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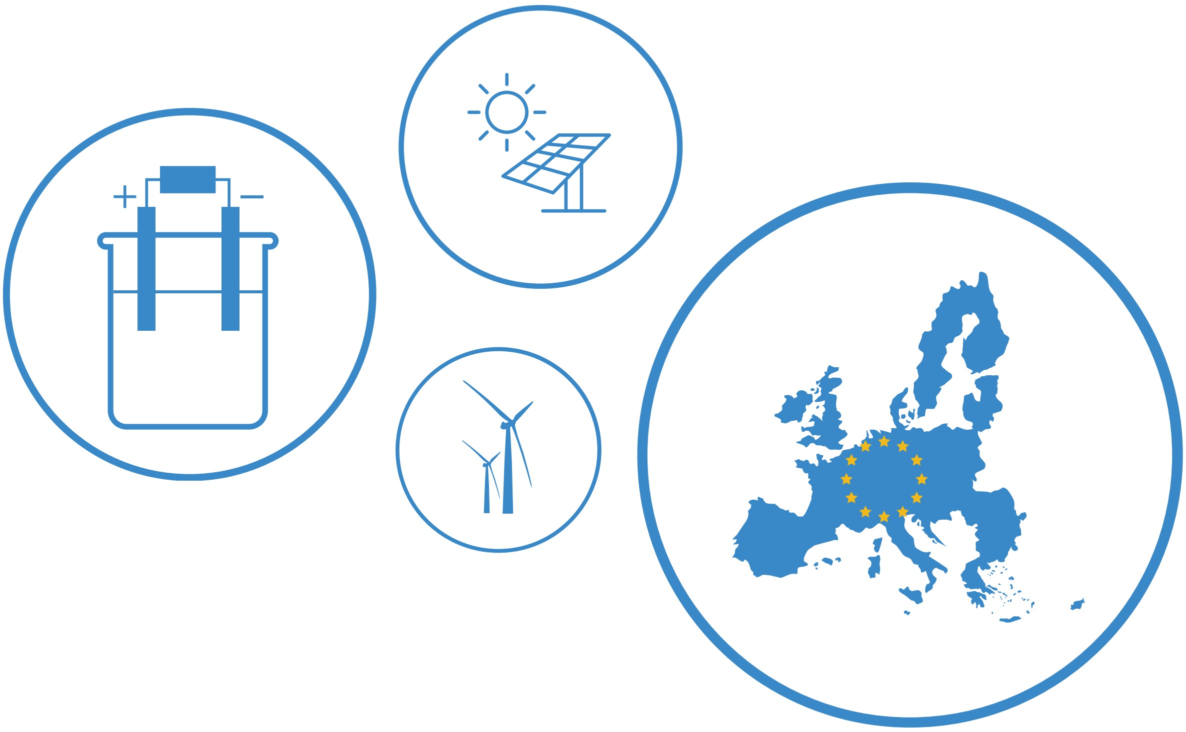
The Cost Challenge: Unlocking the Potential of EU Renewable Hydrogen Production Through Effective Regulation

Policy Paper



The Cost Challenge: Unlocking the Potential of EU Renewable Hydrogen Production Through Effective Regulation

Policy Paper

Version 1.0/January 2025

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This policy paper has been crafted to spark discussion on the production rules for RFNBO (renewable hydrogen) within the European Union. It builds upon previously debated issues in the public sector while incorporating new insights into the pricing and complexity of electrolysers. The primary goal of this policy paper is to present a compelling case for amending the currently adopted regulations to accelerate the production and uptake of renewable hydrogen across the EU.

For reference:

Sochor, J. (2024): The Cost Challenge: Unlocking the Potential of EU Renewable Hydrogen Production Through Effective Regulation
HYTEP: Husinec Řež

Content

Executive Summary

The deployment of renewable hydrogen production capacity is falling short of expectations. Of the 6 GW of electrolyser capacity outlined in A Hydrogen Strategy for a Climate-Neutral Europe by 2024, only a few hundred MW are currently under construction or in advanced planning stages. Several factors contribute to this slower-than-anticipated progress, one of which, as this policy paper argues, is the overly stringent renewable hydrogen production rules. These regulations were developed based on data that do not accurately reflect real-world conditions and are further challenged by persistent issues faced in real-world projects.

Renewable hydrogen is costlier than anticipated in the past

Netherlands: Reports estimate the Levelised Cost of Renewable Hydrogen (LCOH) at 12 € to 14 € per kilogram for 100 and 200 MW projects.

Czech Republic: Data from HYTEP on projects collected in 2023 and 2024 project an LCOH exceeding 15 € per kilogram.

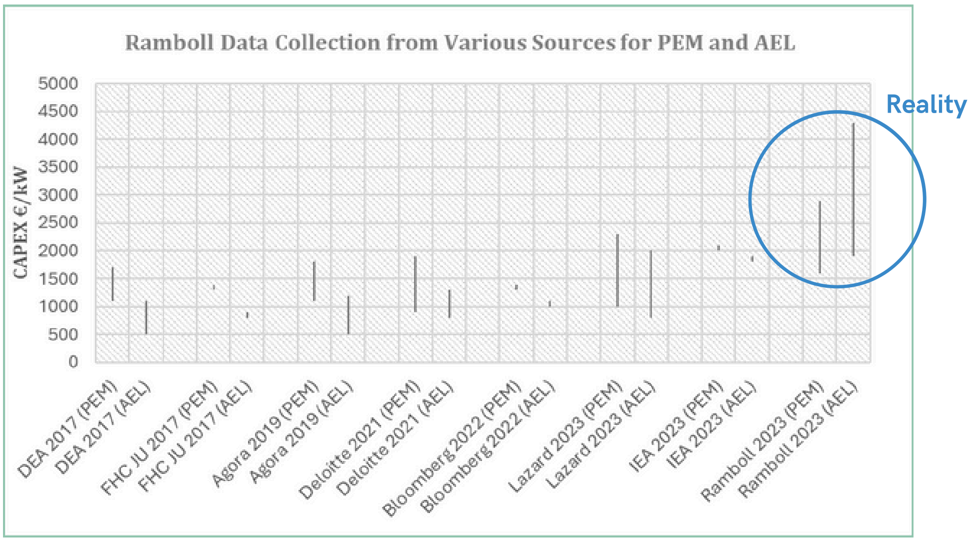
European Hydrogen Bank (EHB): The first funding round reported an LCOH range of 5.8 € to 13.5 € per kilogram across 16 EU countries.

Regional Variations: Certain countries, notably Spain, Sweden, and Greece, demonstrate lower LCOH levels, likely due to favorable renewable energy resources (RES).

Commercial readiness level of electrolysers has been overestimated while levelised cost of renewable hydrogen underestimated

Significant discrepancies exist between real-world data and the assumptions made in studies regarding electrolysers CAPEX. Actual market data shows that prices often exceed 3 000 € per kW installed, highlighting a substantial gap between theoretical estimates and practical realities.

Graph 6: Comparison of IEA CAPEX assumptions from 2019 until 2024



Source: Data from Ramboll reports

Renewable hydrogen prices are primarily driven by three key variables

Capacity factors

Capacity factors (CF) are critical component of LCOH formula, especially given the high cost of electrolysers CAPEX. Capgemini and EIT InnoEnergy study has shown increasing CF from 45% to 60% could lower LCOH by appx. 0.62 € per kilogram. TNO study from Netherlands shown increasing electrolysers CF by 500 additional hours lowers LCOH by 0.8 € per kilogram.

Climate conditions

The same photovoltaic panel with 1 kWp capacity produces varying amounts of electricity depending on location. In the Czech Republic, 1 kWp generates approximately 1 000 kWh per year, while in certain regions of Spain, it can produce over 2 000 kWh annually. This significant difference leads to a notably lower Levelised Cost of Hydrogen (LCOH) in Spain, where prices, according to the European Hydrogen Bank's first round, range from 5 € to 8 € per kilogram. In contrast, LCOH in the Czech Republic is more than double this amount.

