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Item 6 of the provisional agenda
Enabling a hydrogen ecosystem

A comprehensive and science-based terminology, classification and taxonomy for hydrogen

Draft for discussion

Note by the Secretariat

Summary

This document, which includes feedback from the subsidiary bodies of the Committee on Sustainable Energy, is intended to facilitate a discussion on classification of hydrogen that goes beyond colours and supplements the work already presented to the Committee on "Carbon Neutrality in the ECE (United Nations Economic Commission for Europe) Region – Technology Interplay Under the Carbon Neutrality Concept."[*] It includes a number of recommendations on future work on this topic for the Committee to consider.

The Committee is invited to support continuing the policy dialogue on hydrogen projects to foster cooperation and development in the ECE region and with the global resource community. To facilitate this objective, the Committee is invited to consider several recommendations, including to:

(a) Extend the United Nations Framework Classification for Resources (UNFC) to all hydrogen projects and production technologies;

(b) Establish a task force/working group that would prepare the Specifications for the application of UNFC to Hydrogen as a matter of urgency. This task force/working group would ensure coordination with other entities that have been engaged in similar activities to avoid duplication;

(c) Develop a pilot hydrogen production project applying United Nations Resources Management System (UNRMS) principles;

(d) Establish a Guarantee of Origin for Hydrogen (GOH).

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[*] https://unece.org/sustainable-energy/cleaner-electricity-systems/technology-interplay-under-carbon-neutrality-concept

I. Executive Summary

1. At the thirtieth session of the Committee on Sustainable Energy (the Committee) an international panel informed the Committee on current and future hydrogen projects in the United Nations Economic Commission for Europe (ECE) region and identified how to scale them towards a sustainable “hydrogen ecosystem”. The panel presented a transition to carbon neutrality through deployment of hydrogen, harnessing gas infrastructure for hydrogen scaling up, sustainable hydrogen production pathways and hydrogen applications in the transport sector. Following discussion, the Committee concluded that it is necessary to agree on a comprehensive and science-based terminology and classification of different types of hydrogen that would provide a clear taxonomy, foster collaboration and investment flows, and support better understanding of the origin of hydrogen to accelerate its sustainable deployment (ECE/ENERGY/137, paragraph 58). This document has been prepared by the secretariat in response to that request.[1]

2. On current predictions, greenhouse gas (GHG) emissions are projected to rise, leading to a median global warming of 3.2°C by 2100. To avert such a scenario, a fundamental step-change in resource management and the ways we produce and transmit energy will be required. Sustainable hydrogen could be a fundamental part of the energy system in 2050 and beyond.

3. Hydrogen is already strongly present in the mainstream media. For ease of communication, colours, such as green, blue, yellow, grey and others, are used to refer to different production methods. While such colour coding influences perceptions, it conveys little information about associated carbon dioxide emissions, technical feasibility, or many other economic, environmental, social and governance consequences of hydrogen production or trade.

4. ECE member States and other stakeholders are not aligned on how to quantify the sustainability of hydrogen. To overcome this, it is proposed that they could engage via the Committee and develop a comprehensive classification for hydrogen.

5. This document aims to facilitate discussion on classification that goes beyond colours and supplements the work already presented to the Committee on “Carbon Neutrality in the UNECE Region – Technology interplay under the carbon neutrality concept.”[2] It argues for the use of the United Nations Framework Classification for Resources (UNFC) and the formative United Nations Resources Management System (UNRMS) as the tools for consistent evaluation and transparent reporting of hydrogen projects. Harnessing UNFC and UNRMS would facilitate sustainable investment decisions and support decarbonization efforts. Following the UNFC model, the document proposes a three (or more)-dimensional classification scheme that, in addition to GHG emission thresholds, contains many other socio-environmental-economic-governance criteria.

6. The work on a comprehensive hydrogen classification requires significant resources; yet it could pay many times over. Such work could serve to: (i) catalyse low-carbon and renewable hydrogen production; and (ii) facilitate its international trade.

7. The Committee is invited to support continuing the policy dialogue on hydrogen projects to foster cooperation and development in the ECE region and with the global resource community. To facilitate this objective, the Committee is invited to consider the following recommendations, namely to:

(a) **Extend UNFC to all hydrogen projects and production technologies;**

(b) To this end, **establish a task force/working group that would prepare the Specifications for the application of UNFC to Hydrogen** as a matter of urgency. This Task

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[1] Based on research and an early draft done by Merwan Olivier Pâris, Intern, Sustainable Energy Division

[2] https://unece.org/sustainable-energy/cleaner-electricity-systems/technology-interplay-under-carbon-neutrality-concept

Force would ensure coordination with other entities that have been engaged in similar activities to avoid duplication;

(c) **Develop a pilot hydrogen production project applying UNRMS principles;**

(d) Finally, establish a Guarantee of Origin for Hydrogen (GOH).

II. Introduction

8. The latest report of the Intergovernmental Panel on Climate Change's (IPCC) third working group "Climate Change 2022: Mitigation of Climate Change,"[3] issued in April 2022, stated that "without a strengthening of policies beyond those implemented by the end of 2020, GHG emissions after 2025 are projected to rise, leading to a median global warming of 3.2 [2.2 to 3.5] °C by 2100". To avoid the most destructive impacts of climate change, the report called for immediate action leading to a reduction and ultimate elimination of all anthropogenic GHG emissions.

9. Sustainable, low-carbon, and renewable hydrogen production has been proposed as one of the possible pathways to minimize climate change. The development of sustainable, low-carbon hydrogen projects could speed up the rate of decarbonization in hard-to-abate sectors, such as the metallurgy, cement, or fertilizer industries.

