FLORENCE SCHOOL OF REGULATION

ROBERT SCHUMAN CENTRE

POLICY BRIEF

Diversifying risk and maximising synergies in hydrogen technologies: the case of methane pyrolysis

Highlights

- Methane pyrolysis is an endothermic process, in which methane at very high temperatures decomposes into gases, liquids, and solids. It is a well-established process that is now being optimised to produce low carbon or even carbon negative hydrogen.
- The growth of the decarbonised hydrogen economy is at an early stage and technology neutrality is key to ensuring swift decarbonisation at the lowest environmental and economic cost.
- Gas and electricity are becoming highly interconnected, and their future planning should reflect that. Methane pyrolysis is well positioned to provide support across multiple frontiers of an economy-wide drive to decarbonisation.
- Where renewable electricity is scarce, energy efficiency is paramount. Considerations of the energy efficiency of electrified hydrogen production technologies should be an important factor in their deployment.

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Introduction

Most of the ~70 million tonnes (mt)[1] of hydrogen (H2) produced globally every year are used as a feedstock for oil refining and ammonia production. Decarbonised hydrogen is widely expected to emerge as a direct replacement for fossil hydrogen in these applications as well as a low and zero-carbon energy vector[2].

Whilst there is significant uncertainty regarding future demand for hydrogen, the European Commission's Hydrogen Strategy[3] envisages that current feedstock hydrogen in the EU (roughly 10 mt)[4] could be replaced by low and zero-carbon options by 2030. Some scenarios from the EU[5] and the IEA[6] envisage growth of as much as 20mt by 2030 and 68mt by 2050. Certainly, all existing feedstock demand, as well as any additional energy-related demand will have to be based on zero-carbon options by 2050, in line with EU climate objectives.

Achieving these levels of low and zero-carbon hydrogen production will require a swift overhaul of the sector, utilising production methods that are scarcely applied at a commercial level currently[7]. The approach chosen can have significant implications for the cost, speed, and environmental externalities associated with the transition.

This policy brief highlights the importance of considering the growth of a clean hydrogen economy within the context of a wider framework of decarbonisation objectives, without prejudice in the choice of technology needed to achieve them[8]. In doing so, the authors address the issue of technology neutrality through the case of methane pyrolysis.

1. Hydrogen production methods: current and future

1.1. Current production methods

95% of global hydrogen is currently produced with fossil fuels, largely through steam methane reforming (SMR) and auto thermal reforming (ATR) of fossil methane[9] ('grey hydrogen'). These forms of hydrogen production are highly carbon intensive, responsible for ~830 mt of carbon dioxide (CO_2) emissions every year, roughly equivalent to the total emissions of the United Kingdom[10].

At the EU political and policy level, it may be argued that the most widely favoured alternative to SMR and ATR is to produce hydrogen through electrolysis[11]. This process involves passing an electrical current through an electrolyser to split a feedstock, notably water, releasing only hydrogen and oxygen in the process. If the electricity powering the electrolyser is of renewable origin, there are no process emissions. This is called 'green hydrogen'.

Applying carbon capture utilisation and storage (CCUS) to SMR and ATR can reduce CO_2 emissions by 50 - 90%, potentially even more in the future. This approach is referred to as 'blue hydrogen'. SMR and ATR with CCUS is gaining attention as a transitional option, as CCUS technology can be quickly and cost-effectively retrofitted to existing SMR and ATR plants, supporting swift decarbonisation at existing grey hydrogen production sites[12]. Although CCUS can theoretically abate a significant portion of the process emissions, more than 90% capture rate remains expensive at this stage, roughly 60% is more common[13]. Moreover, blue hydrogen still suffers from the same issue of supply chain

1 https://www.iea.org/reports/the-future-of-hydrogen

2 The European Union (EU) aims to cut greenhouse gas emissions by 55% relative to 1990 levels by 2030 as well as to become the world's first climate neutral continent by 2050, goals which are now enshrined in EU law. The EU Hydrogen Strategy foresees a meaningful role for hydrogen in contributing to these goals, namely through sector coupling and as a feedstock in hard to abate sectors. The EU's 'strategic long-term vision for a prosperous, modern, competitive and climate neutral economy' projects a rise in hydrogen use as a portion of energy consumption from around 2% currently, to 13-14% by 2050. In an effort to prepare the future gas market for these changes as well as facilitate decarbonisation of the sector, the EU is currently in the process of revising its gas market legislation.