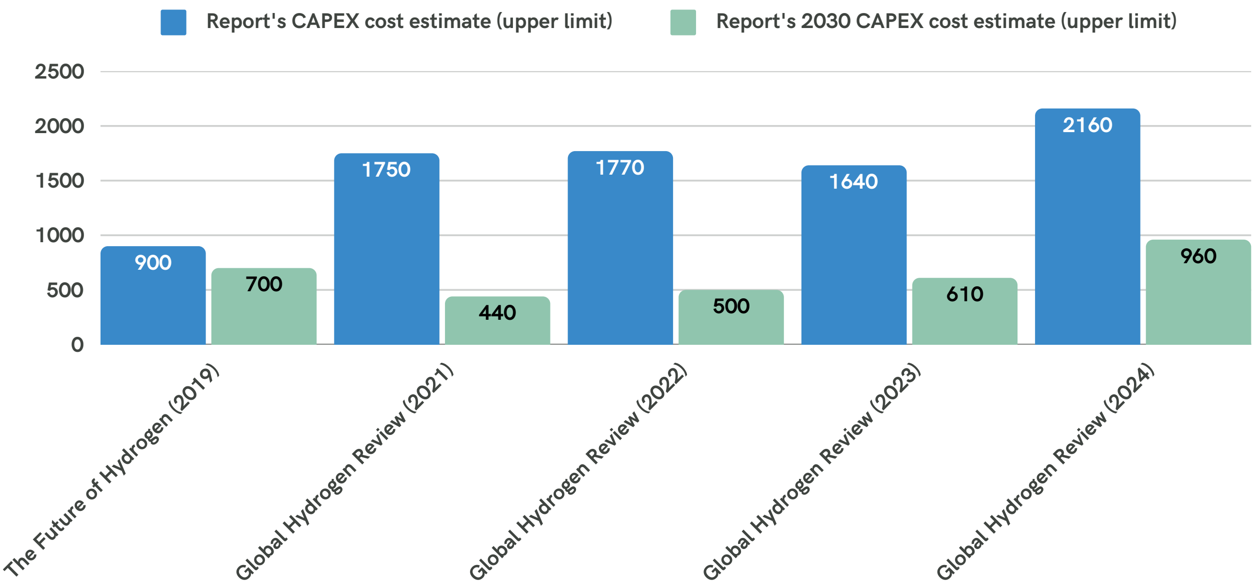
CAPEX of whole electrolyser systems

The capital expenditure (CAPEX) of electrolyser units accounts for over 30% of the LCOH. In practice, based on actual prices from advanced projects, CAPEX alone typically represents at least 5 € of the LCOH.

In 2020, the cost of renewable hydrogen was estimated to range between 2.5 € and 5.5 € per kilogram, reality is higher

The Hydrogen Strategy for a Climate-Neutral Europe estimated the cost of renewable hydrogen at up to 5.5 € per kilogram. The assumptions underpinning Europe's strategy were drawn from the IEA's 2019 Hydrogen Report, which considered electricity prices ranging from 35 € to 87 € per MWh and the cost of electrolyser systems at approximately 600 € per kW. However, CAPEX costs have shown a steady upward trend in successive IEA reports since 2019 and other public literature. Consequently, the LCOH has also risen, and projections for the price of renewable hydrogen by 2030 have been adjusted upwards as well.

Graph 5: Comparison of IEA CAPEX (in €) assumptions from 2019 until 2024



Source: Data from IEA reports

EU hydrogen ambitions not in line with real world projections

The Hydrogen Strategy for a Climate-Neutral Europe (2020) targets 40 GW of electrolyser capacity in the EU and another 40 GW outside by 2030. The REPowerEU Plan (2022) aims to produce 10 million tonnes of RFNBOs in the EU and import 10 million tonnes globally by the same year.

According to the latest report on hydrogen market from the European Union Agency for the Cooperation of Energy Regulators (ACER), only approximately 1.8 GW of electrolyser capacity is expected to become operational by the end of 2026. This forms part of a larger pipeline of hydrogen projects, with around 60 GW of electrolyser capacity aiming for final investment decisions (FID) to be operational by 2030. However, many of these projects remain in early planning stages and are unlikely to meet the projected timelines due to technical, financial, and regulatory challenges.

EU targets for RFNBO

2020

40 GW

Estimated capacity of electrolysers in 2020 by **The Hydrogen Strategy for a Climate-Neutral.**

2022

200 GW

Estimated capacity of electrolysers in 2022 by **REPowerEU plan**. Initial estimate included production capacity in million tonnes.

Hydrogen projects are being canceled each month. Publicly stated reasons often include challenging market conditions, restrictions on RFNBO usage, a lack of committed offtakers, and regulatory uncertainty.

With strict rules on RFNBO production, hydrogen market won’t take off

Additionality

While the principle of additionality aims to encourage the construction of new renewable energy sources (RES) for RFNBO production, its rapid and stringent implementation risk stalling hydrogen market development in less advanced regions. This approach places an undue burden on countries with lower levels of RES penetration, making compliance unnecessarily difficult compared to more advanced nations with well-established renewable energy infrastructure.

Temporal correlation

Temporal correlation rules have been envisaged to reduce the amount of GHG intensive electricity generation when RES do not produce, therefore hourly correlation rules have been set from 2030 onwards. However, production of RFNBO is expensive even without strict rules, due to electricity prices making up to 40% of LCOH. Since CAPEX of electrolysers is high, electrolysers require to be producing renewable hydrogen at higher capacity factor due to amortization than hourly correlation allows (especially in countries with low wind or low solar potential). Strict hourly correlation might ensure lowest GHG emissions, however, significantly increases prices by up to 3.3 € per kg.

Geographical correlation

The geographical correlation requirement aims to minimize grid congestion between neighboring member states. However, this rule disproportionately disadvantages countries with lower RES potential, such as the Czech Republic, and contradicts the logic of an ever expanding interconnected electricity grid. Given that RFNBO production will remain costly even in the mid-term, concerns about large-scale electrolyzer deployment across the EU exceeding cross-border capacity are unfounded.

Strict RFNBO production rules lead to lower capacity factors for electrolysers. Combined with higher-than-expected CAPEX, this results in elevated LCOH. Consequently, the "green premium" becomes too high for many consumers to afford, further dampening demand and project viability.

The rules for renewable hydrogen production should be revised to account for slower adoption rates and incorrect assumptions made in 2023 regarding capacity factors and CAPEX of electrolysers

Rules should be amended under these 4 core principles:

Flexibility: Hydrogen sector requires more flexibility to increase capacity factor of electrolysers to produce renewable hydrogen.
Time: Hydrogen sector requires more time to mature.
Less discrimination: Hydrogen sector must not be discriminated against direct use of electricity.
Energy system compatibility: Hydrogen production should be incentivized when RES are generating in a system friendly way.

Postpone additionality entry in force	Apply additionality for directly connected RES to electrolyser from 2030 onwards. Apply additionality for PPA contracted RES from 2036 onwards and use grandfathering rule until 2040.
Allow to use supported RES	Allow electrolysers to establish PPAs with RES which received either operational (OPEX) or investment (CAPEX) aid.
Establish monthly correlation permanently	Do not phase in hourly temporal correlation. Or allow using monthly correlation until 2036 and then phase in hourly correlation.
Count electricity as fully renewable when prices on day-ahead market hit below 20 € per MWh	Replace current rule which allows to comply with temporal correlation when prices hit below 20 € per MWh with rule which allows to count electricity as fully renewable in the time period when prices hit below 20 € per MWh.
Permit closing PPAs between electrolyser and RES from interconnected bidding zone	Change geographical correlation to allow contracting PPAs between RES and electrolysers which are situated in the interconnected bidding zone (adjacent).

Renewable hydrogen production requires a new, less restrictive approach. Amendments should be made to the DA on RFNBO production, alongside introduction of the DA on low-carbon hydrogen production rules.

Introduction

This policy paper has been crafted to spark discussion on the production rules for RFNBO (renewable hydrogen produced with electrolysis) within the European Union.

It builds upon previously debated issues in the public sector while summarizing new insights into the pricing and complexity of electrolysers learned from 2023 until the date of publication of this policy paper.

In this paper, we explore:

Overly optimistic renewable hydrogen production targets: Whether the goals of the Union strategies have been realistic from the beginning.

Real levelised cost of renewable hydrogen (LCOH): What is the real price for renewable hydrogen when compared to early 2020s estimates.

Underestimation of electrolyser systems investment cost (CAPEX): How hydrogen electrolyer systems CAPEX has been underestimated in the previous studies and what can we realistically expect in the upcoming years.

