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Sustainable Production of Eco-Friendly, Low-Carbon, High-Octane Gasoline Biofuels Through a Synergistic Approach for Cleaner Transportation

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Abstract

This research work seeks to introduce eco-friendly, low-carbon, and high-octane biofuel gasoline production using a synergistic approach. Four types of high-octane gasoline, including SynergyFuel-92, SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100, were generated, emphasizing the deliberate combination of petroleum-derived gasoline fractions using reformate, isomerate, and delayed coking (DC) naphtha with octane-boosting compounds—bio-methanol and bio-ethanol. A set of tests have been performed to examine the effects of antiknock properties, density, oxidation stability, distillation range characteristics, hydrocarbon composition, vapor pressure, and the volatility index on gasoline blends. The experimental results indicated that the gasoline blends made from biofuel (SynergyFuel-92, -95, -98, and 100) showed adherence to important fuel quality criteria in the USA, Europe, and China. These blends had good characteristics, such as low quantities of benzene and sulfur, regulated levels of olefins and aromatics, and good distillation qualities. By fulfilling these strict regulations, Synergy Fuel is positioned as a competitive and eco-friendly substitute for traditional gasoline. The results reported that SynergyFuel-100 demonstrated the strongest hot-fuel-handling qualities and resistance to vapor lock among all the mentioned Synergy Fuels. Finally, the emergence of eco-friendly, low-carbon, and high-octane biofuel gasoline production with synergistic benefits is a big step in the direction of sustainable transportation.

Keywords: gasoline biofuel; bio-methanol; internal combustion engine; sustainability; Synergy Fuels; transportation



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1. Introduction

Until the mid-19th century, humanity used to rely on renewable energy sources, such as burning biomass (wood, crop waste, or charcoal), but the Industrial Revolution of the 20th

century introduced fossil fuels, a new non-renewable energy source [1]. Since then, it has developed into a fundamental energy driver and is still a major contributor to the world’s energy production [2]. Fossil fuels are the primary source of electricity in both developed and developing countries, but this has several disadvantages, including the emission of carbon dioxide, which is a major contributor to air pollution and the cause of millions of premature deaths worldwide [3,4]. In addition to these health and environmental threats, the use of fossil fuels in energy generation systems contributes to the problem of low power generation, which not only results in a significant gap between supply and demand but also decreases people’s life quality [5,6]. Gasoline contains many commercial fractions, like heavy naphtha, light naphtha, isomerase, reformate, hydrocracked naphtha, and catalytic cracked naphtha [7–10]. The incorporation of hydrogen electric vehicles (HEVs) and biofuels plays a key role in promoting sustainable transportation by decreasing the reliance on fossil fuels and leveraging their great energy density [11,12].

The generation of biofuel contributes to decreasing health and environmental issues during the combustion process [13]. The main sources of this dependence are charcoal, fuelwood, and agricultural waste. In Africa, the extensive use of biomass leads to deforestation, degraded soil, and major health issues from indoor air pollution [14]. Children and women, who are frequently in charge of gathering fuelwood, face serious health and safety hazards. When cooking, people are exposed to smoke and related illnesses. Exposure to harmful chemicals results in the deaths of thousands of people each year. Toxic vapors are thought to be responsible for 1.3 million premature deaths annually in underdeveloped nations. The necessity of moving to renewable energy sources is further highlighted by estimates that suggest fossil fuel reserves may run out within the next century [15]. This depletion emphasizes the significance of sustainable energy options, posing a major threat to global energy security. The goals of achieving sustainable development goals and improving living conditions globally depend on addressing energy poverty and expanding access to clean energy.

Since 2015, there has been a substantial change in the global patterns of energy investment. Growing from about 2 to 1 in 2015 to an estimated 10 to 1 in 2024, the proportion of clean power to unabated fossil fuel power investments has grown. According to the International Energy Agency, it is believed that global energy investment surpassed USD 3 trillion for the first time in 2024, with 2 trillion USD going toward clean energy technology and infrastructure. Clean energy expenditures have surged since 2020, with grids, storage, and renewable electricity already receiving greater investment than coal, gas, and oil combined [16]. Global energy investment in fossil fuels and sustainable energy is depicted in Figure 1.

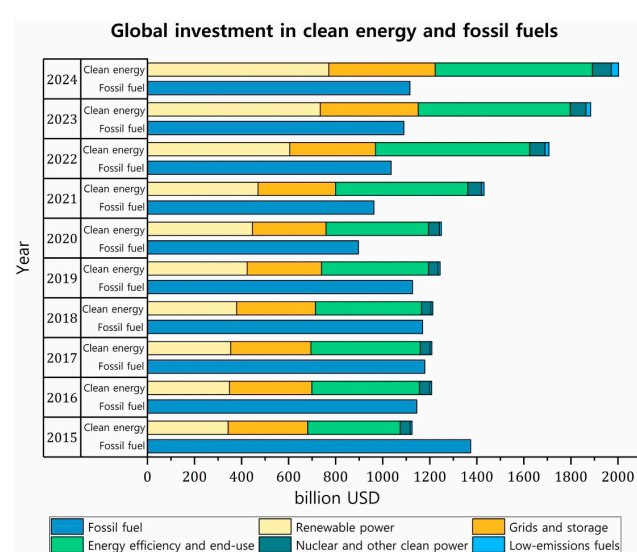


Figure 1. Worldwide energy investment in petroleum fossil fuels and clean energy [17].

Another biofuel that shows promise and has benefits for spark ignition engines is alcohol [10,11]. Other alcohols, particularly those having 1–5 carbon atoms in their structure, are also of scientific and commercial interest, even though bioethanol is the most often used alcohol fuel [18–20]. As oxygenated biofuels, alcohols offer beneficial physicochemical properties [21,22].

Due to its usage as a fuel for transportation, as well as in cosmetics, pharmaceutical, and other industries, bioethanol production and use are growing on a commercial scale globally [23,24]. Due to its high-octane number, speed, burning limit, and evaporation temperature, as well as its low greenhouse gas emissions, bioethanol is the best substitute for gasoline [25]. With about 35% oxygen concentration, the vehicle engine offers more efficient combustion, reducing emissions of hydrocarbons, nitrogen oxides (NO_x), and other harmful particles [26]. Consequently, it can be utilized as engine fuel in the future to lessen air pollution and car damage [27]. Three distinct methods—a dual-fuel system, fumigation, and biodiesel ethanol blend—are used to incorporate bioethanol into diesel engines [28].

The possible use of methanol addition in high-compression-ratio Miller cycle engines was investigated by Shu et al. [29]. The findings demonstrated that using a fuel mixture of gasoline and methanol can increase engine thermal efficiency and improve combustion without altering the load. The effects of ambient pressure and methanol–gasoline fuel blends on exhaust emissions and flame propagation were examined by Radzali et al. [30]. When gasoline's methanol content rose from 0% to 15%, the flame spread out more widely, improving the burn rate even further. Abdellatif et al. [31] studied the development of gasoline biofuel based on petroleum gasoline components, like FCC naphtha, and isomate, reformat, with the inclusion of renewable gasoline additives, such as isopropanol. The results showed that the environmentally friendly gasoline biofuel produced included low aromatic content and low carbon, as well as high-octane gasoline of RON92, RON95, and RON98. Furthermore, Kale and Krishnasamy [32] investigated the experimental study of some octane gasoline boosters as additives, such as ethanol, acetone, methanol, ethyl acetate, isobutanol, diisopropyl ether, and isopropanol, using different blends to produce gasoline biofuel. The produced biofuel was used to run the HCCI engine to examine its performance. The results obtained suggested that HCCI engine technology with the gasoline biofuel, including the mentioned additive blends, could be a sustainable surrogate for prospective transportation and energy generation. Additionally, the whole-gasoline biofuel samples can generate permissible emission grades by properly tuning the fuel concentration. Furthermore, Rahayu et al. [33] studied the effect of n-butanol, iso-butanol, and 2-butanol on the gasoline performance, examining torque, cylinder pressure, and exhaust temperature, as well as emissions properties, such as CO, NO_x, HC, PM, and CO₂ concentrations, for a spark ignition gasoline engine. The results showed that butanol had a synergistic effect in terms of producing high-octane gasoline biofuel.