10. To expand hydrogen production quickly enough to avoid the most destructive impacts of climate change will be difficult given their current state of maturity, and because, to put it simply, more energy is needed to produce hydrogen than is recovered from its use; hydrogen is a carrier (vector), not a source of energy. An abundance of inexpensive energy is therefore a necessity, but such energy is not evenly distributed. Policymakers should, therefore, consider different production options, such as novel ways in harnessing excess renewable energy (power to X), production from fossil fuels through intensifying research on pyrolysis or through expanding current industrial practices in combination with Carbon Capture, Use and Storage (CCUS), or from nuclear power. Looking at the current energy balance of most countries, is seems that the hydrogen production from low-carbon energy alone will not cover the needs of energy intensive industries that produce materials critical for the energy transition.

11. Despite the potential of hydrogen projects to facilitate meeting decarbonization targets, inconsistent and/or insufficient regulatory frameworks and the lack of transparent and liquid international hydrogen markets are additional obstacles to the emergence of a strong hydrogen economy in the ECE region and on a global scale. It will be necessary to synchronize and align national regulatory frameworks and supportive mechanisms to scale up sustainable hydrogen projects[4] and promote international hydrogen trading. Adopting legal definitions and offering a clear taxonomy of hydrogen would "provide legal certainty and foster collaboration and investment flows." ECE's previous work with mineral resources and other raw materials, CCUS, geothermal and other novel renewables could provide an excellent point of departure for setting a regulatory framework for hydrogen.

12. The development of a clear hydrogen classification could improve transparency in the hydrogen market and price-setting to the benefit of all stakeholders - governments and policymakers, industry, the financial sector, and the civil society of all ECE member States.

13. A hydrogen classification could encourage investors to focus on more sustainable projects linked to Design Structure Matrix Methods for large engineering project management and Input-Output tables for national econometric analyses. Key performance indicators and consistent information would follow. In this sense, a hydrogen classification serves as a platform for the measurement of sustainable projects based on key performance indicators and consistent evaluation and communication to stakeholders. It also facilitates decision-making for governments, helps industrial stakeholders work more effectively to meet more ambitious Social-Environmental-Economic requirements which reduces overall

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[3] https://www.ipcc.ch/report/ar6/wg3/

[4] ECE-ENERGY-2021-20-ACN - role of hydrogen – Focus on the Guarantees of Origin

GHG emissions, minimizes energy and economic losses and provides support for communities.

14. Further, a hydrogen classification could take into account capital market regulations being prepared by the European Union (EU) and other ECE sub-regions. It would be based on objective and scientifically derived criteria, indicators, and methodologies.

15. The development of a clear GOH, as highlighted by the Group of Experts on Gas,[5] requires a science-based classification of hydrogen projects that includes CO_2 emissions from the entire value chain. It could include other criteria as well, such as social-environmental-economic viability, technical feasibility or estimates of the metrics that projects carry. This is what the three-dimensional approach of the UNFC and the UNRMS, which is under development, offers.

III. Similarities and differences between terminology, classification, and taxonomy

16. In the context of this document, the following terms are defined:

- **UN hydrogen taxonomy**: a classification system of hydrogen that facilitates hydrogen production and trade by defining associated GHG emissions and its other socio-economic consequences.
- **Project and programme classification**: a way to define various, interconnected projects, in this case the hydrogen production, the energy production it requires, and the hydrogen use, based on common criteria such as carbon intensity of production, other social-environmental-economic criteria, technical feasibility, or estimates of quantities that the projects and programmes carry.
- **Resource Management:** The UNFC Glossary of Common Terms defines resources as “the cumulative quantity of products that are generated and/or consumed by a project from a defined date forward and evaluated at the reference point(s) of the project. A resource has an environmental-social-economic benefit and can be renewable (e.g., solar, wind, groundwater, and natural geological hydrogen) or non-renewable. Resources can be for primary use (e.g., minerals, hydrocarbons, renewable energy, groundwater, pore space for CO_2 storage) and can be derived from or after primary use as secondary resources (e.g., anthropogenic resources, mining residues and tailings, processing or refining residues, construction wastes).” [6] UNRMS Draft Principles and requirements define Management as “the activity of controlling resources or of using or dealing with resources in a way that is effective.”[7]
- Terminology**:** a set of terms, a glossary, commonly used to describe hydrogen and its value chain. It would be produced during a classification process to the extent that the UNFC common glossary will not meet the need.

IV. Existing terminology, taxonomy and classification

A. Commonly used terminology: Colours of hydrogen

17. The currently used informal classification of hydrogen stems from its production methods. Such hydrogen classification is often used by both professionals and the public. It consists of assigning a colour to hydrogen depending on its production and source.

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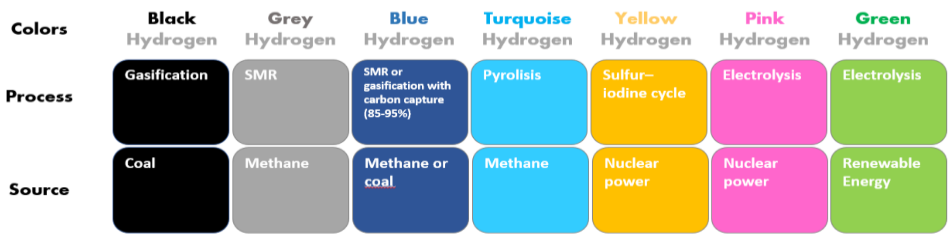
[5] https://unece.org/sites/default/files/2021-04/ECE_ENERGY_GE.8_2021_2_Final.pdf, paragraph 45.

