Unlocking Hydrogen Full Potential as ASEAN Future Energy

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Abstract. Hydrogen or also known as H₂ in chemical writing become one of a high potential renewable fuel, energy storage, and energy carrier. There’s various types of hydrogen based on its processing, which are Black & Brown Hydrogen, Grey Hydrogen (95% of hydrogen produced from this type), Blue Hydrogen, Bio-Hydrogen, and Green-Hydrogen. Blue and green hydrogen is the suitable choices for energy application especially in ASEAN because of carbon capture and storage (CCS) technology that applied on the process and greenhouse gases (GHG) free. But generally, hydrogen application in ASEAN is not optimally unlocked, only a few countries and a few sectors applied hydrogen as renewable energy sources (RESs). The main problems on these issues are hydrogen application cost is not competitive to other RESs. The high cost of hydrogen might cause by high production cost that should be lowered down by applying various technology to the production process such as CMR-SMR. This study critically research on solution of how hydrogen can be used optimally in ASEAN from technical, technology, and economics perspectives.

1. Introduction
ASEAN initiatives to develop the rate of renewable energy application to 23% in 2025 (as shown in graphic 1) and more in 2030 [10] is meeting a barrier which the intermittency of wind and solar energy, as the solar energy become the first majority to be develop as renewable energy sources with 207.8 GW of potential in Indonesia or 47.05% of abundant beside other RESs The second majority is hydro power with 94.3 GW of potential or 21.35% of abundant and wind power take the third place with 60.6 GW of potential or 13.72% of abundant followed with bio energy, geothermal, and oceans power as shown in graphic 2. The problems from wind and solar energy as RESs are their intermittency issues which wind power output varied over time by the natural fluctuation of wind [19] and the wind speed intensity and direction vary constantly in space and time, which are highly unpredictable in nature and cannot be controlled [19], thus the intermittency of wind power seen to reflect the joint effects of lower controllability, lower predictability, and higher variability of wind power compared to conventional generation [19]. The intermittency on wind power is characterized by Gunturu and Schlosser [19] that the wind power cannot be produced in situations with a wind power density or WPD less than 200 W/m² thus with this condition, the power generator will be labeled “no-power”. Solar energy also meet its issues which are the inter-annual solar resource variability, the risk of unavailability of the primary resource. The variability in exceedance probability (EP) in solar generation become the issues in economic overview of solar energy [25]. Graphic 3 represent EP of solar Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI) in two different place, Tabernas and Ilorin. P5 in the graph represent the percentile 5% of each index which represent 95% exceedance probability of annual output.
of a solar plant power. In different scale the P5 differences varies time to time, as the proves that solar power as RESs meet its barrier of uncertainty and variability of energy production’s output based on its location, season, time, time duration, and geography aspects.

In solar power, especially PV generation, energy storages also become an issue as batteries have much long-term issues to be configured like material handling on how material combined and maintain sustainability of the material aggregates. Second one, waste management which is the process how to manage and handle the battery waste as batteries have its own lifetime between 10 until 20 years. Other issues like battery production also become a problem to its own overviews. Hydrogen is the key for those problems, its high efficiency, high energy intensity, and flexibility become the advantages if applied as energy carrier.

[12] Hydrogen (H₂) is a colorless, odorless, tasteless, flammable gaseous substance that is the simplest member of the family of chemical elements. [12] An atom of hydrogen has a nucleus consisting of a proton bearing one unit of positive electrical charge; an electron, bearing one unit of negative electrical charge, is also associated with this nucleus. [12] Under standard conditions, hydrogen gas is a
loose aggregation of hydrogen molecules, each consisting of a pair of atoms, a diatomic molecule, H₂. [12] Hydrogen physical properties also a unique parts to be discussed which it has extremely low melting points for about −259.20 degrees Celsius and boiling points for about -252.77 degrees Celsius that result from weak forces of molecules attraction hence in form of gas, hydrogen expands from high to low pressure at room temperature.