3 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301

4 https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

5 https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

6 https://www.iea.org/reports/world-energy-outlook-2020

7 https://fsr.eui.eu/publications/?handle=1814/66205

8 https://cadmus.eui.eu/handle/1814/68977;jsessionid=761BAE645695C6834E075759B0154132

9 Commonly referred to as 'natural gas'.

10 https://www.iea.org/fuels-and-technologies/hydrogen

11 The EU Hydrogen Strategy targets 6GW of electrolyser capacity in the EU by 2024 and 40GW by 2030.

12 https://ec.europa.eu/info/sites/default/files/iogp_-_report_-_ccs_ccu.pdf

13 https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

methane emissions and fossil fuel lock-in as grey hydrogen, due to the feedstock. Nevertheless, CCUS technology is quickly evolving, with increased capture rates at decreasing costs[14]. Furthermore, decarbonisation pathways typically require extensive application of carbon removal, further supporting the notion that these technologies could have a significant role to play in the future[15]. However, these developments remain uncertain.

1.2 Methane pyrolysis

One emerging hydrogen production method that has very low or even negative carbon emissions is methane pyrolysis, referred to as 'turquoise hydrogen'. Pyrolysis is an endothermic process, in which fuel at very high temperatures decomposes into gases, liquids, and solids[16]. Like grey and blue hydrogen, turquoise hydrogen also uses methane as a feedstock (biomethane or fossil methane)[17]. However, unlike blue and grey hydrogen which use methane as both feedstock and energy input, pyrolysis uses electricity to generate the heat required to power the reaction. Crucially, if the electricity is of renewable origin, there are no process emissions. In this sense, pyrolysis can be considered an electrified hydrogen production method, along with electrolysis[18]. Both pyrolysis and electrolysis can use renewable electricity (RES-E) to power the reaction, one uses water as a feedstock and the other uses methane (of biological or fossil origin), both are zero direct carbon emission options under this scenario.

Another important difference of turquoise hydrogen versus blue hydrogen is that SMR and ATR produce gaseous CO_2 as a co-product, whereas methane pyrolysis produces solid carbon (C) - 'carbon black'. Given its solid form, this carbon can be easily stored without carbon capture infrastructure or more interestingly, directly used in a range of applications[19].

Carbon black is a key strengthening component of rubber products such as tyres, it is also added to electrical equipment for its conductive and insulating properties, as well as for giving pigment to inks and plastics. Moreover, carbon black is as an effective soil improver, and as such can play a role in supporting EU initiatives aimed at carbon sequestration in the agricultural sector as well as forming part of a circular economy[20]. Leveraging agricultural land for carbon sequestration was endorsed in the EU Farm to Fork Strategy[21] and Circular Economy Action Plan (CEAP)[22], as well as being defined through more concrete proposals in the EU's recent carbon farming initiative[23].

Despite being well-established as a process for producing carbon black, pyrolysis optimised for hydrogen production at scale is not as technologically mature as SMR or ATR with CCUS, nor certain forms of electrolysis. According to the IEA, SMR/ ATR with CCUS as well as some electrolysis approaches have a technological readiness level (TRL) of 8-9 out of 11, indicating that they have been deployed at commercial scale[24]. Methane pyrolysis has a TRL of 6, indicating the development of full prototypes but not yet commercial demonstrations. Nevertheless, full scale facilities are likely to follow in the coming years,

14 https://www.iea.org/commentaries/is-carbon-capture-too-expensive , https://www.globalccsinstitute.com/wp-content/uploads/2021/04/Circular-Carbon-Economy-series-Blue-Hydrogen.pdf

15 https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20insights/how%20the%20european%20union%20could%20achieve%20net%20zero%20emissions%20at%20net%20zero%20cost/net-zero-europe-vf.pdf , https://unfccc.int/sites/default/files/resource/Energy_ActionTable_2.1_0.pdf , https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

16 For maximum efficiency and yields, pyrolysis for hydrogen production is best carried out at the highest possible temperature (~700 - ~2,000 °C), with the shortest possible residence time (time atoms spend in the reactor before being broken down into output products).

