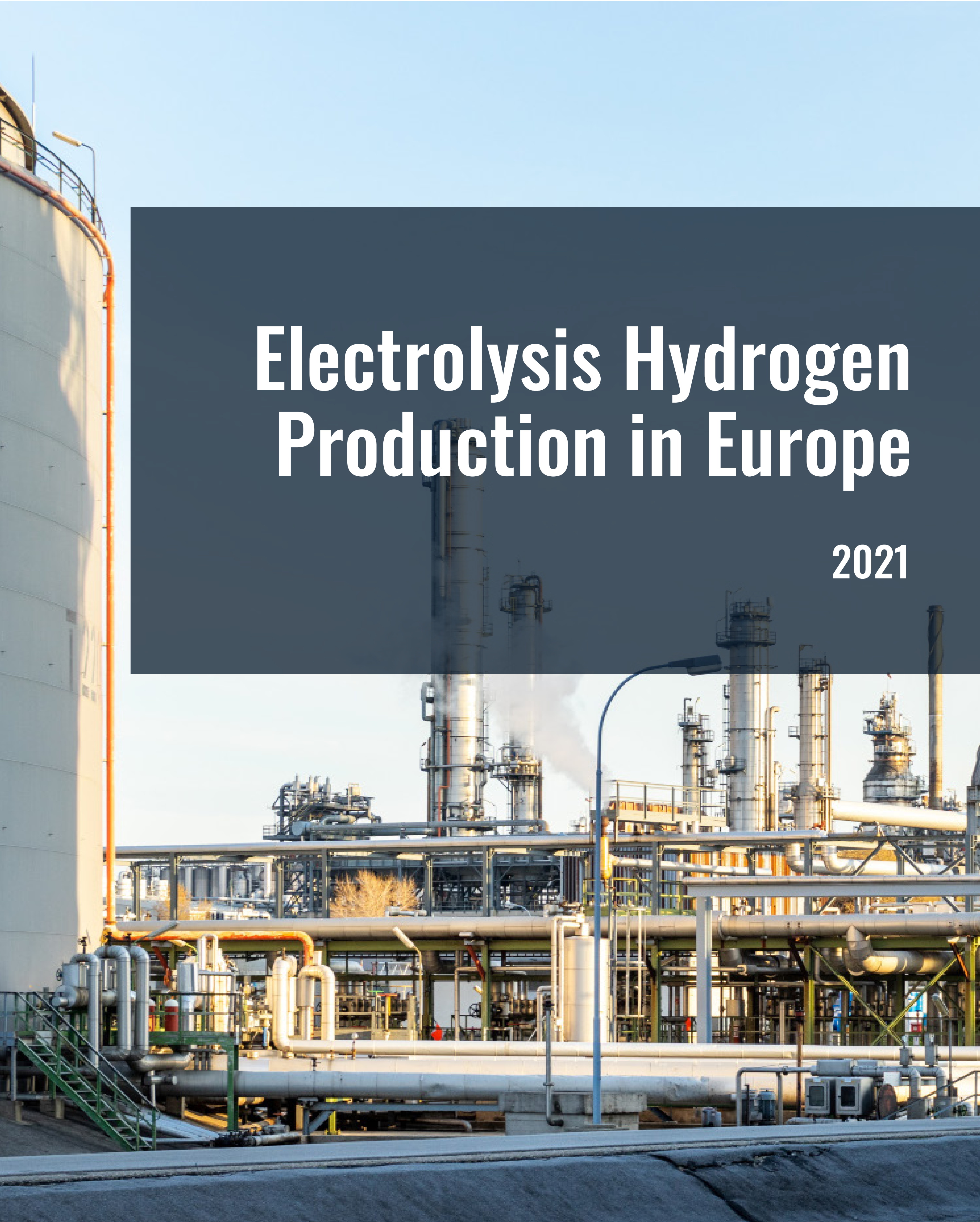
BELLONA EUROPA

Electrolysis Hydrogen Production in Europe

2021



Disclaimer

Bellona endeavours to ensure that the information disclosed in this report is correct and free from copyrights but does not warrant or assume any legal liability or responsibility for the accuracy, completeness, interpretation or usefulness of the information which may result from the use of this report.

Authors:
Marta Lovisolo
Ana Serdoner
Keith Whiriskey

Design and Layout:
Rebecka Larsson

Contents

Getting hydrogen projects right

Over the past year, the European Union has been developing hydrogen plans at lightning speed. Many projects started developing as hydrogen was labelled to be an essential part of the overall EU strategy for energy system integration and decarbonisation plans for various sectors. Last year the Hydrogen Strategy was launched, and the EU committed to developing hydrogen projects on par with other countries around the world. Less than a year since the Strategy was launched, the Clean Hydrogen Alliance is already accepting its first calls for projects.

