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Low carbon hydrogen in the European Union: A coherent regulatory framework

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Take-away Messages

- **The Role of Low Carbon Hydrogen:** The use of low carbon hydrogen based on non-renewable sources is communicated as a necessary transitional solution for the renewable hydrogen market ramp-up, but associated with risks and challenges for climate mitigation.
- **Strategy:** A long-term strategic approach clarifying the role of non-renewable low carbon hydrogen from different sources (natural gas and nuclear-based) is missing on the EU level, but crucial to guide the transition towards a renewable hydrogen economy.
- **Ensuring Positive Effects on Climate Mitigation:** The EUs regulatory framework needs to address the risks and challenges by guaranteeing significant greenhouse gas emission reductions during the entire lifecycle of low carbon hydrogen, including upstream (methane emission), midstream (carbon capture rates and transport leakages) and downstream (leakages in CO_2 storage sites, re-emissions of CO_2 stored in products) emissions.
- **Addressing Regulatory Gaps and Incoherencies:** The current EU legislation exhibits gaps and inconsistencies in regulating low carbon hydrogen production, particularly concerning emissions throughout the production lifecycle, such as the non-permanent storage of captured fossil carbon in products.
- **Importance of a Strategic Approach to Imports:** With the high likelihood of importing low carbon hydrogen, the EU must establish a strategic approach and measures to maintain emission reduction standards, potentially leveraging mechanisms like the Carbon Border Adjustment Mechanism or joint purchases under the EU Energy Platform.

1. Introduction

Renewable hydrogen is necessary for the decarbonization of sectors that are difficult to electrify, such as industry and aviation, and as a storage medium for surplus electricity from renewable sources (Ferrario et al. 2022). The production of hydrogen on a fossil fuel basis has been the dominant production method, but renewable hydrogen has gained considerable relevance in the energy and climate policy debate in recent years. But so far, no significant amounts of renewable hydrogen were produced, as the market ramp-up is still in an early stage (IEA 2023; Hydrogen Europe 2023; Tarvydas et al. 2022). To push the emergence of a market, the European Union adopted a hydrogen strategy as part of the Fit-for-55 package and created detailed framework conditions to promote a sustainable and effective hydrogen economy (European Commission 2020). The regulation of hydrogen in context of decarbonization is particularly challenging due to its novelty and complexity (Janautre 2021). Hydrogen-related issues have to be integrated in the existing framework and new legislation has to be developed to fill in regulatory gaps and provide a coherent approach. The task of developing a coherent EU framework is complicated by varying regulatory needs and challenges for renewable and low carbon hydrogen. Low carbon hydrogen can be produced by a variety of methods using different energy sources. These include the production of low carbon hydrogen on the basis of natural gas with subsequent carbon capture and storage (CCS) and carbon capture and utilization (CCU), as well as the use of nuclear energy to power water electrolysis. Although low carbon hydrogen is not produced with renewable sources, its greenhouse gas (GHG) emissions can be significantly lower than conventional fossil-based production. Therefore, the use of low carbon hydrogen is discussed in the European Union as a way of accelerating the market ramp-up by supplying additional hydrogen for offtakers and paving the way for a renewable hydrogen economy.

While infrastructure development and market design are important issues to be addressed at the regulatory level, the focus of this study is on developing a framework for the production and import of low carbon hydrogen that supports decarbonization and does not disadvantage renewable hydrogen. While the EU's main objective is to produce and import renewable hydrogen, low carbon hydrogen will also play a role, even if it's only during a transitional period to satisfy the demand that cannot be covered until more capacities for renewable hydrogen are build. With the adoption of the Commission Delegated Regulation (EU) 2023/1184 of the second Renewable Energy Directive 2018/2001 (REDII) regarding requirements for the production of renewable fuels of non-biological origin (RFNBOs), the framework for renewable hydrogen is in an advanced phase. Yet, the regulatory framework for low carbon hydrogen is still in development but of utmost importance to address its associated risks and challenges. Therefore, special consideration must be given to a regulatory framework that ensures a positive contribution for climate mitigation and coherence between renewable and low carbon hydrogen.

In this context, the following analysis of the EU regulatory framework for low carbon hydrogen will have three objectives:

1. Outline the existing regulatory framework for low carbon hydrogen production and imports
2. Assess, if the regulatory framework is addressing the risks and challenges associated with low carbon hydrogen and identify deficiencies, e.g. regulatory gaps and incoherencies
3. Propose recommendations with regard to measures that could address those deficiencies to develop a coherent regulatory framework

These three objectives will be addressed by a detailed examination of the current EU legislation relevant for different types of low carbon hydrogen, including the most important directives, regulations, tertiary legislation and initiatives. In the second section, the current and future role of low carbon hydrogen is outlined and compared to the EUs strategic approach towards hydrogen. In the third section, the detailed provisions on different definitions and the integration of low carbon hydrogen in the target architecture for hydrogen is examined. The fourth section covering detailed requirements of low carbon hydrogen production will be structured around the different production methods, namely natural gas-based production with CCS, natural gas-based production with CCU and production using nuclear energy. This allows a nuanced view on the individual challenges of each production method for the regulatory framework, especially in regards to guaranteeing GHG emission reductions throughout the entire life cycle. As hydrogen imports into the EU will play a significant role to secure supply in the future, the analysis of domestic low carbon hydrogen production is followed by an assessment of the EU framework for hydrogen imports in the fifth section. First, the insufficient strategic approach to low carbon hydrogen imports is outlined and recommendations are formulated to integrate low carbon hydrogen in a Union strategy for imported and domestic hydrogen. Second, the implications for hydrogen imports are assessed in context of the requirements for domestic low carbon hydrogen production and the development of a coherent framework between domestic and third-country producers. The third subsection then discusses, if the European Hydrogen Bank can support the implementation of a strategic approach towards low carbon hydrogen imports. In the concluding section, a table summarizing the issues, deficits and recommendations is provided.

2. The Role of Low Carbon Hydrogen in the European Union

Low carbon hydrogen is discussed as a transitional element for the ramp-up of the European hydrogen economy in the coming years. So far, gas-based low carbon hydrogen produced by steam methane reforming only plays a marginal role in the overall supply, as the production in the EU accumulated to only 0.5% of total hydrogen production in 2022 (Hydrogen Europe 2023). According to a study of the EU Joint Research Centre, low carbon hydrogen is estimated to account for 30-50% of total global hydrogen production according to different scenarios for 2050 (Tarvydas et al. 2022). Another scenario from Aurora Energy Research for the European Union concludes that the combined use of renewable and low carbon hydrogen from natural gas with CCS and nuclear energy can significantly ease future demand, but also causes the most emissions in comparison to scenarios based on renewable hydrogen only (Aurora Energy Research 2021).

To increase hydrogen supply, plans for new low carbon hydrogen projects in the EU, for example in the Netherlands (Parkes 2023) and plans for international projects have been put forward. In context of joint declarations for cooperation in the energy field between Germany and Qatar (BMWK 2022), as well as Germany and Norway (Regjeringen 2023), low carbon hydrogen is integrated as a central element. Especially Norway sees a lot of potential for low carbon hydrogen exports to the European Union, as it poses an opportunity to extend domestic fossil-fuel production and safeguard revenues (Cheng 2023; Helgesen 2022). A deepened cooperation regarding renewable and low carbon hydrogen was reiterated in April 2023 with the establishment of an EU-Norway Alliance (European Commission 2023). The ongoing development of capacities for production and new initiatives for cooperation with third-countries show that low carbon hydrogen will play a role in the European hydrogen market, especially if falling gas prices increase competitiveness (Durakovic et al. 2023).

While the European Union prefers renewable hydrogen as the backbone and future of the European hydrogen economy, the European Commission acknowledges low carbon hydrogen in its 2020 EU Hydrogen Strategy and states that "*while in a transition phase, appropriate support will be needed for low carbon hydrogen, this should not lead to stranded* *assets.*" (European Commission 2020). This changed in 2022, when the Commission published its REPowerEU Plan (European Commission 2022) as a response to the energy crisis caused by the Russian invasion of Ukraine. The plans under the hydrogen accelerator in REPowerEU included new and ambitious objectives for the production and import of renewable hydrogen, but without mentioning low carbon hydrogen. Simultaneously, the European Commission writes in the exploratory memorandum of the Gas and Hydrogen Markets Directive that renewable and low carbon hydrogen is expected to represent two-thirds of gaseous fuels in the energy mix in 2050 (European Commission 2021). The anticipation that low carbon hydrogen will be used up until 2050 and beyond indicates that the European Commission considers the use of low carbon hydrogen to be compatible with the climate neutrality targets. Furthermore, this implies a long-term use of low carbon hydrogen going beyond a transitional phase as mentioned in the EU Hydrogen Strategy. An overarching and coherent strategic approach specifying the transitional period for the usage of low carbon hydrogen is therefore missing.

It can be assumed that in the case of REPowerEU, low carbon hydrogen was excluded as a part of the solution for the energy crisis, as it revolves around supply shortages of natural gas, which is the main source for the production of low carbon hydrogen, besides nuclear energy. The temporarily extreme high gas prices significantly decreased cost advantages, making the role of low carbon hydrogen as a transition fuel towards renewable hydrogen debatable (Odenweller et al. 2022). But gas prices are decreasing to pre-war levels and Member States continue to integrate low carbon hydrogen into their strategic vision (European Commission 2024), for example Germany with its updated hydrogen strategy from 2023 emphasizing the role and announcing the support of different low carbon hydrogen technologies for the uptake of the hydrogen market (Bundesregierung 2023). It is therefore crucial that the European Union takes a more comprehensive strategic approach for low carbon hydrogen and outline in more detail, how low carbon hydrogen can be effectively used in the transition to renewable hydrogen, how to ensure positive impacts on climate mitigation and how to regulate imports.

