

CEGH GreenHydrogen Indices

Specification Document

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The specification document was written with support of PwC / [Strategy&](#).

1. Objectives and Approach of CEGH's GreenHydrogen (H₂) Indices

Hydrogen will play an important role in the transition towards a carbon-free energy system. Therefore, it is expected that an actively traded market for green hydrogen will develop over the course of the next decade. One key component for the development of such a traded market is the availability of transparent pricing information which enables market players to value contracts and manage the risk / optimize their portfolios. CEGH aims to support the development of traded hydrogen markets in Austria and surrounding countries ("CEGH market area") by providing market participants with such price information.

Ideally, such an index should be constructed using data from market transactions or at least data from price quotations for transactions. However, such trade data are currently not available in Austria and the surrounding countries the CEGH market area. Reason for this is inter alia that hydrogen is mostly produced and consumed within industrial clusters ("Verbundstandorte") which are operated by companies, joint ventures or companies grouped together in a chemical / industrial park. Within these clusters, the production costs of hydrogen are shared / allocated on a "cost-plus" basis among the partners using long-term contracts. Consequently, it is not yet possible to form an index for hydrogen with delivery points in Austria or Central Europe that is based on market prices.

It is expected that actively traded markets for hydrogen will develop once the required transportation and storage infrastructure for intermediating between producers and offtakers of hydrogen is established and the currently existing price gap between offtaker's willingness-to-pay and production costs is narrowed.

In order to support this transition from long-term purchase contracts towards market-based trading, CEGH aims to publish several Greenhydrogen-Hydrogen price assessments indices, which represent "reservation price"-levels for hydrogen, i.e. the minimum prices at which suppliers of green hydrogen are willing to bring hydrogen volumes into the market. Thus, these "CEGH GreenHHydrogen Price" indices could help project developers and potential offtakers to get an understanding of the level and the drivers of the cost value of hydrogen and to assess the price differences between different production forms of green hydrogen ("shades of green hydrogen").

The "CEGH GreenHydrogen Indices" will be based - for the time being - on a "cost-plus" logic only reflecting the expected production costs of green hydrogen at a "representative" electrolysis site, i.e. project developers / potential offtakers may need to make adjustments in order to capture project-specific differences (e.g. regarding capexCapex levels, power sourcing strategy applied, industrial applications). Depending on the approach for structuring power supply to the electrolyser, the "CEGH GreenHydrogen" indices will differentiate between the following "grades" of green hydrogen:¹

- "CEGH GreenHydrogen PPA-100-Index" (so far "CEGH GreenHydrogen PPA 100" - renaming by 23 October 2023): Electricity purchase via a ("direct line") PPA, i. e. the electrolyzer sources 100% of electricity supplies from a renewable electricity

¹ In practice, there may be even further variations regarding the power sourcing strategies applied by different hydrogen projects (e.g. usage of battery storage / H₂ storage for structuring power supply / H₂ output). Such complexities are not considered in the construction of the CEGH H₂ indices in order to achieve a transparent index design.

generation asset— compliant with the requirements of Art. 4 of the Delegated Act, RED 2 (Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources of the European Parliament and the Council). This source of power supply imposes tight limits on the operating hours of the electrolyzer, which needs to follow 1:1 the operating hours (full load and partial load hours) of the renewable electricity generation asset.² The “CEGH GreenHydrogen ~~PPA 100~~-Index” is a proxy for a RED II compliant hydrogen, for which there is limited supply expected due to very strict requirements defined by the DA / RED II.

- “CEGH GreenHydrogen Forward / Spot Index”: Purchase of green electricity via a combination of grid electricity and guarantees of origin (GoOs); this specification does not meet the requirements of Art. 4 of the Delegated Act, RED 2 (Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources of the European Parliament and the Council), ~~of RED II~~. However, the supply of this type of “green hydrogen” is not limited by the limitations-restrictions on accessing power from renewable assets according to RED II.³ Once grid electricity purchase would meet the requirements of the DA Red II (or in Future RED III), the index could become compliant with RED II (RED III).
- “CEGH GreenHydrogen PPA 40 Index”: Electricity purchase ~~via the electricity grid~~ using a combination of PPA contracts and ~~a combination of~~ grid electricity with and GoOs; in this case, the result is a mix of RED II compliant green hydrogen and non-RED II compliant green hydrogen. It is not compliant with the requirements of Art. 4 of the Delegated Act, RED 2 (Delegated Regulation (EU) 2023/1184 of 10 February 2023 supplementing Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources of the European Parliament and the Council). Once grid electricity purchase would meet the requirements of the DA Red II (or in Future RED III), the index could become compliant with RED II (RED III).