And yet, all of these developments came about without a proper guideline for what constitutes an actual clean hydrogen project or how the priority order for projects within the EU can be established (i.e., sectorial, country by country, access to clean and low-carbon electricity).

Depending on the carbon intensity of the grid, the production of hydrogen can increase emissions to the atmosphere. If all plans to scale up hydrogen are given a free pass, they could risk jeopardising the energy transition; By increasing electricity demand on a carbon-intensive grid without additional dedicated renewable capacity, we will only delay the transition while producing a fuel far from being carbon neutral.

It is absolutely crucial that the production of renewable hydrogen, which is supported by the EU, first proves it will provide emission reductions and drive growth in the generation of renewable electricity. Europe's hydrogen plans should not jeopardise the decarbonisation of grid electricity in the EU, and additional dedicated renewable electricity build-up is necessary to meet the hydrogen production goals. The RES on the grid is required to decarbonise other sectors and reach net-zero by 2050; changing the priority order could increase emissions in the near term and delay emission reductions in other sectors.

The EU is currently facing a choice and it must choose wisely:

- ☐ **Choose one path and hydrogen will reduce emisisons**
- ☐ **Choose the other and hydrogen production from electricity will increase emissions and aggravate the very problem it is trying to fix.**

The purpose of this briefing is to provide a simple and effective way of assessing the climate impact of hydrogen projects and introduce the calculation methodology for the CO_2 intensity of hydrogen into the debate.

In the absence of other clear guidelines for hydrogen projects and their compatibility with the net-zero future, this briefing can be used as a first go-to guide to check whether a hydrogen project proposed today will truly be contributing to climate change mitigation.

The climate impact of hydrogen

Hydrogen is the lightest element in the periodic system and the most abundant chemical substance in the universe. On Earth, hydrogen is usually found in complex molecules such as fossil fuels or water-based molecules. In other words, it cannot be found in its pure form in nature, and it almost always comes with different elements attached to it. As a clean burning fuel, hydrogen is expected to play a major role in the transition to a zero-emission society.

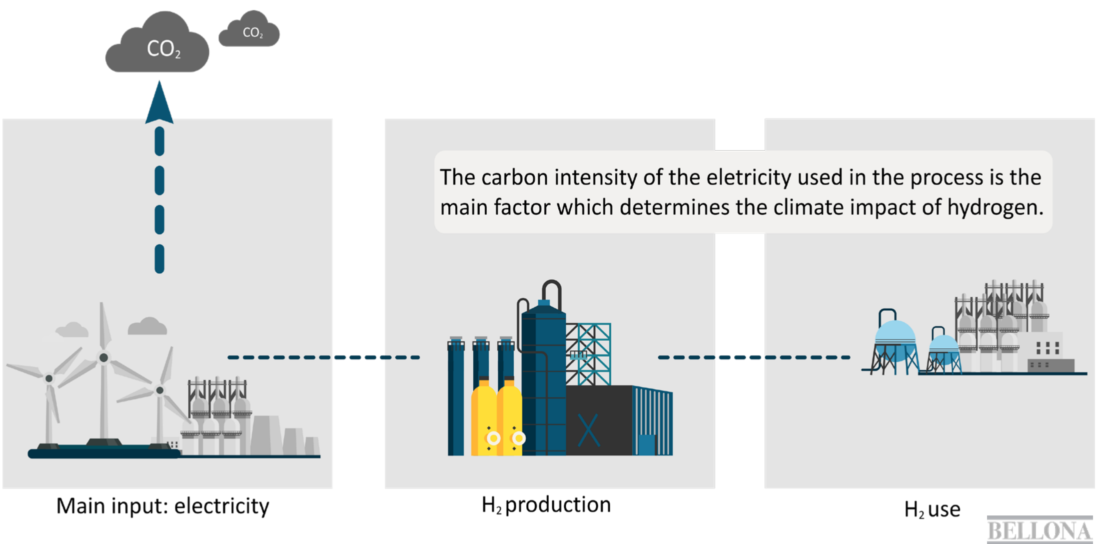
To extract hydrogen from other molecules and use it as a carbon neutral fuel, additional energy is needed; and the energy used in the process needs to be renewable for the overall climate impact to be neutral.

