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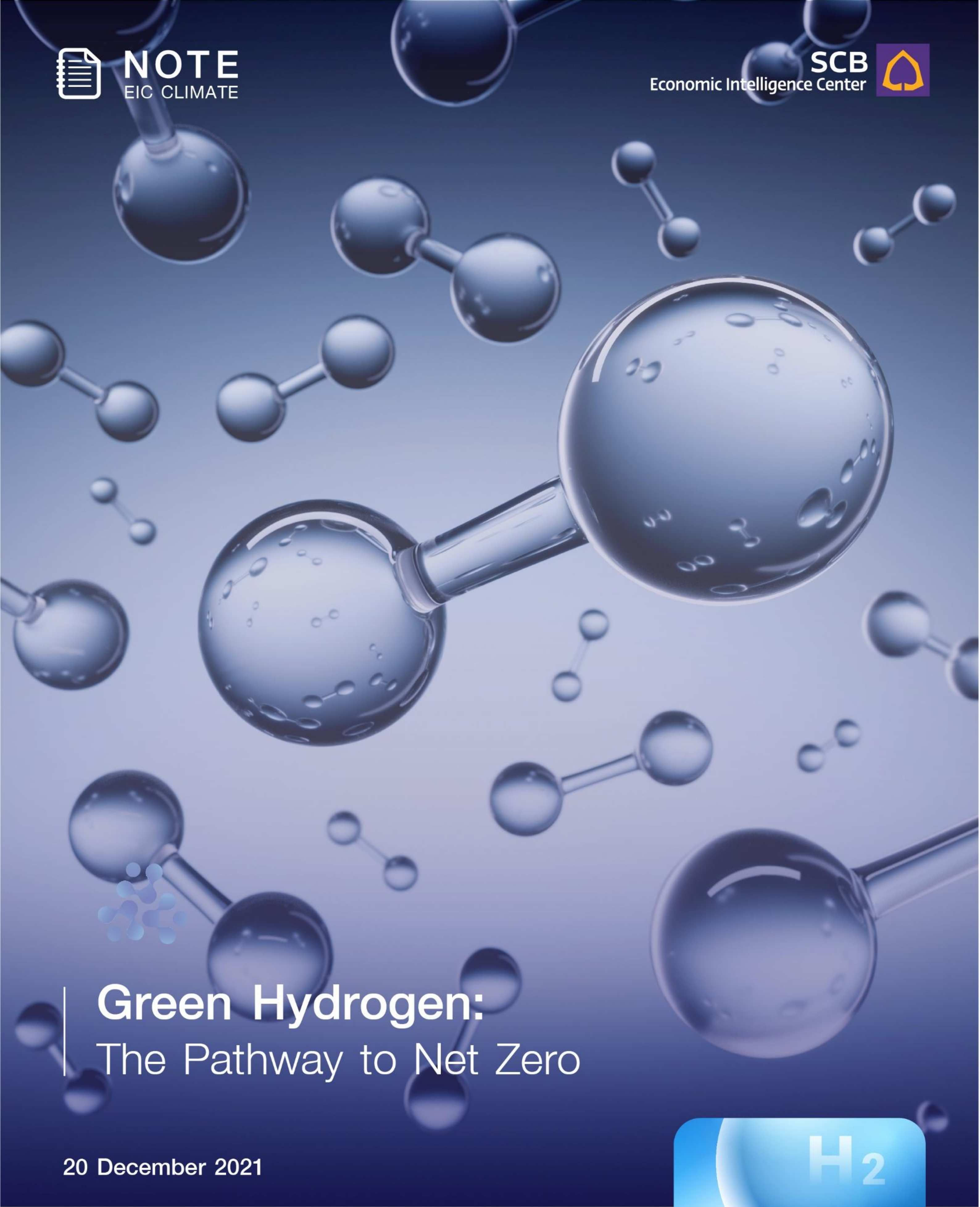


Green Hydrogen: The Pathway to Net Zero

20 December 2021

KEY SUMMARY

- **Hydrogen produced using renewable energy, or green hydrogen, is a vital technology in achieving net zero globally, particularly within hard-to-abate sectors** that currently use hydrogen produced from fossil fuels as a key raw material. If these sectors were able to switch to hydrogen produced without emissions, the industrial sector would be able to achieve significant decreases in greenhouse gas emissions.