[6] https://unece.org/sites/default/files/2022-03/ECE_ENERGY_GE.3_2022_3.pdf

[7] https://unece.org/sites/default/files/2022-04/ECE_ENERGY_GE.3_2022_6.pdf

Figure I

Simplified Cartography of Hydrogen Colours (ECE)



Colors	Black Hydrogen	Grey Hydrogen	Blue Hydrogen	Turquoise Hydrogen	Yellow Hydrogen	Pink Hydrogen	Green Hydrogen
Process	Gasification	SMR	SMR or gasification with carbon capture (85-95%)	Pyrolisis	Sulfur–iodine cycle	Electrolysis	Electrolysis
Source	Coal	Methane	Methane or coal	Methane	Nuclear power	Nuclear power	Renewable Energy

18. “*Green hydrogen*” refers to hydrogen obtained by electrolysis using renewable energy sources (including biomass).

19. “*Grey hydrogen*” represents most current hydrogen production (>90%)[8] and refers to hydrogen produced from fossil fuels, such as from natural gas by means of steam methane reforming, or from electrolysis, powered by non-renewable energy sources.

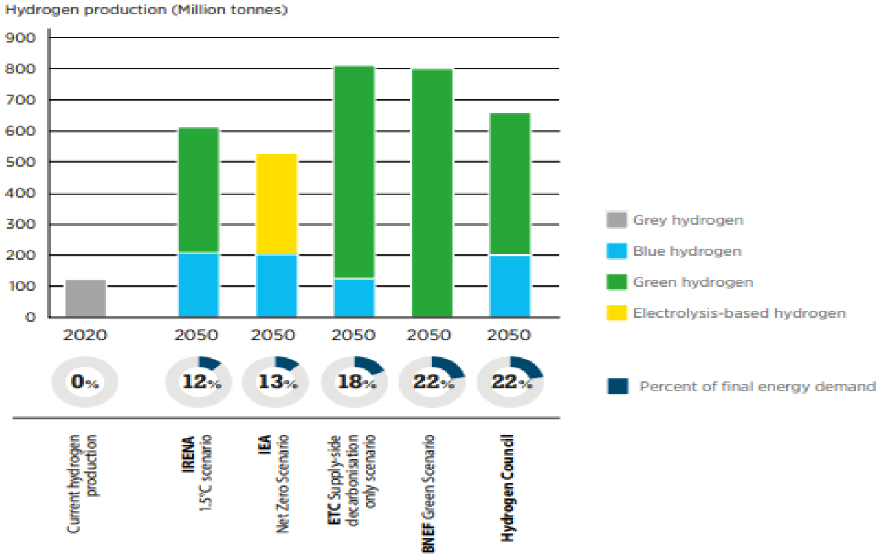
20. *“Black hydrogen*” or “*brown hydrogen*” refers to hydrogen produced using coal gasification.

21. “*Blue hydrogen”* or “*turquoise hydrogen*” refers to hydrogen produced from fossil fuels with resulting CO2 emissions reduced through CCUS. Blue hydrogen does not necessarily consider upstream methane emissions.

22. Hydrogen obtained from nuclear power plants (NPPs) is sometimes referred to as “yellow”[9] if produced via one of several thermochemical cycles (such as sulphur-iodine cycle), or as “pink” if produced electrolytically from electricity produced by NPPs.

Figure II

Forecasts of hydrogen production in 2050



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[8] https://home.kpmg/xx/en/home/insights/2020/11/the-hydrogen-trajectory.html

[9] Pink hydrogen refers to hydrogen produced through electrolysis using electricity from nuclear power plants. Yellow hydrogen refers to hydrogen produced using heat from nuclear power plants, through various thermodynamic processes. Sometimes these two terms are used interchangeably.

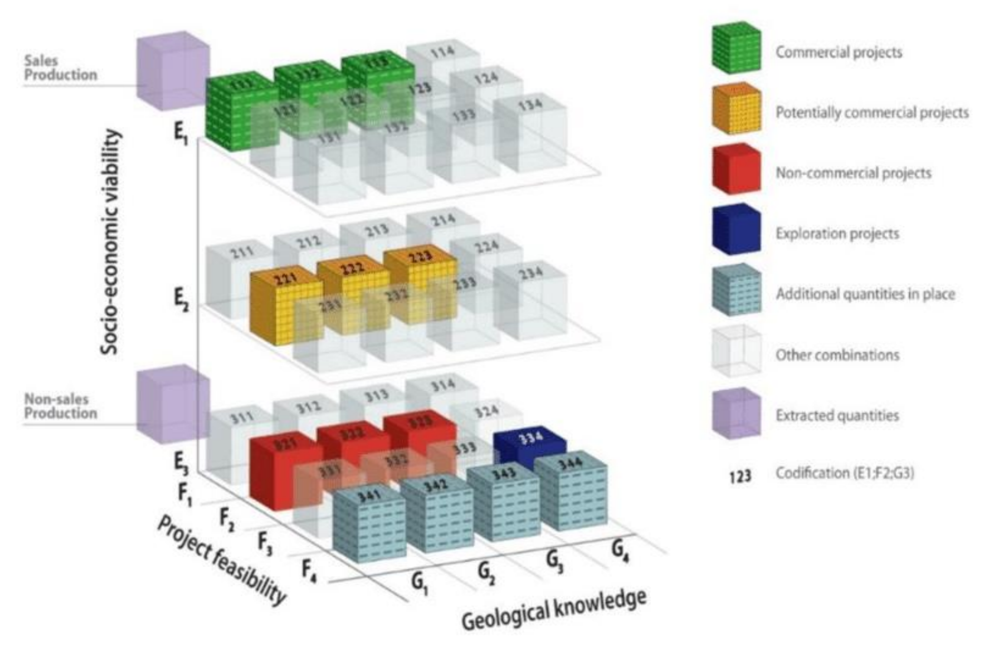
Conclusion

23. A hydrogen classification based on colour has limited value in international trade because the life cycle emissions of a given hydrogen production pathway can vary widely based on deployment-specific variables, such as upstream emissions or rate of carbon capture. The colour-based classification does not take into account the entire value chain when calculating carbon footprint and focuses only on the method of hydrogen production. Furthermore, there are often other production facilities in the value chain to which no colour code is or can be assigned.

