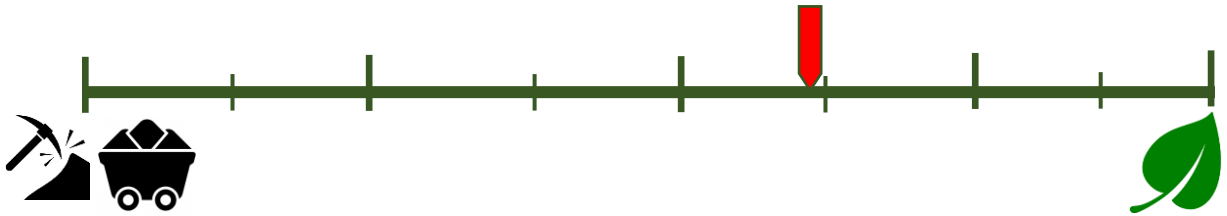
IDENTIFYING THE DIFFERENCES
in between
GREEN, LOW-CARBON and RENEWABLE HYDROGEN

- How much Green is "Green Hydrogen" you are buying?
- Is Green Hydrogen is perplexed with Renewable Hydrogen?
- Is Green Hydrogen is understood the same by various countries and organisations?
- How much Low-carbon Hydrogen is actually low in carbon?
- Which Hydrogen - Low Carbon H_2 or Clean H_2 we actually have in mind?

How much Green is „Green H_2" you are bying?



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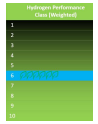
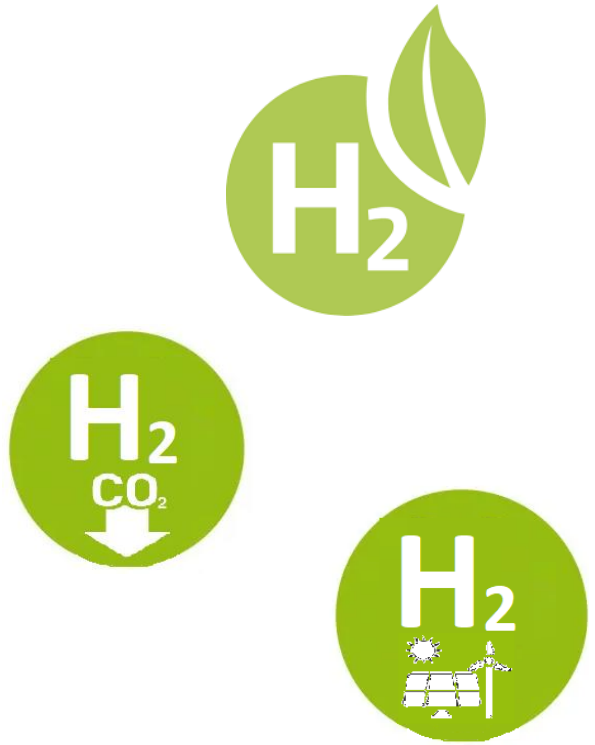
Green, Low Carbon and Renewable Hydrogen
Hydrogen Performance Class

ANNEX

- Why it is important to mark the differences in between Green, Renewable Hydrogen, Low Carbon and Clean Hydrogen?
- Green Hydrogen, GH_2;
- Renewable Hydrogen, REH_2;
- Low Carbon Hydrogen, LCH_2;
- Clean Hydrogen, CH_2;
- Other types of Hydrogen;
- Standardisation and regulation of GH_2, LCH_2, REH_2 and CH_2;
- Hydrogen Performance Class (HPC); 
- Discussion;



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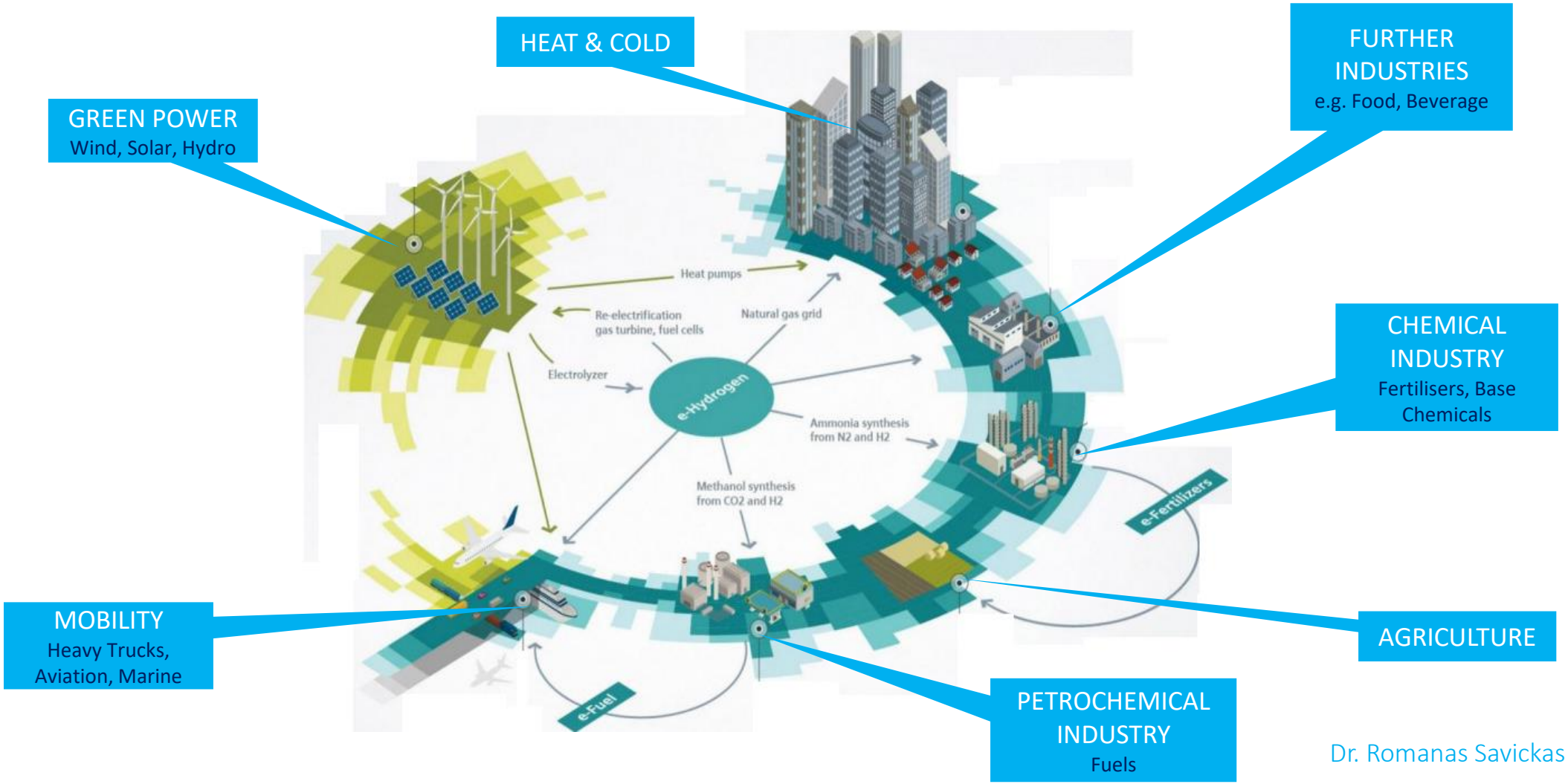
- Hydrogen is essential to implement the Paris Agreement and to reach carbon neutrality by 2050.



