Report outline – CCS enables early and cost-efficient clean hydrogen at scale

This is an outline of a longer ZEP report on CCS and clean hydrogen, expected in autumn 2020.

Clean hydrogen in light of the European Green Deal

On 11 December 2019, the European Commission (EC) presented the European Green Deal – the growth strategy for making the EU's economy sustainable – highlighting the main policy initiatives for reaching net-zero greenhouse gas (GHG) emissions by 2050, whilst ensuring clean economic growth in a just transition.

The EUs climate ambition for 2030 and 2050 is the fundamental objective of the Green Deal. Clean hydrogen is key for reducing emissions and given its cross-sector application, it will be central to the EU strategy for integrated energy systems – ensuring deployment of decarbonisation technologies and providing a stable and flexible energy system, whilst meeting the needs and demands of the electricity, heat, transport and industrial sectors.

Today's energy system in the EU relies on natural gas, oil and electricity (which is just short of 50% fossil based). Clean hydrogen is well suited to be a key clean energy carrier, utilising the energy system with clean hydrogen from both natural gas with carbon capture and storage (CCS) and renewable electricity via electrolysis, resulting in a mix of production technologies, resilience and security for the energy system. The technology-neutral approach is crucial. This is also clearly highlighted in the European Taxonomy for Sustainable Finance (Taxonomy), where manufacturing of both electrolysis- and CCS-based hydrogen is defined as sustainable economic activities, given certain screening criteria.

For many energy intensive industries (EII), decarbonisation through electrification is not possible nor realistic from either a cost or a technological point of view. Clean hydrogen provides one of few options for many industries to decarbonise, particularly those reliant on high temperature operations such as steel production. Fuel switching to hydrogen will be an important part of the EU Industrial strategy, and as such, the EC have proposed the launch of a European Clean Hydrogen Alliance, comprising investors, member states and a community of industry and research organisations.

Introduction to clean hydrogen technologies

Solar and wind power, biomass, hydropower and geothermal energy are primary renewable energy sources in Europe. Integrating the energy supply produced from these sources into the current energy infrastructure presents challenges:

- The intermittent nature of solar and wind energy requires storage and flexible low-carbon electricity generation capacity to ensure security of supply.
- With the growing shares of intermittent electricity production, conditions of oversupply can increasingly occur once the installed capacity of intermittent supply exceeds the level of minimum hourly demand. Innovative flexibility options are required to absorb the growing amount of solar and wind energy.
- The location of renewable energy production and where it will be used requires, in most cases, transportation of renewable energy over long distances. Additionally, if extensive electrification would be possible, a significant increase in the existing electricity infrastructure would be necessary.

- Solar and wind energy technologies mainly produce electricity, the total amount of renewable energy currently constitutes about 18.9%[1] of the primary energy demand. As such, the growing electricity-based renewable energy sources are presently a lesser part of the energy system. Most likely, a considerable part of the energy system will have to rely on the use of molecules-based fuels (energy carriers).

The abovementioned challenges present a strong case for hydrogen, which is a versatile energy vector that can be used across all sectors: EII, transport, electricity production, and buildings, and it can also play an important role for zero-carbon domestic heating.

Hydrogen can provide flexibility for the energy system as a whole. In the shorter term, hydrogen produced from natural gas and combined with CCS, can already be applied on a large scale as part of the energy supply for high-temperature heating in the chemical industry, oil-refining industry and electricity production. In the longer-term, hydrogen can also be produced based on renewable electricity via electrolysis, and subsequently join the hydrogen market created by the frontrunner projects based on natural gas with CCS.

There is no "one size fits all" solution for clean hydrogen with CCS, as it plays a role in a diverse Europe-wide energy mix. However, it must be noted that for most member states, access to renewable electricity for electrolysis hydrogen production is limited and will likely remain so for the foreseeable future[2].

However, for any electricity grid-connected clean hydrogen manufacturing to be defined as sustainable according to the Taxonomy, there is a need to correct an obvious error in the screening criteria for hydrogen manufacturing in the technical annex to the Taxonomy report[3]. The third threshold, "*Average carbon intensity of the electricity produced that is used for hydrogen manufacturing is at or below 100 gCO2e/kWh*", will effectively exclude all electricity grid-connected hydrogen manufacturing sites, regardless of technology used. This error is easily corrected. This third threshold is redundant and can be deleted, since the first threshold delivers the environmental benefit.