B. ECE Classification system: UNFC

24. UNFC is a principles-based system to classify resource projects using a numerical coding system and based on the three fundamental criteria of environmental-socio-economic viability (E), technical feasibility (F), and degree of confidence in the estimate (geological certainty) (G). Combinations of these criteria create a three-dimensional system for classification.

Figure III
Three dimensional UNFC system (ECE)



25. UNFC is a classification of projects that may be extended to apply to interdependent projects. The projects are classified according to social, environmental, and economic maturity and technical feasibility. Projects carry metrics such as sources, products, costs emissions, supply chain elements and product chain elements as scalars and as time series depending on the needs of users. Estimates of the metrics are entered for the projects at the level of classification that the project finds itself with a categorisation reflecting the degree of confidence in the estimate via a range of uncertainty. A resource management matrix method is defined whereby interlinked projects may be seen in combination, e.g., a hydrogen production project may be linked to an energy production project, displaying how the quantities and timings fit together. This is a common need in anthropogenic projects where the sources may be produced while the project is ongoing.

Conclusion

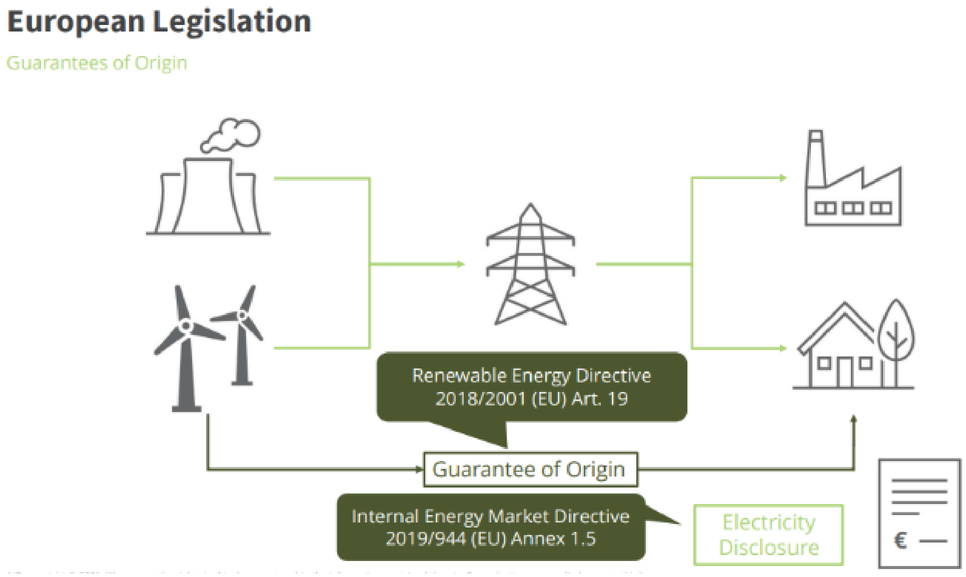
26. UNFC and UNRMS can apply to projects for hydrogen production and use. However, UNFC focuses on its elementary form in production projects. Such projects will need to be linked to cover the whole value chain and systematically include carbon emission thresholds.

UNRMS is intended to chart out framework conditions to help attain the SDGs including the reduction of GHG emissions.

C. Guarantee of Origin

Figure IV

EU Legislation regarding Guarantee of Origin (Association of Issuing Bodies (AIB))



27. The Guarantee of Origin (GO) mechanism was introduced in 2001 by the European Directive 2001/77/EC[10] to give better visibility to producers of renewable electricity. According to the Renewable Energy Directive 2018/2001/EU,[11] the GO-EU is a tracking instrument that energy suppliers can use to inform end consumers on the renewable energy share in the provided electricity, gas or heat/cold and provides information regarding its energy sources.

28. A transferable (tradable) electronic GO establishes a uniform cross-border scheme to make verifiable claims on the basis of renewable energy production throughout the region. Under a GO system there is no need to perform detailed physical tracking of the energy flows since the GO certificates may be traded independently. Therefore, when a GO system is applied, a customer does not need to buy energy directly from the renewable energy producer to claim the positive externalities of the source that the GO represents.

29. The idea of a GOH was pioneered by ECE. Namely, the Committee recognized at its thirtieth session[12] the potential role of a GO in attaining carbon neutrality and proposed to develop a GOH. Stressing the importance of operationalizing the recommendations outlined in ECE/ENERGY/2020/8, the Group of Experts on Gas at its eighth session recommended to:

(a) “*Agree on a comprehensive and science-based terminology for renewable, and low-carbon and decarbonized gases, beginning with hydrogen, and to use the agreed terminology to adapt national legal definitions, provide a clear taxonomy, and foster collaboration and investment flows*”;

(b) “*Develop a tradeable Guarantee of Origin for Hydrogen to decouple physical from commercial flows and thereby accelerate hydrogen deployment. The Group of Experts offered its assistance to member States in developing GO or similar mechanisms.*”

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[10] European Directive 2001/77/EC

[11] Renewable Energy Directive 2018/2001/Eu

[12] ECE/ENERGY/2021/20 – Attaining carbon neutrality - The role of hydrogen: Focus on Guarantees of Origin, https://unece.org/sites/default/files/2021-09/ECE_ENERGY_2021_20-ACN-role-of-hydrogen.pdf

Conclusion

30. The GO mechanism requires the development of a clear terminology to enable the adaptation of national legal definitions and provide a clear taxonomy.