Hydrogen application is very large in various industries like automotive as fuel for FCEV which become a focus in automotive industries in order to climate change and have the biggest potential to applicate hydrogen as energy source as shown in graphic 4 that in 2050 transportation industry take second place to applied hydrogen as energy source after the power generation. On Chemical Industries (CI), hydrogen also take place as hydrocracking agent for example thus make a great potential to CI for applying hydrogen as feedstock or raw material as shown in graphic 4 the chemical industry take fifth place after the commercial use. The majority for hydrogen application is the energy industries which hydrogen take place as energy carrier that shown in the graphic 4 that hydrogen can be power generation buffer materials or direct power generation in industrial energy industry application. The graph shown that hydrogen has many potential to be explore and applied in various industries not only energy.
Hydrogen as energy carrier also meet its own barrier which it’s have a high production cost which impact to its LCOE if applied as energy sources. [16] The hydrogen production costs from electrolysis are influenced by the capital costs of the electrolyzer, its utilization and the (average) electricity purchase price, during the time of operation. High electrolyzer utilization reduces the specific share of electrolyzer capital costs in hydrogen production costs; on the other hand, a higher utilization increases electricity costs, as hours of expensive electricity will increasingly be included. Hence, in order to minimize hydrogen costs, electrolyzer utilization has to be balanced with the electricity price. [22] Hydrogen production cost analysis in the United States shows that electrolytically generated hydrogen is considerably more expensive due to electricity consumption. [8] The cost of hydrogen is highly influenced by the scale of the installation. [8] For instance, the hydrogen production cost from natural gas via steam reforming of methane varies from about 1.25 US$/kg for large systems to about 3.50 US$/kg for small systems with a natural gas price of 0.3 US$/kg. [11] Production cost is strongly affected by the production technology’s advancement level, availability of existing infrastructure, and the feedstock price.

[11] The most financially advantageous methods for hydrogen production are steam methane reforming, coal, and biomass gasification. Many ways and process to produce hydrogen with various advantages and disadvantages. This study limits the research to critically studied the hydrogen production with reactor based or reforming process. To overcome current issues of hydrogen production reactor based, we must know different ways to produce the hydrogen with different reactors and efficiency. The detailed about hydrogen reactors and steam reformer will discussed in the next part. This study critically and systematically think how to engineered the hydrogen production from technology, economical, and engineering overview and will present the efficiency, cost, process, and characteristics of each reactors and it’s impact on hydrogen processing.

2. Hydrogen production
To applied, the abundant of hydrogen itself must through a certain process of chemical reaction, purification, capturing, storage, transport, and consumption. In this part, we will discuss about the hydrogen types that exist to be applied in industrial or commercial sector which we know that the industrial sector has many potential to consume hydrogen as feedstock or energy sources and the commercial sector which has potential too to be applied as energy fuel. As we know the types of hydrogen we will discuss about the production of hydrogen itself especially in steam reforming process because we know that the electrolized hydrogen production type has many uncertain process and technologies to be applied in the short term target.

2.1. Hydrogen types
In hydrogen production, there’s 5 types of hydrogen based on its production process. The first one, black & brown hydrogens which are the processed hydrogen that came from coal gasification that results in high emission and not environment friendly. The second one, grey hydrogens which are the processed hydrogen that came from steam reforming method from various process like coal burning, boiler process in CPI, and other process. But the grey hydrogens will become blue hydrogens if there’s CCS technology applied in the production process. So, the third one from 5 hydrogen types is blue hydrogens which are the environment friendly hydrogen because it’s not produce any emission from the process. The CCS technology is carbon capture and storage technology which carbon dioxide as product from burning process is capture, compressed, and transported to various industries to be utilize or storage. The fourth one is green hydrogens which is came from electrolysis process to produce the hydrogen and the generation of the electrolysis came from RESs generation so make the green hydrogens are emission free and environment friendly hydrogens. The last one is bio hydrogens, which are made from the biobased energy sources like waste, sanitary, and other sources that produce compounds that carrying energy like methane, ethane, or other else. So, this make the bio hydrogens are environment friendly hydrogen to be applied as energy carrier.
From those 5 types of hydrogens, grey hydrogens become the most applied type of hydrogens in current industries because of its high reliability and the easiest way to produce hydrogens. Due to net zero carbon vision in electrification from Paris Agreement, hydrogen production must break into the carbon neutral state which the blue hydrogens, green hydrogens, and bio hydrogens have advantages in it. But the reliability from those 3 types of hydrogens is not the same, green hydrogens have the highest cost of production between those 3 and many undefined technology from the electrolysis process. Like green one, the bio hydrogens meet its barrier too which it have difficult process in the production. So, the blue hydrogens have the highest reliability to be applied in the meantime because the production process has the same flow with grey hydrogens but only differ on its outputting process which is the application of CCS technology. The process of producing the blue hydrogens is processed through the same production flow but with different reactors technology.