Capacity factors (CP) leading to higher renewable hydrogen price: Whether low capacity factors due to stringent renewable hydrogen rules (hourly temporal correlation) lead to very high prices.

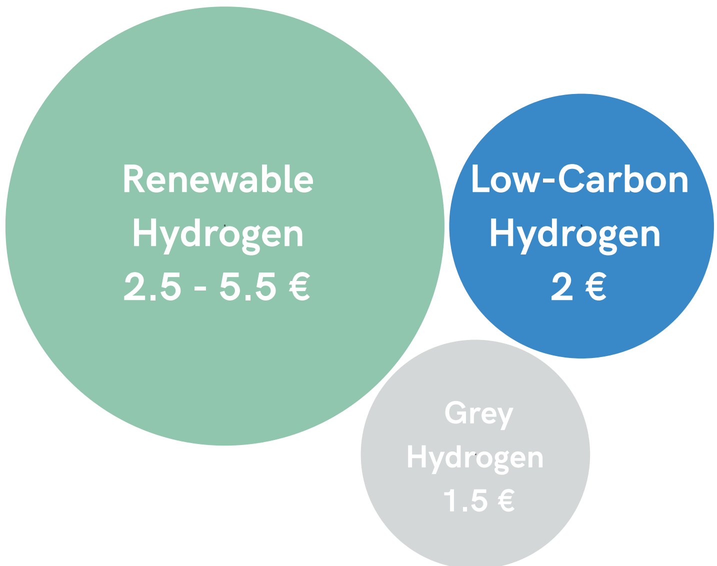
Renewable hydrogen production rules: How should renewable hydrogen production rules be amended to spark renewable hydrogen market creation.

Chapter 1: EU hydrogen ambitions, a glance at reality

The EU began its hydrogen journey in 2020 with the publication of A Hydrogen Strategy for a Climate-Neutral Europe. At that time, around 40 GW of electrolyser capacity was planned to support domestic hydrogen production, with another 40 GW build abroad to supply the European market by 2030 via imports. [1] EU also set an intermediary target of 6 GW of electrolyser capacity by 2024, more than 30x less than installed at the end of 2024.**The goal was to replace nearly 10 million tons of hydrogen production with renewable and low-carbon hydrogen.** In this strategy, European Commission Vice-President Frans Timmermans outlined preferred production pathways for hydrogen, which were later incorporated into directives and regulations, such as the Renewable Energy Directive, FuelEU Maritime or REFuelEU Aviation.

Back in 2020, the cost of renewable hydrogen was estimated to be between 2.5 € and 5.5 € per kg, making it up to four times more expensive than fossil-based hydrogen, which was priced around 1.5 € per kilogram at that time (while now widely accepted price is around 3 € per kg due to LNG being more expensive than import from Russia). Low-carbon hydrogen with carbon capture and storage (CCS) was expected to cost around 2 € per kilogram. **These figures were largely derived from the IEA's 2019 Hydrogen Report**, which assumed prices of 35-87 € per MWh and electrolyser costs of around 600 € per kW.

llustration 1: Estimated cost of hydrogen by EU hydrogen strategy (2020)



Source: Data from A Hydrogen Strategy for Climate-Neutral Europe

However, when it comes to CAPEX, current data from real-world projects indicate that the cost of electrolyser systems is typically above 3,000 € per kW for projects up to 100 MW, five times higher than the 2019 projections by IEA. For example, the TNO study Evaluation of the Levelized Cost of Hydrogen Based on Proposed Electrolyser Projects in the Netherlands reports real-world prices for 100 MW and 200 MW projects at 3,050 € per kW and 2,630 € per kW, respectively (excluding storage costs, as it assumes hydrogen will be injected into a hydrogen grid. [2] In less mature markets with fewer electrolysers manufacturers on the market and EPC providers, these costs are even higher, as shown by a 2023-2024 survey of the Czech Hydrogen Technology Platform's members. [NOTE 1]

In 2022, the EU more than doubled its hydrogen ambitions with the REPowerEU plan, launched in response to Russia's invasion of Ukraine, which triggered an unprecedented energy crisis. REPowerEU shifted away from electrolyser capacity targets and instead set a goal of 10 million tons of renewable hydrogen produced domestically by 2030, alongside another 10 million tons of imports in the form of hydrogen derivatives like ammonia and methanol or LH2.This plan aimed to replace the EU's grey hydrogen consumption and double it in new applications within just eight years. [3]

200 GW **Estimated capacity of electrolysers in order to fulfill 2022 REPowerEU plan. Initial target included production capacity of 10 million tonnes by 2030.**

The EU's hydrogen ambitions have been scrutinized at national levels for the past few years, and recently, concerns have started to surface at the Brussels level. **In July 2024, the European Court of Auditors published a special report** titled The EU's Industrial Policy on Renewable Hydrogen – Legal Framework Has Mostly Been Adopted – Time for a Reality Check. **The report highlighted several key issues**, including the European Commission's failure to conduct a thorough market analysis before publishing its hydrogen strategy. [4] As a result, the EU put forward artificially inflated targets with unclear methodologies, often assuming unrealistic production capabilities for each hypothetical gigawatt of installed electrolyser capacity. The auditors also pointed out that there are no specific targets for low-carbon hydrogen, as only RFNBOs are supported through directives and regulations like the Renewable Energy Directive (RED), FuelEU Maritime, and ReFuelEU Aviation. Finally, the auditors noted that the Commission had not conducted any impact assessments on the temporal correlation and additionality implications for the nascent hydrogen market.

Delegated regulation on establishing a Union methodology setting out detailed rules for the production of RFNBO itself points out in explanatory memorandum that it did not need to be supported by an impact assessment.

''As this is a technical act, it did not need to be supported by an impact assessment or an open public consultation, which are usually only required for major initiatives.
The delegated act draws on the results of several consultation exercises carried out by the Commission implementing of Article 27(3) of the Directive, including inter alia, four meetings of the expert group on renewable fuels and two stakeholder workshops.
The draft delegated act was published for public feedback on the Better Regulation Portal from 20 May to 17 June 2022. Subsequently, several provisions of the proposal were adjusted following the feedback provided by the respondents to facilitate the ramp-up of the production of renewable liquid and gaseous transport fuels of non-biological origin, taking into account the nascent state of the hydrogen industry.
The proposal was lastly discussed in a meeting of the expert group on renewable fuels on 7 December 2022.''

Source: Delegated regulation on establishing a Union methodology setting out detailed rules for the production of RFNBO

With a special report conclusions by European Court of Auditors in mind it is sufficient to say that **EU set overly optimistic targets for renewable hydrogen production back in 2020 and 2022**. Some expectations may be explained with Gartner's Hype Cycle Theory [NOTE 2]. Simply put, EU has been caught in the hype cycle for the past four years. This cycle has created unrealistic expectations, backed by overly optimistic data of RFNBO production costs, that have in turn made assumptions of renewable hydrogen prices artificially cheap. Expectations of lower LCOH and the assumption that hydrogen technologies are commercially viable and ready to be deployed at scale by 2030 have led to an inflated view of their readiness and installed capacity and consequently also their potential impact on emissions that has to be strictly regulated. [NOTE 3]

Various stakeholders and institutions are now beginning to work with real-world data, revealing how expensive and technologically challenging it is yet to deploy hydrogen technologies on mass scale. [5] This is especially true when we consider that hydrogen technologies are not yet as mature as renewable energy sources (RES), batteries, heat pumps, or battery electric vehicles. Some deadlines might have been set to early and do not correspond with market reality.

