Economic deep decarbonization

An OEM's perspective on the fast-growing green H_2 market

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Electric Hydrogen Co.

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Oui, mes amis, je crois que l'eau sera un jour employée comme combustible, que l'hydrogène et l'oxygène, qui la constituent, utilisés isolément ou simultanément, fourniront une source de chaleur et de lumière inépuisables et d'une intensité que la houille ne saurait avoir."
Jules Verne, L'Ile Mysterieuse 1874

[Translation from French]
"*Yes, my friends, I believe that water will one day be used as a fuel, that hydrogen and oxygen, which constitute it, used alone or simultaneously, will provide an inexhaustible source of heat and light of an intensity that coal cannot have."*
Jules Verne, The Mysterious Island 1874

Not long ago, Jules Verne's vision was considered by many a pipe dream, something too expensive to be implemented. However, things are changing: Over the last two decades, companies and countries persisted and succeeded in bringing the cost of renewable electricity from solar and wind energy down to levels not previously imagined. Today, innovative companies, like Electric Hydrogen (EH2) are determined to do the same for electrolysis technology. Combining low-cost renewables and low-cost electrolysis makes Jules Verne's vision a reality. EH2 pushes the vision even further: not only does our industrial scale system make green hydrogen mainstream, but our mission is to bring it to market and decarbonize the most price sensitive industries.

In this first paper of a series, we guide readers through the recent changes in the hydrogen market and how green hydrogen is establishing itself as a critical technology for decarbonization and the global energy transition. EH2 continuously tracks electrolysis projects on a worldwide basis and, in this paper, provides an update on the global electrolysis project pipeline and important changes we see in the market.

In a follow up paper, we will describe EH2's product and scope in more detail and go through our approach to drastically reduce the still relatively high cost of electrolysis technology. We will also show how our technology translates to compelling levelized cost of hydrogen production (LCOH).

I. The onset of the green hydrogen virtuous cycle

Over the last few years, the world of energy has witnessed a paradigm shift when it comes to the lightest and most abundant element in the universe, a molecule long hailed as the fuel of a future that never came… until now. Approximately five decades since the expression "hydrogen economy" was coined by Professor John Bockris in 1970 [1] — we see an unprecedented surge in global interest around hydrogen as a necessary decarbonization tool. Many saw this "old new idea" as another periodic hype cycle, but things are fundamentally different this time. The ingredients for successful and sustained growth of the nascent green hydrogen market are coming together to engage a virtuous cycle characterized by:

(1) the declining levelized cost of fossil-free hydrogen triggered by lower cost renewable power from solar and wind energy along with favorable policies (e.g., US Inflation Reduction Act in 2022 or the EU's REPowerEU plan).

(2) the increasing number and scale of hydrogen projects further reducing hydrogen production cost.

