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REPSOL Fundación

Technologies of the energy transition: Low and zero-carbon hydrogen

EsadeGeo Event Brief
December 2020

This EsadeGeo Event Brief draws insights from the webinar Technologies of the energy transition: Low and Zero-carbon Hydrogen*, organised by EsadeGeo and the Repsol Foundation. For this brief, the speakers' insights were complemented with findings from the most recent literature on the topic.*

The technology

Hydrogen, a versatile energy carrier, can be produced through three main technological routes, which are often identified through a colour code: (1) direct generation from fossil fuels such as natural gas and coal ('**grey**' hydrogen); (2) fossil fuel-based generation with the addition of carbon capture technology to mitigate the resulting CO_2 emissions ('**blue**' hydrogen); (3) water electrolysis using renewable electricity ('**green**' hydrogen). Hydrogen produced through the third route is zero-carbon, whereas 'blue' hydrogen is low-carbon.[1]

At present, approximately 95% of the world's hydrogen is produced from natural gas and coal, with the remaining 5% being produced as a by-product from chlorine production (IRENA 2019). The IEA (2019) estimates that dedicated hydrogen generation from water electrolysis comprises under 0.1% of global production today.

The opportunity: Which sectors can this technology help to decarbonize?

As the urgency of decarbonization rises and the prices of renewable electricity generation drop, 'blue' and 'green' hydrogen in particular are increasingly regarded as important "enablers" of the energy transition. Hydrogen is a versatile energy carrier, which, when produced in its low- or zero-carbon variants, holds the potential to decarbonize four sectors in particular: power, industry, transport and heating.

1. In the **power** sector, hydrogen offers a way to store excess renewable electricity generation and increase the flexibility of the power system. In this way, hydrogen can act as an enabler to an increasingly electrified and renewable energy system, by (a) balancing the intermittency of renewable power production (e.g. through hydrogen storage in salt caverns) and (b) better connecting hubs of renewable electricity generation with demand centres. In this sense, some point out that it is cheaper to transport hydrogen by pipeline than transporting an equivalent

[1] According to IRENA (2019) projections, CO_2 capture efficiencies are expected to reach 85-95% at most; the European Commission (2020a) uses an effectiveness of greenhouse gas capture of maximum 90%.

quantity of electricity through cables (up to ten times cheaper, though conversion efficiency is of course of the essence (van Wijk 2020)).

2. In **industry**, low and zero-carbon hydrogen offers significant decarbonization potential. On the one hand, hydrogen use is currently concentrated in this sector, chiefly for oil refining, ammonia production, methanol production and steel production. Switching this hydrogen – which is currently overwhelmingly produced through the 'grey' route – to 'blue' and 'green' options offers direct decarbonization options. On the other hand, hydrogen can help decarbonise various hard to abate sectors that require intense heat for production, including the steel and petrochemical industries.

3. Within **transport**, low and zero-carbon hydrogen offers a number of solutions, from hydrogen fuel cells (e.g. hydrogen trains being tested in the Netherlands, hydrogen-fuelled passenger vehicles in Japan and South Korea) to synfuel applications and ammonia-powered maritime vessels.

4. Finally, hydrogen can also contribute to decarbonizing space **heating**, for example through the residential fuel cells, or as low-carbon alternatives to pure natural gas heating when blended into the natural gas supply.

A related advantage of hydrogen is that it can partially rely on existing infrastructure, through blending up to 10-20% in most natural gas pipelines (IRENA 2019), and injection up to 100% in polyethylene distribution pipelines (IEA 2019).

The reality: What stage of development and deployment is the technology currently at?

Hydrogen production and usage – in its 'grey' variant – is common in industry and has been for decades. In terms of **technological readiness**, 'green' and 'blue' hydrogen are at earlier stages. Producing 'green' hydrogen through alkaline or polymer electrolyte membrane electrolysis stands at Technology Readiness Levels (TRL) of 9 (early adoption) and 8 (demonstration) respectively; while electrolysis through highly efficient solid oxide electrolyser cells is at a less advanced stage (6-7: large prototype/demonstration). In the case of 'blue' hydrogen, natural gas autothermal reforming and steam methane reforming with CCS are in a demonstration/early adoption phase (TRL 8-9); in the case of coal gasification and biomass/waste gasification with CCS, they are at the large prototype stage (TRL 5) (IEA 2020).

In terms of **production**, less than 0.1% of the world's hydrogen is produced through water electrolysis (IEA 2019). With the objective of decarbonization in mind, the current primary challenge, therefore, lies in scaling up 'blue' and 'green' hydrogen production. Some consider 'blue' hydrogen a stepping stone towards an eventual 'green' hydrogen-dominated sector, while others argue that investments in 'blue' hydrogen might create a lock-in effect (Abnett 2020). The proponents of 'blue' hydrogen argue that gradual expansion of hydrogen applications can allow new infrastructure to be built that can ultimately be used to enable the development of 'green' hydrogen (Dickel 2020).

The hurdles: What are the major obstacles/challenges preventing further uptake?

One of the main obstacles facing the further uptake of 'green' and 'blue' hydrogen is that of **cost**: neither are currently competitive with 'grey' hydrogen. Hydrogen produced from natural gas without CCS ('grey' hydrogen) currently costs around USD1.5-3/kg (IEA 2019). In places with very low natural gas prices, such as the Middle East, costs can be as low as USD1/kg (IEA 2019); in the EU, the cost is around EUR1.5/kg (European Commission 2020a). Adding CCS to create 'blue' hydrogen increases the cost to around EUR2/kg (European Commission 2020a). In the Middle East, for natural gas-based hydrogen with CCS to become competitive with its unabated version, a CO_2 price of around USD50/ton would be needed (IEA 2019). Hydrogen generated from renewable electricity ('green' hydrogen), finally, is estimated to cost around EUR2.5-5.5/kg.

