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Hydrogen Development Strategy for Power Company in Indonesia's Transportation Sector using Scenario Planning

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Abstract:

One of the initiatives undertaken by Power Company to promote the NZE had been stated in its mid-term planning for 2024-2028 is the implementation of green hydrogen in transportation sector by developing hydrogen refuelling station and establishing the green hydrogen plant (GHP), producing hydrogen with the excess capacity of 124 tons per year. This excess hydrogen has been targeted to be one of revenue resources in beyond kWh, but Power Company had not been established the roadmap. Conversely, the National Roadmap of Hydrogen and Ammonia (RHAN) had been launched by government, targeting 3,690 tons hydrogen utilization per year in transportation sector by 2035 and FECV commercialization stage starting from 2031. The objective of this study is to formulate an appropriate strategy for Power Company in utilizing excess hydrogen in the transportation sector through scenario planning approach. Data are analysed using PESTLE, Porter's Five Forces, and semi-structured interview to formulate 2x2 matrix based on the main uncertainties. Four scenarios have been formulated which are called Going Highway, Queueing Tickets, Asking Innovations, and Entering Rest Area as combination of government support and the economic of hydrogen. Shifting to other scenarios should follow the key leading indicators and adjustment to recent working plans need to be done. This study approach can be used as reference for hydrogen producers or policymakers to construct the balanced strategy for hydrogen business development.

Keywords: *Hydrogen, Power Company, Scenario Planning, Transportation Sector*

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1. Introduction

In 2016, Indonesia ratified the Paris Agreement. The 2022 Enhanced NDC stated Indonesia's net-zero emissions target of 2060 or sooner. To reach it, Indonesia aims to reduce emissions 29% (unconditionally) or 41% (conditionally) by 2030 through increased EBT use (23% by 2025) by reducing reliance on fossil fuels, promote eco-friendly technologies, and encourage EBT utilization. Reinforced carbon reduction policies are essential to reach zero-emissions by 2060 (Surya Husada et al., 2022).

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The Ministry of Energy and Mineral Resources (MEMR) and the International Energy Agency (IEA) had released the Indonesia NZE Roadmap for the energy sector in 2060 in September 2022 (MEMR, 2022), highlighting hydrogen as a critical enabler of deep decarbonization, particularly in hard-to-abate sectors where direct electrification is challenging. IEA (2022) projection for Indonesia's plan to reduce its carbon emissions to achieve NZE showed how important hydrogen would be for transportation, industry, and electricity production, especially in areas where it was hard to electrify. In transportation, hydrogen would power large trucks (7% of road transport energy by 2060) and be used most in shipping, covering 50% of fuel needs. Synthetic hydrogen-based fuels would be used in planes.

MEMR (2023) stated that hydrogen would be used in four main sectors, which were industry, transportation, electricity, and global commodities such as Hydrogen National Strategy. For transportation, hydrogen was the candidate fuel for long-haul and heavy-duty vehicles, like delivery trucks. This potential for hydrogen was driven by three factors: the declining costs of renewable energy, electrolyzers and improving capacity factors. The Ministry of Energy and Mineral Resources' NZE model projected growth in low-carbon hydrogen demand from various sectors will increase from approximately 0.2 PJ (equivalent to 26,000 barrels of oil) in 2031, rising to 34.3 PJ in 2040, and peaking to 609 PJ in 2060.

Indonesia had launched National Roadmap of Hydrogen and Ammonia, (RHAN) in April 2025, representing step by step program for implementing hydrogen and ammonia in Indonesia during 2025 – 2060. The period will be divided into 3 (three) major phases: Initiation 2025 – 2034, Development and Integration 2035 – 2045, and Acceleration and Sustainability 2046 – 2060. The infographic for the transportation sector is shown in Figure 1. Between 2025 and 2034, the focus will be on laying the foundation through pilot projects and the early commercialization of HRSs. This phase marks the beginning of real-world trials for fuel cell electric vehicles (FCEVs), including hydrogen-powered cars, buses, and heavy trucks. By 2030, it is projected that around 3,000 FCEVs that consume nearly 438 ton/year will be operating across the country, signaling a serious commitment to cleaner mobility.

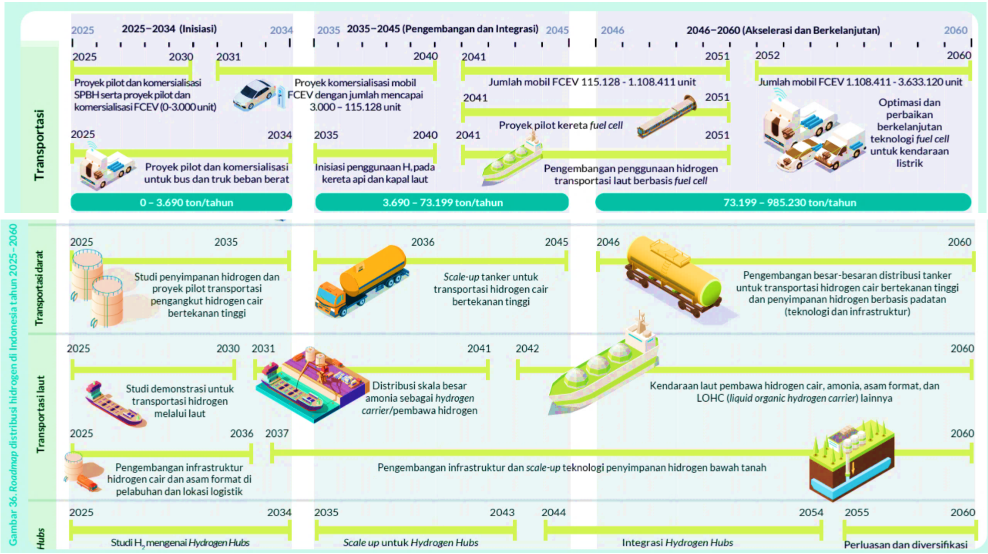

Figure 1. Hydrogen Implementation Roadmap for Transportation Sector in Indonesia

Source: MEMR, 2025

Power Company as one of power producers launched 21 hydrogen plants on November 20, 2023, having a total production capacity of 199 tons of hydrogen per year. Of this amount, 75 tons per year are allocated for generator cooling, while the remaining 124 tons per year are available for excess production, which will be used as hydrogen fuel. As stated in Long Term Planning 2024-2029 to commercialize hydrogen refueling station (HRS) for one of beyond kWh business, Power Company established Indonesia's first HRS in Senayan on February 21, 2024, having a charging pressure range of 0 to 350 bars and a refueling speed of under 5 minutes. For downstream, it has explored cooperation with several transportation companies, such as Transjakarta, Bluebird, and others to develop an environmentally friendly and competitive hydrogen vehicle ecosystem. The rich picture of stakeholders related to hydrogen ecosystems is presented in Figure 2.