- **National investments are the key drivers behind green hydrogen development.** To date, over 200 projects relating to hydrogen production and consumption have been announced around the world. Leading the number of projects is Europe, whose projects cover the entire hydrogen value chain, including midstream and downstream, and which aim to support the integrated hydrogen economy in the European Union and neighboring countries.

- **Declining of production cost in renewable energy and electrolyzer technology together with capacity factor and cost of capital are the main factors to increase competitiveness of green hydrogen market.** This will help to reduce the price of green hydrogen from around 2.5 – 5.5 euros/kg to around 0.67 – 0.84 euros/kg by 2050.

- **Nevertheless, green hydrogen faces key challenges concerning high production costs, the development of technologies relating to storage and transport, and investments in infrastructure to support the growth in hydrogen use, including the concurrent higher demand for renewable energy to produce green hydrogen.**

- **Thailand should prioritize the study and development of the hydrogen industry. Although it is not suitable at this stage to channel investments into the hydrogen industry due to the national context and level of readiness, this will be essential in supporting the development of an integrated energy transition plan, and for drawing lessons on clean energy development from other countries in terms of policy and technology. Doing so will create new business opportunities and increase Thailand's competitiveness over the long term.**

Hydrogen (H_2) is a lightweight, energy dense molecule. Hydrogen can be produced through two main processes: 1) Separation from water (H_2O) through electrolysis, and 2) Separation of methane (CH_4) through the steam reforming process.

Hydrogen produced via the separation of water molecules using renewable energy – or green hydrogen – is a solution that is currently receiving significant attention, as it is produced without fossil fuels or greenhouse gas emissions. Hydrogen is an important raw material in many high-emitting and hard-to-abate sectors, such as oil refining, petrochemicals, metals, and fertilizer production. If these industries were able to use hydrogen that has been produced without greenhouse gas emissions, and without fossil fuels, as a raw material, this will enable significant emissions reductions from resulting products. Hydrogen is therefore a key technology in the global pathway towards net zero emissions.

3 Primary drivers for increased global interest in hydrogen:

- Net zero targets and countries' hydrogen industry development plans
- Possible applications for hydrogen across various sectors, for example, as an industrial raw material, as fuel for transportation, and for energy storage. These make hydrogen an important variable in emissions reductions among hard-to-abate sectors.
- Rapidly decreasing renewable energy costs, which will contribute to lower hydrogen costs.

The net zero emissions targets announced by countries and leading companies around the world are key drivers to encourage clean hydrogen for stepping up to be the vital role in reducing greenhouse gas emissions. Hydrogen can be applied across different sectors, making it beneficial for all the sectors that must quickly reduce their emissions to meet net zero targets. Furthermore, for countries that are competing to become leaders in hydrogen technology, such technologies relating to hydrogen production and consumption constitute a strategically important industry. Governments are therefore racing to provide budgets to support their development, as well as to enact policies to support market demand for such technologies. As a consequence, the technological competition between these countries will help to rapidly reduce the costs of hydrogen technology. For example, the European Union has established the target to reduce the cost of electrolyzers from around 900 euros per KW in 2020 to 450 euros per KW by 2030, which will be key to reducing the cost of green hydrogen. Currently, the cost of green hydrogen in Europe is around 5 euros per kg, and the EU's strategy has set the target to reduce this cost to 1.1 – 2.4 euros per kg by 2030, a decrease of more than half compared to current prices.

