder's price moves the cost of hydrogen by €5.20, more than every other lever combined[7]. The gas price is the second lever, worth €1.97 across its modelled range[7]. Grey hydrogen plus its CO2 bill costs about €2.81 today and rises on a legislated escalator[7,21–23]. Green trades at €6-10[23,24]. The window is real, and it is defined.

Three things could shut it. Upstream methane leakage above 0.63% voids the near-zero claim; the global average, about 0.8%, and the literature's central 1.58% both fail that gate[11,12]. The carbon needs qualified buyers, and qualification takes 12-24 months per market[28,69]. And first plants overrun: 30-50% is the sane planning assumption[49,50].

This expanded edition adds the sector's patent landscape, roughly 250 active families growing about 30% a year, mapped into three corridors and five countable white spaces[18,56–59,62,63]. It is the report's second demonstrated capability, alongside the cost model you can run yourself. Every number below carries a claim id. The receipts are the point.

01 Three key numbers

RESTS ON 7 SEPARATELY SOURCED CLAIMS

On total energy, pyrolysis is the hungrier route. What it saves is electricity.

12 kWh of electricity, not 52-55. The electricity in a kilogram of pyrolysis hydrogen versus the two mainstream electrolyser routes: 77% less, about a fifth[1–6]. Electricity only; the methane feedstock carries most of the plant's total energy[7,8].

€2.44 or €5.24. The modelled cost of a kilogram from a first-of-a-kind modular ~25 t/day plant, February 2026 European inputs: €2.44 with the solid carbon by-product sold at €700 a tonne, €5.24 if it earns nothing, €5.39 if you pay to bury it[7–10].

0.63%. The leakage ceiling (gas escaping before the plant; unburned methane warms far more than CO2) above which the near-zero label fails on 100-year accounting[11,12]. The global average, about 0.8%, and the literature's central 1.58% both fail[11,12].

02 A third colour of hydrogen keeps its carbon solid

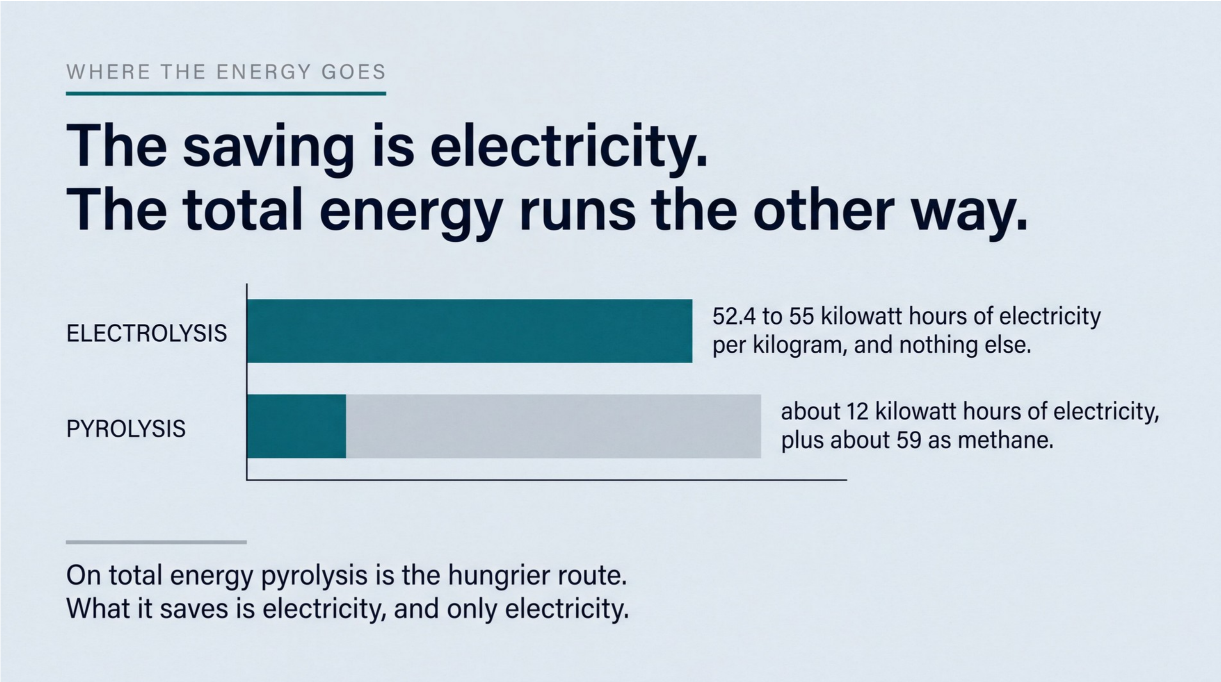
RESTS ON 25 SEPARATELY SOURCED CLAIMS

Green hydrogen splits water with renewable electricity. Grey strips hydrogen from natural gas with steam (steam reforming), venting the CO2. Turquoise's third route, methane pyrolysis, breaks methane into hydrogen and solid carbon: no CO2 at the point of production, external heat feeding the reaction, because the split absorbs energy rather than releasing it[5,13]. The carbon comes out as a solid you can hold.

Chemistry sets the terms. Unaided, the reaction only becomes favourable above 653°C and needs about 1,034°C for 90% conversion at atmospheric pressure; catalysts let it finish several hundred degrees cooler[14,15]. The corpus's best laboratory conversions approach the high nineties, though the single best figure, 98% at 750°C on an iron-molybdenum catalyst, could not be re-verified against its published source and is held lightly[14,15]. The best publicly verifiable result is different and older than you might expect: 95% conversion at 1,065°C in a molten nickel-bismuth alloy, published in Science in 2017[18].

The prize is the electricity bill; the label matters. Electrified pyrolysis draws roughly 12 kWh of electricity per kilogram of hydrogen; the two mainstream electrolyser routes need 52.4-55[1–6]. Electrolysis's energy input ends there; pyrolysis also buys about 59 kWh of methane per kilogram (its €1.83 gas bill over €31/MWh), most of which leaves in the carbon[5,7,8,13]. On total energy, pyrolysis is the hungrier route; what it saves is electricity[1–6]. That distinction is not pedantry. It decides which price movements hurt, and it is why this report claims an electricity saving, never an energy saving[1–7].

EXHIBIT 1



Serinyx Quorum evidence ledger; every plotted value traces to a claim id.

The climate ledger separates the colours too, on GWP100: how strongly a gas warms the planet relative to CO2, over 100 years[6,16,17]. Well to gate, grey averages 11.0 kg of CO2-equivalent per kilogram (range 9-14); electrified catalytic pyrolysis on renewable power reaches 0.45-2.6[6,16,17]. That band assumes renewable power; the cost case prices grid electricity; one contract must do both[6–9,16,17]. And the flattering band is a configuration pick, not the field's average: across the 21-study meta-analysis, pyrolysis as a class averages 3.8 kg[16]. The counterweight section returns to this.

It is early. The sector spans technology readiness levels 4-9 (TRL: a 1-to-9 maturity scale, 9 meaning routine commercial operation), with one sustained producer: plasma-route Monolith, TRL 8-9, producing since 2020[4,18,19]. Hycamite's catalytic plant sits at 7-8, BASF-ExxonMobil's moving-bed design at 5-6[4,18,19]. Integrated modular catalytic electrified systems, our modelled kind, assess at system TRL 4-5 even where components reach 5-7, because integration and control lag component maturity[20].

Four routes, five reactor families, about 25 companies

The field sorts into four broad routes: plasma torches, catalytic beds, molten-metal baths, and thermal designs running from moving beds to pulsed combustion and microwaves[4]. The corpus benchmarks five reactor families across them, and the differences are not cosmetic[5]. Plasma runs hottest (1,500-2,000°C) and hungriest (20-30 kWh of energy input per kilogram) but converts best and is furthest along[5]. Catalytic fluidised beds run at 800-900°C on 8-12 kWh, the lowest energy input of any family[5]. The corpus records those figures as energy input without splitting electricity from heat, so they are not directly comparable with the electricity-only figures elsewhere in this report[5]. Molten metal sits between; microwave and solar thermal remain at TRL 4-5[5]. Cost structures differ too: the build cost is about 40% of the all-in cost per kilogram for plasma against about 20% for catalytic and molten routes, and generic benchmarks put European costs at $2.80-3.50 a kilogram before carbon revenue, falling to $0.80-1.70 net once the carbon is credited[54]. Those are rough dollar yardsticks for comparing families; the adjudicated euro model in the next section governs every headline figure[7–9,54].

