VANOS
JOURNAL OF MECHANICAL ENGINEERING EDUCATION
http://jurnal.untirta.ac.id/index.php/vanos
ISSN 2528-2611, e-ISSN 2528-2700
Volume 9, Number 2, November 2024, Pages 218 - 233

Innovation of Aluminum Waste Fuel Stove

R Dwi Pudji Susilo[1,2,3], Mohamad Abror[4], Muhamad Fitri[5], M. Azizi[6], Dafit Feriyanto[7], Darwin Sebayang[8]

[1,5,6,7,8]Master of Mechanical Engineering Program, Mercu Buana University, Jakarta, Indonesia
Meruya Selatan Street No. 1, Joglo, Kembangan, RT.4/RW 1, Meruya Selatan, Kembangan
West Jakarta City, Special Capital Region of Jakarta 11650, Indonesia
[2,4]Automotive Light Vehicle Engineering, SMKN 1 Ciruas, Banten, Indonesia
Nambo Lebakwangi Street Km 2.5, Pulo Village, Ciruas, Serang Regency, Banten Province, Indonesia
[3]Sulthon Engineering and Education, Banten Province, Indonesia
Puri Citra Housing Complex Block E1 No. 20, RT026/RW 06, Pipitan, Walantaka
Serang City, Banten Province 42183, Indonesia

Corresponding author: rdwisusilo44@guru.smk.belajar.id

Received: 20 September 2024. Accepted: 12 November 2024. Published: 30 November 2024

ABSTRACT

Aluminum waste is a challenging material to manage due to its high production rate from households and industries. This study aims to repurpose aluminum waste into hydrogen gas, which can serve as an alternative fuel for gas stoves. Direct disposal of aluminum waste can lead to environmental damage; hence, this project focuses on developing a system that dissolves aluminum using sodium hydroxide (NaOH) to produce hydrogen gas in a tube reactor. This hydrogen is then used as stove fuel. The comparison between aluminum-fueled hydrogen and conventional fuels, such as Pertalite and LPG, suggests that aluminum waste has potential as a cost-effective fuel source. For instance, one liter of Pertalite at Rp. 10,000 powers a motorbike for approximately 30 km, translating to Rp. 1,428 for a similar distance with aluminum-derived fuel. A 3 kg LPG cylinder costs around Rp. 24,000 and provides 10 hours of fuel, whereas hydrogen produced from aluminum can be cheaper if sourced from waste. Additionally, this design incorporates a refillable reactor that sustains hydrogen supply during combustion, ensuring consistent stove operation. The system is portable, safe, and offers high mobility, making it practical for various applications. This approach not only reduces aluminum waste but also presents an affordable alternative fuel solution, enhancing environmental sustainability.

Keywords: Aluminum Waste Management, Hydrogen Production, Alternative Fuel, Portable Hydrogen Reactor, Renewable Energi

INTRODUCTION

Currently, the primary global energy sources are fossil fuels, specifically natural gas, petroleum, and coal [1]. These fossil fuels originate from the decomposition of organic remains of plants and animals, a process that takes thousands to millions of years [2]. As such, fossil fuels are non-renewable and vulnerable to depletion [3]. In Indonesia, the demand for liquefied petroleum gas (LPG) continues to increase, thereby driving overall fuel demand upwards [4]. With economic growth across various sectors, such as industry, households, commerce, and transportation, as well as population growth, the country's energy needs are steadily rising [5].

According to Indonesia's Ministry of Energy and Mineral Resources (ESDM), national oil reserves are projected to last only about 9.5 more years, with natural gas reserves estimated to be depleted in the next 19.9 years if no new reserves are discovered [6]. Additionally, fossil fuel consumption results in significant carbon dioxide emissions, which have been a major contributor to climate change [7]. Data indicates that carbon dioxide emissions have driven climate change significantly from 1750 to 2005 [8]. In response to these challenges, the Indonesian government has set a target to increase renewable energy use to 23% by 2025 and 31% by 2050, as outlined in Government Regulation No. 79 of 2014 concerning the National Energy Policy (KEN) [9]. However, the country's renewable energy utilization remains slow, with only around 11.31% realized in 2020 [10]. Consequently, developing renewable energy solutions has become crucial to ensure a sustainable energy future for Indonesia.

Aluminum waste presents a promising opportunity as an alternative energy source due to its unique properties: it is easily molded, has excellent thermal conductivity, is lighter than steel, and can be recycled into renewable energy [11][12]. In this context, aluminum waste demonstrates significant potential as an alternative energy source [13]. When processed with a base catalyst (NaOH) and mixed with water, aluminum waste can produce hydrogen gas, a renewable and environmentally friendly energy source [14]. This hydrogen gas can be used for various applications, including as fuel for stoves [15]. This hydrogen gas can be harnessed as fuel, including for gas stoves [15]. Studies also estimate that the global surplus of aluminum waste will reach 5.4 million tons by 2030 and 8.7 million tons by 2040 if current sorting and recycling methods are not improved [16]. This emphasizes the need for innovative approaches to aluminum waste management to both mitigate the surplus and harness its potential as a renewable energy source.

This study aims to develop an aluminum waste-fueled stove, comprising several components: a hydrogen-generating reactor, a storage tank, and a stove unit compatible with conventional LPG stoves. Through this development, the goal is to provide a practical solution for reducing dependency on fossil fuels while supporting Indonesia's renewable energy targets in line with national energy policies. Thus, this innovation is expected to contribute to the provision of a more environmentally friendly and sustainable energy alternative.

