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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Nitida Nakapreecha/Jakapong Pongthanaisawan et. al. (2023). Prospect of hydrogen usage in the industrial sector : Thailand context. In: International Journal of Energy Economics and Policy 13 (3), S. 61 - 72.
https://www.econjournals.com/index.php/ijeep/article/download/14198/7282/33211.
doi:10.32479/ijeep.14198.

This Version is available at:
http://hdl.handle.net/11159/630237

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International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2023, 13(3), 61-72.

Prospect of Hydrogen Usage in the Industrial Sector: Thailand Context

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Received: 11 January 2023 **Accepted:** 17 April 2023 **DOI:** https://doi.org/10.32479/ijeep.14198

ABSTRACT

Hydrogen is receiving attention as a highly clean alternative energy with the potential to replace conventional fuels. However, it is still more expensive than fossil fuels. Using hydrogen in the energy sector will certainly affect energy costs, which for the private sector is an important factor when making decisions about fuel replacement. The objective of this study is to analyze the financial and economic feasibility of using hydrogen as a fuel in the industrial sector. From the financial and economic analysis, hydrogen can be mixed with natural gas in a ratio of no more than 20% by volume and used as fuel in industrial plants that previously used liquefied petroleum gas and fuel oil and are within 50 km of a natural gas and hydrogen mother station. Despite the financial and economic viability, government support is still needed to stimulate the use of hydrogen. The supports include introducing hydrogen to prospective users and ensuring the security of supply; encouraging domestic hydrogen production as well as research and development; developing the necessary infrastructure; and improving regulations and standards to support the supply and use of hydrogen all along the value chain.

Keywords: Hydrogen, Fuel Switching, Greenhouse Gas Mitigation, Industrial Sector, Financial Feasibility, Economic Feasibility
JEL Classifications: Q21, Q42, Q47

1. INTRODUCTION

Hydrogen is an environmentally friendly fuel, as the only byproducts of the combustion of hydrogen and oxygen are water and energy. There are no emissions of greenhouse gases. Examples of hydrogen applications in the energy sector include combustion and fuel cells. It can also be mixed with natural gas to generate electricity or used as fuel for industrial processes that cannot be electrified. The hydrogen storage system could also be used as part of the energy storage system to replace or work with batteries when there is excess electricity from renewable sources like solar and wind. In this case, hydrogen will increase the stability and flexibility of renewable power systems. Hydrogen can also be used as a zero-emission vehicle fuel in the transportation sector. According to the "Net Zero by 2050" report of the International Energy Agency, hydrogen is one of the key technologies that will help the world achieve its greenhouse gas reduction targets (IEA, 2021). Many countries have been studying, preparing, and developing the use of hydrogen in the energy sector. In the United States, the demand for hydrogen is expected to reach 17 million metric tons by 2030 and 63 million metric tons by 2050, which will make up 1% and 14%, respectively, of the total final energy demand. The expected uses include transportation fuel, heating source for residential and commercial buildings, and industrial raw material (Fuel Cell and Hydrogen Energy Association, 2020).

The United Kingdom aims to produce 5 GW of low-carbon hydrogen by 2030 for use in the power, heating, and transportation

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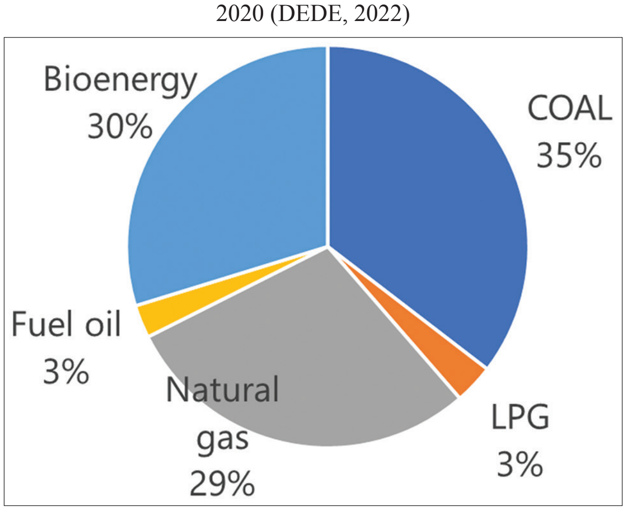
sectors (Secretary of State for Business, Energy and Industrial Strategy, 2020). In addition, an attempt has been made to mix hydrogen with natural gas at a ratio of up to 20% and then transport the mixture through the existing gas pipeline to various consumers. It was found that gas users did not notice any difference in energy performance, which suggests that hydrogen might be used as an alternative fuel to natural gas (John, 2020).

With the aim to achieve carbon neutrality by 2050 (Energy Policy and Planning Office, 2021), Thailand needs to move towards lower carbon energy sources. Accordingly, hydrogen has attracted attention as a potential clean energy alternative to conventional energy. For the electricity sector, , the idea of integrating hydrogen into the national power development plan (PDP) was proposed (Diewvilai & Audomvongseree, 2021). In addition, Diewvilai and Audomvongseree have suggested that achieving the carbon neutrality target in this sector can be made possible through the introduction of hydrogen blending in natural gas and solar PV with battery energy storage systems (Diewvilai and Audomvongseree, 2022). As of 2020, the most common fuel consumed in the industrial sector in Thailand is still fossil fuels, of which all types account for 70%, while bioenergy accounts for 30% (Figure 1). Among the fossil fuels, coal has the largest share (35%), followed by natural gas (29%). Liquefied petroleum gas (LPG) and fuel oil share the same usage ratio of 3%.

The use of hydrogen to replace fossil fuels in the industrial sector will reduce greenhouse gas emissions and other local pollutants such as carbon monoxide (CO), non-methane volatile organic compounds, and fine particles (PM = 2.5).

Although hydrogen is receiving attention as a highly clean alternative energy with the potential to replace traditional fuels, it is still a relatively new kind of energy whose production technology is still under development and has not yet been commercialized with economies of scale. This makes the current price of hydrogen higher than that of fossil fuels, whose technologies have been developed for a long time. Using hydrogen will certainly affect energy costs, which is an important factor for the private sector to consider when deciding whether or not to switch fuels.

Figure 1: Share of fuel consumption in Thailand's industrial sector in 2020 (DEDE, 2022)



The objective of this study is to examine the financial and economic feasibility of using hydrogen in the industrial sector in Thailand. The findings will be useful in future planning for the use of hydrogen as a fuel in the industrial sector.

2. METHODOLOGY

2.1. Analytical Framework for the Analysis

For the private sector, the most significant factor in convincing users to switch fuels is a considerable difference in fuel prices to make the investment worthwhile over time. As a result, a financial and economic feasibility analysis is required to determine the possibility of fuel replacement.