Like any other fuel, hydrogen is only as clean as the ingredients and the energy we use to produce it.

In terms of climate impact, the most promising production of hydrogen is water electrolysis. In this production process, electric current is passed through a solution to split water into hydrogen gas and oxygen gas. However, to produce large quantities of hydrogen, there is a need to have industrial sized installations which use immense amounts of electricity and operate with varying efficiencies.

The climate impact of hydrogen from renewable electrolysis depends on two main variables. First, the carbon intensity of electricity and second, the efficiency of converting that electricity into hydrogen.

To ensure that the final product is low-carbon, the hydrogen must be produced with low-carbon electricity. Simply put, the carbon intensity of electricity used to manufacture electrolysis hydrogen is the determining factor of the carbon intensity of the hydrogen produced.



How do we calculate the carbon emissions from electrolysis hydrogen?

To be able to calculate the carbon intensity of hydrogen, you need two data points: the efficiency of the electrolyser you are using and the carbon intensity of the electricity powering the electrolyser.

Carbon intensity of the electricity

The carbon intensity of electricity is how many grams of emissions are emitted to produce a CO_2 equivalent unit of energy. It is normally expressed in **gCO_2/kWh.**

It is the grams of CO_2 emitted to produce one kWh of electricity.

Normally, this includes the emissions for the construction of the electricity plants divided by the amount of electricity the plant would produce in its lifetime (Life Cycle Assessment).

Efficiency of the electrolyser

To produce hydrogen from electricity, water molecules are split within an electrolyser. Several different technologies exist, and the efficiency of electrolysers varies depending on which technology is used.

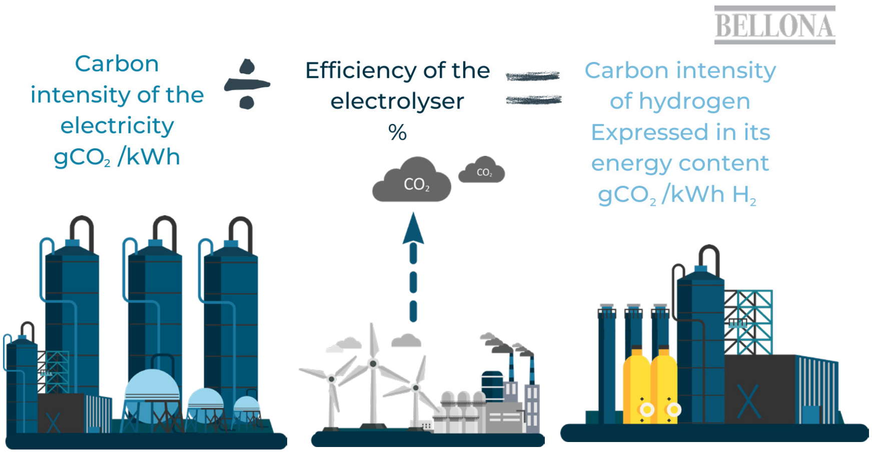
The efficiency is the ratio between the energy that goes in a machine and the work that comes out from it. For instance, a more efficient lightbulb will need less energy to produce the same of light (work) compared to a less efficient one.

The efficiency of an electrolyser is the ratio between how much electricity goes in and how much hydrogen comes out. This is expressed as a percentage.

A 100% efficient electrolyser will produce 100 kWh of hydrogen with 100 kWh of electricity, while a 50% efficient one will need 200 kWh of electricity to produce the same amount of hydrogen.

The main formula you need

Carbon intensity of the electricity divided by the efficiency of the electrolyser will tell us how much CO_2 will be emitted for the Hydrogen we produce. For every unit of hydrogen energy (kWh thermal) we manufacture we can now see how many grams of CO_2 have been emitted to the atmosphere, or the grams of CO_2 per KWh of hydrogen ($gCO_2/kWh\ H_2$).

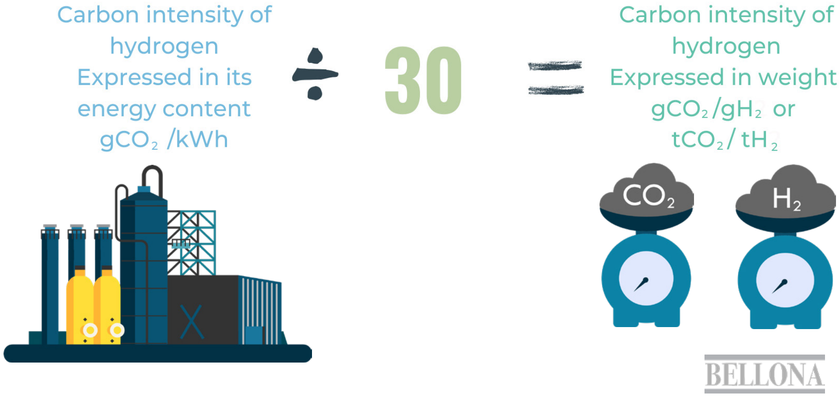


How many tonnes of CO_2 do we emit for a tonne of hydrogen produced?

