CLIMATE SOLUTIONS

INDUSTRY

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CIFF CHILDREN'S INVESTMENT FUND FOUNDATION

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ABOUT BELLONA

Bellona Europa is the Brussels-based branch of the Norwegian Bellona Foundation, an independent non-profit organisation working on the environmental, climate and social issues of our time. We aim to identify, promote and help implement realisable solutions for the protection of nature, the environment and health. To achieve these goals, Bellona continues to work with relevant actors and stakeholders both nationally, and internationally.

Bellona was founded in 1986 in Oslo, Norway, as an environmental action group. Still headquartered in Oslo, we have since expanded with offices in Brussels, Murmansk and St. Petersburg. Our team consists of about 65 employees with diverse professional backgrounds in communication, engineering, ecology, economics, geosciences, law, physics, and political and social sciences.

Our solution-oriented approach to climate issues follows the evaluation of existing options, assessment of associated challenges and promotion of identified solutions. Supported by the breadth of knowledge and skills of our experts, Bellona follows a holistic, trans-sectoral approach to assess the economics, climate impacts and technical feasibility of possible climate options. The challenges of climate action are complex and involve multiple influential actors and stakeholders; from national and supranational governments, to internationally operating billion-dollar companies, and the people living in respective regions and countries. To ensure collective action takes place and in the interest of society and the climate, it is crucial to retain open channels of communication. Bellona does not shy away from, and indeed seeks, the exchange with polluting industries, as well as civil society, academia and governments. We believe that the process of finding solutions to pollution from industries that are currently essential to our economy and the standard of living needs to involve them. Bellona is engaged on several platforms where we aim to initiate discussion and fuel debate to identify the climate solutions we need. We work jointly with scientific institutions on several European research projects, and follow close relationships with fellow climate NGOs across the globe.

INTRODUCTION TO CLIMATE SOLUTIONS FOR INDUSTRY

The financial and political decisions we make in the next few years will echo through the coming generations. To achieve climate goals, investments and policies need to prioritise climate-compatible economic activities.

"In many respects the tasks facing us remind us of elementary school when we were asked to draw how the world would look when we grew up. But this time it is reality that we are drawing. How do you want the world to look?"

Frederic Hauge, General Manager Bellona

Over the past few decades, large investments have been made to increase the generation of renewable energy and industry has begun to take steps to cut its greenhouse gas emissions. While these efforts are a good starting point, we need to do much more to bring emissions to zero by 2050 and hence curb the damaging effects of climate change. It means that we must invest heavily in the solutions that will get us to that goal.

With this report, we aim to contribute to the informed selection of projects fit for the future. The overall goal of the report is to provide a comprehensive and modular database of ready-to-go solutions for the next investment cycle in energy intensive industries. It is a tool which aims to identify, compare and evaluate potential solutions which contribute to significant emission reductions in energy intensive industries.

Built in comparable and standardised building blocks, it aims to provide the reader with a condensed description of shovel ready technologies eligible to contribute to climate change mitigation in energy intensive industries. All of the solutions analysed in this report can collectively contribute to climate change mitigation in industry.

The report is structured into independent blocks defining an activity or technology which, under certain conditions, have the potential to reduce emissions in the steel, cement and chemical industries. For some technologies, specific sustainability criteria and infrastructure needs are defined.

The report aims to create a specific package of options that could be picked from the shelf to be added to the recovery packages planned by the EU – and to be complementary to policies such as the EU Sustainable Finance Taxonomy. The activities and technologies are evaluated according to (1) their contribution to climate change mitigation. To account for their systemic effects, (2) resource efficiency and (3) deployment readiness are also evaluated.