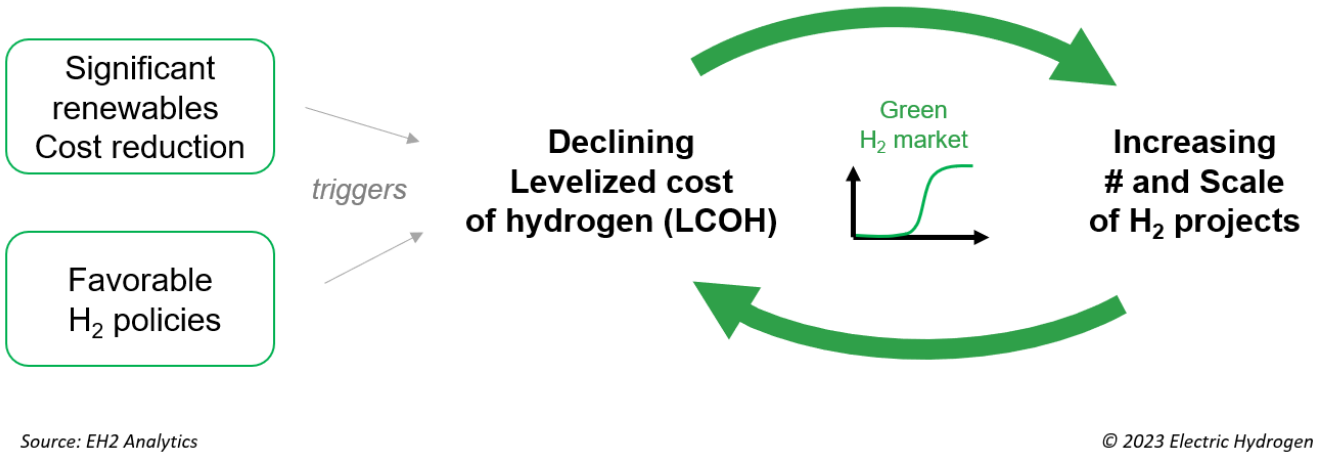
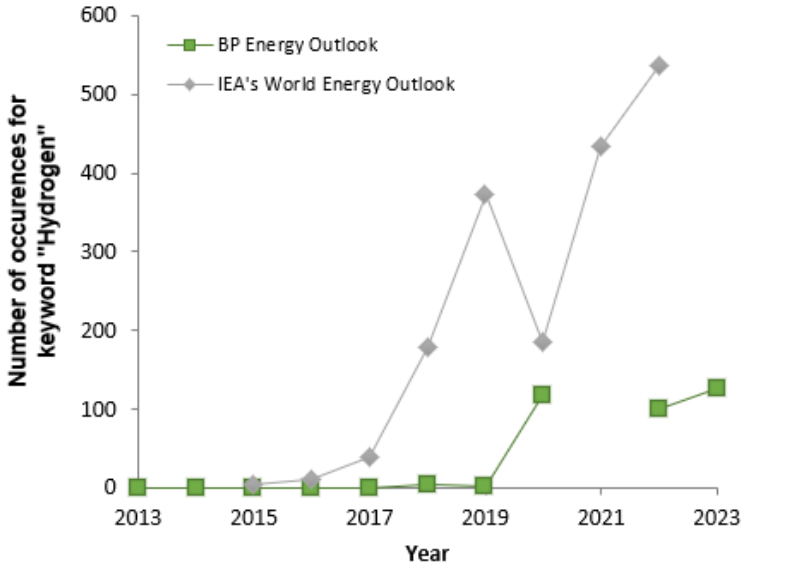


Figure 1 – The green hydrogen virtuous cycle

II. Putting hydrogen on the (energy transition) map

The consensus that hydrogen has an important role to play in the world energy transition has never been stronger. This shift can be seen in recent years by looking at global energy forecasts published annually e.g., the World Energy Outlook [2] by the International Energy Agency (IEA) or the annual Energy Outlook published by BP [3]. As shown in Figure 2, the word “Hydrogen” only appears in the last five to six years. Though seemingly sudden in their forecasts, the uptick in mentions of “hydrogen” is rooted in work that started years ago, or rather, never stopped. Project after project, test after test, scientists, engineers and entrepreneurs in academia, national labs and the private sector have been tirelessly developing and optimizing hydrogen technologies for decades. The result of this continuous effort is that it is now accepted that it is not only technically possibly, but also more and more economically feasible to use green hydrogen to mitigate greenhouse gas emissions in the “hard-to-abate industries" like ammonia, methanol, steel, cement, shipping, aviation, and the intercontinental trade of energy, which are together responsible for at least one quarter of global CO_2 emissions [4]. Electrolytic hydrogen generated by solar, wind or other renewable resources can provide the lowest cost pathway to decarbonize those industries, enabling an “indirect electrification” of sectors that aren’t amenable to direct renewable electrification.



Source: EH2 Analytics

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Figure 2 – Tracking number of occurrences of the word "hydrogen” in key global energy outlooks (IEA and BP)

III. The electrolysis market is taking off

A. The 1GWe of operating capacity milestone in sight

The year 2022 was a record year for electrolysis with about 250 Megawatts electric (MWe) added. These additions surpassed the previous record reached just a year earlier in 2021 – despite the pandemic and the ensuing economic downturn – when 75 MWe came online.

The global capacity for electrolysis sits today at **about 495 MWe** (as of May 2023). What makes the current situation unique is that for the first time in hydrogen history, there is more than 1 GWe of electrolysis capacity currently under-construction, more than twice the operating capacity globally. Out of the 1,230 MWe that are currently under-construction, 492 MWe are expected in 2023 and close to 620 MWe in 2024. Some of these are imminent like Sinopec's 260 MWe plant in Kuqa, China, in its final stages of construction and scheduled to be put into operation on June 30th, 2023. This all means that 2023 will be likely another consecutive record year for green hydrogen project additions and that **the 1 GWe milestone is around the corner, likely to be reached sometime in 2024.**

The installed fleet of electrolyzers is still small, with an average of 2.4 MWe per plant and most electrolysis plants have sub-MWe capacity: the median is today around 180 kWe. However**,** the scale-up trend is clear: There are currently 13 plants operating with a capacity above 10 MWe, half of which came online in 2022. Among the electrolysis plants currently under construction, 19 have a capacity above 10 MWe (an average of 35 MWe and median of 10 MWe for plants being built).