17 It is also possible to use pyrolysis for gasification of solid products such as biomass, however that process is slightly different and more complex than the pyrolysis of gas. See the following resources for more details on pyrolysis of biomass; https://www.sciencedirect.com/science/article/abs/pii/S209549561830901X, https://www.ieabioenergy.com/wp-content/uploads/2021/02/Emerging-Gasification-Technologies_final.pdf.

18 Other electrified hydrogen production methods exist, such as photocatalysis.

19 The market for high-quality carbon black is ~12 mt per year with a value of $17.2 billion and projected growth of 6.1% compound annual growth rate (CAGR) to 2028.

20 Jeffery, S. et al. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture, Ecosystems and Environment 144 175-187; Bier, H., Gerber, H., Huber, M., Junginger, H., Kray, D., Lange, J., Lerchenmüller, H. & Nilsen, P. J. (2020). Biochar-based carbon sinks to mitigate climate change, EBI Whitepaper; Schillem et al., Effect of N modified lignite granulates and composted biochar on plant growth nitrogen and water use efficiency of spring wheat (Archives of Agronomy and Soil Science, DOI: 10.1080/03650340.2019.1582767).

21 https://ec.europa.eu/info/sites/default/files/communication-annex-farm-fork-green-deal_en.pdf

22 https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

23 https://op.europa.eu/en/publication-detail/-/publication/10acfd66-a740-11eb-9585-01aa75ed71a1/language-en

24 https://www.iea.org/articles/etp-clean-energy-technology-guide

with several initiatives well underway[25].

For methane pyrolysis to be commercially viable, certain conditions are necessary. Firstly, economies of scale are key to cost drivers, meaning that production over 10,000 nm^3/hour[26] is typically required to make the operation cost-effective. Secondly, specific operating conditions are needed to produce carbon black at a high enough quality to be saleable in the market. Thirdly, the issue of methane emissions in the supply chain will need to be addressed in line with the European Commission's Methane Strategy and the gas decarbonisation legislation[27] anticipated for later this year[28].

2. Hydrogen production in the context of decarbonisation objectives

The following table outlines some key information about pyrolysis in the context of the dominant prevailing production method (SMR) as well as water electrolysis, arguably the hydrogen production technology most favoured for the medium to long term by EU policy makers.

	Electricity input (kWh per kg H_2)	**Energy efficiency (%)***	**Emissions (t CO_2 eq./ t H_2)**	**Secondary products (t/ t H_2)**
SMR	N/A	70 - 80%	1** – 9	9 (CO_2)
Water electrolysis	60 – 80	50 – 70%	0 – 22***	8 (Oxygen)
Methane pyrolysis	10 – 20	50 – 90%	negative – 4	3 (C)

**The energy retained in the hydrogen relative to the energy inputs into the process (feedstock + heat generation)*

***~1t CO_2 eq./ t H_2 if CCS added, ~9 if not*

****The broad range of CO_2 eq. emissions of water electrolysis is dependent on the origin of the electricity used, i.e., dedicated renewable or energy mix of grid electricity, etc.*

Breakdown of some key characteristics of SMR, water electrolysis and methane pyrolysis, (IEA, FSR, Argonne National Laboratory, Universidad Politécnica de Madrid, BASF[29])

The data illustrates that pyrolysis uses far less RES-E than electrolysis to produce the same quantity of hydrogen, with scope for negative GHG emissions if produced with biomethane feedstock. Moreover, methane pyrolysis derives a potentially valuable co-product, assuming there is sufficient demand for the volumes of carbon black produced[30]. Given that both SMR and methane pyrolysis can use the same feedstock, this data gives an indication that the environmental externalities associated with current hydrogen production methods are not only connected to the feedstock, but rather more with the energy input used to drive the reaction, as well as the nature of the reaction itself[31].

The following section will examine some of these factors and their relevance in a policy context, highlighting the need for coherence between interrelated areas.

25 The world's first commercial scale methane pyrolysis plant is due to come online in the US in 2021, following many years of privately funded research and development from the chemicals sector. Major energy companies are also investing in methane pyrolysis as a means of utilising existing fossil methane resources. For instance, Gazprom have patented a plasma-based methane pyrolysis method in collaboration with Tomsk University. From the public sector, the Australian Renewable Energy Agency (ARENA) part funded a project utilising biogas from sewage to produce hydrogen and graphite as part of a wider public initiative to support research and innovation in this space. BASF are leading the consortium 'ME2H2' along with several partners, with the aim of establishing a pilot methane pyrolysis plant in the coming years and a full-scale plant in ~2030.