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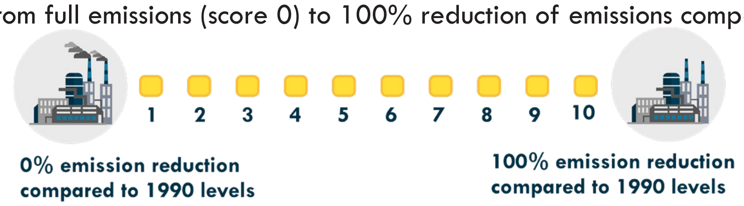
BELLONA CLIMATE SCOREBOARD

This Bellona tool is designed to inform policy makers on the potential of the various technologies aimed at reducing industrial emissions. To assess their climate change mitigation potential and paint the picture of their systemic environmental impact, we used three qualitative screening criteria in our analysis. The same criteria are used in each case to ensure that all of the solutions are compared on an equal basis; the higher the score, the better the environmental performance.

1. Climate change mitigation - measuring a reduction in emissions

If we are to meet out climate targets, we must ensure that low-carbon sectors are expanded and high-carbon sectors are decarbonised. The 'Climate change mitigation' criterion describes the extent of emission reductions caused by the economic activity described[1]. The reduction in emissions is measured by comparing the activity to the conventional production of steel, cement and chemicals. The scale of reductions ranges from full emissions (score 0) to 100% reduction of emissions compared to the baseline (score 10).[2]

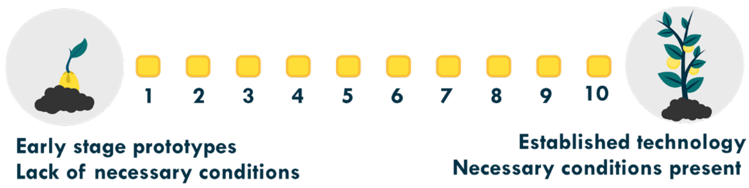


2. Efficient use of resources – measuring systemic effects

Over the past few decades, we've learned that most economic activities have significant systemic effects. Efficient use and reuse of resources is not only the bedrock of climate change mitigation, but also the basis for achieving other environmental goals. This criterion measures the efficiency of resource use of a given technology. All physical resources such as materials, land, water and electricity are considered in the analysis. By describing the requirements for a certain technology and its systemic effects on the rest of the system, the criterion assesses the impact on the entire system. The scale of resource efficiency ranges from 0 (high use of resources) to 10 (no resources required).

3. Deployment readiness – measuring scale and technology readiness

The criterion is an indicator of not only the maturity of the technology analysed, but also of the availability of conditions needed for its sustainable deployment[3]. For instance, for hydrogen both electrolysis maturity and the availability of renewable electricity are considered. The scale of deployment readiness ranges from 0 (low TRL, no conditions) to 10 (high TRL, all conditions present).



The score for each economic activity depends on a case-by-case basis. For that reason, the scoreboard does not aim to provide any quantitative results. Instead, it indicates the general outcome of the technology based on a qualitative analysis of the current predominant technologies. However, a deeper assessment requires quantifiable results (e.g. tCO_2 mitigated per unit of energy invested). To learn more about GHG calculation methodologies which can provide quantitative estimates for various technologies, visit Bellona.org.

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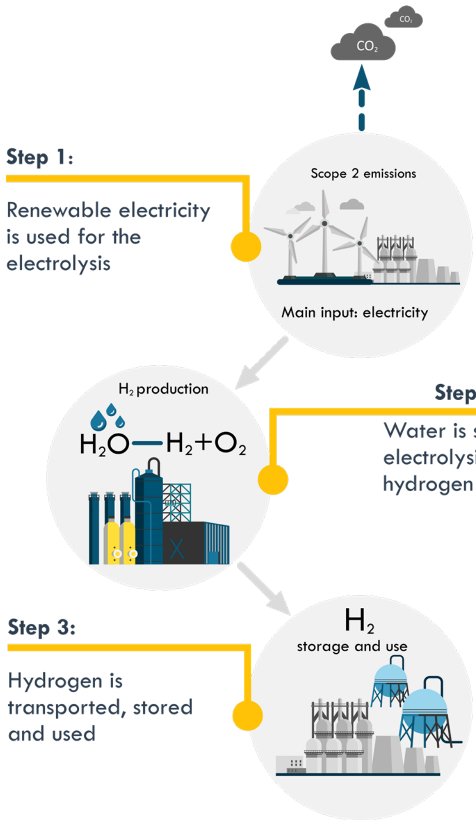
PRODUCING LOW-CARBON HYDROGEN FOR INDUSTRIAL USE