RESEARCH METHOD

Research Methodology

This research employs a design and build research framework, focusing on developing an aluminum waste-fueled stove prototype. The design process utilizes the approach outlined by Pahl and Beitz, aiming to create a functional product that meets user needs, as described in *Engineering Design: A Systematic Approach* [17]. This method involves four main stages:

The Pahl and Beitz design method consists of 4 activities or phases, each consisting of several steps. The four phases are:

1. Planning and Task Clarification: Identifying design requirements and defining tasks for developing the aluminum waste-fueled stove. This phase includes analyzing the problem, with a primary focus on fuel efficiency and user safety.
2. Product Concept Design: Developing and evaluating multiple conceptual alternatives. This phase establishes desired specifications by selecting the design that best fulfills functional and safety requirements.
3. Embodiment Design: Detailing the physical form and main components, including material selection and structural optimization. Initial sketches, both manual and CAD-based, are created to visualize the prototype.
4. Detailed Design: Creating technical drawings and specifications, with specific attention to calculations, material selection, and technical details that ensure functionality and safety. The final prototype is then tested to verify its performance aligns with the established standards.

These four stages are further illustrated in the Research Methodology Flowchart

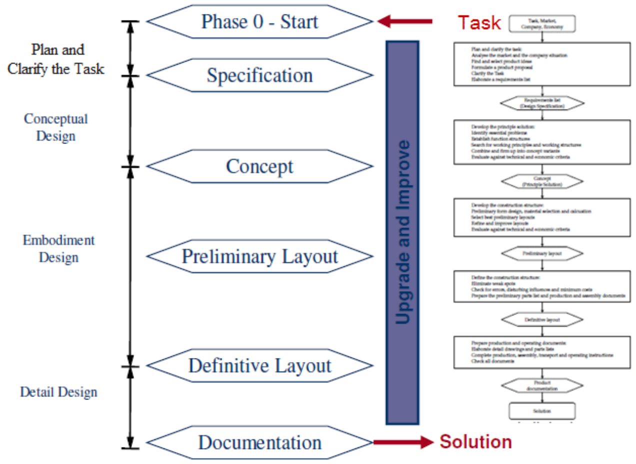

Figure 1. Research methodology flowchart (Source: Created by Pahl and Beitz [17]**).**

Research Sample

The aluminum waste-fueled stove prototype serves as the primary test object in this research. The testing focuses on product characteristics, particularly combustion performance and operational safety. Aluminum waste, used as the primary fuel, serves as the main variable to test the stove's combustion efficiency and durability.

Data Collection

Collected data includes:

1. Fuel Composition: Aluminum waste is combined with other substances to enhance combustion performance.
2. Combustion Duration: Burn time is measured using a stopwatch to evaluate fuel efficiency.
3. Operating Pressure: Pressure is monitored using a gauge to ensure the system operates at safe and optimal levels.
4. Flame Characteristics: The intensity and stability of the flame are observed and recorded under working conditions.

Data is gathered through a series of trials in a laboratory setting and is analyzed quantitatively to assess product performance.

Tools and Instruments

The primary tools in this research include:

1. Welded Reactor: Reactor components are welded to prevent leakage, given hydrogen's light and volatile properties.
2. Pressure Gauge: Equipped with a manometer to monitor pressure within the reactor.
3. Storage Tank: Designed with an outlet to safely contain fuel.
4. Burner: The burner component is designed to ensure a stable flame, with ignition performed after optimal pressure is achieved by adding water and NaOH to the reactor.

To ensure safety, all joints are thoroughly inspected to confirm there are no gaps or leaks that could affect operating pressure.

Research Flowchart

Figure 3 shows the research flowchart, detailing the process from design to final testing. This process includes:

1. Initial Design – Creating design sketches, either manually or with CAD software.
2. Assembly of Tools and Materials – Preparing materials and welding reactor components to avoid leaks.
3. System Testing – Connecting the prototype to the burner and activating the aluminum fuel in the reactor with a mixture of water and NaOH until optimal pressure is reached.
4. Data Collection – Systematically recording data on fuel composition, burn duration, pressure, and flame output.

Input & Output Flow Diagram

Figure 4 illustrates the input-output process, detailing the transformation of aluminum waste into hydrogen gas for practical applications.

Concept Design

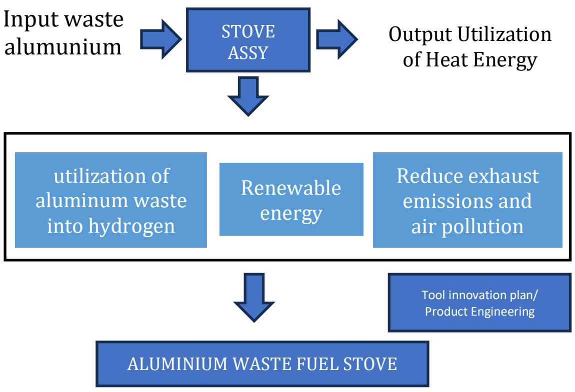

Figure 2. Input and output diagram (Source: Created by author)

Research Tools and Materials

This research utilized the following equipment: welding machine, drilling machine, hand grinder, mechanical caddy tool, aluminum waste material, water, NaOH, iron pipe, angle iron (4x4 cm), pipe cap, elbow, hose, empty refrigerant tube, stop valve, one-way valve, stainless steel clamp, burner, pressure gauge, and regulator.

RESULT AND DISCUSSION

Previous Tool Specifications

From the previous researcher's design [18], entitled "Design of an aluminum foil reactor for hydrogen gas as an alternative energy source".