2.2. Reactor types on Blue Hydrogens

2.2.1. Conventional Steam Methane Reforming (SMR). Conventional SMR is the oldest and conventional reactors technology in hydrogen processing which the most widely used method that used. SMR is generally processed with catalyst that made from precious metals or nickel-based material at temperature about 800-900°C to produce hydrogen from light hydrocarbon fuel source like natural gas (NG) which contains about 95% methane. [23] The hydrocarbons in natural gas react with steam under 3–25 bar pressure (1 bar = 100 kPa) in the presence of a catalyst to produce hydrogen, carbon monoxide (syngas), and a relatively small amount of carbon dioxide. Steam reforming is endothermic, heat must be supplied to the process for the reaction to proceed. [23] Subsequently, in what is called the “water-gas shift reaction”, the carbon monoxide and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen. [23] Steam reforming takes place in a natural gas-fired furnace, which produces considerable CO$_2$ as well. [23] A final process step, carbon capture, is added, where CO$_2$ and other impurities are removed from the gas stream, leaving essentially pure hydrogen as a product. [11] The enthalpy change of reaction is +206.1 kJ/mol, and the enthalpy change in is also greater than zero, which means reforming reaction is a heat-absorbing process and therefore requires a certain amount of external heat. It is generally obtained through the combustion of natural gas. The final gas mixture contains 70-75% hydrogen, with other components including 710% CO, 6-14% CO$_2$, and a small amount of methane (2-6%).

Factors affecting SMR technology include the quality of feed stocks, the choice of fuel and catalyst, the type of reactor, and so on. SMR technology itself is well developed. The current issues of greater concern are how to increase the conversion of natural gas and hydrogen production capacity, and how to reduce the temperature required for the reaction to make the technology become a more desirable production mode. Low temperature steam reforming technology is used to produce syngas at 400-550°C. Its advantage over high temperature reactions is that the lower temperature requirement reduces the energy required for preheating and allows for rapid startup without CO shift reactor. Also, there is a wider choice of materials for the reactor, without limiting it to high-temperature resistant alloys. These advantages can significantly reduce the construction and operating costs of SMR hydrogen production plants. However, certain measures must be taken to eliminate the negative effects of low reaction temperatures on methane conversions. The membrane reactor allows the hydrogen produced by the reaction to be transferred outside the reaction system through hydrogen-selective membrane, thus shifting the reaction equilibrium to the right and greatly improving the conversion of natural gas. The properties of the membrane are of interest. High permeability facilitates the rapid exit of hydrogen from the reaction zone, while the high selectivity makes it difficult for other gases to pass through thus ensuring the purity of hydrogen. Palladium is an ideal membrane material, a palladium-gold composite membrane reactor that permeates hydrogen with 100% purity at low temperature and low pressure (350400 °C, 300 kPa), which can maintain stability over the long period of time tested. On the other hand, the use of catalysts is very important to the operation of membrane reactors. Because the hydrogen
permeation rate is fast with a right membrane material, the catalyst activity largely determines the size of the final hydrogen product stream. Certainly, conventional high temperature steam reforming reaction also requires the involvement of catalysts. Therefore, the development of high-efficiency catalysts has become a popular direction with the development of SMR technology. Most catalysts are obtained by modifying nickel-based materials due to the proven advantages of nickel materials, such as precious metal infusion or the use of TiO$_2$. Another research focus is the combination of carbon capture and storage (CCS) with SMR technologies. Increasing the capture rate of CO$_2$ is beneficial to both the high purity of hydrogen and the reduction of GHG emission. Since SMR technology is essentially the conversion of fossil fuels into hydrogen, the CO$_2$ emissions during the process are significant and do not perfectly meet the expected pursuit of “low carbon” or “clean”. However, SMR is economically less expensive and suitable for large-scale production. If effective means can be adopted to control carbon emissions from the production process, this technology will have a broader and more promising development prospect, which can provide an alternative until the absolute transition to a renewable energy phase for hydrogen production.

It’s reform the steam that has been fed and process it through PSA and water shifter until the steam converted become hydrogens and carbons then the carbon will be carried away from the production or being captured and storage through the CCS technology if applied in the process.