D. Hydrogen Taxonomy: Origins, scopes, benefits and faced issues

31. The EU Taxonomy was established in 2020 by the Regulation (EU) 2020/852[13] of the European Parliament and of the Council on the establishment of a framework to facilitate sustainable investment. The EU Taxonomy is the first ever harmonized classification system of environmentally sustainable economic activities. It is a transparency tool guiding private investment towards environmentally sustainable activities, this way accelerating the transition to a better and cleaner future.

32. The EU Taxonomy defines three categories of economic activities:

- **Environmentally sustainable activities:** To be considered as such, activities should meet four criteria: they must substantially contribute to one of six environmental objectives defined in the Taxonomy Regulation, do no significant harm to any of the other five objectives, adhere to minimum social safeguards and comply with technical screening criteria which are elaborated in so-called delegated acts.
- **Transitional activities**: In the context of those activities substantially contributing to the climate change mitigation objective, the Taxonomy Regulation recognizes activities for which there are no technologically and economically feasible low-carbon alternatives as “transitional” “*if their greenhouse gas emissions are substantially lower than the sector or industry average, they do not hamper the development and deployment of low-carbon alternatives and they do not lead to a lock-in of assets incompatible with the objective of climate- neutrality, considering the economic lifetime of those assets.”*”. Transitional activities are therefore a subset of those environmentally sustainable economic activities that contribute substantially to the climate change mitigation objective.
- **Enabling activities**: activities directly *“enabling other activities to make a substantial contribution to one or more of the environmental objectives. Such enabling activities should not lead to a lock-in of assets that undermine long-term environmental goals, considering the economic lifetime of those assets, and should have a substantial positive environmental impact.”*

33. The first EU Taxonomy focussing on climate change mitigation and adaptation was adopted by the European Commission in June 2021 and has been in force since 1 January 2022. The EU Taxonomy Climate Delegated Act covers 13 sectors of the economy, together contributing to over 80% of the EU’s GHG emissions. According to the EU Taxonomy Climate Delegated Act[14], hydrogen can be recognized as substantially contributing to climate change mitigation if:

- Hydrogen production *“complies with the life-cycle GHG emissions savings requirement of 73.4% for hydrogen [resulting in 3tCO_2eq/tH2] and 70% for hydrogen-based synthetic fuels relative to a fossil fuel comparator of 94g CO_2e/MJ in analogy to the approach set out in Article 25(2) of in Annex V to Directive (EU) 2018/2001”.* The life cycle emission savings are to be calculated by using either of the three alternative methodologies and are to be verified. In case the manufacturing process includes carbon capture with the purpose of underground storage, the carbon transport and storage are to comply with the respective technical screening criteria defined elsewhere in the EU Taxonomy Climate delegated act.
- The power generation from renewable non-fossil hydrogen is deemed sustainable if it meets the 100 g carbon dioxide equivalent (CO_2e) per kWh threshold.

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[13] European Union Taxonomy Regulation

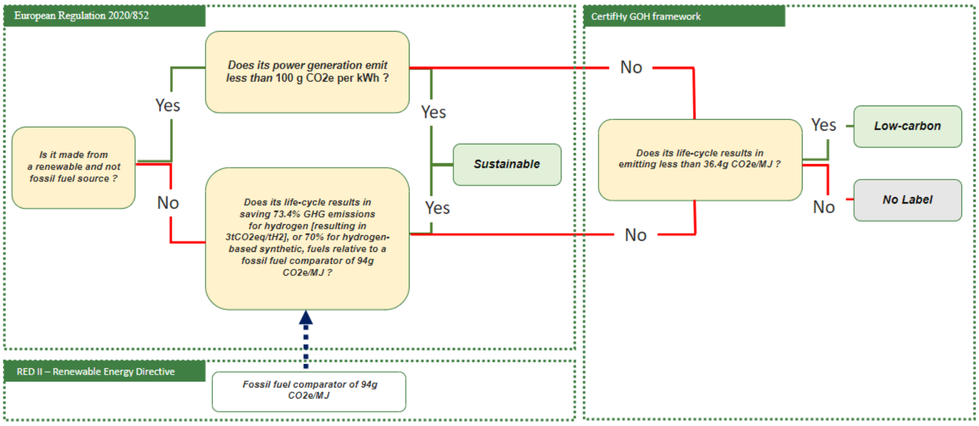
[14] European Union Taxonomy Regulation – First Delegated Act

34. A threshold for “*low-carbon hydrogen*” has been suggested by the CertifHy GOH framework. It is specified that to qualify as “*low-carbon*”, hydrogen production GHG footprint should be equal to or lower than 36.4 gCO_2eq/MJ H2.[15]

35. Finally, consistency with regard to hydrogen purity assumptions is necessary to be able to compare the life cycle emissions of various hydrogen production pathways and to enable the tradability of GOHs. A commonly recognised purity of hydrogen in the industry is 98%, with two percent remaining as impurities, such as air. In principle, most applications in hard-to-abate sectors do not require high-purity hydrogen, so these values could be significantly lower when hydrogen is destined to be used in combustion or as a reducing agent. Lower thresholds would allow the participation of all players in the GOHs market, especially those coming from industry, power-generation, metallurgy, or cement industries. Lower thresholds would also make possible the repurposing of gas infrastructure for hydrogen transportation and storage.

Figure V

The European Union’s hydrogen taxonomy diagram (ECE)



Conclusion

36. The EU Taxonomy takes a holistic view on environmental objectives and is a robust, scientific transparency tool, consistent with the EU’s sectoral policies. In case of hydrogen production, it relies on a technology neutral GHG emissions savings threshold when defining the substantial contribution of the activity to climate change mitigation. The addition of other criteria, such as economic, social and environmental considerations, could ensure that, while providing substantial contribution to climate, the activity does not significantly harm any of the other five environmental objectives.