HYDROGEN FROM ELETRICITY



Hydrogen is the lightest element in the periodic system and the most abundant chemical substance in the universe. It is usually found in complex molecules such as fossil fuels like oil and gas or water.[1] Today, hydrogen in the EU is mainly used in oil and bio-refining (47%), ammonia production (39%), methanol production (8%) and industrial processing (4%)[2].

Hydrogen can be produced in a process known as electrolysis by splitting water (H_2O) into hydrogen (H_2) and oxygen (O_2) with electricity. There are various types of electrolysis, but the most commercial types of electrolysis currently on the market are alkaline and PEM (polymer electrolyte membrane) technologies[3]. However, if the electricity used for the electrolysis is not low-carbon, then the hydrogen produced is not low-carbon either[4].

When it burns, hydrogen produces energy without emitting greenhouse gases. However, the production of the hydrogen itself must be low-carbon for it to deliver emission reductions during its use. Only hydrogen produced with renewable electricity can be considered low-carbon. Once low-carbon hydrogen is produced, it can provide carbon-free heat, energy or act as an ingredient for other products and thus significantly reduce emissions from polluting sectors[5]. In industrial sectors, hydrogen can provide heat and energy, it can be used as a reducing agent for the steel sector or as a feedstock for chemicals[6],[7].

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It can replace the high-carbon hydrogen currently used in for ammonia production (Haber-Bosch process), production of metals such as steel or copper and for the production of chemicals such as hydrogen peroxide[iii].

The key ingredient for the production of low-carbon hydrogen production is an abundant supply of low-carbon and low-cost electricity. Hydrogen is only renewable when it is produced at the same time and place where the corresponding renewable electricity is generated. A temporal and geographical link between the renewables and the electrolysers producing hydrogen is imperative[8]. Research suggests that electricity used for its production must be low carbon (less than 100 gCO_2/kWh) for the hydrogen to be lower in emissions in comparison to conventional, fossil hydrogen that is derived from natural gas[1].

In order to include all emissions from the production of hydrogen with electricity, the full impact of the electricity source needs to be taken into account. For instance, materials and construction emissions from renewable electricity or emissions from fossil fuel use for electricity production in need to be counted[9]. To prevent other environmental impacts, some low-carbon electricity sources shouldn't be supported if the toll on the environment is too high (e.g. nuclear).

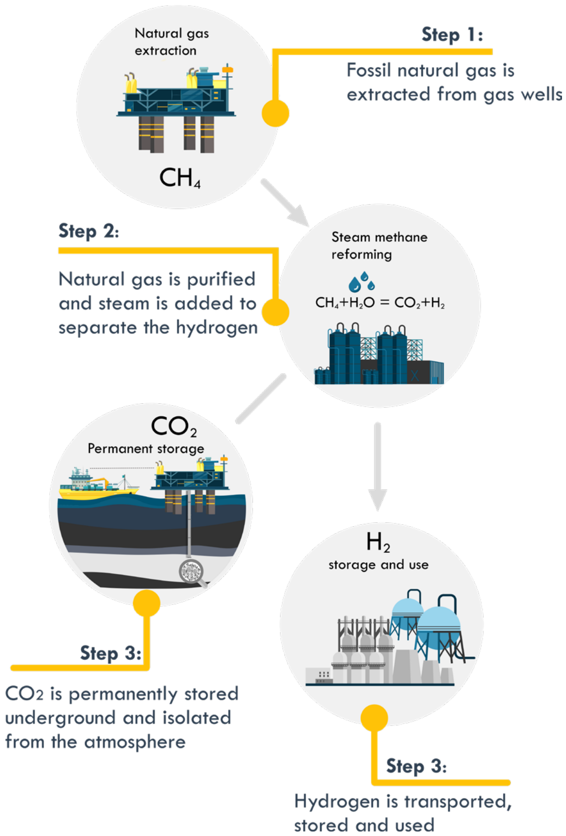
Due to the outlined limiting factors of availability and cost, hydrogen use should be focused. Since hydrogen will be made from electricity, it makes sense to use electricity directly when you can. For instance, it will achieve deeper reductions by replacing fossil hydrogen in the production of ammonia (i.e. fertiliser) rather than supplying fuel cells in the transport sector where a direct use of electricity for powering electric vehicles is much more efficient.

