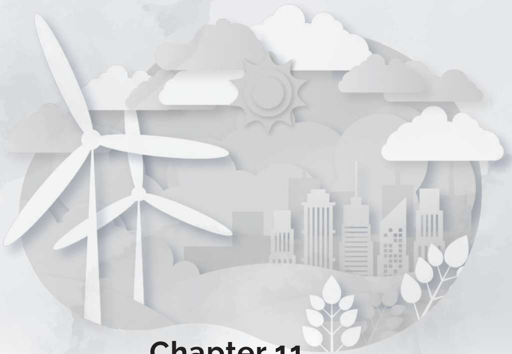

Chapter 11

Unlocking the Potential of Hydrogen in Indonesia

Denny Gunawan

A. Overview of the Importance of Hydrogen

The ever-increasing global population and economic development continue to intensify worldwide energy demand and greenhouse carbon dioxide emissions. To mitigate climate change driven by the large amounts of carbon dioxide gas released into the atmosphere, the world is now embarking on the switch from fossil fuels to alternative clean energy. Hydrogen is expected to play a crucial role as a versatile clean energy carrier and industrial feedstock with numerous applications as illustrated in Figure 11.1. More importantly, clean hydrogen generated using low or zero-emission sources can enable deep decarbonization across the energy and industrial sectors.

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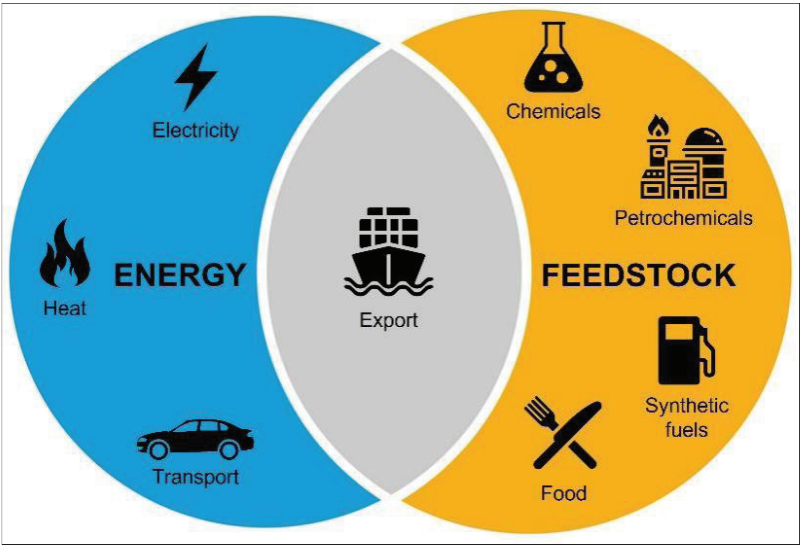
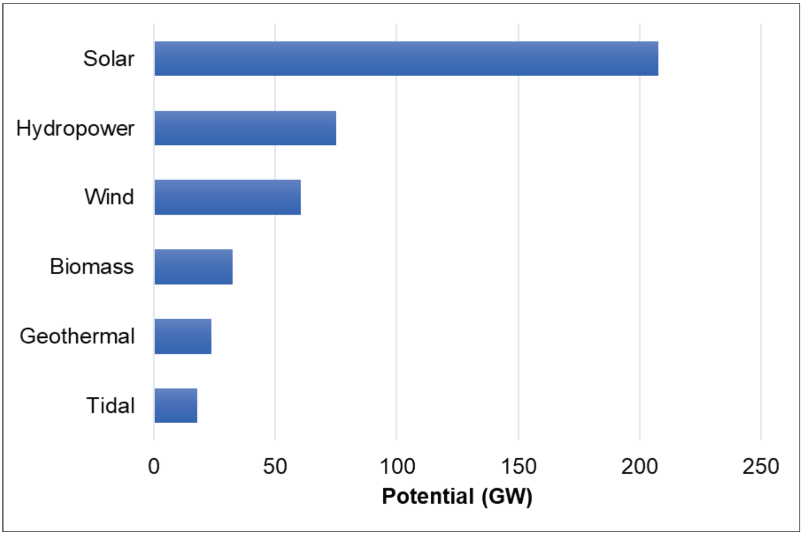
Gunawan, D. (2022). Unlocking the potential of hydrogen in Indonesia. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (209–235). BRIN Publishing.
DOI: 10.55981/brin.562.c11 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8



Source: Adapted from Bruce et al. (2018)

Figure 11.1 Applications for Hydrogen

As one of the world's largest greenhouse gas emitters, Indonesia has committed to achieving a 29–41% reduction in carbon emissions compared to the business-as-usual scenario by 2030 (Dunne, 2019). In this context, hydrogen is one in a suite of technology options to help Indonesia meet its climate targets. Moreover, the abundant renewable resources across the country, including solar, hydropower, wind, biomass, geothermal, and tidal as presented in Figure 11.2 could enable Indonesia to be a worldwide clean hydrogen powerhouse. The global market for hydrogen is projected to reach US$201 billion by 2025 (H2X Global, n.d.). Indonesia holds a huge opportunity to create new revenues by exporting renewable resources from hydrogen and its derivatives, such as ammonia and methanol.



Source: Adapted from Kementerian ESDM (2021)

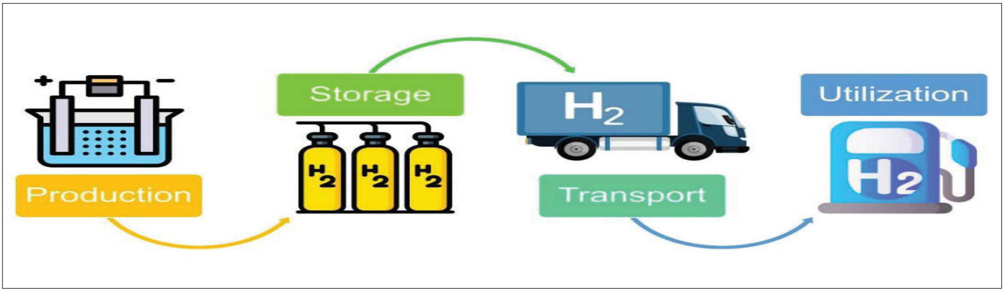
Figure 11.2 Indonesia's Renewable Energy Potential

Despite the enormous potential of clean hydrogen, Indonesia is facing a number of challenges associated with the adoption of hydrogen across its value chain. The high cost of renewable hydrogen production technologies is among the top challenges for clean hydrogen to be cost-competitive with fossil hydrogen. Extensive infrastructure requirements to ensure robust and reliable hydrogen storage and delivery is another concern revolving around the implementation of hydrogen. On top of that, the absence of any hydrogen-related policy and roadmap as well as the slow growth of renewable energy mix in Indonesia are also several potential factors that may hinder the widespread uptake of clean hydrogen in the country.