2.2.2. Packed Bed Catalytic Membrane Reactor (PBCMRs). The conventional SMR has its own advantages and barrier to be applied in hydrogen production, thus the engineered reactor has been developed which is PBCMRs or packed bed catalytic membrane reactors. Depending on the nature of the membrane (porous or dense), there are two types of catalytic membrane reactors. If the membrane is porous, there are three different possibilities of combining the membrane with the catalyst to form the catalytic membrane reactor. One way is to pack the catalyst inside the membrane tube forming a packed-bed membrane reactor. The other way is to impregnate the membrane with a catalyst (forming a catalyst-impregnated membrane reactor). The third possibility is that the membrane itself can act as a catalyst. Packed-bed membrane reactor gives higher yields than a catalyst-impregnated membrane reactor in the case of reactions with a decrease in the number of moles. In the second type of catalytic membrane reactor, in which the membrane is dense (for example, a Pd alloy-membrane) there are two possibilities of combining the membrane with the catalyst. Either a catalyst can be deposited on the membrane or the membrane can act as the catalyst. Catalytic membrane reactors can have the following advantages over conventional packed-bed reactors:

- An integration of reaction and separation into a single process, thus reducing separation costs and recycle requirements.
- An enhancement of thermodynamically limited or product-inhibited reactions resulting in higher conversions per pass.
- A controlled contact of incompatible reactants.
- An elimination of undesired side reactions.

In a catalytic membrane reactor the composition of gases in the reactor tube changes because of the combined effect of reaction and the permeation of gases through the membrane. The permeation can be controlled by having a knowledge of the effect of the various parameters like temperature, pressure, inlet concentrations of the fluid streams, shell-side gas flow, the pore size of the membrane, its thickness and chemical nature, etc. This kind of flexibility may help in controlling and achieving the desired composition of gases in the reactor, leading to higher conversions and selectivities.

2.2.3. Catalytic Membrane Reactors – Steam Methane Reformer (CMRs – SMR). Hydrogen processing is also demand the latest technology approach to overcome the technical and engineering issues on the current technologies that applied. Engineer is now developing the newest technology on hydrogen processing which is catalytic membrane reactors for steam methane reforming that combine the oldest
and conventional technology which is steam methane reformer reactors to produce hydrogen from methane to syngas through water shifter and the effective reactors which is catalytic membrane reactors that can overcome the requirement to produce hydrogen efficiently. The problem in conventional SMR are that the process are highly endothermic and has it limitation on equilibrium reaction. [23] To convert methane, high energy consumption is required (about 800-850 degree Celsius) and in the conventional reactors, high alloy steel is required to make the process operate at low temperature which make the LCOE and O&M cost high and not solving the current problems. The present of membrane catalyst make the smarter integration in the process which higher reactant conversion at the same temperature of conventional reactor and have the same reactant conversion at lower temperature (500-600 degrees Celsius) which make this process called Enchanced Steam Methane Reforming [21] (ESMR). On this process, there are 3 steps of processing the hydrogen which are combustion step where the NG and air are combusted then the product will fed to the reformer to do the reforming steps and last, the separation step to separate the H2 from the chemical reactions. [21] The ESMR process technology is using the multi tube reactor technology which made from single tube membrane reactor (TRL4) with membrane area of 155cm², Nickel-based catalyst, operating temperature of 530-590 degrees Celsius, pressure of 25-42, and feed ratio between CH₄ and H₂O of 1/3.

![Graphic 5. ESMR Separation](image)

As shown in graphic 5, we can see the flux of hydrogen is high and have the same level with CH conversion for about 90% peak in duration with 4-5 days. The graph data shown that the conversion of the NG on short duration of reaction is high enough which give us conclusion that the efficiency of the CMR – SMR is quite high to produce hydrogen rather than the conventional SMR. The membrane reactor concept that showed by Carena is that the membrane area is about 2035 m², heat transfer area for about 419 m², and the catalyst membrane area for about 332 m².
The area of membrane for a single membrane tube is about 900 cm² which has the same number for an ideal reactor design, for the catalyst volume the single membrane tube is requiring about 450 cm³ which have the ratio about 9:1 with the ideal reactor design, and for the heated area the single membrane tube requiring about 900 cm² which have the ratio about 3:1 with the ideal reactor. Graph 6 shows us that the single membrane tube requiring more cost for the hydrogen processing and the ideal tube design can overcome that issues with most efficient way. The integration of membrane has two configuration in general which are In-situ configuration which is the configuration of membrane within one reactor vessel and In-series configuration which is the configuration coupling of membrane and catalyst module. With the concept of reactor integration, we know that the CMRs–SMR has the best way to overcome the conventional processing issue which is the production cost because the CMRs-SMR process the hydrogens chemically and physically, the hydrogens are produced through the reforming process first through the SMR then being catalyst through the CMRs and make the CMRs-SMR become the latest and affordable technology in hydrogens processing to be applied in industries. Their ability to process the hydrogen chemically and physically become interesting concept to be engineered and applied in the hydrogens production.

