Environmental and Climate Technologies
2023, vol. 27, no. 1, pp. 545–558
https://doi.org/10.2478/rtuect-2023-0040
https://content.sciendo.com

Potential Role of Green Hydrogen in Decarbonization of District Heating Systems: A Review

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Received 30.03.2023; accepted 14.08.2023

***Abstract* – District heating will have an increasing role in the decarbonization of energy systems and in improving the security of supply. Although the electrification of district heating via heat pumps and heat storage is seen as the main path to decarbonization, green hydrogen could also be an important energy source for covering peak demand, providing long-term storage in power-to-gas solutions and backup. The study's research question was to identify the potential pathways for replacing natural gas in district heating with hydrogen. Should we focus on using hydrogen and build appropriate infrastructure, or should we use hydrogen-derived synthetic gas, for which we already have an infrastructure? A review of publications was the method used in the study. The results show the existing technological solutions and associated costs for using either hydrogen or hydrogen-derived synthetic gas, i.e., methane.**

***Keywords* – Cogeneration; decarbonization; hydrolysis; methane; renewable energy; Sabatier reaction; synthetic gas; sustainable energy systems.**

1. INTRODUCTION

The European Union (EU) has set a goal to achieve zero carbon emissions by 2050. Hydrogen (H_2) is seen as one of the most important energy carriers for reaching climate neutrality in the future. The final use of H_2 is considered in sectors of heating, industry, and transport (including land, sea, and air) [1]. However, it is emphasized that H_2 is not and will not be a complete substitute for fossil sources, but as a complement to alternative ways to decarbonize final consumption. It is believed that District heating (DH) can have a significant impact on reducing greenhouse gas emissions (GHG). In DH supply, the transition to renewable energy sources (RES) is considered the first solution for de-carbonization. The second step is direct electrification using heat pumps as well as improving the energy efficiency of buildings and industry. Green H_2 production in DH will provide high-grade heating. To achieve sustainability in the energy sector H_2 and modernizing the DH system is essential [2]. To transform DH towards using H_2, we need to assess the possible benefits and drawbacks. The main disadvantages of H_2 production are the high technology costs and the usage of the product since no market has been created [1]. In 2020, the European Commission came out with a concrete strategy, i.e., 'A hydrogen strategy for a climate-neutral Europe'[3]

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which defines the types of H_2 production. From the year 2025 'hydrogen needs to become an intrinsic part of an integrated energy system' and the goal is to produce 10 million tons of hydrogen by 2023. This means that the production of green H_2 will become a crucial part of the EU's energy system and therefore needs to be fully understood[3]. With the development of interest and demand for H_2 technologies, The European Hydrogen Backbone (EHB) has also been created, united by a common vision of a climate-neutral Europe, using the possibilities provided by H_2. REPowerEU [4] can be mentioned as one of the latest projects to achieve greater energy independence from the fossil resources of Russia. The war in Ukraine promoted great interest in the use of alternative energy sources.

Future DH systems may consist of several combined RES sources, which will create synergy in the production of electricity, heat and other resources. These other resources can be H_2, methane, synthetic natural gas (SNG), etc. Looking for synergies, M. Palys studies the possibilities of further use of power-to-hydrogen (PtH2) and its transformation into power-to-ammonia (P2A) and power-to-methane (P2M) [5], in addition to the possibilities of H_2 storage, examining P2A, P2M, PtH2 +gas and power-to-liquid (P2L). Several researchers predict an increase in H_2 studies in the future, and it is highlighted that they may be more focused directly on the advantages and disadvantages [6], [7], and conversion of H_2 into various energy carriers [8]. In many sectors, green H_2 is seen as the best way of storing excess energy during times of low demand and feeding it back into the grid when demand picks up while decarbonizing the industrial and transport sectors. Currently, the use of hydrogen in DH is not particularly emphasized, as the emphasis is mostly on the electrification of DH systems, but despite this, alternative ways of decarbonizing DH systems have also been created. In 2021, one of the largest projects in the USA was launched, i.e., HYGrid [9] is being implemented on Long Island and is intended to decarbonize natural gas networks by mixing green hydrogen into the existing distribution system. As a result of the project, 800 houses in DH system will be heated by mixed fuel (natural gas + hydrogen), and 10 municipal vehicles will be supplied with hydrogen fuel [9]. The injection of H_2 and the use of the mixture in gas networks is much debated. In this regard, E. Latõšov conducted a study for the gas networks of Latvia, Lithuania and Estonia, in order to find out what % amount of H_2 can be used in the gas networks of the aforementioned countries [10].

