Cite this article

Clarke R and Abánades A (2021)

Briefing: Pyrolysis of natural gas to hydrogen: a key energy transition tool.

Proceedings of the Institution of Civil Engineers – Energy **174**(3): 98–102,

<https://doi.org/10.1680/jener.20.00063>

Briefing

Paper 2000063

Received 23/11/2020;

Accepted 01/03/2021;

Published online 15/07/2021

Keywords: carbon capture and storage

(CCS)/energy policy/energy supply/gas/

gas-supply

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Energy

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Briefing: Pyrolysis of natural gas to hydrogen: a key energy transition tool

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To achieve a low carbon dioxide (CO₂) energy future the fossil fuel industry must pivot to make zero-emissions hydrogen through an open, global collaboration. One track to this is ‘pyrolysis’ in which natural gas is split into ‘white’ hydrogen and carbon black. This avoids the need for a massive roll-out of carbon capture and storage sites as envisaged in natural gas reforming or ‘blue’ hydrogen schemes. The advantages of both options are needed to support longer-term efforts to move towards ‘green’ hydrogen where water is split into its elements. By leading the development of all these routes to hydrogen, the energy majors of today will be able to utilise their enormous resources, technical ingenuity and vast capital and lead the future of energy. With the COP26 climate conference just months away, the UK has a critical role in directing efforts to bring hydrogen to the fore both at home and abroad.

Fear of a planetary climate collapse promotes an understandable desire to keep fossil fuels buried underground and rapidly convert the world’s economy from hydrocarbon to low carbon dioxide energy. To reach that urgent ambition requires hydrogen, and masses of it (Nuttall and Bakkenne, 2020), but time is running out (Meinshausen *et al.*, 2009). Global warming exceeds 1°C and the 2015 Paris Agreement goal of limiting the rise to 1.5–2°C is in danger of being lost. While wind and solar energy costs have fallen steadily, analyst McKinsey says the ‘math is daunting’ (Henderson *et al.*, 2020) if the target of net zero carbon dioxide emissions is to be reached by 2050.

In the authors’ view, the fossil fuel energy giants must now rise to a new challenge, to use their enormous resources, technical ingenuity and vast capital to produce fossil-sourced energy with near-zero releases of greenhouse gases. Such action would seal their fate – to be part of the future of energy.

Today’s global efforts on carbon dioxide emissions reduction (‘decarbonisation’) are woefully insufficient and, all too often, they perilously require nature to be a kind of carbon banker. Very few analysts take into account a vast sea of hydrogen that can be won if only the link between fossil fuels and emissions is broken.

In the long run, water will be the main source of hydrogen but in the energy transition period, natural gas could play a major role provided the logistics are critically examined. The goal must be to develop all forms of clean hydrogen, at scale, through global alliances.

1. Hydrogen too

Last April, the UK’s Department for Business, Energy and Industrial Strategy started recruiting staff to implement the UK’s Net Zero 2050 plan – to roll out electric vehicle chargers, power storage and the digital infrastructure to make it all work (UK Government, 2020). Is hydrogen an also-ran? Until 2020, it seemed so, due to the success of solar and wind, offshore wind in particular.

Hydrogen’s public relations is a challenge. To obtain low carbon dioxide or ‘green’ hydrogen requires the use of electrolysis, even though water is becoming a precious resource. Alternatively, if hydrogen comes from natural gas it is deemed to be ‘grey’, tainted by a sense that carbon dioxide emissions were obscured in early trials. Hydrogen bus roll-outs in cities have thus had a mixed reception. Yet WrightBus, a Northern Ireland company, has plans to make 3000 buses and convert 10% of the UK inventory to hydrogen. Road haulage fleets could run on hydrogen too.

As electric cars gain market share the transport eggs must be placed in more than one energy basket.

For steel and glassmaking, the need for high-temperature heat makes hydrogen ideal. In California, an all-electric future looks like playing with fire: in 2019 Pacific Gas and Electric settled a US\$13.5 billion claim its pylons ignited forest fires that destroyed towns, killing many.

In home cooking and heating, hydrogen burns cleanly and, being carbon dioxide-free, hydrogen-fuelled boilers would take the pressure off still-elusive home insulation efficiency targets. The challenge now is to safely access all the hydrogen at present locked up in fossil fuels, to boost the transition to a world of interchangeable clean power and heat.