The following are the specifications of the previous equipment:

1. Reactor
2. Storage tube
3. Burner/stove

Identify Previous Equipment Problems

From the specifications of previous tools or tools that have been designed previously, the following problems were found:

1. From previous research only designed a reactor that is large and not easy to carry and requires a large area [19]. Dimensions of 70 cm x 60 cm indicate less portable or not easy to move or carry.
2. The reactor design is less able to refill and dispose of the remaining residue of the chemical reaction process, Thus, the product is less environmentally friendly [20].
3. Installations that are not easy to refill, or are difficult to fill or make gas Thus, the product becomes inefficient [21].
4. The chemical process uses KOH, which is sometimes rarely available on the market compared to NaOH. According to [22], the availability of raw materials is a preventive measure against shortages that could disrupt the production process.
5. There are no pressure gauges on the reactor and tubes, as a control and safety. Whereas safety is one of the main factors of consumer trust in the product [23].

From the existing design, the next step is to determine the solution principles to be used next.

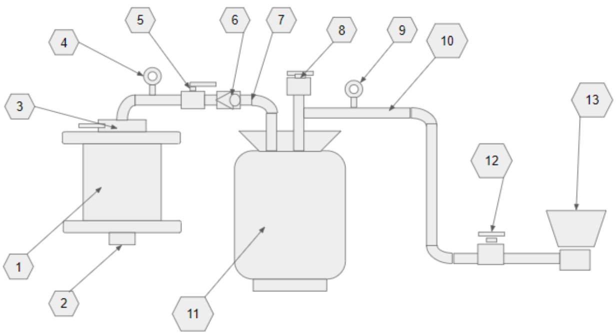

Figure 3. Design drawings of the tool and its installation (Sources: Created by author)

Design of aluminum fuel stove component parts:

1. Reactor
2. Drain
3. Top cover
4. Pressure gauge
5. Stop valve
6. One-way valve
7. Hose
8. Stop valve on storage tank
9. Pressure gauge on storage tank
10. Hose
11. Storage tube
12. Stove regulator
13. Burner/Furnace

Table 1. Image caption 3 components and materials

No	Name	Amount	Material	Note
1	Reaktor	1	Iron pipe and iron flange	
2	Drain	1	Galvanized iron elbow & cap	
3	Top cover	1	Galvanized iron cap	
4	Pressure gauge	2	Iron	0-6 bar
5	Stop valve	2	Brass	
6	One-way valve	1	Iron	
7	Hose	1	Rubber	20 bar
8	Stop valve on storage tank	1	Brass	
9	Pressure gauge storage tube	2	Iron	0-6 bar
10	Hose	1	Rubber	20 bar
11	Storage tube	1	Iron plate	
12	Stove regulator	1	Iron	
13	Burner/ furnace	1	Brass	
14	Klem	12	Stainless steel	

Table 2. Stove specifications

No	Name	Note
1	**Stove Making Materials**	
	Reaktor	stpg iron pipe
	Drain	Iron
	Top Cover	Iron
	Pressure gauge	Iron
	Stop Valve	Brass
	One-way valve	Brass
	Hose	Fibrous rubber
	Storage tube	1 mm iron plate
	Regulator stove	Iron
	Burnner/Furnace	Brass
	Clamp	Stainless steel
	Brackets to hold the reactor and tubes	4cmx4cm angle iron
2	**Dimension Stove**	
	Reaktor	ø 8 cm , h = 21 cm
	Drain	2,5 cm
	Top cover	5 cm
	Pressure gauge	4 cm
	Stop Valve	1/4" /0,63 cm
	One-way valve	1/4" /0,63 cm
	Hose/Hose asetilin	in 0,6-1,3 cm
	Storage tube	ø 23 cm, h = 32 cm
	Regulator Stove	ø 6cm x 6 cm
	Burner/Furnace	ø 6cm x 10 cm
	Clamp	0, 63 cm - 2,54 cm

	Brackets to hold the reactor and tubes	30cmx44cmx42cm
3	**Fuel**	
	Aluminium	Waste al
	Water	300 ml
	NaoH	Customized
4	**Flame**	
	The resulting flame	white
	Maximum pressure	4,88 bar
	Maximum temperature (°C)	1050°C

Finding Solution Principles

After finding the shortcomings of the previous tool, the next step is to look for solutions to existing problems so that further development can be carried out.