However, there should be more good solutions for using green H_2 in the decarbonization of DH systems. The goal of this study was to identify the potential pathways for replacing natural gas in DH with green hydrogen and utilize this hydrogen to produce heat and electricity.

2. METHODS

A review of the literature is structured by assessing the technological stages and possibilities for the production and use of H_2 and H_2-derived CH_4 in DH companies (see Fig. 1). The literature review was created using the publications of the last three years mainly. The research question is how to replace natural gas with H_2 in DH. Wood chip cogeneration would replace natural gas cogeneration, but at the same time an 'energy hub' would be created with three main parts – an electrolysis process for green H_2 production, synthetic methane production, and fuel cells for combined heat and power (CHP). The scheme envisages that the DH company produces heat using a wood chip cogeneration plant. Electricity (E) from RES (wind and solar) ensures the electrolysis process for green H_2 production, and the surplus is transferred to the power grid. Electricity from cogeneration processes is also transferred to the power grid. Compared to other means of producing H_2, this process does not rely on fossil resources and does not directly produce GHG. CO_2 emissions of the cogeneration plant can be used to produce CH_4 in the Sabatier reaction by combining H_2 and CO_2. The produced H_2

can directly be used in fuel cell cogeneration to produce heat (Q) and electricity. CH_4 can be used in the CHP plant to cover heat peak demand or to fire gas turbine or gas engine cogeneration technologies if a larger power-to-heat ratio is required in the energy system. Waste heat from the electrolysis process can be used in DH systems. Thus, the literature review is structured around elements of this hypothetical energy hub of district heating (see Fig. 1) by looking at the latest studies regarding electrolysis, CO_2 capture, synthetic methane production, and fuel cell cogeneration technology. Based on the cited literature in tables, a technology readiness level (TRL) will be shown. The author of the paper will be guided by the criteria set by Riga Technical University to determine the TRL level [11].

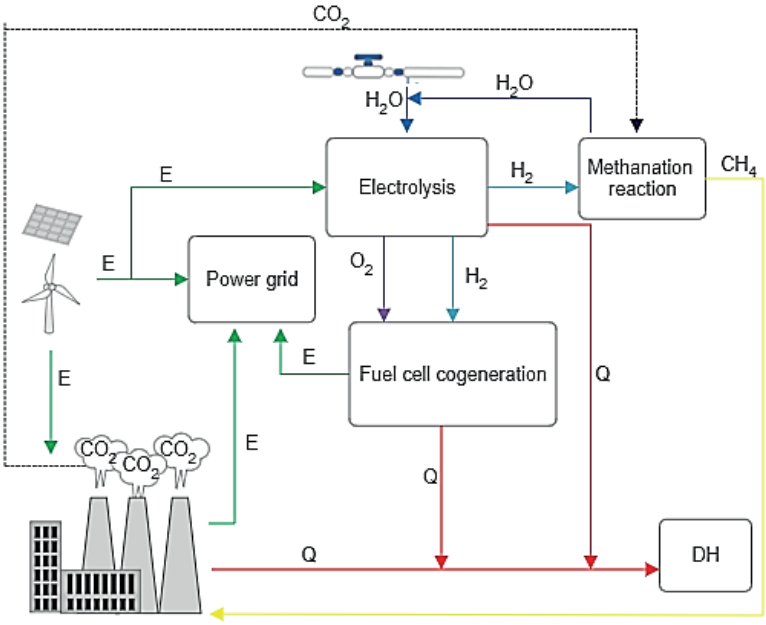


Fig. 1. Green hydrogen in the decarbonization of DH systems. E – electricity; Q – heat; DH – district heating.