26 Normal cubic metres of hydrogen per hour

27 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12766-Gas-networks-revision-of-EU-rules-on-market-access_en

28 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12911-Gas-networks-revision-of-EU-rules-on-market-access_en

29 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Power-to-Hydrogen_Innovation_2019.pdf, https://fsr.eui.eu/publications/?handle=1814/68977 , https://greet.es.anl.gov/files/smr_h2_2019 , https://pubmed.ncbi.nlm.nih.gov/33287054/

30 The use as a soil improver arguably merits most attention.

31 This subject was also explored in a previous policy brief which proposed a taxonomy for renewable gases.

2.1 'Energy efficiency first' and 'energy system efficiency' principles

The energy required for hydrogen production is central to the debate on its future role in the energy sector, as it is a key driver of cost and emissions. Applications of hydrogen, as well as the given technology chosen to produce it, should follow the 'energy efficiency first' principle[32].

The primary factor dictating the energy efficiency of hydrogen production methods is the characteristics of the feedstock. Simply put, the chemical bonds holding together the hydrogen and oxygen molecules in water are considerably stronger than those holding together the carbon and hydrogen in methane. As a result, 60-80 kWh of electricity is required to produce 1kg of hydrogen from water, whereas only 10-20 kWh is required to produce the same amount of hydrogen from methane through pyrolysis, roughly 80% less.

This is important, as hydrogen is far from the only sector in the EU that is likely to be electrified as part of the energy transition to 2050[33]. The demand for RES-E in the EU is forecasted to grow to 2,000 terawatt-hours (TWh) in 2030 and 4,000 TWh in 2050, up from less than 1,000 TWh today[34]. As such, RES-E produced in the EU is likely to be a scarce and valuable commodity.

A recent study[35] indicates it is far from certain that there will be adequate RES-E to meet direct electrification needs as well as fulfil the EU's decarbonised heating, cooling, transport, industry, and hydrogen objectives over the next couple of decades. Cost-effective imported hydrogen/RES-E supply chains will take time to establish and are accompanied by their own unique difficulties and drawbacks. In this context, the 'low electricity' characteristic of pyrolysis may prove valuable.

Fundamentally, electrified hydrogen production is a less efficient use of the energy than direct electrification due to the efficiency losses in breaking down the feedstock. These efficiency losses are roughly five times higher for water electrolysis than for methane pyrolysis, leading to a proportionately higher opportunity cost. Nevertheless, an overall perspective of 'energy system efficiency'[36] also needs to be considered, this will require incorporating decarbonised energy vectors to maximise the productive potential of a renewable dominated energy mix. The scope of low electricity hydrogen production technologies, such as pyrolysis, to somewhat decouple energy efficiency losses from the value of a decarbonised energy vector, should be a key consideration in their perceived usefulness.

2.2 Carbon sinks to meet climate goals

For the EU and other major economies to reach net-zero by 2050 as well as meet the aims of the Paris Agreement, carbon removal technologies will be required to offset emissions in certain hard to abate sectors. This is the conclusion of the decarbonisation pathways mapped by the IEA[37], UNFCCC[38], and IPCC[39].

For example, even if extraction and combustion of hydrocarbons was to stop entirely, methane emissions will continue to be produced in massive quantities by the agriculture and waste sectors; animal agriculture is already comfortably the largest source of methane emissions globally and in the EU[40]. There are several Member State strategies targeting increased biogas production from this methane[41], an approach that is endorsed under the EU Methane Strategy[42]. However, when biogas is directly combusted it releases CO_2, mitigating but not eliminating the emissions issue. One way to avoid the GHGs is by utilising biomethane in pyrolysis, sequestering the carbon into useful products and producing

32 As per Regulation (EU) 2018/1999, the energy efficiency first principle means '…to consider, before taking energy planning, policy and investment decisions, whether cost-efficient, technically, economically and environmentally sound alternative energy efficiency measures could replace in whole or in part the envisaged planning, policy and investment measures, whilst still achieving the objectives of the respective decisions.'.