This study analyzes the financial and economic feasibility of mixing hydrogen with natural gas to fuel industrial boilers. It compares the cost of using hydrogen to the cost of the fuels that are currently used in the industry. The analysis process consists of three steps as shown in Figure 2.

- Step 1: Analysis of costs incurred throughout the supply chain
  The step covers an analysis of the costs that will be incurred by entrepreneurs along the supply chain, such as the cost of hydrogen, the cost of transporting hydrogen, the cost of adjusting equipment and systems, etc.
- Step 2: Analysis of financial and economic feasibility of fuel replacement
  This step is to analyze the cost-effectiveness of fuel replacement in industrial plants by using the financial and economic indices, which are net present value (NPV), internal rate of return, and payback period.
- Step 3: Analysis of ways to promote the use of hydrogen
  From the second step, it can be seen how cost-effective it is to switch fuel to hydrogen in the industrial sector. If the cost increase proves to be substantial, special measures will be required to promote the use of hydrogen in the industrial sector.

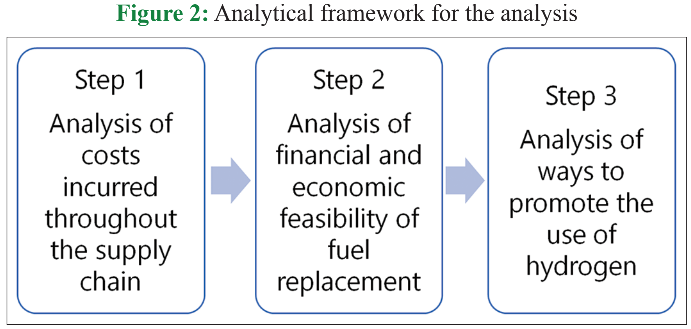
It should be noted that the feasibility analysis in this study only considers the potential business models for each player. It does not include the case where investors may offer more advanced products or services to incentivize partners or enhance their businesses' competitiveness.

2.2. Main Assumption

2.2.1. Fuel ratio

It is assumed that up to 20% by volume of hydrogen is blended with natural gas for use as fuel for industrial plants. This is

Figure 2: Analytical framework for the analysis



consistent with the results of an experiment conducted in the United Kingdom, which demonstrated that mixing hydrogen with natural gas at up to 20% by volume had no discernible effect on the performance of gas-fired appliances and that existing pipelines could still be used (John, 2020). Hydrogen concentrations over 20% by volume may require pipeline system modification for safety reasons (Melaina et al., 2013).

2.2.2. Source of hydrogen

As Thailand does not yet have broad commercial hydrogen production for use in energy applications, it is assumed in this study that the hydrogen used in these applications is mainly imported.

2.2.3. Target group of factories

The target group of factories for fuel replacement is those that use natural gas, LPG, and fuel oil. The scope does not cover the coal-burning plants, as it is anticipated that the operators will eventually be required to switch away from coal, and it is very unlikely that the new plants will choose coal as fuel due to environmental regulations.

Next, transportation viability is examined to determine which groups of factories can access the mixed gas (hydrogen mixed with natural gas).

Given the possibility that Thailand will have to import liquefied natural gas (LNG) in the future due to a significant decrease in natural gas supply and the assumption that Thailand will import hydrogen for energy applications, it is assumed that hydrogen will be injected into the existing natural gas pipeline for the convenience of transportation to users. It is noted that blending hydrogen into gas pipelines is in line with the possible transition towards a carbon neutrality target in the power sector (Diewvilai and Audomvongseree, 2022). Thus, sending the mixed gas through pipelines to both the power and industrial sectors will help the country make the most of the infrastructure it already has.

There is currently a natural gas pipeline network in Thailand, although it does not span the entire nation (Figure 3). The factory along the gas pipeline can obtain the mixed gas directly from the pipeline, but the factories near the pipeline need a vehicle to bring the mixed gas to them.

For factories far from the gas pipeline, truck transportation is needed, and there are a number of issues to consider:

(1) Transporting liquid products is likely to be more cost-effective in terms of volume compared to transporting gaseous products.
(2) Shipping products concurrently is likely to be less expensive than shipping them separately, which costs twice as much.

This leads to the idea that transporting liquefied hydrogen gas and LNG in the same tank would be the most economical for customers. However, a preliminary analysis of the technical feasibility found that these two liquefied gases cannot be transported simultaneously due to their physical limitations. As the temperature and pressure that transform hydrogen gas into a liquid will transform natural gas into a solid (Figure 4), liquefied hydrogen and LNG cannot be transported simultaneously.

The next option to consider for factories located far from the gas pipelines is shipping hydrogen gas separately from natural gas. However, the preliminary financial analysis found that it would increase costs for users in a number of areas, including transportation costs and the cost of installing a storage and regasification system. All of which, when taken into account together with the cost of hydrogen, will create too much of a financial burden for users. This suggests that the use of hydrogen as fuel in factories located far from the natural gas pipeline network would not be financially viable.

This study, therefore, focuses only on the use of hydrogen as fuel in factories located on or near gas pipelines.

2.2.4. Business model

The business model was designed to introduce different types of hydrogen to industrial plants. Hydrogen will be blended with natural gas at up to 20% by volume and will replace the original fuel. The hydrogen used is imported from abroad.

A natural gas transmission network will be used for transportation. At the natural gas and hydrogen (NG&H_2) terminal, hydrogen and natural gas are mixed prior to being transported through the gas pipeline system. Users located on the gas pipeline network can install the pipeline system to connect directly to the main gas pipeline network. This group of factories originally used pure natural gas as its primary fuel source (ERI, 2021).

For factories near the natural gas pipeline network, 40-foot tube trailers will be used to deliver compressed hydrogen and compressed natural gas to users within a 50-km radius of the NG&H_2 mother station. This group of factories originally used LPG and fuel oil as the primary fuel source (ERI, 2021).

The business model is shown in Figure 5.

2.3. Cost Analysis Along the Supply Chain

2.3.1. Fuel price forecast

2.3.1.1. Price forecast for hydrogen

As Thailand has not yet produced hydrogen for commercial use in energy applications, there is a limitation in accessing operating cost data throughout the domestic supply chain. This study employed the analysis of hydrogen costs from "The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs" by the National Academy of Engineering, which provides an analysis of hydrogen production in the United States at different scales and with different technologies (National Academy of Sciences, 2004). Then, the cost of liquefaction and transport, as determined by the analysis of the Economic Research Institute for ASEAN and East Asia (ERIA), is combined to complete the total cost of the supply chain (ERIA, 2020). The cost component of hydrogen and the data source used in the study are shown in Figure 6.