3. Regulatory Framework of Low Carbon Hydrogen Production

The European Union has different types of regulatory instruments at hand to develop the overarching framework for hydrogen, notably the setting of technical production standards and targets to push the production and use. In the following, an overview of the definitions and the integration of low carbon hydrogen in the overarching target structure will be provided.

3.1 Definitions

Low carbon hydrogen is defined in the Gas and Hydrogen Markets Directive, which was adopted by the European Parliament and still requires the formal adoption by the European Council at the time this analysis was written (European Parliament 2024). Low carbon hydrogen is defined in Article 2 (11): *"'low-carbon hydrogen' means hydrogen the energy content of which is derived from non-renewable sources, which meets the greenhouse gas emission reduction threshold of 70% compared to the fossil fuel comparator for renewable fuels of non-biological origin set out in the methodology for assessing greenhouse gas emissions savings from renewable fuels of non-biological origin and from recycled carbon fuels, adopted pursuant to Article 29a(3) of Directive (EU) 2018/2001;"*. Article 9 of the Directive provides further provisions how renewable and low carbon hydrogen should be certified and proposes the introduction of additional delegated acts to specify the methodology to assess the GHG emission savings for low carbon hydrogen (see Section 4 for an in-depth examination). In combination with the delegated act under REDII that defines and sets up detailed requirements for renewable hydrogen production, precise and consistent standards separating low carbon and renewable hydrogen are set. Yet, the 70% GHG emission savings requirement of the Gas and Hydrogen Markets Directive might have to be streamlined with the EU Taxonomy, where hydrogen is considered sustainable when GHG emission savings relative to a fossil fuel comparator of 94g CO_2eq/MJ reach 73.4%, resulting in life-cycle GHG emissions lower than 3tCO_2eq/tH2 (European Commission 2021a: Section 3.10). This poses the question if there will be an adjustment or if the threshold in the EU Taxonomy stays higher and raises the requirements for sustainable financing of low carbon hydrogen, as they are above the standards set in the Gas and Hydrogen Markets Directive.

The ReFuelEU Aviation Regulation (EU) 2023/2405 includes additional definitions for low carbon hydrogen and derived fuels only intended for the aviation sector. While aviation was always covered in the calculations of the total targets and transport sector targets in the different versions of the Renewable Energy Directives, the ReFuelEU Aviation Regulation was proposed to give additional support for the complex task of decarbonizing the aviation sector. The Regulation was negotiated simultaneously with the third Renewable Energy Directive (REDIII) and likewise, the status and integration of low carbon hydrogen in the regulation turned out to be a contested issue between Member States. The adopted text of the ReFuelEU Aviation Regulation now includes provisions for the use of renewable and different forms of low carbon hydrogen and derived products, which are defined in Article 3. These definitions pose a significant extension of hydrogen types in the regulatory framework (see Table 1), adding aviation fuels based on non-fossil low carbon hydrogen into the Regulation, making the use of nuclear energy-based hydrogen eligible for EU targets.

Type	Definition	Legislation	Target Eligibility
Renewable Fuels of Non-Biological Origin / Renewable Hydrogen	'renewable fuels of non-biological origin' means liquid and gaseous fuels the energy content of which is derived from renewable sources other than biomass;	Renewable Energy Directive II (Art. 2, pt. 36)	Renewable Energy, Transport, Industry, Heating & Cooling
Low-Carbon Hydrogen	'low-carbon hydrogen' means hydrogen the energy content of which is derived from non-renewable sources, which meets the greenhouse gas emission reduction threshold of 70% compared to the fossil fuel comparator for renewable fuels of non-biological origin set out in the methodology adopted according to Article 29a(3) to Directive (EU) 2018/2001;	Gas and Hydrogen Markets Directive (Art. 2, pt. 11)	Decarbonization Reduction of REDIII Industry Sub-Target by Using Non-Fossil Low Carbon Hydrogen (Art. 22b, REDIII)
Low-Carbon Gas	'low-carbon gas' means the part of gaseous fuels in recycled carbon fuels as defined in Article 2, point (35), of Directive (EU) 2018/2001, low-carbon hydrogen and synthetic gaseous fuels the energy content of which is derived from low-carbon hydrogen, which meet the greenhouse gas emission reduction threshold of 70% compared to the fossil fuel comparator for	Gas and Hydrogen Markets Directive (Art. 2, pt. 12)	Decarbonization

	renewable fuels of non-biological origin set out in the methodology adopted according to Article 29a(3) of Directive (EU) 2018/2001;		
Low-Carbon Fuels	‘low-carbon fuels’ means recycled carbon fuels as defined in Article 2, point (35), of Directive (EU) 2018/2001, low-carbon hydrogen and synthetic gaseous and liquid fuels the energy content of which is derived from low-carbon hydrogen, which meet the greenhouse gas emission reduction threshold of 70% compared to the fossil fuel comparator for renewable fuels of non-biological origin set out in the methodology adopted according to Article 29a(3) of Directive (EU) 2018/2001;	Gas and Hydrogen Markets Directive (Art. 2, pt. 13)	Decarbonization
Synthetic Aviation Fuels	‘synthetic aviation fuels’ means aviation fuels that are ‘renewable fuels of non-biological origin’, as defined in Article 2, second paragraph, point (36), of Directive (EU) 2018/2001, which comply with the lifecycle emissions savings threshold referred to in Article 29a(1) of that Directive and are certified in compliance with Article 30 of that Directive;	ReFuelEU Aviation Regulation (Art. 3, pt. 12)	Aviation
Synthetic Low-Carbon Aviation Fuels	‘synthetic low-carbon aviation fuels’ means aviation fuels that are of non-biological origin, the energy content of which is derived from non-fossil low-carbon hydrogen, which meet lifecycle emissions savings threshold of 70 % and the methodologies for assessing such lifecycle emissions savings pursuant to relevant Union law;	ReFuelEU Aviation Regulation (Art. 3, pt. 13)	Aviation
Low-Carbon Hydrogen for Aviation	low-carbon hydrogen for aviation’ means hydrogen for use in aircraft the energy content of which is derived from non-fossil non-renewable sources, which meets a lifecycle emissions savings threshold of 70 % and the methodologies for assessing such lifecycle emissions savings pursuant to relevant Union law;	ReFuelEU Aviation Regulation (Art. 3, pt. 15)	Aviation
Renewable Hydrogen for Aviation	‘renewable hydrogen for aviation’ means hydrogen for use in aircraft that qualifies as a ‘renewable fuel of non-biological origin’, as defined in Article 2, second paragraph, point (36), of Directive (EU) 2018/2001, and which complies with the lifecycle emissions savings threshold referred to in Article 29a(1) of that Directive and is certified in compliance with Article 30 of that Directive;	ReFuelEU Aviation Regulation (Art. 3, pt. 16)	Aviation

Hydrogen for Aviation	'hydrogen for aviation' means renewable hydrogen for aviation or low-carbon hydrogen for aviation.	ReFuelEU Aviation Regulation (Art. 3, pt. 17)	Aviation
Low-Carbon Aviation Fuels	'low-carbon aviation fuels' means synthetic low-carbon aviation fuels or low-carbon hydrogen for aviation;	ReFuelEU Aviation Regulation (Art. 3, pt. 18)	Aviation

Table 1: Definitions of hydrogen types in the EU regulatory framework

3.2 Target Structure

The target structure turned out complex due to a contested legislative process. The central legislative act is the third Renewable Energy Directive (EU) 2023/2413 (REDIII), which is setting an EU-wide binding target for the share of renewable energy and sub-targets for different sectors, which have to be collectively achieved by the Member States. The Member States are obligated to propose their individual contribution in their National Energy and Climate Plans (NECPs) under the Governance Regulation (EU) 2018/1999.

Further, the REDIII formulates sector-specific targets that concern RFNBOs, which includes renewable hydrogen, but not low carbon hydrogen. In the transport sector, the share of RFNBOs and advanced biofuels should increase to 5.5% in 2030, of which at least 1% are RFNBOs. Furthermore, 42% of hydrogen used in the industry sector should be renewable by 2030 and reach 60% by 2035 (Article 22a, pt. 1). But if Member States fulfill certain requirements, it is possible to reduce the target for RFNBOs in the industry by 20% in 2030. This reduction is only possible, if the national renewable energy target of a Member State is already achieved and not more than 23% in 2030 and 20% in 2035 of the hydrogen used in the industry is fossil-based (Article 22b). This second requirement can be achieved by using non-fossil low carbon hydrogen, namely hydrogen produced by nuclear energy, as it reduces the share of fossil-based hydrogen.

After an interinstitutional agreement for the REDIII with the provisions described above was reached in the trilogue, the formal approval in the Council was postponed in May 2023 by an objection from France with more demands to strengthen the role of low carbon hydrogen, especially based on nuclear energy. The following negotiations in COREPER I and the Energy Council were finally concluded in June 2023 with another compromise. Already operating ammonia production facilities that require significantly high adaptation costs to be retrofitted to renewable hydrogen can be exempt from the sectoral targets of the industry, depending on a case by case decision from the European Commission (Recital 63). Recital 63 and Article 22b were concessions made to a group of Member States led by France, characterized by a large ammonia industry and an energy mix dominated by nuclear energy that will benefit from the additions. Nevertheless, the negotiations did not achieve that renewable and low carbon hydrogen will be treated equally in the REDIII, preventing hydrogen produced from nuclear energy to be counted directly onto the targets of the REDIII. Yet, in a circulated, but not yet official declaration with explanations to the REDIII amendments, the European Commission "*acknowledges that other sources of fossil-free energy than renewable energy contribute to reaching climate neutrality by 2050 for Member States who decide to rely on such sources of energy.*" (Messad 2023). This declaration would lead to the official recognition of nuclear energy as an equal form of energy to achieve the EUs climate objectives. Yet, which consequences and impacts this declaration will have on the hydrogen framework, as well as general climate and energy legislation is not clear yet.

