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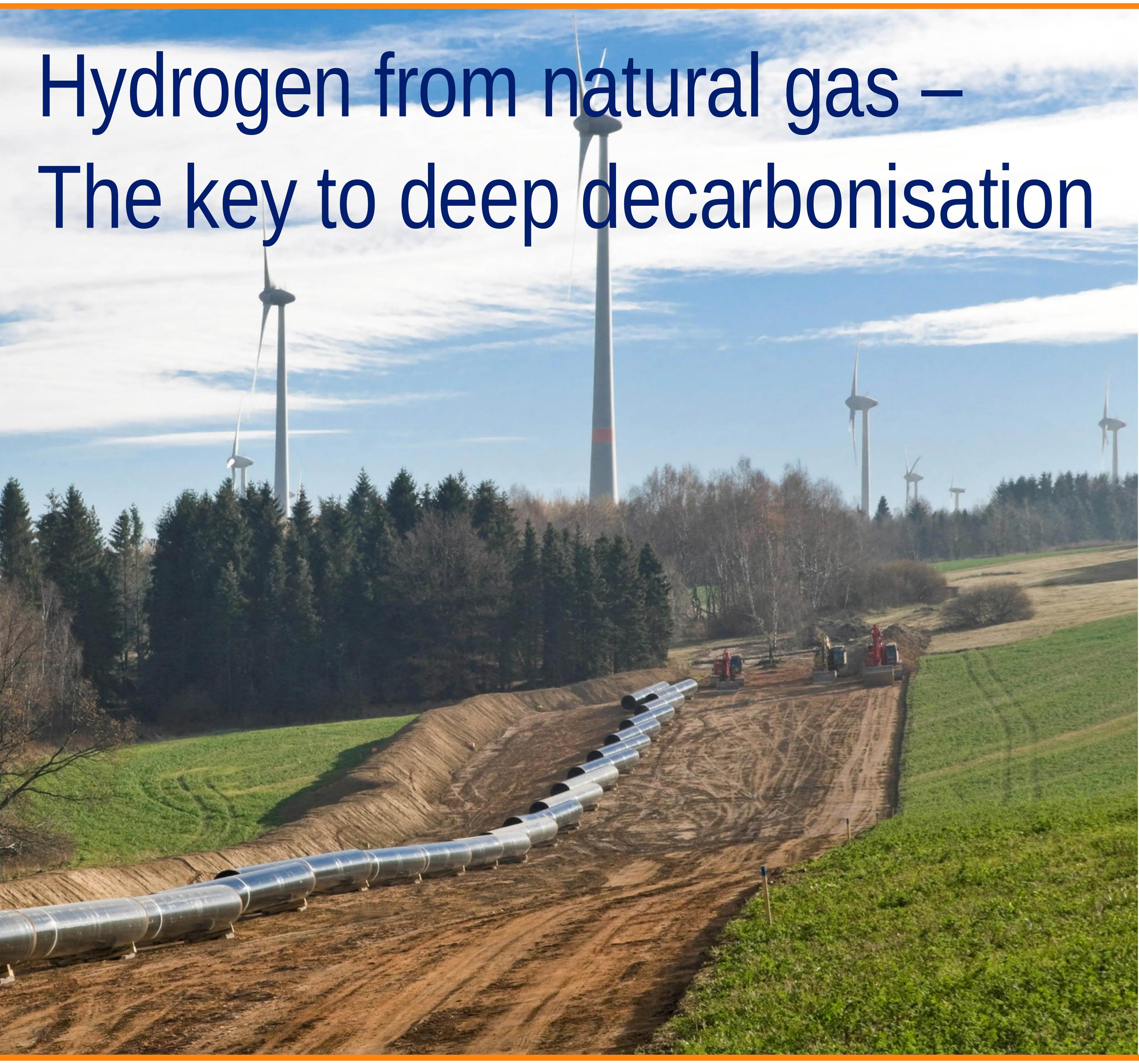
Hydrogen from natural gas – The key to deep decarbonisation



Pöyry Management Consulting

Background and purpose

This Discussion Paper was commissioned by Zukunft ERDGAS to contribute to the debate concerning the deep decarbonisation of the European energy sector required to meet the Paris Agreement targets.