TABLE 1 **Five reactor families and the developers racing them: physics, maturity and capacity**

Reactor family	Operating temp	Energy input (kWh/kg H2, carrier unspecified)	Conversion	TRL	Build-cost share of all-in cost	Named developers (solid-carbon capacity now → announced, t/yr)
Thermal plasma	1,500-2,000°C	20-30	90%	8-9	~40%	Monolith 14,000 → 194,000 (design); HiiROC demo (25-50 bar); Graforce
Catalytic (fluidised bed)	800-900°C	8-12	70-85%	6-7	~20%	Hycamite 6,000; Hazer ~380 → 15,000+; Graphitic Energy ~365 → 30,000+
Molten metal	900-1,100°C	10-15	80-90%	5-6	~20%	Molten Industries (lab); C-Zero exited

Reactor family	Operating temp	Energy input (kWh/kg H2, carrier unspecified)	Conversion	TRL	Build-cost share of all-in cost	Named developers (solid-carbon capacity now → announced, t/yr)
						the route in 2024
Microwave plasma	800-1,000°C	12-18	60-80%	4-5	not benchmarked	Levidian ~15 per nozzle → 50,000 by 2030 (target)
Solar thermal	1,200-1,600°C	solar input	60-80%	4-5	not benchmarked	none at named scale

Sources:[5](temperature, electricity, conversion and TRL columns),[54](build-cost-share column; generic USD benchmarks, adjudicated euro model governs headlines),[4,19,55–59,68](developer column; Monolith's 194,000 is a design figure, its expansion delayed per[48,51–53]); TRL cross-check[4,18–20].

The developer field is thin and young: 25 or so companies worldwide, exactly one at commercial scale, most at TRL 5-7, first commercial plants expected 2026-2028, and disclosed sector funding of only about $1.2bn[4,66]. The named projects give the race its texture. Monolith's Nebraska flagship makes 14,000 tonnes of carbon black a year (about 5,000 tonnes of hydrogen) at a 97%-plus carbon yield, against 50-60% for the furnace process it displaces; its 194,000-tonne expansion remains a design figure, its $1.04bn US loan guarantee never finalised[48,51–53,68]. Hycamite, Europe's catalytic front-runner, has been commissioning a 2,000-tonne-a-year hydrogen plant in Finland since early 2025, consumes about 6.5-10 kWh per kilogram (13% of electrolysis's energy), and holds a marine-classification approval for making hydrogen on board ships from liquefied natural gas[19]. BASF and ExxonMobil signed the sector's biggest corporate validation in November 2025: a joint demonstration plant of 2,000 tonnes of hydrogen a year at Baytown, Texas, on a decade of BASF pilot work[18]. Ekona runs the contrarian no-electricity route, pulsed combustion, with a 200 kg-a-day pilot now, a field demonstration planned for 2027 and a first 20-tonne-a-day commercial unit by 2028; its ~$1.4 a kilogram cost target is a vendor projection at full commercial scale, not a delivered cost[67]. And the field already has a casualty and a pivot: Modern Hydrogen collapsed in late 2025 after raising about $125M, and C-Zero, now Graphitic Energy, abandoned molten media for a solid-catalyst bed in late 2024[48,51–53,55].

The modelled plant in this report is deliberately mid-sized, and the logic is countable. The optimal module is 20-50 tonnes a day, with 25 recommended: below 5, the complexity of running many parallel units dominates; above 100, heat-transfer risks return[54]. Building many identical modules beats building one giant on almost every technical axis (temperature spread under 5°C against 50°C-plus gradients, 10:1 turndown against 3:1, a failure costing one module rather than the whole plant), while the single large unit wins on initial build cost and per-unit maintenance[54]. Factory fabrication runs 20-40% cheaper than site-build, learning follows Wright's Law at 10-15% cost reduction per doubling, and Monolith validated the approach commercially by expanding with 12 identical reactors rather than one larger one[54].

The market these plants would serve is nearly untouched. Europe used 7.9 Mt (million tonnes) of hydrogen in 2023, virtually all grey; active clean capacity reached about 130,000 tonnes a year by late 2025, roughly 1.6% of demand[1]. The chemistry works and the field is open. What decides the race is arithmetic.

03 The model says €2.44 with a carbon buyer, €5.24 without

RESTS ON 17 SEPARATELY SOURCED CLAIMS

Read across any row and the powder does the work.

The economics in this report come from one place: an adjudicated European financial model of a first-of-a-kind modular ~25 t/day plant (about 25 tonnes of hydrogen a day), which the pipeline prefers wherever sources conflict[7–9]. Its base-case levelised cost of hydrogen (LCOH: the all-in cost per kilogram, build and running costs spread over everything the plant ever makes) is €2.44 with carbon sold at €700 a tonne, €5.24 with none[7–9]. The verified February 2026 basis: gas at €31/MWh on TTF (the European benchmark, a per-energy price), electricity €75/MWh, 8% cost of capital (WACC), a €90M build cost, running 91.5% of the year, 20-year life[7–9].

The full matrix is worth staring at, because it contains the whole business case and its failure mode in twelve cells[7].

TABLE 2 **The LCOH scenario matrix: what a kilogram costs as the powder's price moves (€/kg)**

Scenario (inputs)	No carbon revenue	Carbon €300/t	Carbon €700/t	Carbon €1,500/t
Optimistic (gas €25/MWh, electricity €50, WACC 6%, build €75M, 95% uptime)	4.27	3.37	1.47	negative
Base (gas €31, electricity €75, WACC 8%, build €90M, 91.5% uptime)	5.24	4.34	2.44	0.04
Stress (gas €50, electricity €100, WACC 12%, build €110M, 80% uptime)	6.87	5.97	4.07	1.67

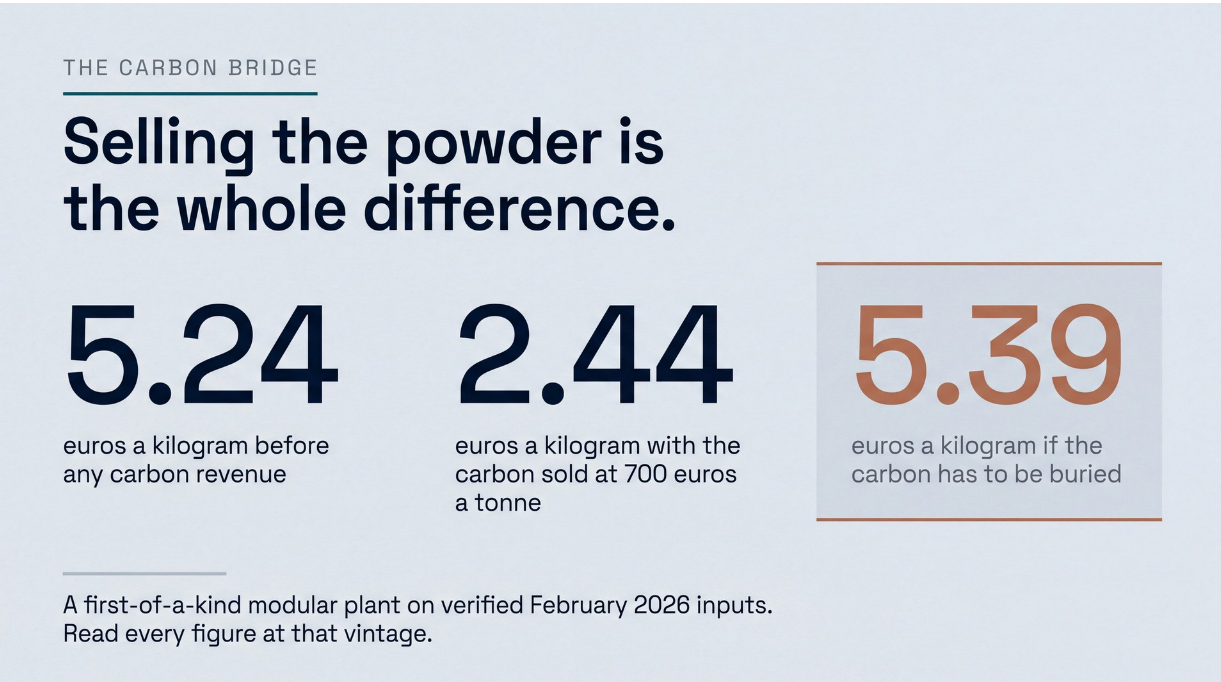
Sources: all cells[7]; scenario inputs[7]; the €700/t column is the report's headline pair[7–9]; the €1,500/t column's inversion logic[7]. February 2026 vintage; see the gas-price warning in the next section[7,8].