The scale of hydrogen needed, particularly in industry uses, can be large. To produce one tonne of raw steel with green hydrogen would require approximately 3.5 to 5 MWh of electricity[10,11,12,13]. This means that the renewable electricity demand of a mid-sized steel mill producing 5 million tonnes of steel per year equals about 17.5 TWh. This is more than the entire annual electricity consumption of Berlin (13.5TWh).

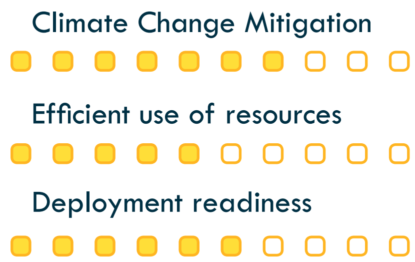
A cross-border approach can significantly save costs and contribute to scaling up and rolling out a hydrogen infrastructure and the needed renewable electricity.

[1] Read more about our approach to quantifying the climate footprint of hydrogen in our positions on the EU Hydrogen Strategy and Sustainability Standards for Hydrogen from Electricity.

HYDROGEN FROM SMR + CCS



CLIMATE SCOREBOARD



Currently, 95% of the global hydrogen production is based on fossil fuels. Conventionally, hydrogen is produced through steam methane reforming (SMR) of natural gas and has an average carbon intensity of 328 gCO_2/kWh[14]. This fossil type of hydrogen is commonly referred to as 'grey hydrogen'. The emissions from this process can be reduced by capturing and permanently storing the CO_2 coming from the SMR process. During the SMR process, high pressure steam (H_2O) reacts with natural gas (CH_4) and produces hydrogen (H_2) and CO_2. In the conventional hydrogen-making process the CO_2 is usually vented, but it can be captured and transported to geological storage sites either on- or offshore[15]. An estimated 71%-92% of CO_2 produced during the process can be captured and stored (CCS)[16,17], thereby lowering the emissions from the hydrogen production. This type of hydrogen is usually referred to as blue hydrogen.

The hydrogen can also be produced by heating the natural gas in the absence of oxygen in a process called pyrolysis, which results in hydrogen and a fine carbon powder[18,19], commonly referred to as carbon black. This powder can be used in different types of products, ranging from newspaper ink to asphalt[20]. If the resulting carbon black is not further processed and released into the atmosphere, this process can potentially result in permanent carbon storage as well[21]. Converting natural gas to hydrogen can only be considered low-carbon when a very high proportion of the CO_2 is captured and stored and when the emissions from natural gas production and leakage are small. If these conditions are met, hydrogen from SMR with CCS can be a low carbon energy carrier and thus be a tool for reducing emissions in some hard-to-abate sectors. When the emitted CO_2 is captured and permanently stored, the hydrogen has a smaller carbon footprint than its fossil equivalent and can be used as a heat source for industry or as a feedstock for chemicals.