2. Fossil's future

Hydrogen is an exit strategy for the fossil fuel industry; it avoids the need to abandon vast reserves of gas and oil that, in practice, the world still needs. However, ClientEarth's litigation (ClientEarth, 2021) shows the industry the time has come to seriously up its game on fugitive emissions, pollution, safety and disclosure. Public trust has to be regained. Its hydrogen must be lilywhite. With oil, the future lies in a myriad of non-fuel products – the plastics, pharmaceuticals and chemicals that underpin modern life. Using microwaves, hydrogen and graphene precursors can be made from waste plastic. The *Financial Times* anticipates that peak oil production is near (Lewis, 2020).

3. Unwelcome guest

Hydrogen is labelled 'grey' if carbon dioxide is vented during its production, in a reformer, the main route to hydrogen today. If carbon dioxide is not to be released, it must be buried or used – for example, for enhanced oil recovery. The Allam Fetsvet process (NETpower) aims to produce pure carbon dioxide in an energy plant that will cost no more than standard natural gas power facilities that, in any case, could run on hydrogen.

Environmentalists worry that buried carbon dioxide might leak out; yet, until recently, there has not been wide interest in carbon dioxide capture and storage (CCS). Columbia University's Julio Friedman notes just 0.1% of today's carbon dioxide emissions are captured (Resources Radio, 2020). Moreover, after a decade's work, the European Union (EU) had spent €424 million on CCS with little to show for it (Rathi, 2018). In the US, uptake of the 45Q tax break suggests there is limited appetite for firm action on CCS. Enticing schemes, such as biomass with carbon capture (BECCS) now look to be deeply flawed. Ongoing alarm over climate-change-driven tipping points makes it clear that the earth and atmosphere can no longer accommodate carbon dioxide on the faint promise of its future capture.

With 'blue' hydrogen the carbon dioxide is captured and with 'green' hydrogen only water and electricity are needed. To unblock the energy transition, say consultants Pöyry (Sarsfield-Hall and Under, 2019), fossil hydrogen must be recovered without producing carbon dioxide. How? By making 'white' hydrogen gas and carbon black, a vital feedstock for the future (Figure 1).

4. Trial separation

Pyrolysis literally means fire and separation. The urgency of the climate crisis has renewed interest in an alternate form

Figure 1. Natural gas is heated in a molten metal, bubbler column where it dissociates into hydrogen and carbon (Geißler *et al.*, 2016)

of carbon capture where both the product (hydrogen, H_2) and by-product (carbon, C) have utility. The idea is simple, to cheaply split natural gas (CH_4) into its elements using free heat. A key hurdle is to prevent carbon micro-particles from coking up the process (Abánades *et al.*, 2012). By avoiding carbon dioxide this is carbon capture with the potential for utilisation, or CCU.

In 1966, early pyrolysisers used a catalytic fluidised bed to split methane. Revived by the EU, the 2006 SOLHYCARB project (Rodat *et al.*, 2010), investigated the use of solar heat. Promising hydrogen yield and costs spurred further work. A breakthrough in the latest study, DECARGAS, has German industry intrigued ('Tin Tower'). Hot metal pyrolysis can deliver competitive costs and a coke-free, high yield of hydrogen (Geißler *et al.*, 2016).

Thus, there are three routes to hydrogen: reforming (cheap but hobbled by its carbon dioxide burden); electrolysis (still expensive and a problem for arid regions); pyrolysis (unproven at scale). Pyrolysing heat could derive from two sources: ohmically, by way of excess renewable power, or thermally, from concentrated solar energy or possibly fusion. Temperatures above $1000^\circ C$ work best. Many locations across the globe meet the prerequisites: natural gas reserves, solar heat or renewable power ('Hydrogen Hot Spots'). Plant sizes could vary, from vast multi-megawatt systems right down to local, fuelling station-sized hydrogen refilling points. If viable, coal is also a long-term source of carbon (Figure 2).

Bill Gates backed Heliogen (Figure 3) a solar concentrating array that uses artificial intelligence to attain temperatures high enough to make cement or directly split water. It could be used to split methane. Australia, Russia and Canada are well endowed with gas. Huge Himalayan solar potential could serve India, Pakistan, Bangladesh and China, and, at night, molten salt heat stores can keep solar plants on. Sand-sourced regenerated silicon is a way to transport hydrogen. In addition, plasma pyrolysis (Schneider *et al.*, 2020) is another promising route to hydrogen.