Read across any row and the powder does the work; read down any column and the whole European input set (gas, electricity, capital, build cost, uptime) moves the answer by about €2.60[7]. Read the corner cells and you get the honest span: €1.47-4.07 with carbon sold, a bankable band that replaced a prior unusable €0.28-7.99 spread built on mixed US and European assumptions[7]. At €1,500 a tonne the model inverts: hydrogen becomes essentially a free by-product (base LCOH €0.04) of a carbon-materials business, though €1,500 plant-wide is arithmetic, not a plan, beyond an unqualified newcomer's reach[7,28].

Where does the money actually go? Gas is the largest running cost at 44% (€1.83 per kilogram at €31/MWh); electricity is second at 24% (€0.98)[7,8]. The rest of the stack is small and dull, which is itself informative: maintenance €0.50 (12%, at 4.5% of the build cost a year), insurance and compliance €0.24, carbon handling €0.24 (€80 a tonne processed), catalyst replacement €0.20, a 22-person operations crew €0.19, water and utilities €0.05[7]. It sums to €4.23 a kilogram, €34.6M a year, before carbon revenue; the model's own summary page says €34.0M, a discrepancy the pipeline carries openly rather than smooths[7,8].

The bridge, so your arithmetic closes: build cost is €1.10 per kilogram (€90M over 20 years at 8%), leaving €4.14 of running costs under the €5.24[7–9]; the model's itemised table sums them at €4.23, a €0.09 residual carried openly[7,8]. Carbon at €700 a tonne takes €2.80 off: €5.24 minus €2.80 is €2.44, the model's own pair[7–9]. Its portfolio table books the credit lower, €2.33 (nameplate carbon against capacity-factored hydrogen); plain 3 kg at €700 gives €2.10[7]. And if nobody takes the carbon at any price, disposal adds €0.15: €5.39, the no-buyer case[10]. The web rendition draws the residuals as a labelled line[7–9].

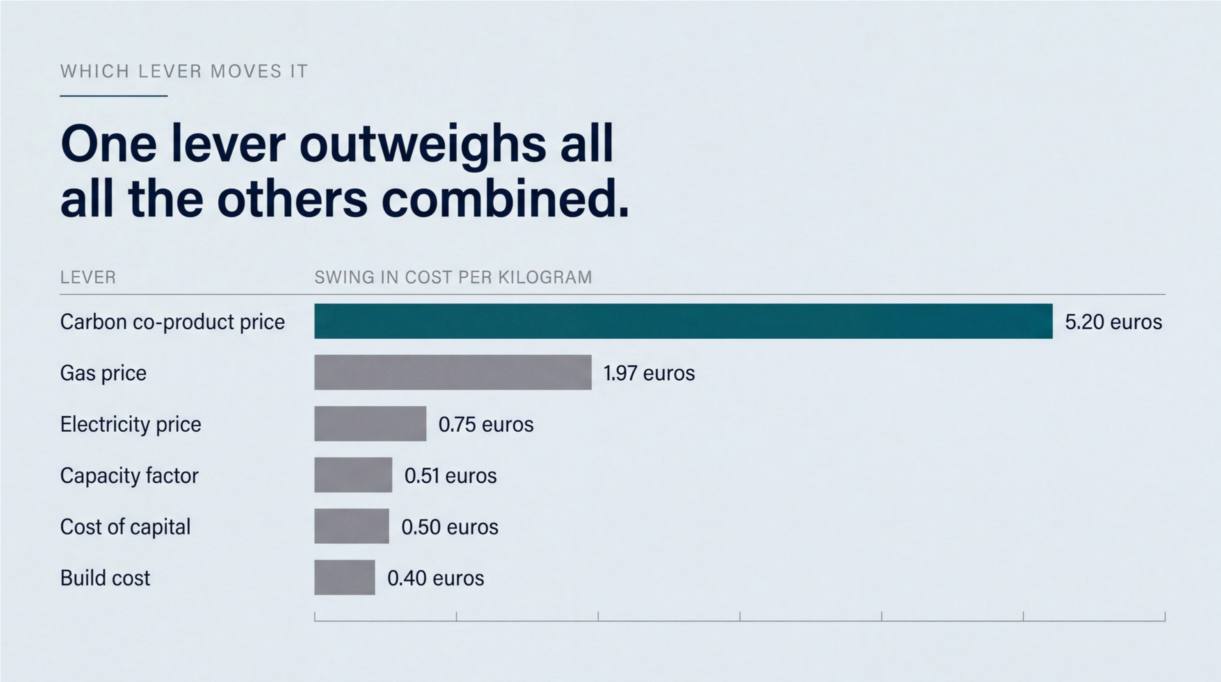
EXHIBIT 2



Serinyx Quorum evidence ledger; every plotted value traces to a claim id.

The lever ranking is lopsided. Swung €0 to €1,500 a tonne, the powder's price moves LCOH €5.20, more than every other lever combined[7]. Gas (€20-50/MWh) moves €1.97; electricity (€40-100) €0.75; uptime €0.51; the cost of capital €0.50; the build cost €0.40[7]. That ordering is the report's standfirst in one chart: the two prices that decide are the powder's and the gas's, and the powder's does most of it[7].

EXHIBIT 3



Serinyx Quorum evidence ledger; every plotted value traces to a claim id.

Two calibration warnings belong beside these numbers, both preserved from the earlier cut. First, the base case discounts plant one at 8%, near the rate only plant five earns; first-of-a-kind capital realistically prices at 9-14%, and the stress case's 12% covers the honest end[7,45]. Second, 91.5% availability is a mature plant's number applied to a system at TRL 4-5[7-9,20]. The counterweight section prices both assumptions.

For an investor the model reads almost too well, which is why its own gate matters. At €700 a tonne the plant clears €60-80M of annual operating profit, pays back its €90M build in 1.1-1.5 years and returns 15-25% a year before debt effects[7]. Grey parity holds whenever the carbon sells above €500 a tonne and the EU CO2 price exceeds €80, both true at the February 2026 vintage; the model's stated condition for a final investment decision is therefore not a technology milestone but a secured carbon offtake at €500 a tonne or better[7]. Paperwork, for once, is cheap: the full certification stack (lifecycle audit, UK and EU low-carbon schemes, product certification) totals €310-610k, a trivial €0.02-0.04 per kilogram, though its longest item runs 12-18 months and sits on the critical path[7].

04 Gas and CO2 set the goalposts; electricity picks the map

RESTS ON 6 SEPARATELY SOURCED CLAIMS

Turquoise hydrogen is a spread trade between two commodity prices it does not control: the gas it buys and the CO2 penalty its grey rival pays. A vintage warning first, strengthened from the earlier cut. Every cost figure above prices gas at the verified February 2026 level, €31/MWh on TTF, when spot ran €31-36 and full-year forecasts said €28-29[7,8]. On 2 September 2026, TTF traded near €71/MWh, more than double the modelled basis and outside the model's entire stress band, which tops out at €50[7,8]. Read every cost figure here at its February 2026 vintage; the web edition's model takes today's prices, and production will refresh before print[7,8]. The gas maths itself is mechanical: at 1.97 euros of LCOH per €30/MWh of gas movement, a doubling of TTF adds roughly €2.60 a kilogram unless hedged[7]. Two structural comforts survive the vintage problem: the 2030 consensus band is €20-33/MWh, back inside the modelled range, and a first-of-a-kind modular ~25 t/day plant draws about 87.6 million cubic metres a year, under 0.1% of any candidate country's consumption, a price-taker with no volume constraint[7,8].

