A harmonised framework for hydrogen quality to enable a cost-efficient European hydrogen market

A Position Paper by H2eart for Europe

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Executive Summary

Defining the system-wide hydrogen quality is one of the key technical questions to be addressed to enable the development of a European hydrogen market. Investment decisions across the hydrogen value chain are already being taken, and regulatory standards on hydrogen quality have a decisive impact on the technical feasibility and economic viability of projects.

While regulatory clarity is therefore needed as soon as possible, inadequate standardisation may risk constraining market development. A harmonised framework is required to ensure interoperability and facilitate cross-border trade; however, its design must balance the inherent trade-off between achieving optimal purity levels for offtakers and enabling a timely and cost-efficient market ramp-up.

Setting uniform, highly stringent purity standards across the system would risk imposing disproportionately high costs. At the same time, the benefits of very high purity levels materialise only to some end-users with particularly sensitive applications, many of whom rely on additional on-site purification regardless of network quality.

A fit-for-purpose regulatory approach should therefore combine harmonisation with flexibility through

- distinguishing between high critical and lower-/non-critical impurities while ensuring a minimum hydrogen content[1],
- aligning hydrogen quality with individual end-use requirements, and
- managing purity across the entire hydrogen value chain.

1 In line with common standards, such as for example the EASEE Gas Common Business Practice on Hydrogen, we consider 98mol-% to be the minimum hydrogen content.

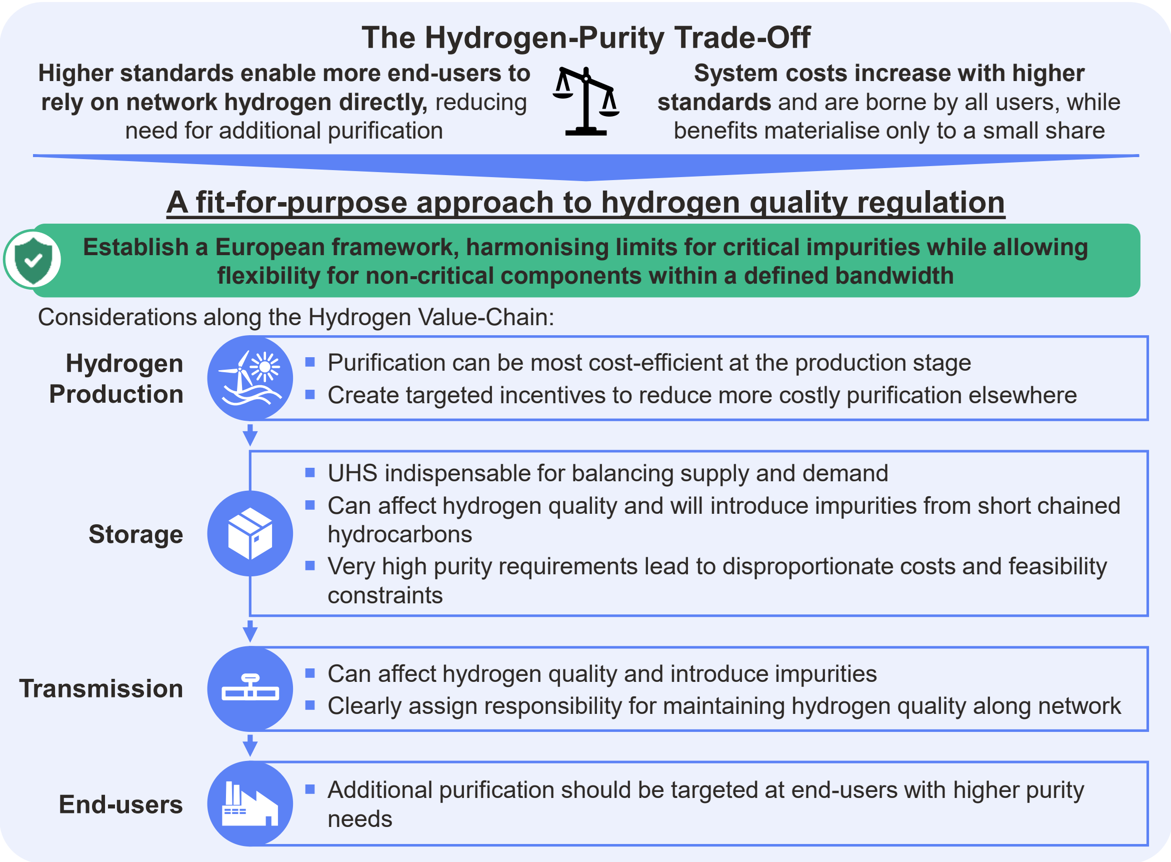
Considerations on hydrogen quality cannot just focus on supply and demand, but need to take into account the infrastructure connecting and facilitating the system. In particular, underground hydrogen storage (UHS) will play a central role in enabling system operability and scale, and its specific technical and economic constraints must be reflected in regulatory design.