Research into creating low-carbon, high-octane gasoline fuels with sustainable and renewable components has accelerated globally [34]. In order to increase octane number while lowering lifecycle greenhouse gas emissions, several institutions have investigated the blending of oxygenated bio-compounds, including ethanol, methanol, isobutanol, ethers (like diisopropyl ether), and esters (like ethyl acetate) [35–37]. Despite their potential, these approaches have a number of advantages, including phase separation in humid environments, problems with material compatibility with current engine parts, volatility-related emissions, and regulatory mix limits. Moreover, there are still significant issues with the trade-offs between octane and emissions, as well as the variation in lifecycle carbon reductions due to feedstock and processing routes. By presenting SynergyFuel, a novel gasoline biofuel formulation that offers a high (RON > 98), a much lower aromatic

content (<20%), and improved blend stability, this study fills these gaps. In contrast to standard alcohol–gasoline blends, SynergyFuel is a drop-in solution that offers better performance and environmental advantages without requiring engine modification, avoiding the disadvantages of current biofuel techniques.

This study aims to develop an environmentally friendly, low-carbon, high-octane biofuel gasoline with synergistic advantages, marking a significant advancement toward sustainable transportation solutions. The innovative approach integrates advanced refining techniques with renewable feedstocks to create a fuel that not only enhances engine performance but also minimizes greenhouse gas emissions. Furthermore, this strategy contributes to improving both the quality and availability of light petroleum fractions, addresses key energy and environmental challenges by offering high-octane biofuels, and supports the reduction in reliance on conventional fossil fuels. The research focuses on formulating four high-performance gasoline grades—SynergyFuel-92, SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100—through the targeted blending of petroleum-based components such as reformate, isomerate, and delayed coking (DC) naphtha with renewable octane enhancers like bio-methanol and bio-ethanol.

2. Research Methodology

2.1. Materials

Figure 2 provides a visual depiction of the materials used in the study, with an emphasis on formulations that increase octane and gasoline fractions sourced from petroleum. The picture's left side depicts an eco-friendly gasoline concept, showing a car being refueled at a green energy-themed station, signifying the use of high-performance or sustainable fuel blends. The image's right side lists the main elements employed in the study, highlighting the importance of various fuel fractions and additives in raising the quality of gasoline.

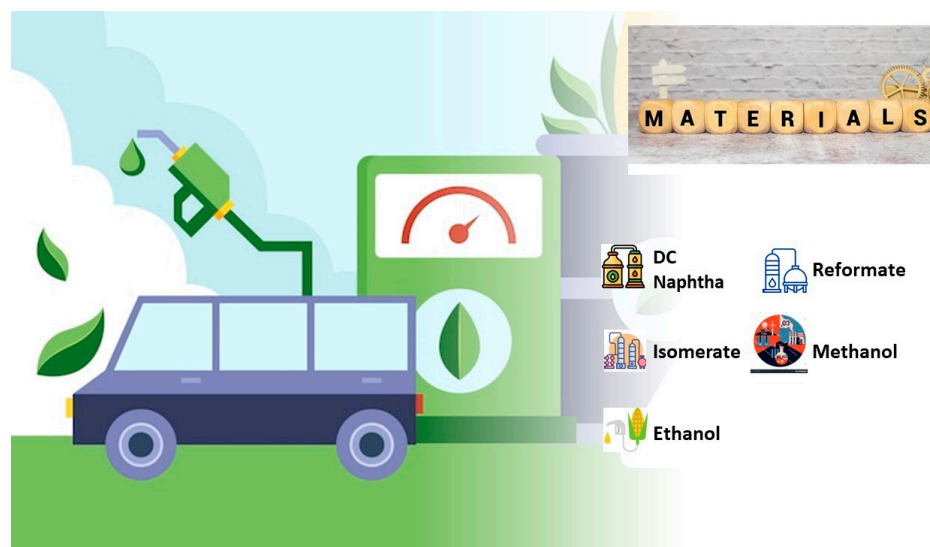


Figure 2. Octane-boosting formulations and petroleum-derived gasoline fractions involved in the research.

DC naphtha is an essential petroleum-derived fraction in gasoline blending that mostly contributes to the fuel's hydrocarbon content. Another important gasoline component, reformate, is produced by catalytic reforming and is high in aromatics, which raises the gasoline's octane rating considerably. Additionally, isomerate—a highly branched hydrocarbon fraction that improves fuel efficiency and aids in maintaining a high-octane

level without raising emissions—is included. Isomerate, DC naphtha, and reformat were procured from the Middle East Oil Refinery (MIDOR) company in Egypt.

The study also included methanol and ethanol, two bio-based octane enhancers, in addition to petroleum-based ingredients. Methanol, which can be produced synthetically or from biomass, enhances combustion properties and lessens engine knocking. An important part of contemporary fuel formulations, ethanol is a well-known renewable fuel additive that dramatically raises the octane number while lowering greenhouse gas emissions [38]. In order to create high-performance gasoline blends with higher octane ratings, which guarantee efficient combustion and a lower environmental impact, this chart clearly illustrates the integration of both traditional and alternative fuel components. In order to satisfy legal requirements and improve engine performance, this study focuses on strategically combining these components to optimize fuel composition.

The sequential process of producing bioethanol from several biomass-based feedstocks is depicted in Figure 3. Cellulosic materials, sugar-based crops, and starch-based crops are the main basic materials used in the process. Carbohydrates found in these feedstocks can be transformed into the fermentable sugars required to produce ethanol.

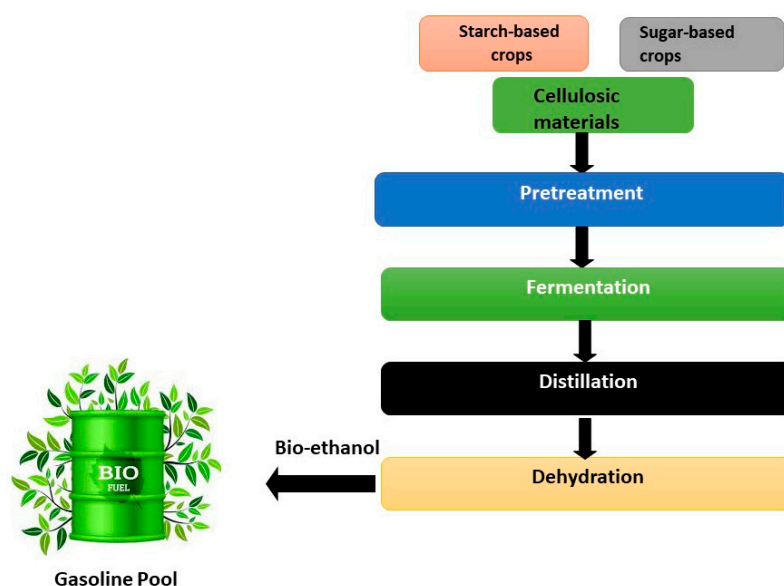


Figure 3. Visual representation of production of bioethanol process from biomass-based feedstocks.

Pretreatment is the initial stage of the process, which entails simplifying complicated carbohydrates to make fermentation easier. This process is essential for cellulosic and starch-based materials because it facilitates the release of fermentable sugars. The substance then goes through a process called fermentation, in which enzymes and microbes—usually bacteria or yeast—turn the sugars into carbon dioxide and ethanol. The yield and efficiency of ethanol are significantly influenced by this biological process. Distillation, a separation procedure used to concentrate ethanol by eliminating water and other impurities, is applied to the ethanol-rich mixture after fermentation.