3. Methodology

3.1. Methodological approach

3.1.1. Renewable energy sources comparing

- Efficiency comparison
  This paper shows the efficiency comparison between the four reactors and how the four reactors can solve the current issues of the hydrogen processing which is the high production cost and LCOE. The efficiency is based on 3 aspects which are temperature requirement, cost delevelization, and the energy consumptions with mathematic models shown in part 4. Cost comparison

  The cost comparison in this study shown by the data from the resources and writers compare it by the data visualization and the potentials of each reactors.

- Reliability comparison
  Reliability comparison of each reactors is visualized by the mathematical models and each reactors database on how the reactors can be applied in real world on industries processing.
• Potentials comparison
  Each reactors have each potentials on the industry, so this paper studies that potentials on how each technologies can overcome the current issues on hydrogen processing.

3.1.2. Hydrogen application and production
• Process design
  The process design on this study is researched based on hydrogen production in general and give comparison between the reactor process design and its efficiency,
• Process devices (Reactors)
• Cost efficiency
  Cost efficiency is compared using the existing math model to conclude which reactors have the lowest cost on the hydrogen production.
• Energy efficiency
  Energy efficiency is compared using the math model to calculate the energy consumption on each reactors which shown on the next part.

3.2 Research methods
• Efficiency and cost data collection and visualization
  Efficiency and cost data collection is collected through several references that gave the data base on the relevant topics and some visualization of the data is sourced by authors.
• Cost delevelization based on technology application
  The mathematical models on cost delevelization is shown on the next part and gave information on how each technology can delevelize the cost of the hydrogen production.
• Technology research
  Technology research is researched from the relevant sources that have relevant topics with this paper and authors summarized it to give scientific explanation and theory.
  Technology comparison
  Based on the researched technology, authors gave the comparison of each technology that can gave the conclusion and recommendation to overcome the current issues.
• Problems observation
• Engineering optimization

3.3. Data collection and analysis procedures
• Efficiency data collected from literature
• Cost data of each RESs collected from literature
• Energy consumption data calculated based on average of reactor applied in industries
• Cost delevelization data calculated based on Indonesia energy price (960 /kwh)

4. Result and discussion
The high production of hydrogen caused by many factors which are technology and technical issues, hydrogen economics issues, and low engineering optimization. Hydrogen application is wide in various industries as discussed in previous part and has many potentials to be applied especially as renewable energy sources as coal and gas has meet its barrier in now world due to carbon regulation and agreement in worldwide that against coal and gas application in energy industries. Graphic 3 shown the cost comparison in combined cycle turbine of hydrogen and natural gas. It can gave us conclusion that when the natural gas has the constant graphic in cost, hydrogens give the linear graph and bypass the graph of the natural gas. Which gave us that the abnormality of the hydrogen cost to be applied as energy sources.
To overcome that economic issues, the technology on the hydrogen production must be engineered with scientific approach to make the application is reliable.

**Table 1. Cost of Various Hydrogens Production Technologies**

| Method                  | Cost ($/kgH₂) |
|-------------------------|---------------|
| SMR                     | 2.08          |
| SMR with CCS            | 2.27          |
| CG                      | 1.34          |
| CG with CCS             | 1.63          |
| ATR with CCS            | 1.45          |
| Biomass gasification    | 1.77-2.77     |
| Direct biophotolysis    | 2.13          |
| Indirect biophotolysis  | 1.42          |
| Photo fermentation      | 2.83          |
| Dark fermentation       | 2.57-6.98     |
| Grid electrolysis       | 5.73-8.54     |
| PV electrolysis         | 5.78-23.27    |
| Wind electrolysis       | 5.27-9.37     |
| Nuclear electrolysis    | 3.56-7.00     |
| High-temperature electrolysis | 2.89-6.03 |
| Nuclear thermolysis     | 2.17-2.63     |
| Solar thermolysis       | 7.98-8.40     |
| S-I cycle               | 1.99-14.85    |
| Cu-Cl cycle             | 1.71-14.20    |
| Ca-Br cycle             | 7.06          |
| Mg-Cl cycle             | 3.67          |

Table 1 gave information of various cost of hydrogen production, as we see the blue hydrogen which is SMR with CCS is costed 2.27 USD for 1 kilogram hydrogen which slightly normal price if compared to another technology especially in electrolysis and thermolysis. But this price is still high and need to
be overcome to make the hydrogen economics better and make the potential of the hydrogen to be applied much wider in the industries especially as RESs.