Providing regulatory clarity on impurity thresholds and purification requirements is essential to unlock investment and avoid delays in infrastructure development. A coordinated, value chain-wide approach is therefore needed to ensure that hydrogen quality standards support, rather than hinder, market scale-up.

As H2eart for Europe, an alliance of European UHS operators, we identify the following key policy asks:

- **Define a minimum hydrogen content and limits for critical impurities** while allowing flexibility for lower-/non-critical components within a defined bandwidth at specified entry/exit points of the system
- **Establish a harmonised European framework** to enable interoperability and cross-border trade and setting out rules for **value chain-wide quality management** with clear roles and accountability across all stakeholders
- **Ensure that impurity thresholds are technically and economically feasible** across the value chain, including for SSOs, particularly in the case of repurposed storage facilities
- **Incentivise purification at the most cost-efficient points in the system**
- **Ensure efficient allocation** of purification costs

Figure 1 Overview of suggested fit-for-purpose approach



Source: Frontier Economics for H2eart for Europe

We would be happy to support ongoing regulatory processes and provide further technical input to ensure that hydrogen quality standards enable a cost-efficient and timely market ramp-up.

Hydrogen quality as a system-wide requirement for the market ramp-up

Hydrogen quality requirements are driven by the need to ensure the safe and efficient operation of European infrastructure and end-use applications across the emerging hydrogen value chain. Different end-use applications exhibit varying sensitivities to impurities in hydrogen: while some uses expected to represent a large share of demand, such as industrial heat or power generation, can tolerate moderate impurity levels, others – including fuel cells and certain catalytic processes – require very high purity hydrogen to avoid performance losses or equipment damage.

Overall hydrogen purity is relevant, as it affects key hydrogen properties, such as calorific value and the Wobbe index, and may also have implications for material compatibility and system integrity. However, it is often the concentration of specific contaminants, such as short-chain hydrocarbons (e.g. methane), moisture, sulphur compounds, oxygen, nitrogen and particulate matter which is critical to specific end-applications.

At present, there is no fully harmonised European framework defining acceptable hydrogen impurity thresholds. Discussions are ongoing regarding which impurity components should be classified as highly critical for end-applications (e.g. sulphur compounds or oxygen), and which components may be less critical (e.g. methane). These discussions also concern how stringent the corresponding limits for these components should be, and how relevant they are from a system perspective. Existing standards and industry practices differ across countries and sectors, reflecting heterogeneous end-use requirements and technical constraints along the value chain.

Current discussions on hydrogen purity levels range from around 98% to 99.97%, reflecting, for example, the distinction in Germany between lower-purity “grade A” hydrogen (98%) and higher-purity “grade D” hydrogen (99.97%). EASEE-gas supports the relevance of the lower end of this range by recommending, in its Common Business Practice (CBP) on hydrogen, a minimum hydrogen concentration equal to or higher than 98% for hydrogen transported through dedicated hydrogen systems.[2] Several Member States, including Germany, the Netherlands and Denmark, have already introduced, or are developing and reviewing, hydrogen purity specifications for hydrogen networks and infrastructure. A broader European consensus on hydrogen quality standards has yet to emerge.