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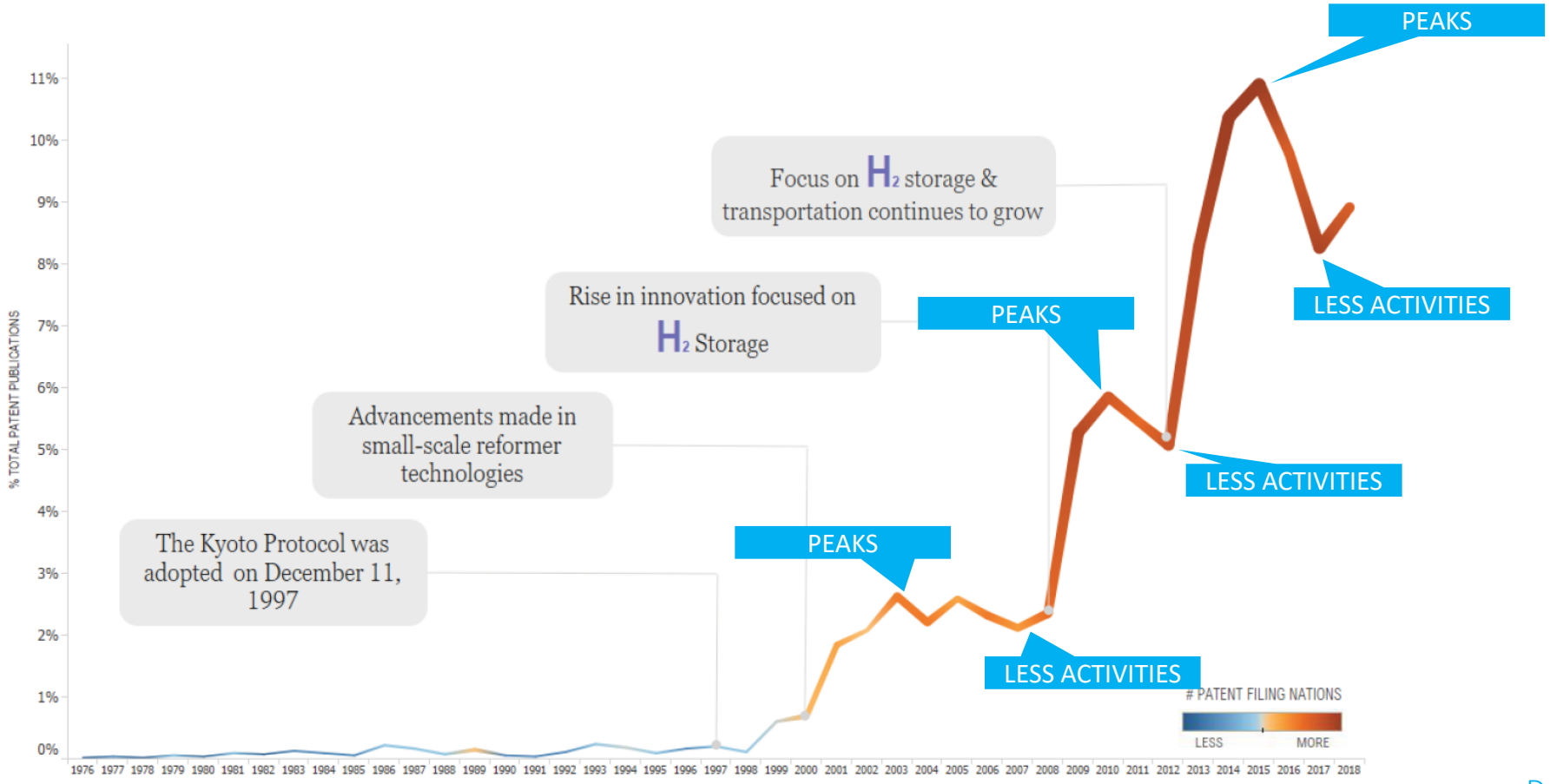
The timeline of Patent publication in the Hydrogen fuel space. The number of filling organisations is represented by the colour and thickness of the sparkline



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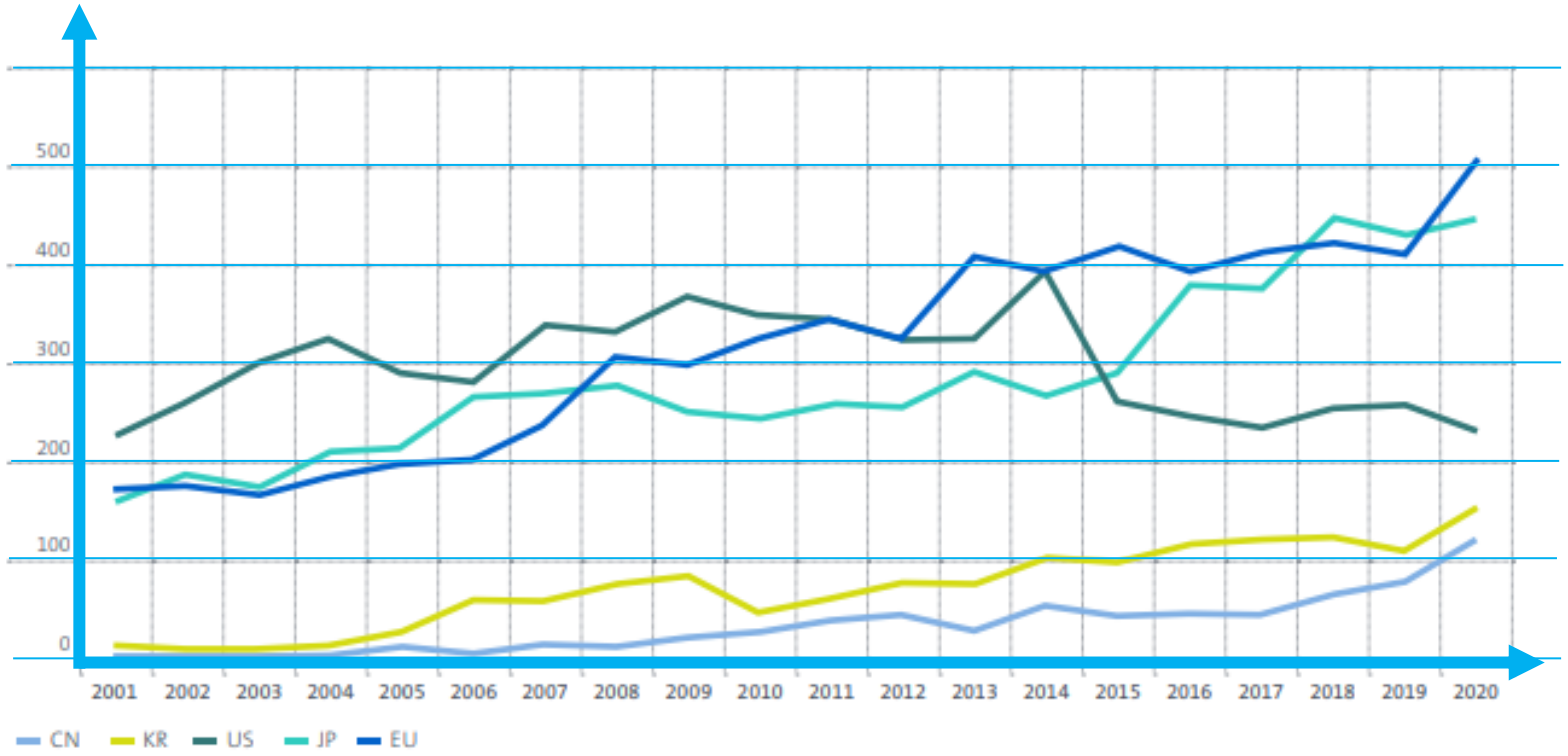
The number of hydrogen-related IPFs (International Patent Families) initiated in each region since 2001:



Pic. International patenting trends in gaseous hydrogen storage, ammonia production, methanol production and alternative hydrogen-based fuels.

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Renewable Energy for remote microgrid settlements

