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A Comprehensive Review of Alternative Fuels for Automobiles: Benefits, Challenges and Future Direction

N. Enoma, I. Inikori O., C.C. Kwasi-Effah, A. Charles, P. D. Ovuru., B.K. Aduwenye
Department of Mechanical Engineering, University of Benin, P.M.B 1154, Benin City, Nigeria

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Abstract

There is an increase in research to encourage the usage of alternative fuels in automobiles due to the depletion of oil sources and certain environmental concerns. Some fuel sources will stand out in this regard with particular benefits, while others will not. Choosing the alternative fuel source that is best for automobiles in the present environment is essential, and understanding the characteristics of various forms of energy is also very essential for recommending an alternative fuel. In this paper, a comprehensive review is carried out on existing literature on the benefits, drawbacks, environmental impact, effects on human health, availability, and economic implications of alternative fuels. This was to determine the fuel that is most cost effective for use in automobiles. The alternative energy sources for vehicles considered are LPG, CNG, hydrogen, biodiesel, methanol. The study reveals that hydrogen is most expensive alternative fuel, followed by biodiesel, methanol, ethanol, compressed air, natural gas, propane, and electricity. The cost of hydrogen is due to the high cost of producing it, as it requires a lot of energy. The study concludes that while there is no one-size-fits-all solution, a combination of alternative fuels can provide a path towards reducing dependence on fossil fuels and mitigating the negative impacts of transportation on the environment. The research highlights the need for investment in research and development and supportive policies and infrastructure, to accelerate the transition towards a cleaner and more sustainable transportation sector.

1.0. Introduction

Fossil fuels, such as gasoline and diesel, have been the primary source of energy for transportation for many decades. However, the extraction, refinement, and use of these fuels have significant environmental impacts. The burning of fossil fuels releases carbon dioxide (CO_2) and other greenhouse gases into the atmosphere, which contribute to global warming and climate change. The transportation sector is one of the largest contributors of CO_2 emissions globally, accounting for nearly 25% of total emissions [1-3].
In addition to emissions from the combustion of fossil fuels, the extraction and refining process also have significant environmental impacts. For example, oil spills from offshore drilling and pipeline leaks can cause harm to marine life and the environment [4-6]. Refining crude oil into gasoline and diesel fuel also produces air pollution, including emissions of sulfur dioxide, nitrogen oxides, and particulate matter [7-10]

Fossil fuels are also non-renewable resources, meaning that they will eventually run out [11-14]. The continued dependence on fossil fuels also contributes to geopolitical instability, as nations compete for access to limited supplies [15-20]

The use of fossil fuels in transportation has a significant impact on the environment, contributing to global warming and climate change, air pollution, and environmental degradation. It is therefore important to consider transition to alternative fuels that are more sustainable and might have a lower impact on the environment.

Finding alternative fuels that are more cost-efficient, sustainable, and ecologically benign is becoming increasingly popular as a result. This study seeks to give a general overview of the best alternative fuels for cars and assess their potential in terms of price, emissions, availability, and infrastructure.

2.0. Alternative Fuels

Alternative fuels for automobiles refer to fuels that can be used as substitutes for traditional gasoline and diesel fuels. Some of the common alternative fuels are ethanol, biodiesel, compressed natural gas (CNG), liquefied natural gas (LNG), hydrogen fuel, electricity, and propane.

Alternative fuels for cars are becoming more popular due to rising transportation demand and the need to lessen the carbon imprint. Although the typical gasoline-powered internal combustion engine has long dominated the automotive industry, it has several disadvantages, including significant pollutants and reliance on limited oil supplies.

2.1. Biodiesel

Biodiesel is a renewable, clean-burning diesel fuel made from biological materials, such as vegetable oils and animal fats. It is considered an alternative fuel because it can be used in diesel engines without any modifications, and it produces fewer emissions compared to conventional diesel fuel.

Biodiesel is produced through a chemical process called transesterification, where the glycerol molecule is separated from the fatty acids found in the biological material. This results in the formation of methyl esters (the chemical name for biodiesel) and glycerol. The methyl esters are then blended with conventional diesel fuel to create biodiesel.

The use of biodiesel as a transportation fuel has several benefits, including:

- Renewable and sustainable: Biodiesel is made from renewable resources, making it a sustainable alternative to conventional diesel fuel.
- Reduced emissions: Biodiesel produces fewer emissions compared to conventional diesel fuel, including fewer greenhouse gas emissions, particulate matter, and toxic air pollutants.
- Biodegradable: Biodiesel is biodegradable, which means that it breaks down much faster than conventional diesel fuel in the event of a spill.
- Energy independence: Biodiesel can be produced from a variety of domestic resources, reducing the dependence on foreign oil.

Despite these benefits, there are also some challenges associated with the use of biodiesel, including:

1. **Cost:** One of the significant challenges in biodiesel technology is the higher production cost compared to conventional diesel fuel. The cost of feedstock, such as vegetable oils and animal fats, can fluctuate, affecting the overall economics of biodiesel production. Additionally, the transesterification process requires specific catalysts and energy inputs, further adding to the production costs. To address this challenge, research and development efforts should focus on finding cost-effective feedstock options and improving process efficiencies. Utilizing non-edible feedstocks, such as algae or waste oils, can offer a more

sustainable and economically viable solution [21-24]. Moreover, advancements in catalyst technology and process optimization can help reduce production costs [25-28]