To put the above figures in perspective, replacing current global ammonia production would require close to 200 GWe of electrolysis at full utilization.

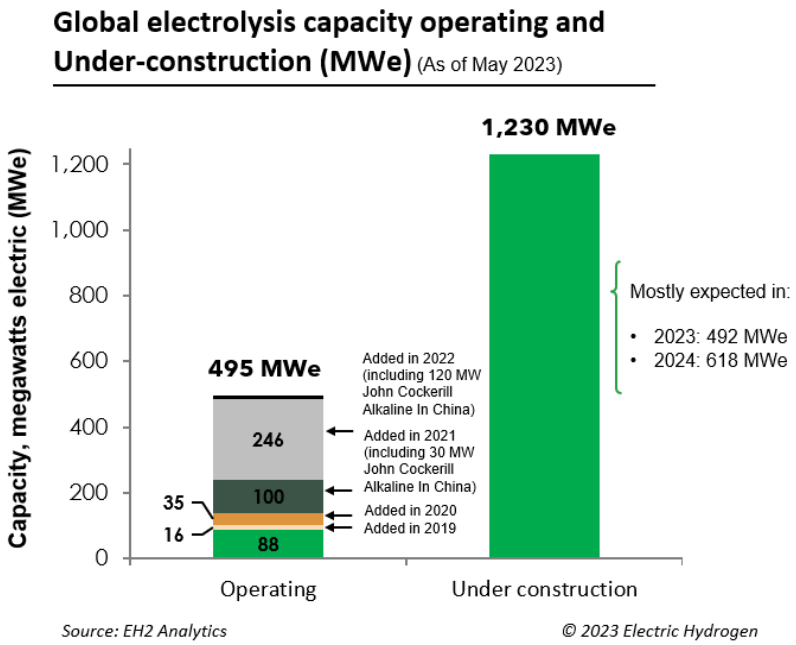

Figure 3 - Electrolysis capacity operating and under-construction

B. Alkaline vs. Proton Exchange Membrane (PEM)

One notable electrolysis plant that started last year is the solar-to-hydrogen 150 MWe alkaline plant built mostly using John Cockerill-Jingli technology (110 MWe by the Sino-Belgian joint venture) for Baofeng in northwest China. This plant alone constitutes nearly a third of the global capacity installed and tipped the alkaline versus PEM electrolysis technology race temporarily towards alkaline: currently the global installed capacity (including the 150 MWe Baofeng plant in China) is split 60% Alkaline and ~34% PEM (the remainder being either unknown or other technologies like solid oxide). However, when excluding the Baofeng plant, there is a more balanced split: ~43% alkaline /~48% PEM.

PEM currently has a slight edge among electrolysis plants under construction: **out of the 1,230 MWe being built, 48% are PEM-based, and 46% chose alkaline** – the latter are largely dominated by two 100MW+ scale Sinopec plants in China.

Given that alkaline technology has reached the tail end of its cost curve while PEM can still tap into lower regions of its own cost curve, one can expect PEM's share of installed capacity to rise as PEM systems are further scaled up and optimized for low-cost industrial deployments. At EH2, our goal is to provide advanced PEM systems at lower installed CapEx than alkaline systems with superior efficiency and that can drive PEM's market share growth even further.