Figure 2. Rich Picture of Hydrogen Issue
Source: Author's Research

Countries around the world have shown strong interest in clean hydrogen. According to IRENA (2024), a total of 46 nations and regional groups had already released official hydrogen strategies, and another 8 had shared roadmaps defining their plans. On top of that, at least 20 more countries were in the process of drafting their own. In total, more than 70 countries are now actively planning how to build a hydrogen economy, as shown in Figure 3. European countries, including the European Union, are leading this movement, having published nearly half of the strategies so far. Countries across the Americas, the Middle East, and North Africa are also moving quickly, accounting for almost 80 percent of the total. These numbers are expected to keep growing as more governments recognize hydrogen as an important part of their clean energy future.

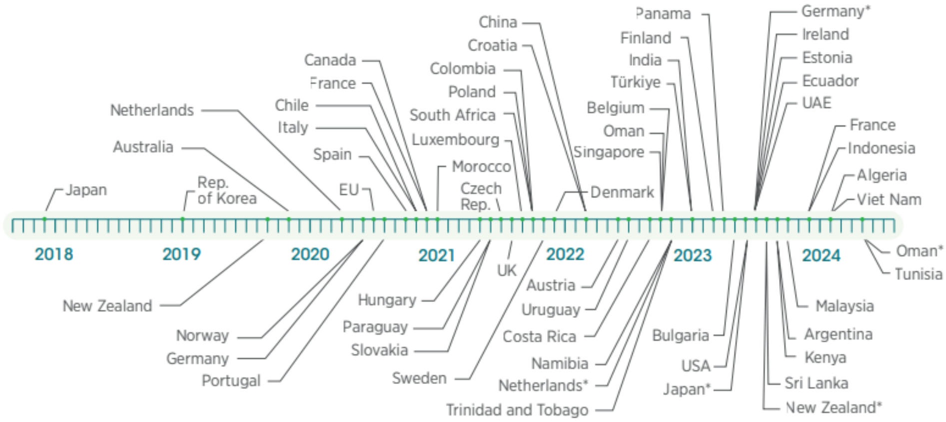

Figure 3. Timeline of Hydrogen Strategies and Roadmaps Launched, per May 2024
Source: IRENA, 2024

This study aims to understand the driving forces and the main uncertainties for formulating strategy scenarios for Power Company in developing its excess hydrogen utilization program for Indonesia's transportation sector. This study will only analyze the business aspect of the hydrogen utilization program by Power Company for transportation using hydrogen molecules, thus will not include detail technological or commercial aspects of hydrogen production process including the technological advancement of various hydrogen production methods.

2. Theoretical Background

PESTLE analysis is all about scanning the external environment of a huge ecosystem by looking at political, economic, social, and technological factors to take into consideration competitive advantage and strategic management (Citilci & Akbalik, 2020). Mukelabai et al. (2022) used PESTLE to analyse the hydrogen technology adoption in Africa focused on indicators relevant to key stakeholders from hydrogen technology developers through to the end-users. PESTLE analysis can be used to consider political, economic, social, technological, legal, and environmental issues that are outside the control of organization and have some impact on it while every issue had some factors (Team FME, 2013). Geopolitics, defined as the interaction of geographical factors (location, space, and resources) with political processes, traditionally examines the impact on interstate power dynamics of concentrated (fossil) energy resources, including their transportation and trade in energy sector (Pepe et al., 2023). PESTLE is used to examine the external macroenvironmental factors that may impact regional hydrogen production (Kokkinos et al., 2023) and identify the key challenges and opportunity for structural transformations necessary in Turkey from external to establish a competitive and sustainable hydrogen economy (Furuncu, 2025).

Porter's Five Forces framework is a strategic tool designed to assess the competitive dynamics within an industry, aiming to identify factors that influence profitability and inform strategic decision-making from a balance of five basic competitive forces: the threat of new entrants, the bargaining power of suppliers, the bargaining power of buyers, the threat of substitute products or services, and the intensity of competitive rivalry (Porter, 1997). Ateljević et al. (2023) mentioned that the five competitive forces concept can be a bit of a threat to a company as they can lead to higher expenses, lower income, and reduced profit. Pangarkar et al. (2024) added two factors needed to be clearly defined, appropriate industry definition such as an industry segment and key driving factor which impacted on industry's profit performance. Porter's Five Forces approach to can be methodologically used to identify the economic market forces that shape the development of hydrogen markets and discuss key obstacles in the supply chain (Aguilera et al., 2022). It can be used to form the external factors of the company providing and fabricating abrasion resistant steel in facing the competitive force (Pranoto & Indradewa, 2024) and help assessing competitive advantage of green hydrogen production in Ceará regarding the state's insertion in the European market (Barbosa & Gomez, 2025).

Scenario planning is a strategic tool that enables organizations to prepare for an uncertain future by exploring a range of potential outcomes, rather than relying on a single forecast to stimulate creative thinking and prepare for a range of potential developments, thereby enhancing decision-making under conditions of uncertainty (Levesque et al., 2006). Amer et al, (2013) explores the use of scenario planning as a strategic tool to navigate uncertainty and complexity in decision-making. It reviews qualitative and quantitative scenario planning methods, highlighting their advantages and limitations. Scenario planning can be defined as scenarios consist of a set of narratives describing different alternative futures, constructed with an iterative approach based on the uncertainties of the context, with the aim to raise awareness of plausible futures and increase performance of the organization (Cordova-Pozo et al., 2023).

The deductive method uses a hierarchy to organize factors and select the two most important ones to create a structure among the factors that have been examined in the scenarios. The scenarios are defined by the combination of two separate axes. Each of the four sections of the 2 x 2 matrix contains one scenario. Using a 2 x 2 matrix allowing flexible selection of 2 – 4 futures based on purpose and it enables mapping both historical and future developments within the same framework (Ramirez & Wilkinson, 2014)

Luo and Wildermuth (2017) mentioned that for studying a wide range of information behaviours, semi structured interview is the most useful while structure interview or survey become too structured that limit open-ended responses. Lune and Berg (2017) suggests an interviewer to know four types of questions to use: essential questions, extra questions, throwaway questions, and probing questions to get the most complete story about a subject or situation under investigation. Essential questions are all about the main focus of the study. Extra questions are like essential questions, but with different words. Throwaway questions may be demographic questions or general questions used to build rapport between interviewers and subjects. Probing questions are used to get more complete answers from subjects.