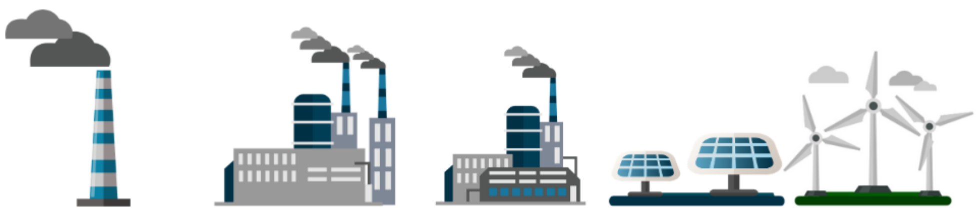
Unlike electricity, hydrogen is different in that we can weight it. It is more common to talk about a kilogram of hydrogen than it is to talk about a kilowatt of hydrogen.

In one kg of hydrogen there are 33.3 kWh of usable energy. This means that 30 grams of hydrogen contain 1 kWh of thermal energy. We can use this simple fact to convert grams of CO_2 per hydrogen energy to grams of CO_2 per grams of Hydrogen. All we need to do is divide by 30.

This simple conversion will tell us how many grams of CO_2 are emitted for every gram of hydrogen we produce (gCO_2/gH_2). And indeed the same for a tonne of CO_2 for every tonne of Hydrogen (tCO_2/tH_2).