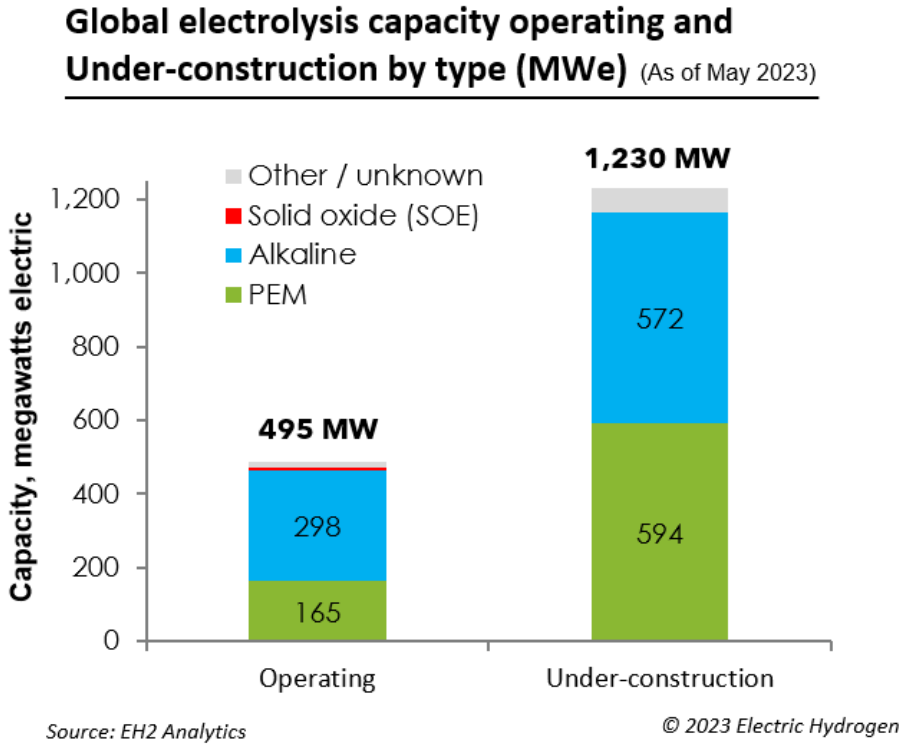

Figure 4 - Electrolysis capacity operating and under-construction by technology type

C. The project pipeline: 1,000 times more capacity in the making

The 1.7 GWe of electrolysis capacity currently operating or under-construction is dwarfed by the total planned capacity: **as of May 2023, a staggering 450 GWe of electrolysis capacity is being planned.** That includes all projects at any level of progress, meaning that some of those might simply be announced but might never break ground. To get a sense of the capacity with the most likelihood of being added among the total announced capacity, **10 GWe are currently at an advanced stage of development**. These are projects that completed feasibility studies and either moved towards FEED (front-end engineering and design), applied for, or received permits, or issued equipment purchase orders. 92 GWe are in early planning with conceptual or feasibility studies in progress.

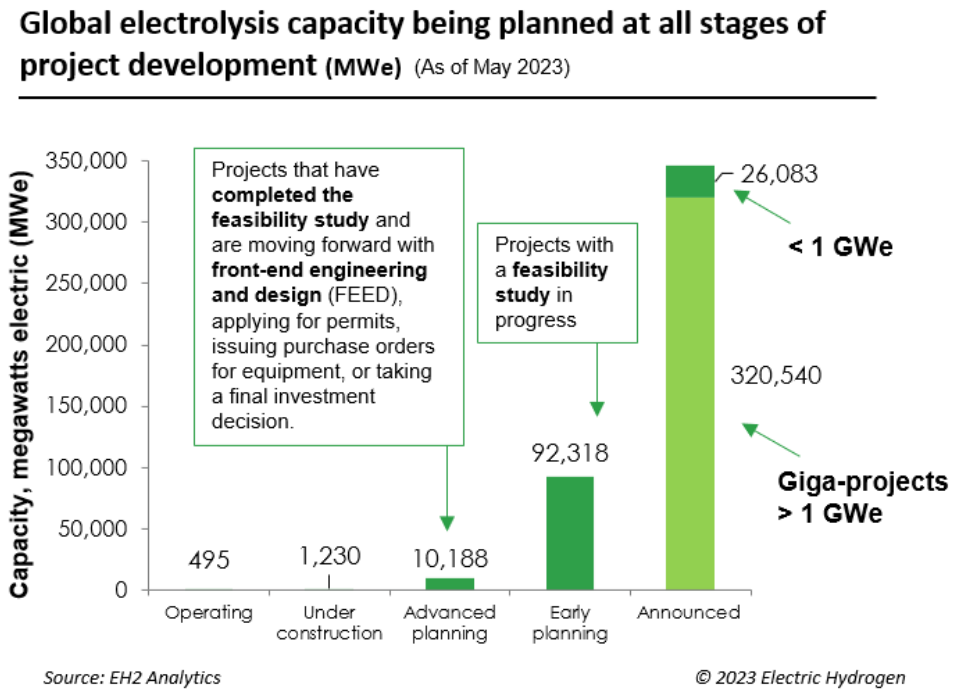

Figure 5 - Global electrolysis capacity in MWe at different stages of development (May 2023)

With 450 GWe of capacity planned or simply announced, the project pipeline is **1,000 times larger** than the existing capacity on the ground. This is one of the clearest indicators that the nascent green hydrogen market is taking off.