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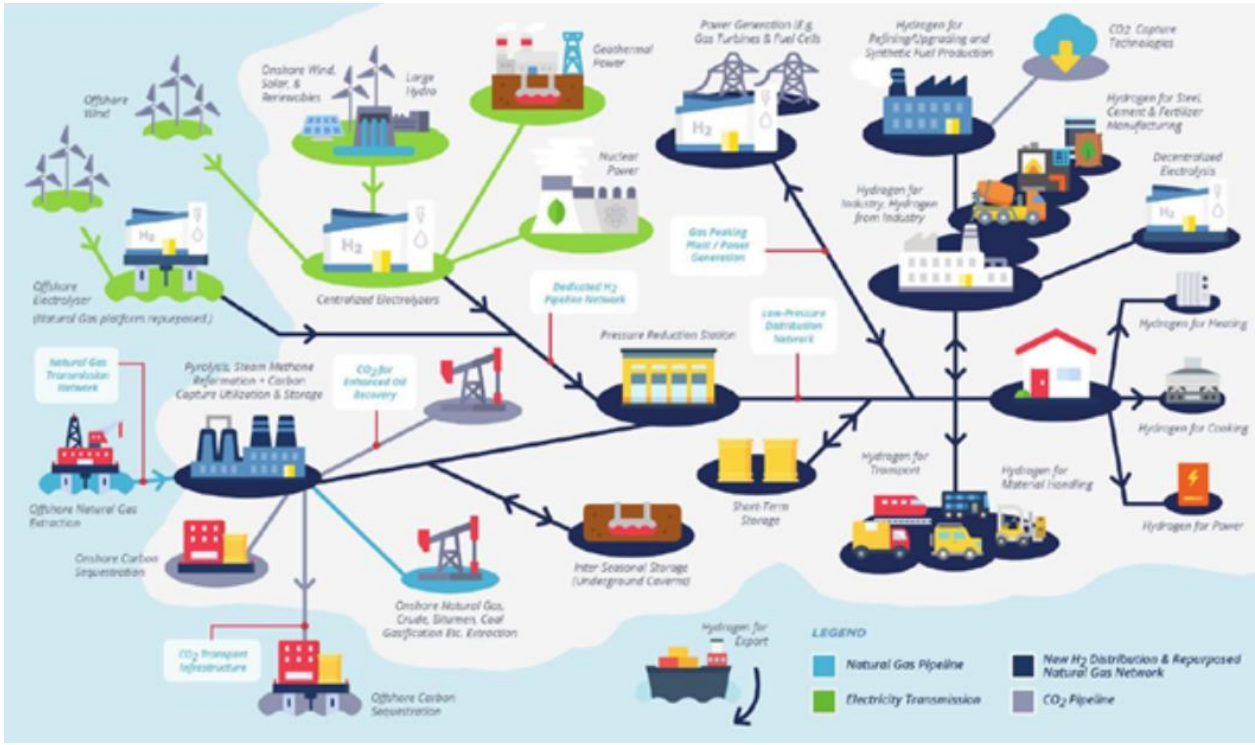
HYDROGEN AS A PART OF INTEGRATED ENERGY SYSTEMS



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HYDROGEN DEFINITION

There are various definitions of Hydrogen, but some of them are used in the same context

- Green Hydrogen;
- Renewable Hydrogen;
- Low Carbon Hydrogen;
- Clean Hydrogen;
- Low-Emissions hydrogen (IPCC);
- Low-GHG emissions hydrogen (IPCC);
- Electricity-based hydrogen (EC);
- Fossil-based hydrogen (EC);
- Fossil-based hydrogen with carbon capture (EC);
- Hydrogen-derived synthetic fuels (EC);
- Etc.

Hydrogen from microalgae

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Different schemes could include additional environmental, social and governance (ESG), UN SDG criteria

SUSTAINABLE DEVELOPMENT GOALS

Green, Low Carbon and Renewable Hydrogen
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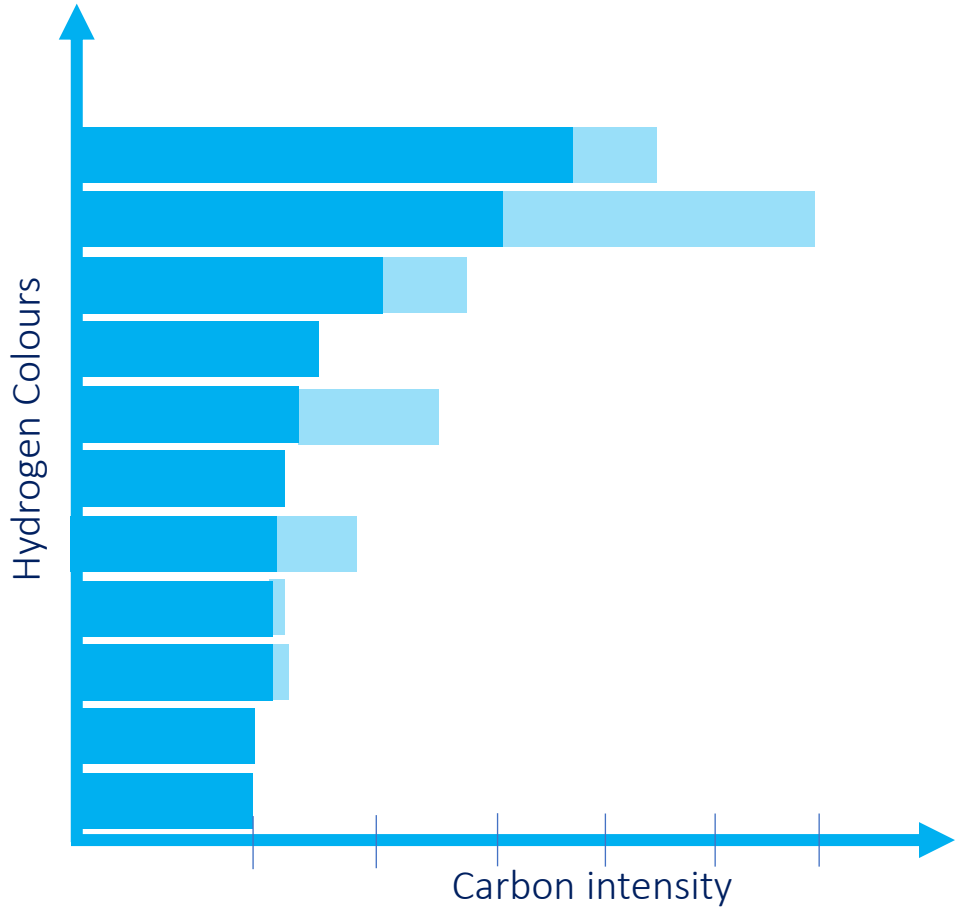
Carbon intensity of Different Hydrogen Colours

No	Hydrogen	Carbon intensity, Min	Carbon intensity, Max
1	Yellow	28.6	32
2	Black	21.8	51.9
3	Grey	10.9	18.4
4	Turquoise	4.4	
5	Blue	2.6	16.2
6	Purple	2.0	
7	Green	0.6	6.6
8	Pink	0.4	2.0
9	Red	0.3	1.8
10	Aqua (oil sands)	0	
11	White	0	



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GREEN HYDROGEN

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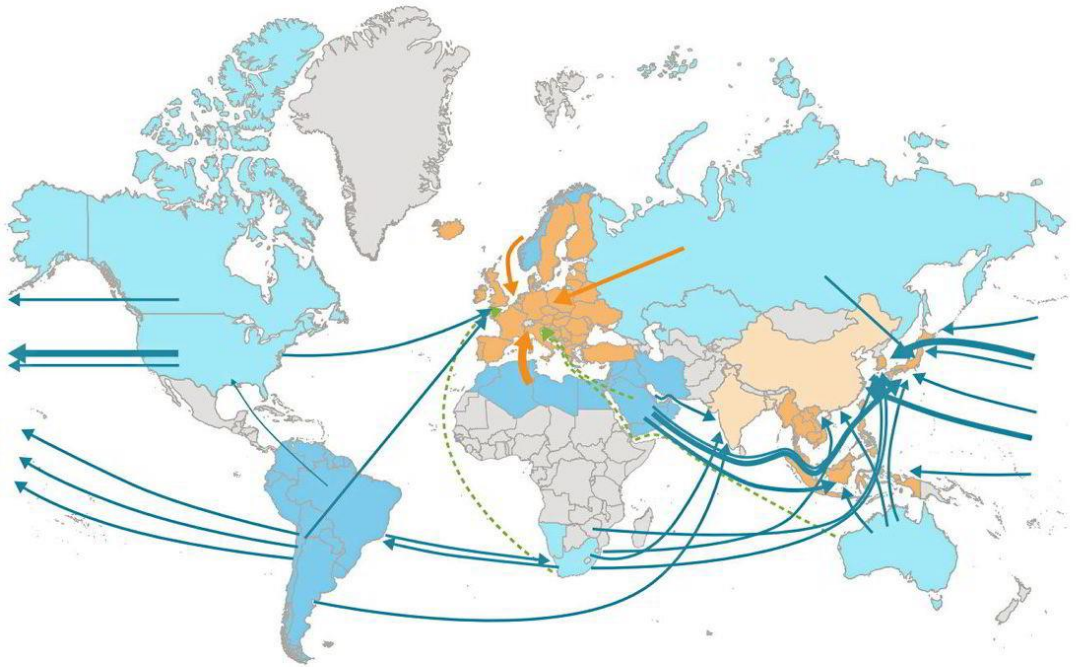
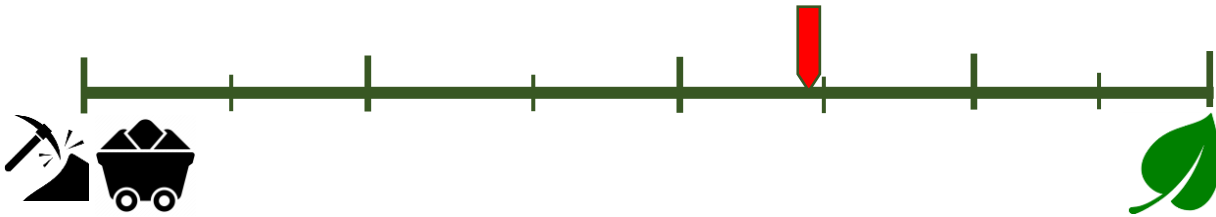
GREEN HYDROGEN

- Various definitions of Green Hydrogen are used globally.
- They differ in Power Generation, GHG emissions and other indicators.
- The global Hydrogen ecosystem is getting higher maturity level with Global Hydrogen Trade picture and import/export countries.
- The Global Hydrogen Trade is possible only having a consensus regarding G/C/L Hydrogen definition and internationally approved G/C/L Hydrogen Standards.
- How much Green is the "Green Hydrogen" you are bying?