The CO2 side moves the other way, on a legislated escalator. At February 2026's EU CO2 price of €81 a tonne, grey effectively costs about €2.81: €2.00 production (the EU energy regulator's figure) plus a €0.81 CO2 bill, assuming full pass-through though free allowances persist to 2034[21-23]. The trajectory is the point: the allowance price averaged about €65 in 2024, €81 by

February 2026, with projections near €85 this year, €100 in 2027 and a €126 consensus for 2030 (range €80-149), lifting grey's effective cost to about €3.26 by 2030 and €3.50-3.80 by 2035[7,21-23]. Imports do not escape: the carbon border levy adds €0.48-0.62 a kilogram to grey imports now, rising toward €0.70-1.00 by the late 2020s as free allowances phase out at 2.5 percentage points a year from 2026 to zero in 2034[7,21]. Every euro on the CO2 price is a euro of headroom turquoise does not have to earn.

Electricity is the quiet third dial, and it is geography. In 2025, wholesale power averaged about €37/MWh in the Nordics, €67 in France, €85-95 in Germany and €106 in the UK; EU futures for 2026 sat near €74, and industrial retail, taxes included, near €190[7,9]. Germany, the Netherlands and Spain already spend 8-9% of their hours at negative prices[7,9]. For an electrolyser this map is destiny; for pyrolysis it is a rounding decision. At €75/MWh, pyrolysis pays €0.60-1.13 a kilogram for electricity against €3.75-4.13 for electrolysis, and a €20/MWh swing moves pyrolysis by €0.16-0.30 against €1.00-1.10 for green[7]. Pyrolysis is structurally insulated from the power-price volatility that whipsaws electrolysers; its exposure concentrates in the gas contract instead[7,8]. Same map, different game.

05 The powder pays the bills, when someone buys it

RESTS ON 23 SEPARATELY SOURCED CLAIMS

The rules and the patents both tilt against a newcomer.

The by-product is the business model: each kilogram of hydrogen brings about 3 kg of solid carbon, about 27,000 tonnes a year at nameplate from a first-of-a-kind modular ~25 t/day plant[7]. The €700 a tonne is the model's blended assumption, averaged over four tiers from commodity black to low-value filler, its market anchors 2024-25 prints, not February 2026[7,27]. The blend is explicit: 10,000-12,500 tonnes of commodity carbon black at €900-1,500, 5,000-7,500 tonnes of specialty conductive and pigment grades at €2,500-5,000, 2,500-5,000 tonnes of battery-graphite precursor at €3,000-10,000, and 5,000-7,500 tonnes of low-value filler at €200-500, blending to €19.2M a year, a €2.33 credit per kilogram of hydrogen as booked[7].

The markets are real, and they are graded like diamonds. Carbon black (the powder that reinforces tyres and pigments inks) is a 2.8-3.2 Mt-a-year European market inside a global market of 14-15 Mt worth $21-24bn, of which tyres take about 70%[26,75]. Q1 2025 Hamburg delivery for standard reinforcing grades ran $1,430-1,470, about €1,320-1,360 in the model's dollars; €700 sits near half that[7,26]. Above the standard grades the ladder climbs steeply, and below them the recovered market (rCB: recovered carbon black, reclaimed from shredded end-of-life tyres) prices purity with brutal clarity: ash content alone spans a near-fivefold spread[75].

TABLE 3 The carbon-product price ladder and the purity gates between its rungs

Rung ($/t, 2024-25)	Price	Gate to clear
Low-value filler / construction	200-500 (€)	none; volume sink[7]
Raw rCB, 15-20% ash	400-600	ash under 20%[75]
Standard rCB, 8-12% ash	800-1,200	ash under 12%[75]
Commodity carbon black (N300-N700)	800-1,200	industry grade specs (ASTM)[75]
Reinforcing grades (N100-N200)	1,000-1,400	industry grade specs (ASTM)[75]
Premium rCB, under 5% ash	1,950-2,285	under 7% then under 5% ash[75]
Premium tyre grade	Q1 2025 N330: 1,430-1,470 (EU)	under 0.5% ash, under 0.1% sieve residue[75,76]
Specialty conductive / pigment	2,500-6,000	conductive and colour specs[75]
Battery-grade (ultra-pure)	5,000-15,000	≤0.025% ash, Fe ≤2 ppm, Ni ≤1 ppm, S ≤0.02%[75,76]

Sources:[75](virgin-grade rows and regional N330 prints),[75](rCB rows),[76](purity-gate column),[7](filler row, €); corroborated by[26](Hamburg N330). N-numbers are ASTM carbon-black grade designations. Pyrolysis carbon's potential ash below 0.1% brackets the top rungs[75].

Pyrolysis starts this climb with real advantages: it is the highest-yield, lowest-emission way to make carbon black, at 85-95% carbon yield against 55-65% for the furnace process and process emissions of 0.1-0.5 tonnes of CO2 per tonne of carbon against about 2.5[75]. Policy is pulling too. The July 2024 EU ban on Russian carbon black opened a 500-800 kt-a-year import gap, and estimated green premiums run 5-20% for tyre grades and 10-30% for European battery graphite[28,30]. Battery graphite is the premium prize: projected EU demand of 480,000 tonnes by 2030 against under 0.1% mined at home[29]. The EU's raw-materials law demands 10% domestic extraction and 40% processing by 2030, yet projections put European flake output 61% below even the mining target, while China controls over 60% of natural graphite, about 80% of synthetic, and over 90% of anode processing, with export permits required since late 2023[29]. The gap exceeds 300-400 kt by 2030; pyrolysis graphite counts as European processing, and capturing 5-10% of that gap would earn €160-400M a year[29].

Between the demonstrator and the megatonne dream, the absorption maths holds. Across six European segments, realistic pyrolysis-carbon capture is 335-990 kt a year by 2030 against 4.5-6.9 Mt addressable[31]. Projected supply is far smaller still: 30-50 kt a year by 2027, 100-200 kt realistic by 2030, under 1-2% of the combined market[77]. Each segment has a measured cracking point where added volume breaks the price: tyre black holds to about 500 kt a year, battery graphite is effectively depression-proof in deficit, biochar and construction carbon crack fastest, above 100 and 50 kt[77]. And a modelled mix strategy prices the whole journey: a 15 kt demonstrator averages about $4,000 a tonne; at 300 kt the average falls to about $2,500; at 3 Mt the mix needs construction and metallurgical carbon as volume sinks, 48% of output for about 8% of revenue, and averages about $1,280[77]. Absorption is a 2035-plus problem, not a 2030 one[31,77].

Qualification, not demand, is the clock. Tyre qualification is a staircase with seven steps, from supplier review (2-4 weeks) through compound development (8-16 weeks) to field trials (26-52 weeks): 12-24 months in total[69]. It has been climbed exactly once: Goodyear's ElectricDrive GT of 2023 was the first commercial tyre with pyrolytic carbon black, under a 20-plus-year feedstock agreement with Monolith[69]. Under 1% of carbon black in new tyres today is recycled or sustainable[28]. The battery lane runs on a comparable clock at a higher bar: 99.95% purity and 18-24 months of cell-maker vetting, with post-processing adding $1,000-2,000 a tonne[28,77]. The lab evidence is genuinely promising, 272 mAh/g of reversible capacity (milliamp-hours per gram, the standard yardstick for anode materials), and iron-ore-catalysed carbon beating natural graphite at high charge rates (120.4 against 70.2 mAh/g), but industrial-scale consistency is unproven, and the EU battery passport arriving February 2027 rewards whoever clears the bar with a low-carbon footprint[77]. Meanwhile the model books €700 from day one; the counterweight returns to that[7].

Post-processing decides which side of the ledger the carbon lands on: unsold, a disposal liability at about -€50 a tonne; processed and qualified, €900-9,000; the processing plant itself, pelletising up to a battery-grade line, is a €20-112M investment[10]. A second lane exists, with a catch. Pyrolysis carbon outlasts certified biochar: less hydrogen in the solid means a more graphite-like, stable material, and it tests 0.2-0.4 against biochar's 0.7 ceiling, implying 200-500-plus years of permanence versus 50-100-plus[32-34]. That underpins carbon-removal crediting, though the methodology remains a draft, not an adopted standard[32-34]. Biochar-class durable removals traded at €132-177 per tonne of CO2 in 2024-2025, Puro.earth's index just beneath at €131.27; none of the €2.44 rests on credits[7-9,27]. And the two lanes exclude each other: a removal credit pays for keeping a tonne verifiably stored for a century or more, a sale sends it into products; it earns as material or removal, never both[27,32-34]. The furthest extension of the credit lane is the biogas endgame: pyrolysing biogenic methane and permanently storing the carbon takes the lifecycle balance net-negative in the best case[78].