At this rate, EH2 **anticipates that electrolysis would likely surpass the rate of PV and wind** development in their early days, as shown in Figure 6.

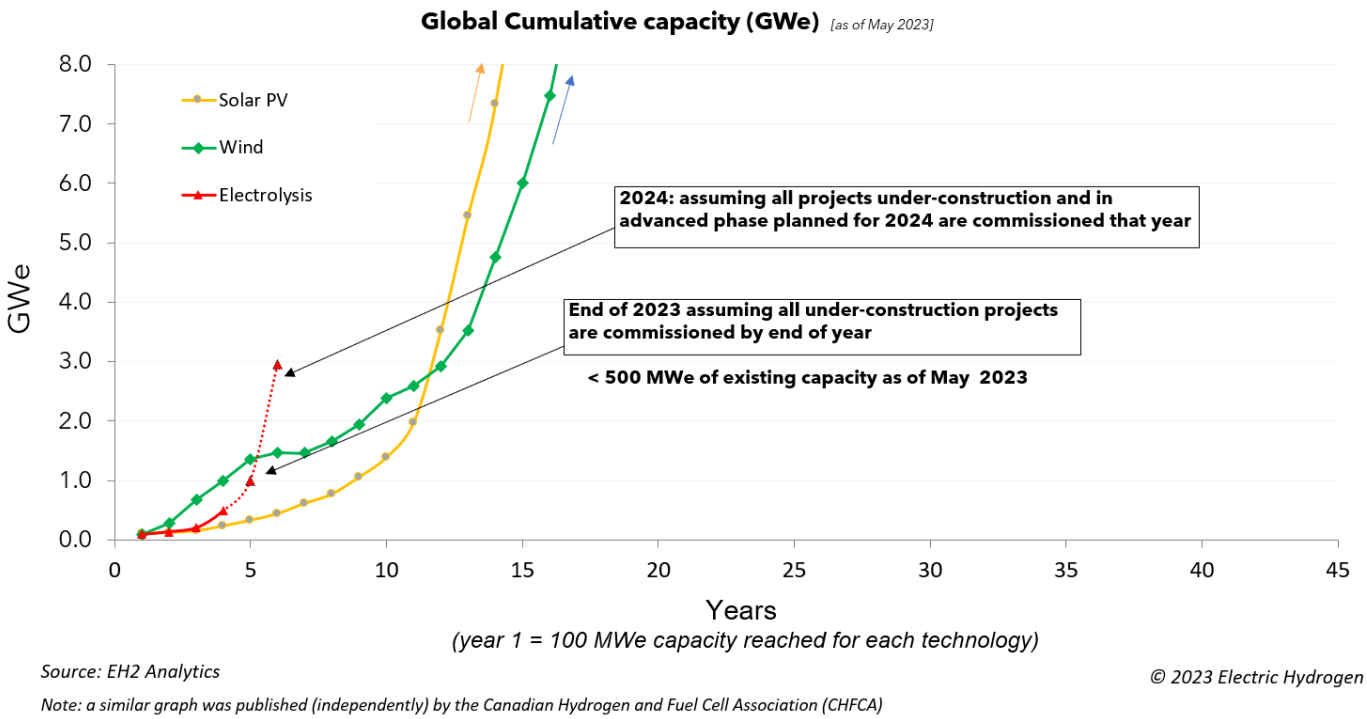

Figure 6 - Comparison of solar PV, wind, and electrolysis installed capacity evolution (All normalized to year 1 when each technology reached its first 100 MWe installed).

D. Market pull dominated by industrial players

As seen above, around 1.7 GWe of electrolysis capacity are either already operating (~1/3) or being built (~2/3), and about 9 GWe are in an advanced stage of development and are very likely to be built in the next few years. **But what sectors are driving this upcoming capacity growth?**

Industrial players are currently the single largest planned hydrogen offtake, dominated by the current uses of hydrogen as a feedstock, replacing mostly grey hydrogen used today in those industries.