Qualitative analysis of content is a valuable alternative to more traditional quantitative content analysis, when the researcher is working in an interpretive paradigm to identify important themes or categories within a body of content and to provide a rich description of the social reality created by those themes/categories as they are lived out in a particular setting. Through careful data preparation, coding, and interpretation, the results of the analysis can support the development of new theories and models, as well as validate existing theories and provide thick descriptions of particular settings or phenomena. It allows researchers to understand social reality in a subjective but scientific manner (Zhang & Wildemuth, 2017). Content analysis is a systematic approach to learning about particular aspects of a body of text or other messages such as pictures or video (Spurdin & Wildemuth, 2017).

3. Methodology

This research is focused on scenario analysis to provide guidance for future strategic decision-making for Power Company, following the research framework in Figure 4. The process begins with an evaluation of the current condition, followed by a comprehensive data collection phase that involves the gathering of both primary data from stakeholder interviews and secondary data from literature study. The collected data is subjected to analysis, divided into external analysis using the PESTLE framework and internal analysis using Porter's Five Forces. These analyses help to identify the ecosystem of hydrogen development correlated to key focal issue, which is defined as a central problem or challenge that needs to be addressed. After identifying the driving forces influencing the focal issue and determining critical uncertainties that could impact future developments, a scenario framework is constructed using these elements as a basis for developing multiple narratives or future scenarios. An early warning system is also included in the process, which monitors key indicators for changes in the external environment. The resulting scenarios are then used to outline the implications and options, guiding decision-makers in adjusting strategies accordingly. Based on the readiness of organization, the implementation plan is constructed.

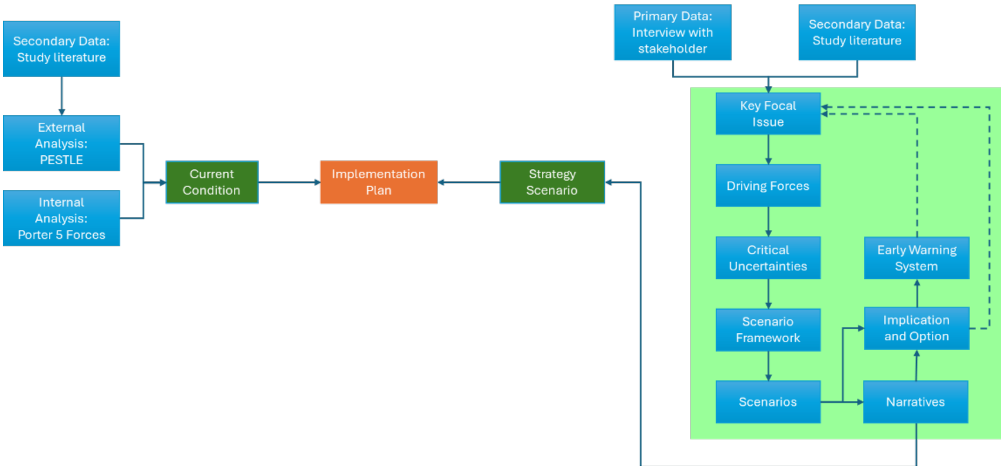

Figure 4. Research Framework
Source: Author's Research

Primary data is gathered using qualitative methods by doing semi-structured interviews with the selected stakeholders, representing the hydrogen business ecosystem, as listed in Table I and the questions are listed in Table II. Secondary data is collected through desk research, gathered and studied from published sources, such as academic papers, journals, published reports, and other trusted internet resources. The goal of a desk report is to focus on all public data and exclude any private or confidential information.

Table 1. List of Interviewees

No	Interviewee	Position	Company	Experience
1	Interviewee 1	Director of Planning and Development	Power Company	23 years
2	Interviewee 2	Vice President of Business Development Division	Power Company	21 years
3	Interviewee 3	Renewable Energy Division	MEMR	10 years
4	Interviewee 4	Business Development	Toyota Indonesia	18 years
5	Interviewee 5	Research professor	Badan Riset dan Inovasi Nasional (BRIN)	14 years
6	Interviewee 6	Head of Center for Research on Energy Policy	Institut Teknologi Bandung	15 years

Source: Author's Research

Table 2. List of Questions

Question Type	Main Focus	Questions
Throwaway	Interviewee background	Please introduce yourself, your position right now, your background and experience relating to hydrogen?

Question Type	Main Focus	Questions
Essential	The driving forces of hydrogen for transportation sector, the most uncertain driving forces	1. In your opinion, how will the future of hydrogen usage in transportation in Indonesia? 2. According to your experience, what are the challenges and obstacle for hydrogen usage in transportation in Indonesia? 3. As the government target on hydrogen use for transportation will begin after 2030, in your perspective, what are the driving forces of hydrogen usage for transportation in Indonesia? 4. In your opinion, along with political, economic, social, technology, legal, and environmental factors, what are the main uncertainties for developing hydrogen for transportation?
Extra	The early warning signals, mitigation options	5. In your opinion, why are those uncertainties considered as the most important and what area will be impacted most? 6. What indicators of uncertainties must be followed for changing to other scenarios? 7. In your opinion, what we need to be prepared for those uncertainties in hydrogen usage for transportation in Indonesia? 8. According to your experiences, how do you think the desired scenario can be achieved?
Probing	Finding more information	9. In your perspective, what is the most suitable usage of hydrogen in the future in Indonesia?

Source: Author's Research

The interview is done particularly for each interviewee at different times for three months. The primary data, which are recorded from interviews will be analyzed using content analysis, a systematic approach to learning about particular aspects of a body of text or other messages such as pictures or video (Spurdin & Wildemuth, 2017). Qualitative analysis of content emphasizes an integrated view of speech/texts and their specific contexts. Such analysis goes beyond merely counting words or extracting objective content from texts to examine meanings, themes, and patterns that may be manifest or latent in a particular text. It allows researchers to understand social reality in a subjective but scientific manner (Zhang & Wildemuth, 2017). This research involves an applications software to transcribe the recording from interviewees and code as single layer.

4. Empirical Findings/Result

Scenario for Power Company to develop the strategy in utilizing excess hydrogen in transportation is constructed using scenario planning framework developed by Levesque (2006). First, Figure 5 shows the Porter's Five Forces analysis result to determine the internal factor of Power Company.