There is even a precedent for the hopeful reading. Recovered carbon black is bifurcating the market into premium-sustainable and standard segments rather than crashing it, with about 1 Mt of capacity projected by 2030 against 18 Mt of demand, and the incumbents, Birla, Orion, Cabot, are betting on tyre-derived rCB rather than pyrolysis, leaving the purity end of the sustainable segment open[77]. Sold, the carbon subsidises every kilogram of hydrogen. Unsold, you pay to bury it[10].

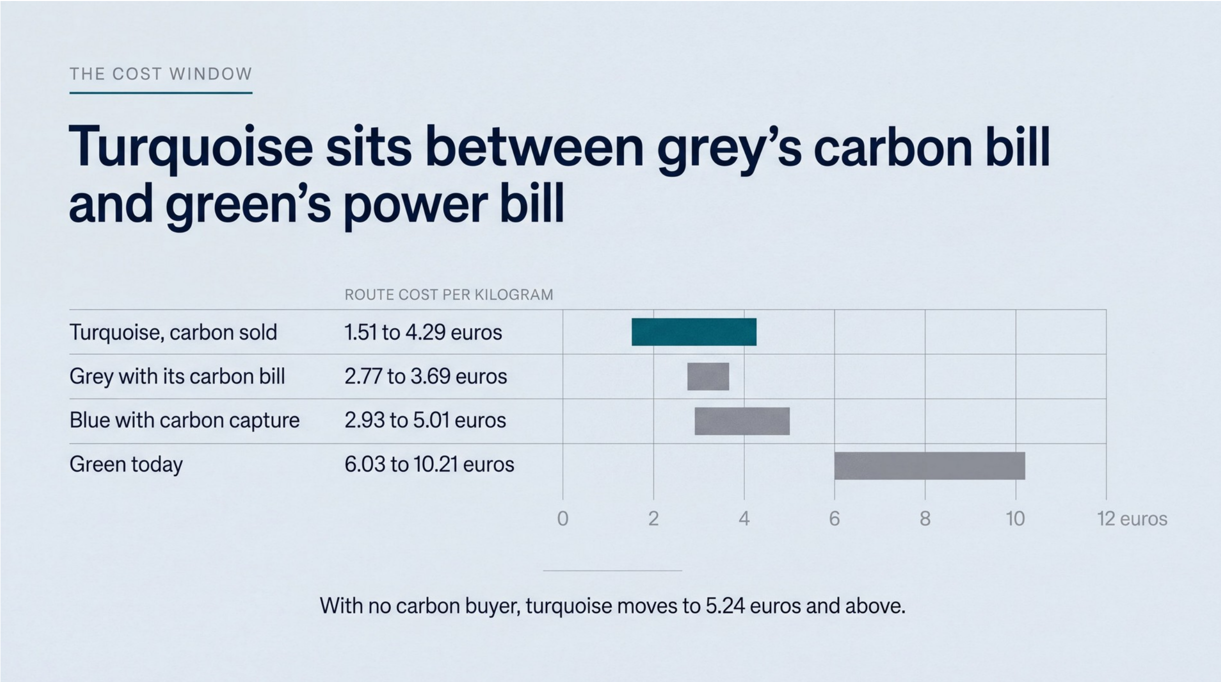
06 The patent map: 250 families, three corridors, five open doors

RESTS ON 10 SEPARATELY SOURCED CLAIMS

This section is the report's second demonstrated capability, patent landscaping, deferred in the earlier cut and delivered here: every figure below traces to a mapped patent family or a public filing statistic[18]. The landscape counts roughly 250 active patent families worldwide, growing about 30% a year since 2019[18].

The timeline is longer than the hype cycle suggests. The arc runs from Tyrer's molten-iron patent of 1931 (US1,803,221) and Steinberg's molten tin of 1998 (US5,767,165) to the 2017 Science paper on molten nickel-bismuth (95% conversion at 1,065°C) that triggered filings by UC Santa Barbara, Shell, TNO and BASF within 18 months, and now to commercialisation-phase IP signalled by the November 2025 BASF-ExxonMobil joint development agreement[18]. The wider context confirms the acceleration: hydrogen-production patent filings grew 280% from 2016 to 2021 (62 to 236 on one count; 555 filings in 2021 on a broader one), and low-emission hydrogen technologies generate twice the patents of established ones[65].

EXHIBIT 4



Serinyx Quorum evidence ledger; every plotted value traces to a claim id.

The families sort into three corridors that barely overlap, which is the single most useful fact in the map. Plasma (TRL 8-9) is anchored by Monolith's families and joined by HiiROC's seven filings on high-pressure plasma, Graforce's three to five, and Levidian's nozzle design[56–59]. Catalytic (TRL 4-7) is the densest corridor, dominated by Hazer's 70-plus patents around iron-ore fluidised beds[56–59]. Thermal and electrified designs (TRL 4-6) carry BASF's moving carbon bed at 900-1,200°C and ExxonMobil's stacked fluidised beds[56–59]. Because the corridors barely overlap, freedom to operate is achievable within a chosen corridor; crossing between them is where the blocking risk lives[56–61].

TABLE 4 The top patent holders: two startups outgun the majors

Rank	Entity	Estimated families	Corridor and anchor patent
1	Hazer Group	70+	Catalytic; WO2017/031529A1 (iron-ore fluidised bed)
2	Monolith	~47 (also countable as 24 cases across 153 applications in 16 countries)	Plasma; US9,574,086 B2 (priority 2014, expires ~2035)
3	BASF (with Linde, ThyssenKrupp)	5-10	Thermal; WO2020244803A1 (moving bed, 900-1,200°C)
4	UC Santa Barbara	5-10	Molten; WO2019099795A1 / US11,814,285B2
5	Topsoe	5+	eREACT EP3574991A1: electrified reforming, not pyrolysis
6	Shell	3-5	Molten salt; CA3096297A1
7	ExxonMobil	3-5	Thermal; WO2022081170A1 (stacked fluidised beds)
8	TotalEnergies / CNRS	2+	Induction-heated autocatalysts
9	TNO	2+	EP3693337A1 (dual-layer carbon wash)
10	Hycamite	undisclosed	Trade-secret strategy, no published numbers

Sources:[55,57,60,61,64](all ranks and counts),[56–59](corridor assignments and anchor patents),[56,57,65](Monolith counting variants),[64](Topsoe and Hycamite rows). Counts are family estimates from public databases and differ by counting method[55,57,60,61,64].

Two honesty notes before anyone invests on this table. Counting methods disagree: Monolith is about 47 patents in ten families on one method, 24 cases spread across 153 applications in 16 countries on another; both are printed because the units differ, not because one is wrong[56,57,65]. And portfolio scale is not corridor presence: Air Liquide holds 500-plus hydrogen patent families overall yet the turquoise landscape found none that are pyrolysis-specific, and Topsoe's heavily fenced electrified-reforming estate covers steam reforming, adjacent IP that constrains reactor-heating choices without blocking the pyrolysis lane itself[64,65]. The startups, not the incumbents, hold the two largest turquoise portfolios[55,57,60,61,64].

Beneath the reactor patents sits a second layer: roughly 150-plus families on steering the carbon itself into nanotubes, graphene, graphite or blacks, including about 45 on floating-catalyst nanotubes, Levidian's 13-plus on microwave graphene, and Monolith's carbon-black position built on its 2014 priority filing[56,57]. This is where the powder's price ladder and the patent map meet: morphology control is the patented route up the rungs[56,57,75].