These are refineries, ammonia, and other chemicals plants, along with new uses of hydrogen as feedstock, such as for steel decarbonization. Mobility applications follow with anticipated uses such as sustainable aviation fuels and hydrogen for heavy duty transport currently dominating that segment. An additional 2 GWe of the current project pipeline is slated for the power export market.

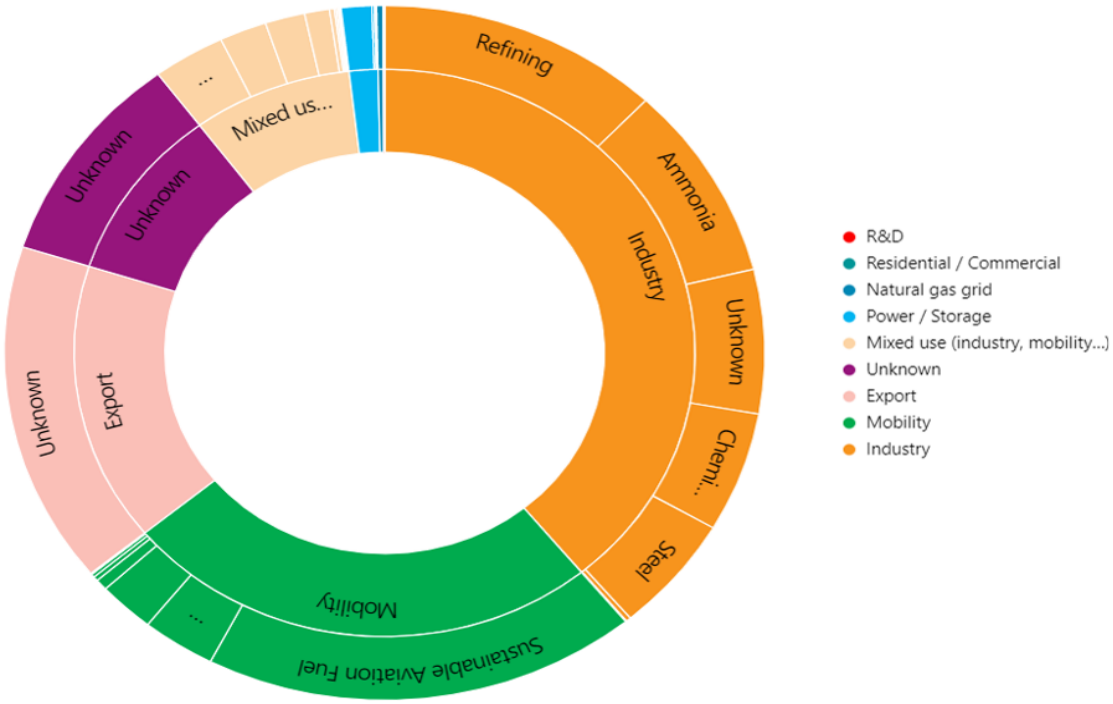

Figure 7 – Share of electrolysis capacity (existing, under-construction, and in advanced planning) by end-use (As of May 1st, 2023)

IV. Conclusion

The green hydrogen market is growing at an unprecedented pace with new records achieved each year and major milestones expected soon (like the first gigawatt of global installed capacity expected in 2024). Individual plants are also becoming larger in a market driven by industrial and infrastructure players.

The above is a validation of **Electric Hydrogen's founding** thesis and its product strategy to provide its customers with **fully integrated 100 MWe electrolyzer systems** to support industrial players in their decarbonization efforts at the lowest cost possible. In a follow-up paper, we will explain Electric Hydrogen's approach to tackle the still relatively high cost of electrolysis technology – the main barrier to wider adoption of green hydrogen. We will show how Electric Hydrogen's technology translates to lowest levelized cost of hydrogen and how the plant performance and LCOH analytics tools – developed by EH2 to support its customers in their green H2 project modeling – can be used to find the optimal project configuration and cost of hydrogen.

Want to contact us?

Get in touch with us here or email Soufien@eh2.com

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[3] Statistical Review of World Energy 2022

[4] Sector by sector: where do global greenhouse gas emissions come from? Our world in data https://ourworldindata.org/emissions-by-sector

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