Status – clean hydrogen from natural gas with CCS can already be produced today at industrial scale

Clean hydrogen production from natural gas with CCS is a proven technology with plants operating globally[4]. The production of clean hydrogen is central to the development of several proposed industrial decarbonisation projects in the UK (HyNet[5], Zero Carbon Humber[6], Net Zero Teesside[7],

[1] Eurostat : https://ec.europa.eu/eurostat
[2] Zero Emissions Platform (ZEP), 2017. Commercial Scale Feasibility of Clean Hydrogen Available at: http://www.zeroemissionsplatform.eu/component/downloads/downloads/1638.html
[3] Taxonomy report: Technical annex, 2020: https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf
[4] Shell Quest Project, Canada. More information at: https://www.shell.ca/en_ca/about-us/projects-and-sites/quest-carbon-capture-and-storage-project.html
[5] HyNet. More information at: https://hynet.co.uk/
[6] Zero Carbon Humber. More information at: https://www.zerocarbonhumber.co.uk/
[7] Net Zero Teesside. More information at: https://www.netzeroteesside.co.uk/

Acorn[8]), and the Netherlands (Hvision[9], Nuon Magnum, PORTHOS[10], Athos). All these projects aim to be operational and provide significant volumes of clean hydrogen by 2030.

The production methods for clean hydrogen are steam methane reforming (SMR), autothermal reforming (ATR), and partial oxidation (POX). These technologies are already proven at a large industrial scale.

The production of hydrogen from renewable electricity via electrolysis requires specific technology. According to a recent study, these hydrogen production methods are confronted with challenges[11] (*challenges in italics*):

- Proton exchange membrane (PEM) electrolysis, equipped with a solid polymer electrolyte (SPE). *New and partially established, high cost of components, acidic environment, low durability, questionable availability of iridium.*
- Solid Oxide Electrolysis (SOE). *Laboratory stage, large system design, low durability.*
- Alkaline Water Electrolysis (AWE). *Low current densities, the electrolyser performance decreases due to formation of carbonates on the electrode, low purity of gases, low operational pressure (3–30 bar), low dynamic operation.*

In conclusion, while early, clean hydrogen at scale can be produced from natural gas with CCS, methods for large-scale production of hydrogen from renewable electricity via electrolysis is still costly and immature. Continued focus on research and innovation in order to progress on the current challenges for electrolysers is important.

Clean hydrogen from natural gas reformation with CCS and from renewable electricity and electrolysis are complementary

Currently, it is more cost-effective and less carbon-intensive to produce hydrogen from natural gas reformation with CCS than from electrolysis[12]. For both technologies, the cost curve is expected to decrease over time[13]. Additionally, with increasing renewable generation capacity, the carbon footprint of electrolysis is also expected to reduce gradually in the future. Producing clean hydrogen from natural gas with CCS at scale up to 2030 would cost approximately USD 6 billion, compared to unabated hydrogen production. In comparison, producing the same volumes of hydrogen with electrolysis would cost approximately USD 20 billion, based on the assumption of a 100% renewable electricity grid[14].

At least 94.8% of the consumed power in hydrogen production with electrolysis must come from renewable sources to be more climate-friendly than the natural gas reforming with CCS route[15]. This

[8] Acorn CCS. More information at: https://pale-blu.com/acorn/
[9] Hvision project: https://www.deltalinqs.nl/h-vision
[10] PORTHOS. More information at: https://www.rotterdamccus.nl/en/
[11] Materials Science for Energy Technologies Volume 2, Issue 3, December 2019, Pages 442-454 Hydrogen production by PEM water electrolysis A review.
[12] Hydrogen for Europe, Final report of the pre-study: https://www.sintef.no/globalassets/sintef-energi/hydrogen-for-europe/hydrogen-for-europe-pre-study-report-version-4_med-omslag-2019-08-23.pdf
[13] IEA, 2019. Future of Hydrogen. Available at: https://www.iea.org/reports/the-future-of-hydrogen
[14] https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf
[15] SINTEF: https://www.sintef.no/en/projects/hyper/

means that, by 2050 and beyond, as renewables penetrate the electricity grid, electrolysis-derived hydrogen from curtailed renewable electricity generation will become more influential.

Volumes of reliable hydrogen production from reformation are complimentary with hydrogen production from curtailed renewables as part of a resilient energy system[16].

Collaboration and hydrogen infrastructure are key to developing clean hydrogen value chains. For an investment to progress in clean hydrogen, there needs to be recognition of the differentiated value with stable support mechanisms[17].

CCS enables early clean hydrogen at scale – creating a route to market for electrolysis-produced hydrogen

The production of early, large volumes of clean hydrogen will provide the signals to industry and governments to invest in hydrogen infrastructure, supply chains, appliances, and industrial fuel switching[18]. Clean hydrogen from natural gas with CCS can then provide an early hydrogen economy, which renewable-sourced hydrogen can enter as its production becomes increasingly cost-effective.