The costs of the following types of hydrogen were analyzed: (1) Gray hydrogen from methane reforming; (2) blue hydrogen from methane reforming with a carbon capture system retrofitted; (3) brown hydrogen from coal gasification; (4) light brown hydrogen from coal gasification with a carbon capture system

Figure 3: Natural gas transmission pipeline system (PTT, 2019)

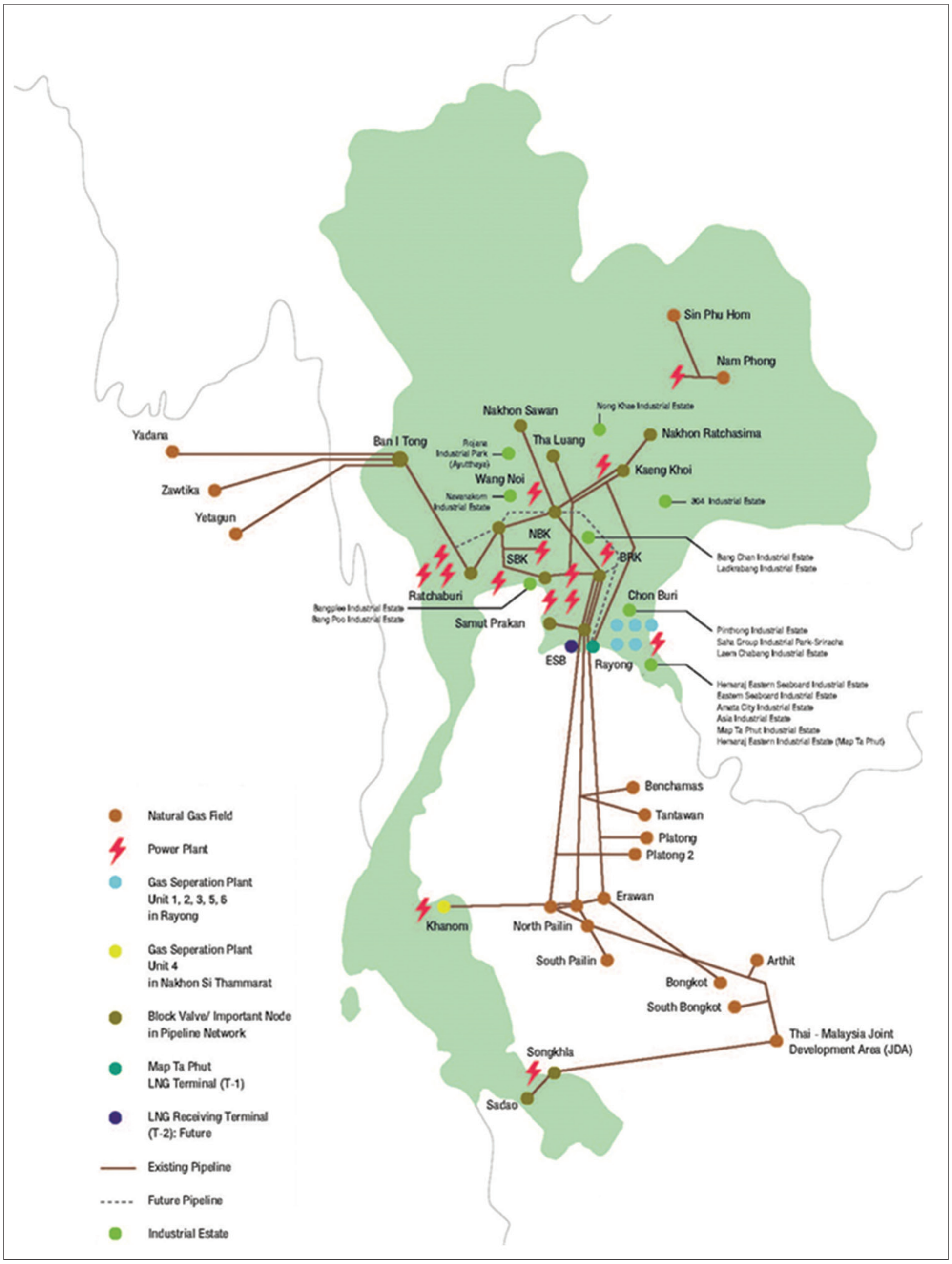
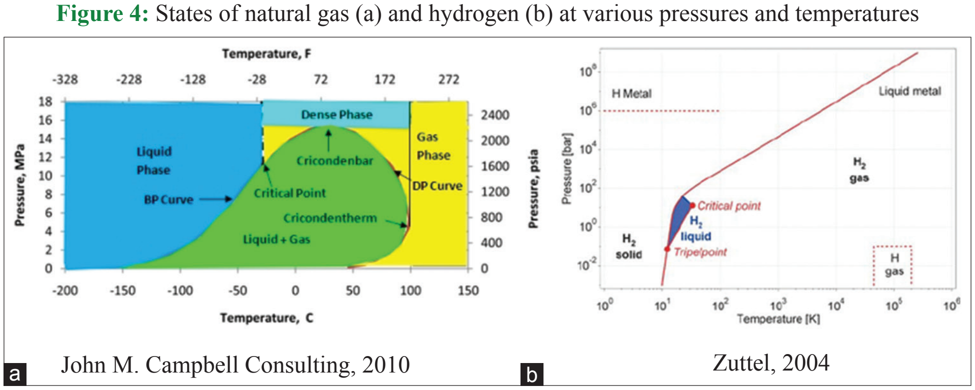


Figure 4: States of natural gas (a) and hydrogen (b) at various pressures and temperatures



retrofitted; and (5) green hydrogen from electrolysis, which uses electricity produced from renewable energy sources, such as solar and wind power.

The information from both sources has been adapted based on the expert's judgement, both in terms of the price level and the year when that price can be reached.

2.3.1.2. Price forecast for natural gas

2.3.1.2.1. Analysis of future natural gas supply

Thailand uses natural gas from both domestic and foreign sources. Each gas source has a different price structure. In analyzing future natural gas prices, therefore, it is necessary to first analyze the trend of future natural gas supply. The price is then calculated using the proportion of natural gas supply from each source.

Thailand's current natural gas supply comes from three primary sources:

(1) Domestic gas fields, both onshore and offshore.
(2) Natural gas imports via pipeline from Myanmar.
(3) LNG imports from abroad.

The natural gas supply for present–2037 is based on the draft National Gas Plan 2018, which estimates the natural gas supply through the end of 2037. Assumptions for natural gas supply from each source are as follows:

(1) Natural gas from domestic gas fields will be supplied in the same quantity as in 2037 until 2040, then gradually decline to zero by 2050.
(2) Natural gas imports from Myanmar will remain at the same level as in 2037 until 2040, after which the imports will cease.
(3) LNG will be imported to meet total natural gas demand, which is growing at a rate of 1% per year, which is the average growth rate for the country between 2019 and 2037, according to the draft Gas Plan 2018.