Each country's hydrogen plan differs based on their existing demand, supply, infrastructure, and energy security contexts. Over 200 projects relating to hydrogen production and utilization have now been announced around the world. Europe is leading this number, where the projects announced cover the entire hydrogen value chain, including midstream and downstream, and aim to support an integrated hydrogen economy focusing on the European Union and neighboring countries. Meanwhile, key oil exporting countries like Saudi Arabia has set the target to become the number one hydrogen producer in the world, with a plan to produce 4 million tons of hydrogen by 2030. On the other hand, Japan and South Korea's hydrogen projects focus more on demand and utilization, and will rely on hydrogen supplies from the global market because both countries do not have sufficient resources to produce hydrogen to meet domestic demand. Japan plans to import hydrogen from Australia, Which has set the target to become a major hydrogen exporter as chille the target to become a major hydrogen exporter, much like Chile. These latter two countries have the natural resources and infrastructure to enable them to become leading hydrogen exporters. Overall, the development of technologies and markets means that hydrogen will become a widely traded global commodity, much like fossil fuels are at present.

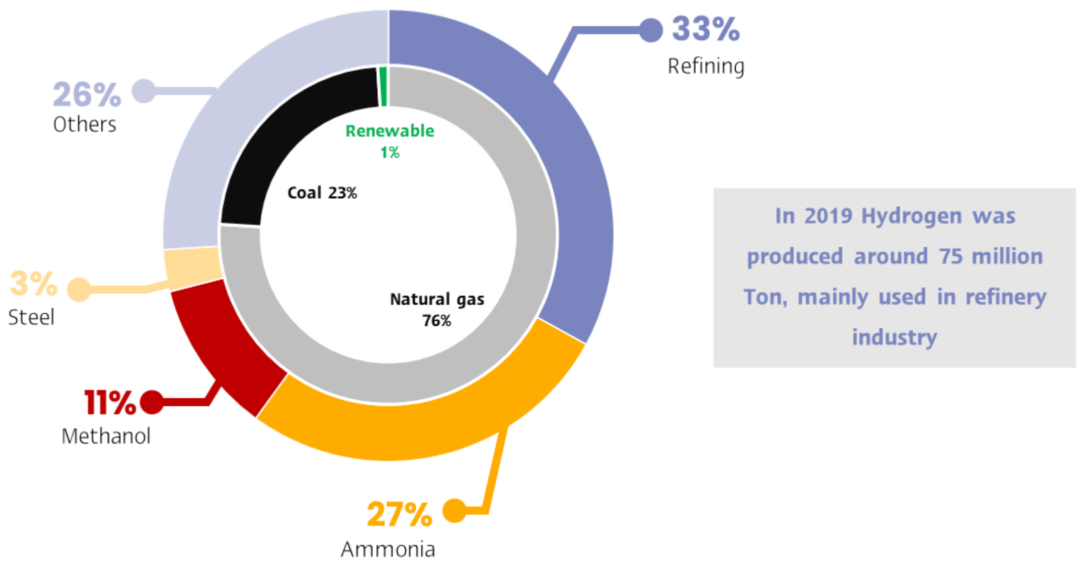
Figure 1: Expected hydrogen transport routes

Source: EIC analysis based on data from McKenzie and Hydrogen council

Considering the higher numbers of hydrogen technology projects that have been announced, as well as governments' support for these projects, IEA has estimated that hydrogen consumption will increase sevenfold, or by 520 million tons, by 2070.

Currently, hydrogen is mainly used as a raw material in the oil refining process; in ammonia production (where it is used as a raw material to produce fertilizer and some types of petrochemicals), and metal production, all of which are hard-to-abate sectors. Hydrogen used in these production processes is generally produced using fossil fuels through a process called "steam reforming," which involves creating a reaction of methane (CH_4) with natural gas and steam at a high temperature to produce hydrogen molecules (H_2) as well as by-products, carbon monoxide (CO) and carbon dioxide (CO_2). Hydrogen produced using this process is called 'Grey Hydrogen,' and the process involves the lowest cost, highest efficiency, and is most widely used. However, the production of grey hydrogen generates greenhouse gas emissions both from the use of fossil fuels, as well as from the production process. As a result, efforts are underway to reduce greenhouse gases from the hydrogen production process by moving away from fossil fuels, or by capturing carbon emissions to prevent its release into the atmosphere.