4. Requirements for Low Carbon Hydrogen Production

A crucial point has not been regulated in the legislative framework yet: the factors included in the calculation of the GHG emission savings that are the basis of the definition of low carbon hydrogen. As low carbon hydrogen is already produced in the European Union and new projects are planned, a prompt clarification of the legislative framework is of utmost importance. These details will be specified by delegated acts that should be adopted 12 months after the date of entry into force of the Gas and Hydrogen Markets Directive (Art. 9, pt. 5).

The factors included in the calculation of GHG emission reductions have to be viewed in context of recent studies that analyzed the climate impacts of gas-based low carbon hydrogen and conclude that positive effects for decarbonization can only be achieved under certain conditions. Most critical is to integrate the entire value chain and lifecycle of hydrogen production in the assessment of GHG emissions, which include upstream emissions during the extraction of natural gas, midstream emissions during transmission and processing of natural gas, as well as downstream emissions during distribution and storage (Bauer et al. 2022; Pettersen et al. 2022). This should be reflected in the European regulatory framework and the delegated acts for the methodology of assessing GHG emission savings should include provisions that cover the entire lifecycle. A methodology for assessing GHG emissions savings is already provided for renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels laid out in the Commission Delegated Regulation (EU) 2023/1185 supplementing REDII. Relevant upstream, midstream and downstream emissions for renewable hydrogen and other RFNBOs, as well as recycled carbon fuels are included in the delegated act. However, special characteristics of low carbon hydrogen and its different production methods have to be addressed separately to cover all risks and ensure coherence between different types of low carbon and renewable hydrogen. To outline necessary elements in the framework for low carbon hydrogen that ensure effective impacts for climate mitigation and to identify synergies with existing legislation and regulatory gaps, the following production methods will be examined in more detail: production with natural gas and carbon capture and storage (also referred to as blue hydrogen);

production with natural gas and carbon capture and utilization, including hydrogen production by pyrolysis (also referred to as turquoise hydrogen) and production using electricity from nuclear power (also referred to as purple, red or pink hydrogen). As the description of hydrogen types with color codes can be ambiguous and fail to describe the specific characteristics of production methods, the more precise descriptions are used in this analysis.

4.1 Gas-Based Hydrogen Production with Carbon Capture and Storage

The colloquial term for hydrogen produced with fossil fuels and subsequent capturing and storing of carbon released in the process is blue hydrogen, but a more suitable way of describing the hydrogen type would be fossil low carbon hydrogen, in order to differentiate from non-fossil low carbon hydrogen based on nuclear energy. Furthermore, this analysis highlights that it is crucial to separately assess regulatory needs for carbon capture storage and carbon capture and utilization in hydrogen production, as the methods pose different challenges.

4.1.1 Existing regulatory framework

As natural gas is the basis of production, the regulatory framework needs to include methane leakages that occur during natural gas production, processing and transmission to cover upstream and midstream emissions. As methane has a higher GHG potential than CO_2, leakages pose a significant threat to climate mitigation efforts (Tollefson 2013). Commission Delegated Regulation (EU) 2023/1185 supplementing REDII for renewable hydrogen and recycled carbon fuels already provides standard values for GHG intensities of energy inputs that include upstream emissions of natural gas, which are listed at 9.7 gCO_2eq/MJ. Nevertheless, leakage rates vary among different natural gas producers and individual monitoring can provide valid data on the GHG emissions of specific suppliers, going beyond standard values. The Methane Regulation, which was adopted by the European Parliament and is awaiting the formal adoption by the Council at the time this analysis was written, provides a basis for a comprehensive reporting and monitoring of methane emissions (European Parliament 2024a). Specifically, the Methane Regulation tackles the issues of methane leakage in natural gas production and could be the opportunity for a more accurate assessment of upstream emissions of low carbon hydrogen and is already linked in the final text of the Gas and Hydrogen Markets Directive (Art.9, pt. 5). Chapter 3 of the Methane Regulation covers the methane emissions in the oil and gas sectors, with detailed monitoring and reporting requirements for operators to provide information on the emission type, location and quantities (Art. 12), a general obligation to mitigate methane emissions (Art. 13), detect and repair leakages (Art. 14), limit and report venting and flaring (Art. 15 and Art. 16) and prevent leakages of inactive wells (Art. 18). These provisions can help to provide comprehensive data of upstream and midstream emissions to be included in the assessment of GHG emissions of low carbon hydrogen. Furthermore, the Methane Regulation is of utmost importance as the EU ETS, which also covers hydrogen production, does not regulate methane-emitting activities, making a complementary regulatory approach necessary (European Commission 2021b). Nevertheless, the Methane Regulation does not introduce a price on methane emissions and only introduces mitigation measures for natural gas production in the EU, while third-country imports are only subject to the reporting, monitoring and verification obligations. Still, the provisions of the Methane Regulation could provide crucial information to prevent the use of natural gas from methane emission-intensive operations to be used for low carbon hydrogen production that would endanger positive impacts on climate mitigation.

After the supply with natural gas follows the process of hydrogen production with carbon capture, which is the key element to achieve emission reductions in comparison to conventional hydrogen production with fossil fuels. There are different technologies for hydrogen production, the most dominant being steam methane reforming, but autothermal reforming and natural gas decomposition are also available technologies. Each technology has different potentials for carbon capture, for example steam methane reforming and autothermal reforming up to 90%, while natural gas decomposition is estimated to reach a 61% capture rate and therefore not promising to reach the EUs standard for GHG emission reduction of 70% (Oni et al. 2022). However, hydrogen production and carbon capture are energy-intensive processes, so not only the achieved capture rates during production need to be considered in calculating the total GHG emission savings of low carbon hydrogen, but also the GHG emissions caused by the energy consumption during the production process, which also differ depending on the used technology (Ibid.; European Commission 2024). The use of fossil fuels to satisfy energy demand (e.g. electricity and heat production) in the capturing process of low carbon hydrogen can lead to additional indirect emissions jeopardizing compliance with the GHG emission reduction target for low carbon hydrogen.

The next crucial part in the production cycle is the transport and permanent storage of the captured carbon. Leakages in CO2-pipelines and storage sites can potentially undermine the emission savings achieved by capturing the CO_2 in the production process (Van Leeuwen et al. 2013; Alcalde et al. 2018). Research of the climate impacts of CCS indicate that annual leakage rates of 0.01% have no significant long-term negative impacts, while leakage rates up to 0.1% cause half of the climate benefits to vanish (Enting et al. 2008; Van Leeuwen et al. 2013). As a result, the overall emission savings may drop under the 70% threshold, even though the low carbon hydrogen did comply with the requirement at the time of production. While the probability of a major leakage event is estimated to be very low, uncertainties about the long-term behaviors of CO_2 in geological storage sites remain (Alcalde et al. 2018). In a scenario of major carbon leakage, the achieved effects on climate mitigation by using low carbon hydrogen are negated as GHG emission savings requirements are not fulfilled anymore. Figuratively speaking, the low carbon hydrogen could retroactively turn back to conventional fossil hydrogen (see Figure 1).

The EU Taxonomy, the EU ETS Implementing Regulation (EU) 2018/2066 on monitoring and reporting and the CCS Directive 2009/31/EC regulating the geological storage of CO_2 are already in force to address these problems. Hydrogen production, CO_2 transport and CCS fall under the EU ETS (EU ETS Directive, Annex I). Accordingly, transported and stored CO_2 from EU ETS installations is not considered emitted under the EU ETS and does not require the surrendering of allowances. Regarding specific provisions on CO_2 transport, the EU ETS Implementing Regulation (EU) 2018/2066 includes obligations to monitor and report leakages during CO_2 transport from EU ETS installations (Art. 49; Annex I, Par. 7). Furthermore, the EU Taxonomy includes provisions and requirements for CCS, including CO_2 transport, to be considered eligible for sustainable financing. Chapter

5.11 states that the transport leakage rates have to be under 0.5% of the mass of CO_2 transported (European Commission 2021a). For the injection and carbon storage, the CCS Directive includes provisions on the operation, monitoring, reporting and post-closure obligations of storage operations, that are of utmost importance to guarantee that the greenhouse gases produced during the production of low carbon hydrogen are permanently stored. Article 13 obligates the storage site operators to monitor potential irregularities and leakage to be published in a report once a year. If leakages occur, operators have to notify the competent authorities in the Member States and put corrective measures in place (Art. 16). After a storage site has been closed, operators are still responsible for monitoring and reporting (Art. 17) for at least 20 years. After 20 years a competent authority of the respective Member State can inherit the responsibilities for the storage site (Art. 18). The site operators have to establish financial security measures to fulfill the obligations set in the CCS Directive (Art. 19.) This includes the costs for surrendering EU ETS allowances in the case of leakages (Art. 19, pt. 1) and the costs for monitoring by Member States up to 30 years after the transfer of responsibilities (Art. 20).

4.1.2 Deficiencies and Recommendations

The EU regulatory framework contains provisions relevant for the production of gas-based low carbon hydrogen throughout the lifecycle. Data reporting obligations and compliance with the provisions and obligations set out in the Methane Regulation should be included in the delegated acts of the Gas and Hydrogen Markets Directive as a basis to assess the upstream emissions in the calculation of GHG emission savings. Regarding midstream emissions, provisions of the EU Taxonomy for leakages during CO_2 transport can be included as a requirement of low carbon hydrogen production operations in combination with the monitoring and reporting obligations of the EU ETS Implementing Regulation (EU) 2018/2066. Regarding downstream emission, risks for decarbonization arise when compliance with the 70% GHG emission reduction threshold is achieved, but leakages causing re-emissions occur after the production process and lead to low carbon hydrogen 'turning back' into fossil hydrogen (see Figure 1).