Source: Getty Images

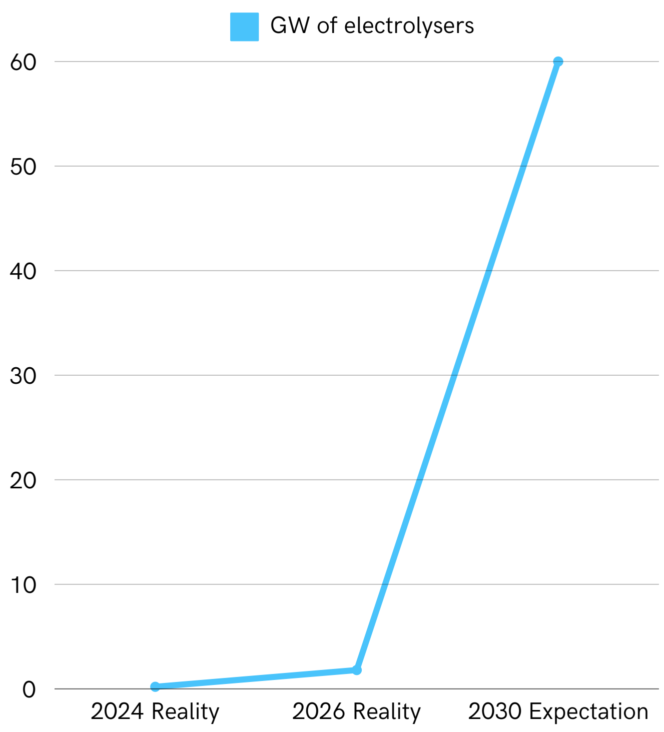
Chapter 2: Renewable hydrogen uptake is more challenging than previously thought

According to the Global Hydrogen Review 2024 published by the International Energy Agency (IEA), global hydrogen demand increased in 2024 and is projected to approach 100 million tons. However, this demand remains largely concentrated in traditional applications such as refining and industrial processes, with less than 1% attributed to newer uses like heavy industry, long-distance transportation, and energy storage. [6] **Globally, around 1.4 GW of electrolyser capacity was in operation by the end of 2023**. This indicates that water electrolysis remains a niche production method, with scaling efforts progressing far more slowly than anticipated in 2021 and 2022, likely due to the high costs of producing electrolytic hydrogen.

In the EU, electrolyser capacity is growing, but it remains well below the targets set by the RePowerEU plan and the European Hydrogen Strategy for at least 6 GW of installed capacity by 2024. According to ACER's November 2024 report on European hydrogen markets, the total installed capacity of electrolysers in Europe reached just over 0.2 GW by the end of 2024. Projects with a combined capacity of 1.8 GW, primarily dedicated to single offtakers or industrial users, are expected to become operational by the end of 2026. [7]

The same report highlights that approximately 60 GW of projects are awaiting final investment decisions (FIDs) and could theoretically become operational by 2030 (see Graph 2). However, achieving this target is highly unlikely as we will argue in this paper. The primary obstacles include, among other, underestimated CAPEX costs for electrolyser systems and the stringent regulations for RFNBO production, which impose overly restrictive criteria on hydrogen producers. These challenges hinder the optimal operation of electrolysers and delay investment decisions.

Graph 2: ACER's market report installed and expected capacity in Europe until 2030 (best case scenario)



Source: Report on European hydrogen market

Various reports from other institutions in 2024 highlighted concerns that Europe's ambitious targets might not be fully realized. According to the 2024 Northwest European Hydrogen Monitor by the International Energy Agency, if all planned projects were completed by 2030, low-emissions hydrogen production in Northwest Europe could exceed 7 million tonnes. [8] However, less than 4% of these projects have reached the commitment stage, meaning they have either secured a final investment decision (FID), are under construction, or are operational.

The research organization BloombergNEF has previously predicted a sharp decline in hydrogen production costs, driven -among other reasons- by the commissioning of large-scale hydrogen production capacities by 2030. However, in May 2024, BloombergNEF estimated that only 30% of the currently announced supply by the end of this decade will likely come in operation, making previous cost reduction predictions unlikely to materialize. Nevertheless, the research firm noted that most of the projected capacity is expected to be developed in the US and Europe. [9]

All previously stated reports correspond with news about various projects across the EU which are being cancelled, with difficult market conditions and a lack of committed offtakers cited as the primary reasons for project failures (see Table 3).

Table 3: Recently discontinued projects for RFNBO production

Project	Company	EU State	Publicly Stated Reason
Porvoo Refinery - 120 MW electrolyser	Neste	Finland	Challenging market conditions, company financial performance, and restrictions on the use of renewable hydrogen due to stringent national regulations for fuel suppliers.
FlagshipONE eMethanol project – 70 MW electrolyser	Orsted	Sweden	Project did not find any long-term offtakers at sustainable pricing due to significantly higher project costs (2-5 times higher than fossil methanol).
SkyFuelH2 project – 200 MW electrolyser	Uniper, Sasol	Sweden	Challenging market situation, sharply rising costs and continued uncertainty effects of regulation to support demand for Sustainable Aviations Fuels.
El Alamillo H2 project – 60 MW electrolyser	Benbros Energy	Spain	Project not yet officially cancelled but pulled out of awarded European Hydrogen Bank funding due to lack of demand for renewable hydrogen.

Source: Data from Hydrogen Insight

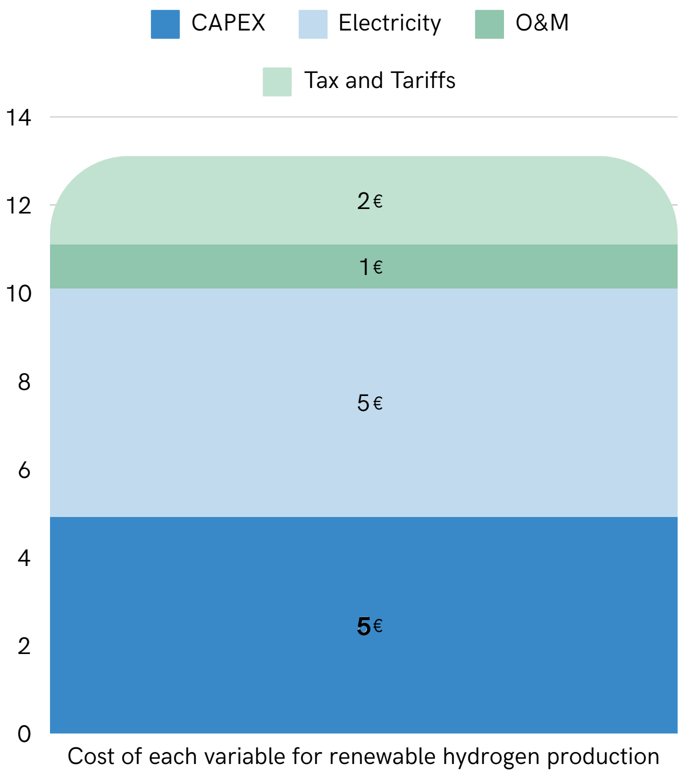
Chapter 3: Commercial readiness level of electrolysers has been overestimated while electrolysers CAPEX underestimated

Technology readiness level (TRL) is a critical parameter indicating how prepared technology is for market deployment. When a technology reaches a certain TRL and becomes commercialized (CRL), this typically drives optimization and a reduction in overall deployment costs. **Although TRL and CRL of electrolysers has been reported as very high for both alkaline and PEM electrolysers market has seen significant underestimations of their capital expenditure (CAPEX).** This issue, in turn, has contributed to the underestimation of the levelized cost of renewable hydrogen (LCOH) in past.

The discrepancy between academic LCOH and strategies estimates and real-world data is evident in many studies. That said, LCOH values can vary considerably based on the methodology and assumptions used for different countries or projects. LCOH calculations generally comprise several key components, including:

1) Electrolyser CAPEX
2) Electricity cost for electrolysis
3) Electrolyser capacity factor
4) Other operating expenditures (OPEX) such as water consumption, maintenance and stack replacements
5) Grid fees
6) Taxes
7) Subsidies (CAPEX or OPEX)
8) Potential revenues from oxygen sales
9) More

Graph 4: TNO Study: Evaluation of Levelised Cost of Hydrogen Based on Proposed Electrolyser Projects in the Netherlands (2024)



Assumption: 100 MWe electrolyser (alkaline or PEM) 9,5% WACC, 4 800 full load hours and 75 € per MWh for electricity