Figure 2: The majority of hydrogen today is produced using fossil fuels. Only a small portion is produced using renewable energy, and this will generally be used in the oil refining industry or as petrochemical feedstock.



Source: EIC analysis based on data from IEA and IRENA

Hydrogen can be produced from a variety of processes and raw materials, leading to differences in production costs and greenhouse gas emissions. Hydrogen production can be classified according to different categories based on the fuel used and the amount of carbon emissions from the production process. These processes are distinguished by color, as follows:

- **Brown hydrogen:** Produced using coal via a ‘coal gasification’ process. Generally, brown hydrogen is produced in China due to the vast amounts of coal resources available. This process releases around 16 kg of carbon per 1 kg of hydrogen produced.
- **Grey hydrogen:** Hydrogen that is produced from the steam reforming process, using natural gas or oil. This process releases around 9 kg of carbon per 1 kg of hydrogen produced.
- **Turquoise hydrogen:** Produced using methane pyrolysis, a process that involves splitting methane into carbon and hydrogen. The carbon that results can be used an industrial raw material. However, the methane pyrolysis process is currently in development and is not used commercially.
- **Blue Hydrogen:** Hydrogen that is produced using the same process as grey hydrogen, but with the addition of carbon capture, utilization and storage technology (CCUS) to reduce carbon dioxide emissions. The production of blue hydrogen will release around 3-6 kg of carbon per 1 kg of hydrogen produced. Blue hydrogen is growing relatively slowly, as it is dependent on the development of larger CCUS facilities that will help to reduce the costs of carbon capture and storage.

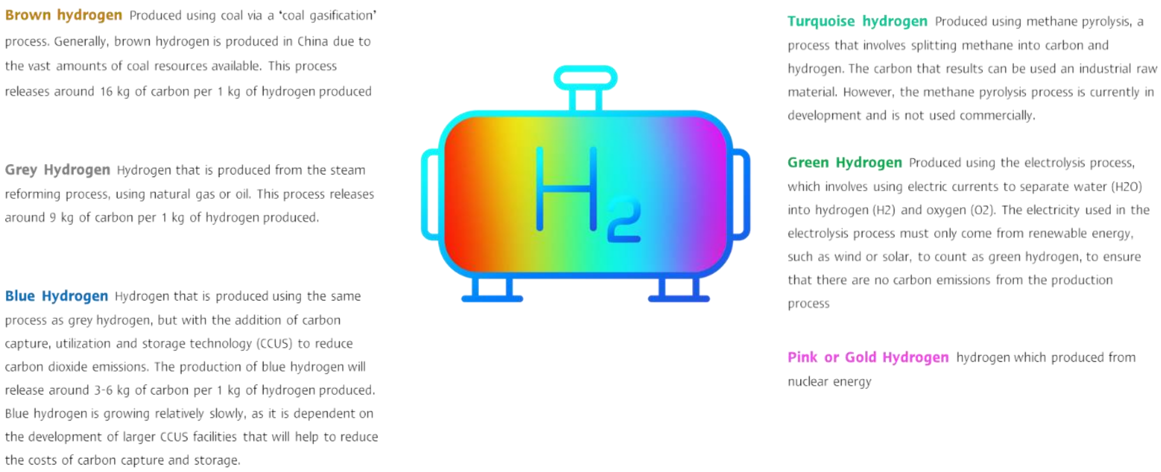
Nevertheless, blue hydrogen has some limitations, as there are difficulties in bringing greenhouse gas emissions from the production process down to zero. This is because only a maximum of 90% of carbon can be captured, and the production of natural gas involves the release of fugitive emissions.