3. PRODUCTION OF GREEN HYDROGEN IN AN ELECTROLYSIS

Three main technological solutions are currently available to produce green hydrogen: alkaline water electrolysis (AWE), proton electrolyte membrane water electrolysis (PEMWE), and solid oxide water electrolysis (SOWE). SOWE technologies are mostly in the development process [12]–[16] but it is also possible to improve the existing technologies. Most studies look at the use of solar and wind as RES [17]–[20]. Articles can be divided into categories of techno-economic analysis [18], [21]–[24], life cycle assessment (LCA) [23], [25]–[27] and levelized cost of hydrogen production (LCOH) [28]–[30]. Many new projects and research are devoted to the improvement of electrolysis technologies. The ELY4OFF project [31] aims to improve PEMWE, making it more flexible, durable, and efficient. The NEWELY project [32] develops a new generation anion exchange membrane water electrolyser (AEMWE) [33]–[37]. It is intended to combine the best technology advantages of AWE and PEMWE. The goal of the HYDROGEN project [38] is to develop membrane electrode assemblies to improve PEMWE performance. The H100fife project [39], being implemented in the UK, and is intended to supply clean energy to produce hydrogen gas for

home heating as a green alternative to natural gas. The implementation of the project envisages connecting the first households in 2024. In the first phase, it is planned to provide 300 households with green H_2 [39].

In several studies, the lifetime of equipment is mentioned, and it is 80 000 AWE, PEMWE 65 000, SOWE 20 000 h [18], [21], [40]–[42]. The working temperature for AWE is 70-90°C, for PEMWE it is 50–80 °C, and for SOWE it is 700–850 °C [40], [42]–[44]. The specific indicators found in the research literature to produce H_2 in the electrolysis process are presented in Table 1.

TABLE 1. SPECIFIC INDICATORS FOR PRODUCING HYDROGEN

REF	Electricity source & electrolysis equipment	TRL	Capacity of electrolysis eq., MW	Electricity consumption, kWh/kgH_2	H_2O consumption H_2, L_{H2O}/kg_{H2}	H_2 demand, t/year	CAPEX, €/kW	Costs of H_2 €/kg
[18]	PV & AWE		5	50	15	500	1100	3.21
[21]			20	49	10	30000	N.A.	3.21*
[24]	PV & wind & AWE	9	1	N.A.	10	0.086	320*	7.85*
[26]		9	1	51.8	8.9	0.154	N.A.	N.A.
[28]		9	N.A.	51	10	100	750**	3.53**
[19]	PV & PEMWE		2	52	15	10.66	1300	3.0
[21]			21	52	10	30000	N.A.	4.35*
[24]	PV &wind & PEMWE	7–9	1	N.A.	10	0.081	396*	6.58*
[26]		7–9	1	54	8.9	0.148	N.A.	N.A.
[28]		8–9	N.A.	58	10	100	1200**	7.04**
[41]	PV & wind & geothermal & PEMWE		10	53.4	9	757	1000	N.A.
[24]	PV & wind & SOWE	5–7	1	N.A.	10	0.115	490*	9.72*
[26]		5–7	1	42.3	8.9	0.188	N.A.	N.A.