This lack of alignment creates uncertainty for producers, infrastructure operators and consumers, as they are unable to assess the technical feasibility and economic implications of meeting future quality standards. Particularly as hydrogen systems scale up and become

[2] EASEE-gas, Common Business Practice on Hydrogen, Quality Harmonisation Working Group, 6 January 2022.

interconnected across borders, this puts the ramp up of the European hydrogen market at risk. Establishing a common understanding of relevant impurities and their acceptable levels is therefore a prerequisite for enabling efficient market development and cross-border trade. Providing greater regulatory clarity with a harmonised hydrogen quality framework is important for market participants facing long lead times and high upfront capital requirements, such as UHS, where early de-risking of investment is essential for timely delivery.

Priorities and perspectives vary among different stakeholders

While there is an agreement that harmonisation is necessary to enable the ramp up of the hydrogen economy, the choice of quality standard itself is discussed controversially among different stakeholders along the value chain. This is not least because the interests of different players differ:

- **Production and import:** Achievable quality standards and impurities differ by production source. While electrolysis is expected to achieve relatively high purity standards by default, quality from other sources, such as ship imports via carrier molecules or blue hydrogen (e.g. SMRs), is subject to more uncertainty.
- **Offtakers**: The required degree of purity varies widely across future end-users. While lower quality standards are sufficient for a number of offtakers, including heat and power generation, some end-applications (i.e. chemical applications) are highly sensitive to a range of impurities.
- **Infrastructure operators:** Finally, pipelines and storage operators are tasked with connecting supply and demand. Transport and storage may introduce contaminants into the hydrogen, especially when utilising repurposed infrastructure. Particularly pure hydrogen standards may make additional purification measures necessary. However, there remains significant uncertainty regarding the purification requirements to potentially remove critical trace compounds.

UHS as an enabler to hydrogen market operability

Underground hydrogen storage (UHS) is an essential enabler of a functioning hydrogen market. It is the only large-scale technology capable of structuring intermittent hydrogen supply patterns to match heterogeneous hydrogen demand patterns. This is especially important for industrial end-users, who are expected to account for the majority of demand in the early years of market development and require a steady baseload supply to ensure continuous operation.

Hence, the timely availability of sufficient underground storage capacities across Europe is key to enabling both a successful ramp-up and the long-term operation of the hydrogen system. A majority will rely on repurposed underground storage facilities.

Given this central role in the system, it is important to consider how UHS affects hydrogen quality. Indeed, UHS can affect hydrogen purity during storage and withdrawal. However, its impact is not unequivocal and depends on several factors, including the type of storage used (e.g. cavern or porous storages) and on the previous use of the site (e.g. newly developed or repurposed natural gas storages site). These factors influence not only overall hydrogen purity, but also the presence and composition of specific trace components.

In practice, the European hydrogen system will rely on a mix of UHS options. The optimal storage solution varies across locations, reflecting geological conditions, cost structures and project timelines. As a result, cavern and porous storage as well as both new and repurposed sites will each play a crucial role in the future hydrogen system.

Uniformly high hydrogen quality is thus unlikely to be achievable along the entire value chain. Focusing the discussion on individual stages – such as UHS as a critical link – risks oversimplifying a system-wide issue and leading to a regulatory approach that is not aligned with overarching system needs.

At any stage in the value chain, hydrogen purity levels can be increased through introducing additional purification and treatment technologies. However, some purification mechanisms come at material costs, increasing costs on the overall hydrogen economy, particularly when repeatedly applied to large hydrogen volumes at different stages throughout the system.

Defining harmonised EU hydrogen quality standards thus inherently involves a trade-off between setting purity levels that are appropriate for the majority of end-use applications and the system-wide costs induced to achieve these standards.

Balancing hydrogen purity and cost-efficient scale-up

Current discussions on contaminant thresholds reflect the different perspectives of stakeholders, with each focusing on their own operational context. We do not believe that a clear consensus on the system-optimal thresholds, engaging all stakeholders along the hydrogen value chain, has been reached yet.

Regulation at union level should therefore answer the question what the most system-cost efficient hydrogen standard would be, balancing needs of all market participants.