The product goes through dehydration, which removes the remaining water content to produce anhydrous ethanol (99% purity or greater), in order to produce fuel-grade bioethanol. To satisfy the requirements for mixing ethanol with gasoline, this step is required. In order to improve octane levels and lower greenhouse gas emissions, bioethanol is then added to the gasoline pool as a sustainable fuel additive. This procedure aids in the creation of cleaner-burning, sustainable transportation fuels. The process of producing bioethanol is clearly illustrated by the graphic, which shows how various biomass sources can be transformed into valuable fuel by a sequence of physical and biological processes.

Figure 4 provides a detailed schematic illustration of the process of producing bio-methanol from biomass-based feedstocks as a sustainable pathway for converting biomass into bio-methanol, upgrading cleaner energy generation while using renewable resources efficiently. The first of several crucial steps is biomass feedstock preparation, which involves collecting and preparing a variety of organic waste products and agricultural residues, including wood chips, straw, and other lignocellulosic sources for conversion. These feedstocks serve as the raw material for bio-methanol production [39].

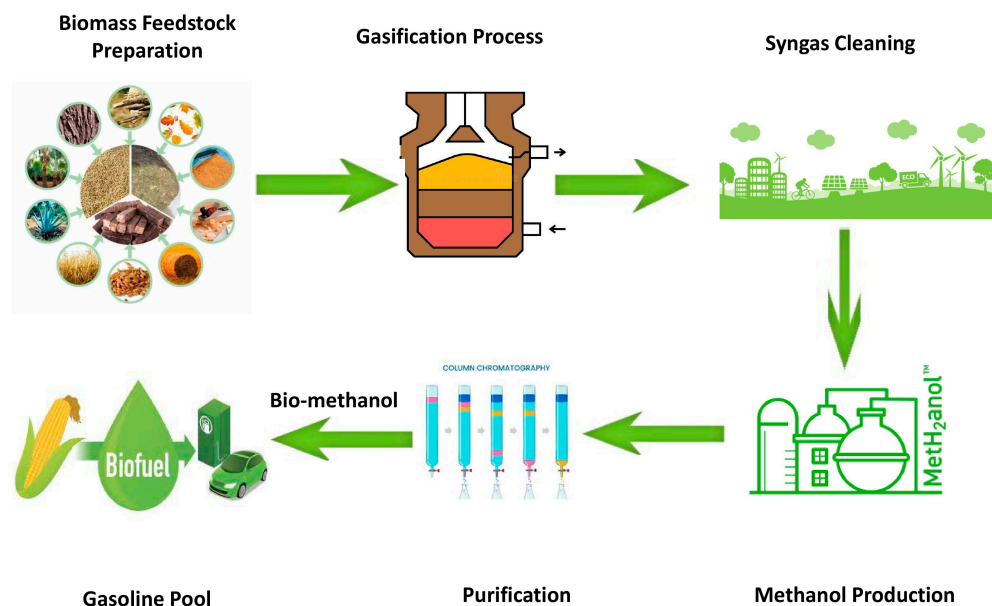


Figure 4. Schematic illustration of bio-methanol generation from biomass feedstock.

The processed biomass is then subjected to high temperatures and a regulated atmosphere with a restricted oxygen supply during the gasification process. Through this process, the biomass is broken down into synthesis gas, or syngas, which is mostly made up of carbon dioxide (CO_2), hydrogen (H_2), and carbon monoxide (CO). The syngas cleaning phase after gasification makes sure that contaminants like tar, sulfur compounds, and particle matter are eliminated. This purification step is essential in order to avoid catalyst deactivation and improve the efficiency of the downstream methanol synthesis process.

The processed biomass is then subjected to high temperatures and a regulated atmosphere with a restricted oxygen supply during the gasification process. Through this process, the biomass is broken down into synthesis gas, or syngas, which is mostly made up of carbon dioxide (CO_2), dihydrogen (H_2), and carbon monoxide (CO). The syngas cleaning phase after gasification makes sure that contaminants like tar, sulfur compounds, and particulate matter are eliminated. In order to avoid catalyst deactivation and improve the efficiency of the downstream methanol synthesis process, this purification step is essential. After being cleaned, the syngas is sent to the methanol production stage, where it is converted into methanol (CH_3OH) by catalysis, using substances like copper, zinc, or alumina, in a reactor. The crude methanol is purified using methods like distillation or column chromatography to reach high purity. After being cleansed, the bio-methanol is added to the gasoline pool as a high-octane, renewable fuel additive that improves combustion and lowers greenhouse gas emissions. Fuel blends that contain bio-methanol help create a more environmentally friendly and sustainable energy environment.

Table 1 provides a thorough examination of a number of fuel constituents, such as DC naphtha, reformate, isomerate, bio-methanol, and bio-ethanol, emphasizing their salient physical and chemical properties, which are pertinent to blending gasoline and octane

enhancement. These elements are essential for altering the characteristics of fuel to increase performance, efficiency, and adherence to current fuel laws. This table highlights the unique characteristics of the fuel ingredients used in petroleum-derived gasoline fractions and octane-boosting formulas. Reformate makes a substantial contribution to high-performance gasoline blending because of its high aromatic content and stability, even though methanol and ethanol offer greater octane ratings and clean burning. DC naphtha has lower octane, and isomerate offers useful blending qualities to satisfy volatility and distillation needs. By choosing and combining these ingredients, high-octane, environmentally friendly gasoline blends can be created that meet current fuel restrictions and performance requirements.

Table 1. Common characteristics of octane-boosting formulations and petroleum-derived gasoline fractions.

Analysis	DC Naphtha	Reformate	Isomerate	Methanol	Ethanol
Fuel density measured at 15 °C, (in kilograms per cubic meter)	724.3	828	663.7	792	794
Reid vapor pressure (RVP), kPa	66.7	13.8	84	35	17
Initial boiling point (IBP), °C	37	73	36	65	78
T10, (°C)	74	106	44	65	78
T30, (°C)	106	118	46	65	78
T50, (°C)	127	130	50	65.5	78
T70, (°C)	147	143	57	65.5	78
T90, (°C)	168	165	75	66	78
FBP, (°C)	186	217	106	66	78
Research octane number (RON)	68	100	86.2	112	111
Motor octane number (MON)	64.8	83.5	83.4	91	92
Olefins, (%)	36.1	0.5	0.1	0	0
Aromatic, (%)	9.1	72.5	0.8	0	0
Knock resistance	low	high	low	high	high

2.2. Methods

Figure 5 lists the several research techniques and standardized tests that are used to examine and assess the performance, composition, and quality of fuels, especially gasoline and related petroleum products. The American Society for Testing and Materials (ASTM) standard that corresponds to each test guarantees consistency and dependability in the testing procedure.



Figure 5. Research the ASTM test method for measuring the physical and chemical properties of gasoline.

To evaluate a fuel’s shelf life and storage performance, oxidation stability assesses the fuel’s resistance to oxidation over time. Engine performance can be hampered by gums and deposits formed by fuels with low oxidation stability. To determine a fuel sample’s

long-term stability, ASTM D252 [40]. measures how long it takes for it to reach a particular degree of oxidation under carefully monitored circumstances.

Gum content in fuels, which may arise from oxidation or contamination during storage, is measured by this test. To quantify the residue left behind and make sure the fuel satisfies quality criteria, ASTM D381 [41]. requires the evaporation of the fuel sample under particular conditions.

An important indicator for assessing a fuel's resistance to knocking or pinging during engine combustion is the research octane number [42]. Better resistance to knocking is indicated by higher RON values, which enhance engine performance and efficiency [43]. Under controlled circumstances, ASTM D2699 [44] measures this property using a standardized test engine. The octane rating that is shown at gas stations is defined in part by MON in conjunction with RON. Figure 6 shows the octane rating equipment for examining RON and MON by the CFR engine.