Based on initial discussions with different market participants, it is expected that most market participants will have a clear preference for RED II (RED III) compliant green hydrogen as long as such hydrogen becomes available at acceptable market price levels. ~~However, some offtakers are also highly price sensitive (e.g. the steel industry is exposed to high levels of international / intra-European competition) and/or need very high volumes as a baseload profile. These Other – industrial - offtakers would also might still~~ be interested in sourcing non-RED II compliant green hydrogen.

CEGH will continue to develop and update the CEGH GreenHydrogen Indices according to market developments. Firstly, a “CEGH Pricing Panel” and a regular review of all components

² ~~In order to~~ To achieve a higher capacity utilization of the electrolyzer despite the limited number of full load hours of wind / PV assets, some project developers also consider to "overcontract" renewable capacity. Such complexities are not considered in the construction of the CEGH H2 indices ~~in order to~~ to achieve a transparent index design.

³ ~~This approach is also in line with requirements for the mobility sector according to the draft RED III Directive and the underlying assumption that these might potentially also be applicable for hydrogen production.~~

should ensure that state-of-the art prices are published. Secondly, in case that market prices become available, market prices will be considered for the CEGH GreenHydrogen Indices.

2. Calculation of the "CEGH GreenHydrogen Spot Index" and the "CEGH GreenHydrogen Forward Index"

The "CEGH GreenHydrogen Spot Index" and the "CEGH GreenHydrogen Forward Index" mirror the cost of "green hydrogen" which is produced using grid electricity and guarantees of origin. Thus, this type of "green hydrogen" does not meet the requirements of RED II ~~and is mostly relevant for offtakers that require high volumes and that are highly price sensitive (e.g. steel industry)~~ as long as grid electricity purchase does not fulfill the criteria of the Delegated Act / Red II.

This index is calculated as the sum of the following components:

+	<i>Electricity (Grid) purchase costs per MWh H₂</i>
+	<i>Costs GoOs per MWh H₂</i>
+	<i>CAPEX per MWh H₂</i>
+	<i>OPEX per MWh H₂</i>
=	<i>H₂ Costs per MWh <u>H₂</u> (Total)</i>

Depending on the type of "product", these H₂ costs are averaged across individual delivery months / years. Time value of money (discount rate) is considered in CAPEX.

The calculation of these components is described in more detail in the following subsections.

a) Modelling electricity procurement costs

The "CEGH GreenHydrogen Spot Index" and the "CEGH GreenHydrogen Forward Index" measure the production costs of an electrolyzer that produces hydrogen (e.g., for use in industry) in a relatively stable manner with no seasonal, monthly and/or weekday structure. In particular, the index calculation is based on the assumption that the electrolyzer operates 6,000 full load hours per year which are equally spread across the months and then optimized based on the lowest hourly prices for each delivery month.⁴

The load profile of power supply to the electrolyzer is determined as follows:

1. The assumed 6,000 full load hours p.a. are distributed proportionally over the individual months of the year, i.e. the electrolyzer is operated for approx. 500 hours each month.
2. For each month, the 500 hours are allocated to the individual delivery hours of the respective month in such a way that the cumulative electricity procurement costs per month are minimized. For this purpose, the individual delivery hours of the month are sorted in an ascending order according to the expected market prices as indicated by

⁴ In order to ensure a sufficiently fast amortization of the investment costs in accordance with industrial practice, 6,000 full load hours of the electrolyser per year are assumed. Moreover, it is assumed that there are no possibilities for intermediate storage of the produced hydrogen volumes which would allow to further optimize power procurement costs by moving the operating hours of the electrolyzer into delivery months / seasons with the lowest expected power prices (cf.: Frontier Economics, „Grünstromkriterien der RED II – Auswirkungen und Kosten der Verfügbarkeit von grünen Wasserstoff in Deutschland“, 2021).

the hPFC ("Hourly Price Forward Curve"). The operation of the electrolyzer is then planned for the 500 hours of each month that have the lowest market prices.

Valuation of the power consumed by the electrolyzer

- When calculating the "CEGH GreenHydrogen Spot Index", the electricity supply volumes are valued using the relevant day-ahead prices for the individual delivery hours that have been established in the "day-ahead" auction on the day before the delivery date.
- When calculating the "CEGH GreenHydrogen Forward Index", the electricity procurement volumes are valued using the relevant forward prices for each individual delivery hours in accordance with the "hourly price forward curve" on the measurement date. Depending on the type of "product", these H₂ ~~prices-costs~~ are averaged across delivery months / years.