### Table 2. Hydrogen Production Reactor Type Comparison

| Reactor Type     | Temperature Requirement (°C) | Efficiency (%) | Energy Consumption (W) | Cost Delevelized [CD] (%) |
|------------------|------------------------------|----------------|------------------------|---------------------------|
| Conventional SMR | 850-900                      | Low            | 1500                   | 0                         |
| PBCMRs           | 500-600                      | Medium         | 1000                   | 33.3                      |
| Reformer-CMRs    | 500-550                      | High           | 900                    | 40                        |
| CMRs – SMR       | 450-650                      | Very High      | 750                    | 50                        |

Table 2 give us the information about comparison of each reactors on its efficiency, energy consumption, temperature requirement, and cost delevelization. As we know, each reactors has the different way to process the hydrogens and based on the literature review the CMRs – SMR is the best choice to be applied and overcome the hydrogen economic issues. As the data shown the conventional SMR has the highest temperature requirement on the processing with range of 850-900 degrees Celsius, and it has energy consumption for about 1500 Watt and make it has the lowest efficiency compared to another reactor with cost delvelization percentage of 0 percent. PBCMR has lower temperature requirement with range of 500-600 degrees Celsius with consumption of energy about 1000 Watt and make it has the medium efficiency to be applied as hydrogen processing technology with cost delevelization rate of 33.3 percent. The third one, reformer-CMR, has lower temperature requirement with range of 500-550 degrees Celsius which slightly lower than the PBCMR, and has energy consumption for about 900 Watt and make it has high efficiency level with cost delevelization percentage for about 40%. Last one, the CMRs – SMR has the very high efficiency with temperature requirement for about 450-650 degrees Celsius and energy consumption of 750 Watt make it has the cost delevelization rate of 50 percent. With this data, we can conclude:

\[
\text{Delevelized Cost} = (100\% - CD) \times \text{Cost}
\]

\[
\text{Conventional SMR : } (100\% - 0\%) \times 2.27 = \frac{2.27\$}{kg \ H_2}
\]

\[
PBCMRs : (100\% - 33.3\%) \times 2.27 = \frac{1.51409\$}{kg \ H_2}
\]

\[
Reformer – CMRs : (100\% - 40\%) \times 2.27 = \frac{1.362\$}{kg \ H_2}
\]

\[
CMRs – SMR : \frac{50}{100} \times 2.27 = \frac{1.135\$}{kg \ H_2}
\]
With this mathematical model, CMR – SMR has the lowest cost to be applied as the hydrogen production technology which can overcome the issues of hydrogen economics. Energy consumption data on table 2 researched based on overall consumption of reactors in industries.

5. Conclusion and recommendation

Hydrogen is one of the best choice to overcome the energy issues in current world with many potentials to be applied especially in energy industries. Hydrogen has it own advantages in energy sources application as it an abundance material in this earth. Application of hydrogen can overcome the intermittency issues of wind and solar power in energy industries which wind power is one of the greatest potential of power generation for renewable energy sources same as the solar power to be applied in energy industries but their intermittency become one of the big challenge that has to be overcome. To overcome those challenge, hydrogen can substitute them as energy sources as hydrogen has many potential too to be applied in energy industries. Hydrogen can be produced through chemical reaction, electrolysis, pyrolysis, and thermolysis with various technologies to be applied in each reaction. This study critically studied about hydrogen production through chemical reaction. Hydrogen production with reaction based can be produce with several technologies like NG conversion, oil conversion, coal gasification, and other else. Due to net zero carbon mission by Paris Agreement, the NG conversion become the most priority to be researched. NG conversion on hydrogen production can be produced through several technologies like conventional steam methane reformer, packed-bed catalytic membrane reactors, reformer catalytic membrane reactors, catalytic-membrane reactors steam methane reformer which has their own way to produce hydrogens with several efficiency and cost analysis. The conclusion from this study, the catalytic-membrane reactors steam methane reformer become the best choice to be applied in hydrogen production which can overcome the hydrogen economy with 50% delevelization cost from the original cost of hydrogen production with about 1.135$/kgH₂. This technology become the latest technology in the hydrogen production that still developed which can be a great potential to be applied in the energy industries. With this technology, hydrogen can be applied as RESs and more reliable to be applied in various industries and can jack up the ASEAN initiatives to applied 23% RESs in 2025 and more in 2030 and can reach the Paris Agreement Goals which is net zero carbon or carbon neutral in industries especially energy industries.

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