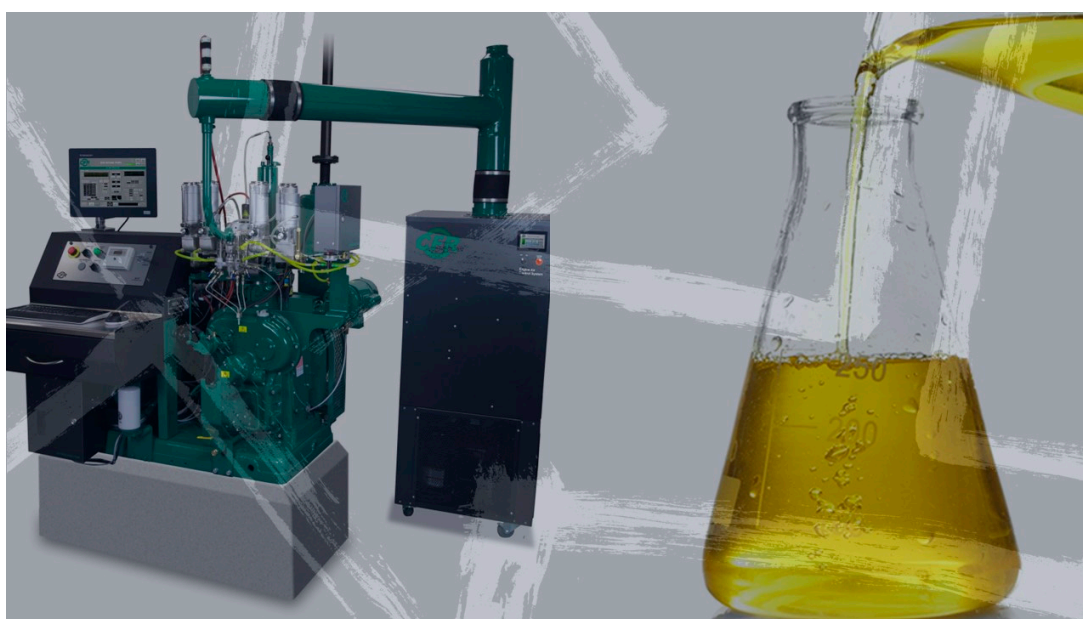


Figure 6. Octane rating equipment for examining RON and MON.

The distillation range test assesses a fuel's ability to evaporate at various temperatures. It offers details on the fuel's volatility, which has an immediate effect on emissions, cold starting, and combustion efficiency [45]. Heating the fuel sample and noting the temperatures at which particular percentages of the sample evaporate are part of ASTM D86 [46]. Furthermore, fuels' sulfur content is a significant environmental factor since burning sulfur compounds releases toxic pollutants like sulfur dioxide (SO_2), polluting the air. ASTM D5453 [47]. ensures adherence to environmental requirements by precisely measuring the sulfur content in fuels using UV fluorescence.

The ASTM D130 [48]. test assesses a fuel's ability to corrode copper parts in engines and storage systems. Over time, corrosive fuels can harm engine components, necessitating expensive repairs. In the current experiment, a copper strip is submerged in the fuel sample under carefully monitored circumstances, and any corrosion or discoloration is evaluated. The volatility of gasoline at 100°F (37.8°C) is measured by RVP.

One crucial physical characteristic that affects fuel's energy content per unit volume is density [49]. Although they may have varying combustion properties, fuels with a higher density often contain more energy [50]. ASTM D4052 [51]. uses digital density meters to measure this attribute exactly. The ASTM D1319 [52]. test determines the ratios of several hydrocarbon types in fuels, including saturates, olefins, and aromatics, which affect engine

deposits, emissions, and combustion behavior. To properly categorize these hydrocarbons, ASTM D1319 [52]. uses fluorescent indicator adsorption techniques.

3. Results and Discussion

The results of the current study explore eco-friendly, low-carbon, and high-octane biofuel gasoline production with a synergistic approach. This creative strategy focuses on using cutting-edge refining methods and renewable resources to produce a fuel that improves engine performance while lowering greenhouse gas emissions.

3.1. Market-Grade Gasoline Fuel

In order to produce eco-friendly, low-carbon, high-octane biofuel gasoline with synergistic benefits, it is better to investigate the physicochemical properties of the market-grade gasoline fuel with an RON of 95. It is produced mainly from petroleum-derived gasoline fractions, including reformat and isomerate, provided by the company MIDOR Egypt. The fuel characteristics of a market-grade gasoline blend that contains 60% reformat and 40% isomerate by volume are thoroughly examined in this investigation, as illustrated in Table 2. The information provides insights into the fuel's suitability for different engine applications and regulatory compliance by encapsulating important attributes related to fuel quality, performance, and environmental effects. Because each metric offers distinct information, the total quality of the fuel may be thoroughly evaluated. The results reported that the values of RON and MON for market-grade gasoline fuel were 94.5. and 84.1. A higher octane rating indicates better antiknock performance.

Table 2. Detailed market-grade gasoline fuel properties containing 60% reformat with 4% isomerate volumetrically.

Analysis	Market-Grade Gasoline
Fuel density measured at 15 °C (in kilograms per cubic meter)	757.66
Sulfur content, ppm	0.2
RVP (kPa)	44.8
IBP (°C)	48
T10 (°C)	80
T30 (°C)	88.6
T50 (°C)	96.2
T70 (°C)	106.8
T90 (°C)	125.4
FBP (°C)	159.4
RON	94.5
MON	84.1
Olefins (%)	1.1
Benzene (%)	0.6
Aromatic (%)	42.7

The fuel density at 15 °C was examined for the market-grade gasoline fuel, and the results reported that the fuel's density was 757.66 kg/m³. This density result indicated good energy content because it is within the normal range for gasoline. Additionally, the sulfur concentration is exceptionally low, as shown by the 0.2 ppm values. This amount is ideal since it reduces the production of sulfur oxides (SO_x), which are dangerous air pollutants, during combustion. Such a low sulfur concentration is frequently necessary to meet strict environmental laws.

The value of RVP for commercially produced gasoline was 44.8 kPa. It impacts evaporative emissions as well as engine starting. Depending on local and seasonal needs, this RVP rating indicates a suitable balance between reduced emissions and ease of starting. While greater RVP values are permitted in colder months for improved cold-start performance, lower values are frequently required in summer months to minimize evaporative emissions.

Unsaturated hydrocarbons called olefins (alkenes) have the potential to cause emissions and deposit formation. The value of olefins for commercial gasoline was 1.1% by volume. According to the limits of use, the percentage of olefins in gasoline cannot be more than 18% by volume. In general, a low olefin concentration is preferred. Furthermore, the value of aromatics content for commercial gasoline was 42.7% by volume. According to the limit of use of the percentage of aromatics in gasoline, it is allowable to not use more than 35% by volume. Although they can increase octane, aromatics can also cause emissions and deposit formation. The 60% reformat content, a content which is known to be high in aromatics, is probably the cause of the relatively high aromatic content, and this has a large negative effect on the environment. To lessen the harmful effects of a high aromatic concentration, the overall qualities of the fuel should be balanced. Moreover, the value of benzene content for commercial gasoline was 0.6% by volume. Because of its toxicity, benzene is a restricted component. The amount of benzene that can be present in gasoline is limited in several places. This relatively low value aids in satisfying regulatory requirements.

Upgrading the fuel would be advantageous, given the 42.7% aromatic level of this commercial gasoline blend, mainly to reduce any possible health and environmental risks. Although aromatics have a major role in the octane rating, large concentrations of these compounds can result in higher emissions of dangerous pollutants such as polycyclic aromatic hydrocarbons (PAHs) and benzene, a known carcinogen. By adding oxygenates like ethanol and methanol as octane boosters and diluting the aromatic concentration, the aromatic content can be decreased, lowering tailpipe emissions and enhancing air quality in general. By putting these upgrading techniques into practice, gasoline can be reformulated to improve engine performance, adhere to stricter environmental regulations, and support a healthier environment.