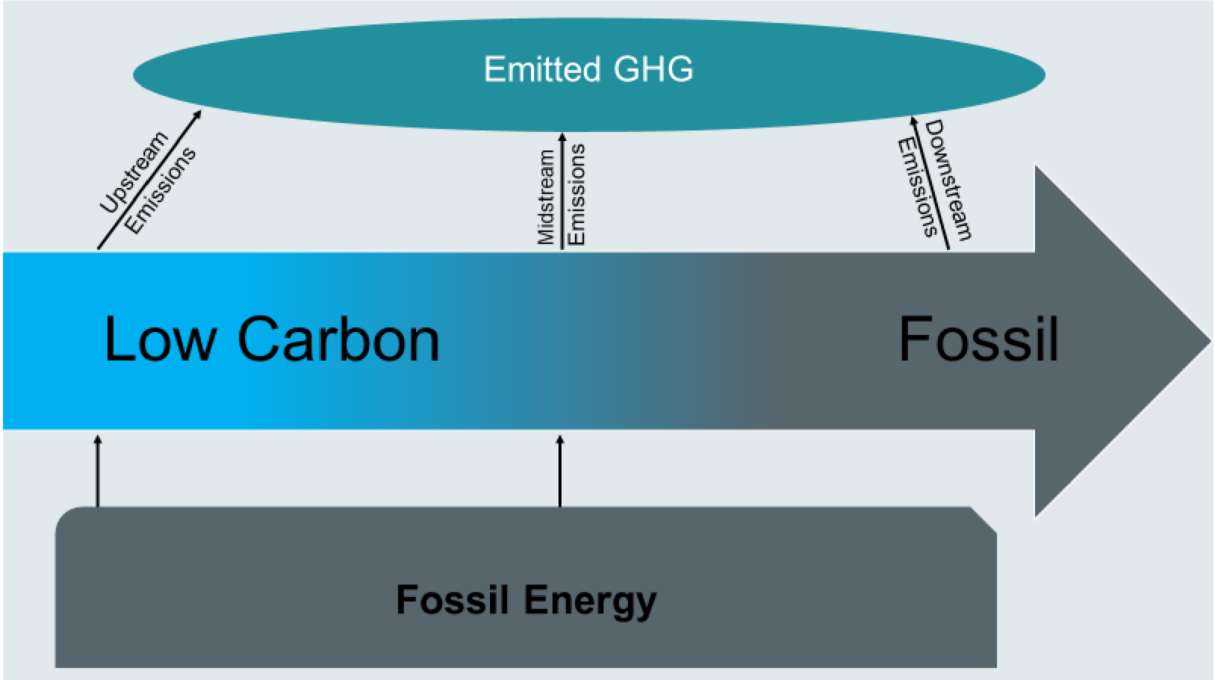

Figure 1: Consequences of Methane Leakages, Fossil Energy Use and CO_2-Leakages on Low Carbon Hydrogen, Figure based on Ramirez et al. (2020)

The provisions of the CCS Directive already provide a comprehensive basis for the regulation of downstream emissions that occur during low carbon hydrogen production. The Directive foresees that potential CO_2 storage sites are assessed regarding their suitability and it is ensured that operators comply with standards and are liable in case leakages occur. Yet, there are uncertainties, if the provisions regarding financial precautions in the case of leakages are sufficient. The necessary financial security to be provided by storage operators is partly based on the costs for EU ETS allowances that would have to be surrendered in the case of a major leakage event. The European Commission outlines that the volume of financial security for allowances can only be based on assumptions, such as estimates or probability distributions, which are associated with significant uncertainties and risks that financial securities are too low (European Commission 2011). The decision about appropriate financial security is ultimately shifted to the Member States (Wifling 2020; European Commission 2024). The unspecified rules on financial security poses the risk that storage operators are not able to compensate leakages and showcases an unresolved issue of the CCS Directive. Additionally, the premise of the financial security mechanism is effective monitoring of storage sites and detection of leakages. The proposed assessment of storage sites by the

European Commission according to a storage readiness level in the Industrial Carbon Management Strategy (European Commission 2024) needs to deliver a harmonized methodology to comprehensively consider the associated risks, e.g. different ways of leakage, leakages outside of the vicinity of the storage site, time delays of leakage events and benefits of different storage mechanisms (Liu 2012; Gholami et al. 2021; Blomberg et al. 2021). Studies indicate that mineral traps are the most permanent and stable storage mechanisms, as the CO_2 transforms into a solid form through carbon mineralization (Kim et al. 2023). The regulatory framework could specifically support storage sites and operations with potential for accelerated mineral trapping (Snæbjörnsdóttir et al. 2020; Khandoozi et al. 2023), as the use of this mechanism mitigates the risks of leakages and the associated negative effects on the climate and has additional potential to create economic advantages (Menefee and Schwartz 2024). In conclusion, a specification of the regulatory framework for tackling the remaining technological and financial risks would be beneficial to ensure effective impacts on climate mitigation are achieved, if CCS is used in such cases as low carbon hydrogen production.

4.2 Gas-Based Hydrogen Production with Carbon Capture and Utilization

Besides carbon storage, there is also the possibility to capture carbon and utilize the CO_2 in industrial processes and products. There are already hydrogen production facilities in Europe that redirect captured CO_2 to other industrial sites for the use as feedstock in their production processes. Currently, all operating gas-based low carbon hydrogen facilities in the EU use carbon capture and utilization rather than carbon storage (Hydrogen Europe 2022: p. 22). For example, in Port Jérôme (France) the captured CO_2 from hydrogen production is processed by agricultural producers, agri-food industry and for other purposes (Air Liquide 2020), while in Pernis (Netherlands) captured CO_2 is transported to local greenhouses (Digital Refining 2021). These examples show that hydrogen production with CCU is already carried out and therefore timely action is needed to include regulatory aspects surrounding the technology in the delegated acts regarding a method to assess GHG emission savings of low carbon hydrogen.

Pyrolysis is another method in development for producing gas-based low carbon hydrogen, which is not yet commercially viable (Schneider et al. 2020). Instead of gaseous CO_2, solid carbon is produced as a byproduct, which can be stored and used as a raw material for a variety of purposes (Obenaus-Emler 2022). As the use of solid carbon from pyrolysis can also be considered as a form of carbon capture and utilization, the regulatory framework might cover this production method as well.

4.2.1 Existing Regulatory Framework

As natural gas is the feedstock of the process, the regulatory framework for upstream and midstream emissions is identical to the low carbon hydrogen production process with carbon capture and storage as described in section 4.1. Therefore, the Methane Regulation, the EU Taxonomy and EU ETS Implementing Regulation on monitoring and reporting are also covering the upstream and midstream emissions for the gas-based low carbon hydrogen production using carbon capture and utilization. But the provisions for downstream emissions need to be adjusted, as the emissions are not permanently geologically stored, but the CO_2 is used as a feedstock to produce various goods, e.g. chemicals, fuels, plastics or minerals (Garcia-Garcia et al. 2020).

The challenge for a coherent framework is to guarantee that there is a positive impact on emission reductions through the use of CCU in low carbon hydrogen production. The concern is quite similar to the points made above regarding carbon capture and storage. Can the 70% GHG emission savings threshold be achieved and sustained after the production process? If the CO_2 would be re-emitted during utilization, the hydrogen can lose its property as low carbon retroactively (see Figure 2), when emissions are not reduced permanently, but only temporally shifted (Umweltbundesamt 2021).

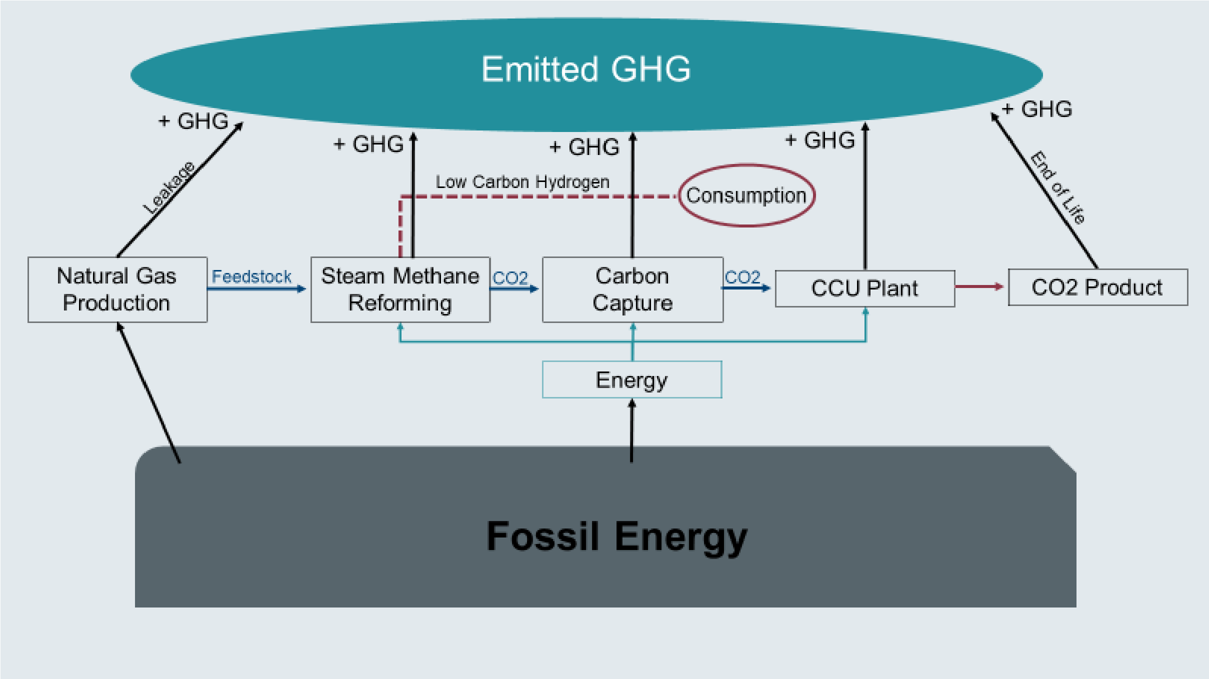

Figure 2: Example for the life-cycle of gas-based low carbon hydrogen production with CCU, modified from Ramirez et al. (2020)