How much Green is „Green H_2" you are bying?



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Green, Low Carbon and Renewable Hydrogen
Hydrogen Performance Class

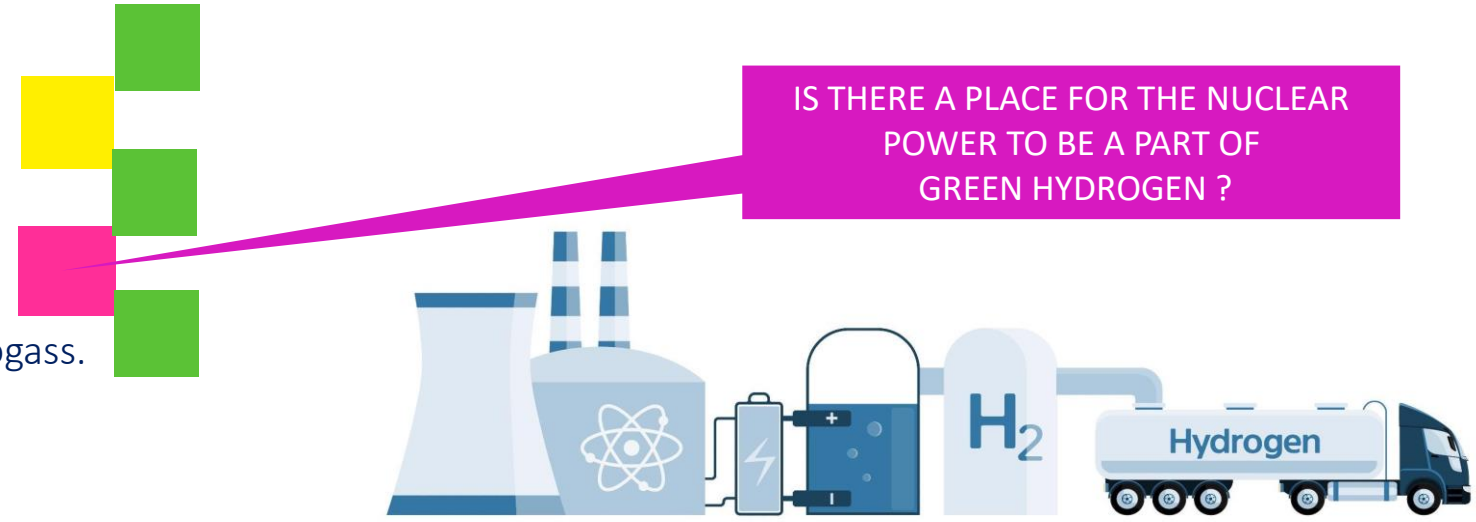
GREEN HYDROGEN DEFINITION, Example

- Green hydrogen is hydrogen generated by renewable energy or from low-carbon power*.
- Green hydrogen has significantly lower carbon emissions than grey hydrogen, which is produced by steam reforming of natural gas.

*Low-carbon power is defined as electricity produced with substantially lower greenhouse gas emissions than conventional fossil fuel power generation. The term largely excludes conventional fossil fuel plant sources, and is only used to describe a particular subset of operating fossil fuel power systems, specifically, those that are successfully coupled with a flue gas carbon capture and storage (CCS) system.

*Low carbon power generation sources include:

- Wind power,
- Solar power,
- Hydropower,
- Nuclear power,
- Biomass and Biogass.



Green, Low Carbon and Renewable Hydrogen
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GREEN /RENEWABLE HYDROGEN DEFINITION, Example

- The European Commission's new Delegated Act (2023 Feb) sets out definitions for what constitutes renewable hydrogen and its derivatives and does not actually allow Green H_2 to be produced using nuclear power.
- The emission intensity of electricity in a bidding zone is lower than 18 grams of CO_2-equivalent (CO_2e) per megajoule, which is equivalent to 64.8gCO_2e/kWh.
- Producers can use grid electricity to produce hydrogen, but only when providing proof that they have bought renewable energy from existing or new projects through an electronic certification scheme*, such as guarantees of origin*.
- The EU has not allowed nuclear power to be used to generate Renewable Hydrogen. And the word "nuclear" is not even mentioned in the document.
- 2023 Feb France and eight other EU member states organisations wrote to the European Commission to call for "low-carbon" hydrogen — made from nuclear energy or possibly fossil gas with carbon capture and storage (ie, blue H_2) to be classed as renewable — with Germany and others fiercely opposed to the idea.
- France and friends lost the argument, but seem to have won a compromise of sorts, with the European Commission promising separate rulings on "low-carbon" hydrogen by the end of next year 31 December 2024.

- https://www.epa.gov/green-power-markets/renewable-energy-certificates-recs
- https://www.iea.org/policies/4044-renewable-energy-guarantees-of-origin-regos

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GREEN HYDROGEN DEFINITION, Example

Green Hydrogen Organization (GH2):

- Label "Green Hydrogen" means that the hydrogen was produced using Renewable Electricity that conforms to the highest standards on emissions; to environmental, social and governance criteria.

The most popular renewable energy sources currently are:

- Solar energy.
- Wind energy.
- Hydro energy.
- Tidal / Ocean energy.
- Geothermal energy.
- Biomass energy.

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RENEWABLE HYDROGEN

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RENEWABLE HYDROGEN DEFINITION, Example

- Renewable hydrogen is hydrogen produced through the electrolysis of water (in an electrolysers, powered by electricity), and with the electricity stemming from renewable sources;
- The full life-cycle greenhouse gas 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;
- Renewable hydrogen is commonly known as green hydrogen. Additional environmental, social and governance criteria or grid-connected production criteria can be specified to further differentiate the product (IRENA).

RENEWABLE H_2 = GREEN H_2 ?

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REQUIREMENTS TO THE RENEWABLE ENERGY (EC)
The European Commission's new Delegated Act (2023 Feb):

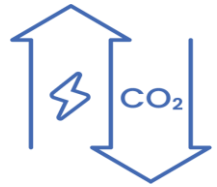
- **Direct connection**

The hydrogen plant should be directly connected to a renewable asset. The renewable asset cannot come into operation earlier than 36 months before the hydrogen plant.

>90%

- **Renewable Power >90%**

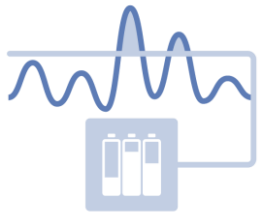
The proportion of renewable power should exceed 90% over the previous calendar year in the bidding zone where the hydrogen plant is operating.



<$18gCO_2e/MJ$

- **Emissions Intensity <$18gCO_2e/MJ$ / $18gCO_2/0.278$ kWh / $64.8gCO_2$ / 1 kWh / $3.24kgCO_2/kgH_2$**

Hydrogen production should take place in a bidding zone where the emissions intensity of the grid is lower than $18gCO_2e/MJ$. The hydrogen plant must acquire a renewable PPA, temporal and geographical correlation also apply.



- **Power from Imbalance Period**

Power supply can be considered renewable if taken from the grid during an imbalance period. The power is either redispatched, or avoids redispatch.

- **Renewable PPA**

A renewable PPA is signed for the supply of power, and the principles of additionality, temporal and geographical correlation apply.

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L O W C A R B O N H Y D R O G E N

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LOW-CARBON HYDROGEN, Examples

- Low-carbon hydrogen encompasses:
  - Fossil-based hydrogen with carbon capture and
  - Electricity-based hydrogen, with significantly reduced full life-cycle greenhouse gas emissions compared to existing hydrogen production.