- If contaminant thresholds are set too stringently, producers and infrastructure operators may face disproportionately high purification and treatment costs, including investments in additional processing equipment and infrastructure adaptation. This could slow down infrastructure deployment and increase the overall cost of transporting and storing hydrogen.
- If contaminant thresholds are set too low, a critical number of downstream users and offtakers with stricter purity requirements may need to invest in additional purification technologies at the point of use. This could impose disproportionate costs on end users and reduce the economic attractiveness of hydrogen for certain applications. This may be particularly relevant for industrial end users planning to use hydrogen as feedstock. These applications are expected to account for a significant share of demand, especially during the hydrogen market ramp-up phase, and can typically be assumed to require high-quality hydrogen.

Both outcomes could hinder a cost-efficient and timely hydrogen market ramp-up.

Higher purity standards increase the number of end-users that can rely on hydrogen directly from the network without requiring additional on-site upgrading. However, only a relatively small share of end-users is expected to require high quality levels for all expected impurities. As a result, the benefits of very high purity standards accrue primarily to a limited group while the associated costs increase and are borne across all end-users.

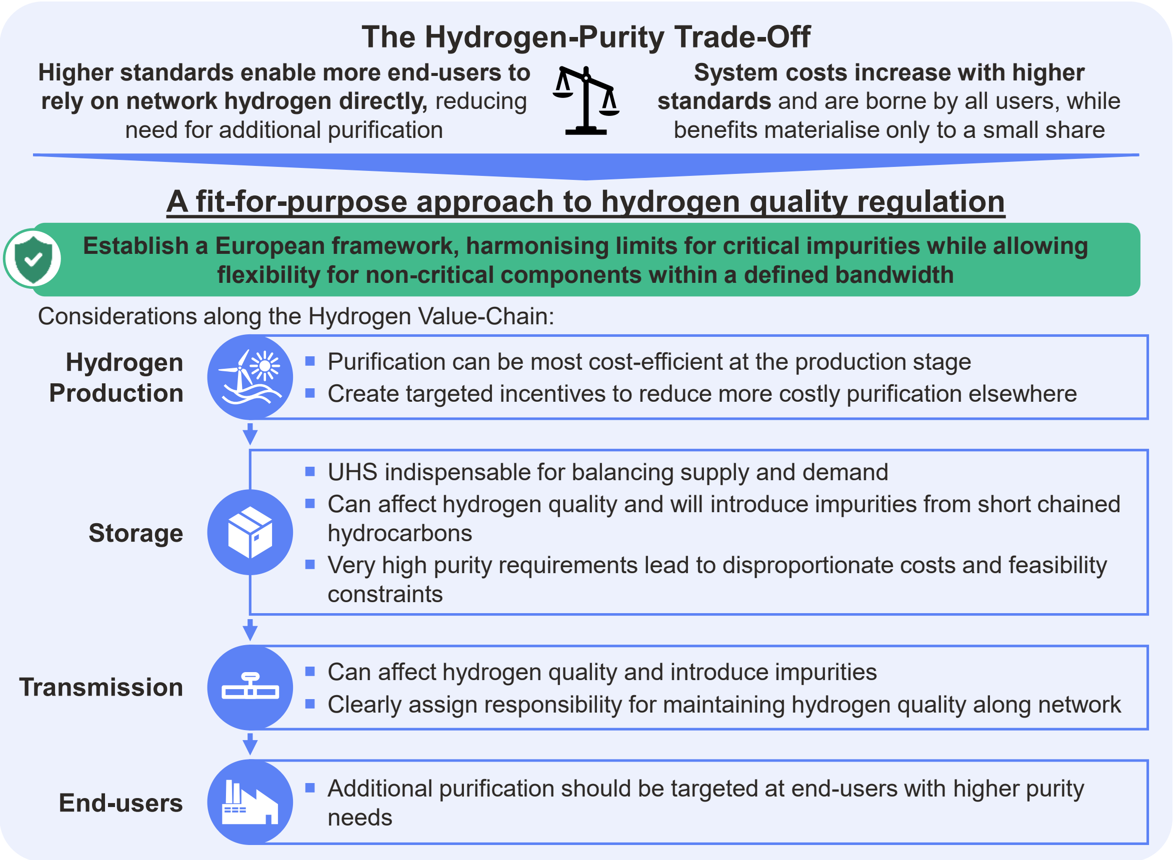
Costs arise as achieving uniformly high purity requires additional purification infrastructure across the hydrogen value chain. This, in turn, can result in disproportionately high hydrogen prices, weaken investment incentives, and slow down infrastructure build-out and overall market scale-up.