* Exchange rate used for currency conversion: $1= €0.93
** Exchange rate used for currency conversion: RMB1= €0.13

It is emphasized that AWE costs are competitive with PEMWE [21]. On the other hand, Wai S. believes that the most frequently used method is PEMWE because it has high performance, cell flexibility, as well as a compact size [40], [45]. The efficiency of the electrolysis processes with high temperatures, such as SOWE, varies depending on the parameters used, but heat losses can be mostly neglected [2], [46]. In addition, by the year 2030, it is thought that most of the H_2 production with electrolysis will be through AWE and PEMWE and that SOWE will be only 2 % of the technology used [2]. Studies on the use of H_2 in DH were carried out by O. Gudmundsson [47]. Blue and green H_2 usage is used for comparison. Blue H_2 is produced using steam-methane reformation, and green – AWE. The DH system consists of CHP and heat pump (HP). Heat loss is assumed to be 10 %, although the author mentions that it is mostly 5–25 %. In green DH it is assumed that the efficiency of electrolysis is 79 %, and heat production is done by air HP with COP of 3.5, and DH distribution network efficiency is 90 %. It is highlighted that 33 % of RES power is needed to supply 99 % of the useful final heat. According to the author's research, it can be concluded that the use of HP in DH systems is more efficient (441 %) than the use of H_2 in these systems [47]. However, energy storage in form of H_2 provides considerably larger options for

use and can be done on a larger scale and over long periods of time. Additionally, the heat generated in the electrolysis process can be used in DH systems. Before the complete substitution of natural gas H_2 can be blended with natural gas or its equivalent produced from RES and used in DH. Some estimates suggest that a mix of 20 % of H_2 and 80 % of natural gas can be achieved [48]. Using the excess heat from electrolysis will increase the useful energy output. Circa 60 % of the energy output in the PtH_2 process is in form of H_2 and 30 % in the form of heat, resulting in wasted energy of only around 5 % [48].

Waste heat from electrolysis process

In the electrolysis process, about 30 % of the input electricity is converted to heat. If we want to increase the use of hydrogen in the EU energy supply, then this loss of energy needs to be addressed. This residual heat can be used in DH systems [2]. Electrolysis processes with low temperatures such as AWE and PEMWE have residual heat at temperatures 60–90 °C and 50–80 °C respectively. This heat could be utilized if the DH system is at least fourth generation, i.e., with temperatures from 30 to 70 °C [2]. Residual heat usage in DH has the potential to increase efficiency and the economic justification of electrolysis usage in the network, as well as it has the potential of decreasing CO_2 emissions in the network [49]. Zhang S. also mentioned in his work the possibilities of using waste heat generated by electrolysis: 'SOEC avoids the inevitable energy loss in AE and PEME, which leads to low-temperature waste heat evaluated as exergy destruction rather than utilized' [50]. It is mentioned that the use of waste heat in the electrolysis process can reduce the required amount of electricity and improve the efficiency of the electrolyzer by 10 %. In the second stage of the 'Stromlückenfüller' project, it is planned to develop the concept that waste heat generated in electrolysis flows into the existing heating infrastructure to heat the biogas fermenter and company premises. As the project developers mention, with such a concept and if the electrolyzer works around the clock throughout the year, it would be able to provide 200 modern apartments [51]. Hu Q. has conducted research on optimal hydrogen control, in which a power-to-heat and hydrogen (P2HH) model is created based on the use of excess heat [52]. Buttler A. emphasizes that it is necessary to carry out more research and projects related to the study of synergy and the possibilities of using waste heat and oxygen [53].

4. CARBON CAPTURE IN COGENERATION STATIONS

The capture of CO_2 can be done directly from the air, and from industrial processes. The technology of CO_2 capture in industrial processes depends on the fuel used and determines the amount of CO_2. DAC has several advantages, such as no transportation costs, but the CO_2 must be stored in a clean form [42]. Carbon capture and storage (CSS) technologies are adsorption, cryogenics, absorption, microbial, and membranes [54], [55]. Currently, most H_2 in the world is produced from fossil fuels, especially natural gas, using steam methane reforming, which is a high-temperature process in which steam reacts with hydrocarbon fuels to form H_2. This H_2 production process produces CO_2 emissions, however, supplementing this technology with a CCS [56]–[60] allows to achieve CO_2-neutral H_2 production. Various technological possibilities for CCS and carbon capture and utilization (CCU) systems have been studied for more than 20 years, and according to statistical data, about 35 commercial objects use CCU in their industrial processes with an annual capture capacity of 45 Mt CO_2 [61]. In recent years, about 300 projects are in various stages of development. It is planned that around 2023 circa 220 Mt CO_2 year will be captured [62].