Blue hydrogen has a higher production cost than grey hydrogen because of the costs associated with setting up the CCUS system. However, there are indications that in the future it could cost less than grey hydrogen if emissions restrictions or emission trading scheme or carbon tax are imposed. Lower CCUS costs will also help to make blue hydrogen more competitive than grey hydrogen in the future.

- **Green hydrogen:** Produced using the electrolysis process, which involves using electric currents to separate water (H2O) into hydrogen (H2) and oxygen (O2). The electricity used in the electrolysis process must only come from renewable energy, such as wind or solar, to count as green hydrogen, to ensure that there are no carbon emissions from the production process. However, if the electricity used to produce hydrogen comes from nuclear energy, it will be called Pink or Gold hydrogen.

By considering the various production processes outlined above, green and blue hydrogen release lower amounts of greenhouse gas emissions than brown and grey hydrogen. However, both green and blue hydrogen have higher production costs and require technological developments to reduce their costs and expand production capabilities.

Figure 3: Types of hydrogen production, color-coded by source



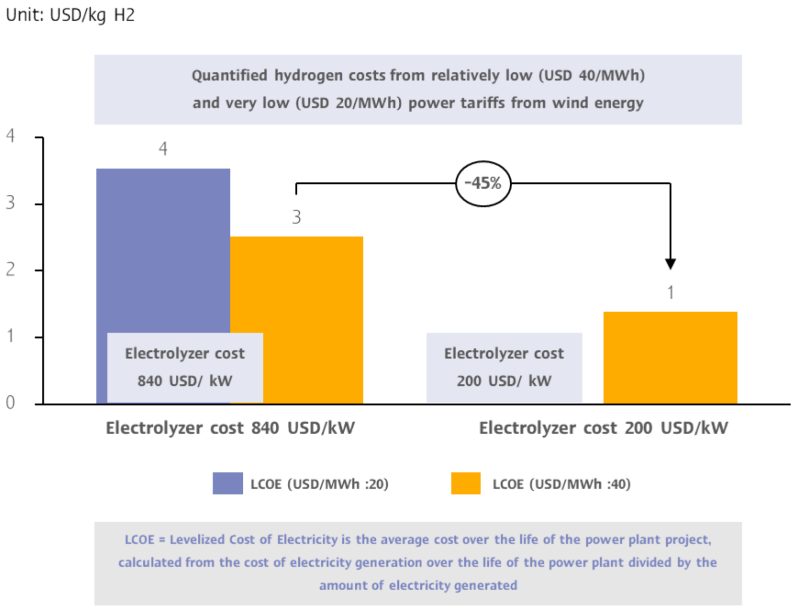
Source: EIC analysis based on data Bloomberg

The main costs of producing green hydrogen derive from four factors:

1. **Cost of renewable energy –** Renewable energy prices, especially wind and solar, continue to decrease. This will help to reduce green hydrogen production costs, particularly in areas with high wind and solar capabilities.
2. **Cost of electrolysis technology –** Likewise, the cost of electrolysis technology is decreasing. The learning rate of the technology is around 20%, which means that the cost of the technology will reduce by around 20% once there is doubling in capacity.
3. **Capacity factor of the electrolysis plant –** The cost of green hydrogen production relies on having enough renewable electricity supply for the entire day to enable the capacity factor of the electrolyzer to remain high. This is so that the price of hydrogen per unit will decrease throughout the lifetime of the electrolyzer.
4. **Cost of capital –** The financial cost of electrolysis remain an important factor in the price competitiveness of green hydrogen. This applies to both hydrogen that is produced using other technologies, as well as green hydrogen (if there is a market for green hydrogen). Bloomberg NEF estimates that the costs of renewable energy and electrolyzer technology, in addition to factors

involving the capacity factor and cost of capital, will help to reduce the price of green hydrogen from around 2.5 – 5.5 euros/kg to around 0.67 – 0.84 euros/kg by 2050.