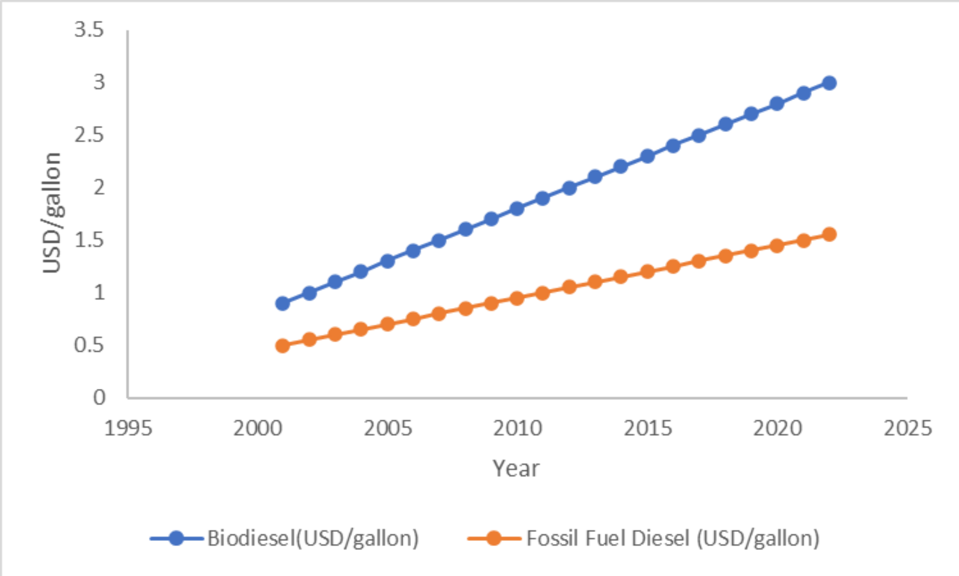

Figure 1: Cost trend of biodiesel compared to fossil fuel diesel

Figure 1 shows that the cost of biodiesel has been increasing steadily since 2001. This is due to a number of factors, including the increasing cost of feedstocks, the increasing cost of production, and the increasing demand for biodiesel. The cost of fossil fuel diesel has also been increasing, but at a slower rate than the cost of biodiesel. This is due to the fact that fossil fuel diesel is a more mature technology and has a more established infrastructure.

Despite the increasing cost of biodiesel, it is still a more environmentally friendly fuel than fossil fuel diesel. Biodiesel produces lower emissions of particulate matter, nitrogen oxides, and sulfur dioxide. Biodiesel is also biodegradable and non-toxic.

As the cost of biodiesel continues to increase, it is becoming more important to develop new methods for producing biodiesel from more sustainable feedstocks. Algae is a promising feedstock for biodiesel production because it can be grown using sunlight and carbon dioxide. Algae-based biodiesel has the potential to be a more affordable and environmentally friendly alternative to traditional biodiesel.

2.**Feedstock Availability and Sustainability:** The availability and sustainability of feedstock pose challenges to biodiesel production. The competition for agricultural land and potential impacts on food production raise concerns about the sustainability of using edible oils as feedstock. Additionally, the use of certain feedstocks, such as palm oil, has been associated with deforestation and habitat destruction. To address these challenges, research should focus on developing alternative feedstock options that do not compete with food production or contribute to environmental degradation. This includes exploring non-food crops, algae, and waste oils as feedstock sources [29-34]. Promoting sustainable agricultural practices, such as precision farming and crop diversification, can also enhance feedstock availability while minimizing environmental impacts.

3.Engine Compatibility: While modern diesel engines are generally compatible with biodiesel blends, older diesel engines may face compatibility issues. Biodiesel's solvent properties can cause degradation of certain materials used in the fuel system, leading to engine malfunctions. To overcome this challenge, proper engine modifications and the use of compatible materials should be implemented. Engine manufacturers and biodiesel producers need to collaborate to ensure engine compatibility and provide clear guidelines for fuel usage [35-40]. Research and development efforts should focus on developing advanced engine technologies that can fully utilize the benefits of biodiesel while minimizing compatibility issues.

4. **Quality Control and Standards**: Maintaining consistent quality control and adherence to standards is crucial for the widespread acceptance of biodiesel. Variability in feedstock composition and production processes can result in variations in biodiesel quality, leading to performance issues and potential engine damage. Establishing robust quality control measures and standards for biodiesel production and distribution is essential. Regular testing and certification processes should be implemented to ensure compliance with quality specifications [41-45]. Collaboration between regulatory bodies, industry stakeholders, and research institutions is essential to develop and enforce comprehensive quality control guidelines.

5.**Sustainability and Environmental Impacts:** While biodiesel offers reduced emissions compared to conventional diesel fuel, it is important to address potential sustainability and environmental impacts associated with biodiesel production. Large-scale monoculture plantations for feedstock production can lead to land-use changes, deforestation, and loss of biodiversity. To mitigate these impacts, sustainable land management practices, such as agroforestry and land restoration, should be promoted. Life cycle assessments should be conducted to evaluate the overall environmental impact of biodiesel production, considering factors such as land use, water consumption, and energy inputs [46-50]. By implementing sustainable practices and ensuring responsible sourcing of feedstock, biodiesel can minimize its environmental footprint.

Overcoming the challenges in biodiesel technology requires a multidimensional approach. Research and development efforts should focus on improving cost-effectiveness, diversifying feedstock options, ensuring engine compatibility, implementing quality control measures, and addressing sustainability concerns. Collaboration among industry, government, and research institutions is crucial for developing innovative solutions, promoting policy support, and achieving the widespread adoption of biodiesel as a sustainable alternative to conventional diesel fuel.