- Low-carbon hydrogen (IRENA) - hydrogen produced from any technology pathway that has a carbon intensity below that of the incumbent fossil-based production pathway (known as unabated fossil hydrogen, produced from natural gas or coal). Low-carbon hydrogen typically meets a threshold designated by a certification scheme and may be produced through pathways such as:
  - abated fossil hydrogen production, in which hydrogen is produced using natural gas, steam methane reforming and a form of carbon capture and sequestration (commonly known as blue hydrogen)
  - pyrolysis of natural gas, in which hydrogen and a solid carbon black product are produced (such hydrogen is commonly known as turquoise hydrogen).
- Low-carbon pathways involve either abated fossil fuels (such as blue or turquoise hydrogen) or electrolysis (such as renewable or green hydrogen) (IRENA).

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C L E A N H Y D R O G E N

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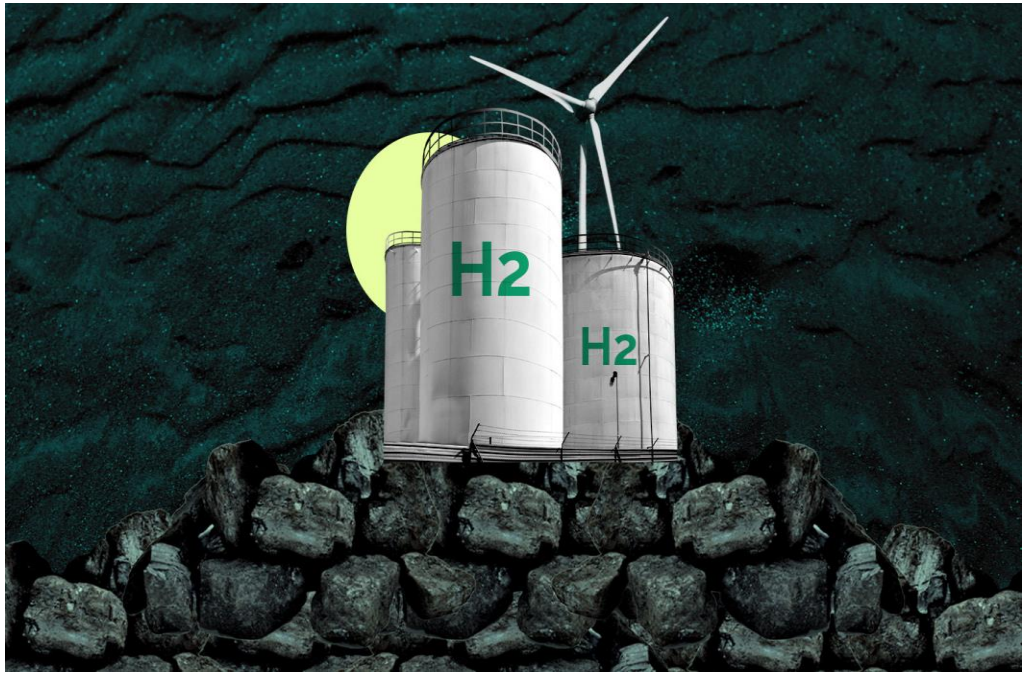
CLEAN HYDROGEN, Examples

- Clean Hydrogen encompasses clean hydrogen generated from both renewables and fossil fuels through the use of carbon capture and storage (CCS) technology.
- Clean Hydrogen (China) - low-carbon hydrogen benchmark is based on the GHG emissions of hydrogen production from coal gasification, which is 29.02 $kgCO_2eq/kgH_2$ (new limit 14);
- Non-low-carbon hydrogen is grey hydrogen, while low-carbon hydrogen includes both green hydrogen produced by renewable energy and non-renewable hydrogen produced by non-renewable energy.



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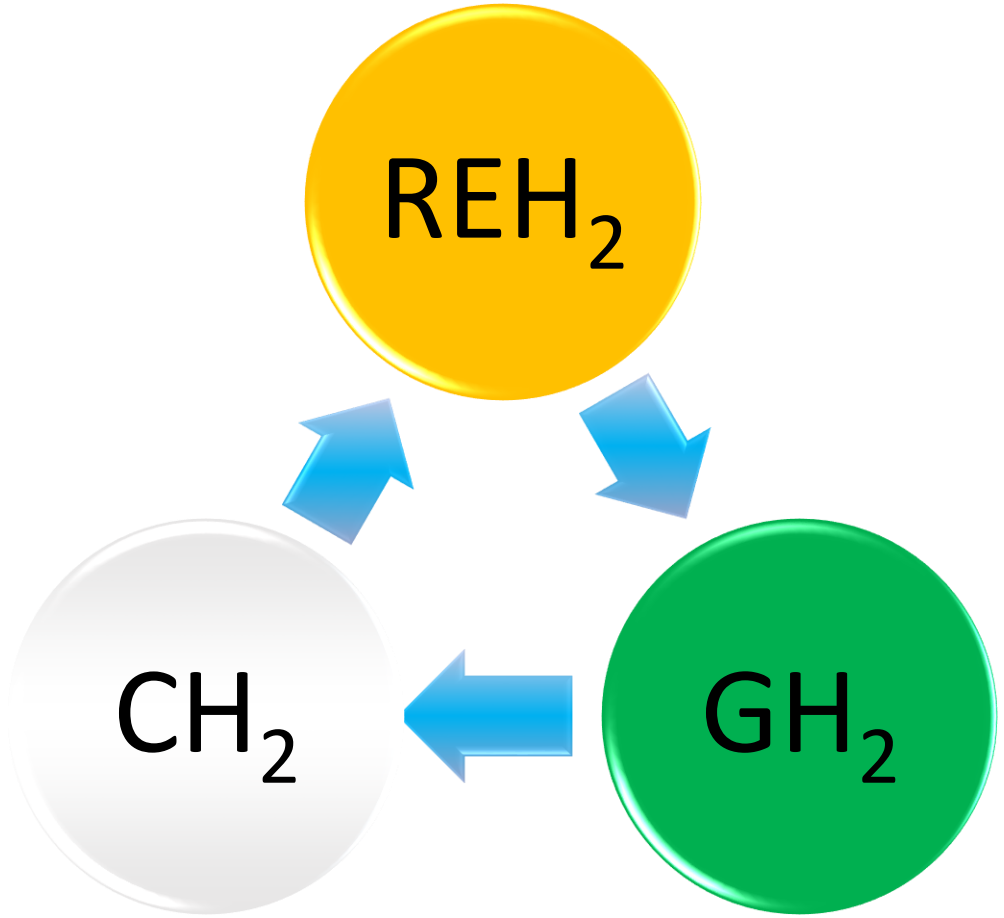
CLEAN HYDROGEN

- Clean Hydrogen refered to Renewable Hydrogen (EC).

CLEAN H_2 = RENEWABLE H_2 ?

RENEWABLE H_2 = GREEN H_2 ?

CLEAN H_2 = GREEN H_2 ?



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OTHER TYPES OF HYDROGEN

Green, Low Carbon and Renewable Hydrogen
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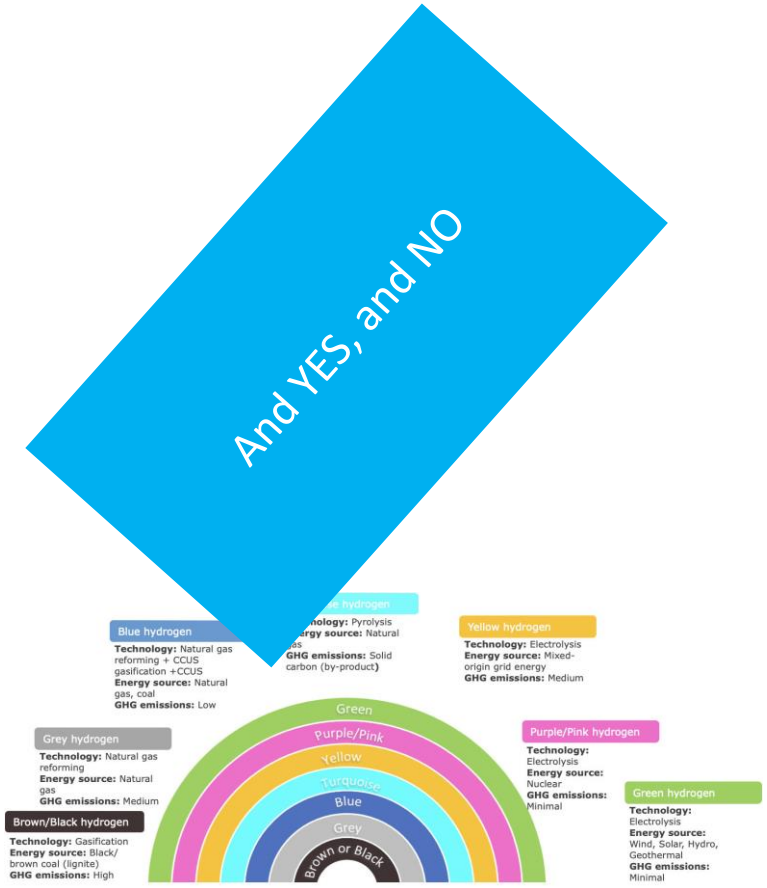
ELECTRICITY BASED HYDROGEN

- 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 greenhouse gas emissions of the production of electricity-based hydrogen depends on how the electricity is produced (EC);
- No Standards and Indicators for gCO_2e/MJ or ESG, the main indicator production method.