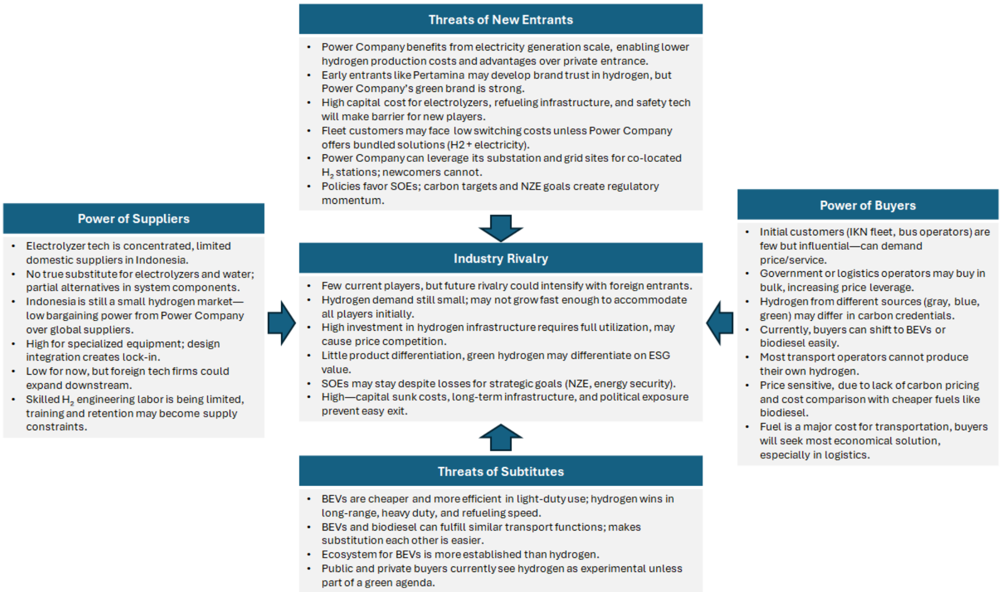

Figure 5. Porter's Five Forces Analysis for Power Company
Source: Author's Research

Key Focal Issue

The key focal issue is how will Power Company strategy to utilize the excess hydrogen in transportation sector in Indonesia.

Driving Forces

Driving forces are gathered from interview results and literature studies then grouped based on its similar meaning. The commitment to achieve NZE, which is political factor, is expressed by Interviewee 2 as "…the global demand to reduce emissions that cause the greenhouse effect and rising temperatures" and Interviewee 4 as "…the global decarbonization pressure, which we know as Net Zero Emission 2060, is the primary driving force that the government, whether it wants to or not, must commit to". One of the technology factors, the battery capacity and charging time limitation, is expressed by Interviewee 1 as "…decarbonization using battery has limitation of distance range that can't be long enough…" and Interviewee 3 as "…hydrogen advantages over batteries are faster charging, and longer distance…"

Combining the interview result and PESTLE analysis, the driving forces are identified in Table III. It shows the dominant force comes from economics, followed by factors derived from social and technology.

Table 3. Driving Forces

Factors	Driving Forces
Political	Commitment to achieve NZE

Factors	Driving Forces
	Collaboration in countries to use green hydrogen
Economic	Fuel oil import dependency Large scale green hydrogen investment required Global hydrogen demand Green hydrogen production becomes cost-competitive Infrastructure cost of green hydrogen is still high Hydrogen vehicle market growth slow down
Social	Low public awareness Strong safety concern Limited social influence Added value from hydrogen supply chain (green jobs)
Technology	Hydrogen production method and resources Pilot project of green hydrogen Fuel cell efficiency from BEVs Battery capacity and charging time limitation
Legal	Global hydrogen policy Government regulation and policy support Standardization about hydrogen
Environment	Abundant resource for green hydrogen

Source: Author's Research

Critical Uncertainties

Critical uncertainties are derived based on the interview result. Most interviewees highlighted the critical uncertainties are economic price of hydrogen and commitment of government support. Economic price of hydrogen is determined based on the interviewee's answer like "…the cheaper hydrogen cost, the more hydrogen develops" (Interviewee 1), "…hydrogen production cost will lower causing hydrogen price more competitive" (Interviewee 2), "…the most important is price that will enter commercial scale and directly used by user…" (Interviewee 3), and "…hydrogen price will be compared to alternative fuels and it should close to fossil fuel price" (Interviewee 5).

The other critical uncertainty considered most by interviewees is commitment of government support, which stated as "…political endorsement, option for public transportation will be strongly determined on how government makes policies" (Interviewee 1), "…how do we create mutually supportive ecosystem…" (Interviewee 3), "…it depends on the government point of view…different government will take different policies…" (Interviewee 4), and "…regulation and incentives commitment from government…" (Interviewee 5).

Figure 5 shows the interviewees perspective on the economic price of hydrogen and commitment of government support to develop the hydrogen ecosystem.

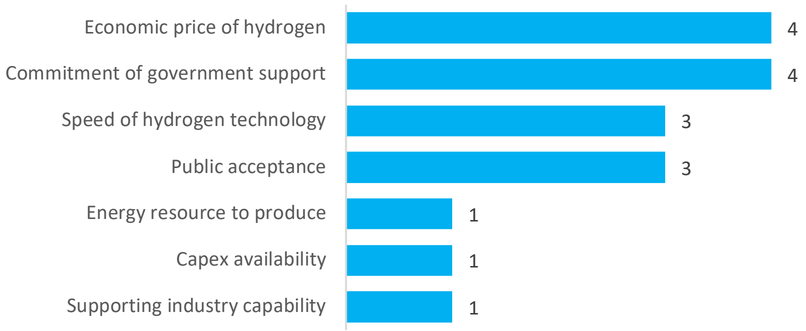

Figure 1. Interview Result for Determining the Main Uncertainty
Source: Author's Research

Scenario Framework and Narrative
As the result of the main uncertainties considered by interviewees are the top two as shown in Figure 5, the scenario framework construction can follow the 2 x 2 matrix to create four scenarios as modelled by Ramirez & Wilkinson (2014). The scenario framework created as combination of high – low government commitment and support versus economic price of hydrogen, competitive or uncompetitive is shown in Table IV.

Table 6. Scenario Framework for Government Commitment and Economic Price of Hydrogen

Government commitment / Economic price of hydrogen	High support	Low support
Competitive	**Going Highway** Hydrogen is cost-effective and fully backed by the government.	**Queueing Ticket** Industry players invest in hydrogen due to price competitiveness, but the government seems to be pessimistic or have other prioritize programs
Uncompetitive	**Asking Innovation** The government backs up hydrogen development with incentives and creates pilot projects, but total costs remain high.	**Entering Rest Area** No serious policy support, and hydrogen remains too expensive.

Source: Author's Research

The scenario narratives are constructed as follows:
1) Going Highway
The Jakarta Post, 23 January 2035 - *Hydrogen takes off, fueled by strong government support and falling costs.*

By the late 2030s, Indonesia hits its stride in hydrogen. The government has backed the sector with clear policies, targeted subsidies, and long-term infrastructure plans. Meanwhile, global technology costs fall, electrolyzer prices drop, hydrogen becomes affordable, and supply chains mature.
Hydrogen is no longer just a pilot project. It's powering trucks across Java, buses in major cities, and even trains and ferries. Refueling stations are common along freight corridors. With more than 3.6 million FCEVs projected by 2060 and nearly half a million tons of hydrogen expected to fuel rail and shipping, Indonesia becomes a leader in clean transport, especially in areas where batteries fall short. Hydrogen doesn't compete with BEVs but complement them. While electric cars dominate city streets, hydrogen fuels the heavy lifters.