V. Recommendations on the proposed way forward for ECE and its member States

37. This section provides a number of recommendations for the Committee to consider.

38. Development of clear and commonly accepted terminology for hydrogen could be the first step towards an ECE hydrogen project classification.

39. ECE member States could evaluate life cycle analysis guidance being developed by the International Partnership for Hydrogen in the Economy (IPHE), to inform the ECE taxonomy. IPHE comprises representatives from 22 countries and the European Commission, many of whom have collaborated for two years to develop mutually agreed upon methods of life cycle analysis of hydrogen production from renewable and fossil feedstock. A working draft was published in 2021, after review by several industry organizations, and may inform future international standards. A revised draft including additional hydrogen production

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[15] CertifHy– Developing a European Framework for the generation of guarantees of origin for green hydrogen

pathways, as well as methods of hydrogen conditioning (e.g., liquefaction) and transport (e.g., via carriers) is planned for release in 2022.

A. Extend UNFC to hydrogen as a first step towards development of a taxonomy

40. As a first step, ECE member States could request extension of UNFC to apply to hydrogen projects and integrate CO_2 emissions thresholds as one of the criteria to evaluate the environmental-socio-economic viability (E axis) of hydrogen production. Member States could additionally review the IPHE “Working Paper Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen” and align future accounting frameworks with this approach to the extent possible, to ensure consistency with other global accounting approaches.[16]

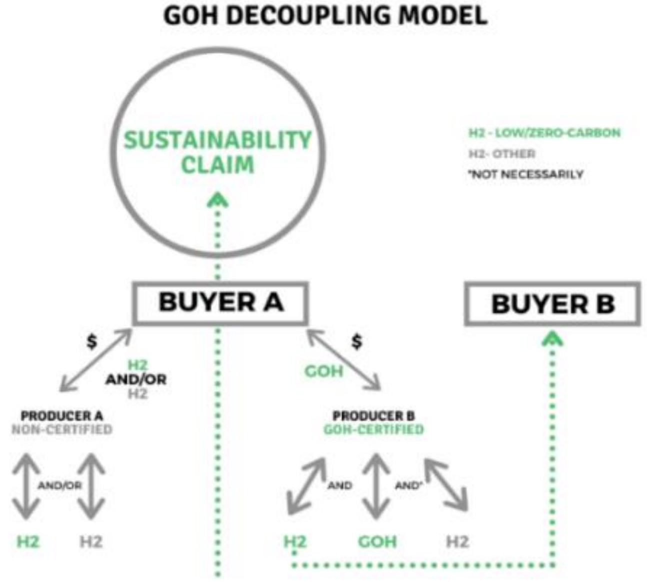
B. Creating an original ECE taxonomy including CO2 emissions thresholds and socio-economics criteria

41. An ECE taxonomy could use the EU Taxonomy Climate delegated act criteria concerning hydrogen production. ECE member States could develop their own classification system using the criteria set out by the EU Taxonomy[17] as a reference. Here various thresholds could be introduced. In addition, it could also include other economic, social and environmental considerations, as described in UNFC. In addition, it could also include other economic, social, and environmental considerations. Regulatory activities in the United States by the U.S. Securities and Exchange Commission (SEC) and by the International Financial Reporting Standards (IFRS) International Sustainability Standards Board (ISSB) could be harmonised with the EU, which would broaden the geographic reach of a future ECE taxonomy.

C. Establishing guarantee of origin for Hydrogen (GOH)

Figure VI

European Union Legislation regarding guarantee of origin (ECE)



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[16] https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021

[17] EC. (2021). Annex to the Commission Delegated Regulation (EU) .../... supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives.

42. ECE could usefully examine existing conformity assessment schemes for hydrogen and other energy production, such as existing IPHE guidance and IPHE guidance currently under development. ECE member States that are not yet a part of IPHE could consider joining and participating in the Hydrogen Production Analysis Task Force. ECE could then identify challenges, best practices, and gaps – any input that may help to design a model procedure for tradeable hydrogen certification. This model instrument should be applicable throughout the whole ECE region. To the point feasible, the GOH assessment should cover the extended cycle of hydrogen manufacturing, not just the immediate production stage.[18]

43. The revenue from selling GOH could be used to support activities on low/zero-carbon hydrogen production. Such a requirement could be used to improve the environmental credentials of the GOH issuer.

D. Developing a pilot hydrogen production project applying UNRMS

44. ECE member States should consider the implementation of UNRMS to hydrogen through a dedicated pilot project.

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[18] Recognises that the main purpose is a reduction in temperature rise, an alternative way is to force the reporting of emissions from all energy carriers, not only from hydrogen cycle.

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Annex

Technical annex for a non-technical reader

I. Hydrogen production methods

A. Hydrogen from natural gas

1. Today, natural gas is the primary source of hydrogen, accounting for about 70%. Less than 5% of hydrogen is generated from low-carbon sources. According to Bloomberg NEF 2020,[19] the levelized cost of hydrogen from natural gas without carbon capture and storage (CCS) ranges from \$0.7/kg – \$2.3/kg, and from natural gas with CCS from \$1.4/kg - \$2.9/kg. Producing hydrogen from gas involves three key methods:[20]

- Steam methane reforming (SMR)
- Partial oxidation
- Methane pyrolysis

2. Hydrogen produced from fossil fuels without CCS is typically termed “grey”, and hydrogen produced from fossil fuels with CCS is typically termed “blue”. Hydrogen produced via methane pyrolysis results in the generation of solid carbon as a by-product and is sometimes described as “turquoise”.

B. Hydrogen from coal

3. Around 25% of hydrogen currently is produced from coal. Coal gasification with CCUS typically costs \$1.9-2.4/kg hydrogen with costs as low as \$1.6/kg hydrogen in China. In terms of emissions, the addition of CCUS at a 90% capture rate can reduce the carbon intensity of this process to below 3 $kgCO_2/kg\ H_2$.[21] The given colour of hydrogen from coal is “*black*” or “*brown*.”