2.3. Methanol

Methanol is a colourless, volatile, and flammable liquid that has been used as an alternative fuel for several decades. It is a simple alcohol composed of carbon, hydrogen, and oxygen, and it can be produced from a variety of feedstocks, including natural gas, coal, and biomass. One of the main advantages of methanol as a fuel is that it can be easily produced from renewable and low-cost feedstocks. This makes it a potentially attractive option for countries looking to reduce their dependence on petroleum and to transition to a more sustainable energy mix.

Another advantage of methanol is that it can be used in a variety of applications, including as a fuel for internal combustion engines and as a feedstock for the production of other fuels and chemicals. Methanol can also be blended with gasoline to produce a fuel with improved combustion properties and reduced emissions.

In terms of its environmental impact, methanol is considered to be a cleaner fuel than gasoline. When burned, methanol releases less greenhouse gas emissions than gasoline, and it also produces fewer toxic pollutants such as nitrogen oxides (NOx) and particulate matter.

Despite its advantages, there are also some challenges associated with the use of methanol as a fuel. For example, it has a lower energy density than gasoline, which means that vehicles powered by methanol require larger fuel tanks to store the same amount of energy as gasoline. Additionally, methanol can be more corrosive than gasoline, which can lead to issues with fuel systems and other engine components. Although methanol has been considered as an alternative fuel for automobiles due to its potential to reduce emissions and dependency on fossil fuels. However, there are several critical challenges associated with methanol technology for automobiles as follows:

1. Fuel Infrastructure: One of the primary challenges in adopting methanol technology for automobiles is the lack of a widespread fuel infrastructure. Methanol refueling stations are limited, making it inconvenient for consumers to access this fuel. The establishment of a comprehensive and robust refueling infrastructure is crucial to support the widespread adoption of methanol as an automotive fuel. This requires collaboration between government entities, fuel providers, and automotive manufacturers to invest in the development of refueling stations [51-53]. Additionally, policies and incentives should be in place to promote the expansion of the methanol fueling infrastructure.
2. Vehicle Compatibility: Another challenge is the need for modifications or specialized vehicles to run on methanol. Methanol has different fuel properties compared to gasoline or diesel, requiring specific engine modifications or the use of dedicated methanol vehicles. Retrofitting existing vehicles can be costly and may not be feasible for all vehicle types. To address this challenge, research and development efforts should focus on the development of flexible engine technologies that can accommodate various fuel types, including methanol. This includes the design and optimization of engines that can operate on both methanol and conventional fuels [54-58]. Additionally, collaboration between vehicle manufacturers and fuel providers is essential to ensure compatibility and optimize vehicle performance with methanol.
3. Safety Considerations: Methanol is highly flammable and has certain toxic properties, posing safety concerns for its handling, storage, and transportation. Proper safety protocols and regulations must be in place to mitigate the risks associated with methanol use. This includes the development of safe refueling practices, storage standards, and emergency response procedures. Public awareness and education campaigns are also crucial to inform consumers about the safe handling and use of methanol as a fuel. Collaboration between regulatory bodies, fuel providers, and safety organizations is essential to establish comprehensive safety guidelines and ensure adherence to best practices.
4. Production and Environmental Impacts: Methanol can be produced from various feedstocks, including natural gas, coal, and biomass. However, the production of methanol from fossil fuel-based feedstocks can still contribute to carbon emissions and other environmental impacts. To address this challenge, the focus should be on promoting the production of methanol from renewable feedstocks, such as biomass or carbon capture and utilization technologies. Research efforts should prioritize the development of sustainable and environmentally friendly methanol production processes [59-60]. Additionally, life cycle assessments should be conducted to evaluate the overall environmental impact of methanol production and use, considering factors such as feedstock sourcing, energy consumption, and emissions.
5. Public Perception and Acceptance: Methanol as a fuel faces public perception challenges, mainly due to its association with toxicity and historical concerns over methanol poisoning. Public education and awareness campaigns should focus on providing accurate information about the safety and benefits of methanol as an automotive fuel. Clear communication of the safety measures, advancements in technology, and environmental benefits can help overcome public resistance and promote acceptance of methanol as a viable alternative fuel option.

While methanol technology for automobiles has the potential to offer environmental benefits and reduce dependency on fossil fuels, several critical challenges need to be addressed. These challenges include fuel infrastructure development, vehicle compatibility, safety considerations, sustainable production, and public acceptance. Collaboration among government entities, fuel providers, automotive manufacturers, and research institutions is crucial to overcome these challenges and pave the way forward for the widespread adoption of methanol as an automotive fuel.

2.4. Ethanol

Ethanol is a bioalcohol that is widely used as an alternative fuel for transportation and energy production. It is a renewable and domestically produced fuel that is made from crops such as corn, sugarcane, and wheat, as well as from agricultural and forestry waste.

One of the main advantages of ethanol as a fuel is that it is renewable and domestically produced, which makes it an attractive option for reducing dependence on foreign oil and reducing greenhouse gas emissions. When burned, ethanol produces fewer emissions than gasoline, including carbon monoxide, volatile organic compounds, and particulate matter. Additionally, ethanol is a high-octane fuel, which can improve engine performance and efficiency.

Ethanol can be blended with gasoline to create a fuel known as E10 (10% ethanol and 90% gasoline) which can be used in standard gasoline engines without modification. Higher ethanol blends, such as E85 (85% ethanol and 15% gasoline), are available for use in Flex Fuel vehicles, which are specifically designed to run on fuels containing higher percentages of ethanol.