Based on the above assumptions, the trend of natural gas supply in Thailand between 2018 and 2070 is shown in Figure 7.

2.3.1.2.2. Concept of natural gas price forecast

Time series modeling is used to forecast future natural gas prices with the assumption that factors influencing the price were latent in the price of the previous period. And if there are no significant changes in macroeconomic factors, the price will continue on its historical path.

The methodology for analyzing natural gas prices from all three sources for the period 2020–2070 is referred to as that in the previous study by Nakapreecha et al., which uses an autoregressive model in which historical price statistics are employed to determine future prices (Nakapreecha et al., 2022).

The price estimate ranges from the present through 2070, or approximately 50 years into the future. Using only the time series technique has a high probability of error as macro-level factors are unlikely to remain unchanged over the next 50 years, especially now that Thailand is in the midst of an energy transformation. In this regard, a number of price forecasts from the International Energy Agency (IEA) are employed to determine macro-level factors, which are then used to develop a model for long-term natural gas price estimates. A specific model is made for each natural gas supply source.

2.3.1.2.3. Price forecast for natural gas from domestic fields

The prices of natural gas from domestic gas fields are based on average prices from the past, which take into account changes in the economy, exchange rates, production costs, and fuel oil prices (ERI, 2020). All of these are latent variables that were already present in the previous price range. Accordingly, time series analysis with an autoregressive model is applied to estimate the future price of natural gas from domestic fields (Equation 1).

$$p_t = \alpha + \sum_{k=1}^{m} \beta_k p_{t-k} + \gamma t \qquad \text{(Equation 1)}$$

Figure 5: Business model of utilizing hydrogen as fuel in industrial plants

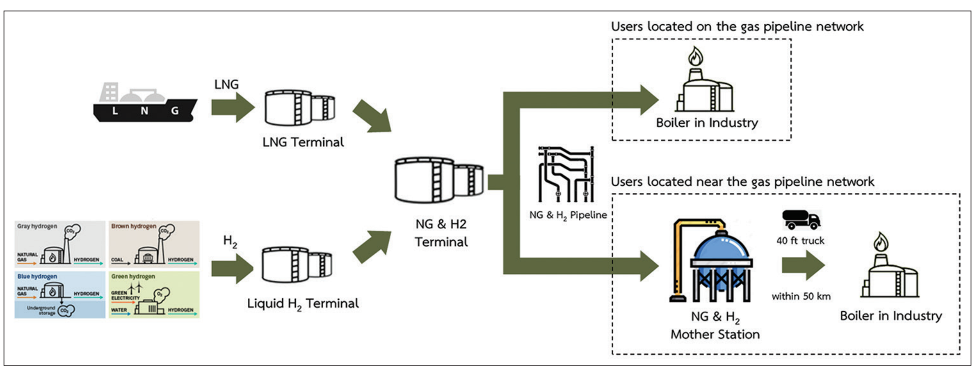
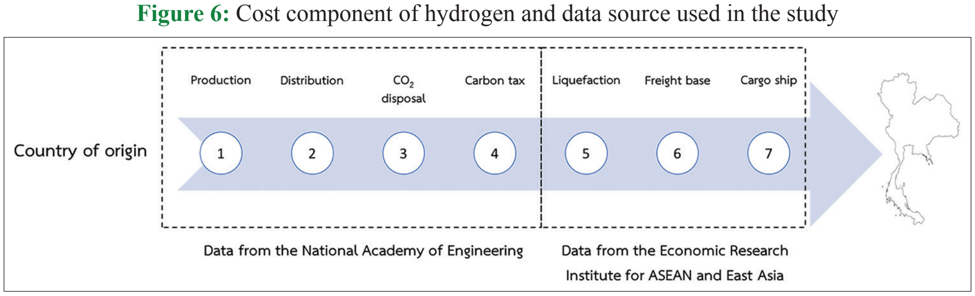


Figure 6: Cost component of hydrogen and data source used in the study



When,
p_t = Natural gas price at month *t*
p_{t-k} = Natural gas price at month *t-k*
α = Constant
β_k = Coefficient of natural gas price at month *t-k*
γ = Average monthly growth rate trend of natural gas price
m = Total months taken into consideration in the model.

Maximum likelihood estimation and the least squares technique are applied to calculate the constant and coefficient.

2.3.1.2.4. Price forecast for natural gas imports from Myanmar
The prices of natural gas from Myanmar were affected by inflation, the exchange rate, changes in production costs, and the price of fuel oil. Similar to the case of domestic gas, these factors were already reflected in the price range before. Thus, time series analysis with an autoregressive model is applied to estimate the future price of this gas.

2.3.1.2.5. Price forecast for LNG
The majority of Thailand's LNG imports are sourced under long-term contracts, but some are sourced on the spot market. The price of LNG imported under long-term contracts depends on the Japan Crude Cocktail (JCC) and Henry Hub prices. The price of LNG imported from the spot market depends on the market's supply and demand at that time, which reflects the demand for natural gas, temperature, season, and global economic conditions. The current cost of imported LNG in Thailand is the average of the costs of long-term contracts from different companies and the cost of imports from the spot market, plus the cost of using the LNG receiving terminal, which is considered a necessary infrastructure and must be added to the cost of natural gas (ERI, 2021).

The Russia-Ukraine conflict has caused widespread concern about gas supply in Europe and has accelerated LNG contracting activity (Farrer, 2022), which consequently impacted Asian spot LNG prices (Figure 8). Although the prices have surged to a level that is several times higher than US Henry Hub prices, there is a signal that they will come off their record highs eventually (Chow, 2023). Thus, this study excludes this unusual event of price volatility.

As LNG is a globally traded fuel and is influenced by international environmental policies, environmental policy issues must be considered when determining the future prices of LNG, for example greenhouse gas emissions reduction targets, sustainable development goals, and net-zero emissions. In this regard, the prices of LNG trading in Japan, determined by the International Energy Agency (IEA), are used as a reference to forecast LNG prices.

However, such prices must be adjusted for the Thai context before being used. The price estimation has been divided into four-time frames: (1) from the present to 2040; (2) from 2041 to 2050; (3) from 2051 to 2060; and (4) from 2061 to 2070. Prices from various IEA scenarios have been applied in each period, as shown in Table 1. The price in Table 1 is then used to develop a model for analyzing the price of LNG using time series analysis with an autoregressive model, as in the case of analyzing natural gas prices from domestic fields and Myanmar.