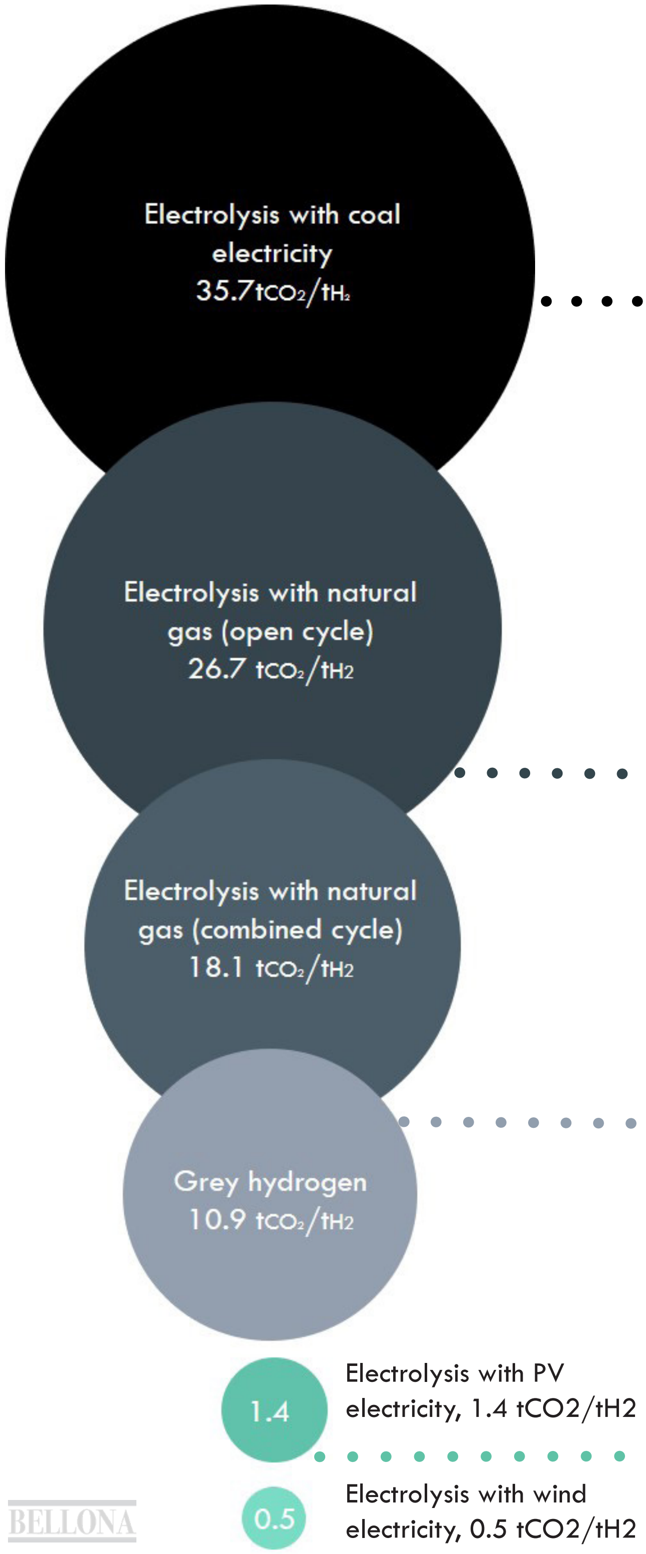


Putting the formula into practice



How is the electricity produced?	Coal	Natural Gas (open cycle)	Natural Gas (combined cycle)	PV	Wind
Carbon intensity of the electricity	750[2] gCO_2/kWh	560[3] gCO_2/kWh	380[3] gCO_2/kWh	30[4] gCO_2/kWh	10[5] gCO_2/kWh
÷ Efficiency of the electrolysers	÷ 70% (0.7)[6]				
= Carbon intensity of hydrogen expressed in its energy content (gCO_2/kWh)	1071 gCO_2/kWh	800 gCO_2/kWh	543 gCO_2/kWh	43 gCO_2/kWh	14 gCO_2/kWh
÷ 30	÷ 30				
= Carbon intensity of hydrogen expressed in weight (tCO_2/tH_2)	35.7 tCO_2/tH_2	26.7 tCO_2/tH_2	18.1 tCO_2/tH_2	1.4 tCO_2/tH_2	0.5 tCO_2/tH_2

How much does hydrogen production via electrolysis emit?



Burning coal to produce electricity to make hydrogen results in **70 times** more emissions than making hydrogen with wind electricity.

Making hydrogen from gas electricity can result in emissions that are **two to three** times higher than making hydrogen directly from gas.

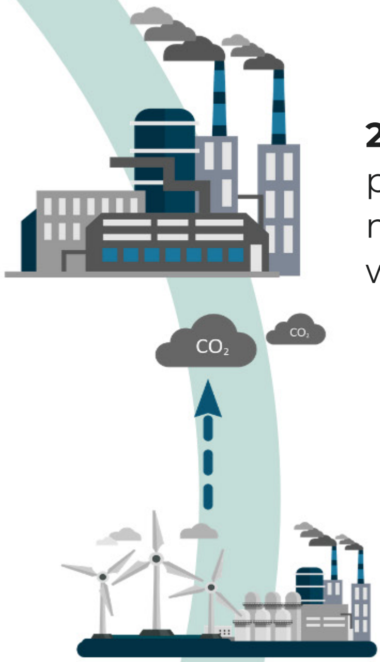
This is hydrogen produced through steam methane reforming (SMR) of natural gas. It currently represents **95%** of the global hydrogen production.

Hydrogen produced via electrolysis from renewables is almost **emission-free.**

5 Key Takeaways

for hydrogen from electricity

1. Low carbon electricity produces extremely low carbon hydrogen. Up to 20 times better than grey hydrogen.



2. Using fossil fuel generated electricity to produce hydrogen is very carbon intensive; it is more than 3 times worse than grey hydrogen when using electricity produced from coal.

3. If done wrongly, hydrogen produced via electrolysis increases emissions instead of reducing them.

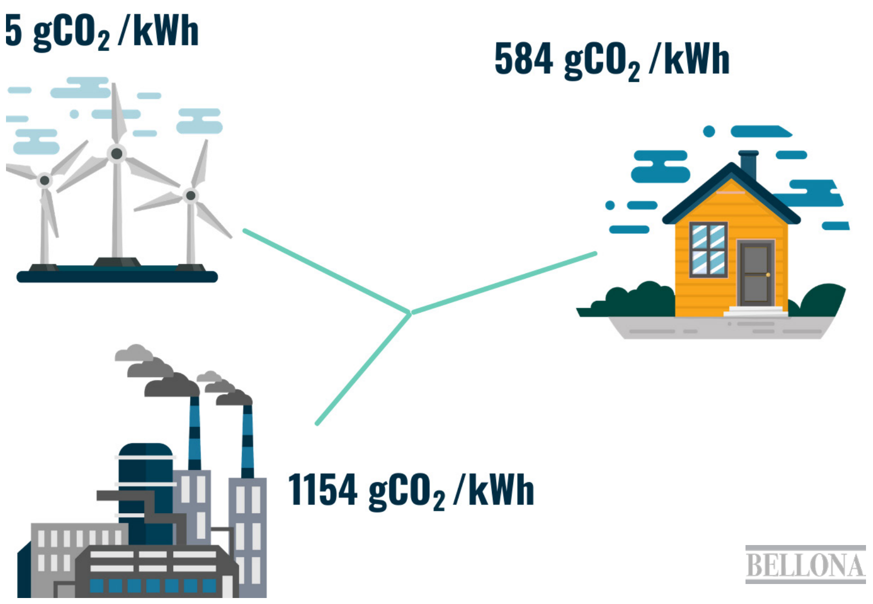
4. Anybody can calculate the carbon intensity of hydrogen, you just need the efficiency of the electrolyser and the carbon intensity of the electricity.