However, there are also some challenges associated with the use of ethanol as a fuel. For example, ethanol has a lower energy density than gasoline, which means that vehicles require a larger volume of ethanol to store the same amount of energy as gasoline. This results in reduced fuel efficiency and increased fuel costs for consumers. Additionally, the production of ethanol from crops like corn can have negative impacts on food prices and can be resource-intensive.

2.5. Compressed Air

Compressed air energy storage (CAES) is a technology that stores energy in the form of compressed air. This technology involves compressing air and storing it in underground cavities, such as depleted natural gas fields, or in above-ground tanks. When the stored air is needed, it is released and expanded through a turbine, generating electricity.

One of the main advantages of CAES as a form of energy storage is its high efficiency. Unlike batteries, which can lose a significant amount of energy as heat during charging and discharging, CAES can store and release energy with minimal losses. Additionally, CAES can provide a large amount of stored energy in a relatively small amount of space, making it well-suited for use in urban areas where space is limited.

Another advantage of CAES is that it can be used to store energy from renewable sources, such as wind and solar power, which can be intermittent and unreliable. By storing energy when it is abundant and releasing it when it is needed, CAES can help to stabilize the power grid and ensure that energy is available when it is needed.

Despite these advantages, there are also some challenges associated with the use of CAES. For example, the technology requires a large amount of energy to compress air, which can limit its overall efficiency. Additionally, the release of compressed air can also produce significant noise, which can be a problem in densely populated areas

2.6. Hydrogen

Hydrogen is a promising alternative fuel for transportation, and many researchers and industries have been exploring its use in fuel cell vehicles. Fuel cell vehicles use hydrogen as a fuel to generate electricity through a chemical reaction with oxygen, which powers an electric motor.

One of the main advantages of hydrogen as a fuel for transportation is that it produces zero emissions when used in a fuel cell vehicle. Unlike internal combustion engines, which produce harmful pollutants such as carbon monoxide and nitrogen oxides, fuel cell vehicles produce only water vapor as a byproduct. Additionally, hydrogen is a versatile fuel that can be produced from a variety of sources, including natural gas, biomass, and water, making it a potentially renewable and sustainable option.
Another advantage of hydrogen as a fuel is its high energy density. Hydrogen has a much higher energy content than traditional battery technologies, which means that hydrogen-powered vehicles have the potential to have a longer driving range and faster refueling times compared to electric vehicles. However, there are several critical challenges associated with hydrogen technology for automobiles some of which is discussed as follows:

1. Infrastructure Development: One of the primary challenges in adopting hydrogen technology for automobiles is the lack of a widespread hydrogen refueling infrastructure. Hydrogen refueling stations are limited in number and distribution, making it inconvenient for consumers to access this fuel. The establishment of a comprehensive and robust hydrogen infrastructure is crucial to support the widespread adoption of hydrogen as an automotive fuel. This requires significant investment in infrastructure development, including the construction of refueling stations, transportation networks, and storage facilities [61-63] Collaboration between government entities, fuel providers, and automotive manufacturers is essential to drive the development of hydrogen infrastructure.

2. Hydrogen Production: Another critical challenge is the large-scale production of hydrogen. Most hydrogen is currently produced from fossil fuels through processes such as steam methane reforming, which can contribute to carbon emissions. To enable a sustainable hydrogen economy, the focus should be on promoting the production of hydrogen from renewable sources, such as electrolysis powered by renewable energy. However, the efficiency, cost, and scalability of renewable hydrogen production technologies need to be further improved [64-66]. Research and development efforts should focus on advancing electrolysis technology and exploring alternative methods for sustainable hydrogen production.
3. Storage and Distribution: Hydrogen has low energy density compared to conventional fuels, which poses challenges for its storage and distribution. Hydrogen can be stored as a compressed gas, liquefied, or in solid-state materials, but each method has its limitations in terms of energy density, safety, and cost. Moreover, transporting and distributing hydrogen requires dedicated infrastructure and specialized equipment, which adds to the overall challenges. Research and development efforts should focus on developing innovative hydrogen storage and distribution solutions, such as advanced materials for high-density storage or hydrogen carrier technologies [66-68]. Additionally, the development of standardized protocols and regulations for hydrogen storage, handling, and transportation is crucial to ensure safety and efficiency.
4. Cost and Affordability: Hydrogen fuel cell vehicles are currently more expensive than conventional internal combustion engine vehicles or battery electric vehicles. The high cost of fuel cell systems, hydrogen production, and infrastructure development contribute to the higher cost of hydrogen vehicles. To overcome this challenge, there is a need for technological advancements, economies of scale, and supportive government policies to drive down the cost of hydrogen production and fuel cell systems. Continued research and development efforts, as well as collaborations between industry stakeholders, can help

accelerate cost reductions and improve the affordability of hydrogen technology for automobiles.

As observed in Figure 2, the cost of hydrogen as fuel has been increasing steadily since 2001. This is due to a number of factors, including the increasing cost of producing hydrogen, the increasing cost of transporting hydrogen, and the increasing demand for hydrogen. The cost of fossil fuel diesel and PMS has also been increasing, but at a slower rate than the cost of hydrogen. This is due to the fact that fossil fuel diesel and PMS are more mature technologies and have a more established infrastructure. Despite the increasing cost of hydrogen as fuel, it is still a more environmentally friendly fuel than fossil fuel diesel and PMS. Hydrogen produces zero emissions of particulate matter, nitrogen oxides, and sulfur dioxide. Hydrogen is also a renewable fuel, which means it can be produced from water using renewable energy sources such as solar and wind power. As the cost of hydrogen as fuel continues to increase, it is becoming more important to develop new methods for producing hydrogen more efficiently and cost-effectively. Hydrogen fuel cells are a promising technology for producing hydrogen on-demand, and they have the potential to make hydrogen as fuel more affordable and accessible.