2) Queueing Ticket
Kompas, 23 February 2035 - *Hydrogen becomes cost-competitive, but the government stays on the sidelines*.
By the mid-2030s, hydrogen prices fall as tech breakthroughs and smart local production powered by renewables. It becomes affordable enough to challenge diesel in freight, mining, and industrial transport. But while the technology is ready, the policy isn't. The government hasn't followed through with its hydrogen roadmap. There are no large-scale incentives, no coordinated infrastructure plan, and public refueling stations are almost non-existent.
Even so, the private sector stepped in. Logistics companies, mining firms, and industrial parks start building their own hydrogen hubs. Some fleets convert to FCEVs because it simply makes sense. But progress is uneven. Without national coordination, hydrogen grows, but only in pockets. It's a promising future, just not a shared one.

3) Asking Innovation
Media Indonesia, 23 October 2035 - *Hydrogen is politically popular, but still too expensive to go mainstream.*
The government is fully behind hydrogen. Policies are in place, public demonstrations roll out, and state-owned fleets adopt hydrogen vehicles. But despite all the support, one thing hasn't changed: the price. Green hydrogen remains expensive between $4.5–6.5 per kg mainly due to global supply chain delays and high capital costs.
FCEVs are seen mostly in state-backed projects: PLN, Pertamina, and a few public bus systems. Hydrogen is present but far from thriving. Private investors are cautious, and without price parity, mass adoption never really comes. By 2045, hydrogen in transport still relies heavily on government funding. It's stable, but fragile and surviving more as a public commitment to decarbonization than a commercial breakthrough

4) Entering Rest Area
Koran Tempo, 02 December 2035 - *Hydrogen fails to gain traction, surpassed by the EV boom*.
Despite all the early excitement around hydrogen, it never gets off the ground. The government shifts focus to battery electric vehicles, which are growing fast, cheap, and easy to integrate. With no clear incentives and hydrogen still too expensive, the private sector moves on.

By 2060, Indonesia reaches its ambitious BEV targets for 25 million electric cars, 170 million motorcycles, and a grid that supports nearly 200 TWh of transport electricity use annually. Meanwhile, hydrogen is stuck in research labs and a few outdated pilot projects. The country misses the RHAN target of 3.6 million FCEVs. Hydrogen in transport never becomes more than an idea. Indonesia leans fully into the battery path and leaves hydrogen behind.

Implications and Options

The implications and options will be different in each scenario. The details of each implication and option are as follows.

For Going Highway scenario, hydrogen becomes widespread for heavy-duty vehicles like intercity buses, long-haul trucks, port logistics, and even trains in Indonesia transportation sector. Public transport systems in major cities (like Jakarta, Surabaya, or Bandung) begin to switch from fossil fuels to hydrogen-powered fleets so that charging and refueling stations like SPKLU for BEVs and HRS for FCEVs serving different segments of the market efficiently. Hydrogen also opens up new export and maritime opportunities, aligning with national shipping decarbonization plans and fossil fuel demands in the transportation sector decrease significantly. As large-scale power producer and grid operator, Power Company becomes green hydrogen producer, using surplus power from solar, geothermal, and hydro power plants for electrolyzers that will expand revenue, not just from electricity sales, but also from hydrogen-as-a-service, especially in industrial zones and freight. Technically, it will create better power quality in grid, while hydrogen production smooths electricity demand, especially at times when EV charging drops. In this scenario, Power Company should be hydrogen leader and grid integrator to maximize the benefit by building utility-scale green hydrogen plants near renewables, positioning as hydrogen supplier for mobility and industry, collaborating with other SOEs for hydrogen in transportation sector and ammonia exports, and developing hydrogen supply chain to make logistic cost cheaper.

In Queueing Ticket scenario, without a national policy, growth for hydrogen demand in transportation sector is fragmented and unequal, Java leads, while Eastern regions lag. Public transport misses out cities lack funding and coordination to invest in hydrogen. Some forward-looking companies, especially in mining, cement, logistics, and industrial estates, invest in hydrogen on their own. Hydrogen still plays a major role in decarbonizing high-emission sectors, but it's not a cohesive national story. If Power Company is slow to respond, private players will build their own hydrogen supply, powered by captive solar or hydro systems. It risks being sidelined in regions where self-contained green hydrogen ecosystems emerge. The option for Power Company is to be flexible partner and enabler, by offering green electricity packages for private producers, partnership with industrial zones as energy service provider, monetizing grid support, reliability, and digital services, supporting government to fasten developing regulation about hydrogen, while developing small scale hydrogen ecosystem.

When Asking Innovation scenario has happened, hydrogen buses appear in some public fleets (like TransJakarta), but most deployments are symbolic or state-owned while private companies are reluctant to switch, waiting for prices to fall before investing in FCEVs. Hydrogen transport relies heavily on government funding, not market demand, creating long-term sustainability concerns and BEVs continue to expand in urban and light commercial transport, leading the decarbonization effort. Power Company will face slow and uncertain return on building capacity for hydrogen production and supply. Infrastructure risks becoming underutilized if fuel cell vehicles don't scale fast enough and hydrogen projects may require cross-subsidization from its profitable segments. The option for Power Company is to be pilot operator and policy advocate by building more hydrogen pilots projects (hydrogen buses, heavy duty vehicles, HRS) but avoiding large capital investment and deploying modular or scalable electrolysis. Pushing for policy to give incentives for early adopters, guaranteed off-takers and collaborating with other players to conduct hydrogen research should also be taken while maintaining upgrade human resource competency and capability for hydrogen related fields.

Entering Rest Area shows BEVs domination across nearly all segments, not just cars and motorbikes, but also electric trucks and light commercial fleets. Public investment focuses entirely on SPKLU expansion, and cities compete to electrify their bus fleets which will make hydrogen abandoned as a transport solution, used only in industrial or export applications (e.g., ammonia, steel). For Power Company, this will create a massive new electricity demand, nearly 200 TWh by 2060 just from EVs and change grid upgrades, charging load management, and smart grid investment become urgent priorities. Meanwhile, hydrogen becomes a missed diversification opportunity, leaving it fully dependent on the electricity market. Power Company should be BEV enabler and grid optimizer by pausing hydrogen investment in the transport sector and focusing on developing and expanding EV charging, and smart grid. It may continue to explore R&D but only hydrogen pilots with low-risk innovation exposure to maintain optionality for future hydrogen shifts (e.g., maritime, aviation, industry).