Previous discussion papers have put forward decarbonisation pathways that rely heavily on ‘all-electric’ solutions. These depend predominantly on renewable electricity to deliver decarbonisation of all sectors. This paper offers an alternative to an ‘all-electric’ solution by building an alternative pathway that allows the inclusion of gas based technologies alongside the ‘all-electric’ pathway technologies. The new pathway demonstrates that hydrogen from natural gas can be an essential complement to renewable electricity. The pathway also considers the benefits of utilising methane pyrolysis technology in Europe to produce zero carbon hydrogen.

Decarbonising the energy sector

Awareness of climate change impacts and the need for deep decarbonisation has increased greatly in recent years. In response to this growing awareness and the urgency of decarbonisation, policy makers have taken action and in 2015 agreed to what is known as the Paris agreement. This has set the target to limit the expected global average temperature increase to significantly less than 2°C, with the ambition to keep to the limit to less than 1.5°C.

In order to achieve such necessary and ambitious targets, the European economy, and in particular the energy sector, needs to significantly reduce CO_2 emissions to a fraction of current levels (e.g. -80%, -95%) with a growing consensus that net zero emissions will be required. Many changes will be required in how we work, travel, heat our homes and how we obtain the energy necessary to carry out all these activities.

From the 1990 baseline of 5,751MtCO_2, a 24% reduction in CO_2 emissions had been achieved by 2016 across Europe (EU28 plus Norway and Switzerland). Limiting the temperature increase to <1.5°C by 2050 will require a reduction of emissions by another three times the amount already achieved.

In 2018 the EU published its vision for the future of energy in Europe ‘A Clean Planet for All’[1] which aims at creating a “prosperous, modern, competitive and climate neutral economy by 2050.” A set of pathways has been developed and assessed that rely heavily on renewable energy and energy efficiency, with a limited role for natural gas and hydrogen.

Different pathways to decarbonisation

In order to investigate alternative decarbonisation scenarios, Pöyry uses a pathway approach, imagining and modelling different possible futures for the European energy system and analysing the implications and risks from choosing a certain path. A pathway is defined by the constraints that are placed on certain technologies that can contribute to decarbonisation. By keeping the underlying assumptions, such as the development of demand, technology developments and commodity costs consistent between the pathways, we are able to see the impacts of varying the constraints. The analysis in this paper builds on Pöyry’s ‘Full Energy-Sector Decarbonisation Study’[2], which compared an ‘All-Electric’ pathway with a more balanced ‘Zero Carbon Gas’ pathway.

In the ‘All-Electric’ pathway, decarbonisation was mainly achieved through restricting options to electrification, and no hydrogen or other zero carbon or decarbonised gas was allowed. The ‘Zero Carbon Gas’ pathway, on the other hand, allowed various forms of ‘zero carbon gas’ to contribute on an economic basis. This pathway showed a reduction in delivery risks and costs compared to the ‘All-Electric’ pathway.

In this study, a ‘Zero Carbon Hydrogen’ pathway has been developed, which uses identical assumptions to the ‘Zero Carbon Gas’ pathway, with the addition of pyrolysis as an available technology to produce hydrogen alongside electrolysis and steam methane reformation with carbon capture and storage.

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1 European Commission. “A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.” 2018.

2 Pöyry Management Consulting. “Fully decarbonising Europe’s Energy system by 2050.” 2018.

Study summary messages and conclusions

Renewables will play a significant role in all pathways as a cost-effective form of clean energy in the future. In the Zero Carbon Hydrogen pathway, renewables dominate in the power sector, and passenger vehicles and non-process heat sectors are electrified.

Relying on very high levels of electrification in an 'all-electric' future is a high risk strategy. EU targets are more likely to be achieved if hydrogen from natural gas is included in the solution. The 'All-electric' pathway relies on new nuclear, fast grid reinforcement and a solution to the inherent lack of seasonal storage. It also risks failing to decarbonise sectors that cannot easily be electrified raising the real possibility that overall decarbonisation targets may be missed.

Zero carbon hydrogen produced from natural gas can significantly reduce these risks when used as part of the energy mix. It can therefore be an **essential** complement to renewables for the successful deep decarbonisation of the European economy. Hydrogen makes a significant contribution to the heavy transport and process heat sectors and allows non-process heat to decarbonise where electrification is not feasible.