CONCEPT DESIGN

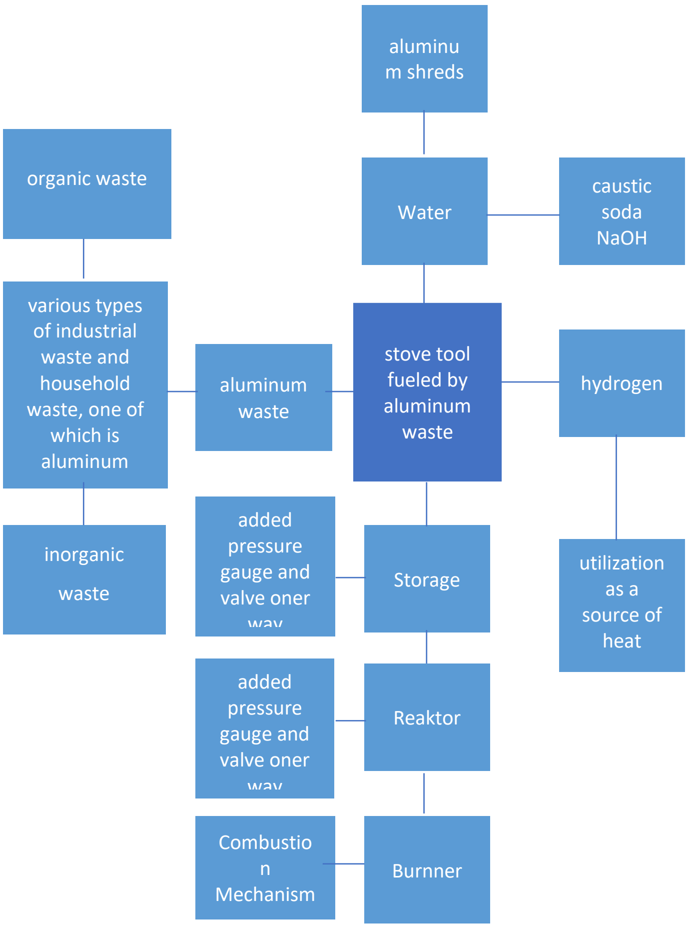

Figure 4. Flowchart of design concept for stove using aluminum waste fuel (Sources: Created by author)

Tool Development and Design

1. The dimensions are designed to be smaller so that it is easy to carry, while still being safe to use. With a portable design, production costs can be reduced [24].
2. The reactor design is designed so that it can be opened and closed and disposed of when the process is complete but can be refilled so that the hydrogen gas production process can continue, Thus, it can make the consumers more comfortable in using it [25].
3. The installation is made so that the flow entering the tube can be removed or closed so that it can create a reaction or reprocess the gas without disrupting the ongoing process of filling or making gas.
4. The chemical process uses NaOH which is widely available on the market.
5. The cylinder design in figure 3 is equipped with a pressure gauge (4), stop valve (5), and one-way valve (6).

The dimensions of the reactor and storage tube are combined in one bracket measuring 30 cm x 44 cm x 42 cm. while the burner is outside the bracket for easy use. The reactor when separated has a diameter of 8 cm, a total height of 21 cm, a cover of 5 cm, and a drain of 2.5 cm. Hydrogen storage tank diameter 23 cm, height 32 cm, equipped with pressure gauge, ¼" stop valve. The hose or hose uses an acetylene welding hose that has a pressure size of 20 bar/2 Mpa, 6-13 mm, ISO 3821.

Evaluation of Technical and Economic Sides

Technical Review:

1. It is hoped that the designed device will produce hydrogen gas faster due to the addition of a cap, drain, and valve, along with a portable design that increases its flexibility [26].
2. The tool designed is expected to allow the reactor tube to be removed or separated from other components when the pressure has been met and you want to refill or close some parts of the system.
3. It is hoped that tools with a simpler installation design will be able to reduce production time, thus making the production process smoother [27].
4. The designed tool is expected to meet safety and environmentally friendly aspects, thereby increasing its market value [28].
5. The manufacturing materials can use reusable materials as an implementation of environmentally friendly products [29], such as pipes used in reactors, and storage tubes can be made from modified refrigerant tubes using a drill and welded by adding nipples .

Study from an economic perspective:

1. By using the new equipment, it is hoped that production costs can be reduced. By reducing production costs, the product can be sold at a lower price and reach a wider audience [30].
2. The tool has been modified and is expected to be able to provide gas for burning the stove
3. The new tool is expected to increase hydrogen gas production
4. The burner or stove part can be used from an LPG gas stove so it is compatible with pliers already on the market so it makes it more economical, just make a reactor and storage tube and the installation can be used.

Product Development

The development of the aluminum waste fuel stove employs two fundamental approaches, namely: Fundamental approach and Reverse engineering.

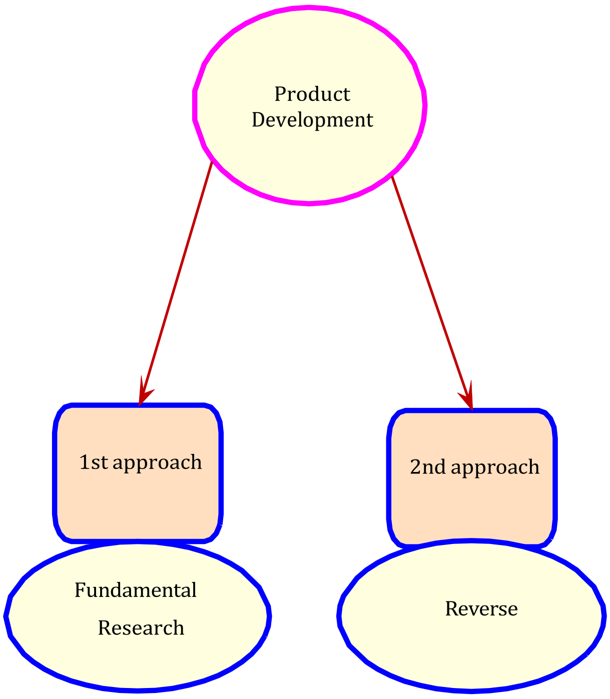

Figure 5. Product development approach
(Sources: Created by author)

1. Fundamental approach
2. Reverse engineering

This approach to innovative aluminum waste fuel stoves uses *Fundamental Approach*. According to [31] product development, it is important to pay attention to the needs and fundamental problems of the consumers.