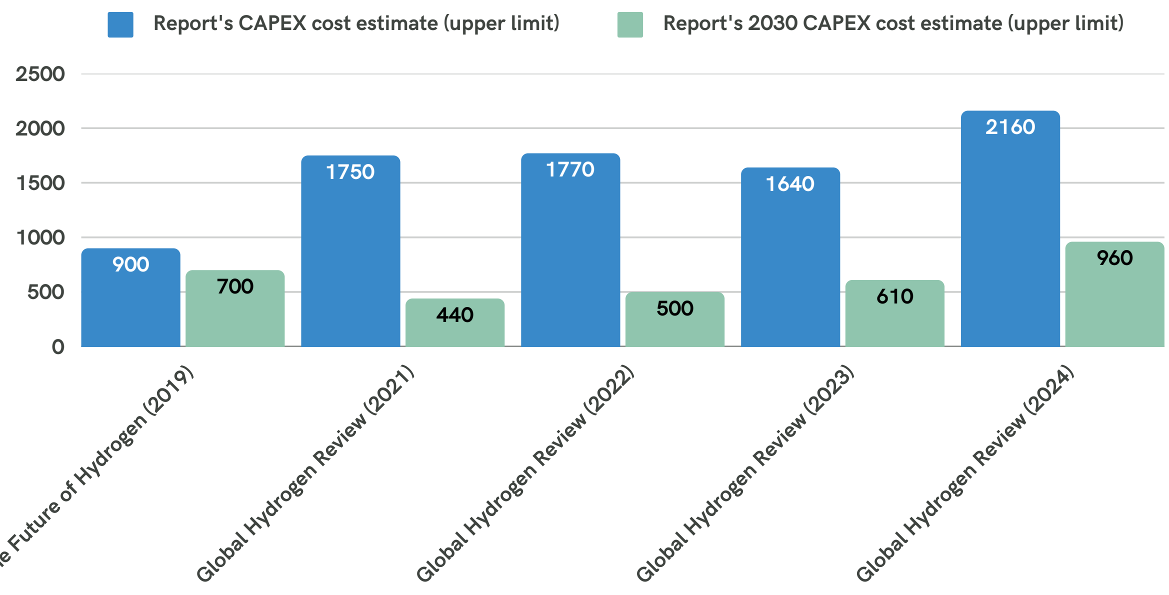
Together, these components determine the hydrogen production cost for each project or region. In recent months, LCOH has continued to trend upward in various studies compared to years prior to 2023. While some assumptions regarding electricity costs for electrolysis, have remained stable or changed depending on local conditions, we argue significant shifts in capacity factor (due to strict regulation) and CAPEX assumptions have driven higher price estimates in more recent studies.

For example, BloombergNEF reported in 2024 that the average system-level cost of electrolysers manufactured in Europe, or the U.S. is approximately 2 500 $ per kW installed. Previously, BloombergNEF had predicted a gradual decline in costs from 2022 onward. However, their 2024 survey revealed a median increase of 57% in capital costs compared to 2022. The primary cause, according to BloombergNEF, is inflation. Though we argue another significant factor may be the unreliability of their earlier data. [10]

57%	**Estimated median increase of BloombergNEF capital expenditures for electrolyser systems from 2022 until 2024**

The International Energy Agency (IEA), provide valuable data for CAPEX assumptions. Comparing IEA reports from 2019 to 2024 reveals that electrolyser system CAPEX (including equipment, balance of plant, engineering, procurement, and construction costs) has been consistently underestimated in recent years due to focusing on stack mostly. Notably, CAPEX varies by electrolyser type and nameplate capacity, making it challenging to produce general estimates (on top of that, it seems bigger electrolysers do not drive price of the whole system down as much as was previously predicted). CAPEX assumptions often rely on data collected a year prior to publication, which can introduce additional delays (see Graph 5).

Graph 5: Comparison of IEA CAPEX (in € per kW) assumptions from 2019 until 2024



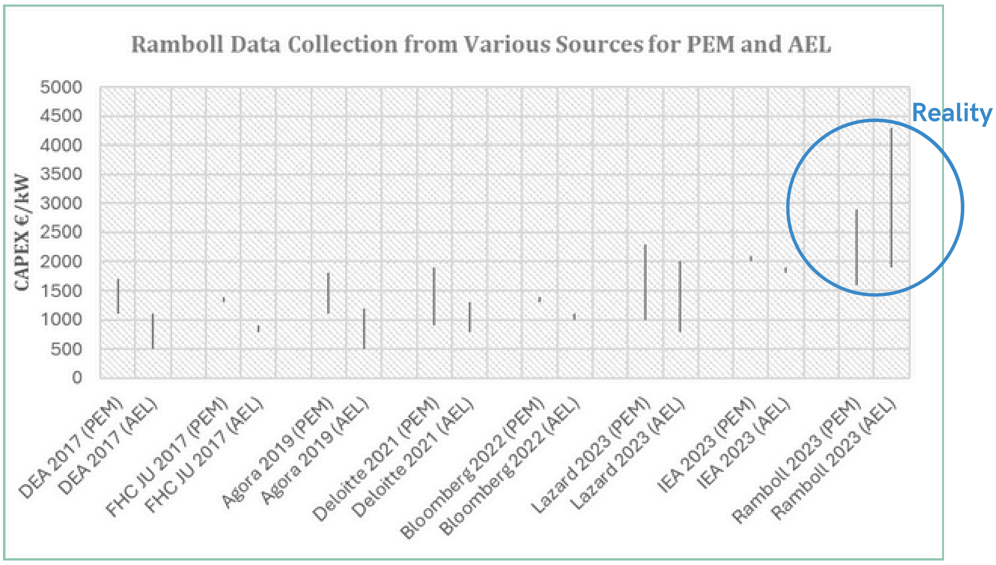
Source: Data from IEA reports

Real-world data on electrolyser system pricing began to emerge in public discussions from 2023 onwards. For instance, the 2023 Ramboll whitepaper Achieving Affordable Green Hydrogen Production Plants highlights that the cost expectations for green hydrogen production systems used in public estimates prior to 2023 were 1.3 to 3.3 times lower than real-world figures, making those earlier estimates inaccurate. [11]

Ramboll emphasizes that hydrogen production plants are highly complex and customized to their specific environments, meaning they cannot follow the same cost-reduction trends observed in batteries and solar panels which are highly modular and mass produced. While certain components, like stacks and other mass-producible parts, will benefit from cost reductions, these are not the main drivers of electrolyser CAPEX system costs.

For each type of electrolyser, Ramboll compares indicative prices from various sources and its own projects, providing valuable insights into the real-world and academic pricing landscape (see Graph 6).

Graph 6: Comparison of IEA CAPEX assumptions from 2019 until 2024



Source: Data from Ramboll reports

The significant discrepancies between real-world data and the assumptions made in various studies can largely be attributed to the lack of initial real-world data and operational projects from 2020 until now. When comparing real-world data with the assumptions underpinning EU strategies, it becomes evident why imposing strict criteria on hydrogen production plants was initially considered the right approach not only due to climate concerns, but at the same time the expected price premium for renewable hydrogen production was far lower than it has turned out to be in reality.

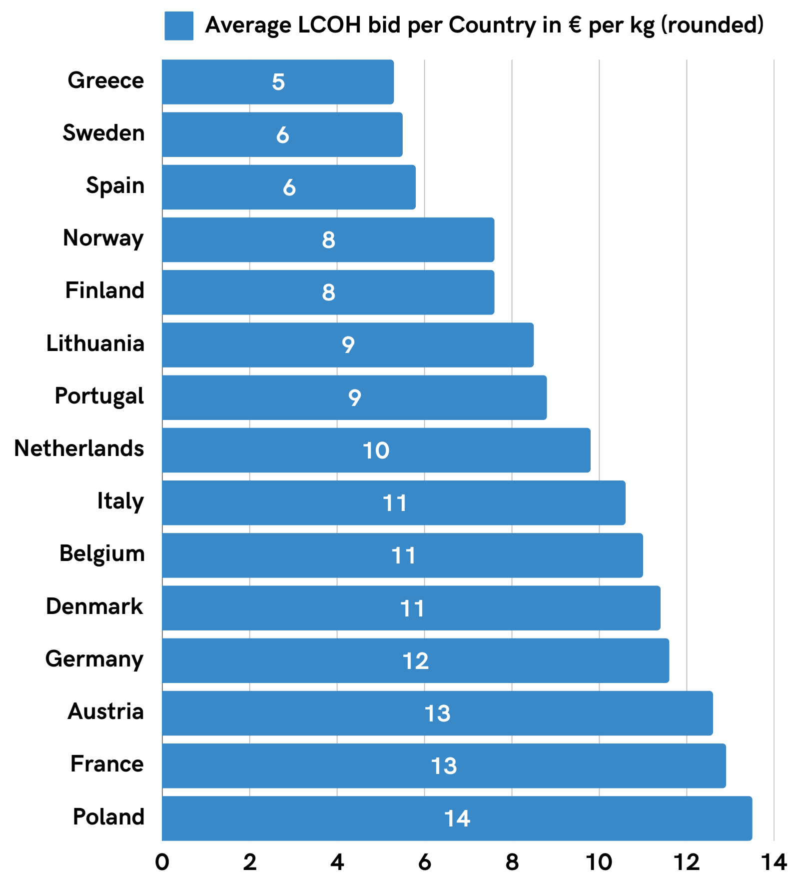
The European Commission, lacking real-world data, assumed that RFNBOs could be produced at much lower costs, even under stringent regulations that effectively reduced electrolyser capacity factors. This miscalculation has highlighted the challenges of aligning ambitious policy goals with economic realities.