While limiting critical impurities and maintaining an appropriate Wobbe index remains essential for network operability, there is a risk that a uniform purity standard set at an economically too stringent level would impose disproportionate costs on the system. This could in turn hinder the development of an interconnected European hydrogen system.

A fit-for-purpose approach to hydrogen quality regulation

A fit-for-purpose approach to hydrogen quality regulation should balance the need for system interoperability with the objective of enabling a timely and cost-efficient market ramp-up. The current lack of harmonisation and remaining uncertainty around impurity thresholds underline the importance of establishing a common framework that provides clarity to market participants while avoiding disproportionate system costs.

Figure 2 Overview of suggested fit-for-purpose approach



Source: Frontier Economics for H2eart for Europe

Harmonising critical components while allowing flexibility

To facilitate the ramp up of the hydrogen economy, it is crucial to create reliable thresholds for all market participants. At the same time, we consider it to be vital to allow for flexibility in impurity levels coming from different parts of the hydrogen value-chain – including different production pathways, import terminals, underground storage facilities and transmission networks – to reduce overall system costs and engage all infrastructure partners.

A pragmatic and progressive approach would therefore be to **harmonise limits for critical trace components at European level**, while **allowing flexibility for lower-/non-critical impurities within a defined bandwidth**. Within this framework, hydrogen producers and network operators could determine, or contractually agree on, appropriate purity levels, using the European framework as a reference point rather than complying with a single uniform standard.

The key regulatory decisions would therefore centre on identifying the critical trace components that materially affect system operability, and on defining threshold levels that are appropriate for the majority of applications. This requires balancing technical feasibility with economic efficiency: Standards have to be sufficiently robust to guarantee interoperability while avoiding unnecessary costs for applications that do not require equally high purity levels.

Managing hydrogen quality across the value-chain

The effectiveness of a fit-for-purpose hydrogen quality framework ultimately depends on how quality is managed across the entire value chain. Impurities can be introduced or removed at multiple stages – from production and import to storage, transport and final use. Understanding these interactions is essential to ensure that quality requirements are implemented in a way that is both technically feasible and cost-efficient. Introducing thresholds for dedicated critical components can support both objectives.

Production and import

Higher purity levels can often be achieved efficiently at the **hydrogen production** stage. Our suggestion of allowing a bandwidth for lower-/non-critical impurities should therefore ensure to maintain incentives for producers to deliver sufficiently high purity levels. Targeted incentives at production points could help reduce the need for more costly purification measures elsewhere in the system. At the same time, any requirements imposed at entry points must remain consistent with the overall objective of enabling the rapid sourcing of large volumes of low-cost hydrogen and supporting an effective market ramp-up.

This consideration extends to **import terminals**, where hydrogen from different sources with varying quality levels will need to be integrated. Ensuring compliance with defined limits for critical trace components at these entry points is essential.

Introducing thresholds for individual critical components can ensure that a wide range of sources can be drawn upon, supporting a quick market ramp-up.

Storage

As set out earlier, the ramp-up of the hydrogen system will require significant **storage capacity** to balance supply and demand. UHS plays a central role in this context, with its implications for hydrogen quality varying depending on storage characteristics and site conditions.

In particular, the type of UHS (e.g. cavern or porous formations) and the previous use of the site (e.g. newly developed or repurposed natural gas storage) impact both overall purity levels and the composition of trace components. Further, the operational conditions of UHS (in particular very high pressure range and duration for chemical reactions, high delivery rates) are challenging and may require larger scale purification plants on site.

For hydrogen discharged from repurposed UGS sites, a key consideration is the presence of short-chain hydrocarbons, in particular methane. Components that may be introduced by storing hydrogen in UHS (e.g. sulphur-components) can be managed to levels comparable to those in the transport network using established technologies.