Valuation of required ~~G~~uarantees of ~~O~~origin (~~G~~oO)

- ~~The market for guarantees of origin is currently largely semi-liquid. Initial price assumptions so that no market prices can be observed for most types of guarantees of origin except for guarantees of origin for Nordic hydro. Price assumptions were initially defined with PwG.~~
- ~~The Pricing Panel will in future set the value of the GoOs; these price assumptions will be reviewed~~ are regularly reviewed.
- Depending on the further development of the market for GoOs, this approach may need to be adjusted in the future.

Conversion into H₂

- The costs of power supply [in EUR per MWh_{electric}] are converted into costs per unit of hydrogen produced by dividing the high heating value (HHV) efficiency of 70 % of the electrolysis process. Therefore, the result of all indices is denoted in EUR per MWh_{HHV}.

Grid Costs

- Grid Costs are not considered in the calculation of the indices. For the time being, grid costs are exempted by law for the production of green hydrogen. If this regulatory exemption would end, the electricity costs would significantly increase (e.g. considering "Netzebene 5" by 46.667 EUR/MWh).

b) Calculation of Capex ~~and Opex~~

Determination of the ~~capex~~Capex per MW of capacity

The amount of ~~capex~~Capex considered in the calculation of the "CEGH GreenHydrogen"-Indices refers to the investment costs for a standard (new) PEM electrolyzer in Austria,

whereby only the costs for the installation of the plant within the "battery limits" depicted in figure 2 are taken into account:

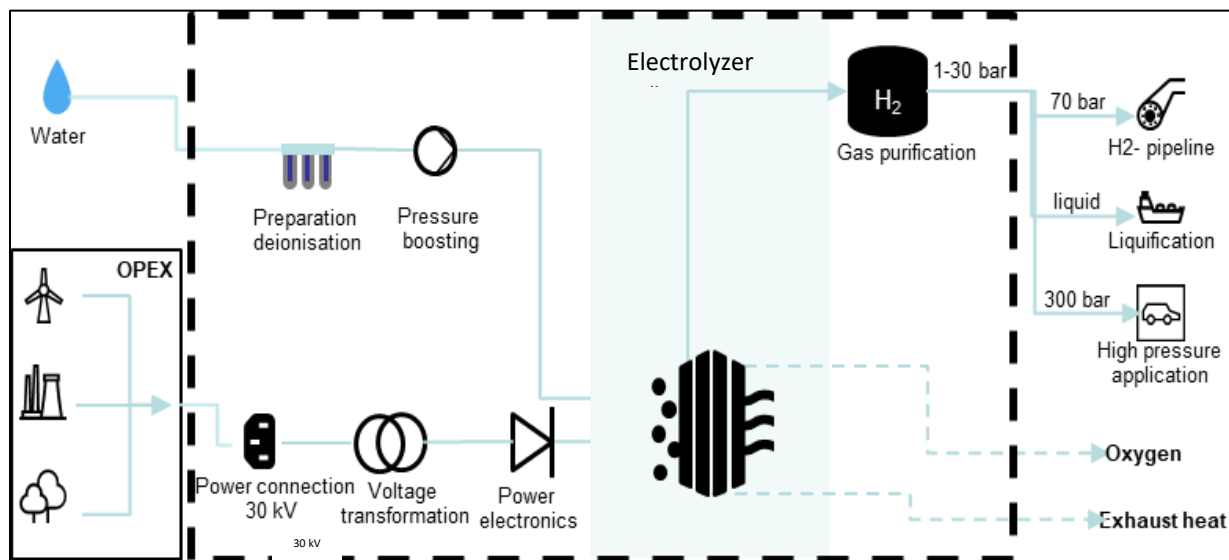


Figure 1

For example, the plant components required for hydrogen storage, ~~transport~~transport, and ~~transformation from high to medium voltage~~the further processing of the hydrogen after purification are not included within these (battery) limits and are therefore not included in the calculation of Capex.⁵

Starting with 23 October 2023, Capex considered in the index calculation was increased by 14 %.

Consideration of learning curve effects in the determination of H₂ forward price assessments

- Forward prices for hydrogen refer to the market prices for hydrogen in a future delivery period. Therefore, when accounting for Capex in the forward price of hydrogen, it must be taken into account that both significant "scale" and "learning curve" effects are expected to occur as the cumulative number of electrolyzers produced increases over time. It is assumed that these effects will have a significant effect on the Capex values.
- Based on the cost development of PEM electrolyzers, it was determined that a cost depression of 14% could be achieved for each doubling of the cumulative number of electrolyzer units produced. This estimate was projected into the future based on the expected growth of the number of deployed electrolyzers.