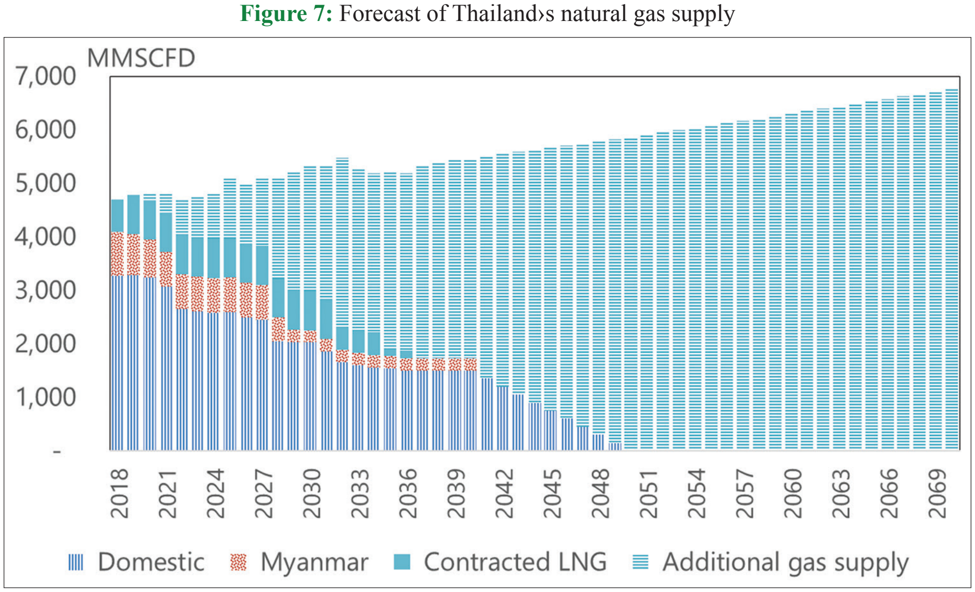
2.3.1.2.6. Average natural gas price
The prices of natural gas from all three sources were utilized to estimate the average natural gas price using the weighted average method based on the sources of natural gas supply.

2.3.1.3. Price forecast for mixed gas

It is assumed that hydrogen will be injected into natural gas pipelines to be sent to users. The mixing ratio is increased progressively, starting from 5% in 2031–2040 to 20% in 2060–2070 (Table 2).

The price of hydrogen and natural gas from the previous section is used for analyzing the price of a hydrogen-natural gas mixture (mixed gas) based on the hydrogen mixing ratio shown in Table 2 by using Equation 2.

Figure 7: Forecast of Thailand›s natural gas supply



$$P_{mixed\ fuel} = \frac{\left(P_{H_2} HHV_{H_2} V_{H2}\right) + \left(P_{NG} HHV_{NG} V_{NG}\right)}{\left(HHV_{H_2} V_{H2}\right) + \left(HHV_{NG} V_{NG}\right)} \quad \text{(Equation 2)}$$

When,

$P_{mixed\ gas}$, P_{H2}, P_{NG} = Prices of mixed gas, hydrogen, and natural gas, respectively (THB/MMBTU)

HHV_{H2}, HHV_{NG} = Heating values of hydrogen and natural gas, respectively (MMBTU/MMSCF)

V_{H2}, V_{NG} = Volumes of hydrogen and natural gas, respectively (MMSCF).

2.3.1.4. Price forecast for LPG and fuel oil

Like LNG, LPG and fuel oil are fossil fuels; thus, they are likely to be influenced by international environmental policies. Accordingly, LPG and fuel oil prices are analyzed using the same methodology as LNG prices. The price estimation of both fuels has been divided into four-time frames using prices from IEA scenarios and natural gas prices.

2.3.2. Cost analysis

Cash flow throughout the life of the project is evaluated at this step, considering cash inflow and outflow for each player in the hydrogen business model as shown in Figure 5. The key players involved are hydrogen and LNG retailers and industrial plants that switch their fuels to mixed gas. The cash flow of the players is shown in Table 3.

If retailers of hydrogen and LNG are able to set prices to cover all costs, this will encourage them to enter this business. For users, what will encourage them to switch fuels is that fuel switching can result in cost savings and a short payback period; the prices of the new fuel are stable; and the seller can guarantee the security of fuel supply.

2.4. Analysis of Financial and Economic Feasibility

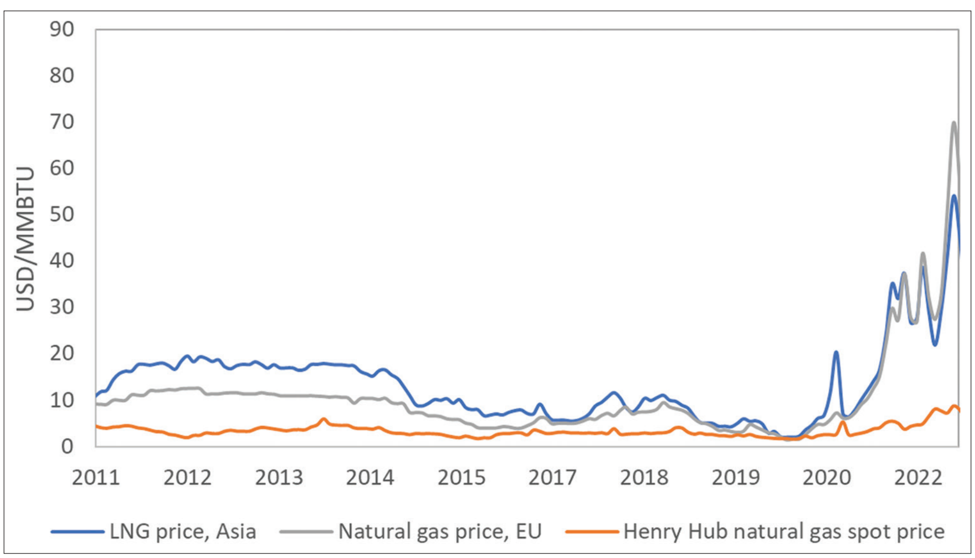
In general, the financial feasibility analysis considers the financial return from the difference between the direct revenue (or cost savings) and the total cost paid over the course of the project through the "financial internal rate of return" (FIRR). The economic feasibility analysis considers the economic return by adding indirect benefits to society that are not monetary revenue, such as the benefits of reducing greenhouse gas emissions and PM2.5, and comparing them to the total cost of the project using the "economic internal rate of return" (EIRR). In other words, FIRR evaluates the direct benefit to the business (as revenue or savings), while EIRR evaluates both the direct benefit to the business and the indirect benefit to society (as environmental improvement).

The assessment of the benefits that each player will obtain from switching fuels should take into account both the direct and indirect benefits. Accordingly, the FIRR and EIRR are analyzed to assess the direct and indirect benefits of using hydrogen as fuel in the industrial sector. The NPV and internal rate of return (IRR), and simple payback period (SPP) are also evaluated.

2.4.1. NPV

The NPV indicates the profitability of the investment or project. It can be calculated from Equation 3.