The European Commission is aware of the regulatory needs and writes in the Communication on Sustainable Carbon Cycles from 2021: "*Industrial installations capturing CO_2 for utilisation or storage must also properly monitor, report and account the quantity and origin of the CO_2 they process. The EU needs an efficient system for the traceability of captured CO_2 that can track how much fossil, biogenic or atmospheric CO_2, respectively, is transported, processed, stored and potentially re-emitted to the atmosphere each year. This will allow a differentiation between industrial solutions that permanently remove carbon dioxide and those that store the carbon for shorter periods or without a net decrease of the CO_2 concentration in the atmosphere.*" (European Commission 2021c). The role of CCU and the respective CO_2 sources is further elaborated in the Industrial Carbon Management Strategy of 2024. Accordingly, after 2040, biogenic and atmospheric CO_2 should become the main source for carbon-based industrial processes and transport fuels and the replacement of fossil-based CO_2 feedstocks is described as a main benefit of CCU (European Commission 2024). But the strategy does not further indicate an exact timeframe when fossil carbon should be phased out as a source for CCU completely, leaving the option for a potential use open.

While the Industrial Carbon Management Strategy lays out the role of CCU in energy and climate policy, the current European regulatory framework, lacks comprehensive and harmonized standards for CCU and consequently for low carbon hydrogen production with CCU. In the revised EU ETS Directive (EU) 2023/959, a new provision was added, clarifying the rules for CCU by installations covered under the EU ETS, which also includes hydrogen production. Article 12 (3b) states: *"An obligation to surrender allowances shall not arise in respect of emissions of greenhouse gases which are considered to have been captured and utilised in such a way that they have become permanently chemically bound in a product so that they do not enter the atmosphere under normal use, including any normal activity taking place after the end of the life of the product."*. Further delegated acts should specify the requirements to ensure that greenhouse gases are permanently chemically bound in a product and not re-emitted. Until the adoption of the delegated acts, there are two specific provisions that include rules for the utilization of fossil CO_2: the first can be found in Article 49(1b) of the EU ETS Implementing Regulation (EU) 2018/2066 on monitoring and reporting, in which it is stated that CO_2 "*transferred out of the installation and used to produce precipitated calcium carbonate, in which the used CO_2 is chemically bound*" can be subtracted from the emissions subject to the EU ETS. This reiterates that the only possibility to utilize fossil CO_2 in a climate-neutral way is by permanent storage in a product. The second specific provision for the use of captured fossil carbon can be found in the Delegated Regulation (EU) 2023/1185 of REDII, specifying a methodology for assessing GHG emission savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels. Additional to the general provisions of the EU ETS Directive and the EU ETS Implementing Regulation, the delegated act specifically describes the possibility to use fossil CO_2 from EU ETS installations in the production of renewable fuels up until 2041 (Annex I, Art. 10a), on the condition that carbon pricing was taken into account upstream. Therefore, producers of renewable fuels are not responsible for the surrendering of allowances, but the initial installation causing fossil CO_2 emissions. This indicates that low carbon hydrogen producers have to surrender allowances if the fossil CO_2 is sold to renewable fuel producers.

4.2.2 *Deficiencies and Recommendations*

There are various deficiencies in the regulatory framework for gas-based low carbon hydrogen with CCU. According to the EU ETS Directive and the EU ETS Implementing Regulation on monitoring and reporting, only permanent storage of fossil CO_2 from EU ETS installations in a product should be exempted from the surrendering of allowances. These provisions ensure the mitigation of GHG emissions. Yet, the described delegated act of REDII enables the use of fossil CO_2 from EU ETS installations for the production of renewable liquid and gaseous transport fuels of non-biological origin, which will inevitably result in re-emissions of captured CO_2 during use and provides limited mitigation effects (Abanades et al. 2017; La Hoz Theuer and Olarte 2023). Although initial producers of the CO_2 need to fulfill surrender obligations in the EU ETS, the use of fossil CO_2 for the production of renewable fuels risks that requirements for renewable energy are watered down and that fuels containing fossil CO_2 are eligible for the achievement of the EUs renewable energy targets. Furthermore, the Industrial Carbon Management Strategy does not provide a pathway for the phase-out of fossil CO_2 use after 2040.

As outlined, the most crucial aspect to be tackled is the status of non-permanent CCU, as it poses the highest risks for effective climate mitigation through re-emissions. But the regulatory framework also needs to specify requirements for permanent CCU. A first step will be the proposals for a delegated act of the EU ETS Directive specifying requirements for permanently chemically bound greenhouse gases, to clarify under which conditions CCU can be exempted from surrendering obligations. The distinction between permanent and non-permanent storage is not trivial. A study commissioned by the European Commission on Guidelines for Lifecycle Assessment of Carbon Capture and Utilization recommends, that re-emissions expected to occur during a 500-year period should be treated as immediately emitted, i.e. non-permanent. Only if re-emissions occur later than 500 years, the delayed emissions can be ignored (Ramirez et al. 2020). Other studies also conclude that temporary storage of fossil carbon in products have marginal or no climate benefits (Müller et al. 2020) and that only permanent storage is compatible with the objectives of the Paris Agreement (De Kleijne et al. 2022).

One legislative act already provides timeframes for carbon storage in products. The Carbon Removal Certification Regulation, which was adopted by the European Parliament and is awaiting the formal adoption by the European Council by the time this analysis was written, provides a framework for permanent carbon removals and carbon storage in products (European Parliament 2024b). Yet, the Regulation only covers atmospheric and biogenic carbon sources, excluding fossil carbon and therefore the use of captured carbon from natural gas as a byproduct of hydrogen production (European Commission 2022a). Still, the provisions could be used as a blueprint to regulate carbon capture and utilization from fossil sources. The Regulation introduces separate definitions for permanent carbon removals and carbon stored in long-lasting products. Article 2, point 1(9) states that permanent carbon removals should store captured carbon for several centuries, including permanently chemically bound carbon in products, in accordance with the provisions in the EU ETS Directive. Article 2, point 1(11) introduces non-permanent carbon storage in products, which is defined as any practice or process that captures or stores carbon for at least 35 years in long-lasting products, which should be complemented by on-site monitoring of the stored carbon. Furthermore, liability mechanisms for re-emissions will be specified through delegated acts (Art. 8, pt. 3(i)).

A similar framework for fossil carbon, providing a necessary distinction between permanent and non-permanent types of carbon capture in products with monitoring and liability mechanisms is highly necessary. Yet, the 35-year timeframe for carbon storage in products of the Carbon Removal Certification Regulation seems insufficient for the permanent storage of fossil carbon. A distinct approach for fossil CCU is therefore necessary to set an appropriate timeframe that ensures climate benefits through the use of CCU. The adoption of EU ETS delegated acts on chemically bound greenhouse gases to identify eligible CCU product or product groups and a coherent implementation of the Industrial Carbon Management Strategy focused on the proper and permanent storage of fossil carbon could become a sound legal basis for low carbon hydrogen production with subsequent carbon utilization.

4.3 Hydrogen Production using Nuclear Electricity

The third possibility for the production of low carbon hydrogen is the use of nuclear power, as the generated energy has lower greenhouse gas emissions than fossil technologies (Utgikar and Thiesen 2006) and therefore was coined by the EU legislators as fossil-free and non-renewable low carbon hydrogen. The electricity from nuclear power plants (NPPs) can be used to produce low carbon hydrogen via electrolysis, as is the plan in Member States with a high share of nuclear power such as in France (Scamman and Newborough 2016). Besides the production via electrolysis, hydrogen can also be produced in NPPs utilizing the heat by high temperature electrolysis or different copper-chlorine cycles, which also differ in their environmental and climate impacts (Karaca et al. 2020).

4.3.1 Differences to Gas-Based Low Carbon Hydrogen Production

All nuclear-based production methods are fundamentally different from gas-based low carbon production and thus require a different approach to assess upstream, midstream and downstream emissions. The challenges for gas-based low carbon hydrogen production are inherent in the feedstock of the production process, the natural gas. Risks of upstream emissions caused by methane leakages and midstream and downstream emissions caused by CO_2 leakages in different forms after processing the natural gas are the factors affecting GHG emissions. For nuclear energy, the feedstock itself is not the cause of GHG emissions. The emissions are dependent on a multitude of factors and vary from case to case depending on uranium production and processing, fuel fabrication, reactor type, construction and operation, as well as the nuclear waste storage and disposal and decommissioning of the nuclear power plants (Lenzen 2008).

The inclusion of these factors to assess lifecycle emissions and GHG emission savings according to the Gas and Hydrogen Markets Directive have to be discussed. At the same time, the key challenge for hydrogen production based on nuclear energy is the coherence of the regulatory framework with renewable hydrogen production, as both production methods involve electricity production to power electrolyzers. Despite the similarities, nuclear-based hydrogen is defined under the same provisions in the Gas and Hydrogen Markets Directive as gas-based low carbon hydrogen, namely the requirement to achieve 70% GHG emission savings in comparison to fossil hydrogen. This raises some questions about the regulation of nuclear-based hydrogen and its coherence with renewable hydrogen production. Additionally, the role of nuclear-based hydrogen for EU climate and energy policy is a contested issue among Member States (see Section 3.2).

