Development and Application Status of the Methane Pyrolysis Technology

Energy Research Lab: Ting, Fu-Pin; Lee, Tai-Chen; Chou, Li-Fen; Wang, Pai-Yi

1. Research background

The issue of net-zero emissions by 2050 is driving the energy transition to low-carbon energy. With hydrogen recognized as a critical technology for accelerating carbon reduction pathways, integrating hydrogen into power systems is becoming increasingly important. Taipower (TPC) is actively developing various decarbonization pathways to achieve the goal of net-zero power transition by 2050. In February 2023, TPC co-signed a Memorandum of Understanding (MoU) with Academia Sinica on "Carbon Reduction and Green Energy Technology Development and Application." The initial focus is on integrating decarbonized hydrogen production technology with microturbine generation, aiming to verify the feasibility of power generation applications. Given that de-carbon hydrogen technology is an option for hydrogen supply, this article will provide an overview of its current development status in the global market.

2. Comparison of technical characteristics of hydrogen production[1][2][3]

Table 1 shows a comparison of various hydrogen production technologies. Decarbonized hydrogen technology, known as methane pyrolysis, utilizes natural gas as its raw material for hydrogen production. During the pyrolysis process, it concurrently generates carbon black, resulting in what is referred to as Turquoise Hydrogen. The advantage of this technology lies in the solid form of carbon produced during hydrogen production, which facilitates subsequent carbon capture, storage, or utilization. Additionally, the theoretical energy required for the process is approximately 75 kJ, making it the most energy-efficient hydrogen production method compared to steam methane reforming (SMR) and water electrolysis. SMR is a hydrogen production process that utilizes natural gas as its raw material. It currently supplies approximately 95% of the global industrial hydrogen demand. However, hydrogen production by SMR comes with carbon dioxide emission (CO_2). To mitigate this, Carbon Capture and Storage (CCS) technology is employed alongside SMR to reduce CO_2 emissions. The resulting hydrogen is commonly referred to as Blue Hydrogen. On the other hand, the cleanest form of hydrogen, known as Green Hydrogen, is produced by water electrolysis from renewable sources. Green Hydrogen is recognized as a critical source for achieving the net-zero emissions goal by 2050. However, the current challenges of water electrolysis are the high energy consumption and costs.

Table 1: Comparison of different hydrogen production technologies

Items	Methane pyrolysis	Steam methane reforming	Water electrolysis
raw material	natural gas	natural gas	water
Process reaction	$CH_4 \rightarrow C_{(s)} + 2H_2$	$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$	$2H_2O \rightarrow 2H_2 + O_2$
Theoretical reaction energy	75 kJ (per 2 mole H_2)	126 kJ (per 2 mole H_2)	572 kJ (per 2 mole H_2)
Carbon production	carbon black	carbon dioxide (CO_2)	—

3. The international development and application status of the methane pyrolysis technology [4][5][6][7]

Based on the energy sources of the cracking process, methane pyrolysis can be divided into three categories: thermal decomposition, plasma decomposition, and catalytic decomposition. Table 2 gives an overview of the current status of the three methane pyrolysis technologies.

Table 2. Overview of the current status of the methane pyrolysis technology

Company	Technical type	Reaction temperature (℃)	Carbon type	Hydrogen content (vol. %)	Scale of hydrogen production	Technical stage
BASF (Germany)	thermal	1,000~1,400	carbon black	~92	—	Small demonstration plant is expected to enter mass production in 2030
Monolith Materials (U.S.A)	plasma	1,700~2,000	carbon black	~95	> 5,000 tons/year	Commercialization demonstration
Graforce (Germany)	plasma	~2,000	carbon black	~98	> 5,000 tons/year	Commercialization demonstration
Hazer Group (Australian)	thermal + catalytic	~900	graphite	~92	< 500 tons/year	Small demonstration plant

3.1 Thermal decomposition type

At present, BASF applies the technology to develop many verification plans. It's expected to be a commercial mass production scale demonstration in 2030, and the current technology maturity level (Technology Readiness Level, TRL) is about 3. The main goal of the technology development is hydrogen production, while the by-product carbon black is used commercially. The technical principle is using electrodes to directly heat a fluidized moving-bed reactor to 1,000~1,400 ℃, drive the cracking reaction to break the methane bond with high-temperature energy, decompose to produce hydrogen and carbon black, and the hydrogen content of the produced gas can reach about 92 vol.%.

3.2 Plasma decomposition type

In 2012, Monolith Materials, an American company, developed plasma cracking technology to produce carbon black. The principle of cracking is to use plasma, provide a high temperature of about 2,000 ℃ as the energy source for methane bond breaking, and produce hydrogen and carbon black. At present, the TRL of this technology is about 8, and this company is currently implementing the Olive Creek commercialization demonstration program. In 2020, the company launched the first phase of the verification program at the Olive Creek demonstration plant in Nebraska, USA, and has completed the scale verification of the annual production of 5,000 tons of hydrogen and 15,000 tons of carbon black. They expected to complete the second phase verification of 60,000 tons of hydrogen and 180,000 tons of carbon black annually in 2024.

In addition, Graforce is another international developer of plasma cracking technology. This technology is widely used to crack biomass methane gas, wastewater, biomass raw materials, ammonia, plastic waste gas, and other sources into hydrogen or various compositions of synthesis gas and carbon black. Based on the 3 MW concept plant specifications, the hydrogen production capacity is expected to be approximately 290 kg/hr, and the solid carbon production capacity is approximately 875 kg/hr, with the purity of the produced hydrogen reaching approximately 98 vol. %.

3.3 Catalytic decomposition type

The process method first proposed by the American company Universal Oil Products (UOP) in the 1960s is used in refining oil refineries to supply hydrogen demand continuously. The principle of this technology is to integrate the thermal/catalyst-driven cracking reaction because the catalyst (such as iron, nickel, and cobalt-based) has an auxiliary reaction effect so that it could reduce the reaction temperature significantly by about 900 ℃ compared with the reaction temperature of the pyrolysis technologies mentioned above. The catalytic decomposition type technology can produce hydrogen and carbon black (or graphite) with less energy consumption required for cracking. Currently, the leading cracking technology promoted by the Australian company Hazer Group, with a TRL of about 3, is only in the stage of a small demonstration plant. However, the cracking technology mainly aims to produce high-value graphite while producing hydrogen. In 2019, the company built a cracking demonstration plant in Perth, Western Australia, using biogas from a wastewater treatment plant as the feedstock, which is expected to produce about 100 tons of hydrogen and 380 tons of synthetic graphite per year. Trial mass production began in July 2023, and the operation demonstration period is expected to be three years. In addition, the company also signed a memorandum of understanding (MOU) with well-known companies in Japan and France in 2023 to introduce the technology to produce hydrogen for applications in power generation, industry, and transportation.

4. References

[1] "State of the Art of Hydrogen Production via Pyrolysis of Natural Gas", *ChemBioEng Reviews*, vol. 7, no. 5, pp.150-158. 2020

[2] "Methane Cracking for Hydrogen Production: A Review of Catalytic and Molten Media Pyrolysis," *Energies*, 2021, 14, 3107.

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[4] German company BASF official website, "Clean hydrogen: Methane pyrolysis" https://www.basf.com/global/en/who-we-are/sustainability/we-produce-safely-and-efficiently/energy-and-climate-protection/carbon-management/innovations-for-a-climate-friendly-chemical-production.html#text-1002215085

[5] American company Monolith Materials official website https://monolith-corp.com/

[6] German company Graforce official website https://www.graforce.com/en/

[7] Australian company Hazer Group official website https://hazergroup.com.au/