Modeling of Hydrogen Infrastructure for Fuel Cell Applications and Its Impact on Hydrogen Economic Era, Case Study in Semarang

Bayu Murti 1,a) Sulistyо 1,2) Jaka Aminata 1,3)
1. Master Program of Energy, School of Postgraduate Studies, Diponegoro University, Semarang, Indonesia
2. Department of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Semarang, Indonesia
3. Department of IESP, Faculty of Economic and Bisnis, Diponegoro University, Semarang, Indonesia

Abstract
The current global trend is a shift in the use of fossil energy to hydrogen, known as the "hydrogen economy". At present transportation (automotive) is looking for alternative fuels as a substitute for fuel oil. In addition to using electricity as a driving force, hydrogen fuel is used as one of the fuels which can also be considered an option. This study seeks to determine the profile of energy consumption in Semarang district starting from the transportation to a certain year. The output of this research is about hydrogen infrastructure and making possible steps for a decision by knowing the profile of energy consumption in Semarang. Finally it will be known the potential of hydrogen infrastructure development which can become a guideline in determining the right policy in carrying out hydrogen infrastructure development in Semarang. The capacity of hydrogen production in Semarang is approximately 1,000 m3 / hour. The production breakdown per day is: 550m3 / hour x 24 = 13,200m3. It can be maximized the production of hydrogen for 360 days per year is 4,752,000m3. The prediction of the hydrogen needs of 2020 in Semarang is 1,955,780 m3. Thus the production of hydrogen in Semarang can be fulfilled.

Keywords: hydrogen fuel, oil fuel, production, transportation, Semarang

DOI: 10.7176/JETP/10-3-04
Publication date: July 31st 2020

INTRODUCTION
Background research because air pollution has worsened in major cities around the world, so the use of car transportation must be limited and measures introduced to encourage clean vehicles[1]. The transportation sector is a major contributor to the emergence of global warming around 20% of greenhouse gas emissions caused by the transportation sector [2]. Hydrogen is an energy storage medium for electricity produced from renewable energy sources that makes important connections in the sustainable and emission-free energy chain from start to finish. Unlike fossil energy, hydrogen will not run out because hydrogen is the most common element found in nature. Hydrogen can be used both to produce electricity and as a fuel which makes it very suitable for stationary and mobile applications [1]. The current global trend is a shift in the use of fossil energy to hydrogen, known as the "hydrogen economy" [1]. One key to expanding alternative energy is to produce and introduce vehicles driven by energy sources other than petroleum fuels, such as hydrogen gas, so that each energy source is converted into electrical energy to drive a vehicle. Developing alternative energy diversification at the consumer level will prevent price increases and dependence on one fuel can be reduced [3].

Basic theory
Fuel cells are electrochemical cells that are similar to batteries, the difference is that the reactants consumed by fuel cells can be replenished continuously. Fuel cells produce electricity from outside hydrogen and oxygen supplies. Fuel cells are different from batteries where electricity is produced from internal energy. The electrodes in the battery react and change when the battery is charged or discharged, while the fuel cell electrode is catalytic and relatively stable[4]. Hydrogen needs infrastructure for distribution. [5].

RESEARCH METHODOLOGI
Case study was taken in Semarang. Semarang is also known as one of the metropolitan cities in Indonesia, where traffic congestion has always been a major problem in metropolitan cities. Based on data from DPAAD Semarang in 2014, the number of vehicles in Semarang reached 1,305,636. The number of vehicles in Semarang has also caused traffic jams in Semarang. The most prominent impact of the increasing number of vehicles in Semarang is increased air pollution.

RESULTS AND DISCUSSION
In 2014, energy consumption (Gj) in Semarang was calculated by the calculation below. We can see the calorie equation for joules can be written as:

\[ 1 \text{j} = 0,2388 \text{cal} \]  (1)
The calculation of energy in Gj in Semarang can be written as:

**Diesel fuel energy in 1 year**

1 liter of diesel fuel = 10,546 kcal
1 liter of diesel fuel = 44,145 Kj / liter

In Semarang, diesel fuel consumption within 1 year of 2014 was = 187,495 kl (Pertamina source).

Diesel fuel energy in 1 year is:

- diesel fuel energy in 1 year = 187,495 kl x 44,145 Kj / liter
- diesel fuel energy in 1 year = 8,276,966,775 Kj
- diesel fuel energy in 1 year = 8,276,966,775 Gj

**Premium energy in 1 year**

1 liter of Premium = 10,509 Kcal
1 liter of Premium = 43,990 Kj / liter

In Semarang the consumption of premium within 1 year in 2014 was = 349,448 kl Premium.