Testing Aluminum Fuel Stoves

Table 3. Test results for stove materials

Test	Waste AL	Na OH	Water (ml)	Pressure (bar)	Price (Rp)	Time (minute)	Max Temp
1	10 gr	20 gr	300	2,54	660	8	*525 °C*
2	10,5 gr	3- gr	300	2,98	945	8,53	529 °C
3	11 gr	35 gr	300	**3,44**	1090	9,02	534 °C
4	11,5 gr	40 gr	300	**3,90**	1235	9,45	539 °C
5	12 gr	45 gr	300	**3,38**	1380	10,03	543 °C
6	12,5 gr	50 gr	300	**4,88**	1525	10,5	548 °C

Effect of Temperature/Temperature on Time

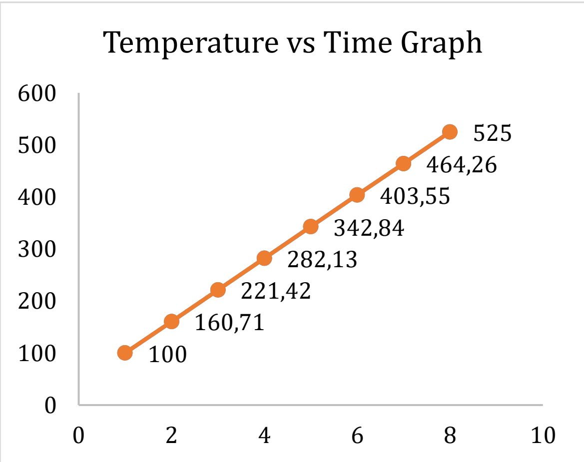

Figure 6. Graph of temperature against Test time 1 (Sources: Created by author)

From the results of the first test, the heat transfer rate was compared with the time, the data was 60.71 °C/minute, the ignition time was 8 minutes, the max was 525 °C. The calculation of the heat transfer rate is as follows:

Heat transfer rate = $\Delta T/Dt$

Where

ΔT	=	*Temperature Changes*
Δt	=	*Time changes*
ΔT	=	*T2-T1*
Δt	=	*x2-x1*
ΔT	=	*525 – 100 = 425 °C*
Δt	=	*8 – 1 = 7 minutes*

Heat transfer rate = 425/7 = 60,71 *°C/min*

Effect of Pressure on Temperature/Temperature

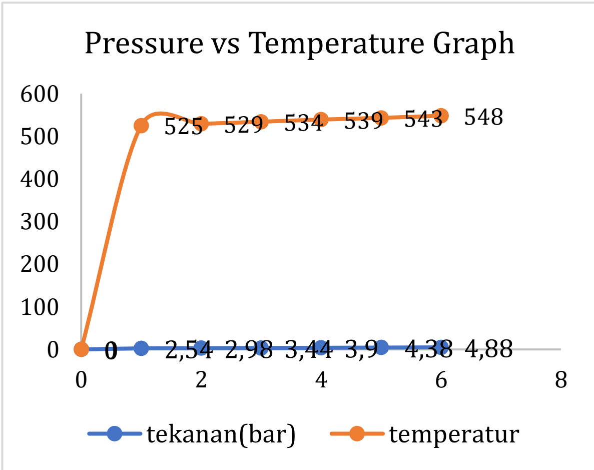

Figure 7. Pressure versus temperature graph (Sources: Created by author)

To find the ratio between pressure and temperature in this situation, we can use the ideal gas law, expressed by the equation:

$PV = nRT$

Where:

P is the absolute pressure (in pascals)

V is the volume of the gas

N is the number of moles of gas

R is a universal gas setting

T is the absolute temperature in kelvin

We want to find the ratio of pressure to temperature, so we can use another form of the ideal gas law:

T1P1=T2P2

Where 1P1 and 1T1 are the first pressure and temperature, and 2P2 and 2T2 are the second pressure and temperature.

If we use the appropriate units, we can structure this equation as follows:

T1P1=T2P2

Then we can construct this equation with the given values. Keep in mind that the temperature should be in kelvin. So, we need to convert the temperature from degrees Celsius to kelvin by adding 273.15:

T1 = 525+273.15=798.15

P2 = 2.54bar×100,000Pa/bar=254,000Pa

Then we determine the given value:

P2 = ?Pa

T2 = ?K

Using the equation:

T1P1=T2P2

we can find the values of P2 and T2.

From the equation T1P1=T2P2, we can solve for P2 and T2:

P2=T1T2·P1

Using the given values:

P2 = 798.15T2·254,000

To find the value of T2, we can construct the ideal gas equation:

P1V1/T1 = P2V2/T2

Since we have no information about the volume, we cannot solve this equation without additional information. However, we can construct the equation for T2 as follows:

T2 = P1P2T1

Substitute the P2 value from the previous equation:

T2 = 254,000(T2/798.15)·254,000·798.15

Next, we can solve these equations for P2 and T2. Let's do the math:

The results are P2≈254,000Pa and T2≈798.15K.

Effect of Time on Fuel Consumption

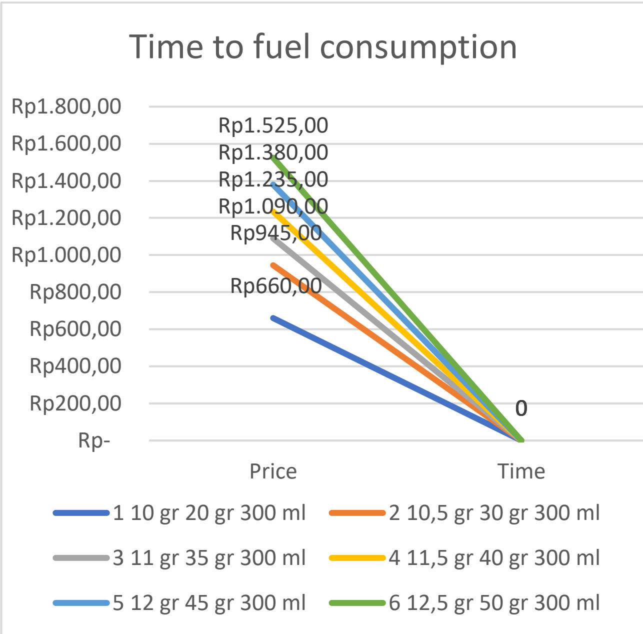

Figure 8. Time versus fuel consumption graph (Sources: Created by author)