Chapter 4: Renewable hydrogen requires high electrolyser utilisation to become more competitive with grey hydrogen

The challenges of RFNBO production in the European Union are well illustrated by the results of the first round of the European Hydrogen Bank (EHB). The average LCOH for RFNBO production ranges from 5.8 € to 13.5 € per kilogram across 16 EU countries, considering only those countries which applied more than two projects (see graph 7). [12] However, substantial variations in LCOH exist between projects, likely due to differences in project scale, maturity, and access to RES.

Since the bidding price was the sole criterion for funding allocation, the **selected projects will receive between 0.37 € and 0.48 € per kilogram of RFNBO** even though the bidding cap was set to 4.5 € per kilogram. The first **EHB round approved seven projects in Spain, Portugal, Norway, and Finland**. Yet, by November 2024, six months after the results were announced, one of the seven projects had declined the funding, citing insufficient demand as the main issue. Meanwhile, the Hysencia project in Spain launched an offtake auction in the same month, aiming to secure buyers for at least 1 700 tons of RFNBO. There is no additional public information regarding other five projects.

Graph 7: Average bidded LCOH of renewable hydrogen in EHB



Source: Data Innovation Fund (EHB)

Despite Spain having some of the most favorable conditions and most projects for RFNBO production applied to EHB, **Rystad Energy calculated the LCOH** for the Hysencia project **at approximately 6.81 € per kilogram**, (potentially excluding costs for storage, distribution, or revenue). [13]

Compared to grey hydrogen prices, RFNBO costs are two to three times higher, even in Europe's most favorable regions. A survey conducted by the Czech Hydrogen Technology Platform in 2023 and 2024 among Czech electrolyser projects showed significant variation in indicative RFNBO prices, depending on the projects' stages of development. However, there is a consensus that RFNBO prices in the Czech Republic are unlikely to drop below 15 € per kilogram with strict RFNBO rules.

For comparison, the primary hydrogen production method in the Czech Republic is the partial oxidation of oil residues, which results in an LCOH of approximately 3-4 € per kilogram (according to data from Orlen Unipetrol). **When applying the Czech RFNBO production price, renewable hydrogen production in the Czech Republic becomes five times more expensive than grey hydrogen.**

Czech Republic

over 15 €

Average indicated price of renewable hydrogen in the Czech Republic from 2023 and 2024 data.

Spain

6 €

Average indicated price of renewable hydrogen in Spain according to EHB first round data .

3-4 € per kilogram of hydrogen, indicative price of grey hydrogen produced by partial oxidation of oil residues in the Czech Republic

Source: MAN

Considering that RFNBO consumption targets must be met in the transport and industrial sectors across all EU countries, including those with less favorable renewable energy conditions, it is essential for the EU to adopt flexible rules for RFNBO production. Without such flexibility, the green premium paid in Spain will be a lot lower compared to the higher costs in countries like the Czech Republic, further hindering the adoption of renewable hydrogen across the EU due to economic constraints.

Transport target by 2030

14 000 tons of RFNBO

The quantity of RFNBO required for consumption in the Czech Republic by 2030, as mandated by RED transportation targets.

Industry target by 2030

6 000 tons of RFNBO

The quantity of RFNBO required for consumption in the Czech Republic by 2030, as mandated by RED industry targets.

By adopting flexible rules for RFNBO production, higher utilisation rates of electrolysers will be achieved. Higher utilisation rates offer additional benefits, such as reducing the amount of hydrogen storage as well as capacity installed needed, particularly in the absence of a hydrogen network. This has a positive knock-on effect, lowering the overall CAPEX for the entire electrolyser plant resulting in lower LCOH. Various studies have shown positive impact of increasing capacity factors of electrolysers on the LCOH.

A widely cited 2024 TNO study [14] concluded that increasing electrolyser capacity factors by just 500 additional hours per year could reduce the cost of renewable hydrogen by 0.8 € per kilogram in the case of Netherlands.

Increasing capacity factor by 500 additional hours reduce cost of RFNBO by 0.8 € per kilogram.

Capacity factors are a critical component of the LCOH formula, especially given the high cost of electrolysers. In 2024, Capgemini and EIT InnoEnergy published a whitepaper titled Reducing Low-Carbon Hydrogen Investment and Operating Costs, which found that halving electrolyser CAPEX from 1 980 € per kW installed could reduce LCOH by 1.33 € per kilogram. Moreover the paper also calculated an even greater impact from decreasing electricity prices and increasing capacity factor for lower LCOH cost. For instance, increasing the capacity factor from 45% to 60% could lower LCOH by approximately 0.62 € per kilogram. [15]

Increasing capacity factor from 45 % to 60 % lowers cost of RFNBO by 0.62 € per kilogram.

Chapter 5: Strict rules for renewable hydrogen production add significant costs, academic studies show

The European Union has chosen to support hydrogen production by incentivizing so-called renewable fuels of non-biological origin (RFNBOs). These are defined in Article 1, Point 36 of the Renewable Energy Directive (RED) as liquid or gaseous fuels whose energy content is derived from renewable sources other than biomass. [16] Under EU legislation, RFNBOs include renewable hydrogen, renewable ammonia, renewable methanol, and e-fuels.

Renewable hydrogen is produced through electrolysis from fully renewable electricity while complying with rules of additionality, temporal correlation and geographical correlation. Renewable hydrogen must not exceed 3.38 kg of CO_2 per 1 kg of hydrogen produced.

Renewable Fuels of Non-biological Origin

defined in Renewable Energy Directive

Are liquid or gaseous fuels the energy content which is derived from renewable sources other than biomass

Including:

- **Renewable hydrogen**
- **Renewable methanol**
- **Renewable ammonia**
- **E-fuels**

The **debate surrounding RFNBO production rules was intense**. The European Commission received approximately 337 contributions from across Europe, primarily from companies and business associations (72.59%) and non-governmental organizations (8%), with most submissions originating from Germany, Belgium, Spain, the Netherlands, and Italy (53%). [17] While some NGOs advocated for stricter RFNBO production rules—calling for hourly temporal correlation and additionality requirements to apply immediately after the delegated regulation came into force—the industry was more skeptical. On the one hand, clearer rules facilitated some final investment decisions (FIDs); on the other, concerns emerged in public discussions regarding the viability of projects due to low electrolyzer utilization under stricter regulations. [18]

It is important to note that the Commission's initial draft (leaked in May 2022) proposed much stricter requirements than the final version. The draft advocated for hourly temporal correlation starting in 2027 and additionality rules with a 24-month implementation period, as opposed to 36 months. [19] The Commission initially set the stage with overly strict rules but gradually eased them under pressure from various hydrogen stakeholders. However, the original rules were never entirely eliminated; instead, exemptions and grandfatherings were introduced.

EU RFNBO rules are build on three essential rules:

Additionality

Only RES which started operating less than 36 months before electrolyser came into operation, are allowed to be either directly connected to electrolyser or to close PPAs with exemption until end of 2027.

Temporal correlation

Electricity produced from RES has to be linked to and consumed by electrolyser in the same month it was produced until 2029 and then hourly (starting from 2030 onwards).

Geograhical correlation

Electrolyser has to be located in the same bidding zone as RES to decrease grid congestion.