3.2. Eco-Friendly, Low-Carbon, and High-Octane Biofuel Gasoline Production

Making high-octane, low-carbon, and environmentally friendly biofuel gasoline is a big step towards sustainable transportation. This creative strategy focuses on using cutting-edge refining methods and renewable resources to produce a fuel that improves engine performance while lowering greenhouse gas emissions. The manufacturing of biofuel gasoline reduces dependency on fossil fuels and advances carbon neutrality by using feedstocks generated from biomass, such as cellulosic materials, algae, or non-food crops. In addition, sophisticated procedures such as hydrotreating, catalytic cracking, and blending with oxygenate are used to maximize the fuel's chemical makeup and guarantee high octane ratings for better engine knocking and combustion efficiency. The automotive industry's future is expected to be cleaner, more efficient, and ecologically conscious thanks to this sustainable fuel substitute.

The first step in generating eco-friendly, low-carbon, and high-octane biofuel gasoline is selecting the materials feedstocks and their percentages in gasoline pools. The current work seeks to produce four types of high-octane gasoline, including SynergyFuel-92, SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100, emphasizing the deliberate combination of petroleum-derived gasoline fractions with octane-boosting compounds. Table 3 demonstrates the Synergyfuels constituents, utilizing octane-boosting formulations and petroleum-derived gasoline fractions. The different ratios of methanol, ethanol, DC

naphtha, reformate, and isomerate show a customized strategy for reaching particular octane goals while maximizing fuel efficiency and maybe taking environmental concerns into account. Formulating fuels that satisfy performance requirements and regulatory standards requires an understanding of how these components work in concert.

Table 3. SynergyFuel constituents utilizing octane-boosting formulations and petroleum-derived gasoline fractions.

Hydrocarbon Fraction	SynergyFuel-92	SynergyFuel-95	SynergyFuel-98	SynergyFuel-100
Reformate	14	16	25	26
Isomerate	13	11	8	9
DC Naphtha	34	27	20	14
Methanol	15	15	15	15
Ethanol	24	31	32	36

The slow change in composition throughout the SynergyFuel grades is a clear indication of the deliberate blending of various hydrocarbon fractions and additives. Higher octane ratings are a result of reformate, which rises from 14% in SynergyFuel-92 to 26% in SynergyFuel-100. Reformate is well-known for its high aromatic content and octane-boosting qualities. The mix is optimized by adjusting the quantity of isomerate, another desirable gasoline component with strong octane properties. Because it has a lower octane rating than reformate and isomerate, the presence of DC naphtha, a straight-run gasoline fraction, drops as octane requirements rise. This modification raises the level of reformate to make up for the decreased octane value.

Notably, the steadily rising percentage of ethanol and the steady presence of methanol in all fuel categories highlight their significance as renewable fuel ingredients and octane boosters. Because the proportion of methanol stays at 15%, this change probably consistently raises octane and may also help with combustion efficiency. The percentage of ethanol rises dramatically from 24% in SynergyFuel-92 to 36% in SynergyFuel-100, emphasizing its contribution to the fuel's renewable content and ability to achieve better octane ratings. By using biofuels, this formulation approach not only maximizes fuel performance but also complies with the increasing environmental concerns. SynergyFuel's ability to provide a variety of gasoline options suited to various engine requirements and consumer preferences is made possible by the careful balancing of these components, demonstrating the complexity of contemporary fuel composition.

The attributes of four gasoline blends made from biofuel (including SynergyFuel-92, -95, -98, and 100) are thoroughly examined in Table 4. This table also compares them to the fuel quality requirements set forth by the USA (ASTM D4814 [53]), Europe (EN 228 [54]), and China (GB 17930-2016 [55]). The assessment ensures that the gasoline made from biofuel satisfies worldwide regulatory standards by examining important factors affecting engine compatibility, fuel performance, and environmental compliance.

The experimental results indicated that the gasoline blends made from biofuel (SynergyFuel-92, -95, -98, and 100) showed adherence to important fuel quality criteria in the USA, Europe, and China. These blends had good qualities, such as low quantities of benzene and sulfur, regulated levels of olefins and aromatics, and good distillation qualities. Fulfilling these strict regulations positions SynergyFuel as a competitive and eco-friendly substitute for traditional gasoline.

Table 4. Characteristics of produced biofuel-derived gasoline blend adhering to global standard regulations.

Property	Unit	SynergyFuel-92	SynergyFuel-95	SynergyFuel-98	SynergyFuel-100	USA (ASTM D4814)	Europe (EN 228)	China (GB 17930-2016)
Clarity	-	No visible impurities	No visible impurities	No visible impurities	No visible impurities	No visible impurities	No visible impurities	No visible impurities
RON	-	91.8	95.1	97.8	100	≥91 (Regular), ≥95 (Premium)	≥95 (Regular), ≥98 (Premium)	≥92, 95, 98
MON	-	81.1	83.1	85	86.6	≥82	≥85	≥85
Density at 15 °C	(kg/m ³)	756.75	764.76	775.91	779.05	720–775	720–775	720–775
Reid Vapor Pressure	(kPa)	45.5	40.8	35.4	33.1	48–103 (Seasonal Variation)	45–90	40–88
Sulfur Content	(ppm)	3.2	3.7	3.7	4	≤10	≤10	≤10
Benzene Content	(% v/v)	0.2	0.2	0.3	0.3	≤1.0	≤1.0	≤1.0
Aromatics	(% v/v)	13.1	13.9	19.6	19.7	≤35	≤35	≤40
Olefins	(% v/v)	12.5	10	7.7	5.5	≤18	≤18	≤24
Appearance	-	bright and clear	bright and clear	bright and clear	bright and clear	bright and clear	bright and clear	bright and clear
Initial Boiling Point	(°C)	53.6	56.8	59	60.8	≤35	≤35	≤35
Distillation 10%	(°C)	73.9	75.4	79	79.2	50–70	50–70	50–70
Distillation 50% (°C)	(°C)	96	94.1	95.9	93.2	77–121	70–120	70–120
Distillation 90%	(°C)	117.8	113.1	114.2	109.6	150–190	≤180	≤190
Final Boiling Point	(°C)	132.9	127.2	129.3	124.3	≤225	≤210	≤215
Residue	(% v/v)	1.2	1.1	1.1	1.1	≤2	≤2	≤2
Existent Gum	(mg/100 mL)	1.8	1.5	1.3	1.1	≤5	≤5	≤5
Oxidation Stability	(min)	>415	>415	>415	>415	≥360	≥360	≥360
Copper Corrosion, (3 h at 50 °C)	-	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1

Additionally, oxidation stability testing addresses a crucial factor: the stability of gasoline during storage. The SynergyFuel blends had oxidation stability values of over 415 min, which is far longer than the 360 min minimum required by international regulations. This lengthy stability guarantees that the fuel's quality and performance characteristics will not be significantly impacted by longer storage periods. Another crucial test is the copper corrosion test, which determines how corrosive the gasoline is to copper components in the fuel system. Every SynergyFuel grade receives a Class 1 classification, which denotes a low risk of corrosion. By guaranteeing compatibility with the materials used in fuel systems, this rating helps to preserve their integrity and avoid harm. Additionally, this is complemented by existing gum testing, which measures the quantity of residue produced during evaporation to guarantee that the fuel stays clean and does not cause deposits to form in the engine based on the mentioned results. The use of existing gum in gasoline is allowable, but not above 5% by volume.

Finally, the proposed biofuel gasoline strategy offers a significant advancement toward sustainable transportation by integrating renewable resources and advanced refining techniques. Building on the earlier discussions, this approach not only enhances engine performance and reduces greenhouse gas emissions but also optimizes the use of petroleum-

derived components, like DC naphtha, reformat, and isomate, thereby contributing to reduced reliance on fossil fuels.