Premium energy in 1 year is:

- Premium energy in 1 year = 349,448 kl x 43,990 Kj / liter
- Premium energy in 1 year = 15,372,217,520 Kj
- Premium energy in 1 year = 15,372,217,520 Gj

**Pertamax energy in 1 year**

1 liter Pertamax = 10,622 Kcal
1 liter Pertamax = 44,463 Kj / liter

In Semarang, the consumption of Pertamax within 1 year of 2014 was = 16,804 kilo liters of Pertamax.

Pertamax energy in 1 year is:

- Pertamax energy in 1 year = 16,804 kl x 44,463 Kj / liter
- Pertamax energy in 1 year = 747,156,252 Kj
- Pertamax energy in 1 year = 747,156 Gj

Table 1 below shows a simulation of the rate of growth of fuel consumption in Semarang according to Public Relations of PT. Pertamina Marketing Operation Region (MOR) IV Central Java-DIY Jl. Pemuda No.114 is 0.3% per year, so the consumption of fuel oil in Semarang in 2014 to 2024 can be predicted using LEAP software. In 2014, diesel fuel energy in 1 year = 8,276,966,775 Gj. Premium energy in 1 year = 15,372,217,520 Gj. Pertamax energy in 1 year = 747,156 Gj. Total energy is obtained from the sum of the total diesel fuel, premium and Pertamax energy. Solar energy in 1 year = 8,276,966,775 Gj. Premium energy in 1 year = 15,372,217,520 Gj. Pertamax energy in 1 year = 747,156 Gj. After adding up the results were 24,396 Gj in 2014.

Table 1. Relationship between Energy needs in Semarang throughout the year and GJ units.

| Year | fuel oil (Gj) |
|------|--------------|
| 2014 | 24,396.0     |
| 2016 | 24,542.6     |
| 2018 | 24,690.1     |
| 2020 | 24,838.4     |
| 2022 | 24,987.7     |
| 2024 | 25,137.8     |

Infrastructure that might be built in Semarang.

Design data for hydrogen production from Samator Kec. Bambe, Kab. Gresik by Bp. Ponari, Hydrogen Plant division, and Bp. Sampoerno, as the leader are as follows:

1. Design capacity for hydrogen production in the samator with a cap. Design plant 1,000 m3 / hour. With a volume of 1m³ = 0.0810 kg, it will produce 81kg / hour. Production breakdown per day: 550 m3 / hour x 24 hours = 13,200 m3 or 1,069,2kg
2. General selling prices Estimated between Rp. 62,000 / m3
3. H2 tube trailer with Fill capacity @ 4,000 m3 with working pressure of 200 kg / cm2.

**Prediction if the vehicle is directed to hydrogen fuel**

Prediction if the vehicle is directed to hydrogen fuel with the calculation of a hydrogen heating value (HHV) of
12.7 MJ / m³ [6]. can be written as:

\[12.7 \text{ MJ/m}^3 = 12,700 \text{ KJ/m}^3\]  \hspace{1cm} (20)

\[1 \text{ m}^3 = 12.7 \text{ MJ} = 0.0127 \text{ GJ}\]  \hspace{1cm} (21)

With mathematical equations, the calculation will be obtained in Table 2. The relationship between energy needs in Semarang throughout the year is changed to m³, with 1 m³ = 12.7 MJ = 0.0127 GJ. can be written as table 2 below.

| Year | Energy Demand (GJ) | Energy Demand (m³) |
|------|---------------------|---------------------|
| 2014 | 24,396.00           | 1,920,945           |
| 2015 | 24,469.20           | 1,926,709           |
| 2016 | 24,542.60           | 1,932,488           |
| 2017 | 24,616.20           | 1,938,283           |
| 2018 | 24,690.10           | 1,944,102           |
| 2019 | 24,764.10           | 1,949,929           |
| 2020 | 24,838.40           | 1,955,780           |
| 2021 | 24,912.90           | 1,961,646           |
| 2022 | 24,987.70           | 1,967,535           |

| Year | Energy (m³) |
|------|-------------|
| 2014 | 1,920,945   |
| 2015 | 1,926,709   |
| 2016 | 1,932,488   |
| 2017 | 1,938,283   |
| 2018 | 1,944,102   |
| 2019 | 1,949,929   |
| 2020 | 1,955,780   |
| 2021 | 1,961,646   |
| 2022 | 1,967,535   |

**Figure 1.** Prediction of the amount of hydrogen used in Semarang. The x-axis writes the amount of hydrogen needed per m³, and the y-axis writes the year.