The overarching aim of this chapter is to provide a strategy recommendation for developing clean hydrogen industry in Indonesia. This chapter is expected to be a reference for various stakeholders, including government, industry, and research community to build Indonesia's hydrogen economy in a coordinated manner. The first few sections discuss the opportunities and challenges of clean hydrogen in Indonesia from both technical and economic perspectives. The following sections take the analysis further by synthesizing a national hydrogen strategy recommendation on how those opportunities can be realized within Indonesia while tackling the associated challenges.

B. Hydrogen Value Chain

The key challenge for the widespread growth of the hydrogen market is the scale-up of its value chain with affordable costs. The technologies underpinning the hydrogen value chain can be classified as production, storage, transport, and utilization as illustrated in Figure 11.3.



Source: Adapted from Bruce et al. (2018)

Figure 11.3 Hydrogen Technology Value Chain

1. Hydrogen Production

Hydrogen can be produced via several technological processes using different sources at varying greenhouse gas emissions. Currently, global hydrogen production is predominantly made from fossil fuels through steam methane reforming (SMR) and coal gasification. These two conventional pathways to produce gray hydrogen emit substantial amounts of carbon dioxide. Therefore, it is important to note that hydrogen may exhibit different cleanliness levels depending on its production. Based on the raw materials, synthesis methods, and carbon emissions, hydrogen is classified into numerous shades. Several hydrogen shades, currently or potentially utilized in Indonesia, include gray, blue, turquoise, pink, and green hydrogen as presented in Table 11.1.

Table 11.1 Selected Five Shades of Hydrogen

Color	Source	Process	Carbon footprint	Cost (US$/kg H_2) *
GRAY HYDROGEN	Natural gas or coal	SMR or gasification	High	0.50-1.70 (natural gas) 1.20-2.10 (coal)
BLUE HYDROGEN	Natural gas or coal	SMR or gasification with CCS	Low to medium (10-15% are emitted)	1.00-2.00 (natural gas) 1.50-2.80 (coal)
TURQUOISE HYDROGEN	Natural gas	Methane pyrolysis	Solid carbon (byproduct)	3.10-3.80
PINK HYDROGEN	Nuclear energy	Electrolysis or thermal splitting	Minimal	2.50-3.23
GREEN HYDROGEN	Renewable electricity	Electrolysis	Minimal	3.00-8.00

* Levelized cost of hydrogen in 2020

Source: Adapted from IRENA (2020) with additional information obtained from IEA (2021), Sánchez-Bastardo et al. (2021), and World Nuclear Association (2021a)

a. Gray Hydrogen

Gray hydrogen is produced from fossil fuels via SMR or coal gasification. This shade of hydrogen accounts for 96% of current worldwide hydrogen manufacturing (Taibi et al., 2018). In SMR, natural gas reacts with steam at elevated pressure and temperature to generate syngas (a mixture of hydrogen and carbon monoxide gases). On the other hand, coal gasification involves a reaction between coal with oxygen and steam at high temperatures and pressure to produce hydrogen and carbon monoxide gases. SMR and coal gasification are mature hydrogen production technologies that exist on a large scale across the world. The current levelized cost of hydrogen from natural gas and coal are approximately US$0.50–1.70 and US$1.20–2.10/kg hydrogen, respectively (IEA, 2021).

In the context of Indonesia where natural gas and coal resources are abundant, the existing hydrogen manufacturing plants across the country are dominated by SMR and coal gasification. Indonesia's gray hydrogen is commonly produced in the national oil and gas refinery facilities. Subsequently, hydrogen is supplied to oil processing units, ammonia plants for fertilizer industry, and methanol manufacturing plants. However, using gray hydrogen in various industries in Indonesia entails significant carbon dioxide emissions and therefore is unsuitable for achieving net-zero emissions targets.

b. Blue Hydrogen

Blue hydrogen is gray hydrogen coupled to carbon capture and storage (CCS) technology. This shade of hydrogen could assist in the reduction of carbon footprints from existing hydrogen plants during the early phase of energy transition while minimizing the pressure on renewable energy growth to produce green hydrogen. The current levelized cost of blue hydrogen is estimated to be around US$1.00–2.00 and US$1.50–2.80/kg hydrogen for CCS-coupled SMR and coal gasification, respectively (IEA, 2021). With the improved CCS technology and carbon pricing policy, future forecasts suggest that blue hydrogen could be more cost-competitive than gray hydrogen by 2030.

Indonesia is pursuing this shade of hydrogen to reduce carbon dioxide emissions from hydrogen manufacturing. For example, the Indonesian state-owned oil and gas enterprise, is now assessing the integration of CCS technology into its gray hydrogen production facilities. However, blue hydrogen has several limitations that make it inappropriate as a long-term solution. First, blue hydrogen is produced from finite resources and therefore is not sustainable. Second, the efficiency of CCS is expected to be approximately that 85–90%, implying 10–15% of the carbon dioxide is emitted (Leung et al., 2014). Although blue hydrogen significantly reduce carbon dioxide emissions, it should not be seen as the ultimate solution as it does not meet the requirements of a net-zero future.

c. Turquoise Hydrogen

Turquoise hydrogen is generated via natural gas pyrolysis with no carbon dioxide emissions. Through the pyrolysis process, the carbon in methane is solidified into carbon black, providing additional revenue. Turquoise hydrogen is still at the pilot stage in the United States. The challenges are its higher capital cost than blue hydrogen, particularly at a small scale, and the possibility of carbon coke in decreasing the catalyst lifetime and clogging up the reactor. The levelized cost of turquoise hydrogen is US$3.10–3.80/kg hydrogen (Sánchez-Bastardo et al., 2021). Resolving technical issues and scaling up the production could help reduce the cost and make it more competitive.