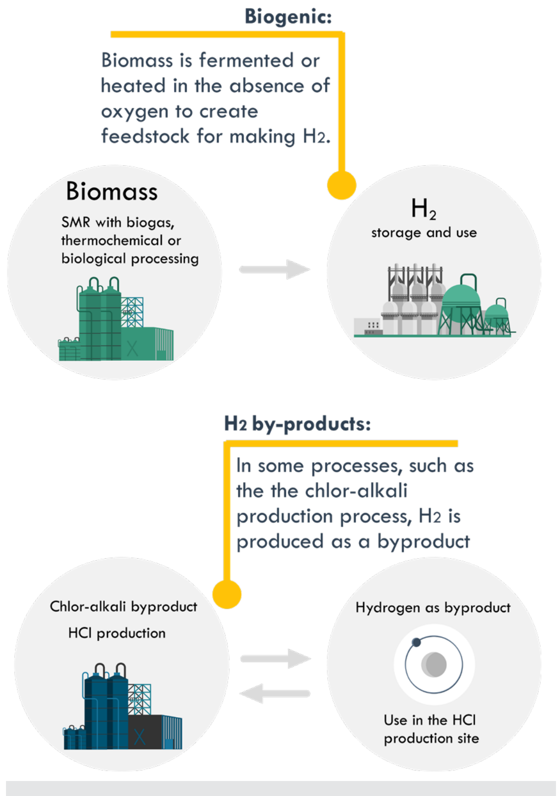
Provided that upstream emissions of the natural gas supply chain are low and most of the CO_2 from the SMR process is permanently stored, hydrogen from SMR+CCS can achieve significant emission reductions[22], especially in industrial applications. When used in the direct reduction ironmaking process, low-carbon hydrogen has a >80% emission abatement potential compared to BF-BOF steel production, by emitting around 0.4 tCO_2 per tonne of crude steel. However, fugitive greenhouse gas emissions from the extraction of fossil fuels also need to be factored into that calculation[23]; if these emissions are too high, the potential emission reduction is significantly lower. Overall, hydrogen from renewable electricity has a higher mitigation potential of >95%.

The addition of CCS to the hydrogen process results in a 5-14%[15] reduction in efficiency levels, so finding applications where the hydrogen gas can be directly used can help to avoid further efficiency losses. In order to calculate and ensure climate benefits, all emissions in the SMR+CCS including possible methane leakage should be accounted for[24].

Even though hydrogen made from natural gas with CCS is not zero carbon, it could help lower emissions in energy intensive industries. By encouraging larger infrastructural investments and penalising the use of unabated natural gas, hydrogen from SMR+CCS can also provide a push for the more rapid roll-out of electrolysis hydrogen and low-cost renewable electricity on a larger scale.

The planning and development of a hydrogen network is dependent on the expected supply and demand. In terms of its transport and use, hydrogen from SMR+CCS would benefit from the same sort of cross-border approach for infrastructure as hydrogen from renewable electricity. Additionally, hydrogen plants with CO_2 capture would need an adjacent CO_2 transport and storage infrastructure, which could also be used to reduce emissions from nearby industry[25].

HYDROGEN FROM OTHER SOURCES



A very small quantity of the hydrogen produced today comes from biogenic sources and other industrial processes[26].

Biogenic sources of hydrogen

Just as hydrogen can be extracted from a fossil fuel, it can be extracted from a from biomass or a biomass based-fuel[27], [28]. If available, sustainable biomass such as algae[29] or organic waste can be processed through gasification or pyrolysis to extract hydrogen. If the biomass has already been processed into biogas, the hydrogen can be produced by biogas reforming, which is similar to natural gas reforming. In this process, the resulting CO_2 can be captured and geologically stored, thereby improving the climate performance of the hydrogen produced. Just as natural gas, the biogas can be heated in the absence of oxygen to split it into hydrogen and carbon black which can then be permanently stored. The biomass can also be directly gasified in the absence of oxygen, resulting in a syngas that can be further refined to hydrogen[30].

Hydrogen as a by-product

Hydrogen can also be produced as a by-product in processes that aim to primarily produce another molecule. One such process is the production of chlorine and caustic soda. An electric current is passed through salt water, which dissociates and recombines through exchange of electrons into chlorine, caustic soda and hydrogen.