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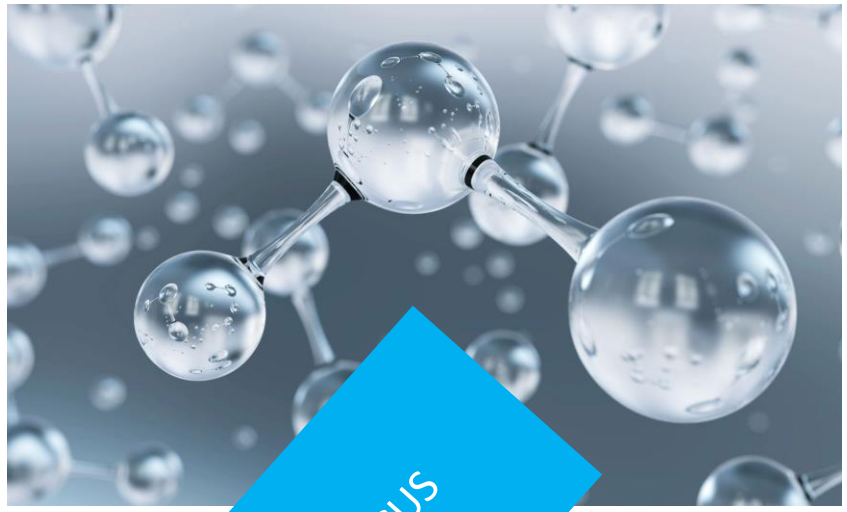
FOSSIL-BASED HYDROGEN

- Fossil-based hydrogen refers to hydrogen produced through a variety of processes using fossil fuels as feedstock, mainly the reforming of natural gas or the gasification of coal;
- This represents the bulk of hydrogen produced today. The life-cycle greenhouse gas emissions of the production of fossil-based hydrogen are high (EC).
- No Standards and Indicators for gCO_2e/MJ or ESG, the main indicator fuel type.



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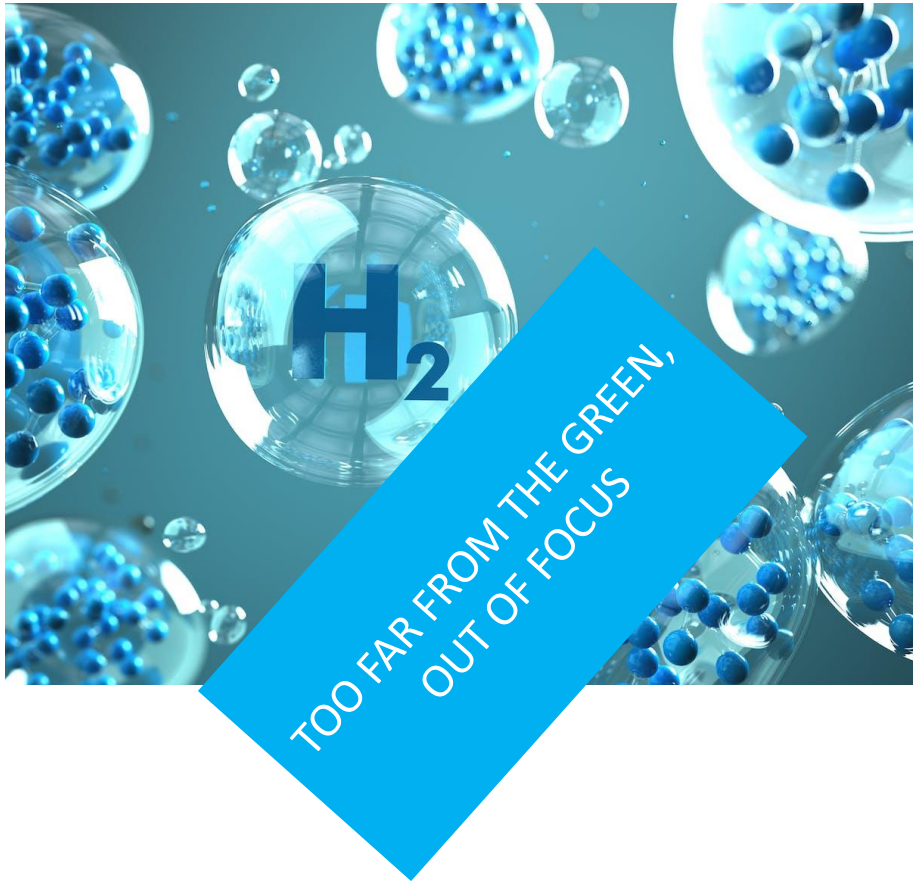
FOSSIL-BASED HYDROGEN WITH CARBON CAPTURE

- Fossil-based hydrogen with carbon capture is a subpart of fossil-based hydrogen, but where greenhouse gases emitted as part of the hydrogen production process are captured;
- The greenhouse gas 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 greenhouse gas capture (maximum 90%) needs to be taken into account.
- No life – cycle green house gasses emissions assessment.



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HYDROGEN-DERIVED SYNTHETIC FUELS

- Hydrogen-derived synthetic fuels refer to a variety of gaseous and liquid fuels on the basis of hydrogen and carbon;
- For synthetic fuels to be considered renewable, the hydrogen part of the syngas 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 fertilisers;
- Synthetic fuels can be associated with very different levels of greenhouse gas emissions depending on the feedstock and process used;
- In terms of air pollution, burning synthetic fuels produces similar levels of air pollutant emissions than fossil fuels;

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HYDROGEN CERTIFICATION SYSTEMS

- At the moment, none of the existing hydrogen certification systems are suitable for cross-border trade.

- There are gaps in standards and in ecolabelling and certification design, resulting in insufficient information in certificates to allow fair comparison across borders.

- Significant gaps exist in the following:
  - clear information on greenhouse gas emissions produced during hydrogen production and/or transportation;
  - common standards used;
  - ecolabelling;
  - compliance with environmental, social and governance criteria.

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Summary of voluntary market mechanisms with published technical criteria (IRENA)

TITLE	LABEL	EMISSIONS THRESHOLD ($kgCO_2eq/kgH_2$)	BOUNDARY	POWER SUPPLY REQUIREMENT FOR ELECTROLYSIS	HYDROGEN PRODUCTION PATHWAY	CHAIN OF CUSTODY MODEL
Australia **Smart Energy Council** Zero Carbon Certification Scheme	Renewable H_2	No threshold				Unclear
China **China Hydrogen Alliance** Standard and Assessment for Low-carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen Energy	Renewable H_2	4.9				Not specified
	Clean H_2	4.9				Not specified
	Low-carbon H_2	14.5		n/a		Not specified
European Union **CertifHy** Green and Low-Carbon Hydrogen Certification	Green H_2	4.4				B&C
	Low-carbon H_2	4.4				B&C
Germany **TÜV SÜD** CMS 70	Green H_2 (non-transport)	2.7				B&C
	Green H_2 (transport)	2.8				Mass
Japan **Aichi Prefecture** Low-Carbon Hydrogen Certification	Low-carbon H_2	No threshold				B&C
International **Green Hydrogen Organisation** Green Hydrogen Standard	Green H_2	1.0				Not specified

*Aligned with REDII methodology and may be updated once EU delegated act is finalised.

Indicates threshold value

Includes upstream methane
To point of production
To point of use

Power supply requirements
- GO + additionality
- GO required
- No GO/additionality specified
- Solar, wind or hydro
- Nuclear
- Grid (or unspecified)

Hydrogen production pathway specified
- Electrolysis
- Fossil SMR/ATR with carbon capture
- Biogas SMR

Notes: ATR = autothermal reforming; B&C = book and claim; GO = guarantee of origin; SMR = steam methane reforming.