Early Warning Signals

To determine the early warning signals, interview session is summarized and combined by references from literature, represented in Table V. For example, the hydrogen production cost is stated as "…cost of producing hydrogen…" (Interviewee 1), "…hydrogen price can be seen from levelized cost of hydrogen (LCOH)" (Interviewee 2), and "…production, storage, and price of hydrogen can be higher…" (Interviewee 5). Power Company should follow these signals for helping the decision maker identify the right scenario and adjust the corporate strategy, especially for the medium- or long-term planning.

Table 5. Early Warning Signals

Scenario / Indicators	Going Highway	Queueing Ticket	Asking Innovation	Entering Rest Area
Hydrogen Production Cost	Levelized cost of green hydrogen below $2/kg due to cheap RE and tech advances.	Tech-driven cost reductions push hydrogen below $4/kg, usually from private innovation.	Green hydrogen cost remains above $5/kg, requiring subsidies to operate pilots.	Green hydrogen costs stay high (> $6/kg), making it uncompetitive long-term.
Renewable Electricity Tariff	RE tariffs are transparent, competitive (<6 cent USD/kWh), enabling green hydrogen economics.	Private RE projects offer competitive tariffs under bilateral agreements or wheeling schemes.	RE tariffs remain high or opaque, requiring financial support or subsidies to support H_2 production.	RE tariffs stay above market parity (>8 cent USD/kWh), preventing hydrogen production initiatives.
Hydrogen Price in Other Countries	Comparable markets (e.g. Japan, EU) show hydrogen price at $2–4/kg.	Other markets drop to $3–4/kg with tech scaling and power PPA efficiency.	Global prices stay high ($5–6/kg), challenging domestic competitiveness.	Hydrogen remains above $6/kg globally, preventing acceptance.
Global Adoption Rate of Hydrogen Vehicles	Global FCEV adoption exceeds 5 million vehicles, setting a strong precedent.	Growth in specific use-cases (e.g. ports, mining trucks), not widespread.	Adoption grows slowly; global FCEV fleet under 1 million by 2030.	FCEV adoption stagnates or regresses as OEMs refocus on BEVs.
Fuel Cell Efficiency	Fuel cells achieve >60% efficiency, widely used in fleets and buses.	Private innovations boost efficiency to 55–60% in logistics and mining sectors.	Fuel cell tech still maturing, efficiency around 40–50% with limited commercial scale.	Fuel cells stagnant at ~40% efficiency; R&D investment declines.
Infrastructure Investment	SPBH and H_2 logistics infrastructure funded in national development plans.		Infrastructure only available in pilot scale or limited to city centers, dominated by SOE-driven pilots.	
OEM and Vehicle Market	Automakers begin commercializing FCEVs for fleets in Indonesia.	Private demand for FCEVs grows, especially in mining, logistics, or industry.	Automakers have commercial line for FCEV, showing they are ready for hydrogen but minor selling.	Automakers withdraw FCEV offerings or shift full focus to BEVs.
National Policy and Planning	National hydrogen policy is ratified and supported by budgets, mandates, or regulations.	RHAN or equivalent strategy exists but needs to follow up by consistent	RHAN or equivalent strategy exists but needs to follow up by consistent	Gov't continues heavy BEV subsidies without equivalent hydrogen support.

Indicators \ Scenario	Going Highway	Queueing Ticket	Asking Innovation	Entering Rest Area
		enforcement or budgeting.	enforcement or budgeting.	
Regulatory Follow-Through	Government establishes regulations and policy to speed up RHAN goals achievement, supported by budgets or mandates	No legal obligation to follow RHAN or hydrogen roadmap targets.	The government mandates to continue regulations for hydrogen and enhance research and development of hydrogen.	RHAN remains a plan with no formal legal status or implementation body.
Hydrogen Incentive Policy	Government provides production and consumption subsidies or mandates.	No consistent incentive policy; market relies on business cases and RE cost.	Incentives exist but are limited to R&D or SOEs; no broad market pull.	No significant hydrogen-specific policy exists; BEV continues to dominate.
Hydrogen Infrastructure Readiness	Hydrogen refueling stations are operational in key corridors and industrial zones.	Infrastructure develops ad-hoc, enabled by private funding or foreign JV.	H_2 stations built as one-off projects in pilot cities only.	No infrastructure beyond pilot/demonstration scale.
Hydrogen Ecosystem Creation	Hydrogen ecosystem (supply chain, demand hubs, policy) well established nationally.	Ecosystem driven by private clusters (e.g. SEZs) not national coordination.	Ecosystems exist mostly in pilot/demo form with limited integration.	The hydrogen ecosystem remains fragmented or fails to develop.

Source: Author's Research

5. Discussion

The findings of this study underscore the four scenarios created based on the two main uncertainties, government supports and hydrogen economics. Determining the right scenario should be done by assessing the early warning signal to current conditions. The result is presented in Table VI.

Table 6. Early Warning Signal Assessment Result

Indicators	Reference	Scenario Related
Hydrogen Production Cost	According to RHAN (MEMR, 2025), green hydrogen cost in Indonesia reached \$10 - \$11/kg in 2023	Entering Rest Area
National Policy and Planning	Indonesia has set fundamental of hydrogen development by announcing SHN (2023) and RHAN (2025), followed by regulation supports. By now, the incentive for BEV is continuing while no commercial hydrogen vehicle yet.	Asking Innovation

Indicators	Reference	Scenario Related
Regulatory Follow-Through	MEMR has announced the hydrogen regulation need and its target timeline unitl 2029 to implement RHAN in Indonesia during GHES 2025 event in April 2025.	Asking Innovation
Infrastructure Investment	Pilot projects for hydrogen have been created by SOEs and private companies such as HRS in Senayan (PLN), 22 locations for GHP (PLN), Ulubelu GHP (Pertamina), HRS in Karawang (Toyota).	Asking Innovation
OEM and Vehicle Market	There is commercial hydrogen vehicle offered by manufacturers, even there hasn't sell in Indonesia yet, like Toyota Mirai, Hyundai Nexo for passenger car and XCIENT for heavy duty truck, and Honda Clarity fuel cell (discontinued in 2021)	Entering Rest Area
Renewable Electricity Tariff	Electricity tariff from renewable energy produced by IPP varies by its resource. The average for all renewable energy is 9.2 cUSD/kWh (using 1 USD = IDR 16,261) (PLN, 2025)	Entering Rest Area
Fuel Cell Efficiency	Well-to-wheel energy efficiency is 6.8 - 29.2% (Lu, et al., 2022) while vehicle efficiency ranging from 50.2 - 61.1% (Di Pierro, 2024)	Entering Rest Area
Global Adoption Rate of Hydrogen Vehicles	As reported by SNE Research (2025), from January 2024 to March 2025, global hydrogen vehicle sales declined 21.6% in 2024 to 12,866 units and another 11.2% in early 2025.	Entering Rest Area
Hydrogen Ecosystem Creation	Hydrogen pilot projects in Indonesia is done but still separate from each other. There is no connected distribution line from GHPs to HRS in Senayan (PLN), for example, while Pertamina and Toyota also created its own pilot project. Study to create connected ecosystem is still on going.	Entering Rest Area
Hydrogen Infrastructure Readiness	PLN has established a pilot project of hydrogen production (22 location for GHP) and distribution (HRS in Senayan). Pertamina plans to build HRS in Daan Mogot and GHP from geothermal. From private sector, Toyota has established HRS in Karawang.	Asking Innovation
Hydrogen Incentive Policy	The government is continuing incentives for BEV, both for manufacturer and owner but no incentives already for hydrogen early adopter. Some research has been conducted by BRIN, MEMR, in collaboration with SOEs.	Asking Innovation
Hydrogen Price in Other Countries	Based on S&P Global (2025), pump (retail) prices peak at \$34.33/kg in North America, \$13.36/kg in Europe, and \$10.96/kg in Asia-Pacific. On the other hand, green hydrogen from PPA, Alkaline, and PEM vary from 2.98 – 9.89 USD/kg.	Entering Rest Area