33 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R1999&from=EN

34 https://fsr.eui.eu/publications/?handle=1814/71439

35 https://cadmus.eui.eu/bitstream/handle/1814/71402/RSC%202021_55.pdf?sequence=1

36 https://www.hydrogeneurope.eu/wp-content/uploads/2021/06/Hydrogen-Europe-Position-Paper-on-the-Fit-for-55-Package.pdf

37 https://www.iea.org/reports/ccus-in-clean-energy-transitions

38 https://unfccc.int/climate-action/marrakech-partnership/reporting-tracking/pathways/energy-climate-action-pathway#eq-1 , https://unfccc.int/sites/default/files/resource/Energy_ActionTable_2.1_0.pdf

39 https://www.ipcc.ch/sr15/chapter/spm/

40 https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf

41 For example as part of national energy and climate plans (NECPs) https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en, https://ec.europa.eu/energy/sites/default/files/documents/de_final_necp_main_en.pdf , https://ec.europa.eu/energy/sites/default/files/documents/fr_final_necp_main_en.pdf

42 https://ec.europa.eu/energy/sites/ener/files/eu_methane_strategy.pdf

clean hydrogen in the process. This creates a virtuous circular economy supporting multiple decarbonisation objectives.

However, pyrolysis of biomethane currently struggles to be economically competitive with pyrolysis of fossil methane or indeed other decarbonised hydrogen production methods[43]. If the value of biomethane pyrolysis as a carbon sink was reflected in the price of its products, this price gap could perhaps be bridged, and large quantities of agriculture and waste sector emissions avoided.

2.3 Lifecycle Assessment (LCA)

One key guiding force in the development of the decarbonised hydrogen economy will be the taxonomy delegated act on sustainable investments[44]. The threshold set for renewable hydrogen production under the taxonomy is 3 tonnes (t) of CO_2 for every tonne of hydrogen produced. This excludes unabated SMR and ATR as well as the majority of grid powered electrolysis. However, it could also exclude methane pyrolysis as well as SMR/ ATR with CCUS, depending on the lifecycle assessment (LCA) applied. For example, emissions from blue hydrogen can be 0.6 – 3.9t CO_2 equivalent/ t H_2, depending on the scope of the LCA and the associated supply chain methane emissions[45].

The application of this threshold will have meaningful implications for the cost and emissions associated with the growth of the hydrogen landscape, for example through initiatives such as the European Clean Hydrogen Alliance (ECHA)[46]. Direct emissions warrant prominent consideration, but they should also be considered in terms of the ripple effects in other sectors. For example, an increase in grid electricity emissions due to the opportunity cost of RES-E allocation, as well as opportunities for carbon sequestration.

3. Policy recommendations

3.1 Create a flexible and adaptive basis for an evolving hydrogen economy

Much of the debate on hydrogen surrounds potential future applications in new areas, such as transportation and industry. Nevertheless, there are already 70 – 100 mt of CO_2 emissions released every year associated with existing hydrogen demand in the EU. These are the clear priority and should be eliminated by 2030 in line with the European Commission's Hydrogen Strategy.

In the long-term, RES-E prices and availability as well as electrolyser costs are likely to reach levels where green hydrogen is commonly an environmentally efficient and economically competitive production source, in addition to an effective grid balancing tool[47]. However, in the short to mid-term a considerable degree of green hydrogen use will likely be contingent on transportation of hydrogen from areas with cheap and abundant RES-E to existing hydrogen demand centres[48], or the import of RES-E requiring new long-distance transmission lines. This transcontinental infrastructure will take considerable time to establish, and significant variables remain as regards how and where that network will develop[49].

Methane pyrolysis has an advantage in this regard as the projected cost of production is typically lower than for electrolysis and considerably less strongly connected to the price of RES-E. For areas with relatively high RES-E prices but established hydrogen demand and biomethane production, such as the Benelux region, methane pyrolysis can be a potentially cost-effective and efficient means of producing clean hydrogen without the requirement of elaborate infrastructure.