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CertifHy industry consortium.

- The carbon threshold is 4.4 $kgCO_2eq/kgH_2$, but it will be aligned to RED II for the carbon intensity limit of renewable and non-renewable hydrogen, using nuclear or fossil fuels with CCS, at 60% less than the carbon intensity of steam methane reforming.

China Hydrogen Alliance Standard and Assessment (an industry-led scheme to assess the life cycle emissions for hydrogen). It has three categories for hydrogen:

- Low carbon, clean and renewable.
- The maximum level of emissions for certification as low carbon hydrogen is 14.51 $kgCO_2eq/kgH_2$, while clean and renewable hydrogen are capped at 4.9 $kgCO_2eq/kgH_2$.

Green **Hydrogen Organisation (GH2)** Green Hydrogen Standard. Voluntary industry standard, issued in May 2022, defines green hydrogen as hydrogen produced through the:

- electrolysis of water with 100% or near 100% renewable energy and with close to zero GHG emissions: ≤1 $kgCO_2eq/kgH_2$ (average over a 12-month).
- Calculated the GHG emissions, including any emissions from production, water desalination and treatment, and on-site or purchased renewable electricity.

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UK Low Carbon Hydrogen Standard.

- This standard defines what constitutes low-carbon hydrogen at the point of production. The standard sets a bar of 20 gCO_2eq/MJ of hydrogen, which corresponds to roughly 2.4 $kgCO_2eq/kgH2$.

US Department of Energy Clean Hydrogen Production Standard (CHPS) and Bipartisan Infrastructure Law (BIL).

- Hydrogen produced with a carbon intensity equal to or less than 2 $kgCO_2eq/kgH_2$ at the site of production.

EU Taxonomy.

- The emissions savings threshold to qualify as contributing to climate change mitigation is 3.0 tCO_2eq per 3.0 tH_2.

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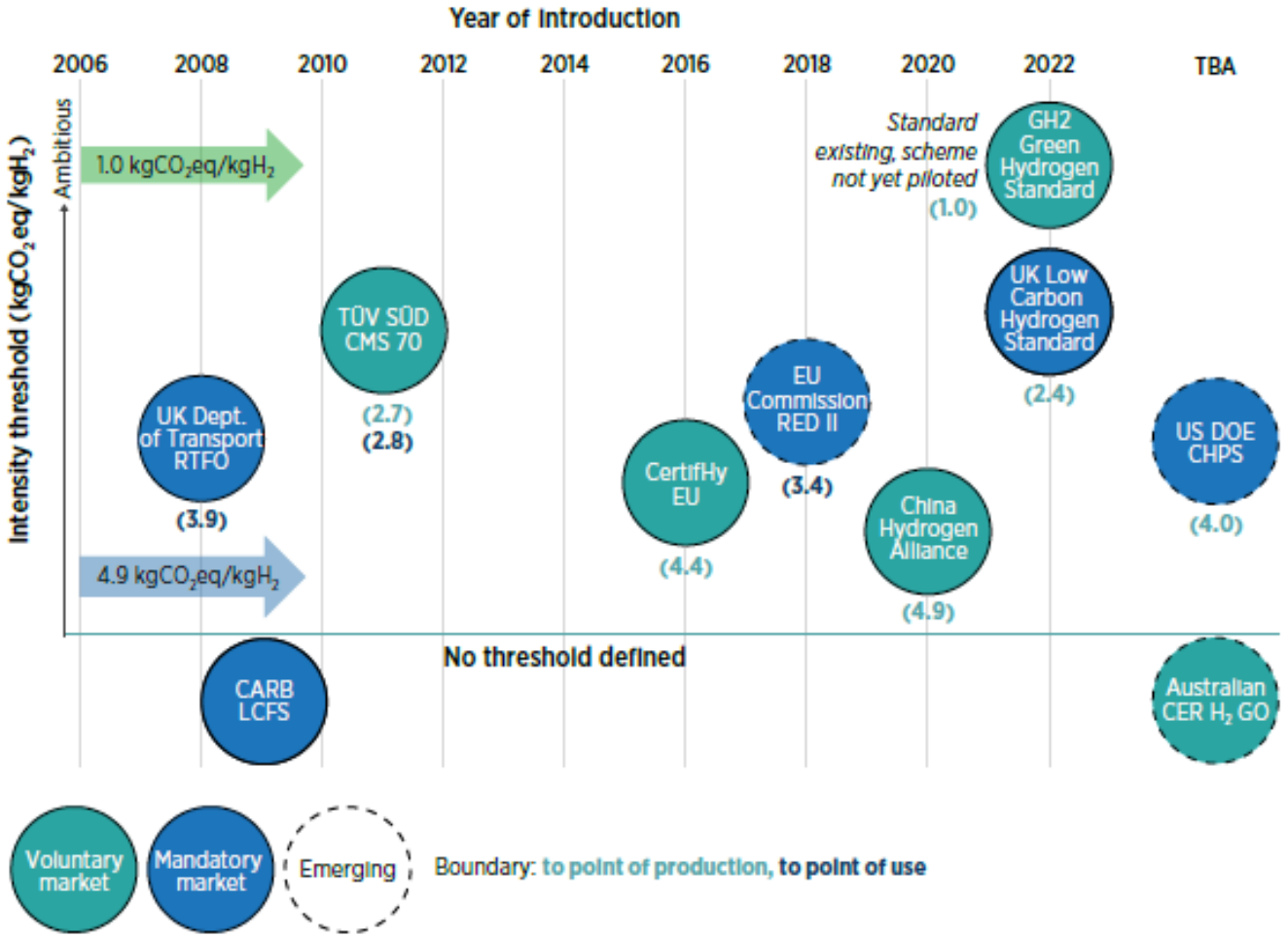
Timeline of emerging and existing voluntary schemes and regulatory mechanisms (IRENA)



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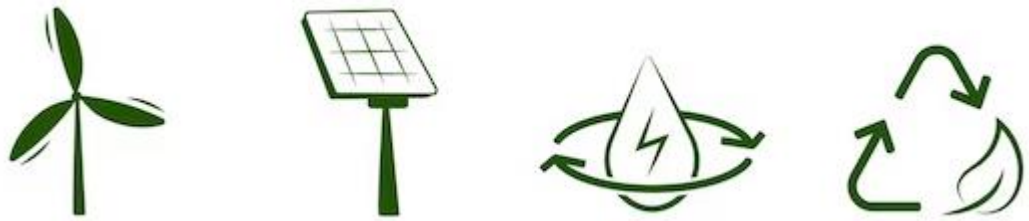
THE KEY CRITERIA:

$kgCO_2eq/kgH_2$, Water Usage, Energy Source / Consumption

- If the distinguishing criteria in $kgCO_2eq/kgH_2$ and other elements, such as water usage, energy source and consumption, specified by the certification scheme are met, a label – such as “low-carbon hydrogen” – can be provided for the product.
-
- While the labels of different certification schemes might use the same wording, the standards criteria against which they are evaluated could differ. This may lead to confusion among consumers.