Development of pyrolysis will allow cost-effective, practical and secure development of hydrogen at scale and foster competition in the energy sector. Pyrolysis has key advantages – it is cheaper and more scalable than electrolysis and overcomes many of the barriers associated with widespread deployment of CCS (which would be necessary for SMR to produce zero carbon hydrogen).

Hydrogen reduces the risks of missing decarbonisation targets

The 'Zero carbon Hydrogen' pathway reduces the risk that Europe fails to meet its decarbonisation goals. It could also result in lower costs and minimise disruption for residential and industrial users. Analysis shows that there are several prerequisites of an 'All-Electric' pathway that, if not met, would jeopardise meeting decarbonisation targets. Allowing hydrogen to play a role will significantly reduce these risks. The following table presents the risks to decarbonisation and the impact on the different pathways that we have analysed.

Risk description	Risk in 'All-Electric'	Risk in 'Zero Carbon Gas'	Risk in 'Zero Carbon H_2'	Benefits of 'Zero Carbon Hydrogen' pathway
Electrification of heavy good vehicles is not technically feasible within timeframe	✖	*none*	*none*	Hydrogen provides alternative in heavy transport
Biomass supply chain does not deliver the volumes needed for power and heat	✖	*none*	*none*	Very limited use of biomass in transport, heat and power
Nuclear power faces greater than expected political opposition and is not deployed	⚠?	*none*	*none*	No new nuclear power generation is needed to be across Europe
Nuclear power cannot be operated flexibly (e.g. turn off for several days)	⚠?	⚠$	⚠$	Limited reliance on nuclear power, since no new plants built
Heat pumps fail in cold conditions before reaching the -15º design limit	⚠?	⚠$	⚠$	
Heat pump supply chains do not develop quickly enough	⚠$	⚠$	⚠$	Reduced reliance on heat pumps due to use of more stand-alone hydrogen boilers
Energy efficiency in residential properties evolves slower than expected, making heat pumps impractical	⚠$	⚠$	⚠$	
Electricity grid reinforcement (incl. distribution, transmission, interconnection) cannot keep pace with demand and renewables growth	⚠?	⚠$	⚠$	Exisiting gas grids and hydrogen use provide alternative energy source
CCS faces greater than expected political opposition and/or technical obstacles resulting in limited availability	*None*	⚠?	⚠$	Methane pyrolysis offers a viable alternative as a method of providing energy (hydrogen)

✖ Risk of missing targets – no other option available ⚠? Significant cost increase, risk of missing targets ⚠$ Cost increase

Hydrogen has an essential role in the heat and transport sectors

Hydrogen provides a feasible and practical option for those sectors and applications that are very difficult, or impossible, to electrify. These include:

- **Industrial process heat.** Very high temperature process heat applications (e.g. glass production, plastics and rubber manufacturing) cannot be electrified and otherwise can only decarbonise with biomass or CCS. This, in turn, introduces supply chain, political, and technical issues;
- **Space heating.** Many buildings are unsuitable for the use of heat pumps (e.g. poor insulation, cold weather, no space for radiators or underfloor-heating, excessive disruption to homes or businesses);
- **Heavy road transport.** It is impractical to use very large batteries / overhead lines for the haulage sector;
- **Waterborne transport[3].** Electrification is not feasible due to long journeys and therefore extended periods between possible re-charging.

In order for hydrogen to play a role in these sectors it requires a scalable and low carbon production method that can only be achieved with the use of natural gas.

Pyrolysis can be a cost-effective and scalable solution to hydrogen production

This is the first European decarbonisation study to consider methane pyrolysis as a third hydrogen production method alongside steam methane reforming with CCS and electrolysis.

Steam methane reforming (SMR)[4] reacts methane (CH_4) with steam under pressure to produce hydrogen and CO_2. In order for the process to be carbon-neutral, it needs to be combined with carbon capture and storage (CCS) of the CO_2 produced. The key advantage of this technology is that it is currently the most developed option, especially at scale, and as such presents the cheapest form of hydrogen production even with the addition of CCS.

Electrolysis is another existing technology that splits water (H_2O) into hydrogen and oxygen using electricity. There are no direct CO_2 emissions from this process. The hydrogen produced can be only be considered zero carbon if the electricity used is itself zero carbon. The fact that there are no direct carbon emissions and no other by-products that need to be stored, make this option attractive, although there are questions around cost and scalability.