Table 4. Price table for Aluminum and NaOH waste

Material	Quantity (gr)	Price (Rp)
Aluminium	1	10
NaOH	1	28

From the graph and table above, it can be seen that the longer or longer the duration of use, the more fuel will be used. From table 3, it can be seen from the first test reaction that 10 grams of Al mixed with 20 grams of Naoh and 300 ml of water produces a pressure of 2.54 bar and a duration of 8. minutes with a maximum temperature of 525^{0}C with a price of Rp. 660. And the 6th test with 12.5 gr Al, 50 gr NaOh, 300 ml Water, produces a hydrogen pressure of 4.88 bar, duration 10.5 minutes, price Rp. 1,525

Chemical Reactions in Reactors

In the reactor room temperature, aluminum reacts with water to form aluminum hydroxide and hydrogen as follows:

$$2Al_{(s)} + 6H_2O_{(1)} \qquad 2Al(OH)_{3(s)} + 3H_{2(g)}$$

The reaction between aluminum and water with Sodium Hydroxide (NaOh) for hydrogen production can be shown in the following reaction:

$$2Al + 6H_2O + 2NaOH \qquad 2NaAl(OH)4$$

$$NaAl(OH)_4 \qquad NaOH + Al(OH)_3$$

The reaction that takes place is:

$$\mathbf{2Al + 6H_2O \qquad 2Al(OH)_3 + 3H_2}$$

Morphology Chart

No	Component	Sub. Function	Items	alternative			
1	reactor	As a place for chemical reactions at, water, NaOh	Material	Stainless steel	Stainless steel	alloy	Carbon steel
			Shape	cylindrical	cylindrical	Cubic	Spherical
			Thicknees geometry	10 mm Diameter 5x200mm	10 mm Diameter 5x200mm		
2	storage tube	as a place to store hydrogen from the reactor	Material	Cast iron	Stainless steel	Alloy	Carbon steel
			Shape	Pipe tube	cylindrical	Cubic	spherical
			Thicknees	1 mm	2 mm	3 mm	
			Geometry	Diameter 3x			
3	Bunner	Place of fire	Material	copper	brass	Cast iron	
			Geometry	Pipe Tube	cylindrical	Cubic	Spherical

Figure 9. Morphology Chart (Sources: Created by author)

Note: the one chosen is colored brown to design this stove, you need a morphology chart to make it easier to select the materials and design to be used.

Objective Tree

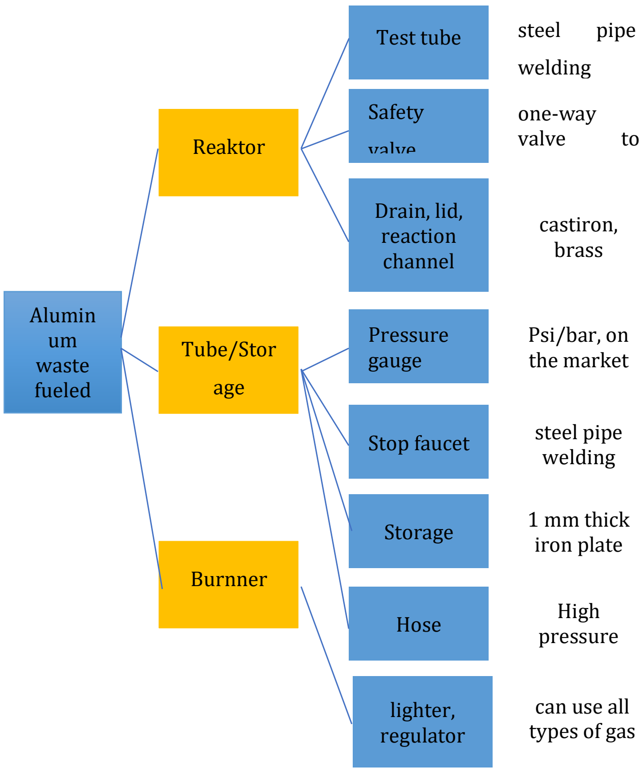

Figure 10. Objective tree (Sources: Created by author)

The Objective Tree in this tool is used to trace from the beginning of the concept so that in the end you can see the reasons for choosing materials/specifications in developing the tool that has been designed.

Weighting the Impact of Development on Tools

Next, determine the weighting value for the impact of tool development as follows:

Table 5. Weighting

Hydrogen	Portable	Refillable	Robust
Quality	80%	80%	80%
Quantity	80%	90%	80%
Mobility	90%	90%	70%
Production time	80%	90%	80%
Safety	80%	80%	80%
	410%	430%	390%