Figure 8: Natural gas prices (USD/MMBTU)



Source: International Monetary Fund, 2023

Table 1: Reference price of natural gas in the last year of each time period (USD/MMBTU)

Time period	Target price for the last year of each period	Referred from	
		Price	Source
Present – 2040	10.26[1)]	15.55[2)]	New Policies Scenario for the Year 2040 (IEA, 2014)
2041 – 2050	7.50[1)]	8.50[1)]	Delayed Recovery Scenario for the Year 2040 (IEA, 2020)
2051 – 2060	5.50[1)]	5.70[1)]	Sustainable Development Scenario for the Year 2040 (IEA, 2020)
2060-2070	4.1[1)]	4.1[1)]	Net Zero Emission (NZE) Scenario for the Year 2050 (IEA, 2021)

[1)] Real price, [2)] Nominal price

$$NPV(DC) = \sum_{t=0}^{t=T} \frac{CF_t}{(1+DC)^t} \quad \text{(Equation 3)}$$

When,
NPV = NPV of the project (unit: THB)
DC = Discount rate
CF = Cash flow
t = Time.

2.4.2. Internal rate of return (IRR)

The internal rate of return is one of the most common criteria to measure the value of an investment project. It can be calculated by using Equation 4.

$$IRR = \left\{ x \middle| \sum_{t=0}^{t=T} \frac{CF_t}{(1+x)^t} = 0 \right\} \quad \text{(Equation 4)}$$

When,
IRR= Internal rate of return (percent)
t = Time period that cash flow is obtained
T = Time period that final cash flow is obtained
CF_t = Net cash flow during a single period.

In the study, both the FIRR and the EIRR of the project were evaluated. As for the EIRR, the benefits of reducing greenhouse gas emissions and PM2.5 are taken into account. In this regard, the average European Emission Allowance (EUA) price for January–December 2020 of 24.8 €uro/t-CO2 and the externality of 495 €uro/kg-PM2.5 are used (Holland and Watkiss, 2002).

Table 2: Hydrogen mixing ratio in the natural gas stream (percent by volume)

Year	Hydrogen mixing ratio (percent by volume)
2031–2040	5
2041–2050	10
2051–2060	15
2061–2070	20

Table 3: Cash flow of players in the hydrogen business model

Player	Cash inflow	Cash outflow
Retailer of hydrogen and LNG	Revenue from selling hydrogen and LNG to cover investment and operating costs	Hydrogen and natural gas costs Investment and operating costs of terminals Cost of transporting compressed hydrogen and compressed natural gas to customers via truck Cost of installing hydrogen pipeline and/or cost of transporting mixed gas via natural gas pipeline Other equipment costs Cost of business management and operation
Hydrogen user	Cost savings from switching to new fuel	Cost of hydrogen storage and regasification systems Cost of burner and boiler modifications Other equipment costs Cost of business management and operation

The cost information was obtained from the industrial surveys (ERI, 2021)

2.4.3. Payback period (PB)

The payback period (PB) is the amount of time it takes for a company to recoup its initial investment through net cash inflows (Atrill and McLaney, 2009). It can be calculated from Equation 5.

$$PB = min\left\{ x \sum_{t=1}^{t=x} CF_t > C_0 \right\} \quad \text{(Equation 5)}$$

When,
PB = Payback period (year)
CF_t = Net cash flow during a single period
C_0 = Initial investment
t = Time period that cash flow is obtained.

2.5. Analysis of Ways to Promote the Use of Hydrogen

Since the private sector is mostly involved in the hydrogen business, the first consideration is whether or not private investment is financially possible. Generally, if the financial return is satisfactory, market mechanisms will encourage investors to invest in the business. The government only needs to help eliminate various regulatory and legal barriers that impede business operations (Nakapreecha et al., 2022).

But if it turns out that the financial rate of return is not viable but there are interesting economic returns and the government believes that fuel replacement should be encouraged, the government needs to provide support to stimulate the project. The support includes funding for equipment or system modifications, price compensation, or other financial assistance measures, as in the case of policies to promote electricity generation from other renewable energies, etc.

3. RESULTS AND DISCUSSION

3.1. Fuel Price Forecast

3.1.1. Hydrogen price

The forecast of hydrogen prices is shown in Figure 9 and Table 4.

It can be seen that the price of fossil-based hydrogen (gray, blue, brown, and light brown hydrogen) is comparable. On the other hand, the prices of green hydrogen, which is derived from renewable energy, are initially much higher than those of fossil-based hydrogens, but the price difference between the two groups narrows over time. The price of all types of hydrogen is likely to decrease in the future.

3.1.2. Natural gas prices

The forecast of natural gas prices is shown in Figure 10.

From the forecast, natural gas prices from all three sources will increase before 2040, with Myanmar gas prices being the highest, followed by LNG and domestic natural gas.

After 2040, the price of natural gas from domestic sources will continue to increase. Yet its price is still lower than LNG's. The rise in domestic gas price is in line with the trend of natural gas supply in the future, which will be more challenging, both in terms of the declining reserves of active gas fields and the complex geological structure of gas fields in the Gulf of Thailand. In addition, if Thailand were to discover natural gas production reserves in the Andaman Sea in the future, which is a deep-water source, it might have to use technologies that are more advanced and more expensive than those used in production in shallow waters like the Gulf of Thailand.

In contrast, global LNG prices will decline after 2040 due to the influence of international environmental policies. As a result, the demand for LNG on the global market will decrease, resulting in lower prices in the long run.

The upward trend in gas prices from all three sources causes the average price of natural gas in Thailand to rise initially. However, it will start to decline after 2040 in line with the trend in LNG prices, which will then become the country's main natural gas source.

3.1.3. Mixed gas prices

The forecast of mixed gas prices is shown in Figure 11.

Depending on the mixing ratio, the mixed gas prices will vary with the prices of NG&H_2. As the proportion of hydrogen in mixed gas is only 5–20%, which is less than the proportion of natural gas, the price of mixed gas tends to follow the price of natural gas.

3.1.4. LPG and fuel oil prices

LPG and fuel oil prices have the same trend as LNG prices, which will be influenced by international environmental policies, causing the demand in the world market to decrease. This results in lower prices for these two fuels in the long run (Figure 12). The price of LPG tends to be lower than that of fuel oil. This is consistent with the possibility that fuel oil prices may be more affected by carbon prices, making its prices higher than LPG prices.

3.2. Financial and Economic Feasibility of Utilizing Hydrogen as Fuel in the Industrial Sector

In general, fuel users will switch to new fuel only when the price difference between the existing fuel and the new fuel is substantial enough to make the investment in fuel system modification worthwhile. Therefore, FIRR is the primary factor when considering fuel replacement, whereas EIRR, which represents the benefits to society, will be a deciding factor if FIRR is not viable.