Post-combustion carbon capture is one of the most known technologies [63]. This is the

preferred method of use when modernizing an existing power plant [55]. There are several post-combustion processes of CC. In the amine process, CO_2 is treated with liquid amine solutions. In a reaction between CO_2 and amine, the solution captures CO_2 at a temperature of about 50 °C and atmospheric pressure [64]. About 90 % of CO_2 from the flue gas can be absorbed this way. Carbon dioxide can be released later when heat is applied. There are some pilot plants where this amine-based carbon capture is used, e.g., Maasvlakte (MPP 3) pilot plant Electrabel, E.ON – Hitachi Power Europe in the Netherlands [64]. This plant projects to capture about 1.1 Mt of CO_2 per year [64]. In the Potassium Carbonate absorption case, a potassium carbonate process is used to decarbonize the flue gas. This chemical absorption process consists of two pieces of equipment – an absorber and a stripper. The absorber operates at 48.01 °C and 1004.49 mbar of pressure. But the stripper operates at 40.03 °C and 2000 mbar of pressure [65]. In Aqueous Post-Combustion CO_2 capture (APCC) water is used as a solvent for CO_2. In this process, it is possible to capture 97.4 % of the CO_2 from flue gas. The operational temperature (temperature of solvent) is 30 °C at 30 bar pressure. After CO_2 has been captured by water, it can be separated from it again. This desorption process happens at 30 °C at 15 MPa pressure. After sorption in water and desorption afterward, it is possible to gain CO_2 gas with a purity of 80 mol%. In APCC power usage ratio is 22.74 MWh/tCO_2 [66]. Johnsson F. investiges the possibilities of Swedish production facilities to reduce CO_2 emissions. The proposed project examines CO_2 capture based on amines in all Swedish production plants with annual emissions of 500 kt CO_2 or more. The study mentions that the costs of installing this type of CC equipment range from €80/t CO_2 to €135/t CO_2, depending on emission source [67]. Jiang Y. investigates one of the latest developments in CO_2-Binding Organic Liquids. The performed simulation highlights that compared to aqueous amine technologies the costs are much lower ($38.8 per ton CO_2 to $45.3 per ton CO_2) [68].

Eliasson A. studies the use of CSS in the DH network, thereby reducing emissions and increasing efficiency [69]. The work is based on five thermal loads with three receiving facilities. CCS is configured in 3 variations: a) work all the time at a constant capacity throughout the year, b) variable reception load throughout the year, and c) variable capacity depending on seasonality. The duration of the project is 25 years (including 2 years of construction). The results show that, depending on the capacity, it is possible to capture 44–455 kt/year of CO_2. Scenarios a, b, and c show the degree of utilization (%), where scenario b has obtained 100 % regardless of system capacity [69]. Beiron J. studied biomass and waste CHP in Sweden [70]. The author believes that the Swedish DH industry has great potential for bio-energy CCS (BECCS). Therefore, the possibility of CO_2 capture in 110 biomass or waste-fired cogeneration plants is being investigated. CHP capacity ranges from 7–540 MW, heat ratios 0.1–0.65, steam turbine efficiency 88 %, boiler efficiency 90 %, and DH system operating parameters 90/50 °C. The obtained results show that the potential of CCS capture is 10–12 Mt/year of CO_2. CCS system reduces electricity output by 20 % and the level of DH production by about 40–60 %. However, it is possible to save it by regenerating heat [70].