Figure 4: The cost of green hydrogen will decrease with the price of electricity and electrolyzer costs.



Source: EIC analysis based on data from IEA and IRENA

3 Key challenges to the growth in hydrogen use:

- The cost of producing green hydrogen remains higher than grey hydrogen
- The development of storage and delivery technologies
- Investments in infrastructure to support the growth in hydrogen use, including the need for more renewable energy to produce green hydrogen.

Although hydrogen use is expected to rise in the future, hydrogen technologies continue to face challenges concerning costs, technological limitations, and investments in infrastructure. The cost competitiveness of blue and green hydrogen is dependent on the prices of natural gas and renewable electricity, respectively. At present, the cost of hydrogen produced from natural gas is between 0.7 – 1.6 kg H2. Adding in carbon capture, the cost will increase to around 1.2 – 2.0 USD. Meanwhile, producing hydrogen using renewable electricity will generally cost around 3.2 – 7.7 USD. This therefore poses a significant challenge, because the cost of producing green hydrogen is up to twice as high as grey hydrogen. Nevertheless, the cost of green hydrogen projects is expected to decline rapidly, as the costs of electrolyzers and renewable energy will also decrease.

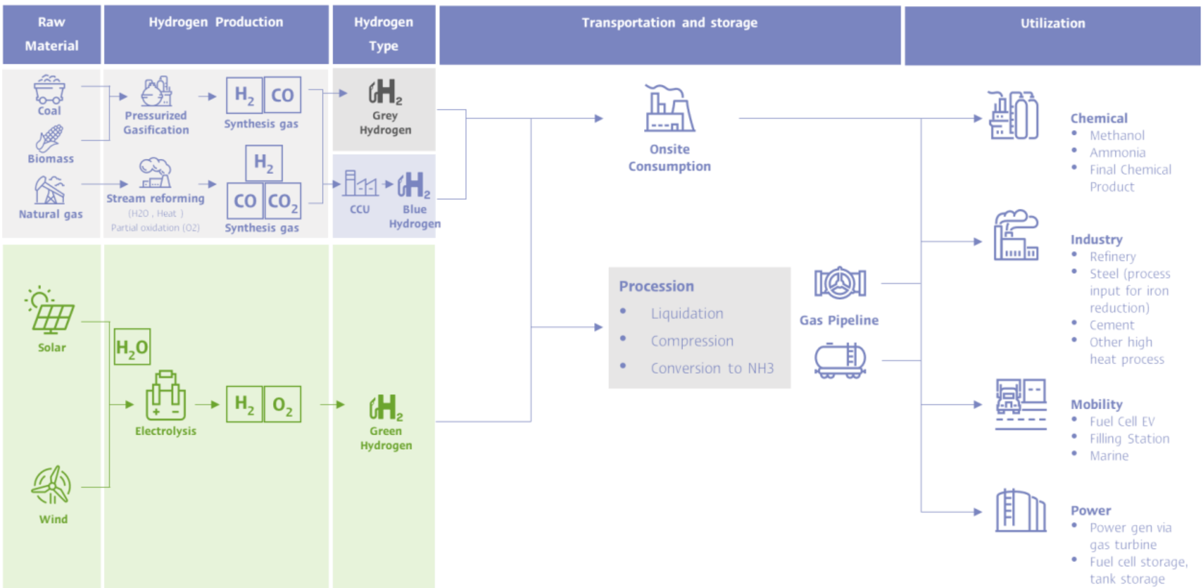
A unique property of hydrogen creates a key challenge in its storage and transportation. Given that hydrogen is a gas with low volumetric energy density, storing hydrogen requires high pressure and a low temperature to transform it into liquid hydrogen. Otherwise, it must be stored in an organic chemical such as ammonia, or in metal hydrides. In addition, hydrogen is the smallest element, meaning that leakages occur very easily, and it can make metal more brittle and highly flammable. A small portion of hydrogen can be transported via natural gas pipelines. However, transporting hydrogen alone requires a special pipeline, which either requires new investments or investments to improve existing natural gas pipeline systems. These challenges mean that it will be hard to produce a distributed hydrogen system that can compete with other clean technologies, in particular with electricity from renewable energy. Looking ahead, it is likely that the development of hydrogen technology will be concentrated closer to the major users, namely the refinery, petrochemical and metal sectors, and closer to major producers who are able to reduce their production costs through economies of scale.