3.2.1. Gasoline Hydrocarbon Composition

Figure 7 compares the hydrocarbon composition of the manufactured SynergyFuel variants (SynergyFuel-92, -95, -98, and 100) with that of market-grade gasoline, with an emphasis on the aromatic, olefin, and benzene content. The objective is to draw attention to the variations in these crucial elements, which have a big influence on emissions, fuel efficiency, and adherence to environmental laws. A thorough evaluation of the SynergyFuel blends' characteristics and any potential benefits or drawbacks in comparison to traditional gasoline is made possible by an understanding of these variances.

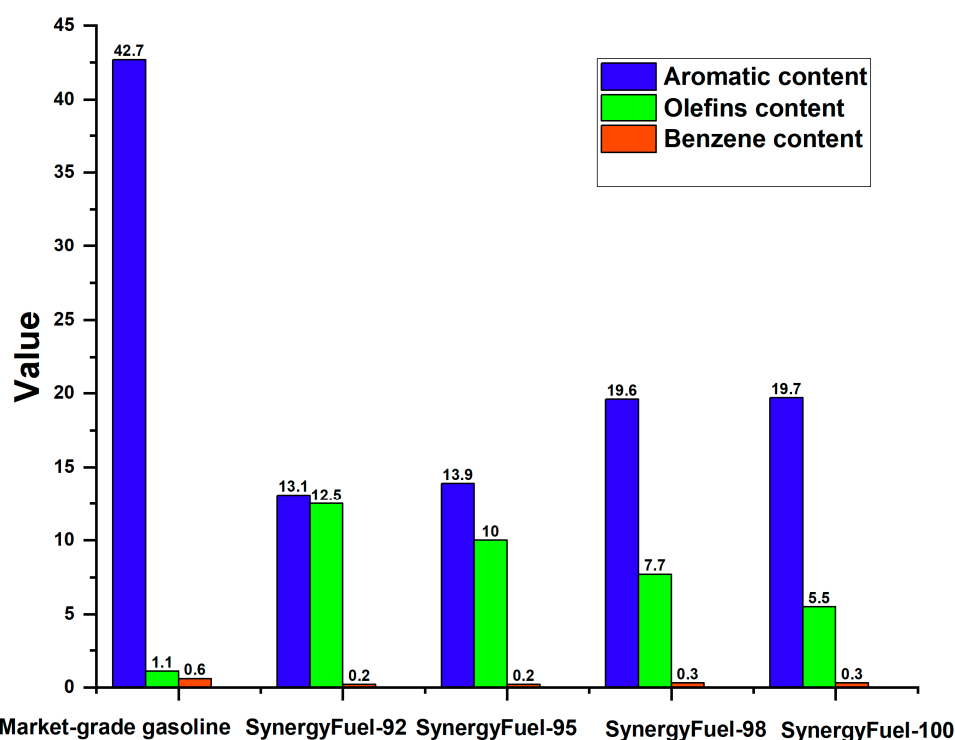


Figure 7. Hydrocarbon composition of produced SynergyFuels in comparison with market-grade gasoline.

When looking at the aromatic content, a clear pattern becomes apparent. The aromatic concentration of market-grade gasoline is substantially higher (42.7%) than that of all SynergyFuel variations, which vary from 13.1% to 19.7%. This significant variation implies that SynergyFuel formulations place a higher priority on lower aromatic concentrations, which could result in fewer toxic aromatic chemical emissions during burning. Although aromatics contribute to greater octane ratings, their elevated presence is associated with raised air pollution. SynergyFuel's reduced aromatic content may therefore support improved air quality. In addition, the fuels vary in their olefin proportions. As previously explained, olefins—unsaturated hydrocarbons that can contribute to deposit formation and decreased fuel stability—are present in SynergyFuel variants at levels ranging from 5.5% to 12.5%, compared to the minimal content (approximately 1.1%) noted in market-grade gasoline.

All gasoline types have relatively low levels of benzene concentration, a crucial characteristic because of its toxicity. The benzene content of SynergyFuel variations ranges from 0.2% to 0.3%, whereas market-grade gasoline contains 0.6%. These low benzene levels show

that SynergyFuel blends and market-grade gasoline are made to adhere to strict benzene restrictions, guaranteeing that exposure to benzene poses little health concern.

Finally, the analysis of the hydrocarbon composition showed that SynergyFuel blends often include less aromatic content than market-grade gasoline, indicating an emphasis on lowering hazardous emissions. All fuel types have consistently low quantities of benzene; however, the olefin concentration varies. The potential for SynergyFuel blends to provide a more ecologically responsible substitute for traditional gasoline while preserving respectable performance attributes is highlighted by these compositional variations. A more thorough evaluation of the overall quality and performance of the gasoline might be possible with additional investigation into other fuel characteristics.

3.2.2. Gasoline Anti-Detonation Characteristics

The octane performance of the market-grade gasoline and the SynergyFuel range is clearly shown in Table 5. MON measures knock resistance under more extreme engine conditions (higher temperatures and loads), and RON performs the opposite function [56,57]. The antiknock properties in terms of MON and RON for the produced synergyfuels in comparison with market-grade gasoline are illustrated in Figure 8. The market-grade gasoline's RON of 94.5 is exceeded by SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100, according to the RON values, which gauge the fuel's resistance to knocking under comparatively mild engine conditions. This implies that under normal driving circumstances, these SynergyFuel versions provide better knock resistance. The market-grade gasoline has a slightly higher RON (91.8) than SynergyFuel-92.

Table 5. Gasoline anti-detonation characteristics of the produced SynergyFuels in comparison with market-grade gasoline.

Fuel Type	RON	MON	Gasoline Octane Sensitivity (S)	Antiknock Index (AKI)
Market-grade gasoline	94.5	84.1	10.4	89.3
SynergyFuel-92	91.8	81.1	10.7	86.45
SynergyFuel-95	95.1	83.1	12	89.1
SynergyFuel-98	97.8	85	12.8	91.4
SynergyFuel-100	100	86.6	13.8	93.3

MON measures knock resistance under more extreme engine conditions (higher temperatures and loads). Higher MON values (83.1, 85, and 86.6, respectively) are displayed by SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100 in comparison with the market-grade gasoline (84.1), suggesting superior knock resistance in demanding situations. The MON (81.1) of SynergyFuel-92 is significantly lower than that of the market-grade gasoline.

The difference between RON and MON, or sensitivity (S), is a measure of how variable the fuel's performance is under various engine loads. Figure 9 presents the gasoline octane sensitivity for the produced SynergyFuels compared to market-grade gasoline. The knock resistance of the fuel is more susceptible to variations in engine running circumstances when the sensitivity value is higher. Compared to market-grade gasoline (10.4), SynergyFuel types exhibit higher sensitivities (10.7, 12, 12.8, and 13.8), indicating that variations in engine load and speed may have a greater impact on their performance.