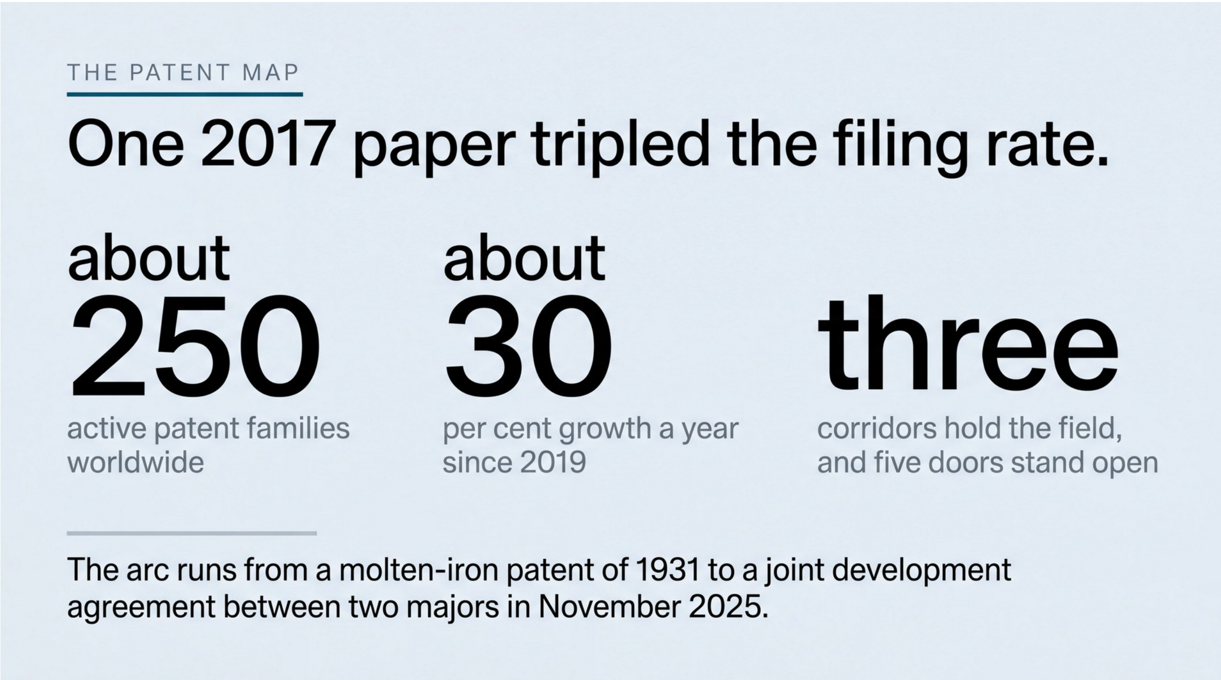
The white spaces are specific and countable, five doors still open[62,63]. No granted patent anywhere links pyrolysis carbon to battery-anode performance metrics such as capacity above 350 mAh/g. CO2-based catalyst regeneration by the inverse Boudouard reaction (running the carbon-deposit chemistry backwards with CO2) is essentially unpatented despite active academic work. Only one patent covers decomposition below 500°C. Biogas-tolerant catalysts are almost absent. And the foundational carbon-catalyst patents of Muradov have expired, opening carbon-catalysed decomposition to all comers[62,63]. Geography adds a sixth, softer opening: the US hosts about 44% of developers and the only commercial plant, Europe supplies about 45% of global R&D funding, and Chinese domestic filings are rising with limited English-language visibility[65]. The map says the field is young enough to enter and old enough to mine. It also says the window is narrowing; the counterweight prices that[58–61].

07 Eleven colours, one locked door, and a green pipeline mostly on paper

RESTS ON 22 SEPARATELY SOURCED CLAIMS

Hydrogen's colour wheel is bigger than the grey-green argument suggests. A global scorecard spans eleven pathways, from coal-derived hydrogen at $1.37-3.00 a kilogram carrying 18-20 kg of CO2-equivalent, through grey at $1.00-2.00, blue at $1.50-4.00, turquoise at $1.50-3.00 (TRL 5-6, and 2-16 kg depending entirely on configuration), nuclear-powered pink at $1.70-4.00, to green at $3.00-8.00 and speculative geologic white anywhere from $0.50 to $20[70]. On the European ledger, at February 2026 prices, the comparators line up like this: grey effectively about €2.81 with its CO2 bill[21–23]; blue (gas with carbon capture) €2.80-4.50[23,24]; green trading at €6-10 on the EEX HYDRIX spot index (electricity €205-260/MWh), with 2030 green projected at €2.50-5.00[23,24]. So €2.44 turquoise, carbon sold, undercuts grey-plus-CO2-price and today's green; €5.24 without carbon beats only green[7–9,21–24]. An external check in the corpus lands close, not on top: a 2024 industry analysis puts turquoise at €3.00 with carbon sales, €0.56 above our base, inside its band; that figure could not be re-verified at a public source[7,25].

EXHIBIT 5



Serinyx Quorum evidence ledger; every plotted value traces to a claim id.

The climate ledger deserves the same side-by-side honesty as the cost ledger, in both directions.

TABLE 5 **Lifecycle emissions by route: the electrons decide, for everyone (kg CO2-equivalent per kg H2, GWP100, well to gate)**

Route	Best	Base	Worst
Coal gasification	19.0	24.4	26.0
Grey (steam reforming)	9.0	11.2	14.0
Blue, steam reforming with 55% capture	4.5	5.5-6.5	8.2
Blue, autothermal reforming with 93% capture	1.5	2.0-3.0	4.0
Green electrolysis on grid power	3.0	17.2	41.4
Green electrolysis on renewables	0.3	2.0	2.5
Pink (nuclear)	0.4	0.5-1.5	2.2
Turquoise, plasma on grid power	2.0	4.5	8.1
Turquoise, electrified catalytic on renewables	0.45	1.5-2.5	2.6
Biogas pyrolysis with permanent carbon storage	net-negative	-0.5 to 0.5	1.5

Sources: all cells[16,17]; turquoise renewable band corroborated by[6,16,17]; biogas row[78]. Calibrators: literature means run pyrolysis 3.8, steam reforming 11.0, renewable electrolysis 2.02, pink 0.41[16]; upstream leakage overlays[11,12,16,46]; blue's capture-rate reality check[71].

Read the table symmetrically. Grid-powered electrolysis without additionality guarantees runs 3.0-41.4, at the top end nearly three times worse than unabated grey, while renewable-powered electrolysis averages 2.02[16]. Blue's best rows assume capture rates no commercial project has yet demonstrated at 95%[71]. And turquoise's flattering 0.45-2.6 belongs to one configuration on renewable power, while the class averages 3.8[6,16,17]. Where the electrons come from decides the colour, for electrolysers and pyrolysers alike[16].

Now the locked door. Turquoise cannot qualify as an RFNBO (renewable fuel of non-biological origin, the EU's legal category for electrolytic hydrogen made with new renewable power), because the definition requires electrolysis[7]. That locks it out of Europe's richest support lane: the pilot Hydrogen Bank premiums of €0.37-0.48 a kilogram went exclusively to RFNBO projects, and RED III (the EU's renewables law) reserves quotas of 42% of industrial hydrogen by 2030 and 60% by 2035 for RFNBOs, with a carbon-intensity ceiling of 3.4 kg CO2-equivalent per kilogram[7,72–74]. Turquoise's lane is the Low-Carbon Hydrogen Delegated Act, in force since December 2025, demanding at least 70% greenhouse-gas reduction against the fossil comparator; the UK's scheme, by contrast, explicitly names gas splitting producing solid carbon as eligible[7].

The consolation is that the subsidised rival is scaling slower than its press releases. Announced electrolyser capacity for 2030 runs 230-520 GW (gigawatts); installed capacity at the end of 2023 was about 1.4 GW, and only 4% of the pipeline had reached a final investment decision[70]. Real installations cost about $3,000 per kilowatt against the $1,800 the cost models assume, while 25 GW a year of electrolyser manufacturing capacity sits underused[70]. Europe's REPowerEU target of 20 Mt of renewable hydrogen by 2030 has about 0.9 Mt under contract, 4.5%[74]. Auction price discovery is running (seven pilot Hydrogen Bank projects at €0.37-0.48; six auction-as-a-service projects at €0.33-1.88), and two state-aid waves mobilised €5.4bn and €13bn across 80-plus projects, but typical large-project permitting still runs three to seven years[74]. Global demand context makes the stakes plain: the world used about 100 Mt of hydrogen in 2024, 43% in refining and 33% in ammonia, under 1% of it low-emission; the net-zero path needs 660 Mt of clean supply by 2050, stated policies deliver about 200[70]. The race is not turquoise against green. It is every clean colour against grey's incumbency, under a CO2 price that climbs for all of them[7,21,70].