⁵ To some extent, hydrogen production can also be structured by adapting the pressure (so called „line-packing“); however, this is limited to a few hours (about four), a whole day's baseload cannot be achieved by this.

- -The year 2022 was defined as the base year, which means that a doubling for the costs of the ~~electrolyzes~~electrolyzer would already take effect in 2023 and again in 2025. The cost degression value and projections will be reviewed regularly by the Pricing Panel.

Determination of the expected economic life

- The expected economic lifetime of an electrolyzer depends primarily on the technology used and the expected number of full load hours per year. For PEM, a guaranteed lifetime of 60,000 hours was assumed. This will be reviewed regularly ~~by the Pricing Panel.~~⁶

⁶ Regarding the AEL, a lifetime of 90,000 hours could be considered.

Capital costs to be applied

- Weighted Average eCost of eCapital of approx. 9 % (9 instead of previously 8 %, update by 23 October 2023) for Renewable Energy Project Development. This value will be reviewed regularly ~~by the Pricing Panel~~.

c) Calculation of OPEX

- The Opex for maintenance etc. as well as costs for the purchase of water are not taken into account as these costs are assumed not to medially affect the pricing. In principle, Opex of 3 % of the total Capex may be considered appropriately.

3. Calculation of the “CEGH GreenHydrogen ~~PPA 100~~-Index”

The "CEGH GreenHydrogen ~~PPA 100~~-Index" measures the cost of “green hydrogen” which is produced using power supplies sourced via a RED II compliant PPA. Thus, this type of “green hydrogen” meets the requirements of the DA of RED II and is mostly relevant for offtakers who want to purchase RED II compliant green hydrogen.

This index is calculated as the sum of the following components:

$$\begin{array}{r}
 + \quad \textit{Electricity (PPA) purchase costs per MWh H}_2 \\
 + \quad \textit{CAPEX per MWh H}_2 \\
 + \quad \textit{OPEX per MWh H}_2 \\
 \hline
 = \quad \textit{H}_2 \textit{ Costs per MWh H}_2 \textit{ (Total)}
 \end{array}$$

The resulting price index measures the cost value per MWh of delivery of hydrogen over a 10-year period (i.e. aligned to the maturity of the PPA). Time value of money (discount rate) is considered in CAPEX.

The calculation of these components is described in more detail in the following subsections.

a) Calculation of Cost of Power Supply

The "CEGH GreenHydrogen ~~PPA 100~~-Index" index measures the production costs of an electrolyzer that sources its power via a RED II compliant PPA with PV and windfarm projects located in Austria. The capacities of the renewable power production plants are split at a ratio of 1:1 between wind and PV. Thus, the operating mode of the electrolyzer is in a ratio of “2:1” of the full / partial load hours of the renewable power: 1 MW (electric) of electrolyzer capacity is matched by 2 MW (electric) of PPA capacity.⁷

The total operating hours of the electrolyzer are assumed to be approx. 4,000 full load hours.

These power supply volumes are valued using PPA prices on the measurement date. These PPA prices measure the market prices for PPA with wind and PV projects in Austria with a maturity of 10 years. Aurora Energy Research GmbH (Aurora) is the source of the methodology for calculating the pay-as-produced Power Purchase Agreement prices (PPA Prices) based on ~~German~~-baseload electricity futures for the next three front years. The PPA pPrices do not reflect Aurora’s view of the market and third parties may not rely in any way on the PPA pPrices to the extent they can be ascertained here.

The model was updated on 23 October 2023 resulting in an increase of PPA prices. In addition, we took out learning curve effects in the determination of fundamental forward prices.

The costs of power supply [in EUR per MWh_{electric}] are converted into costs per unit of hydrogen produced by dividing the high heating value (HHV) efficiency of 70 % of the electrolysis process. Therefore, the result of all indices is denoted in EUR per MWh_{HHV}.

⁷ See footnote 3.

Grid Costs

- Grid Costs are not considered in the calculation of the indices. For the time being, grid costs are exempted by law for the production of green hydrogen. If this regulatory exemption would end, the electricity costs would significantly increase (e.g. considering "Netzebene 5" by 46.667 EUR/MWh).

b) Calculation of Capex ~~and Opex~~

- The amount of Capex per MWh is calculated using the same approach as described in section 2. B.) with the number of full load hours p.a. set equal to ~~approx~~ approx. 4,000 leading to an economic lifetime of ~~approx~~ approx. 15 years.

c) Calculation of OPEX

- The Opex for maintenance etc. as well as costs for the purchase of water are not taken into account as these costs are assumed not to medially affect the pricing. In principle, Opex of 3 % of the total Capex may be considered appropriately.