Indonesia could potentially pursue the production of turquoise hydrogen as a strategy to decarbonize its natural gas resource utilization. Noting that Indonesia's natural gas reserve is abundant, turquoise hydrogen production is a potential technological route to continue using natural gas with zero carbon emissions. In addition, the black carbon byproduct could generate additional revenues by selling it as a reinforcing material to local and foreign rubber product manufacturers, especially automobile tire producers.

d. Pink Hydrogen

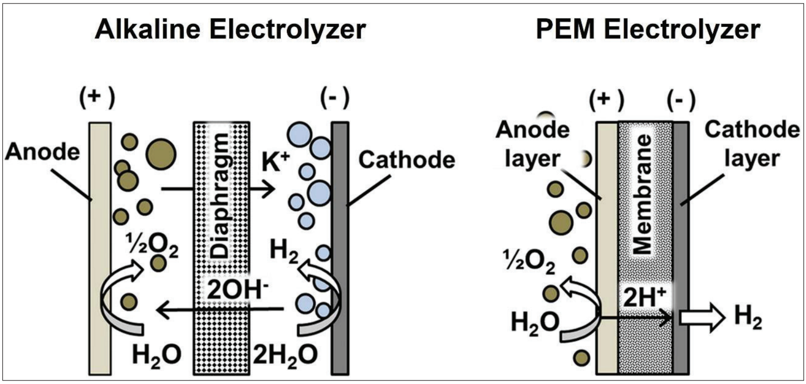
Hydrogen from nuclear-powered electrolysis is known as pink hydrogen. Although nuclear is not classified as a renewable energy source, the electricity derived from nuclear is carbon-free and hence is attractive to producing clean hydrogen. Furthermore, the heat generated from the nuclear reactor can be potentially harnessed to generate hydrogen via the thermal splitting of water or the thermal electrolysis process. The levelized cost of pink hydrogen is estimated to be US$2.50–3.23/kg (World Nuclear Association, 2021a).

With Indonesia's abundant uranium resources in Kalimantan and possibly West Papua (World Nuclear Association, 2021b), pink hydrogen is attractive zero-carbon hydrogen to be produced in the country. However, the realization of pink hydrogen largely depends on the social and political acceptance of nuclear energy which is currently considered low in the context of Indonesia. Overcoming these social and political issues revolving around nuclear energy can make pink hydrogen appealing to be incorporated into Indonesia's clean hydrogen mix.

e. Green Hydrogen

Green hydrogen means hydrogen generated from renewable energy. It is considered the most suitable form of hydrogen for energy transition toward net-zero emissions. Water electrolysis powered by renewable electricity has received tremendous attention for producing green hydrogen. The process involves two electrodes in the electrolyte solution and is connected to the renewable power supply. When a sufficient potential difference is applied between the electrodes, water is split into hydrogen on the cathode and oxygen on the anode.

To date, alkaline and proton exchange membrane (PEM) electrolyzers are the most advanced electrolyzer technologies with their advantages. Figure 11.4 depicts the setups of alkaline and PEM electrolyzers and selected characteristics of alkaline and PEM electrolyzers are presented in Table 11.2. Alkaline electrolyzers, which use a potassium hydroxide electrolyte, are the most commercially available and mature method for water electrolysis with lower capital costs. However, PEM electrolyzers, which are currently more expensive, offer a much smaller footprint, higher current density, and output pressure (Bruce et al., 2018; Schmidt et al., 2017).



Source: Esposito (2017)

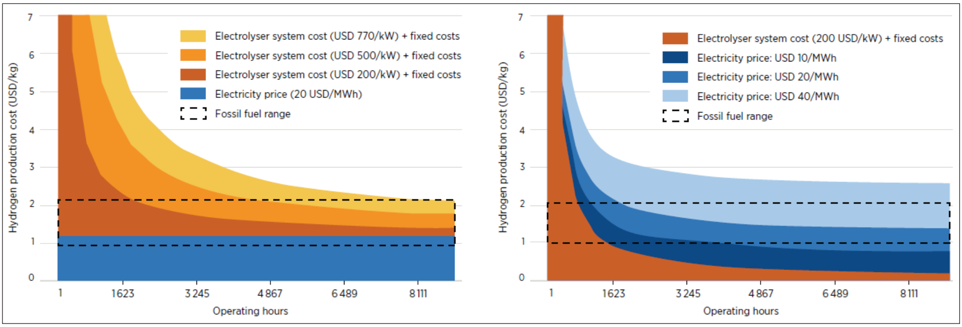
Figure 11.4 Schematic Diagrams of Alkaline and PEM Electrolyzers

Table 11.2 Selected Characteristics of Alkaline and PEM Electrolyzers

	Alkaline Electrolyzer	PEM Electrolyzer
Electrolyte	Aqueous KOH	Polymer membrane
Current density (A cm^{-2})	0.2–0.4	0.6–2.0
Cell pressure (bara)	<30	<70
System efficiency (kWh $kg_{H_2}^{-1}$)	4.5–6.6	4.2–6.6
Lifetime (h)	60,000	50,000–80,000
Capital cost for the entire system, >10 MW (US$ kW^{-1})	500–1000	700–1400

Source: Schmidt et al. (2017) & Taibi et al. (2020)

Major barriers to green hydrogen production are its high capital and operational costs. Green hydrogen is still much costlier (US$3.00–8.00/kg hydrogen) compared to gray and blue hydrogen (IEA, 2021). The production cost of green hydrogen is influenced by renewable electricity price, electrolyzer cost, and operational capacity as shown in Figure 11.5. The largest cost component for hydrogen production is the price of renewable electricity to power the electrolyzer system. Consequently, a low electricity cost is necessary to make green hydrogen production more competitive with other shades of hydrogen. However, declining renewable electricity cost alone is likely insufficient to reduce green hydrogen costs to the fossil hydrogen range. Lowering the cost of the electrolyzer and increasing its efficiency is also essential. Shortly, green hydrogen could be on par with blue and even gray hydrogen if continuous improvements in renewable power and electrolyzer technologies, as well as rapid process scale-up, are made.