08 The first plant is won on siting and subsidy, not chemistry

RESTS ON 16 SEPARATELY SOURCED CLAIMS

Permitting comes first, and pyrolysis starts in a no-man's-land. Europe's electrolyser fast-tracks exclude it, so a 20-50 tonne-a-day plant triggers the full chemical stack: industrial-emissions permitting with no size threshold, the EU's major-accident regime (Seveso, lower tier) from just 5 tonnes of hydrogen on site, a full environmental assessment likely[35–37]. No EU best-practice rulebook (BREF) yet covers pyrolysis: 2-4 months more[35–37].

The clock is knowable step by step, which is exactly what makes it manageable. Months 0-3: initiation and pre-application consultation. Months 3-6: environmental screening (capped at 60 days) and scoping (30 days). Months 6-18: the environmental report, safety studies and public consultation of 30-90 days. Months 12-18: the permit applications, environmental, building, Seveso and grid. Months 18-24: decisions, with the environmental conclusion capped at 90 days. Months 24-36: construction-phase approvals. Months 36-42: commissioning permits to commercial operation[72,73,79]. Per-permit durations explain where the risk hides: the environmental assessment runs 12-24 months, the industrial-emissions permit 6-18, and the grid connection 12-36 months, long enough to exceed the entire environmental path; appeals add 30-60 days of administrative review and 3-12 months of judicial review, though Germany's hydrogen acceleration law can strip appeals of suspensive effect[35,36,79]. Statutory fast lanes exist on paper: 18 months for projects of common interest, 12 months inside renewables-acceleration areas[72,73,79].

The biggest lever is dull: an address. Brownfield siting on an existing industrial estate cuts 6-12 months and 40-60% of permitting cost; realistic timelines run 8-14 months for a Flanders brownfield to 24-36 for a French or Dutch greenfield[37]. The engineering agrees with the lawyers: converting a retiring steam-reforming site reuses gas pretreatment, purification, compression, utilities and permits, worth $25-70M, with only the reactor heart needing replacement[54].

Public money de-risks the rest, and the menu is wide but oddly shaped. The EU Innovation Fund's IF25 net-zero call (€2.9bn) admitted pyrolysis explicitly; it closed in April 2026, and no successor is yet announced, so the route is indicative rather than open (refresh check, 2 September 2026)[38]. Its gates set the shape of any successor: at least 50% avoidance versus steam reforming, emissions under 6.84 tonnes of CO2 per tonne of hydrogen, at most €200 per tonne avoided[38]. The odds are structural: no pyrolysis project had won Innovation Fund support by early 2026, the prior net-zero round was 6.1 times oversubscribed and funded 25% of applicants (85 of 337), yet 30% of eventual winners were improved resubmissions[39]. For a first-of-a-kind modular ~25 t/day plant of €75-110M, a realistic grant is €45-54M, roughly half the build cost: milestone-based, nothing upfront, clawed back proportionally if the plant achieves under 75% of its promised avoidance[7,40].

TABLE 6 The funding menu: build-cost lanes open to pyrolysis, operating premiums mostly locked

Instrument	Envelope	Rate or value	Open to pyrolysis?
EU Innovation Fund (IF25 net-zero call; closed April 2026, successor pending)	€2.9bn	up to 60% of relevant costs	Yes, explicitly[38]
European Hydrogen Bank auction 3, Topic 2 (low-carbon lane)	€400M of a €3bn round	up to €4/kg for 10 years	Yes; first auction lane open to non-RFNBO hydrogen[38]
Hydrogen Bank Topics 1 and 3	€600M / €300M	up to €4/kg for 10 years	No (RFNBO-only / maritime)[38]
IPCEI Hydrogen (joint European state-aid projects; German envelope)	€14bn across four waves	up to 100% of the funding gap	Case-by-case[80]
H2Global auctions	€0.9bn + €3.5bn	up to €4/kg for 10 years	No (RFNBO-only)[80]
German carbon contracts for difference	€4bn	operating support	Industrial-decarbonisation lane[80]
France 2030 hydrogen (ADEME call covers pyrolysis)	€7bn (2020-30)	up to 45% of the build cost	Yes[41–44,80]
French hydrogen contract for difference	200 MW cap	up to €4/kg for 15 years	No (electrolysis-capped)[80]
Dutch DEI+	up to €30M per project	25-45% of costs	Yes[41–44]
UK third hydrogen allocation round	named eligibility	named eligibility (support type not mapped)	Yes; names gas splitting producing solid carbon; UK and EU routes exclude each other[41–44]
Critical Raw Materials Act strategic-project status	held by one pyrolysis firm	15-month permitting; €7.5-75M European Investment Bank-class debt	Yes[41–44]
State-aid stacking ceiling (CISAF, the EU's state-aid framework, June 2025)	caps €150/200/350M by region	15/20/35% aid intensity	modelled maximum ~€92.5M of build-cost aid (~€147.5M with operating support) for a €75-110M plant in an 'A' assisted area; theoretical headroom, not a commitment[80]

Sources:[38](EU instruments),[80](national instruments and the build-cost-open/operating-locked pattern),[41–44](Dutch, UK and raw-materials routes),[38](IF25 parameters and closure),[80](stacking ceiling); RFNBO lock-out context[7].

The pattern in that table is the policy story in miniature: the capital-expenditure lanes are technology-open, while the operating-premium lanes are mostly reserved for electrolysis[7,80]. A pyrolysis developer can get help building the plant; it must then sell hydrogen and carbon at market prices while its green rival collects a per-kilogram premium[7,74].

Survive the first build and the learning curve pays you back: build costs fall 30-50% by the fifth plant, lenders fund more (debt share 35-50% to 60-75%), and capital costs compress from 9-14% to 6-8%[45]. But the clock is honest only in decades: pilot to demonstration takes 2-3 years, demonstration to first commercial 3-5, commercial to scale 5-7, totalling 10-15 years on the recommended path (6-10 aggressive, at high risk; 16-22 conservative)[54]. Turquoise cannot rescue 2030 targets, only 2035-2040 ones[54]. Which is the point: the first plant is a siting, subsidy and financing project that happens to contain a reactor[7,37,40].

THE COUNTERWEIGHT: LEAKS, MISSING BUYERS, FIRST-PLANT PAIN AND A CLOSING WINDOW

The bear case is specific; part of it is physics. It comes in four instalments.

First, leaks. Leaked gas counts against the clean label. The global supply chain averages about 0.8%; the literature's central estimate is 1.58%[11,12]. Near-zero needs under about 0.63% (100-year accounting) or 0.22% (20-year): both figures fail both gates[11,12]. At 1.58%, the leak adds warming worth 47% of the CO2 from burning the entire feed gas (130% on the 20-year metric)[11,12]. Only best-documented routes, 0.06-0.08% on the Norwegian chain, pass with margin[11,12]. The physics is also finance: above 0.63% a plant loses carbon-credit eligibility, and in the severe stress case, project NPV (lifetime value in today's money) goes negative without credits[7,32,33]. Independent published studies corroborate the stakes: 1-3% leakage adds 1.0-3.5 kg of CO2-equivalent per kilogram (100-year), and splitting the emissions ledger between hydrogen and carbon (allocation) swings results 0.5-2.0 more[16,46]. And the marketing bands flatter: the 0.45-2.6 figure belongs to electrified catalytic plants on renewable power, while the literature's mean for pyrolysis as a class is 3.8, with grid-powered plasma at 2.0-8.1[16]. For symmetry, blue's floor rests on capture rates no commercial project has demonstrated at 95%, so scepticism cuts both ways[71].

Second, the buyers may not show up. A tonne cannot be sold and credited at once: a removal credit pays for keeping it verifiably stored for a century or more, a sale sends it into products; it earns as material or removal, never both[27,32–34]. The credit market bought about 8 Mt in 2024, and Microsoft alone took 64% of it (the top buyers together about 80%): a handful of cheques, not a market[47]. The materials lane is gated by qualification clocks the model does not price: battery graphite needs 99.95% purity and 18-24 months of cell-maker vetting, premium tyre grades need under 0.5% ash, under 1% of today's tyre carbon black is recycled or sustainable, and the model books €700 from day one[7,28]. At scale the arithmetic breaks: 30% of projected 2050 hydrogen demand would mean about 180 Mt of carbon a year, nine to thirteen times the 14-20 Mt market[26,31,48]. History punishes exactly this shape of optimism: US shale gas fell 67% between 2010 and 2014 when supply flooded in, and lithium crashed about 90% from its 2022 peak in the oversupply that followed; commodity-grade carbon at megatonne scale courts the same fate, which is why the segment cracking points and the mix-by-scale discipline in section four are load-bearing, not decoration[77].