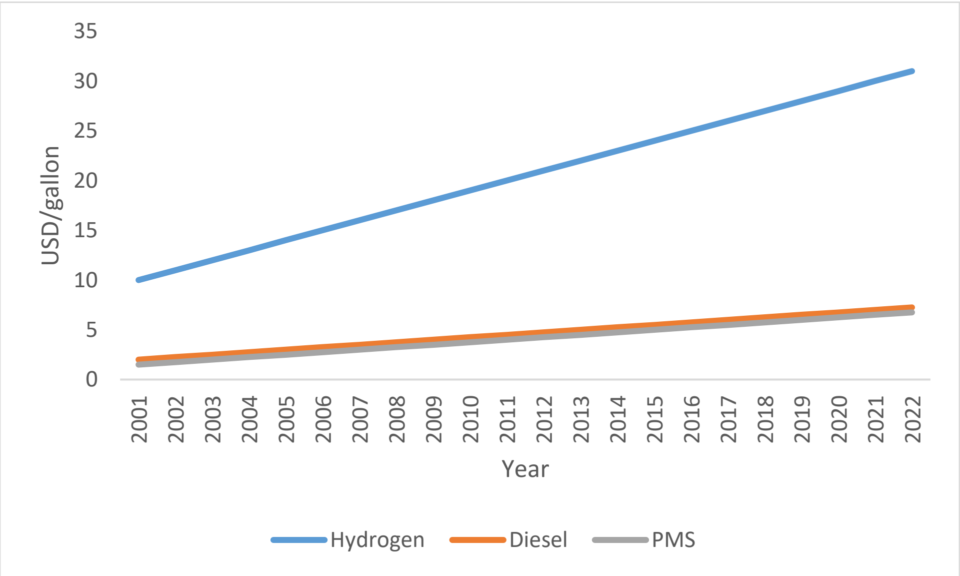

Figure 2: Cost of Hydrogen compared to diesel and PMS

5. Public Perception and Acceptance: Hydrogen technology for automobiles still faces challenges in terms of public perception and acceptance. Concerns regarding safety, the potential for hydrogen leakage, and the availability of refueling infrastructure may impact public confidence in hydrogen vehicles. Public education and awareness campaigns should focus on providing accurate information about the safety measures, advancements in technology, and environmental benefits of hydrogen as an automotive fuel. Demonstration projects and public-private partnerships can play a crucial role in showcasing the benefits and addressing public concerns, ultimately fostering greater acceptance of hydrogen technology.

While hydrogen technology for automobiles offers the potential for zero-emission transportation, several critical challenges need to be addressed. These challenges include infrastructure development, hydrogen production, storage and distribution, cost and affordability, as well as public perception and acceptance. Collaboration among government entities, fuel providers, automotive manufacturers, and research institutions is crucial to overcome these challenges and pave the way forward for the widespread adoption of hydrogen as an automotive fuel.

2.7. Natural Gas (CNG & LNG)

Natural gas is a promising alternative fuel for transportation, and has been used as a fuel for vehicles for many years. Natural gas vehicles (NGVs) are powered by compressed natural gas (CNG) or liquefied natural gas (LNG), and can offer several advantages compared to conventional gasoline or diesel vehicles.

One of the main advantages of natural gas as a fuel is its low cost. Natural gas is typically less expensive than gasoline or diesel, which makes it an attractive option for fleet operators and individual consumers. Additionally, natural gas has a lower carbon content compared to gasoline or diesel, which means that NGVs produce fewer greenhouse gas emissions when used as a fuel.

Another advantage of natural gas as a fuel is its abundance. Natural gas is widely available in many countries, and is produced domestically in many regions, which reduces dependence on foreign oil. Additionally, natural gas can be produced from a variety of sources, including conventional natural gas wells, coalbed methane wells, and shale gas formations, making it a potentially sustainable and renewable option.

However, there are also some challenges associated with the use of natural gas as a fuel for transportation. For example, the infrastructure for producing and distributing natural gas as a fuel for vehicles is still limited in many areas, which makes it difficult for consumers to adopt the technology. Additionally, natural gas vehicles are typically more expensive than conventional gasoline or diesel vehicles, which can be a barrier to adoption.

2.8. Propane (LPG – Liquefied Petroleum Gas)

Propane, also known as liquefied petroleum gas (LPG), is a popular alternative fuel for vehicles. It is a clean-burning and domestically-produced fuel that offers several benefits compared to traditional gasoline and diesel fuels.

Advantages of using propane as a vehicle fuel include:

- Lower emissions: Propane produces fewer harmful emissions compared to gasoline and diesel, which makes it a more environmentally-friendly fuel. When used as a vehicle fuel, propane reduces carbon monoxide, hydrocarbon, and nitrogen oxide emissions by approximately 20-30%.
- Lower fuel costs: Propane is typically less expensive than gasoline or diesel on a per-gallon basis. This can result in significant cost savings for consumers, particularly for those who cover a lot of miles in their vehicles.
- Improved engine performance: Propane is a high-octane fuel that provides a consistent and reliable power source for vehicles. It helps to improve engine performance and provides a smoother, quieter ride compared to gasoline or diesel.
- Domestic production: Propane is domestically produced in the United States, which reduces dependence on foreign oil.
- Wide availability: Propane is widely available in the United States and can be found at a large number of fueling stations. This makes it a convenient fuel option for many drivers.