5. Production of Methane from Hydrogen

It is believed that power-to-gas technologies will bring new opportunities in the field of energy and transport by producing environmentally friendly [71]. Methanation reactor (MR) can be based on chemical technologies, and these technologies currently are more advanced than biological methods [71]. One of the oldest and most recognizable is the Sabatier reaction (SR), and already in 1900, the reaction of CO_x and H_2 in combination with Ni to form CH_4 and H_2O was indicated [72]. Later, research has modified the original reaction method and showed the possibility of using metals from groups 8–10 of the periodic table as catalysts. SR

based power-to-gas systems have the potential to reduce CO_2 emissions and store excess power production from intermittent renewable sources in form of synthetic methane [73]. The infrastructure for the use and storage of synthetic methane is readily available and competitive compared to the changes required to take advantage of the opportunities provided by H_2 [74]. There are four types of: fluidized bed reactor [75]–[77], three-phase reactor [78], fixed bed (adiabatic and isothermal) [79] and structured reactors [75], [80], [81]. The CO_2 methanation process can be considered one step reaction or two-step reaction – a combination of reverse water-gas shift (RWGS) and CO methanation [82]. Using the CO_2 methanation process, it is necessary to use base catalysts, and the most frequently used are aluminium, titanium, zirconium, magnesium and silicon [45], [83], [84]. The ratio H_2:CO_2 is 4:1 [40], [41], [44], [85]. The specific indicators found in the research literature to produce methane from H_2 are presented in Table 2.

TABLE 2. SPECIFIC INDICATORS FOR PRODUCING METHANE

REF	Process	TRL	System input			CH_4 production
			CO_2	H_2	Electricity	
[86]	Electrolysis & SR	5–7	2.94 kg	0.51 kg	0.33 kWh	1 kg
[41]			4166 t/year	757 t/year	2094 MW/year	1363 t/year
[44]			63/94.5/126/157.5 Nm^3/h	254/378/504/630 Nm^3/h	N.A.	35.665 MWh/year
[87]	Electrolysis & CO_2 MR		N.A.	17.5 kt/year	N.A.	21 kt/year
[88]			967.93 kg/h	180 kg/h	0.08 kg/h	401.02 kg/h
[40]	Electrolysis & biological H_2 methanation	3	7335 t/year	1344 t/year	N.A.	3.58 million Nm^3/year
[89]	Electrolysis & catalytic MR	5–9	50 Nm^3	200 Nm^3	N.A.	49.9 Nm^3
[74]	Electrolysis & fixed bed reactor	3	1.27 t/h	23.1 t/h	0.30 kWh/kg_{LNG}	46.2 t/h

6. FUEL CELL COGENERATION

Although the principle of operation of fuel cells (FC) was discovered in the 19th century, the fuel cell cogeneration can be considered as the relatively new technology [90]. Currently it is widely used in many The Organization for Economic Cooperation and Development countries such as Japan and USA [91]. FC technologies are divided into alkaline fuel cells (AFC), proton exchange membrane fuel cells (PEMFC), solid oxide fuel cells (SOFC), hydrogen fuel cells (HFC) [92]–[94], direct methanol fuel cells (DMFCs) [95]–[97], molten carbonate fuel cell (MCFC) [98]–[100], and phosphoric acid fuel cell (PAFC). Several important projects are in the development process, e.g., the project SWITCH in Italy [101], whose goal is focused on SOFC green and safe production of H_2, heat and electricity, as well as using biomethane and methane in reverse mode. In 2021, another project – SO-FREE Future-ready Energy [102] was launched in Italy, with the aim to develop SOFC system for use in CHP.

MCFC operates at a temperature of 600–700 °C and makes direct transformation of chemical energy (natural gas, methanol, hydrogen) into electrical energy and by-product heat [103]. An additional benefit of using the technology is that it also acts as a CCS [104]–

[106]. PAFC operates at a temperature of 149–219 °C, and the technology is freely available on the market. Given that the technology is already widespread, researchers are focusing more on developing system synergies with other available systems [107]–[113]. One such author is M. Tomas, who has conducted a study on the possible increase in temperature. The main elements, or innovations, are the use of a polybenzimidazole membrane doped with phosphoric acid [114]. A similar study was also conducted by Griffin J. studying polybenzimidazole membrane with phosphoric acid. In contrast to the previous study, a reduced temperature with an operating range of 60–150 and variable water vapor activity is studied [115]. FC micro-CHP is mostly used in private homes, and commercially available power is from 300 W to 5 kW. Most of the commercially available micro-CHPs use natural gas as the main fuel. In recent years, several authors have studied various technological possibilities [116]–[121] for fuel cells. Hashemi A. has researched the creation of a hybrid system of FC, wind turbine, hydrogen storage and electrolyser, to cover the operation of wind generators during peak loads [122]. As a result, the wind farm capacity has increased by 2.8 %.