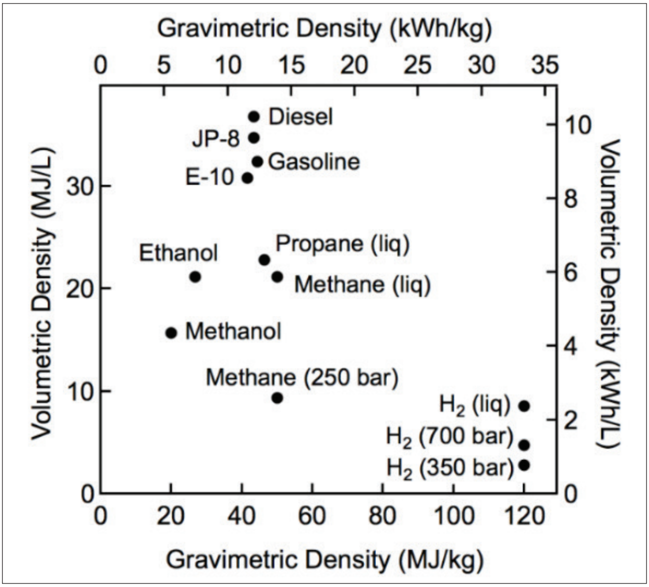


Source: IRENA (2020)

Figure 11.5 Hydrogen Production Cost as a Function of Electrolyzer Capital Cost, Electricity Price, and Operating Hours

2. Hydrogen Storage

Hydrogen storage is a crucial technology if widespread applications of hydrogen are expected. As a result, establishing robust and reliable hydrogen storage is of importance. Although hydrogen exhibits high gravimetric density, the volumetric density of hydrogen in either gaseous or liquid state is relatively low as illustrated in Figure 11.6. Consequently, efficient hydrogen storage with low space requirements and inexpensive cost is challenging. In general, hydrogen storage techniques can be classified into two main categories: physical- and material-based storage (Moradi & Groth, 2019).



Source: U.S. Department of Energy (n.d.)

Figure 11.6 Gravimetric and Volumetric Energy Density of Hydrogen Compared to Other Fuels

a. Physical-Based Storage

The physical-based hydrogen storage system comprises compressed gas, cryo-compressed, and liquid hydrogen storage (Moradi & Groth, 2019). In unpressurized gaseous form, hydrogen has a low volumetric density and requires a huge storage space. Thus, keeping large volumes of hydrogen in an unpressurized system is not economically viable due to space limitations and high capital costs. Compression of hydrogen gas is the most common and mature technique to improve its volumetric density. The compressed hydrogen can then be stored in pressure vessels at dedicated facilities.

If large volumes of hydrogen are required, hydrogen can be injected into underground geological formations (Osman et al., 2021). For example, depleted hydrocarbon reservoirs are appealing sites to store hydrogen underground due to their storage capacity.

Salt caverns are another potential underground storage medium. The key advantages of hydrogen storage in salt caverns are their high impermeability and flexibility of hydrogen discharge rate, duration, and volume (Osman et al., 2021).

Hydrogen can also be physically stored in its liquid or supercritical phase through liquefaction or cryo-compression. Compared to gas compression, these two processes exhibit higher capital and operation costs, mainly due to the extensive energy requirements for cooling to cryogenic temperature and expensive materials for cryogenic storage vessels. However, both technologies could be more viable if the hydrogen demand is very high.

b. Material-Based Storage

Although physical-based hydrogen storage offers volumetric density improvement, the space requirement is still considered large compared to other fuels. Converting hydrogen into its material derivatives with higher volumetric energy densities is attractive to improve storage efficiency. Ammonia, methanol, and metal hydrides are appealing candidates for material-based hydrogen storage.

Ammonia is a promising material-based hydrogen carrier because of its high hydrogen density and flexibility in its utilization. Conventionally, ammonia is produced via the Haber-Bosch process where nitrogen reacts with hydrogen at high temperature and pressure in the presence of a catalyst. The facilities for ammonia production exist widely in Indonesia. Therefore, storing hydrogen as ammonia does not require a high capital cost to build new infrastructures. Ammonia can be utilized by extracting its stored hydrogen or directly used as fuel. More importantly, ammonia can be easily liquefied and its storage, as well as delivery methods, are well-established. However, liquid ammonia has a higher gravimetric density than compressed and liquid hydrogen, thus leading to heavier storage (Aziz et al., 2020). In addition, releasing hydrogen from ammonia requires a relatively huge amount of energy, and a separation process is necessary to obtain high hydrogen purity.

Methanol is also a promising candidate for liquid organic hydrogen carriers that could enable carbon dioxide utilization via hydrogenation. Since methanol is liquid at ambient temperature and pressure, storage and transport are easy with the existing infrastructure. Methanol can be used directly as liquid fuel or split to release hydrogen via thermolysis, steam reforming, and partial oxidation with a low energy requirement.

Metal hydrides have recently emerged as a solid-state hydrogen storage option. The key advantage of metal hydrides is their much higher volumetric densities compared to the gaseous and liquid forms of storage. In addition, storing hydrogen as metal hydrides could minimize the hazards of pressurized hydrogen gas or liquified hydrogen. Unfortunately, the use of metal hydrides is mainly limited to stationary applications. Metal hydrides are deemed challenging to apply for mobility uptake because of the temperature requirements, the weight of storage units, and poor kinetics of hydrogen release (Bruce et al., 2018).

3. Hydrogen Transport

The delivery of hydrogen from the producers to end users is essential for a viable hydrogen infrastructure. Currently, hydrogen is typically produced near industrial facilities that use hydrogen as the feedstock. For instance, SMR and coal gasification plants in Indonesia are predominantly located within oil and gas refineries or petrochemical industries to serve as reagents for hydrotreating, hydrocracking, hydrogenation, or ammonia production. In this case, hydrogen transport is relatively simple and inexpensive due to the short distance and low or moderate quantity. Since hydrogen is emerging as an energy vector and feedstock for decarbonizing a number of major economic sectors, transporting hydrogen at a longer distance and in higher quantity is important. The key challenge is the investment cost required to build the appropriate infrastructure. In the context of Indonesia, hydrogen transport is even more challenging due to its geographical conditions.

Generally, hydrogen may be transported using land transports such as trucks and rails with inexpensive costs for short-distance delivery and low volumes of hydrogen. If delivery across islands and international export is required, hydrogen transport by ship is a transport mode that can be used. In addition to those three modes of hydrogen transport, pipeline offers simultaneous distribution with greater delivery distance (Bruce et al., 2018). Although pipeline distribution is considered a suitable delivery method to support widespread hydrogen uptake, transport of hydrogen via pipeline is complex. To reduce the pressure on new pipeline infrastructure installations, injecting hydrogen into the existing natural gas pipeline is an attractive option that can also help decarbonize the gas sector. If pure hydrogen is demanded, new pipelines or upgraded existing natural gas pipelines are necessary due to the gas property differences.