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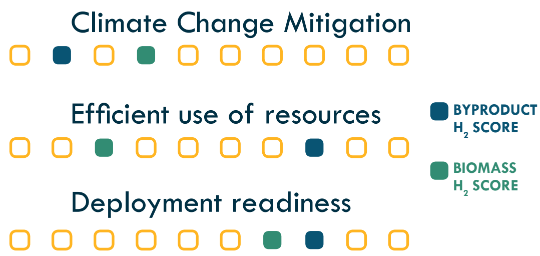


0.03t of hydrogen is produced per ton of chlorine during this process[31]. However, most of the hydrogen by-products created in industrial processes are usually used on-site already[32], so their further use in other applications is very limited.

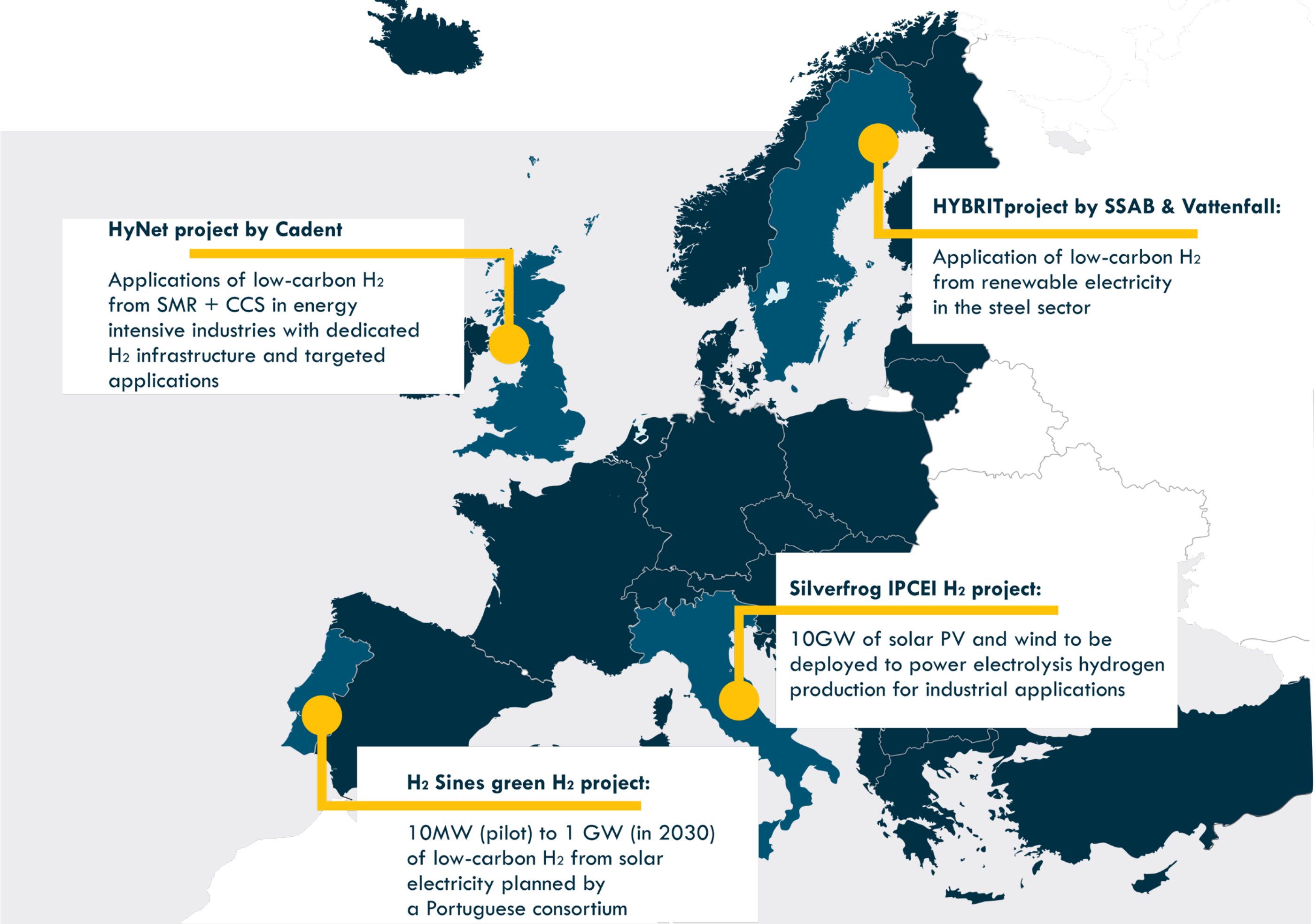
Overall, the climate impact of any given hydrogen molecule is dependent on three major factors:

1. **Hydrogen is only as clean as the ingredients it's produced from:** Indirect emissions of the feedstock for H_2 production, such as biomass land use change and upstream methane emissions, need to be taken into account.
2. **Only low-carbon electricity makes low-carbon hydrogen:** If the H_2 is produced from a water-based brine or water and electricity is used to extract the hydrogen, the origin (GHG intensity in gCO_2/kWh) of the electricity must be taken into account.
3. **Unabated production of fossil hydrogen is no longer acceptable:** If the H_2 is produced from a carbon-based molecule, the CO_2 or carbon produced in the process must be isolated and permanently stored to achieve emission reductions - particularly if the carbon content comes from a fossil source such as natural gas.

It's important to note that the more steps there are in hydrogen production, the less efficient the process will be. These differences in process efficiency also influence the final climate impact of the hydrogen. Finally, the chosen application of the hydrogen is the last factor determining its effectiveness as a climate change mitigation tool. Targeted large-scale applications (e.g. in industry) of very low-carbon hydrogen (e.g. from electrolysis with only renewable electricity) will always achieve the highest emission reductions, but might not be available on a large scale in the near future. This is why other low-carbon alternatives for hydrogen production are relevant in the decades to come.

The climate impact of hydrogen production projects will depend on their entire lifecycles, including the type of electricity they consume, the CO2 capture rate they have and the lifecycle impact of any other inputs going into the projects.

HYDROGEN PROJECTS IN THE EU



Some of the projects illustrated in the map above are pieces of International Projects of Common European Interest. For instance, the H_2 Sines project is connected to the IPCEI named ‘Green Flamingo’, which aims to develop an Iberian green hydrogen export hub connected to the Port of Rotterdam via a maritime route[33]. While some IPCEIs have a clear cut case for the production of renewable hydrogen due to their potential for renewable electricity generation, other IPCEIs such as the ‘Blue Danube’[2, 34] and ‘Green Octopus’[3, 35] could have challenges ensuring all of the renewable electricity to reach the scales they aim for.

Some of the other relevant hydrogen projects in the EU include:

- H-vision project[36]: H_2 production with SMR and CCS in the Netherlands, to be used in the chemical industry. CO_2 emission reductions are projected to be 2.2 Mt per year in by 2026 to 4.3 Mt per year by 2031
- NorthH_2 project[37]: New wind farms in the North Sea to provide electricity for a large-scale electrolyser in Eemshaven (3-4 GW of wind electricity to 2030, 10 GW to 2040).
- Hydrogen Delta[38]: Realisation of a large pilot (on a ~ 100 MW scale) and a large-scale green hydrogen factory (on a ~ GW scale) by 2025. Blue hydrogen is used in the transition phase.
- Puertollano H2R project for the fertilizer industry – Spain[39]: 100 MW “Puertollano II” solar field for electrolysis, with the aim to produce green ammonia by 2021.

While there is no shortage of plans for hydrogen production, their progress will need to be followed up to ensure they are producing truly low-carbon hydrogen.

For more practical information on how to quantify the climate impact of hydrogen production, read our papers on the EU Hydrogen Strategy and Sustainability Standards for Hydrogen from Electricity.

[2] Production of renewable hydrogen using 2 GW of electrolyser capacity and transport this to countries along the Danube.
[3] Production of several GWs of renewable hydrogen with RES from the North sea aimed at the decarbonisation of neighbouring industry clusters including steel, refining, and chemicals.

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