Yuan-Hu L. studies the possibilities of using FC in DH supply [123]. The study focuses on the unused energy source latent heat of water, which is a possible solution for improving efficiency in the overall system. The results of the research show that by creating a system and using the cascade heat utilization technology of the DH supply system, investments are reduced by 50 %, thus obtaining a payback period of less than two years [123]. Boulmrharj S. also studies the use of FC in the heating and electricity supply of buildings. A hybrid system consists of solar PV, H_2 tanks, electrolysis equipment and FC. Solar PV capacity is 255 W for each module and the total number of modules is 8. PEMWE with a capacity of 800 W and PEMFC with a capacity of 1.2 kW is used for electrolysis. The results are obtained from simulations, and it is indicated that the efficiency of such a system is 64 % (considering produced heat and electricity) [124].

7. CONCLUSIONS

The aim of the study was to determine the possible technologies and pathways for the decarbonization of DH systems, i.e., replacing natural gas with green H_2. The literature review shows that the role of DH in the utilization and conversion of H_2 has been addressed in a relatively small number of studies. Therefore, the review addressed separately H_2 production in electrolysis, CCU, production of synthetic methane, and fuel cell technology. Currently, PEMWE is among the most accessible technologies for H_2 production in the electrolysis process, but it is believed that as the use of H_2 increases, it will be replaced by SOWE. In addition, waste heat from electrolysis can be used in DH.

There are several CCS and CCU technologies, and some of them are used specifically for industrial processes, and some are more universal. If a completely new power plant can be built, then the planners have an opportunity to choose the best possible method. However, upgrading of the existing plants with CC technology is often needed. At present, one of the most efficient and well-known technologies that can also be fitted onto an existing plant is amine solutions technology. Methane production is well known and it has been produced for decades, but the main challenge is ‘green methane’ production. Many publications that were found are focusing on the use of SNG in methane production. Some of the recent publications examine the use of biogas for methane production, but studies on using H_2 as the main product input for methane production are relatively few.

FC technologies are widely used today, but relatively few studies consider H_2 as a primary fuel. This is understandable, due to the limited development of hydrogen infrastructure.

Another finding is that the use of FC is mostly for transport and not so much to produce electricity and heat. In building supply systems, FC is considered mostly as micro-CHP, which are with limited capacity. PAFC or MCFC technologies are intended for use in industrial facilities and DH systems.

Difficulties in storing and transporting H_2 are defined as the main obstacles in the H_2 economy. Therefore, to reduce the risks, it is believed that the production of methane could avoid these difficulties. DH system could be used to produce methane, thus providing the opportunity to use captured CO_2. The produced methane can be used to cover peak load and serve as energy storage for excess power produced by intermittent renewable technologies. Synthetic methane can also be distributed via the natural gas network, thus decarbonizing buildings and industrial facilities that do not use heat from the DH system. The existing natural gas storage facilities would serve as the storage of synthetic methane. Fuel cells in DH allow direct use of produced H_2, thus reducing energy conversion losses and the need for fuel storage and transportation. The obtained heat can be used in the DH network, while the electricity can be directed to the power grid or to the electrolysis process to produce H_2. Thus, a CHP plant of DH system becomes an energy hub that helps to utilize captured CO_2, provides energy storage, and allows to substitute a natural gas with green synthetic methane.

The data from this publication can be used for the techno-economic modelling of energy hubs based on the DH systems, where hydrogen plays an important role. This study will be continued with modelling of the energy hub for a specific DH system on an hourly basis, using advanced energy system modelling tool.

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