Source: Author's Result

As assessed in May 2025, from Table V, 5 out of 12 (41.6%) indicators meet the Asking Innovation scenario and the rest (58.4%) indicators meet the Entering Rest Area scenario. It can be concluded that the scenario is shifting from Entering Rest Area to Asking Innovation.

For this result, Power Company can keep doing programs that matched to the options of scenarios but delayed or recalculate the feasibility for nonrelevant program which need large investments and commercial. The timeline for those project implementation can be aligned to RHAN.

Several countries have been developed hydrogen ecosystems. Japan was the first to adopt the "Basic Hydrogen Strategy" in 2017, which aims to increase the use of hydrogen in commercial sectors. It showcases the concept of the "Hydrogen Economy" and its vision for 2050, with an action plan to achieve it by 2030. In 2020, Japan had the largest hydrogen refuelling station network in the world. Despite the progress toward spreading hydrogen in transportation, it's not meeting the goals of the Basic Hydrogen Strategy. Many private HFCV owners discontinued their vehicles because of driving range, vehicle performance, future viability, fuel tank safety, and the lack of stations (Khan, U., et al, 2022).

South Korea has successfully developed an early market for hydrogen mobility, led by fuel cell passenger cars, thanks to strong support policies. However, the fuel cell vehicle (FCV) market is still in its infancy and faces challenges that must be overcome to achieve mass adoption. A recent survey of current and potential FCV users identified key obstacles from a consumer perspective. These obstacles include concerns about vehicle durability due to frequent recalls and repairs, access to hydrogen refuelling stations (HRSs), and fuelling reliability. Additionally, there are concerns about renewable energy sources, as Korea's hydrogen production heavily relies on fossil fuels. Both current and prospective customers show limited concern for environmental benefits. FC cars are the largest, but only 1.5% of drivers prefer them (Park, J. et al., 2025).

Germany is committed to developing new technologies and commercializing fuel cells. The government has assisted industry and research institutions, as detailed in Germany's National Hydrogen Strategy. While the fuel cell mobility market is nascent, Germany has the third largest fleet of FCEVs, with 1,016 on-road passenger vehicles as of January 2021. However, the hydrogen mobility market faces significant challenges, especially for passenger FCEVs. This is due to issues such as supply and cost, production, German automakers, profitability and availability of stations, and demand for vehicles. To ensure future success, it is crucial to accelerate progress on reducing vehicle production costs and increasing supply, especially for German-made vehicles, and invest in refuelling infrastructure and hydrogen production technologies (Trencher and Edianto, 2021).

6. Conclusions

Four scenarios are generated based on two main uncertainties identified, the support and commitment of the government for hydrogen development in the transportation sector and the economic of hydrogen. The Going Highway scenario is taken when the government provides comprehensive support and hydrogen is competitive to fossil fuel or BEVs. The Queueing Ticket scenario is carried out if the hydrogen economies occur faster, but the development of hydrogen ecosystem is not supported by government policy. The Asking Innovation scenario was implemented when the government established a clear hydrogen development roadmap, showing its support and commitment, yet hydrogen technology remains costly and uncompetitive. In case of no clear support and commitment from government and slow technological progress results in the economics of hydrogen not being achieved, the Enetring Rest Area scenario is taken.

The early warning signal assessment results the closest scenario happened recently is Asking Innovation. Several recommendations can be made for Power Company as follows:

1. As hydrogen implementation in transportation sector has been established by government through RHAN, Power Company should adjust the hydrogen development program for the transportation sector into long-term, medium-term, and short-term planning.
2. Keep doing any research, benchmarking, and pilot project of hydrogen not only in transportation sector but also in other industry sectors by collaborating with researchers, government, and private sectors to fulfil technology gap, specially in green hydrogen development.
3. As government support for hydrogen development has already presented, Power Company need to maintain the wave by encouraging government policy to provide incentives for early adopters, to provide special electricity tariffs for hydrogen production, such as subsidies for certain types of fuel, to make LCOH more competitive.
4. Based on the interview results, one of the barriers to entry for hydrogen vehicles in Indonesia is the unclear regulation related to the standard of hydrogen use for transportation. Collaborating with all stakeholders, it is necessary to encourage the government accelerating the completion of standards and regulations for the implementation of hydrogen in the transportation sector.

Although there is currently a change in the scenario towards the better, it is necessary to pay attention to the risk of political changes that could be switched to the Entering Rest Area or other scenarios. The initiation phase in RHAN, putting fundamentals for hydrogen ecosystem development, is targeted to be completed in 2030, while Indonesia will hold general elections for president and government in 2029. The global hydrogen demand for transportation, the stagnation of technology improvement, and discontinuation of hydrogen vehicles by its owners towards to less significant reduction in cost of vehicle and hydrogen production are other risks for getting the competitive price.

While this research focuses on scenario construction for excess hydrogen utilization for Power Generation company, future research is needed to explore the risks for each scenario using risk framework and quantify the risk that occurs for each scenario.