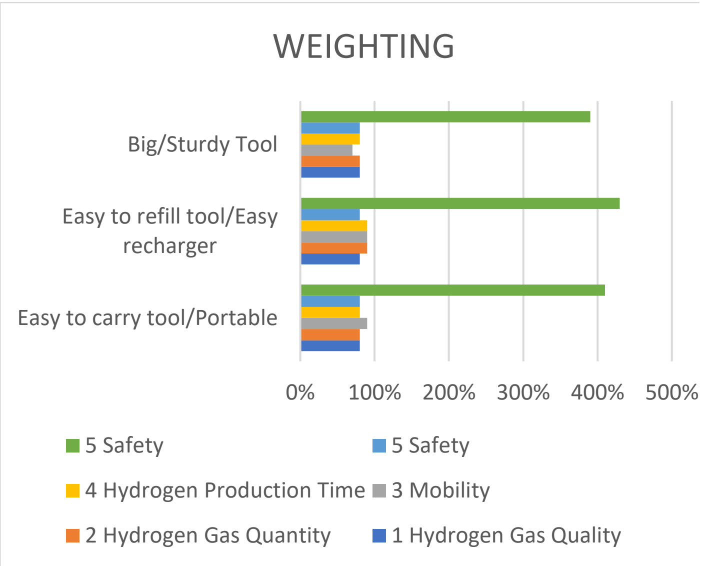

Figure 11. Weighting Chart
(Sources: Created by author)

Based on the weighting percentage of the design, the stove is designed to be easy to refill and reprocess in the reactor, ensuring a continuous supply of gas. Its size is not too large, making it portable and easy to place without taking up too much space. Additionally, the stove is designed for good mobility and portability. Most importantly, safety for the user and workplace safety for others are prioritized.

CONCLUSION

Based on the comparative analysis, the stove powered by aluminum waste has a cost that is nearly equivalent to using pertalite in vehicles. In 10 minutes, a vehicle can cover a distance of approximately 5-7 km, with a cost of pertalite around Rp 1,428 per kilometer. Regarding the use of LPG, assuming a 3 kg gas cylinder is used continuously for 10 hours, it incurs a cost of about Rp 400 in 10 minutes. Although the cost of hydrogen fuel from aluminum is slightly cheaper, at around Rp 50, subsidized LPG remains more economical. However, if unused aluminum waste is utilized, the fuel cost can be significantly lower. This reactor design is created to be easily refillable, possesses high mobility, and, most importantly, ensures safety for the user. The primary focus of this design is to guarantee a continuous supply of hydrogen during the combustion process, with a storage tank and stove installation that are simple, portable, and safe.

REFERENCES

[1] N. A. Sasongko *et al.*, *Teknologi Energi Fosil*. Bogor: Unhan RI press, 2023.

[2] P. Siagian *et al.*, *Energi Baru Terbarukan Sebagai Energi Alternatif*.

2023.

[3] R. R. Al Hakim, “Model Energi Indonesia, Tinjauan Potensi Energi Terbarukan untuk Ketahanan Energi di Indonesia: Sebuah Ulasan,” *ANDASIH J. Pengabdi. Kpd. Masy.*, vol. 1, no. 1, 2020, doi: 10.57084/andasih.v1i1.374.

[4] Juliza Hidayati and Jeffrey Panama, “Tinjauan Permintaan Gas Global dan Distribusi LPG di Indonesia: Studi Pustaka,” *Talent. Conf. Ser. Energy Eng.*, vol. 2, no. 3, 2019, doi: 10.32734/ee.v2i3.757.

[5] I. M. Setiabudi, G. Kartikasari, and W. Kusumaningrum, “Membangun Ketahanan Energi & Komitmen Global Melalui Formulasi Standar Energi Baru,” *STANDAR Better Stand. Better Living*, vol. 3, no. 1, pp. 13–17, 2024.

[6] A. Falathi and A. Adiwardhana, “Laporan Kinerja Kementrian ESDM 2021,” 2021.

[7] S. Ainurrohmah and S. Sudarti, “Analisis Perubahan Iklim dan Global Warming yang Terjadi sebagai Fase Kritis,” *J. Phi J. Pendidik. Fis. dan Fis. Terap.*, vol. 3, no. 3, p. 1, 2022, doi: 10.22373/p-jpft.v3i3.13359.

[8] C. Luo and D. Wu, “Environment and economic risk: An analysis of carbon emission market and portfolio management,” *Environ. Res.*, vol. 149, pp. 297–301, 2016, doi: https://doi.org/10.1016/j.envres.2016.02.007.

[9] PP No. 79, “PP No. 79 Thn 2014.pdf.” pp. 1–36, 2014.

[10] A. E. Setyono and B. F. T. Kiono, “Dari Energi Fosil Menuju Energi Terbarukan: Potret Kondisi Minyak dan Gas Bumi Indonesia Tahun 2020 – 2050,” *J. Energi Baru dan Terbarukan*, vol. 2, no. 3, pp. 154–162, 2021, doi: 10.14710/jebt.2021.11157.

[11] L. Hakim and I. Marsalin, “PEMANFAATAN LIMBAH ALUMINIUM FOIL UNTUK PRODUKSI GAS HIDROGEN MENGGUNAKAN KATALIS NATRIUM HIDROKSIDA (NaOH),” *J. Teknol. Kim. Unimal*, vol. 6, no. 1, p. 68, 2018, doi: 10.29103/jtku.v6i1.470.

[12] W. P. H. Siregar, M. Fawaid, and D. H. Abizar, “Pengaruh Penggunaan Reflektor Dan Pendingin Pasif Untuk Mengoptimalkan Daya Keluaran Pada Modul Surya,” *J. Sains dan Teknol.*, vol. 21, no. 2, pp. 52–58, 2022.

[13] F. Ramayanti, R. Junaidi, and I. Purnamasari, “PRODUKSI GAS HIDROGEN MENGGUNAKAN ALUMINIUM DARI LIMBAH KALENG MINUMAN DENGAN KATALIS NATRIUM HIDROKSIDA (NaOH),” vol. 5, no. September, pp. 54–62, 2024.