In the study, users of fuels used in boilers were classified into 3 groups: natural gas, LPG, and fuel oil users. The results of the

Figure 9: Forecast of hydrogen prices

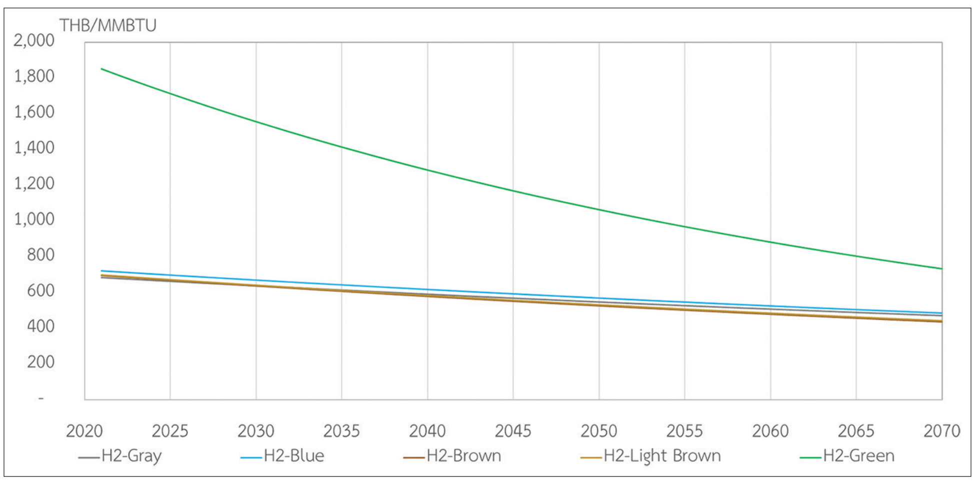
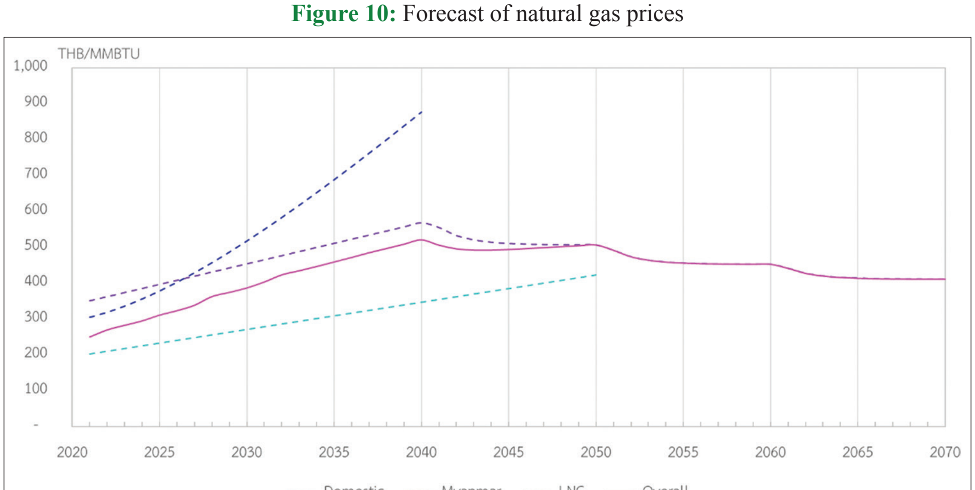


Figure 10: Forecast of natural gas prices



financial and economic feasibility analysis of replacing existing fuels with hydrogen mixed with natural gas are shown in Table 5.

From Table 5, the use of mixed gas between hydrogen and natural gas in factories located along the gas pipeline, which previously used natural gas, would not be financially or economically beneficial. This is because natural gas, the existing fuel, is cheaper than new fuel, and their emission rates are not significantly different.

But when the mixed gas is used to replace LPG or fuel oil in factories located within a radius of 50 km of the NG&H_2 mother station, it will be financially and economically beneficial. In addition, it has a short payback period of only 2.52–3.04 years. This suggests that a mixed gas of hydrogen and natural gas is an attractive option for this group of factories in terms of reducing both fuel costs and emissions.

A further analysis is done to investigate maximum distance between the industrial plant and the NG&H2 mother station that positive NPV can still be obtained (Table 6). It is found that if fossil-based hydrogen is used to replace LPG and fuel oil, the maximum distance that an LPG user and a fuel oil user can be from the NG&H_2 mother station is 106–107 km and 152–153 km, respectively. If green hydrogen, which is more expensive, is used, the maximum distance for LPG users and fuel oil users is 85 km and 130 km, respectively. The analysis also shows that although the financial return at the maximum distance is not very high, the economic return is interesting, especially for the fuel oil replacement.

Table 4: Forecasted prices of different types of liquid hydrogen shipped to Thailand

Type of hydrogen	Year	Forecasted price of liquid hydrogen shipped to Thailand			
		USD/kg	THB/kg	USD/MMBTU	THB/MMBTU
Gray	2021	2.89	90.23	21.00	656.07
	2050	2.27	70.79	16.48	514.67
	2060	2.12	66.07	15.38	480.41
Blue	2021	3.06	95.55	22.24	694.69
	2050	2.35	73.29	17.06	532.84
	2060	2.21	68.89	16.03	500.85
Brown	2021	2.95	92.11	21.44	669.70
	2050	2.17	67.66	15.75	491.96
	2060	2.01	62.64	14.58	455.42
Light brown	2021	2.96	92.42	21.51	671.97
	2050	2.18	67.97	15.82	494.23
	2060	2.04	63.57	14.80	462.24