The delivery of hydrogen in its physical-stored form is difficult due to the lack of perfectly suitable infrastructure. Storing hydrogen as chemicals or material derivatives with more mature infrastructure (e.g., ammonia, methanol, and synthetic natural gas) can be a promising solution during the transition period toward hydrogen economy while further expanding pure hydrogen transport infrastructure. Indonesia is one of the largest ammonia and methanol producers in the world. Consequently, Indonesia has sufficient capability to distribute those material-based hydrogen carriers.

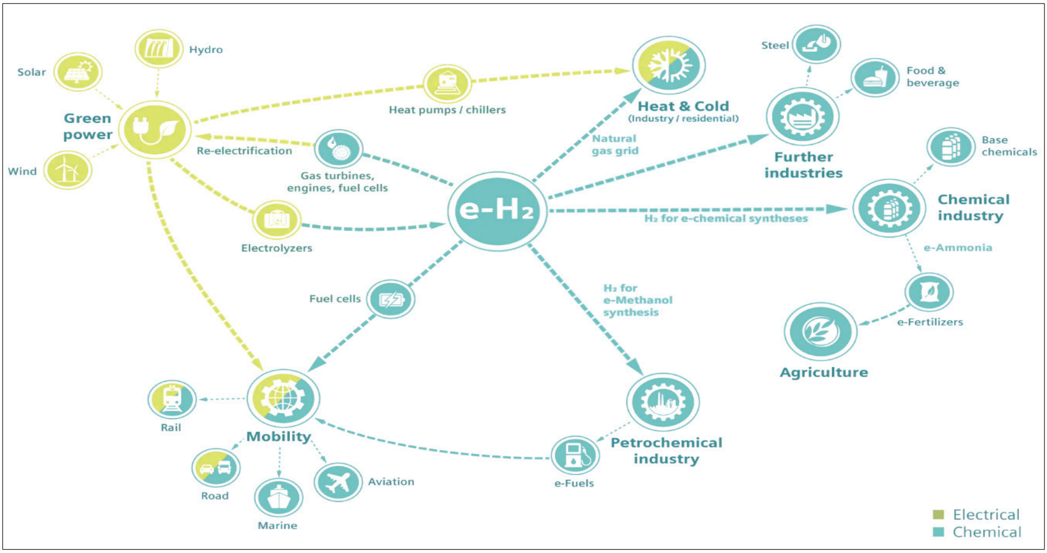
4. Hydrogen Utilization

For years, hydrogen has been extensively used as a reagent in numerous industries. Today, the top three uses of hydrogen are petroleum refining (33%), ammonia production (27%), and methanol synthesis (11%) (IEA, 2019).

In a petroleum refinery, hydrogen is predominantly required for hydrotreatment and hydrocracking processes. Hydrotreatment uses hydrogen to remove sulfur, nitrogen, and other contaminants from petroleum oil to create a cleaner fuel. Hydrocracking is a process that cracks long-chain heavy hydrocarbons to form valuable products such as gasoline, kerosene, diesel, and avtur. In addition to fossil refinery, hydrogen plays a key role in biorefinery as a reagent in the hydrodeoxygenation process to produce biofuels.

The chemical sector takes the second and third places for the largest sources of hydrogen demand including ammonia and methanol manufacturing. Ammonia is produced via a mature Haber-Bosch process by reacting nitrogen with hydrogen at high temperature and pressure in the presence of a catalyst. Currently, ammonia is mainly adopted as a feedstock for agricultural fertilizer production. More recently, ammonia is also seen as a highly potential carbon-free fuel. As the third-largest industry using hydrogen, methanol synthesis typically proceeds via carbon dioxide or carbon monoxide hydrogenation. Approximately 65% of methanol is consumed for chemicals and fuel additives production (Dalena et al., 2018).

As the world races to decarbonize, green hydrogen is expected to have broader applications. Through power-to-X (P2X) framework, hydrogen could enable deep decarbonization of hard-to-abate sectors, which is widely known as sector coupling (Figure 11.7). P2X is defined as a method of converting renewable electricity into liquid or gaseous chemical energy via electrolysis (Gunawan, 2022). Producing hydrogen through water electrolysis is at the core of P2X due to the versatility of hydrogen across different sectors.



Source: Schnettler (n.d.)

Figure 11.7 Power-To-X Framework for Decarbonizing Hard-To-Abate Sectors Using Hydrogen

The primary challenge of integrating renewable energy into the existing grid in the electricity sector is its intermittency. At times, the energy supply is higher than the demand, while the generated power is too little at other times. For instance, solar electricity production depends on the amount of sunlight reaching the solar panels and wind-generated power depends on wind velocity and air density. Therefore, adequate storage solutions are essential to resolve intermittency and ensure grid stability. Even though battery is the most common storage solution, its capacity and storage timespan are limited (Hydrogen Council, 2017). On the other hand, hydrogen offers a promising solution for long-term storage, facilitating the resilience of the grid system. Excess renewable electricity can be converted through electrolysis into hydrogen gas during oversupply. The produced hydrogen can then be transformed back to electricity using a fuel cell or a gas turbine during power deficits.

In terms of power distribution, hydrogen represents a promising energy carrier thanks to its high energy density. Hydrogen can be distributed over long distances via pipelines with nearly 100% efficiency (Hydrogen Council, 2017). In the national-level energy system, this could enable a centralized or decentralized primary or backup power source. Furthermore, in the context of global energy supply, hydrogen is a powerful enabler to exporting renewable electricity at competitive pricing, potentially ramping up national revenue.

As a versatile energy vector, hydrogen can link heat and electricity sectors (Gurieff et al., 2021). Nowadays, heating applications for domestic and industrial purposes are dominated by petroleum oil, natural gas, or coal as fuel. For example, liquefied petroleum gas (LPG) and liquefied natural gas (LNG) are typical cooking gases utilized in Indonesia. Coal or natural gas are burned to produce heat in industries requiring high thermal energy input (e.g., petrochemical and cement manufacturers). Hydrogen can help decarbonize the heat generation process through two different scenarios. The first scenario is the natural gas enrichment with hydrogen. Blended 10–15% hydrogen with natural gas can be applied using the existing infrastructures and appliances, thereby reducing the cost needed for system upgrades (Bruce et al., 2018). The second scenario, deemed more consistent with the net-zero targets, utilizes pure hydrogen to replace fossil fuels for heating applications. However, this approach will require replacing or upgrading of the existing infrastructures and appliances, rendering high capital costs.