[14] S. Wahyuni, L. Hakim, and F. Hasfita, “Pemanfaatan Limbah Kaleng Minuman Aluminium sebagai Penghasil Gas Hidrogen menggunakan Katalis Natrium

Hidroksida (NaOH)," *J. Teknol. Kim. Unimal*, vol. 2, no. November, pp. 31–42, 2017.

[15] Muthaharussayidun, S. Anis, and W. Aryadi, "Uji Produksi Gas Hidrogen Melalui Elektrolisis Plasma Air Laut Dengan Katalis Koh Dan Zat Aditif Etanol," *J. Inov. Mesin*, vol. 1, no. 1, pp. 14–21, 2019, doi: 10.15294/jim.v1i1.40222.

[16] S. Van den Eynde *et al.*, "Forecasting global aluminium flows to demonstrate the need for improved sorting and recycling methods," *Waste Manag.*, vol. 137, pp. 231–240, 2022, doi: https://doi.org/10.1016/j.wasman.2021.11.019.

[17] P. G and B. W, *Engineering Design; A systematic Approach*. 1988.

[18] Kahar, "DESAIN REAKTOR ALUMINIUM FOIL GAS HIDROGEN SEBAGAI SUMBER ENERGI ALTERNATIF," *J. Pertan. terpadu*, 2016.

[19] A. Pratama, B. Basyirun, Y. W. Atmojo, G. W. Ramadhan, and A. R. Hidayat, "Rancang Bangun Kompor (Burner) Berbahan Bakar Oli Bekas," *Mek. Maj. Ilm. Mek.*, vol. 19, no. 2, p. 95, 2020, doi: 10.20961/mekanika.v19i2.42378.

[20] E. A. P. Utama and E. Komara, "Faktor yang Mempengaruhi Minat Pembelian Produk Ramah Lingkungan (Studi Kasus pada Gen Z di Jabodetabek)," *J. Ekon. Manaj. dan Perbank. (Journal Econ. Manag. Banking)*, vol. 7, no. 3, p. 90, 2022, doi: 10.35384/jemp.v7i3.259.

[21] W. Widyastuti, E. Suparti, and A. E. Tontowi, "Pemetaan Efektivitas dan Efisiensi Metode Desain Produk: Telaah Pustaka," *Tekinfo J. Ilm. Tek. Ind. dan Inf.*, vol. 12, no. 2, pp. 79–96, 2024, doi: 10.31001/tekinfo.v12i2.2277.

[22] D. Sudiantini *et al.*, "PENGARUH PENGENDALIAN PERSEDIAAN BAHAN BAKU TERHADAP KELANCARAN PROSES PRODUKSI," *J. Ekon. Manaj. Pariwisata dan Perhotelan*, vol. 1, no. 3, pp. 283–288, 2022, doi: 10.55606/jempper.v1i3.615.

[23] N. Nador, N. Hiayati, and M. Rizal, "Pengaruh Kualitas Produk ,Harga Produk Dan Keamanan Produk Terhadap Keputusan Pembelian," *Ris. Manaj. Prodi Manaj.*, pp. 89–101, 2018.

[24] M. E. Nazarudin and A. Suryadi, "Pengembangan Produk Wastafel Portable Secara Manual Dengan Metode Design for Manufacture and Assembly (Dfma)," *Juminten*, vol. 2, no. 2, pp. 36–47, 2021, doi: 10.33005/juminten.v2i2.228.

[25] S. Ma'ruf, "Pengaruh Kemudahan Penggunaan, Kegunaan, Persepsi Risiko, Dan Kenyamanan Terhadap Sikap Konsumen Dalam Belanja

Online (Studi Pada Toko Online Lazada.com," *J. Fak. Ekon.*, no. 3, pp. 535–549, 2018.

[26] M. R. Dzakwan, M. R. Wijaya, and M. R. Qinthara, "Analisis Perbandingan Efisiensi Penggunaan Gas pada Kompor Gas Portabel dengan Kompor Gas Konvensional," *J. KMTM Akad. UNS*, 2020.

[27] D. T. Pratama and H. S. Kurniawan, "Optimasi Masalah Penugasan Menggunakan Metode Hungarian untuk Meminimalkan Waktu Produksi," *Bull. Appl. Ind. Eng. Theory*, vol. 1, no. 1, pp. 16–20, 2020.

[28] H. N. Hanifah, N. Hidayati, and R. Mutiarni, "Pengaruh Produk Ramah Lingkungan/Green Product Dan Harga Terhadap Keputusan Pembelian Produk Tupperware," *JMD J. Ris. Manaj. Bisnis Dewantara*, vol. 2, no. 1, pp. 37–44, 2019, doi: 10.26533/jmd.v2i1.345.

[29] M. Taufiqurrohman and M. Yusuf, "Pemanfaatan Energi Terbarukan dalam Pengolahan Daur Ulang Limbah," *J. MENTARI Manajemen, Pendidik. dan Teknol. Inf.*, vol. 1, no. 1, pp. 46–57, 2022, doi: 10.34306/mentari.v1i1.141.

[30] A. Henri Slat, "Analisis Harga Pokok Produk Dengan Metode Full Costing Dan Penentuan Harga Jual," *110 J. EMBA*, vol. 1, no. 3, pp. 110–117, 2013.

[31] F. Husniar, T. R. Sari, A. M. Safira, and E. R. Kamila, "Strategi Pengembangan Produk Baru Sebagai Upaya Dalam Meningkatkan Daya Saing Perusahaan," *J. Ris. Manaj. dan Akunt.*, vol. 3, no. 2, pp. 22–34, 2023, doi: 10.55606/jurima.v3i2.2156.