An important factor determining the competitiveness of green hydrogen in particular is **electricity and natural gas prices**. If gas prices are low, renewable electricity must be available under USD10/MWh to be cost-competitive with natural gas-based hydrogen with CCUS; if gas prices are higher, 'green' hydrogen could become competitive at electricity prices around USD30-45/MWh (IEA 2019).

The price, size, operational frequency and efficiency of **electrolysers** will be another critical factor. In this sense, scale will be of the essence: while the average unit size of electrolysers was in the 0.1 MWe range in 2000-2009, they have recently risen to the 1MWe scale, and projects currently under development or discussion are in the 10-100 MWe range (IEA 2019). Scale will also be critical in **renewable electricity generation** for 'green' hydrogen (the IEA holds that "producing all of today's dedicated hydrogen output from electricity would result in an electricity demand of 3 600 TWh, more than the total annual electricity generation of the European Union" (2019)). For 'blue' hydrogen, the scale and availability of CCS will be vital.

Further important challenges include questions of **conversion efficiency** and the **geographical distance** between heavy industry demand centres and areas with very low-cost renewable electricity generation (Hydrogen Council 2020). The development or retrofitting of the **infrastructure** to generate, transport and distribute hydrogen is another very important issue, as is the critical question of the development of **markets**. At this stage in the development of 'green' and 'blue' hydrogen, questions of sequencing will be very important. Policies and **regulations** can play a critical role in overcoming many of these challenges.

In the EU: What is the current EU landscape for low and zero carbon hydrogen?

In recent months the EU has laid out its intention to become a world leader in low and zero-carbon hydrogen technology. At the national level, activity on this front has also been high: ministers of the Pentalateral Energy Forum made a joint political declaration on their commitment to the deployment of hydrogen ("Joint Political Declaration" 2020),[2] the Spanish government approved its Hydrogen Roadmap in October 2020, Germany published its National Hydrogen Strategy in June 2020, and France had already launched its Hydrogen Deployment Plan in 2018. Almost all EU member states have also included hydrogen in their National Energy and Climate Plans (NECPs).

Prior to 2020, there was no overarching, structural policy for hydrogen development in the EU and statutory and regulatory provisions were lacking, though some national and EU schemes supported selected areas and supported R&D and demonstration projects (Conti 2020b). This all changed this year: in July 2020, the European Commission announced on the same day two interrelated plans: the EU's Strategy for Energy System Integration (European Commission 2020b) and the **Hydrogen Strategy** (European Commission 2020a).

The Hydrogen Strategy outlines a phased vision for hydrogen development in the EU. In the **first phase** (2020-2024), the goal is to install at least 6GW of renewable ('green') hydrogen electrolysers in the EU by 2024 (producing up to 1 million tonnes of hydrogen). Scaling up the manufacturing of electrolysers (including large units, up to 100MW) is critical in this phase, and the approach would be fairly local (local renewable electricity sources powering electrolysers next to existing demand centres). This phase also includes decarbonising existing hydrogen plants through CCS retrofitting, planning medium range and backbone transmission infrastructure, and creating the regulatory framework for a hydrogen market while incentivizing supply and demand in lead markets.

The **second phase** (2025-2030) sees hydrogen becoming an intrinsic component of the integrated energy system, with 40GW of renewable energy electrolysers by 2030 and a production of up to 100 million tonnes of hydrogen. While grey hydrogen installations would continue being retrofitted, the EU sees 'green' hydrogen gradually becoming cost-competitive with other forms of production over these five years. 'Green' hydrogen would start to play a flexibility role

[2] On June 15, ministers from Austria, Belgium, France, Germany, Luxembourg and the Netherlands, plus non-EU member Switzerland, pledged to "enable a forward-looking European hydrogen infrastructure and liquid market in the near future."

in the power system, and local hydrogen clusters ('hydrogen valleys') would develop where residential applications become a possibility. The need for an EU-wide logistical infrastructure would simultaneously emerge, and part of the existing gas grid could be repurposed for longer-distance transport. International trade with countries to the EU's East and South also becomes an option. On the policy side, demand side policies would be key, along with EU investment and support to continue building the hydrogen ecosystem.

In **the third phase** (2030-2050), 'green' hydrogen technologies would reach maturity and be deployed at a large scale, which will require a massive increase in renewable electricity generation. Hydrogen and hydrogen-derived synfuels would achieve further integration in aviation and shipping, as well as hard-to-decarbonize industrial and commercial buildings.

The full strategy will require investments of hundreds of billions of euros in production capacities, refuelling stations and adapting end-use sectors, among others. The report outlines a number of instruments to support these investments, including a new **Hydrogen Alliance** (which was announced by the Commission in its Industrial Strategy in March 2020). This alliance will seek to replicate the success of the EU's 'Battery Alliance' by bringing together experts from industry, academia and finance (European Commission 2020c).

Providing a comprehensive terminology and certification criteria is one of the pending regulatory issues (Conti 2020a), and it is also highlighted in the report. Finally, the strategy also outlines support lines for **research and innovation** and concludes by highlighting the **international dimension** of hydrogen, including opportunities for cooperation with EU neighbouring countries – such as Ukraine and Southern Neighbourhood countries – and the development of a structured international hydrogen market in euro.

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