Hydrogen can also power vehicles using a fuel cell generating electricity to run the car. Fuel cell electric vehicles (FCEVs) offer numerous key benefits such as long travel distances without refueling along with a fast-refueling rate (Hydrogen Council, 2017). Although past attempts to switch to FCEVs were baffled by the presence of battery electric vehicles (BEVs) mainly due to the lack of hydrogen refueling infrastructure, the benefits of FCEVs render them necessary in decarbonizing passenger cars, heavy-duty transport, and public transport (buses and trains). In Indonesia, for instance, the state-owned Indonesian Railways Company (PT KAI) submitted a memorandum of understanding (MoU) to Alstom on a project for hydrogen-powered trains in 2019 (Aditiya & Aziz, 2021).

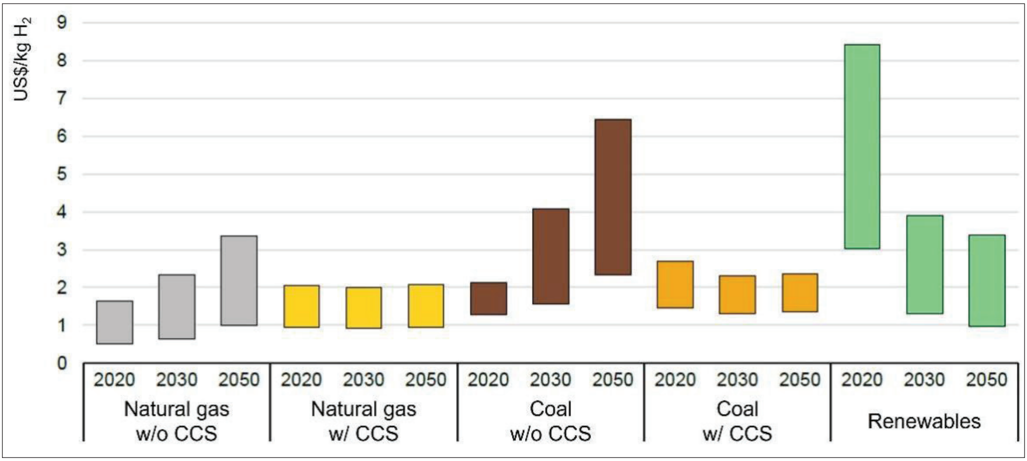
As an industrially important feedstock, hydrogen is essential in manufacturing chemicals and fuels, as described earlier. Replacing the existing gray hydrogen with green hydrogen can significantly reduce carbon footprints. In addition, carbon dioxide from emission points or the atmosphere can be processed using green hydrogen to produce valuable chemicals and fuels via methanation, hydrogenation, or Fischer-Tropsch, thereby helping close the carbon loop in heavy sectors (Daiyan et al., 2020).

C. Existing Barriers for Hydrogen Uptake in Indonesia

Hydrogen is a compelling energy carrier and industrial feedstock, and mainly green hydrogen offers a promising pathway toward a net-zero future. In Indonesia, numerous green hydrogen initiatives have appeared in recent years by state-owned and private companies. The highly abundant renewable resources, ranging from solar, hydropower, wind, biomass, geothermal to tidal, are the main driver for the green hydrogen industry in Indonesia. Nevertheless, a number of barriers that may limit the uptake of hydrogen-related technology in Indonesia exist and need to be tackled before the full benefits of hydrogen are manifested.

1. High Production Costs

At the moment, green hydrogen produced using renewable electricity is costlier than gray and blue hydrogen. In addition, utilizing green hydrogen for new downstream applications can be more expensive than its fossil counterparts. In terms of production, the major contributors to the green hydrogen price are the costs for renewable electricity generation and electrolyzers. Nevertheless, the levelized cost of green hydrogen is expected to fall by 2050 thanks to the continuous improvements in cost and performance of renewable and electrolyzer technologies. More importantly, the cost of green hydrogen could be more competitive compared with gray and blue hydrogen, as presented in Figure 11.8, if supporting policies are implemented.



Source: IEA (2021)

Figure 11.8 Levelized Cost of Hydrogen Production by Technology in 2020 and the Estimated Cost in 2030 and 2050 Under the Net-Zero Emissions Scenario

2. Lack of Hydrogen Infrastructure

Up to now, most of the hydrogen in Indonesia is produced near utilization sites, such as petroleum refinery, biorefinery, and petrochemical manufacturing plant. Consequently, dedicated hydrogen transport infrastructures are limited, especially for long-distance delivery. For fuel cell electric vehicle applications, hydrogen uptake is also currently hindered due to the absence of refueling stations. Therefore, investments in hydrogen infrastructure with a long horizon are needed.

3. Absence of National Hydrogen Strategy

Developing a hydrogen economy requires a coordinated effort by the government, industry, and research community. A national hydrogen strategy, which comprises a roadmap and a set of policies, is essential to synergize all stakeholders. The lack of a clear national strategy indicates the poor commitment made by the government on hydrogen and eventually discourages potential investors.

4. Insufficient Recognition of Hydrogen Value

Today, the hydrogen capability to reduce carbon footprints in various sectors is recognized as a concept but does not receive enough valuation. In Indonesia's energy statistics, hydrogen is not listed in the total final energy consumption (Kementerian ESDM, 2020). While the government continues to increase cash subsidy for fossil fuels which accounts for 8% of Indonesia's total budget in 2020 (Sumarno & Sanchez, 2021), the incentives to promote the use of green hydrogen are lacking, thereby restricting potential markets for green hydrogen.

D. Indonesia's Pathway to a Hydrogen Economy

The hydrogen economy decarbonize hard-to-abate sectors such as cement, steel, chemicals, and heavy-duty transportation. These sectors are difficult to electrify directly using renewable electricity due to the nature of the processes, high-temperature heat requirements, and/or high-density energy source requirements. As nearly a third of global carbon dioxide emissions are attributed to these sectors, a viable alternative solution to decarbonize hard-to-abate industries is vital. Hydrogen, particularly green hydrogen, appears to be the most promising decarbonization pathway for these sectors.