However, there are also some disadvantages of using propane as a vehicle fuel, including:

- Lower energy density: Propane has a lower energy density compared to gasoline and diesel, which means that vehicles need more fuel to travel the same distance.
- Range limitations: Vehicles running on propane typically have a shorter range compared to gasoline or diesel vehicles. This can be a problem for long-distance travelers.

- Refueling infrastructure: Although propane is widely available, the refueling infrastructure is not as developed as for gasoline and diesel. This can make it more difficult for drivers to find a propane refueling station, particularly in rural areas.

Propane is a clean-burning, domestically-produced alternative fuel that offers several advantages for vehicles, including lower emissions, lower fuel costs, improved engine performance, and widespread availability. However, it also has some disadvantages, such as lower energy density, range limitations, and a less-developed refueling infrastructure.

2.9. Electricity

Electricity is a rapidly growing alternative fuel for vehicles. Electricity is considered as an alternative fuel under energy policy act of 1992. Electricity is a type of alternative fuel for vehicles that is rapidly growing in popularity due to its various benefits and benefits to the environment. Electric vehicles (EVs) operate by storing electrical energy in batteries, which are then used to power an electric motor. The electrical energy is generated from renewable sources, such as wind or solar power, or from conventional sources, such as coal or natural gas. The electric vehicle converts electric energy stored in batteries to mechanical energy using electric motors. It offers several advantages over traditional gasoline and diesel fuels.

Advantages of using electricity as a vehicle fuel include:

- Zero emissions: Electric vehicles produce zero tailpipe emissions, making them a clean and environmentally-friendly alternative to gasoline and diesel vehicles.
- Low operating costs: The cost of charging an electric vehicle is typically less than the cost of refueling a gasoline or diesel vehicle, which can result in significant cost savings for consumers.
- Improved efficiency: Electric vehicles are highly efficient, with energy conversion rates of up to 80-90%, compared to 20-30% for gasoline or diesel vehicles. This translates into longer driving ranges and lower energy costs.
- Quiet operation: Electric vehicles are known for their quiet operation, which makes them an ideal choice for city driving.
- Reduced dependence on fossil fuels: By using electricity as a vehicle fuel, drivers can reduce their dependence on finite fossil fuels, and support the growth of renewable energy sources.

However, there are also some disadvantages of using electricity as a vehicle fuel, including:

- High upfront costs: Electric vehicles can be more expensive than gasoline or diesel vehicles, particularly when considering the cost of the batteries.
- Limited driving range: Electric vehicles have a limited driving range compared to gasoline or diesel vehicles, which can be a problem for long-distance travelers.
- Charging infrastructure: Although charging infrastructure is rapidly growing, it is still not as developed as the refueling infrastructure for gasoline and diesel. This can make it more difficult for drivers to find a charging station, particularly in rural areas.

Electricity is a promising alternative fuel for vehicles that offers several advantages, it has the potential to reduce dependence on fossil fuels, reduce harmful emissions and more. However, there are also some disadvantages, such as high upfront costs, limited driving range, and a less-developed charging infrastructure.

This is a major challenge in a country with not enough electricity like Nigeria and some other African countries.

2.10. Fuel Cell

A fuel cell is a form of battery that produces electricity through the electro-chemical reaction of fuel and oxygen, as opposed to burning fossil fuels. Energy can be produced from hydrogen using a technology called fuel cells. In a fuel cell, hydrogen can be used directly as fuel. [69-72]

Fuel cells are a type of alternative fuel for vehicles that convert hydrogen gas into electricity, which is then used to power an electric motor. Fuel cells offer several advantages over traditional gasoline and diesel fuels, and are considered to be a promising alternative for the transportation sector.
Advantages of using fuel cells as a vehicle fuel include:

- Zero emissions: Fuel cells produce zero tailpipe emissions, making them a clean and environmentally-friendly alternative to gasoline and diesel vehicles. The only byproduct of a fuel cell is water vapor.
- Long driving range: Fuel cell vehicles have a longer driving range compared to battery electric vehicles, which can be a problem for long-distance travelers.
- Fast refueling: Fuel cell vehicles can be refueled in a matter of minutes, which is much faster than charging an electric vehicle.
- Efficient energy conversion: Fuel cells have energy conversion rates of up to 60%, which is higher than the 20-30% conversion rate of gasoline and diesel vehicles.
- Reduced dependence on fossil fuels: By using hydrogen as a vehicle fuel, drivers can reduce their dependence on finite fossil fuels and support the growth of renewable energy sources.

However, there are also some disadvantages of using fuel cells as a vehicle fuel, including:

- High upfront costs: Fuel cell vehicles can be more expensive than gasoline or diesel vehicles, particularly when considering the cost of the fuel cell stacks and hydrogen storage systems.
- Limited hydrogen infrastructure: The hydrogen refueling infrastructure is not as well developed as the gasoline or diesel refueling infrastructure, which can make it more difficult for drivers to find a refueling station.
- Hydrogen production: Currently, the majority of hydrogen is produced from fossil fuels, which negates some of the environmental benefits of using fuel cells as a vehicle fuel. However, hydrogen can also be produced from renewable sources, such as wind or solar power.

Fuel cells are a promising alternative fuel for vehicles that offer several advantages, including zero emissions, long driving range, fast refueling, efficient energy conversion, and reduced dependence on fossil fuels. However, there are also some disadvantages, such as high upfront costs, limited hydrogen infrastructure, and the challenge of producing hydrogen from renewable sources.