By contrast, the removal of short-chain hydrocarbons such as methane requires technologies such as pressure swing adsorption (PSA), which results in efficiency losses and significant additional investments. Deploying such technologies on-site is challenging and often impossible for installation at existing facilities due to space constraints, environmental permitting restrictions and economic considerations, particularly for repurposed storage sites. Meeting very high purity requirements across all kinds of components at UHS sites can lead to disproportionate costs and feasibility constraints.

These considerations underline the need for a regulatory framework that fully reflects the role of all market participants - including storage system operators (SSOs) in enabling hydrogen market development. SSOs should be recognised as central actors in system integration, with targeted support addressing their specific constraints, including space limitations, environmental conditions and the technical challenges associated with purification. Policy and regulatory frameworks should explicitly account for storage-related challenges and ensure that requirements are aligned with operational realities.

In particular, the critical component thresholds should be defined at levels that are both technically and economically feasible for SSOs. This is particularly important for repurposed storage facilities, where components such as methane will likely be introduced. Thresholds should reflect a proportionate balance between end-use requirements and technical and economic feasibility. This would help avoid limiting their contribution to system scale-up and flexibility.

Transmission

Hydrogen transmission networks should not be viewed as a neutral passage equating entry and exit purity. In practice, transmission infrastructure – particularly repurposed natural gas pipelines – can affect hydrogen quality and introduce impurities.

Regulatory frameworks should therefore clearly assign responsibility for maintaining hydrogen quality along the network. While higher purity levels at production or import points can reduce downstream requirements, they cannot substitute for quality obligations within the transmission system itself. In general, the European quality specification regarding the hydrogen entering the transmission system should also be in place for hydrogen leaving the system. Against this backdrop, specific thresholds for certain components and impurities would also be beneficial for transport infrastructure operation, enabling targeted quality management, network integrity and efficient operation.

Taken together, these considerations highlight that hydrogen quality is a system-wide issue that cannot be addressed efficiently through uniform standards alone. Instead, it requires a coordinated, value chain-wide approach that combines harmonised limits for critical components with flexibility and targeted purification where needed.

Targeting increased purity requirements where needed

The early development of the hydrogen market is expected to rely on regional clusters. Within these clusters, hydrogen purity levels can be aligned more closely with specific end-user requirements. Where certain applications require lower levels of key components – such as short-chain hydrocarbons – additional purification should be targeted at end-users with higher purity needs, rather than applied across the system.

A uniform, system-wide purification approach would be disproportionate, as hydrogen at reasonable purity levels is already sufficiently pure for most applications, including power generation and industrial heat. Where specific use-cases require thresholds exceeding the system wide standards, further purification can be introduced at the consumer level or may even be readily available (for example in the chemical industry).

Critical consumers, such as fuel cell applications and selected industrial sectors (such as the semiconductor industry or catalytic processes more generally), are highly sensitive to impurities and require hydrogen qualities well above mobility-grade. However, these applications typically rely on on-site, application-specific purification to ensure consistent quality and protect high-value equipment, regardless of the purity level provided by the network.

This reinforces that imposing uniformly high purity requirements across the entire network would neither remove the need for local purification nor represent a cost-efficient solution for the majority of users.

Allocating purification costs efficiently

Hydrogen quality regulation has important implications for how purification costs are allocated across the system. Costs incurred by infrastructure operators to meet agreed minimum purity levels should be recoverable within regulated frameworks or reflected in negotiated tariffs.

Cost allocation for measures required to meet system-wide minimum standards across the value chain should be considered carefully to ensure that responsibilities and incentives are aligned from a system perspective. This should also include any measures required at connected storage sites to comply with these standards. By contrast, costs associated with higher purification levels – driven by specific requirements of specific consumers – could be allocated separately, for example through individual or contractual arrangements.

About H2eart for Europe

H2eart for Europe is an EU-wide, CEO-led alliance committed to accelerating the decarbonisation of the European energy system at lowest cost to society by scaling up underground hydrogen storage (UHS). Launched in Brussels on 23 January 2024, the alliance provides fact-based analysis to support policymakers and draws on the expertise of its members, leading companies shaping the future of hydrogen storage across Europe. We are committed to investing in UHS infrastructure to meet the flexibility needs of a decarbonised energy system.

The organisations listed below are the members of H2eart for Europe.

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