Third, first plants hurt, and the base case does not price the pain. First-of-a-kind plants run 15-55% dearer than mature successors on OECD Nuclear Energy Agency data; 30-50% construction overruns are the sane planning assumption, with 25-40% contingency; full-wrap (fixed-price) completion guarantees are essentially unavailable[49,50]. Yet the base case assumes 91.5% availability and 8% capital from day one of a TRL-4-5 system[7–9,20]. Four unknowns survive every desk study and only a built plant resolves them: catalyst lifetime at industrial scale, the carbon output's actual quality distribution, grid-connection cost, and the capacity factor achieved during ramp-up; the first alone is material, since a five-fold catalyst replacement rate adds €0.80 a kilogram[7]. FEED (front-end engineering design, the detailed engineering study before a final investment decision) exists precisely to shrink that list, and the model prices the next phase at €2-4M over 6-12 months[7]. Technology risk is not hypothetical either: the molten-metal route's carbon-purity problem forced C-Zero's pivot in late 2024, and carbon lifted from molten nickel-bismuth carries about 83% metal contamination without a dedicated separation step, engineered around, not solved at scale[55]. The sector's own 2025: Modern Hydrogen collapsed after raising about $125M, Monolith's $1.04bn loan guarantee was never finalised, and roughly 50 hydrogen projects were cancelled globally[48,51–53]. Sequenced, the report's own numbers (8-36 months of permitting, a successor funding call, the build, 18-24 months of qualification) land full carbon revenue near the decade's turn, as 2030 green arrives at €2.50-5.00, and the recommended scale-up path runs 10-15 years end to end[23,24,28,37,38,54].

Fourth, the rules and the patents both tilt against a newcomer. Regulation locks turquoise out of the RFNBO premium lanes that pay green producers up to €4 a kilogram, leaving it to compete at market prices in a subsidised arena[7,38,80]. And the IP window is closing from above: BASF and ExxonMobil jointly hold a position on electrically heated moving and fluidised beds the analysis calls a formidable barrier, UC Santa Barbara's broad molten-alloy claims and Shell's wide molten-salt space could block entrants to those corridors, and the majors' shift to deployment IP narrows the period in which startups and institutes can still stake blocking patents[58–61]. The five white spaces of section five are real, but they are white because nobody has proven them worth fencing yet, or because the fences are being built now[58–63].

None of this says the dark horse cannot run. It says it runs only on documented low-leakage gas, into qualified offtake, inside a defended patent corridor, financed by someone who has priced the overrun[11,12,28,49,50,56–59].

HOW WE KNOW

This report showcases two Quorum capabilities, as its brief specified. Techno-economic modelling: every cost figure traces to an adjudicated European LCOH financial model, and the web rendition lets you run that model yourself. Patent landscaping: every patent count and family in section five traces to a mapped public filing. The earlier cut deferred the patent capability honestly, because the first harvest's briefed folders contained no countable patent facts; the expansion round lifted that deferral with a dedicated harvest of the corpus's IP landscape analyses, nine claim rows resting almost entirely on publicly verifiable patent numbers, the strongest citation class available[18,55,57,60–64].

The original research spans reactor, financial, carbon-market, lifecycle, permitting, funding, competitor and patent analyses. This draft maps 100 claims across two recorded harvest passes: 40 claims from 18 documents in round one (15 carrying claims), 60 more in the expansion, including the patent rows (harvest log). The fleet for this cut: seven agents (harvester, composer, editor, fact, adversary, layman, reconciler) plus an expansion harvester, the review seats same-vendor, a recorded pilot deviation. Claims are classed adjudicated (the reconciled financial model, preferred where sources conflict), published, or dossier (internal, generalised).

Conflicts the adjudication settled, listed so you can judge the preference: €2.44 against an industry analysis's €3.00 (not publicly re-verifiable)[25]; the blue and green comparator bands[23,24]; 3.0 against 3.5 kg of carbon per kilogram[7]; the global carbon black market's three corpus figures, 14-15, 18 and about 20 Mt, each printed at its own source's figure and spanned as 14-20 where aggregated[31,48,75,77]; the running-cost total's €34.0M summary against its €34.6M itemised table, the detail preferred and the €0.09 residual drawn[7]; Monolith's output (4,500 against 5,000 tonnes) and start year (2020 against 2021), and its patent count (about 47 patents against 24 cases across 153 applications), different units both printed[4,18,19,56,57,65,68]. One steam-reforming energy claim mixed bases inside its own source and was dropped; lacking a like-for-like total-energy row, the report claims an electricity saving, not an energy saving[1–6].

Evidence cut-off: the February 2026 vintage of the Rev A model; patent counts are family estimates from public databases at the same vintage[55,57,60,61,64]. 57 of 100 claims carry stale-risk flags (prices, indices, funding calls, capacities) and need refreshing before print; the sharpest is the gas price itself, live TTF at about €71/MWh on 2 September 2026 against the €31 modelled basis[7,8]. Not established: a Europe-specific patent-office filing series (geography rests on developer and funding shares)[65]; price history to backtest the model, which projects from one vintage; catalyst lifetime at industrial scale, the model's own open item[7]; the collection fleet's size, unrecorded in the corpus.

WHAT WOULD CHANGE OUR MIND

1. **Leakage above the gate.** If the contracted gas route cannot document leakage below 0.63% (100-year), the near-zero claim fails and credit revenue collapses[7,11,12,32,33]. Watch: supplier-verified leakage data for European pipeline routes[11,12].

2. **Carbon that will not sell.** If the carbon earns nothing, LCOH rises to €5.24 (€5.39 with burial), losing to grey at about €2.81[7–10,21–23]. Watch: Hamburg delivered prices, and the second tyre or first battery qualification deal after Goodyear's 2023 first[26,28,69].

3. **Green arriving cheap and early.** If green reaches its projected 2030 floor of €2.50 before a first plant is financed, the window all but closes: the margin is six cents, erased by a €1/MWh gas move[23,24]. Watch: the EEX HYDRIX index against its €6-10 band, and the share of the 230-520 GW pipeline reaching final investment decision[23,24,70].

4. **A corridor fenced shut.** If the BASF-ExxonMobil electrified-bed position, or the broad molten-alloy and molten-salt claims, mature into granted families that span the catalytic and thermal corridors, the freedom-to-operate premise of section five fails for new entrants[56–61]. Watch: grant decisions and oppositions on the named anchor families, and whether any of the five white spaces gets its first granted patent[62,63].

09 Small print

ABOUT THE RESEARCH CORPUS

This report is a summary of a much larger evidence base. The figures below state the size of the research corpus synthesised here, measured on the working corpus at build time.

Topic research corpus	1,051 files · 549 MB · approximately 2.08 million words across 16 research domains
Deepest domains	Regulatory and permitting (102 files), carbon valorisation (69), reactors (65), financial modelling (52)
Distilled into this report	100 tagged claims across two harvest rounds
Independently referenced	80 references; 47 verified links, 11 live but access-restricted
Review before release	4 external review seats plus a consolidated review · 82 findings resolved · 7 gates passed

Corpus word counts cover machine-readable text files; total sizes include datasets and rendered assets. Sources marked adjudicated passed the source study's own multi-model verification before this report used them.

THIS IS A SHOWCASE

You have read about one word in two hundred and seventy.

7,700
words in this report

2.08 million
words of research behind it

16
research domains, from reactors to permitting

A commissioned engagement is not a longer version of this document.
It is the study underneath it, run on your question.

THIS IS A SHOWCASE

About one word in two hundred and seventy of the research behind it.

This report runs to roughly 7,700 words. It is a summary of a study holding approximately 2.08 million words of research across 1,051 documents and 16 domains, from reactor engineering and the patent landscape to permitting, funding and the financial model that produced every cost figure quoted here.

What you have read here is a showcase. It demonstrates a handful of Quorum's capabilities on a topic chosen to be legible in twenty minutes. A commissioned engagement is not a longer version of this document; it is the study underneath it, run on your question, with your sign-off on the brief and a full audit trail you can hand to a board or an investment committee.

For a full piece of research or advisory work, contact Lorenz at lorenz@serinyx.com.

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