For clarity, the RED itself does not explicitly mandate which specific rules—such as additionality or temporal and geographical correlation—should be included in the delegated act on RFNBO production methodology. Instead, it outlines these rules and refers to a future impact assessment of the methodology. Article 26, Paragraph 6 states:

> *''Renewable fuels of non-biological origin are important to increasing the share of renewable energy in sectors that are expected to rely on gaseous and liquid fuels in the long-term, including for industrial applications and in heavy-duty transport. By 1 July 2028, the Commission should assess the impact of the methodology defining when electricity used for producing renewable fuels of non-biological origin can be considered to be fully renewable, including the impact of additionality and temporal and geographical correlation on production costs, greenhouse gas emissions savings, and the energy system and should submit a report to the European Parliament and the Council. The report should assess in a particular the impact of that methodology on the availability and affordability of renewable fuels of non-biological origin for industry and transport sectors and on the ability of the Union to achieve its targets for renewable fuels of non-biological origin, taking into account the Union strategy for imported and domestic hydrogen while minimizing the increase in greenhouse gas emissions in the electricity sector and the overall energy system. If that report concludes that the methodology falls short of ensuring sufficient availability and affordability and does not substantially contribute to greenhouse gas emissions savings, energy system integration and the achievement of the Union targets for 2030 for renewable fuels of non-biological origin, the Commission should review the Union methodology and, where appropriate, adopt a delegated act to amend the methodology to provide the necessary adjustments to the criteria in order to facilitate the ramping-up of the hydrogen industry.''*

Source: Renewable Energy Directive

In academic discourse, **several scientific studies have analysed the effects of temporal correlation and additionality on the final cost of renewable hydrogen production**, often considering greenhouse gas (GHG) emissions from a system-level perspective. The assumptions underlying these studies are critical to understanding their conclusions.

Study 1

In **2024 study Temporal Regulation of Renewable Supply for Electrolytic Hydrogen, Elisabeth Zeyen et al**. examined the GHG emissions associated with hypothetical modelling of electrolyzer production. [20] Zeyen argues that additionality is essential in all modelled scenarios of electrolytic hydrogen production to prevent increased emissions. She also highlights that production with high-capacity factors results in significant emissions when based on annual or monthly correlation, whereas hourly matching minimizes emissions but leads to significantly higher costs. To address these costs, affordable energy storage is necessary. However, the study does not provide detailed assumptions regarding electrolyzers or storage system costs.

In practice, achieving low-cost storage remains challenging, particularly with on-site low- or high-pressure storage in steel tanks. Given that most current hydrogen consumption is inflexible, Zeyen estimates that hydrogen production costs under hourly temporal correlation are 2.6x higher than those under monthly correlation. Nevertheless, Zeyen concludes that from a GHG emissions perspective, hourly temporal correlation is preferable as it achieves the lowest overall emissions. Additionally, the price premium associated with hourly matching becomes less significant if hydrogen consumption from electrolyzers is flexible.

Price premium for renewable hydrogen becomes less significant if hydrogen consumption is flexible.

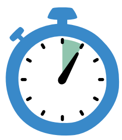
Hourly correlation decreases emissions but increases price of RFNBO 2.6 times.

Study 2

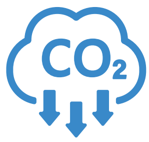
Other researchers have examined the flexibility of green hydrogen production and reached different conclusions. For instance, **Oliver Ruhnau and Johanna Schiele, in their 2023 study Flexible Green Hydrogen: The Effect of Relaxing Simultaneity Requirements on Project Design, Economics, and Power Sector Emissions**, argue that adopting more flexible temporal correlation rules—such as yearly or monthly correlation—can significantly LCOH. [21] Specifically, they find that using yearly correlation decreases the LCOH by 3.4 € per kilogram, while monthly correlation results in a reduction of 3.3 € per kilogram.

Ruhnau and Schiele contend that there is little evidence to suggest that green hydrogen production without strict temporal correlation would lead to increased power sector GHG emissions. They note that electrolyzers would typically operate in response to market price signals, ramping up when electricity prices are low (due to renewable energy oversupply) and scaling down when prices are high (typically driven by fossil fuel production) while operating on base load.

The authors emphasize that monthly temporal correlation strikes a favorable balance under EU regulations. It could deliver over half of the power sector emissions reductions achieved under annual correlation while only increasing costs by about 10%. Moreover, power system decarbonises over time as well. They advocate for allowing operators to flexibly produce renewable hydrogen to navigate the trade-offs between aligning with renewable energy availability, responding to market prices, and maximizing electrolyzer utilization.



Adopting monthly temporal correlation reduces price by 3.3 €.



Monthly correlation does not increase power sector GHG emissions.

Operators should be allowed to produce RFNBO flexibly.

Study 3

Another noteworthy study from **2023, Cost Competitiveness of Green Hydrogen and the Effects of the European Union Regulatory Framework, by Jonathan Brandt, Thore Iversen, Christoph Eckert, and others**, explores the implications of EU regulatory scenarios on renewable hydrogen production. [22] Their model compares two scenarios: a permissible one where only renewable energy sources (RES) are used directly or via power purchase agreements (PPAs) in compliance with delegated act rules, and an impermissible one where grid electricity, without any regulatory requirements, is used alongside directly connected RES and PPAs with RES.

The findings reveal that the impermisible scenario does not increase GHG emissions compared to grey hydrogen. This partially challenges the European Commission's and NGOs' concerns about rising emissions. The researchers attribute this to the tendency of electrolysers in this scenario to operate on cheap electricity, predominantly from RES. The unrestricted use of grid electricity in this scenario also reduces the levelized cost of hydrogen (LCOH) by 0.55 € to 1.62 € per kilogram compared to scenarios that prohibit grid electricity use.

However, the study also highlights risks. If hydrogen is produced with no rules whatsoever, the resulting GHG emissions could increase by 2.73x compared to grey hydrogen. This estimate assumes the average emission intensity of electricity across the EU, underscoring the importance of maintaining some regulatory oversight to prevent significant GHG emissions.

If electricity from grid is allowed, price of electrolytic hydrogen decreases from 0.55 to 1.62 € per kg.

Combined use of grid electricity and delegated act rules does not increase GHG emissions.

If hydrogen is produced without rules, GHG emissions are 2.73x higher than grey hydrogen.

Chapter 6: At least six amendments to the rules are needed to accelerate renewable hydrogen production in the EU

Hydrogen production is fundamentally a decarbonization challenge. While hydrogen producers aim to develop their projects from the ground up, the European Union seeks to ensure that hydrogen production does not result in higher GHG emissions than grey hydrogen. However, oftentimes the issue of energy security, resilience and competitiveness is overlooked. Unlike the electrification of transport—via direct electricity use or batteries—or heating through heat pumps, which generally reduces emissions due to significant efficiency gains (in most countries), the electrification of hydrogen production through electrolysis does not inherently achieve the same outcome compared to grey hydrogen in lowering GHG emission from the beginning. This discrepancy underscores the complexity of ensuring that hydrogen production contributes effectively to decarbonization efforts without inadvertently increasing emissions.

For that reason, rules for renewable hydrogen production are desirable, but as we have shown in the previous chapters, those rules were built on data not representing reality, expecting faster cost reductions. Considering that electricity is the most efficient form of energy for end-use across nearly all applications, and acknowledging the importance of regulations for market stability, we propose amending only few selected rules. This approach aims to establish a genuine ramp-up period for renewable hydrogen while maintaining realistic expectations. At the same time, it ensures that hydrogen production does not gain undue preference over direct electrification.

We urge European Commission to amend rules to preserve regulatory certainty and kick start renewable hydrogen production and drive European competitiveness by amending:

Additionality

Temporal correlation

Geograhical correlation

Additionality

Additionality rule is applied for directly connected electrolysers.	Article 3 of RFNBO DA (direct connection)	Apply additionality for directly connected electrolyser from 2030 onwards.
Additionality rule is applied from January 2028 for electrolysers connected via grid with PPAs with grandfathering until 2038 if electrolysers start producing renewable hydrogen before 2028.	Article 5 of RFNBO DA (grid with PPA)	Apply additionality for electrolysers connected via grid with PPAs from January 2036. Grandfathering rule until 2040.
Additionality rule for electrolysers connected via grid with PPAs prohibits use of CAPEX or OPEX supported RES.	Article 5 (b) of RFNBO DA	Using OPEX or CAPEX supported RES should not be prohibited under PPAs.