4. Calculation of the “CEGH GreenHydrogen PPA 40 Index”

The “CEGH GreenHydrogen PPA 40 Index” index is calculated under the assumption that renewable electricity is sourced via a combination of a RED II compliant PPA Austrian PV and wind (40% of the hydrogen production) and grid electricity combined with guarantees of origin (60% of the hydrogen production). This index is set up to reflect the cost levels of a number of existing electrolyzer projects which aim to optimize Capex per unit of hydrogen by increasing the annual number of running hours by using both PPA and grid electricity. The index is not compliant with the DA of RED II.

This index is calculated as the sum of the following components:

+	<i>PPA Electricity purchase costs per MWh H₂</i>
+	<u><i>Electricity (Grid) purchase costs per MWh H₂ Residual power supply</i></u>
+	<i>CAPEX per MWh H₂</i>
+	<u><i>OPEX per MWh H₂</i></u>
=	<i>H₂ Costs per MWh H₂ (Total)</i>

As the market prices of PPA reflect the costs of a 10-year supply contract for electricity, this index also measures the costs of hydrogen supply for a 10-year period. Time value of money (discount rate) is considered in CAPEX.

The calculation of these components is described in more detail in the following subsections.

a) Calculation of Cost of Power Supply

The calculation of the “CEGH GreenHydrogen PPA 40 Index” is based on the assumption that the electrolyzer runs in total 6,000 hours p.a. using power that is sourced both via a RED II compliant PPA and via the electricity grid. This allows the project to reduce the amount of Capex that needs to be priced into each unit of hydrogen produced.

In order to optimize the total costs of power, it is necessary to ensure that the residual load requirements (i.e. the power amounts that need to be sourced from the grid) are allocated to the delivery hours with the cheapest power prices. This is achieved by applying the following steps:

1. The production hours of the electrolyzer (6,000 hours p.a.) are allocated pro-rata to the individual months of the year in order to achieve a stable “baseload” hydrogen production profile optimized on a yearly basis (pay-as-produced first PPA and second grid electricity).
2. ~~The electrolyzer is set to operating mode in each delivery hour during which the PPA also delivers any electricity.~~ Individual hours in which electricity is supplied under the PPA can also be “topped up” by procurement on the market in order to use the full output of the electrolyzer in favorable (“cheap”) hours. The additional procurement on the market is controlled in such a way that the “PPA hours” are first used in the electrolyzer and then additional quantities are procured on the market in order to achieve the 5006,000 full-load hours per month/year.

3. For each delivery month-year, the hours ~~during which the PPA does not deliver power~~ are sorted according to the expected power price, ~~and t~~ the delivery hours with the lowest power prices are selected until 500-6.000 operating hours per month-year are reached for the electrolyzer.

The costs of PPA supplies are valued using the PPA prices (obtained by Aurora as described before) and the sourcing of ~~residual load from the grid~~ electricity is valued using the hPFC.⁸ We also slightly adjusted the GoO curve.

The costs of power supply [in EUR per MWh_{electric}] are converted into costs per unit of hydrogen produced by dividing the high heating value (HHV) efficiency of 70 % of the electrolysis process. Therefore, the result of all indices is denoted in EUR per MWh_{HHV}.

Grid Costs

- Grid Costs are not considered in the calculation of the indices. For the time being, grid costs are exempted by law for the production of green hydrogen. If this regulatory exemption would end, the electricity costs would significantly increase (e.g. considering "Netzebene 5" by 46.667 EUR/MWh).

b) Calculation of Capex and Opex

- The calculation of Capex and Opex follows the procedure outlined in section 2.

We highly appreciate your comments or questions to the CEGH GreenHydrogen Indices. Please use the following E-Mail address for your communication: info@cegh.at

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⁸ The CEGH H₂ indices aim to measure the expected costs of hydrogen. The expectation of the costs of power supply are fully captured by the "hPFC" (which can be interpreted as an expectation of future spot prices under some conditions). Thus, no additional corrections / risk premia for price structure risks, risks resulting from changes in shape over time ("cannibalization") and/or short-term price volume-correlation (-> after day-ahead is closed) are considered. Hence, the index should be not affected by inherently subjective assumptions on the aforementioned risk and the possible impact they might have on costs.

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