Implementing green hydrogen as a widespread energy carrier in Indonesia will require meticulous national strategies and a set of comprehensive national policies to overcome existing barriers. Unfortunately, Indonesia has not formulated any hydrogen roadmap and policies yet. To stimulate the development of the hydrogen industry in Indonesia, herein, a national hydrogen strategy, which comprises a detailed national hydrogen roadmap and enabling policies, is proposed according to Indonesia's current position and existing barriers in hydrogen uptake across the country.

1. Establishing Indonesia's National Hydrogen Roadmap

Developing a sustainable hydrogen economy in Indonesia to achieve net-zero emissions targets can be daunting without comprehensive early planning. While many countries have published their hydrogen strategies, Indonesia has not drafted any step-by-step roadmap to incorporate hydrogen in its energy policies. To accelerate the uptake of hydrogen across different applications on the path to net-zero emissions, the following national roadmap is proposed to the Indonesian government. Indonesia's national hydrogen roadmap should aim for an integrated system across the hydrogen value chain. To meet net-zero emissions by 2060, the roadmap has to focus on green hydrogen as the ultimate target due to its suitability to combat climate change. This proposed national hydrogen roadmap adopts a step-by-step approach including five transition phases. Electrolyzer capacity milestones in each phase are set by considering the best policy scenario proposed by Tampubolon et al. (2021).

Phase 1 (2022–2025)

Indonesia shifts from gray/black hydrogen to blue hydrogen by deploying CCS technology in the existing gray/black hydrogen production facilities. The initial focus is to reduce carbon footprints in industrial applications that already use hydrogen as the feedstock. Hence, the existing hydrogen storage and transport infrastructure can still be used. At the same time, the government has to facilitate the uptake of hydrogen in new downstream applications (e.g., fuel cell power plants, fuel cell electric vehicles, and heating appliances) through project collaborations with stakeholders.

Phase 2 (2026–2030)

Indonesia continues to generate and utilize blue hydrogen while starting the green hydrogen initiative by developing demonstration plants with at least 10 MW capacity each. For instance, the government could build a water electrolyzer for hydrogen production in the North Kalimantan Green Industrial Park (Gunawan, 2022). This steppingstone is expected to encourage state-owned and private heavy industries to build green hydrogen production facilities and gradually phase out fossil hydrogen. At this stage, hydrogen is also likely to expand its applications to public transport (e.g., fuel cell electric buses and trains) in major cities. If possible, the existing facilities provide infrastructure and a number of refueling stations are built to supply the hydrogen demand from fuel cell electric public transport.

Phase 3 (2031–2040)

Indonesia develops five green hydrogen hubs in its major islands including Sumatra, Java, Kalimantan, Sulawesi, and Papua with a total capacity of at least 100 GW (Tampubolon et al. (2021) proposed 138.7 GW capacity as the best policy scenario in 2040). Prospective locations for the green hydrogen hubs are presented in Figure 11.9 based on each renewable energy potential. All industries are expected to use green hydrogen as the feedstock and energy source by building hydrogen power plants. Blue hydrogen can still be used in limited quantities to ensure sufficient supply to meet the demand while ramping up national green hydrogen capacity. The hydrogen applications are further extended to private vehicles (e.g., fuel cell electric cars) and gas networks using natural gas enrichment scenario. In addition, at this crucial phase, Indonesia has to focus on developing the hydrogen infrastructure, including large-scale storage systems (e.g., pressurized vessels and underground storage) and hydrogen pipelines across the country for long-distance delivery.

Source: Adapted from IESR (2018)

Figure 11.9 Prospective Locations for the Green Hydrogen Hubs according to Renewable Potential and Installed Capacity Including Variable Renewables (Solar, Wind, and Tidal) and Controllable Renewables (Hydropower, Biomass, and Geothermal)

Phase 4 (2041–2050)

Indonesia scales up its electrolyzers to a total capacity of at least 200 GW (Tampubolon et al. (2021) proposed 229.1 GW capacity as the best policy scenario in 2050) by upgrading the facilities in selected sites with huge potential for renewables and land availability such as Kalimantan and Papua hubs. The production of blue hydrogen is phased out, but natural gas may still serve as raw material for turquoise hydrogen production if viable. At this phase, Indonesia is expected to continue the construction of hydrogen infrastructures to ensure a just energy transition while developing a capability to export hydrogen and its derivatives.

Phase 5 (2051–onward)

Indonesia becomes a global hydrogen powerhouse in which green hydrogen reaches maturity and is deployed across various sectors. Green hydrogen, ammonia, and methanol are exported to resource-constrained countries in Asia-Pacific such as Singapore, Japan, and South Korea, thereby generating additional revenues.

2. Establishing Supporting Policies to Overcome Barriers

In addition to a national roadmap, the government should support the development of a green hydrogen economy through enabling policies to overcome existing barriers. The policies reflect the government's commitments to integrating hydrogen into the national energy system toward a net-zero future across all sectors.

Regarding hydrogen production, green hydrogen currently suffers from higher costs due to expensive renewable energy technologies and electrolyzers. Numerous policies can help reduce the cost of green hydrogen. First, the government should set optimistic yet realistic targets for national renewable energy share and electrolyzer capacity. The proposed national hydrogen roadmap targets could attract domestic and foreign investors. Second, cutting taxes and providing incentives for the installations of renewable energy infrastructures and electrolyzers will increase capacity growth rate, thus reducing the price as well as ramping up revenues and the rate of return. Support for research to improve electrolyzer efficiency via funding and international collaborations are also essential to lower the capital costs.

Another significant challenge of hydrogen is the lack of infrastructure for storage and transport. To overcome financial issues for infrastructure developments, the government has to collaborate with developed countries through global trading agreements. In addition, green policies need to be formulated to encourage private sectors to develop hydrogen infrastructure. For instance, a carbon taxing policy where carbon dioxide emissions are priced as the environmental cost could stimulate industry to phase out fossil fuels and build the capacity to produce, store, and transport green hydrogen. More importantly, a national timeline to phase out high-emission technologies will push industries to develop end-use technologies that align well with hydrogen, thereby creating a new market for green hydrogen.

References

Aditiya, H. B., & Aziz, M. (2021). Prospect of hydrogen energy in Asia-Pacific: A perspective review on techno-socio-economy nexus. *International Journal of Hydrogen Energy*, *46*(71), 35027–35056. https://doi.org/10.1016/j.ijhydene.2021.08.070

Aziz, M., Wijayanta, A. T., & Nandiyanto, A. B. D. (2020). Ammonia as effective hydrogen storage: A review on production, storage and utilization. *Energies*, *13*(12), 3062. https://doi.org/10.3390/en13123062

Bruce, S., Temminghoff, M., Hayward, J., Schmidt, E., Munnings, C., Palfreyman, D., & Hartley, P. (2018). *National hydrogen roadmap: Pathways to an economically sustainable hydrogen industry in Australia*. CSIRO.