Methane pyrolysis seems well-positioned to help

43 https://fsr.eui.eu/publications/?handle=1814/68977, https://monolithmaterials.com/assets/20-mono-0010_brochure_091520.pdf
44 The taxonomy establishes thresholds for hydrogen production, delineating the level of emissions beyond which hydrogen production is not considered to be consistent with EU climate change goals nor in line with the principle of 'doing no significant harm'.
45 https://www.energy-transitions.org/publications/making-clean-hydrogen-possible/#download-form
46 https://ec.europa.eu/growth/industry/policy/european-clean-hydrogen-alliance_en
47 https://www.agora-energiewende.de/en/publications/making-renewable-hydrogen-cost-competitive/
48 For example, the EU Hydrogen Strategy envisages 40GW of electrolyser capacity in the Neighbourhood region by 2030, namely from Northern Africa and Ukraine, where there is cheap RES-E and existing transport infrastructure. From an industry perspective, the proposed 'EU Hydrogen Backbone' from Gas for Climate, plans for roughly 40,000km of hydrogen transportation pipelines, largely repurposed from existing fossil methane infrastructure.
49 For example, where infrastructure will be required and how stranded assets can be effectively avoided, as well as issues regarding energy security and independence.

support rapid decarbonisation of the hydrogen sector, and it could be supported, along with other innovative technologies, through carbon contracts for difference and innovation funds[50].

3.2 Maximise the efficient allocation of renewable electricity and support carbon sinks

The decarbonisation and expansion of the hydrogen economy is not only an opportunity for sector coupling and cutting emissions in hard to abate sectors, but it can also have synergies outside of the energy sector. For this reason, coherence between policies is key. When considering the relative value of different hydrogen production technologies, the parameters should not be limited to the hydrogen sector, but rather reflect the wider implications in other affected sectors. There are two key areas in which this needs to be considered.

Firstly, the issue of 'additionality' needs to be tackled. This means ensuring that renewable hydrogen really is renewable and does not (directly or indirectly) lead to increased production of electricity with fossil fuels to make up for RES-E captured by hydrogen production. This can be addressed in the conditions under which power-to-gas facilities are permitted to operate to produce renewable hydrogen, i.e., during periods of surplus RES-E or requiring operators to only consume RES-E from dedicated 'additional' RES-E. These arrangements could be based on a corporate power purchase agreement or direct lines[51] and should not contribute to Member State renewable energy targets. Such an approach will favour electrified hydrogen production technologies that have a higher level of electricity to hydrogen conversion efficiency.

Secondly, the value of hydrogen production methods that have wider value in decarbonisation aims across the economy needs to be reflected through support schemes. For example, the carbon sequestration potential for pyrolysis of biomethane, as described in 2.2. This could be addressed in the actions under the EU carbon farming initiative[52], CEAP[53], and the next steps following the publication of the taxonomy delegated act on sustainable investments[54].

Conclusions

It is alluring to subscribe to the notion that abundant, cheap, emission-free hydrogen is within reach. It may be, and we should work towards this goal. However, the picture of how that hydrogen economy may look is far from settled. There is no need to hang all hopes on a single technology. An arsenal of different technologies deployed strategically to serve a range of interconnected purposes, including but not limited to the production of clean hydrogen, might be the jigsaw that makes the picture.

As regards methane pyrolysis, it has the potential to assist the decarbonisation of the gas and electricity sectors through supporting the decoupling of clean hydrogen cost and availability from the cost and availability of RES-E. Moreover, pyrolysis of biomethane specifically can contribute to the EU's circular economy and carbon sequestration ambitions through sequestering carbon from methane into useful products. These individual areas are integral to the wider decarbonisation drive, and methane pyrolysis is an example of how they are interconnected. The specific characteristics of methane pyrolysis can be valuable in the short to mid-term whilst RES-E is scarce, as well as contributing to long term climate ambitions by providing a sink for methane emissions produced in the waste and agriculture sectors.

At this stage, remaining open and inclusive to all possible contributing technologies and keeping coherence between interrelated aims and initiatives can help to reach net zero as quickly and efficiently as possible. The gas market decarbonisation legislation set for later this year, as well as support under EU research and innovation programmes, such as 'Horizon 2020' and the 'Innovation Fund', need to reflect this reality.

50 In a recently published works, the IEA indicate that almost half of the CO_2 reductions in the energy sector from 2030 to 2050 will come from technologies that are known but still currently under development.

51 https://cadmus.eui.eu/handle/1814/68977

52 https://op.europa.eu/en/publication-detail/-/publication/10acfd66-a740-11eb-9585-01aa75ed71a1/language-en

53 https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

54 https://ec.europa.eu/finance/docs/level-2-measures/taxonomy-regulation-delegated-act-2021-2800_en.pdf

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