5. Hydrogen production needs to be thought as an extension of the electricity grid, as the carbon intensity of the grid determines the climate impact of hydrogen.

Producing Hydrogen in Europe Today

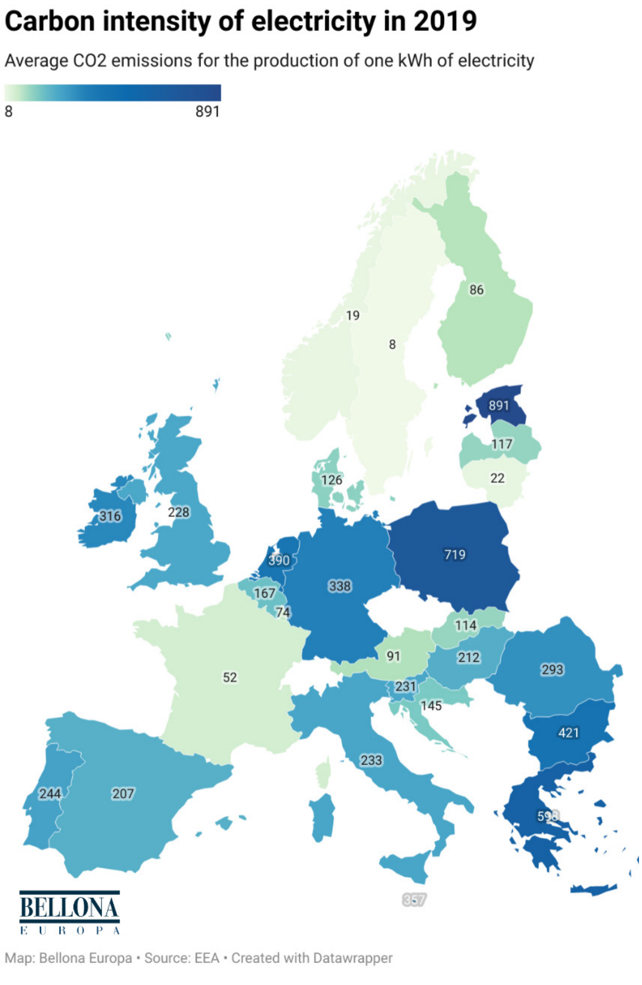
Electricity in Europe is produced from a mix of many different sources, each with its own carbon intensity and some which are incompatible with the goals of the Paris Agreement. Therefore, when we plug in an appliance, the emissions linked with our electricity use do not depend on one specific electricity plant, but from the average of all the plants powering the grid our house is connected to in that particular moment.

For instance, a house is connected to a grid powered by a windmill and a coal-fired power plant in the example below. They both produce one kilowatt of electricity every hour. In one hour, the windmill is responsible for 15 grams of CO_2, so its carbon intensity is 15 gCO_2/ kWh. At the same time, to produce the same amount of electricity, the coal-fired power plant emits 1154 grams of CO_2, so its carbon intensity is 1154 gCO_2/ kWh. Overall, the carbon intensity of the electricity used in our home is the average between the two carbon intensities – so 584 gCO_2/kWh is the overall electricity mix's carbon intensity.



In real life, grids are much more complex, with a lot of different producers and consumers with very diverse sizes. However, the principle remains the same. If we know the carbon intensity of the electricity mix, we can calculate the climate impact of any given energy user connected to the grid, including an electrolyser used to produce hydrogen.

What is the climate impact of producing hydrogen today in your country?