Figure 11: Forecast of mixed gas prices

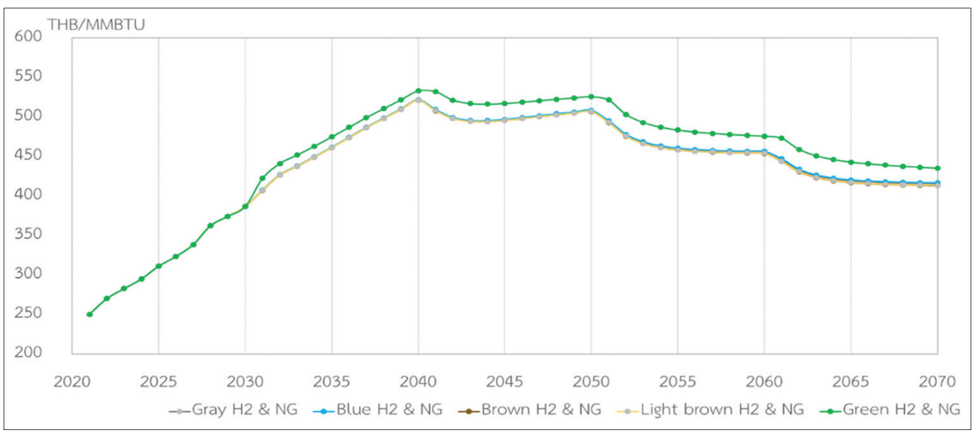


Figure 12: Forecast of liquefied petroleum gas and fuel oil prices

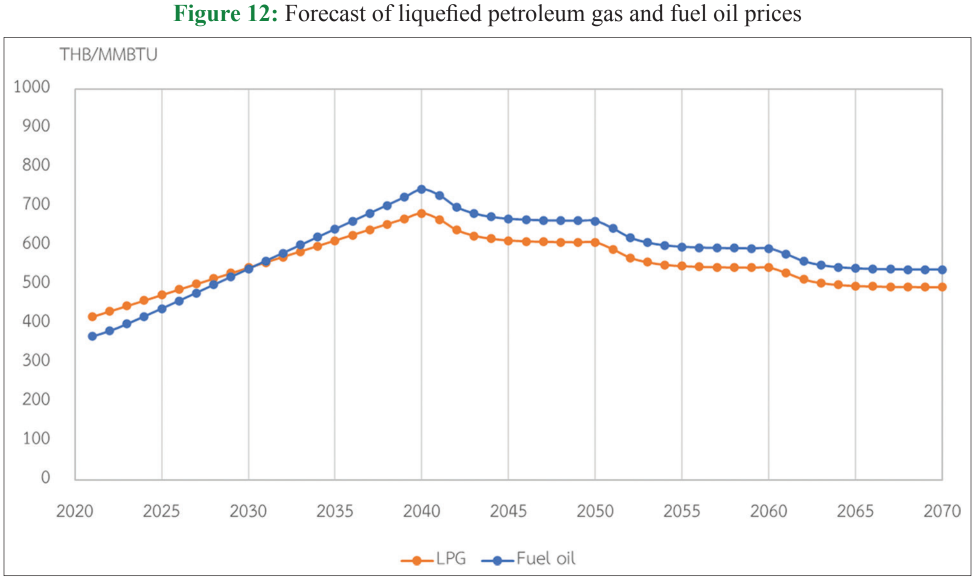


Table 5: Financial and economic feasibility analysis of utilizing hydrogen as fuel in the industrial sector

Hydrogen	Index	User located on the gas pipeline network	User located within 50 km from the NG&H_2 mother station.	
		Natural gas	LPG	Fuel oil
Gray	NPV (MTHB)	−4.19	12.23	20.06
	FIRR (%)	Not feasible	62	71
	EIRR (%)	Not feasible	70	278
	Payback period (year)	-	2.63	2.52
Blue	NPV (MTHB)	-4.34	12.08	19.92
	FIRR (%)	Not feasible	61	71
	EIRR (%)	Not feasible	69	277
	Payback period (year)	-	2.65	2.53
Brown	NPV (MTHB)	−4.14	12.28	20.12
	FIRR (%)	Not feasible	62	71
	EIRR (%)	Not feasible	70	278
	Payback period (year)	-	2.63	2.52
Light brown	NPV (MTHB)	-4.16	12.26	20.10
	FIRR (%)	Not feasible	62	71
	EIRR (%)	Not feasible	70	278
	Payback period (year)	-	2.64	2.52
Green	NPV (MTHB)	−7.98	8.44	16.27
	FIRR (%)	Not feasible	50	61
	EIRR (%)	Not feasible	58	266
	Payback period (year)	-	3.04	2.85

Table 6: Sensitivity analysis of distance between user and the NG&H_2 mother station

Index	LPG replacement					Fuel oil replacement				
	Gray H_2	Blue H_2	Brown H_2	Light brown H_2	Green H_2	Gray H_2	Blue H_2	Brown H_2	Light brown H_2	Green H_2
Maximum distance (km)	107	106	107	107	85	153	152	153	153	130
NPV (MTHB)	0.05	0.07	0.10	0.08	0.02	0.03	0.05	0.08	0.06	0.17
FIRR (%)	12	11	11	11	14	15	15	15	15	16
EIRR (%)	29	29	29	29	4	212	212	212	212	213
Payback period (year)	5.76	5.73	5.76	5.76	5.55	8.04	8.01	8.03	8.04	7.64

4. CONCLUSIONS AND POLICY IMPLICATIONS

For the private sector, the most important factor in encouraging users to switch fuel is having a large enough fuel price difference to make the investment worthwhile in the long run. The second factor is the assurance that there will be a continuous supply of fuel. In addition, it must be a more cost-effective option compared to other options.

Based on a financial and economic feasibility analysis, hydrogen can be mixed with natural gas (at a ratio of no more than 20% by volume) and used as fuel in industrial plants that previously used LPG and fuel oil and are within 50 km of the NG&H_2 mother station. This is because the price difference between the two fuels is large enough to make the investment in fuel system modification worth it. It should be noted that using domestic gas to blend with hydrogen makes fuel replacement for this group of users financially and economically feasible. As domestic gas is significantly cheaper than imported gas, it helps bring down the overall price of the mixed gas.

Users located further away from the NG&H_2 mother station can still use hydrogen. The maximum distance at which it is still financially viable to use fossil-based hydrogen is 106–107 km for LPG users and 152–153 km for fuel oil users. And the maximum distance at which using green hydrogen is still financially viable is 85 km for LPG users and 130 km for fuel oil users. Although the financial return for this group of users is not very high, the economic return is still interesting, especially for the fuel oil replacement.

Even though switching from LPG and fuel oil to mixed gas can be financially viable on its own and the government does not need to provide any financial support because the market will drive investment in this business, it still needs other supports from the government, such as:

1. Introducing hydrogen to prospective users and ensuring the security of supply.
2. Promoting domestic hydrogen production as well as hydrogen research and development. These will benefit the country in a number of ways, including lowering reliance on energy imports, reducing the loss of foreign currency, developing clean energy technologies in the country, as well as creating green businesses and jobs in the country. Priority should be given to low-carbon hydrogens, particularly blue hydrogen, which Thailand is capable of producing from domestic gas. Green hydrogen should also be focused on, as it is carbon-free and offers a sustainable option for the long term.
3. Developing the necessary infrastructure to support the growth

of industries that produce, store, transport, and use hydrogen in the energy sector, as well as those that trade hydrogen internationally.

4. Improving regulations and standards to support the supply and use of hydrogen throughout the value chain.

In addition to the industry, the government should consider the use of hydrogen in the electricity and transportation sectors, which are the other two energy-intensive sectors with large greenhouse gas emissions. Transitioning to clean energy in these sectors will enable the country to meet its climate targets and create a sustainable energy future.

5. FUNDING

This work is part of the project entitled "Policy recommendation on the promotion of commercial use of hydrogen in Thailand" under a funding of Energy Policy and Planning Office, Ministry of Energy, Thailand.

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