3.0. Cost comparison of alternative fuels

Figure 3 shows the cost trend of hydrogen, biodiesel, methanol, ethanol, compressed air, natural gas, propane, electricity, conventional fossil fuel diesel and PMS from 2001 to 2022. As you can see, the cost of all alternative fuels has increased over time, but the cost of hydrogen has increased at a faster rate than the other alternative fuels. This is due to the fact that hydrogen is a more difficult fuel to produce and transport. The cost of fossil fuel diesel and PMS has remained relatively stable over time.

From Figure 3, hydrogen is observed to be most expensive alternative fuel, followed by biodiesel, methanol, ethanol, compressed air, natural gas, propane, and electricity. The cost of hydrogen is due to the high cost of producing it, as it requires a lot of energy. The cost of biodiesel is due to the cost of the feedstocks, such as soybeans and rapeseed. The cost of methanol is due to the cost of the feedstocks, such as wood and natural gas. The cost of ethanol is due to the cost of the feedstocks, such as corn. The cost of compressed air is due to the cost of the equipment needed to compress the air. The cost of natural gas is due to the cost of extracting and transporting it. The cost of propane is due to the cost of extracting and transporting it. The cost of electricity is due to the cost of generating it.

- The cost of alternative fuels has been increasing over time. This is due to a number of factors, including the increasing cost of feedstocks, the increasing cost of production, and the increasing demand for alternative fuels.
- The cost of alternative fuels is still higher than the cost of fossil fuel diesel and PMS. However, the cost of alternative fuels is decreasing, and they are becoming more competitive with fossil fuel diesel and PMS.
- There are a number of ways to manage the cost of alternative fuels. These include:
    - Using government incentives. Governments can offer subsidies or tax breaks to help offset the cost of alternative fuels.
    - Developing new technologies. Researchers are working on new technologies to produce alternative fuels more efficiently and cost-effectively.
    - Increasing the demand for alternative fuels. As the demand for alternative fuels increases, the cost of production will decrease.

Alternative fuels are a promising option for reducing greenhouse gas emissions and improving air quality. However, the cost of alternative fuels is still higher than the cost of fossil fuel diesel and PMS. There are a number of ways to manage the cost of alternative fuels, and as the technology improves and the demand for alternative fuels increases, the cost of alternative fuels will likely decrease.

The way forward for alternative fuels is to continue to develop and deploy these technologies. Governments can play a role in this by providing incentives for the development and use of alternative fuels. In addition, businesses can play a role by investing in research and development of alternative fuels and by developing new products and services that use alternative fuels.

As the technology for alternative fuels continues to improve and the cost of alternative fuels continues to decrease, we can expect to see a greater adoption of alternative fuels in the future. This will help to reduce our reliance on fossil fuels and improve our air quality.

3.1. Findings and Discussion

1. Alternative fuels offer a range of benefits, including reduced greenhouse gas emissions, improved air quality, and decreased dependence on fossil fuels. They have the potential to contribute to sustainable transportation and mitigate the environmental impacts of conventional gasoline and diesel.
2. The cost of alternative fuels has generally increased over time, and is still higher compared to fossil fuel diesel and gasoline. The cost variation among alternative fuels can be attributed to factors such as feedstock costs, production processes, and infrastructure development.
3. Managing the cost of alternative fuels can be achieved through government incentives, technological advancements, and increasing demand. Subsidies, tax breaks, and research funding can help offset the higher costs and encourage wider adoption.
4. The future of alternative fuels relies on continued research, development, and deployment. Governments play a crucial role in supporting the development and use of alternative fuels through policies, regulations, and financial incentives. Businesses also have a responsibility

to invest in research and development, as well as in the creation of new products and services that utilize alternative fuels.

5. As technology improves and costs decrease, alternative fuels are expected to become more competitive with conventional fuels. This will likely lead to increased adoption and a shift towards a more sustainable and environmentally-friendly transportation sector.

6. Despite the progress and potential of alternative fuels, there are challenges to overcome, including infrastructure development, energy density limitations, range concerns, and high upfront costs. Addressing these challenges will require collaboration between stakeholders, including governments, industries, and research institutions.