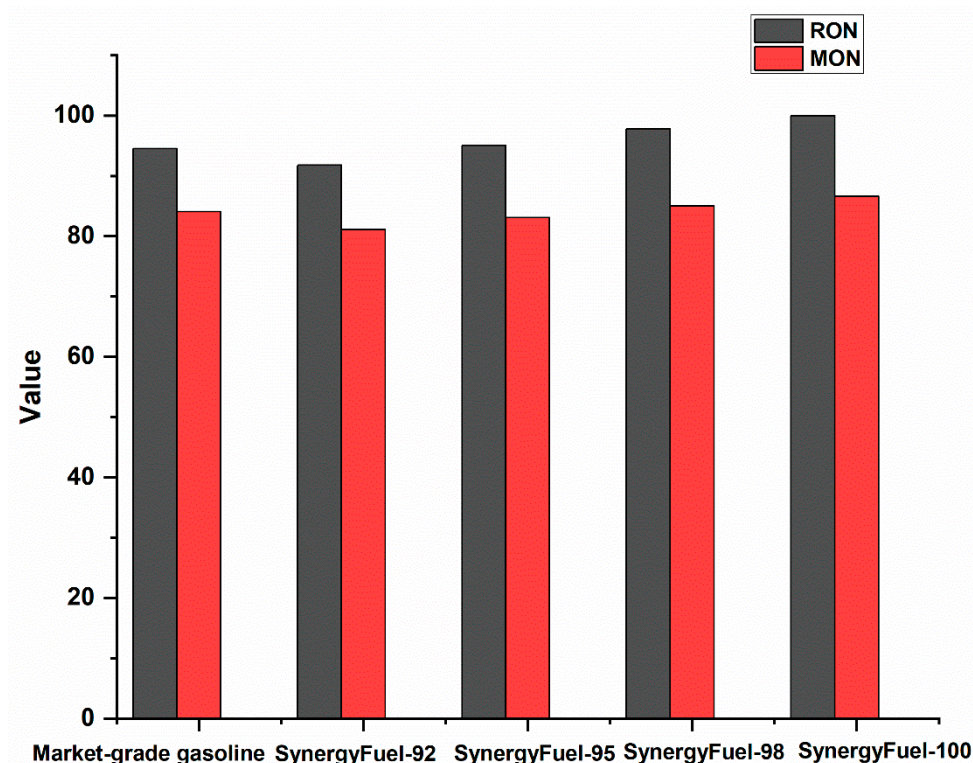


Figure 8. Antiknock properties in terms of MON and RON for the produced SynergyFuels in comparison with market-grade gasoline.

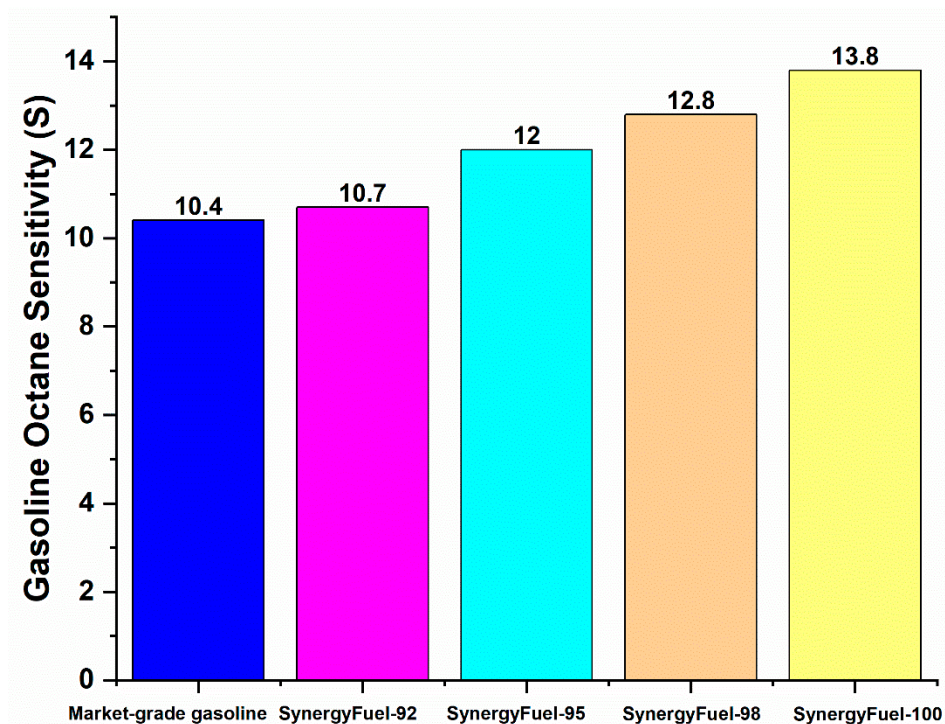


Figure 9. Gasoline octane sensitivity for produced SynergyFuels compared to market-grade gasoline.

The average of RON and MON is used to compute the Antiknock Index (AKI), sometimes referred to as the Road Octane Number: $(RON + MON)/2$. It offers a useful indicator of a fuel’s overall resistance to knocking under actual driving circumstances. The AKI values of SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100 are higher than the market-

grade gasoline's AKI values of 89.3, at 89.1, 91.4, and 93.3, respectively. On the other hand, SynergyFuel-92 has an AKI of 86.45, which is less than the market-grade gasoline AKI.

Finally, SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100 have better knock resistance than market-grade gasoline, as shown by their higher RON, MON, and AKI values, according to the examination of anti-detonation properties. This implies that these SynergyFuel versions might provide improved engine performance and knocking protection. Greater performance variability under varying engine loads is indicated by the SynergyFuel mixes' higher sensitivity levels. According to this data, SynergyFuel-92 is the only blend that performs worse than the market-grade gasoline across all measures. Fuel compositions can be optimized, and fuel attributes can be customized to fit engine requirements and driving circumstances with the use of these insights.

3.2.3. Gasoline Distillation Characteristics

To elaborate on the distillation curve analysis, it is critical to take into account how various boiling point ranges affect various engine operating features [58]. Particularly in colder climates, the low-end boiling points (IBP to T10) are essential for cold-start performance. Ample light components in fuels allow for easy vaporization, which promotes rapid ignition and seamless engine startup. Warm-up performance and drivability are influenced by the mid-range boiling points (T30 to T70). For smooth acceleration and quick throttle control, these fractions must evaporate enough to guarantee effective combustion throughout the engine's warm-up period [59].

Emissions and combustion efficiency are significantly influenced by the high-end boiling temperatures (T90 to FBP). High-boiling fuels might not evaporate all of their constituents, which could result in incomplete combustion and higher emissions of particulate matter and unburned hydrocarbons. Additionally, engine deposits may occur as a result of the presence of higher-boiling components [60]. These problems can be lessened with a reduced FBP, as in the SynergyFuel versions, encouraging cleaner combustion and lessening engine fouling.

The produced SynergyFuel variants (SynergyFuel-92, -95, -98, and -100) are compared to market-grade gasoline in this investigation to look at their distillation curves, as illustrated in Figure 10. Distillation curves show the temperature at which various fuel percentages evaporate, hence illuminating a fuel's boiling range. These curves offer vital information about possible emissions, engine start-up, warm-up performance, and fuel volatility. Key distinctions exist between the distillation properties of market-grade gasoline and SynergyFuel blends, affecting engine performance and environmental impact.

The figure shows that, up to around 80% distilled volume, the distillation profiles of the market-grade gasoline and all SynergyFuel variants are comparable. This suggests that both fuels have similar early and mid-range volatility characteristics. But in the higher distillation range, especially above 90% distilled volume, noticeable differences become apparent. When compared to the SynergyFuel versions, the market-grade gasoline exhibits greater FBP, indicating the presence of heavier hydrocarbon components that need higher temperatures to evaporate entirely.

The final boiling points of SynergyFuel variations are often lower, with SynergyFuel-100 showing the lowest. This could be explained by the unique makeup of the SynergyFuel blends, which include oxygenates and possibly fewer heavier hydrocarbons than regular gasoline. The final boiling point of gasoline blends is known to be lowered by the inclusion of ethanol in particular.