C. Hydrogen from renewable energy

4. One type of “*green*” hydrogen is created through the process of electrolysis where renewable electricity is used to split water into its components – oxygen and hydrogen. At present, its market share remains low – accounting for less than 5% of total hydrogen production – and, according to the International Energy Agency, there is about 300MW of electrolyser capacity installed worldwide. To meet the current objectives of the EU, this would need to increase to 6GW by 2024 and to 40GW by 2030. Proton-exchange membrane, alkaline, or solid-oxide electrolysers can be manufactured and deployed to accomplish this objective.[22]

D. Hydrogen from biomass

5. Hydrogen from biomass, or biohydrogen, is produced through living micro-organisms from lignocellulosic biomass based on renewable resources. It is currently in a pilot-scale demonstration stage with few applications entering the commercialization phase. It is often seen as a form of green hydrogen.[23]

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[19] Hydrogen Economy Outlook Key messages March 30, 2020 - BloombergNEF

[20] UNECE – Technology Brief - Hydrogen

[21] UNECE – Technology Brief – Hydrogen - 2021

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E. Hydrogen from nuclear power

6. Some countries may choose to pursue nuclear power with a view that it can play an important role in their energy mix as a viable decarbonization option. Other countries have decided not to use nuclear power for a variety of reasons, some because of their endowment of natural resources and others because of their concerns relating to safety and waste. Nuclear power is considered by some countries an important source of low-carbon electricity and heat. In the future, for those countries that choose to do so, nuclear power can also be used to produce what is considered “pink” or “yellow” hydrogen via several low-carbon processes. About 100-130 new nuclear reactors of the scale of Hinkley Point C could provide sufficient electricity to meet the projected hydrogen demand of 650 million tonnes/year in 2050. This implies a doubling of the world’s installed nuclear capacity. Small modular nuclear reactors are an alternative to the designs of established nuclear units. There are a number of research and development (R&D) projects that intend to offer nuclear power generation as a distributed energy source, down to the 15 MW scale and capable of supplying electricity to 10,000 houses. Electrolysers can be integrated with existing nuclear power plants, such that the nuclear plants supply electricity and/or heat to the electrolyser. Such hybrid energy systems can increase the viability of nuclear plants by serving as an additional revenue stream for the plant. The hydrogen produced can then be utilized to decarbonize regional industries.

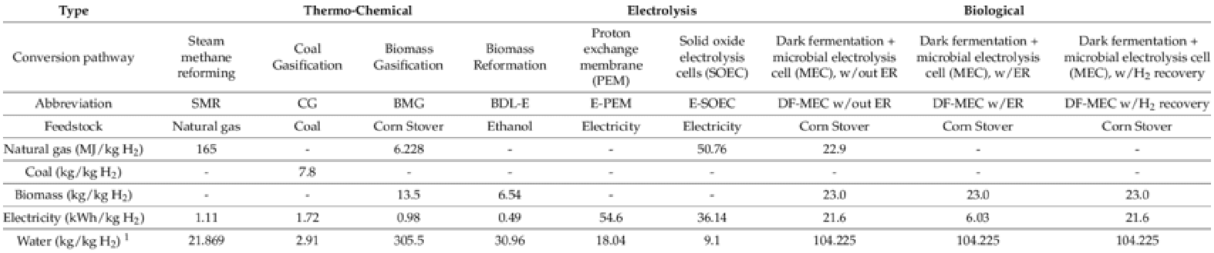
7. The given colour for this sort of hydrogen production is “*yellow*” or “*pink*.”

F. Hydrogen production energy cost

8. Hydrogen production may require various sources of electricity and energy supply depending on the production technology.

- **Electrolysis:** An ideally efficient electrolysis system would require 39 kWh of electricity to produce 1 kg of hydrogen. However, the devices commonly found in operation for this process are less efficient and have an effective electrical efficiency of 70-80%. A typical operational figure is about 50 kWh[24] per kg of hydrogen.
- **Methane pyrolysis**: Producing 1 kg of hydrogen through methane pyrolysis requires about 5 kWh[25] of electricity for process heat.
- **Steam Methane Reforming:** Producing 1 kg of hydrogen through Steam Methane Reforming (SMR) requires around 165 MJ of heat (or 45 kWh of energy in electrical units, slightly less that what electrolysis requires).

9. The table below compares costs of different hydrogen production methods.



Type	Thermo-Chemical				Electrolysis		Biological		
Conversion pathway	Steam methane reforming	Coal Gasification	Biomass Gasification	Biomass Reformation	Proton exchange membrane (PEM)	Solid oxide electrolysis cells (SOEC)	Dark fermentation + microbial electrolysis cell (MEC), w/out ER	Dark fermentation + microbial electrolysis cell (MEC), w/ER	Dark fermentation + microbial electrolysis cell (MEC), w/H_2 recovery
Abbreviation	SMR	CG	BMG	BDL-E	E-PEM	E-SOEC	DF-MEC w/out ER	DF-MEC w/ER	DF-MEC w/H_2 recovery
Feedstock	Natural gas	Coal	Corn Stover	Ethanol	Electricity	Electricity	Corn Stover	Corn Stover	Corn Stover
Natural gas (MJ/kg H_2)	165	-	6.228	-	-	50.76	22.9	-	-
Coal (kg/kg H_2)	-	7.8	-	-	-	-	-	-	-
Biomass (kg/kg H_2)	-	-	13.5	6.54	-	-	23.0	23.0	23.0
Electricity (kWh/kg H_2)	1.11	1.72	0.98	0.49	54.6	36.14	21.6	6.03	21.6
Water (kg/kg H_2) [1]	21.869	2.91	305.5	30.96	18.04	9.1	104.225	104.225	104.225

10. To put these figures in a new perspective, 1 kg of hydrogen contains 33.33 kWh of usable energy, whereas petrol and diesel only hold about 12 kWh/kg.[26]

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[24] Werner Zittel; Reinhold Wurster (1996-07-08). "Chapter 3: Production of Hydrogen. Part 4: Production from electricity by means of electrolysis". *HyWeb: Knowledge - Hydrogen in the Energy Sector*. Ludwig-Bölkow-Systemtechnik GmbH.