**Table 3.** Predictions of total hydrogen usage in Semarang.

| Year | Hydrogen (m³) |
|------|---------------|
| 2014 | 1,920,944,882 |
| 2016 | 1,932,488,189 |
| 2018 | 1,944,102,362 |
| 2020 | 1,955,779,528 |
| 2022 | 1,967,535,433 |
| 2024 | 1,979,354,331 |

The design capacity of hydrogen production in Samaror is 1,000 m³ / hour. Production breakdown per day: 550 m³ / hour x 24 hours = 13,200 m³. It can be maximized the production of hydrogen for 360 days per year is 4,752,000 m³. In 2020 based on table 2, hydrogen demand prediction in Semarang = 1,955,780 m³.

**Comparison of fuel and hydrogen costs**

In 2014, diesel fuel consumption in Semarang was = 187,495 kl of diesel fuel. In 2014, the use of premium in Semarang was 349,448 kl Premium. In 2014, the use of Pertamax in Semarang was = 16,804 kl Pertamax, then the total cost is as follows:

1. Diesel fuel 187,495 kl x Rp. 9,500 / l = Rp. 1,781,202,500,000
2. Premium 349,448 kl x Rp. 6,550 / l = Rp. 2,288,884,400,000
3. Pertamax 16,804 kl x Rp. 9,200 / l = Rp. 154,596,800

The total fuel costs in Semarang, if all added up are as follows:

\[\text{Rp.} \ 1,781,202,500,000 + \text{Rp.} \ 2,288,884,400,000 + \text{Rp.} \ 154,596,800 = \text{Rp.} \ 4,070,241,496,800\]  \hspace{1cm} (22)
From table 1, in 2020, fuel prediction in Semarang is 24,838Gj.

The total fuel costs of Semarang in 2014 divided by the total energy in 2014 are as follows:

\[
\text{Rp. 4,070,241,496,800 divided by 24,396 Gj = Rp. 166,840,527.} 
\]

The price of fuel per 1Gj = Rp. 166,840,527.-

The total cost of fuel in 2020 is the price of fuel per 1Gj multiplied by the total energy in 2020 with the following equation:

\[
\text{Rp. 166,840,527 x 24,838 Gj = Rp. 4,143,985,009,626.} 
\]

The price of 1Gj of hydrogen can be calculated by the calculation below.

1m³ of hydrogen = 0.0127Gj

1Gj = 1 / 0.0127 = 78.740m³

Price of 1Gj = 78.740m³ x Rp. 62,000

Price of 1Gj = Rp. 4,881,880

From table 1, the total hydrogen costs obtained in the city of Semarang in 2020 are:

\[
\text{Price of 1Gj hydrogen x total Gj hydrogen} \\
\text{24,838Gj x Rp. 4,881,880 = Rp. 121,256,135,440} 
\]

CONCLUSION
From this research it can be concluded that: 1. The design capacity of hydrogen production in samators is 1,000 m³ / hour. Details of production per day: 550m³ / hour x 24 hours = 13,200m³. Hydrogen production can be maximized for 360 days per year so total hydrogen production in Samator is 4,752,000m³. In 2020, predicted hydrogen demand in Semarang = 1,955,780 m³. The need for hydrogen if all vehicles are diverted with hydrogen by 2020 can be fulfilled. 2. predicted total fuel costs in 2020: Rp. 166,840,527 x 24,838 Gj = Rp. 4,143,985,009,626. - 3. Predictable total hydrogen costs in Semarang in 2020 = 1Gj price of hydrogen x total Gj of hydrogen. 24,838Gj x Rp. 4,881,880 = Rp. 121,256,135,440

Acknowledgments
The author gratefully acknowledge to Master Program of Energy, School of Postgraduate Studies, Diponegoro University, Semarang, Indonesia.

References
[1] Rosyid, Oo Abdul, *Infrastruktur hidrogen untuk aplikasi fuel cell dalam era ekonomi hidrogen*, Balai Besar Teknologi Energi (B2TE-BPPT), Kawasan Puspiptek Serpong, Tangerang, 2009.
[2] The World Bank, *Low-emission transport*, (http://www.worldbank.org/en/topic/transport/brief/low-emission-transport;, 2014.
[3] Liun Edwaren, *Analisis Keekonomian Bahan Bakar Produk Nabati dan Hidrogen Nuklir*. Pusat Pengembangan Energi Nuklir (PPEN) –BATAN, Jakarta, 2011.
[4] Matthew, Mench M., *Fuel Cell Engines*, Jhon Wiley & Sons, Inc., Hoboken, New Jersey. United States of America, 2008.
[5] Isdiriyani Nurdin, http://www.energi.lipi.go.id/, 2005.
[6] Fung Michele, fact, https://hypertextbook.com/facts/2005/MichelleFung.shtml, 2005.