4.3.2 Coherence with Renewable Hydrogen Production

The requirements for renewable hydrogen production can be found in the Commission Delegated Regulation (EU) 2023/1184 establishing a Union methodology for the production of RFNBOs. The central requirements are additionality, temporal correlation and geographical correlation. In order to avoid that the additional demand of renewable electricity for hydrogen production needs to be supplemented by non-renewable energy sources to satisfy demand in other sectors, the requirement of additionality was introduced (Art. 5). The requirement should ensure, that only additionally built renewable energy installations are used for renewable hydrogen production. The requirements of temporal and geographical correlations are only relevant for electrolyzers that are supplied by electricity from the grid instead of a direct connection to the renewable energy installation. The temporal correlation requirement should ensure that the electricity consumption for hydrogen production coincides with the generation of renewable electricity (Art. 6). Finally, geographical correlation requires that an electrolyzer and renewable energy facility is in the same or neighboring bidding zone and further formulates rules to prevent grid congestions (Art. 7).

As nuclear electricity could be used to power electrolyzers, it needs to be assessed if the requirements for renewable hydrogen production are also necessary to apply in the case of nuclear hydrogen production. This assessment is crucial to avoid that renewable hydrogen producers, which have to adhere to strict rules, are disadvantaged by exemptions granted for nuclear-based hydrogen producers.

The first issue is the introduction of the additionality requirement for nuclear hydrogen. Just like renewable energy, nuclear energy is used to supply the electricity system and measures have to be taken to prevent negative effects of nuclear hydrogen production on electricity supply of other sectors. As the characteristics of NPPs and renewable energy installations, like wind and photovoltaic, are significantly different, the additionality requirement is difficult to be transferred. The most significant difference is, that renewable energy installations are more scalable, cheap and can be built in large numbers in a shorter amount of time. On the other side, the number of NPPs is significantly smaller, as they are large installations which require high amounts of investment and long construction times. An identical formulation of the additionality rule would implicate that only new nuclear capacities can be used for hydrogen production. In practice, this interpretation would stop any nuclear hydrogen production, as the construction of new NPPs for the sole purpose of electricity production for electrolyzers is unfeasible and therefore, other additionality requirements have to be developed to cover the peculiarities of nuclear power production. A major factor to be discussed, is if NPPs have capacities for hydrogen production after providing electricity base load for the energy system and if the additional electricity generated for hydrogen production might increase electricity prices through the necessity to dispatch more expensive generation units to satisfy the demand in the electricity system. Additionally, an assessment is necessary to rule out that increasing electricity demand for hydrogen production leads to the need of fossil power generation to substitute increasing demand, which in turn increases overall GHG emissions.

The second requirement of temporal correlation should also apply to nuclear hydrogen production. As NPPs can regulate their electricity output and are not dependent on intermittent input like in the case of solar and wind energy, the requirement of temporal correlation can be realized more easily. The third requirement of geographical correlation can be adopted as well, as the prevention of gird congestions should be ensured regardless of the source of electricity used for hydrogen production.

Besides the three requirements covering the production process itself, the rules for nuclear hydrogen production need to be coherent with the rules for renewable hydrogen production in terms of financial support. The delegated regulation on a Union methodology for the production of RFNBOs states in Article 5 (b): *"the installation generating renewable electricity has not received support in the form of operating aid or investment aid[…]"*. This should prevent operators from simultaneously receiving support for the renewable energy installation and generation, as well as the supply of electricity for renewable hydrogen production. For a coherent regulatory framework, it has to be discussed if a similar rule should be adopted for other forms of hydrogen production. Especially in the case of nuclear power, government funding is imperative for the construction and operation of nuclear power plants and state aid has officially been granted by the European Commission for nuclear energy projects (Černoch and Zapletalová 2015; Barkatullah and Ahmad 2017). The details for nuclear power need to be clarified, as NPPs can receive subsidies and other financial support in different forms, "*such as government-funded loans, governmental liability in case of plant failure, industry dumping or tax relief*" (Suna and Resch 2016) or for the decommissioning of plants, for example under Council Regulation (Euratom) 2021/100. The effect of these subsidies on the competitiveness between nuclear and renewable hydrogen needs to be assessed and the EU regulatory framework needs to tackle this issue to achieve a coherent approach for low carbon hydrogen that does not lead to disadvantages for renewable hydrogen production.

4.4 Interim Conclusion

Summarizing the key points of this chapter, Figure 3 illustrates factors to be considered in a regulatory framework for gas-based low carbon hydrogen production. It covers the upstream, midstream and downstream emissions which should be included in the delegated acts of the Gas and Hydrogen Markets Directive to guarantee the 70% greenhouse gas emission savings.

The upstream emissions include methane leakages during gas production, transport and distribution of natural gas. The monitoring and reporting of methane leakages will be covered under the Methane Regulation, the EU Taxonomy and the EU ETS Implementing Regulation on monitoring and reporting. The provisions can then be linked to the central methodology for the calculation of GHG emission savings required under the Gas and Hydrogen Markets Directive. Downstream emissions are mainly composed of CO_2 leakages occurring during transport and distribution of CO_2, leakages of storage sites or re-emissions occurring at the products end of lifetime if it is produced with captured fossil carbon. CO_2 transport and distribution, as well as storage is covered under the CCS

Directive and these provisions can be linked to the methodology of the Gas and Hydrogen Markets Directive, although uncertainties regarding the liability in case of major leakage events remain and complementary guidance and support to facilitate carbon mineralization during CCS could reduce risks of leakages. Major incoherencies and regulatory gaps can be identified in the framework for carbon capture and utilization. As low carbon hydrogen production facilities transferring the captured CO_2 for use in other industrial processes or products are already operating, the risk of re-emission is imminent, therefore the regulatory framework for the use of fossil carbon needs to be clarified as soon as possible. While the Carbon Removal Certification Regulation does not cover the utilization of fossil carbon, it can still be used as a blueprint to enhance the regulatory framework and ensure effective impacts on climate mitigation.

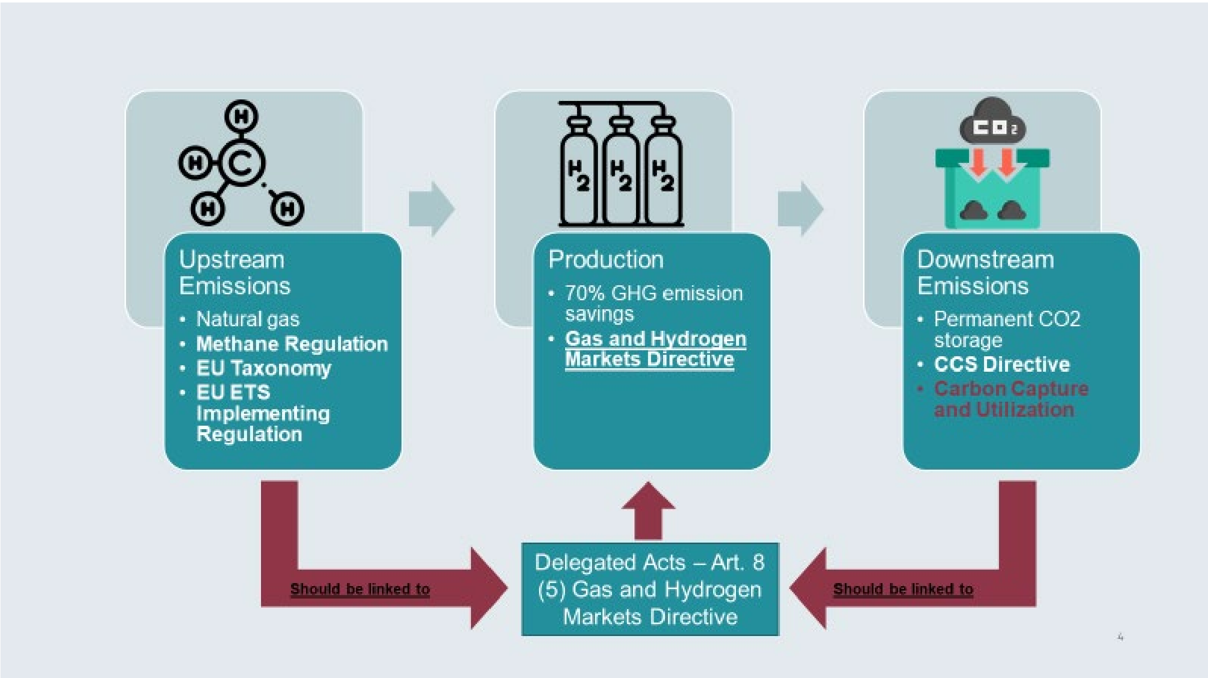

Figure 3: Overview of the Regulatory Framework of Gas-Based Low Carbon Hydrogen Production in the EU

While nuclear-based hydrogen also falls under the umbrella of low carbon hydrogen, the energy sources and production methods differ significantly. Therefore, the regulatory framework needs to be adjusted to the specific challenges of nuclear power and be coherent with renewable hydrogen production. The requirements of additionality, temporal correlation and geographical correlation were introduced for renewable hydrogen production, but the introduction of similar requirements for nuclear hydrogen production should be discussed to prevent negative impacts on the electricity system and disadvantages for renewable hydrogen production. While the rules for temporal and geographical correlation can be transferred to nuclear hydrogen production, additionality needs to be adjusted to the properties of NPPs and nuclear electricity production. An additionality rule imposing that only new capacities can be used for nuclear hydrogen production is unfeasible, therefore the requirements should be adjusted to ensure that negative impacts of the use of nuclear power for hydrogen production on electricity prices, electricity supply for other sectors and overall emission intensity of the electricity system are assessed and limited. Furthermore, equal rules for the eligibility of financial support for installations generating electricity for hydrogen production have to be developed.