Temporal correlation

Monthly temporal correlation is aplied until 2029. Hourly temporal correlation applies from 2030 onwards for grid connected electrolysers under PPAs.	Article 6 of RFNBO DA	Do not phase in hourly correlation in 2030. Or allow using monthly correlation until 2035 and then phase in hourly correlation.
Allow to produce RFNBO when prices on day-ahead market hit below 20 € per MWh.	Article 6 of RFNBO DA	Replace current rule which allows to automatically comply with temporal correlation when prices hit below 20 € per MWh on day-ahead market with rule which allows to count electricity as fully renewable in the time period when prices hit below 20 € per MWh on day-ahead market.

Geograhical correlation

Electrolyser has to be located in the same bidding zone as RES.	Article 7 of RFNBO DA	Amend geographical correlation to allow contracting PPAs between RES and electrolysers which are situated in the interconnected bidding zone (adjacent).

Additionality

The delay of the additionality rule would provide projects in less RES advanced countries with more time to progress, reflecting the slower-than-expected development within the EU. Even in Germany, often considered the most advanced hydrogen market with well-defined subsidies and targets, the number of final investment decisions (FIDs) and projects has increased only slightly, from 3% to 9%, since early 2024. This means that just about 1 GW of electrolysis capacity—10% of the government's target—is expected to be operational by 2030. [23] The Czech Republic has its own challenges. To meet RED targets, up to 400 MW of electrolyser capacity should be online by 2030. However, only 130 MW of new capacity is currently planned, with just 100 MW of projects in advanced stages of development. Due to the commercial novelty of hydrogen technologies, these projects face significant hurdles, including meeting the 2027 grandfathering additionality rule and securing sufficient Power Purchase Agreements (PPAs) in the Czech market, where PPAs are still in their infancy.

The current additionality rules do not allow the use of PPAs to contract renewable energy sources (RES) that have received either CAPEX or OPEX subsidies. This approach conflicts with the support mechanisms adopted by most EU member states to promote RES deployment and mitigate the effects of electricity generation cannibalization (especially with solar). **Although PPA market has been envisaged to gradually replace state supported RES production capacities, most Member States still provide funding in the form of investment or operational aid.** The amount of aid is also dependent on different climate conditions each country has. For example, 1 kWp of photovoltaic produces yearly 1 MWh of electricity in the Czech Republic, however that same 1 kWp of photovoltaic produces more than 2 MWh of electricity in Spain. Therefore, while in Spain PPA market might be one of the most advanced in the EU, reasons for that are mostly hidden in how economical it is to build RES without subsidies.

Temporal correlation

Temporal correlation rules have been envisaged to reduce the amount of GHG intensive electricity generation when RES do not produce, therefore hourly correlation rules have been set from 2030 onwards. However, since production of RFNBO is expensive even without strict rules, and electricity makes up to 40% of LCOH, flexibility in production of RFNBO should be maintained with monthly correlation. **Since CAPEX of electrolysers is high (as shown in this paper) electrolysers require to be producing renewable hydrogen at higher capacity factor than hourly correlation allows (especially in countries with low wind or low solar climate)**. Making electrolysers more flexible won't necessarily solve the issue of them not being used most of the time, not until their CAPEX drops to much lower levels with new modular designs which could be on the market by the end of this decade. It is also essential to point out that electricity grid itself decarbonizes through integration of RES or nuclear power plants. Strict hourly correlation might be best for GHG emissions, however, significantly increases prices by up to 3.3 € per kg as shown in previous chapter.

Another flexibility measure under temporal correlation rule could increase electrolysers utilization while being system friendly from GHG emission perspective. When prices hit below 20 € per MWh, electrolysers should be allowed to produce renewable hydrogen and electricity they consume should be categorized as fully renewable (having 0 g of CO_2 per kWh). In this realistic scenario, electrolysers would be running at lower than maximum output for most of the time, however, they would ramp up when electricity becomes cheap on hourly basis. Electricity becomes cheap only when RES are producing (due to overcapacity and zero marginal production cost). This issue is highlighted in ACER's 2024 report, Progress of EU Electricity Wholesale Market Integration, which reveals that in the EU-27 bidding zones, there were 7,117 hours with electricity prices below 5 € per MWh in 2023. [24]

Geograhical correlation

The geographical correlation requirement aims to minimize grid congestion between neighboring member states. **However, this rule disproportionately disadvantages countries with lower RES potential, such as the Czech Republic, and contradicts the logic of an interconnected electricity grid.** Given that RFNBO production will remain costly even in the mid-term, concerns about large-scale electrolyzer deployment across the EU exceeding cross-border capacity are unfounded.

Therefore, the geographical rules should be revised to permit sourcing RES from neighboring countries or bidding zones, fostering greater flexibility and fairness in the development of renewable hydrogen.

Conclusion

European Union has set wide target for RFNBO consumption for each Member State. However, three key factors limit RFNBO production within the EU: **i) the availability of renewable electricity iii) low capacity factors due to strict rules on RFNBO production and ii) the high capital costs of electrolysers**. While the challenge of securing enough electrolysers at reasonable prices affects almost all EU countries and can be addressed through sector maturing, ensuring sufficient renewable energy is more difficult for countries with less favourable climate and geographical conditions for wind and solar power.

Rules should be amended under these 4 core principles:

Flexibility: Hydrogen sector requires more flexibility to increase capacity factor of electrolysers to produce renewable hydrogen.
Time: Hydrogen sector requires more time to mature.
Less discrimination: Hydrogen sector must not be discriminated against direct use of electricity.
Energy system compatibility: Hydrogen production should be incentivized when RES are generating in a system friendly way.

Postpone additionality entry in force	Apply additionality for directly connected RES to electrolyser from 2030 onwards. Apply additionality for PPA contracted RES from 2036 onwards and use grandfathering rule until 2040.
Allow to use supported RES	Allow electrolysers to establish PPAs with RES which received either operational (OPEX) or investment (CAPEX) aid.
Establish monthly correlation permanently	Do not phase in hourly temporal correlation. Or allow using monthly correlation until 2036 and then phase in hourly correlation.
Count electricity as fully renewable when prices on day-ahead market hit below 20 € per MWh	Replace current rule which allows to comply with temporal correlation when prices hit below 20 € per MWh with rule which allows to count electricity as fully renewable in the time period when prices hit below 20 € per MWh.
Permit closing PPAs between electrolyser and RES from interconnected bidding zone	Change geographical correlation to allow contracting PPAs between RES and electrolysers which are situated in the interconnected bidding zone (adjacent).

Notes

[NOTE 1]: Indicative price per kW installed in the Czech Republic is usually higher than 3500 € per kW, especially for projects smaller than 10 MWs. Methodology regarding pricing is however difficult to establish, since some members included cost of storage (which is always different for each project) and some did not.

[NOTE 2]: Gartner's Hype Cycle Theory is a method developed by the research and consultancy firm Gartner. It explains how the hype surrounding disruptive technologies evolves over time. The cycle moves through several stages: starting with the innovation trigger, followed by the peak of inflated expectations, then the trough of disillusionment, progressing to the slope of enlightenment, and finally reaching the plateau of productivity. Hydrogen is currently in the trough of disillusionment phase.. GARTNER, Inc.: *Gartner Hype Cycle.* (https://www.gartner.com/en/research/methodologies/gartner-hype-cycle)

[NOTE 3]: Levelised Cost of Hydrogen is metric used for indicative production price of hydrogen, mostly renewable hydrogen, when considering various variable such as electricity price, CAPEX of hydrogen production plant, capacity factor and other.

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List of Abbreviations

CAPEX	....	Capital Expenditure or Capital Expense
CCS	....	Carbon Capture and Storage
CF	....	Capacity Factor
CRL	....	Commercial Readiness Level
DA	....	Delegated Act
EHB	....	European Hydrogen Bank
FID	....	Final Investment Decision
GHG	....	Greenhouse Gases
GW	....	Gigawatt
kW	....	Kilowatt
LCOH	....	Levelised Cost of Hydrogen
LNG	....	Liquified Natural Gas
NGO	....	Non-governmental Organisation
OPEX	....	Operational Expenditure or Operational Expense
PPAs	....	Power Purchase Agreements
RES	....	Renewable Energy Source
RFNBO	....	Renewable Fuels of Non-biological Origin
TRL	....	Technology Readiness Level