[25] *Karlsruhe Institute of Technology. "Hydrogen from methane without CO2 emissions"*

[26] http://www.h2data.de/

II. European Union hydrogen taxonomy

11. In April 2021, the European Commission published the first delegated Act to the Taxonomy Regulation which directly addresses hydrogen. According to this delegated Act[27], hydrogen can be recognized as sustainable if:

- Hydrogen production "*complies with the life-cycle GHG emissions savings requirement of 73.4% for hydrogen [resulting in 3tCO_2eq/tH2] and 70% for hydrogen-based synthetic fuels relative to a fossil fuel comparator of 94g CO_2e/MJ*"

- The power generation from renewable non-fossil hydrogen is deemed sustainable if it meets the 100 g CO_2eq per kWh threshold.

- The draft Annex I sets out additional requirements concerning manufacturing activities for carbon capture and storage: the CO_2 transported from the installation where it is captured to the injection point does not lead to CO_2 leakages above 0.5% of the mass of CO_2 transported (paragraph 5.11); Appropriate leak detection systems are applied; and a monitoring plan is in place, with the report verified by an independent third party (paragraph 5.11).

12. Additionally, as part of the European Green Deal[28], both complementary documents "*A hydrogen strategy for a climate-neutral Europe*"[29] and *"An EU Strategy for Energy System Integration"*[30] identify hydrogen and other synthetic fuels as crucial to reach decarbonization. "A hydrogen strategy for a climate-neutral Europe," for example, outlines its own hydrogen classification*:*

- **Electricity-based hydrogen** refers to hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), regardless of the electricity source. The full life cycle GHG emissions of the production of electricity-based hydrogen depends on how the electricity is produced

- **Renewable hydrogen** is hydrogen produced through the electrolysis of water where the electricity used comes from renewable sources. The full life cycle GHG emissions of the production of renewable hydrogen are close to zero. Renewable hydrogen may also be produced through the reforming of biogas (instead of natural gas) or biochemical conversion of biomass, if in compliance with sustainability requirements.

- **Fossil-based hydrogen** refers to hydrogen produced through a variety of processes using fossil fuels as feedstock, mainly through the reforming of natural gas or the gasification of coal. This represents the majority of hydrogen produced today. The life cycle GHG emissions of the production of fossil-based hydrogen are significantly higher than that of production using renewable electricity.

- **Fossil-based hydrogen with carbon capture** is a subset of fossil-based hydrogen, but where GHGs emitted as part of the hydrogen production process are captured. The GHG emissions of the production of fossil-based hydrogen with carbon capture or pyrolysis are lower than for fossil-fuel based hydrogen, but the variable effectiveness of the GHG capture (maximum 90%) needs to be considered.

- **Low-carbon hydrogen** includes fossil-based hydrogen with carbon capture and electricity-based hydrogen, with significantly reduced full life cycle GHG emissions compared to the average existing hydrogen full life cycle GHGs. It is noteworthy to mention that the CertifHy GOH framework specified that to qualify as "low-carbon", hydrogen production GHG footprint should be equal to or lower than 36.4 gCO_2eq/MJ H2. This threshold is, however, temporary.

- Hydrogen-derived synthetic fuels refer to a variety of gaseous and liquid fuels based on hydrogen and carbon. For synthetic fuels to be considered renewable, the hydrogen

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[27] European Union Taxonomy Regulation – First Delegated Act

[28] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

[29] COM(2020) 301 final

[30] COM(2020) 299 final

part of the synthetic gas should be renewable. Synthetic fuels include, for instance, synthetic kerosene in aviation, synthetic diesel for cars, and various molecules used in the production of chemicals and fertilizers. Synthetic fuels can be associated with quite different levels of GHGs depending on the feedstock and process used. In terms of air pollution, burning synthetic fuels produces similar levels of air pollutant emissions as fossil fuels.

III. UNFC

13. In September 2017, at its twenty-sixth session, the Committee on Sustainable Energy approved the publication of an updated UNFC.[31] UNFC is a resource project-based and principles-based classification system for defining the environmental-socio-economic viability and technical feasibility of projects to develop resources. UNFC provides a consistent framework to describe the level of confidence of the future quantities produced by the project. These projects range from early conceptual studies through to a fully developed project that is producing and reflecting standard value chain management principles.

14. UNFC is a principles-based system in which the products of a resource project are classified based on the three fundamental criteria of environmental-socio-economic viability (E), technical feasibility (F), and degree of confidence in the estimate (G), using a numerical coding system. Combinations of these criteria create a three-dimensional system. Categories (e.g. E1, E2, E3) include, in some cases, Sub-categories (e.g. E1.1). The first set of Categories (the E axis) designates the degree of favourability of environmental-socio-economic conditions in establishing the viability of the project, including consideration of market prices and relevant legal, regulatory, social, environmental and contractual conditions. The second set (the F axis) designates the maturity of technology, studies and commitments necessary to implement the project. The third set of Categories (the G axis) designates the degree of confidence in the estimate of the quantities of products expected from the project. The Categories and Sub-categories are the building blocks of the system and are combined in the form of "*Classes*".

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[31] United Nations Framework Classification for Resources – Update 2019