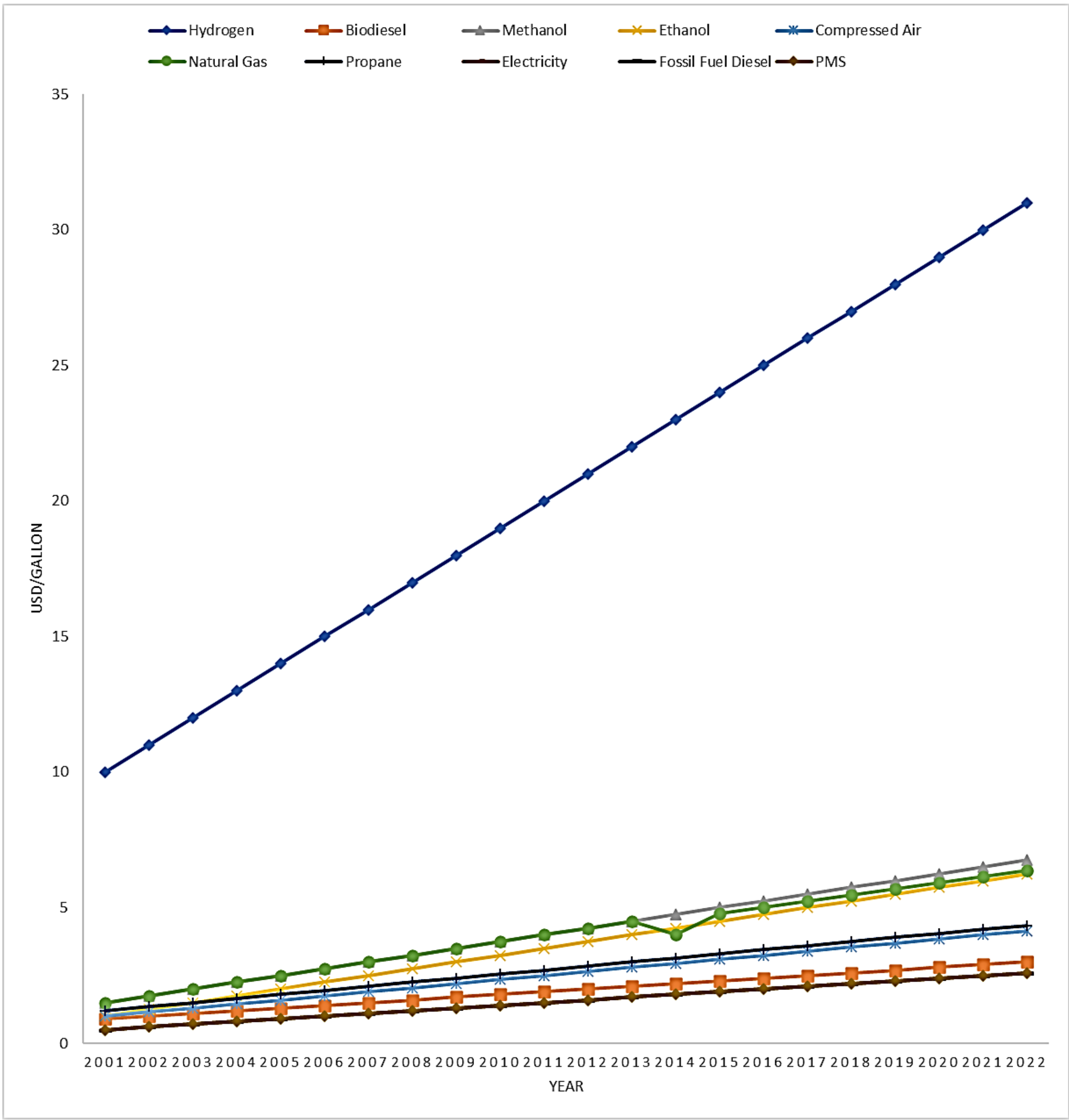

Figure 3: Cost comparison

Based on the findings, the best choice of alternative fuel depends on the specific circumstances, preferences, and priorities of the user. Here are a few considerations for selecting an alternative fuel: a.Availability: Consider the availability of the alternative fuel in your region. Some fuels, like gasoline and diesel, have well-established infrastructure, while others may have limited availability. (b) Emissions Reduction: If reducing greenhouse gas emissions and air pollution is a priority, options like electric vehicles (EVs) and hydrogen fuel cell vehicles (FCVs) offer zero tailpipe emissions. (c)Cost: Evaluate the cost of alternative fuels, including the fuel itself, the required infrastructure, and vehicle costs [73-86]. Consider the availability of subsidies, incentives, and tax breaks that can help offset the higher upfront costs. (d) Driving Range: Consider your typical driving patterns and the required driving range. Some alternative fuels, like biodiesel and ethanol, have driving ranges similar to conventional fuels, while others, like electric vehicles, may have limited range but are suitable for shorter commutes or urban driving. (e)Infrastructure: Assess the availability and accessibility of refueling or recharging infrastructure for the alternative fuel you are considering. Having a reliable and convenient infrastructure is crucial for the practicality of using alternative fuels. (f) Environmental Impact: Consider the overall environmental impact of the alternative fuel throughout its lifecycle, including production, distribution, and disposal. Evaluate its potential for reducing dependence on fossil fuels and supporting renewable energy sources.

4.0 Conclusion

Alternative fuels offer promising solutions for reducing greenhouse gas emissions, improving air quality, and decreasing our dependence on fossil fuels in the transportation sector. Our exploration of various alternative fuel options has revealed a range of advantages and disadvantages associated with each fuel type. Biofuels such as biodiesel and ethanol offer renewable sources that can be produced domestically, but their availability and impact on food production raise concerns. Compressed air and hydrogen demonstrate potential as clean fuels, but their limited infrastructure and high production costs present challenges. Natural gas and propane provide advantages in terms of cost and lower emissions, although infrastructure limitations and energy density issues need to be addressed.

Electricity, particularly for electric vehicles, offers zero tailpipe emissions, reduced operating costs, and improved efficiency, but concerns regarding charging infrastructure and higher upfront costs remain. Fuel cell technology, utilizing hydrogen, presents zero emissions and longer driving ranges, but its high costs and limited infrastructure pose barriers to widespread adoption.

The choice of the best alternative fuel for automobiles depends on several factors, including availability, emissions reduction goals, cost considerations, driving range requirements, infrastructure development, and environmental impact. It is essential for individuals and policymakers to assess these factors and prioritize their objectives when making decisions about alternative fuels.

As technology advances and economies of scale are achieved, the cost of alternative fuels is expected to decrease, making them more competitive with traditional fossil fuels. Government incentives, research and development efforts, and increasing demand for alternative fuels can further facilitate their adoption and accelerate the development of infrastructure.

In the pursuit of a sustainable and cleaner transportation sector, a comprehensive approach is necessary. This includes a combination of alternative fuels, improved vehicle efficiency, enhanced public transportation systems, and the development of renewable energy sources. By embracing these measures, we can work towards a future with reduced emissions, improved air quality, and enhanced energy security.

Conflict of Interest

The authors declare no conflict of interest

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