References:

Aguilera, R. F., & Inchauspe, J. (2022). An overview of hydrogen prospects: Economic, technical and policy considerations. *Australian Journal of Agricultural and Resource Economics.* John Wiley and Sons Inc. https://doi.org/10.1111/1467-8489.12458

Amer, M., Daim, T. U., & Jetter, A. (2013). A review of scenario planning. *Futures, 46,* 23–40. https://doi.org/10.1016/j.futures.2012.10.003

Barbosa, M. C., & Gomes, R. L. R. (2025). The contributions of Michael Eugene Porter's five competitive forces in the strategic planning of green hydrogen production in Ceará and its export to Europe. *IOSR Journal of Business and Management, 27*(3, Ser. 7), 65–74. https://doi.org/10.9790/487X-2703076574

Cordova-Pozo, K., & Rouwette, E. A. J. A. (2023). Types of scenario planning and their effectiveness: A review of reviews. *Futures.* Elsevier Ltd. https://doi.org/10.1016/j.futures.2023.103153

Di Pierro, G., Bitsanis, E., Tansini, A., Bonato, C., Martini, G., & Fontaras, G. (2024). Fuel cell electric vehicle characterisation under laboratory and in-use operation. *Energy Reports, 11,* 611–623. https://doi.org/10.1016/j.egyr.2023.12.013

Furuncu, Y. (2025). PESTEL and SWOT analysis of hydrogen economy in Turkey. *International Journal of Hydrogen Energy, 113,* 161–169. https://doi.org/10.1016/j.ijhydene.2025.02.408

Hydrogen Council, & McKinsey & Company. (2025). *Hydrogen: Closing the cost gap – Unlocking demand for clean hydrogen by 2030.* Hydrogen Council. https://hydrogencouncil.com/en/hydrogen-closing-the-cost-gap/

International Renewable Energy Agency (IRENA). (2024). *Green hydrogen strategy: A guide to design.* Abu Dhabi: Author. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Jul/IRENA_Green_hydrogen_strategy_design_2024.pdf

Khan, U., Yamamoto, T., & Sato, H. (2022). Understanding the discontinuance trend of hydrogen fuel cell vehicles in Japan. *International Journal of Hydrogen Energy, 47*(75), 31949–31963. https://doi.org/10.1016/j.ijhydene.2022.07.141

Kokkinos, K., Karayannis, V., Samaras, N., & Moustakas, K. (2023). Multi-scenario analysis on hydrogen production development using PESTEL and FCM models. *Journal of Cleaner Production, 419,* 138251. https://doi.org/10.1016/j.jclepro.2023.138251

Kouchaki-Penchah, H., Bahn, O., Bashiri, H., Bedard, S., Bernier, E., Elliot, T., & Levasseur, A. (2024). The role of hydrogen in a net-zero emission economy under alternative policy scenarios. *International Journal of Hydrogen Energy, 49,* 173–187. https://doi.org/10.1016/j.ijhydene.2023.07.196

Len, C. (2025). *Green hydrogen in Southeast Asia: Connecting national strategies with public support* (ISEAS Perspective No. 33). ISEAS – Yusof Ishak Institute. https://www.iseas.edu.sg/wp-content/uploads/2024/08/ISEAS_Perspective_2025_33.pdf

Ling-Chin, J., Giampieri, A., Wilks, M., Lau, S. W., Bacon, E., Sheppard, I., & Roskilly, A. P. (2024). Technology roadmap for hydrogen-fuelled transportation in the UK. *International Journal of Hydrogen Energy, 52,* 705–733. https://doi.org/10.1016/j.ijhydene.2023.04.131

Lu, Q., Zhang, B., Yang, S., & Peng, Z. (2022). Life cycle assessment on energy efficiency of hydrogen fuel cell vehicle in China. *Energy, 257,* 124731. https://doi.org/10.1016/j.energy.2022.124731

Marzouk, O. A. (2024). Expectations for the role of hydrogen and its derivatives in different sectors through analysis of the four energy scenarios: IEA-STEPS, IEA-NZE, IRENA-PES, and IRENA-1.5°C. *Energies, 17*(3), 646. https://doi.org/10.3390/en17030646

Ministry of Energy and Mineral Resources of Indonesia. (2022, September 2). Energy ministry, IEA launch NZE roadmap [Press release]. https://www.esdm.go.id/en/media-center/news-archives/luncurkan-peta-jalan-nze-sektor-energi-indonesia-ini-hasil-pemodelan-iea

Ministry of Energy and Mineral Resources. (2024). *Handbook of energy and economic statistics of Indonesia 2023.*Center for Data and Information Technology on Energy and Mineral Resources. https://www.esdm.go.id/assets/media/content/content-handbook-of-energy-and-economic-statistics-of-indonesia-2023.pdf

Mukelabai, M. D., Wijayantha, K. G. U., & Blanchard, R. E. (2022). Hydrogen technology adoption analysis in Africa using a Doughnut-PESTLE hydrogen model (DPHM). *International Journal of Hydrogen Energy, 47*(74), 31521–31540. https://doi.org/10.1016/j.ijhydene.2022.07.076

Nnabuife, S. G., Oko, E., Kuang, B., Bello, A., Onwualu, A. P., Oyagha, S., & Whidborne, J. (2023). The prospects of hydrogen in achieving net zero emissions by 2050: A critical review. *Sustainable Chemistry for Climate Action, 2,*100024. https://doi.org/10.1016/j.scca.2023.100024

Pangarkar, N., & Prabhudesai, R. (2024). Using Porter's five forces analysis to drive strategy. *Global Business and Organizational Excellence, 43*(5), 24–34. https://doi.org/10.1002/joe.22250

Park, J., & Kim, C. (2025). Current challenges to achieving mass-market hydrogen mobility from the perspective of early adopters in South Korea. *Sustainability, 17,* 2507. https://doi.org/10.3390/su17062507

Pepe, J. M., Ansari, D., & Gehrung, R. M. (2023). The geopolitics of hydrogen: Technologies, actors, and scenarios until 2040. *SWP Research Paper,* 1–48. Stiftung Wissenschaft Und Politik (SWP).

PLN. (2024b). *Journey PLN dalam pengembangan hidrogen.* Presented in FGD KBLI H2, Double Tree Jakarta by Division of Corporate Business Development and Investment.

Porter, M. E. (1997, February 1). Competitive strategy. *Measuring Business Excellence*. https://doi.org/10.1108/eb025476
Pranoto, A., & Indradewa, R. (2024). Analysis of external factors based on Porter's five forces method at PT Gipan Metal Teknik Indonesia. *Advances in Social Humanities Research, 2*(2), 304–311.
Ramirez, R., & Wilkinson, A. (2014). Rethinking the 2×2 scenario method: Grid or frames? *Technological Forecasting and Social Change, 86,* 254–264. https://doi.org/10.1016/j.techfore.2013.10.020
Surya Husada, V., & Erar Joesoef, I. (2022). Legal policy of the Indonesian government to achieve net zero emissions. *Journal Research of Social Science, Economics, and Management, 2*(1). https://doi.org/10.59141/jrssem.v2i1.248
Trencher, G., & Edianto, A. (2021). Drivers and barriers to the adoption of fuel cell passenger vehicles and buses in Germany. *Energies, 14*(4). https://doi.org/10.3390/en14040833
Zhang, Y., & Wildemuth, B. M. (2016). Qualitative content analysis. In B. M. Wildemuth (Ed.), *Applications of social research methods to questions in information and library science* (2nd ed., pp. 318–329). Libraries Unlimited.