In summary, the regulatory framework for gas-based low carbon hydrogen needs to be focused on capturing all points in the production lifecycle where the GHG emissions reduction target could be compromised. For nuclear-based hydrogen production, the challenges of the regulatory framework concern the prevention of disadvantages for renewable hydrogen production.

5. Import of Low Carbon Hydrogen

While domestic hydrogen production will be crucial for the emergence of the European hydrogen economy, it will be necessary to import hydrogen from outside the EU to satisfy future demand. The European Commission laid out their plans in the REPower EU Plan, estimating that an annual import of 10 million tonnes of renewable hydrogen is necessary in addition to 10 million tonnes of domestic renewable hydrogen in 2030 (European Commission 2022). To develop a coherent framework for producers inside and outside the European Union and to ensure sufficient GHG emission reductions, aligned requirements for the import of low carbon and renewable hydrogen have to be established.

Alongside detailed requirements of the EU regulatory framework described in Section 4, a comprehensive import strategy and integration of different instruments should set the long-term objectives and principles that will guide European action in the next years. As a central initiative on the EU level for coordinated purchases of hydrogen, the European Hydrogen Bank and EU Energy Platform can support the implementation of the strategy and regulatory details for the hydrogen that is imported through its mechanism. Additionally, the initiatives can facilitate standard setting in the international hydrogen market, realizing a coherent approach for hydrogen imports in the EU and among the Member States. On the basis of the points made in the former chapters it will be discussed how a strategy, regulatory framework and mechanism for the import of low carbon hydrogen can be developed that is coherent with the provisions for domestic production in the EU.

5.1 Import Strategy for Low Carbon Hydrogen

An import strategy should be developed to ensure a coherent approach to hydrogen imports in the European Union and between domestic and third-country producers, as well as between renewable and low carbon hydrogen imports. The obligation for a development of a Union strategy for imported and domestic hydrogen is introduced in REDIII (Art. 22a, pt. 3). Using the information on hydrogen development provided by the Member States in their NECPs, the European Commission is tasked with the development of a strategy assessing the domestic market, but also touches upon the issue of supply security and the development of a level playing field in the global hydrogen economy. If the strategy will include the assessment of low carbon hydrogen or only renewable hydrogen is not specified in the respective article.

Crucial for the development of a level playing field in the global hydrogen economy are certification schemes and international standards. Therefore, the strategy could be used to build a framework for assessing eligible certification schemes and standards, guaranteeing similar requirements of the production of renewable and low carbon hydrogen. Work on international certification schemes has progressed in the recent years, for example with the voluntary certification scheme CertifHy. While CertifHy was initiated by the European Commission, is financed by the EU's Clean Hydrogen Partnership and governed by a steering group including representatives from DG MOVE, DG ENER and DG CLIMA, CertifHy is not developed as a binding certification scheme for imports into the European Union. A central certification scheme might not be adopted, instead multiple schemes and approaches can be reviewed for coherence with European standards and approved for imports (for examples see German Energy Agency and World Energy Council Germany 2022; White et al. 2021). The strategy could be used to develop a framework for certification schemes, prescribing what different factors need to be included and provide a list of certification schemes that are permitted in Union territory that is updated regularly.

But a complete alignment between EU standards and certification schemes is not given, as the example of CertifHy shows (CertifHy 2022). If GHG emissions in the production chain from well to gate are equal or less than 36.4 gCO_2eq/MJ, hydrogen is certified as low carbon in the CertifHy scheme, which is significantly higher than the thresholds set in EU legislation (see Table 2).

	Fossil-Fuel Comparator	Emission Savings Rate	Emission Intensity of Low Carbon Hydrogen
Gas and Hydrogen Markets Directive	94 gCO_2eq/MJ	70%	28.2 gCO_2eq/MJ
EU Taxonomy	94 gCO_2eq/MJ	73.4% (Hydrogen) 70% (Hydrogen-Based Synthetic Fuels)	25.004 gCO_2eq/MJ 28.2 gCO_2eq/MJ
CertifHy	91 gCO_2eq/MJ	60%	36.4 gCO_2eq/MJ

Table 2: Comparison of Emission Intensity Thresholds of Low Carbon Hydrogen

A comprehensive approach to low carbon hydrogen imports in the Union strategy would be beneficial. It could include provisions on low carbon hydrogen, not to specifically support the purchase, but to ensure standards and compatibility with energy and climate goals. The Union strategy could ensure that low carbon hydrogen fulfills at least similar requirements in comparison to the EU standards and include guidelines for certification schemes that clarify the extent of deviance that is allowed. Furthermore, an assessment of the demand for imported renewable and low carbon hydrogen and supply options could give valuable information for Member States, industry, and exporting third-countries in planning production capacities and the transition of industries and sectors. Additionally, it can be an opportunity to incorporate factors, which countries should be prioritized on the basis of costs, supply security, diversification and governance (Piria et al. 2022).

5.2 Requirements for the Import of Low Carbon Hydrogen

As briefly mentioned in the last section, the rules set out in the EU regulatory framework should also be eligible for hydrogen producers in third-countries, intending to export into the European Union. If imported renewable and low carbon hydrogen with lower production standards is accepted in the EU market, it would not only lead to unfair conditions for EU producers, but also undermine the case of hydrogen as a tool for global decarbonization. The European Union should use external economic relations to support the energy transition in exporting countries and foster strict requirements to achieve emission savings. Therefore, imported renewable and low carbon hydrogen should be defined in the same way and linked to similar requirements as set in the EU regulatory framework. While different certification schemes are being developed in different parts of the world (German Energy Agency and World Energy Council Germany 2022), a complete alignment of standards in every detail is unrealistic, as it would require the EU to enforce and monitor detailed rules in the energy policy domain of third-countries. Therefore, certain key standards should be established, but some flexibilities in the production method will remain.

This is also acknowledged in Recital 3 of the REDII Delegated Regulation (EU) 2023/1184 for renewable hydrogen. It states, that the rules set out for the production of renewable hydrogen should apply inside and outside the territory of the EU. But when third-countries have different concepts, hydrogen producers can provide evidence, that these are equivalent to those of the EU. Article 9 of the delegated act lays down the option to prove compliance with the requirements of the delegated act by using international voluntary schemes that have to be recognized by the European Commission. With the delegated act, the standards for the import of renewable hydrogen are set. But such provisions do not exist for the import of low carbon hydrogen yet, even if import projects of low carbon hydrogen are planned.

To achieve a coherent approach to hydrogen imports and prevent carbon leakage, disadvantages for domestic producers and foster global decarbonization, the requirements set in the EU regulatory framework for low carbon hydrogen production, as proposed in the former section, should also be eligible for third-country producers. This is already considered in the Gas and Hydrogen Markets Directive. Article 9 (4) states, that the obligation of a 70% GHG emission saving and the respective methodology for the assessment to be specified by delegated acts, "*shall apply regardless of whether low carbon fuels are produced within the Union or are imported*". Third-countries that aspire to export low carbon hydrogen to the EU would therefore be obligated to comply with the delegated acts that assess how the emissions savings should be calculated. Furthermore, additional information about the geographic origin and feedstock type have to be made available, but demands by the European Parliament to provide specific information on the energy content derived from non-renewable sources and achieved level of GHG emission reduction was not included in the Directive (European Parliament 2023b).

This paper already addressed which issues should be covered by these delegated acts. Crucial are the integration of upstream, midstream and downstream emissions. Regarding the upstream emissions of gas-based low carbon hydrogen, Chapter 5 of the Methane Regulation covers methane leakages outside of the territory of the European Union by obligating importers located in the European Union to ensure that monitoring and reporting requirements for natural gas production are complied with in third-countries. While natural gas as a feedstock for low carbon hydrogen production in the European Union is therefore covered, the import of gas-based low carbon hydrogen itself is not subject of the Regulation. Article 2 (41) of the Methane Regulation defines importers as: *"[…] a natural or legal person who, in the course of a commercial activity, places crude oil, natural gas or coal originating from a third country on the Union market[…]"*. This poses the problem that gas-based low carbon hydrogen could be placed on the EU market, even if significant upstream emissions occurred during the production process. The proposal of the European Commission initially included that the placement of fossil energy on the Union market is covered under the Methane Regulation (European Commission 2021d). This might have led to low carbon hydrogen as a processed fossil energy product to fall under the Methane Regulation, which is not possible anymore, after a narrower definition was agreed on.

Another possibility to ensure minimum requirements for emission savings is Regulation (EU) 2023/956 establishing a Carbon Border Adjustment Mechanism. Hydrogen was included into the CBAM after a political agreement was reached in the legislative process of the regulation. The instrument introduces carbon pricing for imports of specific goods and is mirroring the EU ETS for products to be imported in the EU to prevent carbon leakage. In this context, hydrogen producers from third-countries have to provide information about the emitted CO_2 during production and under specific circumstances buy CBAM certificates to be allowed to sell their products in the EU. This could be an opportunity to indirectly enforce the rules of the Gas and Hydrogen Markets Directive and its delegated acts in third-countries aspiring to export into the EU. While methane emissions are not covered by the CBAM (European Commission – DG TAXUD 2023), it might pressure monitoring and reporting of emissions and tackle potential CO_2 leakages occurring during carbon capture and storage or utilization, as the CCS Directive does not include provisions how to engage with carbon capture and storage in third-countries. The issue is acknowledged in the Industrial Carbon Management Strategy with a prospect to recognize storage sites that comply with equivalent conditions of the EU in the future (European Commission 2024). Similarly, provisions for the use of CCU and the handling of CCU products is missing, but the European Commission recognizes in the Industrial Carbon Management Strategy, that an international framework for CCU-based fuels and carbon stored in products needs to be developed. Until then, the CBAM would give an opportunity to include CCS and CCU activities and ultimately regulate upstream, midstream and downstream emissions occurring during low carbon hydrogen production in third-countries. At the same time, details about lifecycle emissions in the hydrogen production with nuclear energy could be made mandatory for third-countries. This way, a framework for imports and coherence with domestic hydrogen production could be developed.