The introduction of early volumes of hydrogen from reformation of natural gas and CCS will enable member states and the EC to establish the regulation and legislation frameworks required to drive the development of a hydrogen economy.

Total emissions reductions from the establishment of early hydrogen markets today with reformed natural gas and CCS, will be greater than the emissions reductions from waiting for an electrolysis hydrogen market to form post 2030.

European CO2 infrastructure will unlock early volumes of clean hydrogen

To ensure that hydrogen can be deployed at scale in Europe before 2050, investment in CO2 infrastructure will be required[19]. Cross-border CO2 transport and storage infrastructure will connect industrial clusters – including clean hydrogen production facilities, creating an infrastructure backbone to which industrial emitters could plug in to benefit from the applications for CCS. This shared CO2 transport and storage infrastructure is the ultimate European project, a strategic and instrumental policy decision; safeguarding jobs, industrial activity and economic growth, thus preserving Europe's welfare and future-proofing Europe for a climate-neutral economy.

It must be noted that the potential use of clean hydrogen in the short term, depends on different options that can be implemented; as such, it is essential to review and benchmark all possible CO2 mitigation options on a case by case basis. Also, the continuous improvement of the energy

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[16] Navigant, 2019. Gas for Climate: The optimal role for gas in a ne-zero emissions energy strategy Available at: https://www.gasforclimate2050.eu/files/files/Navigant_Gas_for_Climate_The_optimal_role_for_gas_in_a_net_zero_emissions_energy_system_March_2019.pdf

[17] Zero Emissions Platform (ZEP), 2017. Commercial Scale Feasibility of Clean Hydrogen Available at: https://zeroemissionsplatform.eu/wp-content/uploads/ZEP-Commercial-Scale-Feasibility-of-Clean-Hydrogen-report-25-April-2017-FINAL.pdf

[18] IEA, 2019. Future of Hydrogen. Available at: https://www.iea.org/reports/the-future-of-hydrogen

[19] Material Economics, 2019. Industrial Transformation 2050. Pathways to Net-Zero from EU Heavy Industry.
Available at: https://materialeconomics.com/material-economics-industrial-transformation-2050.pdf?cms_fileid=303ee49891120acc9ea3d13bbd498d13

efficiency of industrial processes and off-gas product recovery must be considered since this changes the need for energy significantly.

As such, in the Dutch H-vision project, the potential hydrogen demand and the supply of off-spec gasses that will serve as feedstock for the hydrogen production, have been assessed. The surplus off-spec gasses are a result of ongoing efficiency improvements, the electrification of the production process (increased use of electricity for general operations and rotating equipment), and the use of clean hydrogen for high-temperature heating processes.

Both electrification and energy efficiency have a significant impact on energy consumption. For industrial companies, these developments are relevant and should be included to provide a realistic view on the short-term and future demand for hydrogen. Next to this, as a result of these developments, the off-gases or refinery fuel gases will, in most cases, increase, creating an oversupply situation due to the lower steam demand and will block the further deployment of electrification or efficiency improvements. Therefore, clean hydrogen is a crucial option for the petrochemical and oil-refining industry to be able to further improve operations and to increase the share of renewable energy via electrification.

Draft Conclusions

It is clear that clean hydrogen should play a crucial role in the European Green Deal and in achieving both the 2030 and the 2050 climate targets. However, it is not yet clear how the EC will encourage and integrate the clean hydrogen economy – from production, to wholesale markets, regulation and end-use. Given that there are multiple objectives where clean hydrogen can play an important role, it is key that a European clean hydrogen strategy is coherent, consistent and technology neutral.

In order for any electricity grid-connected manufacturing of clean hydrogen, regardless of technology, to be defined as sustainable by the European Taxonomy for Sustainable Finance, the screening criteria's third threshold must be deleted. This third threshold is redundant, since the first threshold delivers the environmental benefit.

CCS with its shared CO2 infrastructure enables early, clean hydrogen at scale, which can kick-start a European clean hydrogen economy, helping to safeguard jobs, industrial activity and economic growth, thus future-proofing Europe for a climate-neutral economy.

Enabling early, large volumes of clean hydrogen will provide strong signals to industry and member states to invest in hydrogen infrastructure, supply chains, appliances, and industrial fuel switching. It will also enable member states and the EC to establish the policies and regulatory frameworks needed to drive the development of a European clean hydrogen economy. This will also pave the way for the scaling-up of electrolysis-produced hydrogen, as renewable electricity becomes more abundant, creating a technology-neutral market, where clean hydrogen regardless of technology, can co-exist and compete on equal terms.