Daiyan, R., MacGill, I., & Amal, R. (2020). Opportunities and challenges for renewable power-to-x. *ACS Energy Letters*, *5*(12), 3843–3847. https://doi.org/10.1021/acsenergylett.0c02249

Dalena, F., Senatore, A., Basile, M., Knani, S., Basile, A., & Iulianelli, A. (2018). Advances in methanol production and utilization, with particular emphasis toward hydrogen generation via membrane reactor technology. *Membranes (Basel)*, *8*(4), 98. https://doi.org/10.3390/membranes8040098

Dunne, D. (2019). *The carbon brief profile: Indonesia*. https://www.carbonbrief.org/the-carbon-brief-profile-indonesia

Esposito, D. V. (2017). Membraneless electrolyzers for low-cost hydrogen production in a renewable energy future. *Joule*, *1*(4), 651–658. https://doi.org/10.1016/j.joule.2017.07.003

Gunawan, D. (2022). *How power-to-x technology could help decarbonise Indonesia's industrial sector*. The Conversation Indonesia. https://theconversation.com/how-power-to-x-technology-could-help-decarbonise-indonesias-industrial-sector-174405

Gurieff, N., Moghtaderi, B., Daiyan, R., & Amal, R. (2021). Gas transition: Renewable hydrogen's future in eastern Australia's energy networks. *Energies*, *14*(13), 3968. https://doi.org/10.3390/en14133968

H2X Global. (n.d.). *Global hydrogen demand*. Retrieved November 24, 2022, from https://h2xglobal.com/global-hydrogen-demand/

Hydrogen Council. (2017). *How hydrogen empowers the energy transition*. https://hydrogencouncil.com/wp-content/uploads/2017/06/Hydrogen-Council-Vision-Document.pdf

International Energy Agency (IEA). (2019). *The future of hydrogen: Seizing today's opportunities*. https://www.iea.org/reports/the-future-of-hydrogen

International Energy Agency (IEA). (2021). *Global hydrogen review 2021*. https://www.iea.org/reports/global-hydrogen-review-2021

Institute for Essential Services Reform (IESR). (2018). *Potensi dan kapasitas terpasang energi terbarukan Indonesia tahun 2018*. https://iesr.or.id/infografis/potensi-dan-kapasitas-terpasang-energi-terbarukan-indonesia-tahun-2018

International Renewable Energy Agency (IRENA). (2020). *Green hydrogen policy: A guide to policy making*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf

Ministry of Energy and Mineral Resources Republic of Indonesia (Kementerian ESDM). (2020). *Handbook of energy & economic statistics of Indonesia 2020*. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2020.pdf

Kementerian ESDM. (2021). *Berapa potensi energi terbarukan di Indonesia?* https://databoks.katadata.co.id/datapublish/2021/03/09/berapa-potensi-energi-terbarukan-di-indonesia

Leung, D. Y. C., Caramanna, G., & Maroto-Valer, M. M. (2014). An overview of current status of carbon dioxide capture and storage technologies. *Renewable and Sustainable Energy Reviews*, *39*, 426–443. https://doi.org/10.1016/j.rser.2014.07.093

Moradi, R., & Groth, K. M. (2019). Hydrogen storage and delivery: Review of the state of the art technologies and risk and reliability analysis. *International Journal of Hydrogen Energy*, *44*(23), 12254–12269. https://doi.org/10.1016/j.ijhydene.2019.03.041

Osman, A. I., Mehta, N., Elgarahy, A. M., Hefny, M., Al-Hinai, A., Al-Muhtaseb, A. a. H., & Rooney, D. W. (2021). Hydrogen production, storage, utilisation and environmental impacts: A review. *Environmental Chemistry Letters*, *20*, 153–188. https://doi.org/10.1007/s10311-021-01322-8

Sánchez-Bastardo, N., Schlögl, R., & Ruland, H. (2021). Methane pyrolysis for zero-emission hydrogen production: A potential bridge technology from fossil fuels to a renewable and sustainable hydrogen economy. *Industrial & Engineering Chemistry Research*, *60*(32), 11855–11881. https://doi.org/10.1021/acs.iecr.1c01679

Schmidt, O., Gambhir, A., Staffell, I., Hawkes, A., Nelson, J., & Few, S. (2017). Future cost and performance of water electrolysis: An expert elicitation study. *International Journal of Hydrogen Energy*, *42*(52), 30470–30492. https://doi.org/10.1016/j.ijhydene.2017.10.045

Schnettler, A. (n.d.). *At the dawn of the hydrogen economy*. Retrieved November 24, 2022, from https://www.powermag.com/siemens-dawn-hydrogen-economy/

Sumarno, T. B., & Sanchez, L. (2021). *How Indonesia can achieve both a COVID-19 recovery and its climate targets*. International Institute for Sustainable Development. https://www.iisd.org/system/files/2021-10/indonesia-achieve-covid-19-recovery-climate-targets.pdf

Taibi, E., Blanco, H., Miranda, R., & Carmo, M. (2020). *Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5°C climate goal*. International Renewable Energy Agency. https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

Taibi, E., Miranda, R., Vanhoudt, W., Winkel, T., Lanoix, J.-C., & Barth, F. (2018). *Hydrogen from renewable power: Technology outlook for the energy transition*. International Renewable Energy Agency. https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power

Tampubolon, A. P., Tumiwa, F., Simamora, P., Pujantoro, M., Godron, P., Breyer, C., Gulagi, A., Oyewo, A. S., & Bogdanov, D. (2021). *Deep decarbonization of indonesia's energy system: A pathway to zero emissions by 2050*. Institute for Essential Services Reform. https://iesr.or.id/download/deep-decarbonization

U.S. Department of Energy. (n.d.). *Hydrogen storage*. Retrieved November 24, 2022, from https://www.energy.gov/eere/fuelcells/hydrogen-storage

World Nuclear Association. (2021a). *Hydrogen production and uses*. https://www.world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.aspx

World Nuclear Association. (2021b). *Nuclear power in Indonesia*. https://world-nuclear.org/information-library/country-profiles/countries-g-n/indonesia.aspx