5.3 Integration of Low Carbon Hydrogen in the European Hydrogen Bank

The European Commission introduced the European Hydrogen Bank in March 2023, with the purpose to foster the market ramp-up of renewable hydrogen and help achieve the Unions objectives (European Commission 2023b). The focus of the European Hydrogen Bank (EHB) in its current development stage is on the domestic renewable hydrogen market of the European Union with its main instruments being auctions to award fixed premiums to renewable hydrogen producers using the Innovation Fund and the development of an EU Auction Platform, providing an opportunity for Member States to pool resources for additional auctions. While the Commission notes that the international leg of the EHB responsible for imports is still in development, some elements are already outlined. Notably, the concept of the EU Auction Platform is considered to be used for the support of international auctions for renewable hydrogen and furthermore double-sided auctions on the international scale with the EHB as an intermediary between producer and offtaker might be introduced. Additionally, the EHB is expected to assess demand of domestic and imported renewable hydrogen and provide resources for Member States and companies to coordinate bilateral and multilateral relations with third-countries in the field of hydrogen. Also, the EHB might be linked with the EU Energy Platform to safeguard the diversification of renewable hydrogen imports. The communication states that factors like political risks and quality of governance in third-countries intending to export renewable hydrogen to the EU should be considered and it is planned to develop a coordinated EU strategy for the import of renewable hydrogen (Ibid. p.10-13). In summary, the EHB and EU Energy Platform can become key initiatives to foster the import of renewable hydrogen, but which role does low carbon hydrogen play?

In the primary objective of the EHB to "*connect future supply of renewable hydrogen with our demand of 20 million tonnes of renewable hydrogen.*" (Ibid. p.2), only renewable hydrogen is included. Nuclear-based hydrogen is mentioned once as a form of fossil-free low carbon hydrogen with the potential of substituting natural gas, but not considered further. Most importantly, the main instruments laid out in the EHB communication, namely fixed premium auctions, double-sided auctions and the EU Auction Platform to pool Member State resources only relate to the import of renewable hydrogen. The exclusivity of the main instrument to renewable hydrogen is reasonable, as EU and Member States funds are funneled to renewable hydrogen producers and incentives are given in third-countries to turn to renewable instead of low carbon hydrogen, which also has more impact on the reduction of GHG emissions on a global scale and reduces the risk of carbon lock-ins.

Yet, multiple Memoranda of Understanding between the EU and third-countries are listed in the EHB communication that include propositions for low carbon hydrogen, see the MoUs between the EU and Egypt/Israel 2022 (European Commission 2022c), Japan 2022 (European Commission 2022d) and Ukraine 2023 (European Commission 2023c). Therefore, the EU is actively seeking out possibilities to import low carbon hydrogen without a strategic line of action, despite the significance of a coordinated approach to ensure low carbon hydrogen imports do not harm the achievement of national, European or global climate goals. Furthermore, the EHB communication covers additional important issues to be included in a comprehensive import strategy, like the consideration of political risks and quality of governance in third-countries intending to export hydrogen to the EU and the assessment of demand and supply of hydrogen on a global scale. The scope of these elements should be extended to low carbon hydrogen to assess factors beyond GHG emission reductions and ensure comprehensive sustainability of low carbon hydrogen imports.

The EHB and the EU Energy Platform can also play a central role in safeguarding compliance with the detailed requirements for low carbon hydrogen that is imported into the European Union. If Member States pool their demands for hydrogen imports it might allow the preferred purchase of low carbon hydrogen that complies with the demanded standards. In the same vein, as the EHB or joint purchases under the EU Energy Platform have the potential to pool demands for high volumes of hydrogen, it could have a leverage on third-country suppliers to comply with EU standards, if they want to sell into the European Union. A crucial difference to the auctions of renewable hydrogen through the EHB should be, that no premiums are given to low carbon hydrogen. The sole purpose in using the EHB mechanism or joint purchases under the EU Energy Platform for low carbon hydrogen should be the compliance with sustainability and fostering of standards that ensure GHG emission reductions and not the financial support of imports. These should be reserved for renewable hydrogen.

Finally, the linkage of the EHB with the EU Energy Platform to ensure import diversification of Member States joint purchases should also be expanded to low carbon hydrogen. As dependencies can evolve between a Member State and a third-country supplier regardless if the hydrogen is renewable or low carbon, both options should be covered in the regulatory framework to prevent strong import dependencies.

6. Recommendations

The analysis outlined the need for a more comprehensive approach of the European Union towards low carbon hydrogen. While the ultimate objective is the rapid development of a renewable hydrogen economy, low carbon hydrogen is already being produced in the EU and imports from third-countries are planned on the EU and Member State level. While key elements of the regulatory framework have been adopted, regulatory gaps and incoherencies are still present. Table 3 summarizes the different challenges and issues identified in this analysis with the recommendations how to tackle the problems to create a coherent regulatory framework for low carbon hydrogen in the European Union.

Subject	Challenge / Issue	Recommendation
Strategy	Missing approach to low carbon hydrogen in EU Hydrogen Strategy and REPowerEU	Development of a strategic approach to ensure low carbon hydrogen provides positive effects on climate mitigation; specification of the transitional phase towards renewable hydrogen
Low Carbon Hydrogen Production	Factors to be included in the methodology for assessing 70% GHG emission savings in the Gas and Hydrogen Markets Directive are not specified	Inclusion of upstream, midstream and downstream emissions occurring during the production of low carbon hydrogen in the assessment of GHG emission reductions to ensure effective impacts on climate mitigation; linkages with relevant EU legislation covering emissions in the production lifecycle
Gas-based Low Carbon Hydrogen Production	Upstream and midstream emissions occurring during gas production, processing and transport significantly impact the embedded emissions of low carbon hydrogen	Inclusion of upstream and midstream emissions in assessing GHG emission reductions by linking the Methane Regulation covering upstream emissions of gas production, as well as the EU ETS Monitoring Regulation and EU Taxonomy covering leakages during gas transport with the requirements for low carbon hydrogen production
Gas-based Hydrogen Production with Carbon Capture and Storage	Downstream emissions can occur through leakages in CO_2 storage sites, revoking GHG emission reductions achieved during low carbon hydrogen production	Introduce stringent requirements to identify storage readiness of possible sites to minimize the risk of leakages. In the case of leakages, financial security provisions need to ensure that leakages are fully compensated
Gas-based Hydrogen Production with Carbon Capture and Utilization	The regulatory framework for the utilization of carbon from fossil sources is incoherent; it is crucial to identify, if use cases of CCU	Clarify provisions about the utilization of captured fossil carbon. The non-permanent storage of fossil carbon in products should not be

	providing positive impacts for climate mitigation or re-emissions nullify the effects of carbon capture	eligible for low carbon hydrogen, as the positive effects for climate mitigation are nullified through re-emissions. Besides the relevant provisions of the EU ETS Directive, the Carbon Removal Certification can be used as a blueprint to regulate the utilization of fossil carbon by providing a foundation for the monitoring of carbon stored in products
Hydrogen Production using Nuclear Electricity	Renewable hydrogen production is subject to strict requirements to ensure hydrogen production does not have negative impacts on the electricity system and does not hamper decarbonization in other sectors. Hydrogen production using nuclear electricity might also lead to distortions in the electricity system, but similar rules have not been adopted	Develop requirements for nuclear electricity used for hydrogen production that prevent negative impacts on electricity prices, electricity supply for other sectors and decarbonization of electricity generation. Furthermore, introduce requirements for temporal and geographical correlation
Hydrogen Production using Nuclear Electricity	Renewable energy installations generating electricity for hydrogen production are not allowed to have received support in the form of operating or investment aid. So far, similar rules have not been proposed for the use of nuclear electricity	Providing a coherent framework for the eligibility of installations producing electricity for hydrogen production. The rules for financial support should be aligned to nuclear hydrogen production to prevent disadvantages for renewable hydrogen production
Import Strategy	A strategic approach to imports ensuring sustainability and security of supply is crucial. While the development of a Union strategy for imported and domestic hydrogen is included in REDIII, details about the content and integration of low carbon hydrogen are missing	Develop a strategy that ensures EU standards for imported low carbon hydrogen are complied with, sets guidelines for certification schemes, provides an assessment of demand and supply to manage the transition to a renewable hydrogen economy and prevents carbon lock-ins
European Hydrogen Bank and EU Energy Platform	The international leg of the European Hydrogen Bank manages hydrogen imports, but does not cover low carbon hydrogen.	Integrate low carbon hydrogen in the European Hydrogen Bank and use pooled demand as leverage to push third-country producers to comply with EU standards

Table 3: Recommendations for a coherent regulatory framework for low carbon hydrogen in the European Union

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Ariadne’s thread through the energy transition: The Kopernikus project Ariadne leads the way in a joint learning process with representatives from politics, business and society, exploring options for shaping the energy transition and providing scientific guidance to policy makers along the pathway towards a climate-neutral Germany.

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Who is Ariadne? In Greek mythology, Ariadne’s thread enabled the legendary hero Theseus to safely navigate the labyrinth of the Minotaur. This is the guiding principle of the Ariadne energy transition project, in which a consortium of over 25 partners is providing guidance and orientation for shaping the energy transition through excellent research as a joint learning process between science, politics, business and society.
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