Pyrolysis is the decomposition of methane into hydrogen and solid carbon (C). The technology has been developed since the 1990s[5] and has the potential to play an important role in hydrogen production in the future. This is because the residual carbon produced by the process is in solid rather than gaseous form and therefore requires no complex storage in underground caverns, as is the case with CCS. Additionally, this solid carbon can be used in existing industries, such as carbon black for tyres or in concrete for construction, or potential new uses, such as graphene.

Utilising pyrolysis mitigates the risk that widespread CCS deployment may not be possible in those countries where political opposition or technical challenges exist[6].

3 Waterborne transport has not been analysed in detail in this study, as it was considered out of scope.

4 Both steam methane reforming (SMR) and auto-thermal reforming (ATR) are potential processes of splitting methane into hydrogen and CO_2. For the purposes of this paper, we will use the term SMR, but no particular preference is indicated through this.

5 IEA. “The future of hydrogen report.” 2019.

6 This study assumes that the availability of CCS in Europe is limited to Norway, UK, Belgium, Denmark, Ireland, Netherlands and Poland. Electrolysis and pyrolysis are available in all countries.

‘Zero Carbon Hydrogen’ pathway insights

Our analysis for the ‘Zero Carbon Hydrogen’ pathway has identified the following key insights:

Heat pumps and hydrogen boilers decarbonise the space and water heating sector. Heat pumps are deployed where practical and account for 50% of heat capacity, with hydrogen boilers contributing 27%. Hydrogen makes up 49% of fuel used; biomethane and electricity both contribute around 14% each in 2050.

Post-combustion CCS gas is used in process heating, where available, whereas in other countries hydrogen is deployed. CCS accounts for 18% of capacity in the segment, while hydrogen accounts for 56% in 2050.

Light passenger transport is mostly electrified, due to the high efficiency of battery electric vehicles. However, larger vehicles are decarbonised using hydrogen, as longer journeys and heavier weight makes batteries impractical in this segment. Hydrogen accounts for 42% of all fuel used in transport (LDV and HDV sectors) in 2050.

Renewables (solar PV and wind) account for 76% of power capacity and 72% of power generation. As conventional thermal power plants are decommissioned, they are replaced by hydrogen and CCS power plants. No new nuclear plants are commissioned.

Hydrogen demand is primarily met through pyrolysis and steam methane reforming with CCS gas. Electrolysis deployment is limited because there are insufficient periods of low electricity priced periods normally associated with excess renewable generation, due to flexible demand side response, especially from electric vehicles. Pyrolysis is widely deployed in the countries where CCS is not available. Pyrolysis makes up 55% of hydrogen production, while SMR with CCS supplies 30%, and electrolysis 15% in 2050.

Policy makers’ role in securing a hydrogen future

Policy must play a significant role in achieving decarbonisation. Specifically it must enable industries to make the investments and adaptations necessary in order to develop a hydrogen energy economy. Accordingly, European and national policy makers will need to recognise the importance of hydrogen from natural gas in decarbonisation efforts and consider the following.

Policies that support the role of hydrogen in decarbonisation efforts and allow different technologies (including zero carbon gas) to compete on an equal basis should be developed to achieve the most efficient outcome.

Targets for zero carbon gas in the European energy mix should be set (including renewable gas from bio-sources and decarbonised gas), in order for investment in zero carbon gas options to become attractive and for innovation to progress.

Research into implementation of hydrogen technologies should be supported. These include fuel cells, hydrogen based fuels and methane pyrolysis methods, as well as uses for end use carbon products.

Investments in energy networks should be considered based on the impact of the investment on decarbonisation. The role of hydrogen from natural gas and the role of existing gas networks in enabling decarbonisation should be recognised, and research into converting natural gas networks to hydrogen should be supported. This should include demonstration projects from proof of concept towards implementation. Policy makers should ensure a level playing field for investments in infrastructure to support decarbonisation, whether it be the expansion of electricity grids or the conversion of natural gas grids.

Contact details

Name:	Richard Sarsfield-Hall Benedikt Unger	Email:	richard.sarsfieldhall@poyry.com benedikt.unger@poyry.com
Address:	Pöyry Management Consulting	Tel:	+44 (0) 207 932 8249
	King Charles House Park End Street Oxford, OX1 1JD	Tel: Email:	(switchboard) +44 (0)1865 722660 consulting.energy.uk@poyry.com

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