5. Not so black

Carbon black, the co-product of pyrolysis, has high value. If high-grade carbon is produced, the applications are manifold: in grid-scale battery electrodes, steelmaking with CCS, fibres, tyres and – the prize – industrial graphene. Would the carbon be stored? In Russia, mountains of sulfur have not been burnt because the fumes are noxious, the effects are local but transient and the yellow piles may have uses in future batteries. For carbon, the choice is starker: when not burnt, irredeemable, global consequences are avoided if the carbon black is used in a circular economy.

6. Integrated action

Is electricity with batteries the future? Not without hydrogen. To navigate inter-seasonal power demand without large-scale hydrogen production and storage would be perilous to energy

Figure 2. Notional hydrogen scenario, 2040 (map: adapted from The World Bank, Solargis)

Figure 3. Renewable energy-rich regions could make hydrogen from natural gas without producing carbon dioxide (image: Heliogen)

security. Hydrogen is already a major global industry. However, an Achilles heel limits its future in clean energy: hydrogen must divorce itself from its absolute need for carbon capture and storage. In the authors' opinion, with few exceptions – one is Equinor's H2H project – carbon dioxide is a troublesome by-product. Conventional thinking supposes that natural gas reforming with CCS is best since, apparently, it is the cheapest option. Yet such studies omit to show where enough carbon dioxide storage sites exist given the apparent resistance of the public to carbon capture; they simply do not trust it (Whitmarsh *et al.*, 2019). Hydrogen, the authors submit, should mainly be 'white' or 'green' – derived from plentiful natural gas using pyrolysis, or from renewable power using electrolysis.

In one area, perhaps, CCS has a niche future – by way of the direct air capture of carbon dioxide for synthesis (with clean hydrogen) into jet fuel. It is only acceptable to use the atmosphere if the irksome carbon dioxide debt is paid upfront, in full. However, hydrogen-fuelled aircraft, like the Airbus ZEROe, could be a cheaper option in the long run.

The technical innovations outlined here have the potential to bring a sea of hydrogen into play, enabling an energy transition to proceed on the titanic scale required. The next steps are crucial. The fossil fuel industry has a once-in-a-lifetime opportunity to take the lead and re-write the clean energy narrative. Extending hydrogen's role requires a combination of trust, policy clarity and billion-dollar, industrial-scale deployments. The clinching arguments are about energy integration and local-scale action. A top-down conversion of a gas grid today is unthinkable: the change must be bottom up. Pyrolysis would drive the use of valuable gas assets through a step-by-step

conversion to hydrogen, while integrating renewable energy, storage and fuel cells.

7. UN climate change conference of the parties (COP26)

In the UK, some big projects are already in play, for example Leeds-H21, Teeside Hydrogen and HyNet, not to forget the H2H venture in Hull. With coronavirus recovery plans being hotly debated across Europe, hydrogen is emerging as a front-runner. The UK must seize the initiative that its presidency of the vital COP26 climate conference provides. With co-host Italy's backing, and the impetus of a new US administration, the UK must champion clean hydrogen and present a vision and firm plans.

Specifically, the hosts need to lead international negotiations to achieve a collaborative, open-source, clean hydrogen development plan. Everyone wins when patents are pooled; that applies to hydrogen as much as it does to vaccines. The UK's hydrogen projects need to be funded at scale. The fossil fuel companies would be expected to take a leading role here under the intense gaze of international scrutiny. Trust is vital if the financial, technical and physical resources needed are to be tapped. Alok Sharma, the UK minister in charge of COP26, already has the headlines. The 2021 climate conference is all about the energy transition, clean transport and the finance needed to make it all happen.

Declaration of interests

Richard Clarke has no interests in hydrogen pyrolysis projects or investments. Ortec Finance does not invest in capital

projects. Alberto Abánades has been involved for several decades in decarbonisation research, by applying technologies ranging from nuclear and solar to methane pyrolysis.

Note: the authors label pyrolytic hydrogen ‘white’ hydrogen. Elsewhere it has been called ‘turquoise’ or ‘blue-green’. From the authors’ perspective, only electrolytic hydrogen can be a shade of green. It is the only form of hydrogen that is both clean and sustainable.

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