Due to hydrogen's transport limitations, green ammonia has instead assumed a key role in hydrogen transport One way to overcome the limitations around transporting and storing hydrogen is by reacting hydrogen (H2) and nitrogen (N2) together to produce ammonia (NH3). Nitrogen is produced by separating nitrogen from air, through a process that is used widely used in industries. It is easier to store and transport ammonia than nitrogen gas, and there are already transport infrastructures in place for ammonia given that it is a widely-traded global commodity, and is a Feedstock and raw material in the production of fertilizers and petrochemicals.

Today, industrial ammonia production mainly uses grey hydrogen. If the ammonia industry is able to transition to green hydrogen, this will help to reduce greenhouse gas emissions from the industry. However, to use ammonia as a hydrogen carrier, an additional process for separating hydrogen and nitrogen is needed. Such a process will require energy to separate the two gases, and this will lead to a lower energy efficiency of hydrogen overall (because energy is lost during the production process, through conversion to ammonia, and in the process of separating hydrogen from nitrogen). Therefore, a lower renewable energy cost will be essential for the use of green ammonia and green hydrogen.

The production of green hydrogen will significantly increase the demand for electricity. The hydrogen industry must therefore have key infrastructures in place in terms of electricity systems and renewable electricity generation capacity. Europe's hydrogen strategy has outlined a target to achieve 500 MW of electrolyzer capacity by 2050 (against a maximum electricity demand of 546 GW). Goldman Sachs estimates that if the EU were to meet this target, electricity demand will need to double to meet the needs of green hydrogen production alone – meaning that green hydrogen production will become the activity that consumes the highest proportion of electricity in Europe. Consequently, the transition to a hydrogen economy must then be followed by investments in infrastructure for electricity generation, in hydrogen transport and storage, as well as hydrogen service stations in case hydrogen fuel cell electric vehicles (HFEV) are used in the future.

Figure 5: Hydrogen Ecosystem



Source: EIC analysis based on data from BCG Woodmac and Global Energy Venture

Implications for Thailand

Based on the issues and challenges discussed above, Thailand still faces several limitations to the wider adoption of hydrogen for reducing greenhouse gas emissions. Thailand faces limitations in terms of resources, infrastructure, and participation in the technological value chain relating to hydrogen production, transport, storage and utilization. The pricing structure for renewable energy in Thailand remains high, and the volume of renewable electricity generation is not currently sufficient enough to allow green hydrogen production to compete with other fuels. Moreover, Thailand does not yet have the carbon pricing mechanisms to encourage investments in clean technologies, as these still require a carbon tax or a carbon market to make them competitive.

The country's hydrogen strategy should be developed within the short-term. The role of hydrogen in the energy transition must be integrated with the context of Thailand's infrastructure system, energy consumption, and industrial landscape. An important strategic question to first consider is whether hydrogen will be used as an energy source, or as chemical feedstock.

- **As an energy source:** The use of hydrogen for electricity generation is limited by several factors. The first concerns transportation, as discussed above. The second is that, in the case of hydrogen combustion, this may lead to the creation of nitrogen oxides (NOx), gases that are dangerous to human health and which contribute indirectly to greenhouse gas emissions. Third, the round-trip efficiency of hydrogen is only around 50%, which means that its use will not be worthwhile if electricity can already be generated directly from renewables. Given this, investing in hydrogen to generate electricity, to compete with renewable energy-generated electricity, or to use alternately with natural gas, is not a cost-effective solution for Thailand's electricity system at present.