The European Environment Agency (EEA) reports the annual average carbon intensity of the electricity mix for European countries, factoring in imports and exports at the borders. This is calculated by adding all the carbon emissions derived from producing the electricity used in each country, divided by the amount of electricity used. As the carbon intensity of the electricity mix is very diverse across Europe, doing the same activities in two different countries or even regions of the same country (i.e. north sweden vs south sweden) can have a remarkably different climate effect.

As we can see in the map , the average carbon intensity of Sweden in 2019 was 8 gCO_2/kWh, while in Estonia was 891 gCO_2/kWh – over a hundred times more. If you plug in a small electric heater (of 1 kW) for one hour in Sweden results in only 8 grams of CO_2 emissions, while the same activity in Estonia emits one hundred times more.

As with an electric heater or a light bulb, if we use the electricity from the grid to produce hydrogen, the same applies. Applying the formula that we saw before, we can calculate how many tonnes of CO_2 are emitted for every tonne of hydrogen we produce.

From Electricity to Hydrogen

The climate footprint of electrolysis with European grid mix

Applying the formula that we saw before, we can calculate how many tonnes of CO_2 are emitted for every tonne of hydrogen we produce.

Assuming our electrolyser has a 70% efficiency, producing one tonne of hydrogen in Sweden emits 0.4 tonnes of CO_2, while in Estonia, the same electrolyser emits 42.4 tonnes of CO_2.

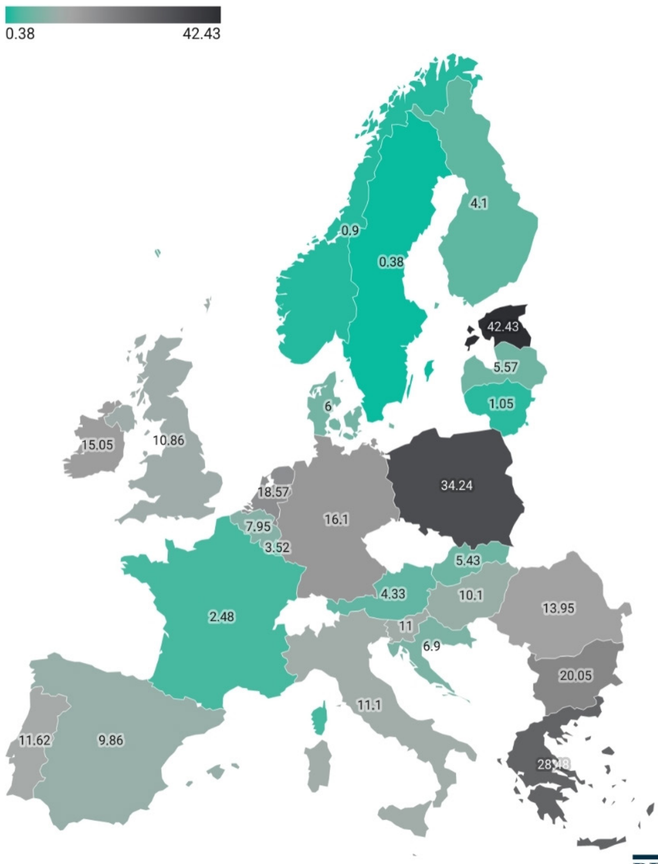
Their climate effect is therefore very different.

Producing hydrogen through SMR we emit 10.9 tonnes of CO_2 for every tonne of hydrogen produced.

As we can see in the map on the right, in more than ten Member States producing hydrogen through electrolysers connected to the grid would produce even more emissions than producing it with the traditional fossil and carbon intensive gas based grey hydrogen technique (SMR).

Potential carbon intensity of grid-connected electrolysis hydrogen

Tonnes of CO2 per tonne of Hydrogen, compared to grey Hyrodgen (10.9 tCO2/tH2)



Map: Bellona Europa • Source: EEA • Created with Datawrapper

It's important to note that the carbon intensity of countries across Europe is changing over time, as countries are shifting to low-carbon electricity sources. Therefore, this map is just a snapshot of what it would have meant to plug in an electrolyser to each given electricity grid for 2019. Using the formula shown above, new conclusions can be derived as the electricity mix changes.