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Hydrogen Performance Class

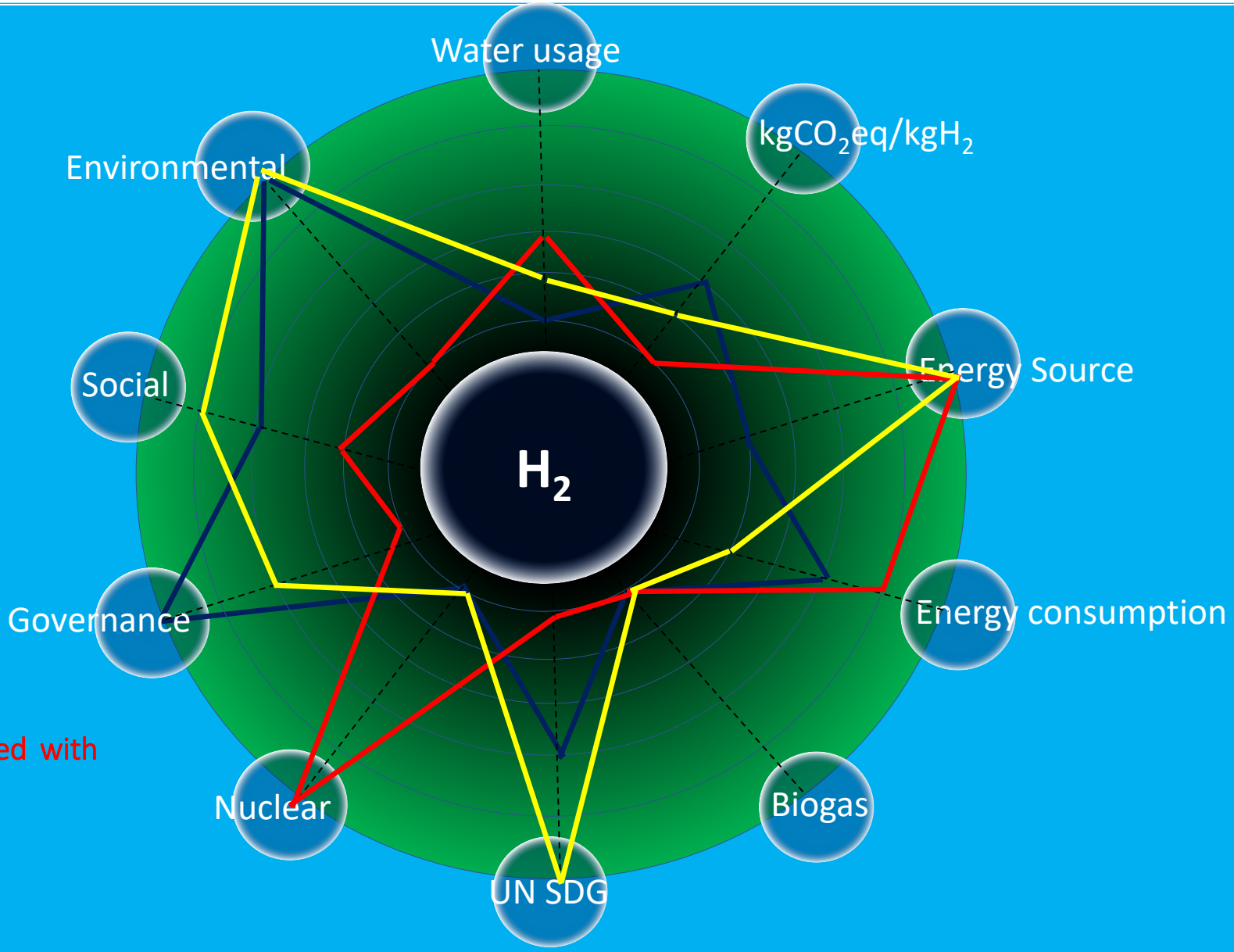
THE KEY CRITERIA:

Environmental, Social, Governance ESG,
United Nations Sustainable Development Goals compliance UN SDG

- The Standards for Green Hydrogen should be higher. The Green hydrogen should be produced, transported and used in ways that aim to minimize environmental, social and governance consequences, while optimizing development opportunities.
- Life-Cycle approach should be used.
- No Nuclear.
- Biogas can be used.

Green, Low Carbon and Renewable Hydrogen
Hydrogen Performance Class

MODELLING KPI



The line colours are not associated with "Hydrogen Colours"

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Green, Low Carbon and Renewable Hydrogen
Hydrogen Performance Class

THE EXAMPLE OF HYDROGEN PERFORMANCE CLASS: Average and Weighted

$$\text{H}_2\ \text{Performance Class (average)} = \bar{X}\left(\text{kgCO}_2\text{eq/kgH}_2;\ \text{Energy Source};\ \text{Energy consumption};\ \text{Environmental};\ \text{Social};\ \text{Governance};\ \text{Nuclear};\ \text{Biogas};\ \text{UN SDG};\ \text{Water usage};\right)$$

$$\text{H}_2\ \text{Performance Class (weighted)} = \sum\left(K_1 \times \text{kgCO}_2\text{eq/kgH}_2;\ K_2 \times \text{Energy Source};\ K_3 \times \text{Energy consumption};\ K_4 \times \text{Environmental};\ K_5 \times \text{Social};\ K_6 \times \text{Governance};\ K_7 \times \text{UN SDG};\ K_8 \times \text{Water usage};\ K_9 \times \text{Biogas};\ K_{10} \times \text{Nuclear};\right)$$

K_n - weight coefficient, defined by methodology

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Green, Low Carbon and Renewable Hydrogen
Hydrogen Performance Class

Hydrogen Performance Class (Average)
1
2
3
4
5
6
7
8
9
10

Hydrogen Performance Class (Weighted)
1
2
3
4
5
6
7
8
9
10

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CONCLUSIONS

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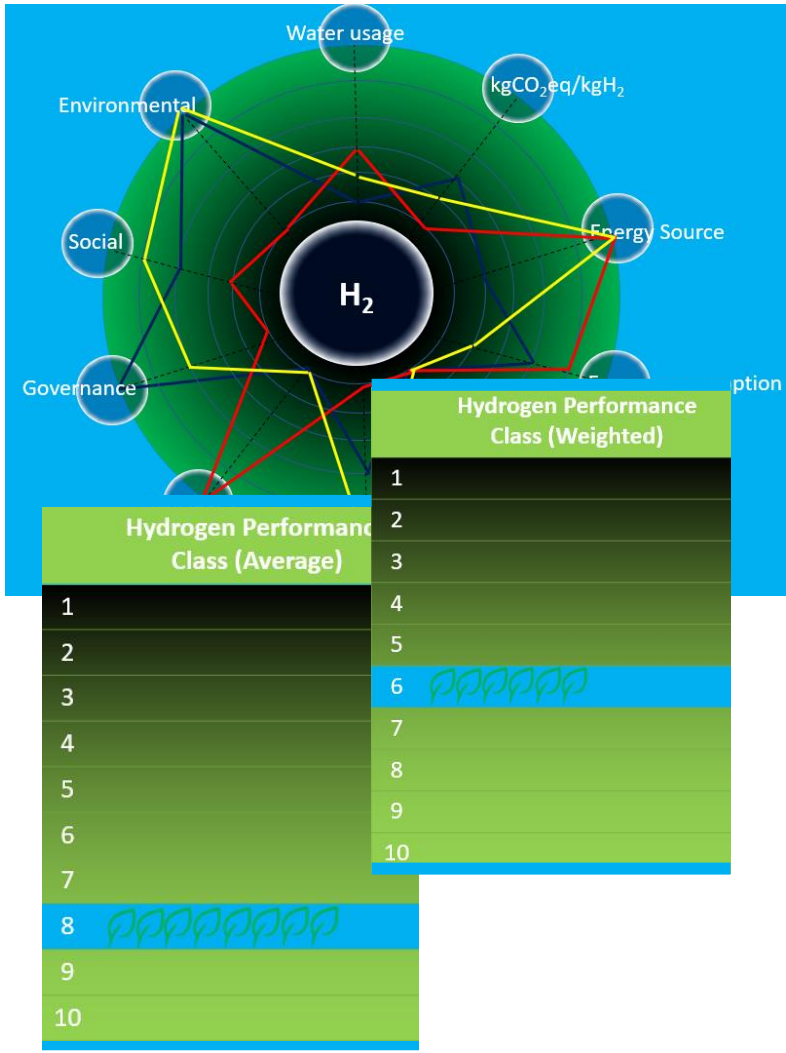
Green, Low Carbon and Renewable Hydrogen Hydrogen Performance Class

- There are the various definitions of hydrogen, some of them are used in the same context;
- The definitions of Green, Renewable, Low Carbon and Clean Hydrogen are likely to be mixed in between;
- The Hydrogen colour scheme is based on the method of production, and the same to the Hydrogen assigned colour may have various carbon intensity in certain limits;
- Due to a various carbon intensities and other KPI parameters, the "Green Hydrogen" can be interpretated in various ways, therefore the local production and global Green Hydrogen trade (import/export) faces serious inadequacies;
- There are no globally recognised Hydrogen standardisation requirements. The initial steps taken at one country level (or region as EU) or via various organisations are not inline with each other, and have different KPI and standardisation schemes;
- The Global Principles and Methodology should be developed;
- Proposed Hydrogen KPI model and Hydrogen Performance Class based on average or weighed key criteria's as emissions $kgCO_2eq/kgH_2$, ESG, Water Consumption and others;



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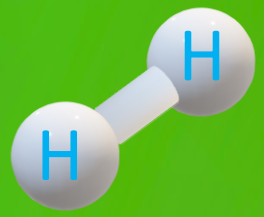

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THANK YOU

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