  At a later stage, hydrogen may not only need to compete with existing greenhouse gas emitting technologies, but with other types of clean technologies for each use case as well. In the short term, greenhouse gas emissions can be reduced by increasing energy efficiency, increasing renewable energy consumption, and by switching from fossil fuel-based energy to electrification, such as by changing steam boilers and using electric vehicles. These options are much more economical than using hydrogen, as they are already proven and require no investments in new technology infrastructure. For example, a new technology such as a hydrogen fuel cell electric vehicle (FCEV) will have to compete on price with internal combustion engine vehicles that use fossil fuels, with battery-powered EVs (BEV), as well as biofuels that reduce the greenhouse gas emissions of internal combustion engines.

However, hydrogen contains important energy properties that can enhance the security of electricity systems that contain a high proportion of renewable energy. This is because hydrogen does not have storage limitations (when compared to a battery, which cannot store energy for a long period of time, or pumped storage, which must be constructed in a strategically beneficial location), and it can ramp up electricity generation quickly when needed. In this case, using hydrogen as an energy reserve for when there is insufficient electricity supply will help to create a flexible and secure energy system. Finally, once the proportion of renewable electricity generation in Thailand increases, Thailand should consider investing in producing and using hydrogen as an energy reserve, as part of its investments to transition its electricity infrastructure towards net zero.

- As chemical feedstock: Hydrogen is currently used as a key raw material in oil refineries, where it is used to separate unwanted substances such as sulphur, oxygen, and hydrogen from oil (also known as hydrotreating) to improve oil quality and reduce pollutants that could be released via combustion from internal combustion engines. Likewise, ammonia is an essential raw material in the petrochemical industry. Because these hard-to-abate sectors use hydrogen as a feedstock, and are unable to electrify their production processes, this means that **there are no alternatives to replace hydrogen as a chemical feedstock** (instead, they can replace grey hydrogen with blue or green hydrogen).

Figure 6: Viability of using hydrogen to reduce carbon emissions, by sector

Source: EIC analysis based on data from Economist, Aug 2021

Replacing grey hydrogen with green or blue hydrogen within industries that already use hydrogen is the first step in the commercial production and use of hydrogen globally. In Thailand, efforts to reduce greenhouse gas emissions in these industries must occur quickly, particularly among industries that risk facing carbon taxes in the export market. However, over the shorter term, reducing greenhouse gas emissions using proven, cost-effective technologies are the main option for these industries, since the cost of producing green hydrogen is still uncompetitive compared to grey hydrogen. Furthermore, renewable electricity generation capacity is not yet high enough to support green hydrogen production.

As outlined above, increasing the production of renewable electricity is a necessary requirement of the hydrogen industry. Even so, Thailand currently has a low proportion of renewable energy production. Plans for hydrogen production and consumption should therefore align with the readiness of Thailand's electricity industry, and follow assessments of the infrastructure investments needed in each use case compared to other clean technologies. Distributed hydrogen systems might therefore not be cost-effective when considering the context of infrastructure investments. Finally, Thailand's hydrogen strategy should consider hydrogen's role in supporting new industries or clean technologies, for example, using hydrogen to produce drop-in biofuels, as hydrotreating is one of the key processes in increasing biofuel quality.

Hydrogen is the key to a net zero future in Thailand and globally. Although the national context and readiness level means that it is not currently suitable to ramp up investments in the hydrogen industry in Thailand, it is necessary to continue studying and monitoring the development of the hydrogen industry. Not only to support Thailand's integrated energy transition plan, but also to draw lessons from other countries on clean technology development, whether in terms of policy, technology, or competition governance, which could potentially be applied in Thailand. Doing so will ensure that the energy transition presents new business opportunities and enhances Thailand's competitiveness over the long term.

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