Conclusions

1. Powering hydrogen production with European grid electricity could rapidly increase emissions.

o The average carbon intensity of European Electricity grids is still far too dirty to allow for the manufacture of Green Hydrogen.

o 2019 Germany, Grid powered hydrogen electrolysis would have resulted in 16 tonnes of CO2 per tonne of hydrogen. This is far in excess of unabated fossil grey hydrogen at 10.9 tCO2/ tH2 and around 5 times green hydrogen at 3tCO2/tH2.' with 'o In 2019 in Germany, grid powered production of hydrogan via electrolysis would have resulted in 16 tonnes of CO2 per tonne of hydrogen. This is far more than the emissions from the production of fossil grey hydrogen at 10.9 tCO2/ tH2 and around 5 times more than emissions from green hydrogen at 3tCO2/tH2 (the threshold suggested in the Sustainable Finance Taxonomy).

o Only a small handful of countries, such as Sweden and Norway have electricity grids clean enough to produce renewable hydrogen

2. Renewable hydrogen will contribute towards reducing greenhouse gas emissions in the Union only if it is produced from additional renewable electricity.

o Otherwise incentives for the production of more fossil electricity are provided, which would lead to an increased level of emissions

o Demand for renewable electricity in the EU will increase as a result of direct electrification (e.g., EVs) and other climate plans such as the coal phase out.

3. Direct connection of renewables to hydrogen production is the best way to guarantee the production of near zero emissions green hydrogen.

o A direct connection is a dedicated connection directly from a renewable electricity generator to a hydrogen producers

o A direct connection assured renewables are used and not high carbon grid mix electricity.

Conclusions

Clean hydrogen will be needed to decarbonise certain sectors, such as energy-intensive industries and if done in parallel with deployment of additional renewable electricity, it can play a vital role in reducing emissions from several sectors.

The climate emergency we face means that future hydrogen projects must deliver. To do so, we must make sure that renewable electricity is used in the hydrogen making process to avoid the risk of increasing emissions compared to conventional fossil hydrogen production.

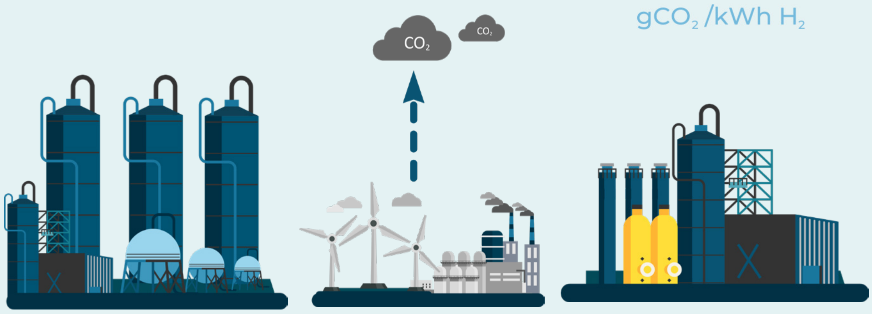
Hydrogen is not a climate solution in itself - it is an energy carrier that requires lots of renewable electricity for its production.

Therefore, we must make sure that the electricity used in hydrogen production is renewable and that it is additional to the renewable electricity we need for other purposes.

This will also help to ensure that plans to boost up hydrogen don't delay the energy transition in other sectors.

Formula for calculating the climate impact of H_2

Carbon intensity of the electricity gCO_2 /kWh ÷ Efficiency of the electrolyser % = Carbon intensity of hydrogen Expressed in its energy content gCO_2 /kWh H_2



Carbon intensity of hydrogen Expressed in its energy content gCO_2 /kWh ÷ 30 = Carbon intensity of hydrogen Expressed in weight gCO_2/gH_2 or tCO_2/tH_2

BELLONA

REFERENCES:

1. http://www.h2data.de/

2. LCA of Hard Coal: 660-1050 $kgCO_2$-eq/MWh_{out} and Lignite: 800-1300 $kgCO_2$-eq/MWh_{out} (Turconi et al. (2013) "Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations")

3. LCA of Natural Gas: 380-1000 $kgCO_2$-eq/MWh_{out} (Turconi et al. (2013))

4. LCA of Solar Energy: 13-190 $kgCO_2$-eq/MWh_{out} (Turconi et al. (2013))

5. LCA of Wind: 3-41 $kgCO_2$-eq/MWh_{out} (Turconi et al. (2013))

6. Conversion efficiency of $P2H_2$ systems is in the range of 50–70% (IRENA (2018) "Hydrogen from Renewable Power: Technology Outlook for the Energy Transition"

7. Grey Hydrogen: hydrogen produced through steam methane reforming (SMR) of natural gas. It currently represents 95% of the global hydrogen production. This technique has an average carbon intensity of 328 gCO_2/kWh (or 10.9 tCO_2/tH_2). Read more here: https://www.frompollutiontosolution.org/hydrogen-from-smr-and-ccs