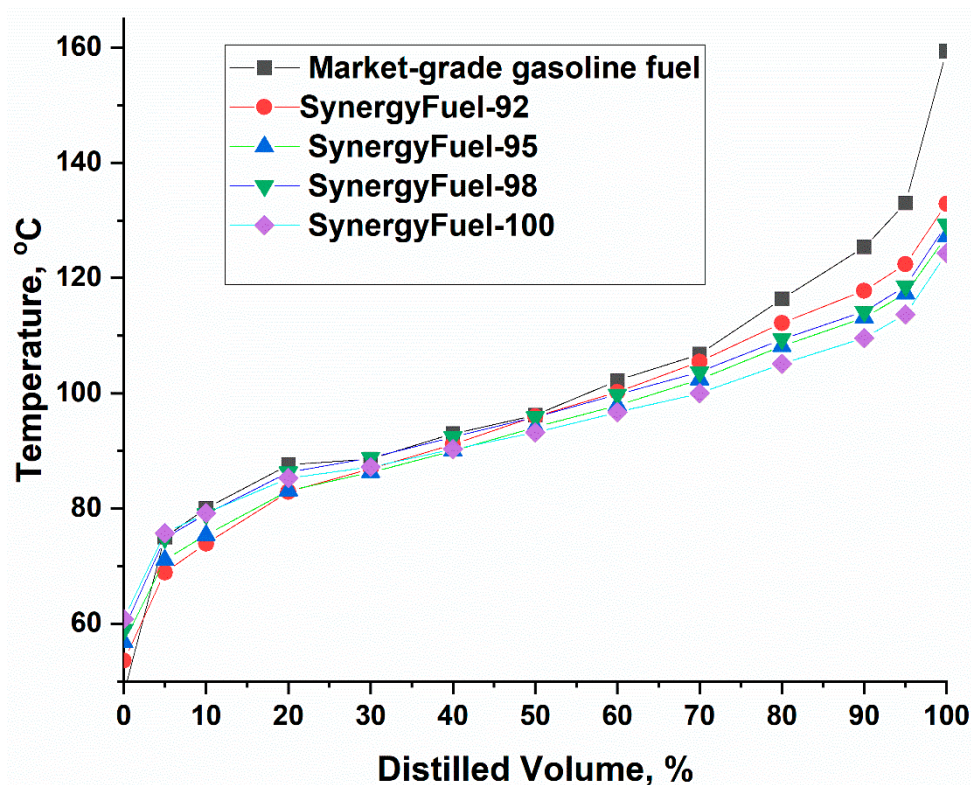


Figure 10. Several distillation curves for the produced SynergyFuels in comparison with market-grade gasoline.

3.2.4. Gasoline Fuel RVP

RVP, which is a crucial measure of a fuel's volatility and reflects its propensity to evaporate, is expressed in kPa (kilopascals) [61]. Engine starting, evaporative emissions, and the possibility of vapor lock are all greatly impacted by RVP. To evaluate SynergyFuel's performance and environmental impact, it is crucial to comprehend its RVP values in comparison to market-grade gasoline. The RVP of the produced SynergyFuel variations (SynergyFuel-92, -95, -98, and -100) is compared to that of market-grade gasoline in this investigation, as can be shown in Figure 11. The RVP of the market-grade gasoline was 44.8 kPa. With an RVP of 45.5 kPa, SynergyFuel-92 had a somewhat higher RVP than the other SynergyFuel variations, which were 40.8 kPa for SynergyFuel-95, 35.4 kPa for SynergyFuel-98, and 33.1 kPa for SynergyFuel-100.

Significant ramifications exist for the differences in RVP across the various fuel types. Greater volatility, as demonstrated by SynergyFuel-92's increased RVP, can make engine starting easier, especially in colder weather. However, particularly in warmer regions, increased volatility also raises the possibility of evaporative emissions, which contribute to air pollution. On the other hand, lower RVP values, as shown by SynergyFuel-95, -98, and -100, indicate less volatility, which improves fuel stability and reduces evaporative emissions. On the other hand, extremely low RVP readings might occasionally cause problems when starting engines in colder climates.

The SynergyFuel versions' declining RVP trend points to a conscious attempt to lower evaporative emissions without sacrificing start-up performance. In order to reduce air pollution during the summer, when temperatures are higher and evaporation is more noticeable, RVP is regulated seasonally in several areas. SynergyFuel-95, -98, and -100 have reduced RVP values, which makes them especially appropriate for usage in regions with strict evaporative emission regulations.

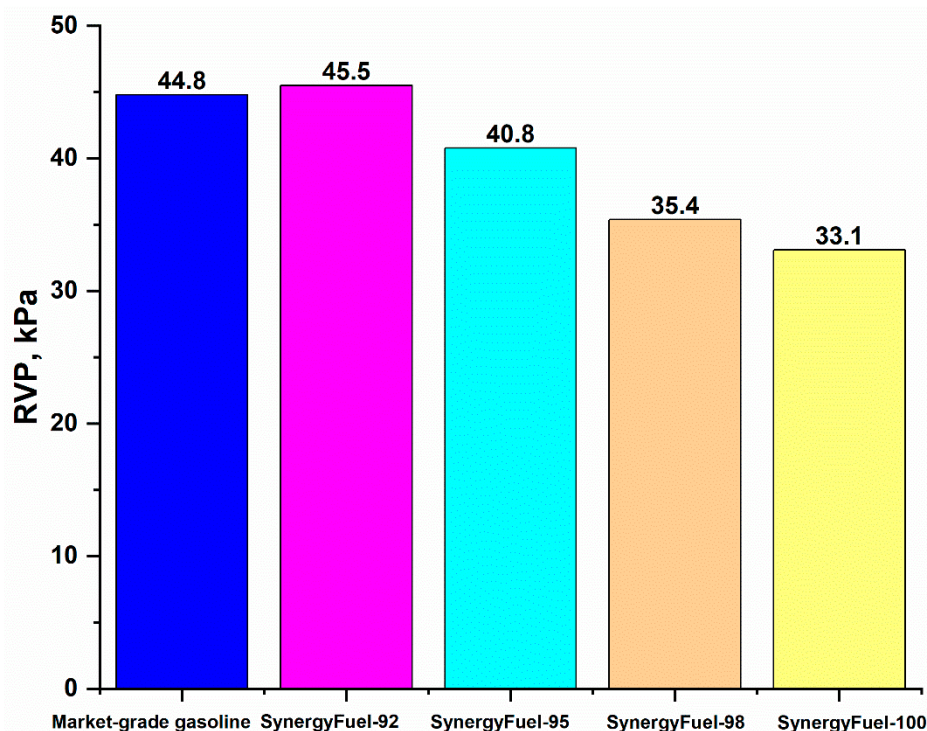


Figure 11. Gasoline fuel RVP for produced synergyfuels in comparison with market-grade gasoline.

Finally, the SynergyFuel range generally showed less volatility than market-grade gasoline, with RVP declining as the octane number rose, according to the examination of RVP values. Efforts to reduce evaporative emissions and adhere to environmental requirements are made easier with this feature. Nonetheless, SynergyFuel-92's increased RVP might be advantageous for cold starting. Optimizing fuel formulations and guaranteeing compatibility with various engine requirements and environmental circumstances require a balanced evaluation of these issues.

3.2.5. Gasoline Fuel Density

Figure 12 presents a comparative analysis of fuel density among various gasoline formulations, specifically highlighting the densities of SynergyFuel variants in relation to standard market-grade gasoline. The data is visually represented as a bar graph, with each bar corresponding to a different gasoline type. The x -axis delineates the specific gasoline being assessed, including market-grade gasoline, SynergyFuel-92, SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100. The y -axis quantifies the density of the gasoline at a controlled temperature of 15 °C, providing a standardized measure for comparison. The density of market-grade gasoline was 757.66. SynergyFuel-92, SynergyFuel-95, and SynergyFuel-98 all exhibited varying densities, with SynergyFuel-92 registering at 756.75, 95 at 764.76, 98 at 775.91, and 100 at 779.05. Each fuel type has a distinct and accurate data point, thanks to the labeling of the numerical value on top of each bar.

It seems that the fuel density and the SynergyFuel number (92, 95, 98, and 100) are exactly proportional. A comparable increase in density occurs when the SynergyFuel number rises. Out of all the fuels evaluated, SynergyFuel-100 has the greatest density value, indicating the existence of a possible relationship with the formulation.

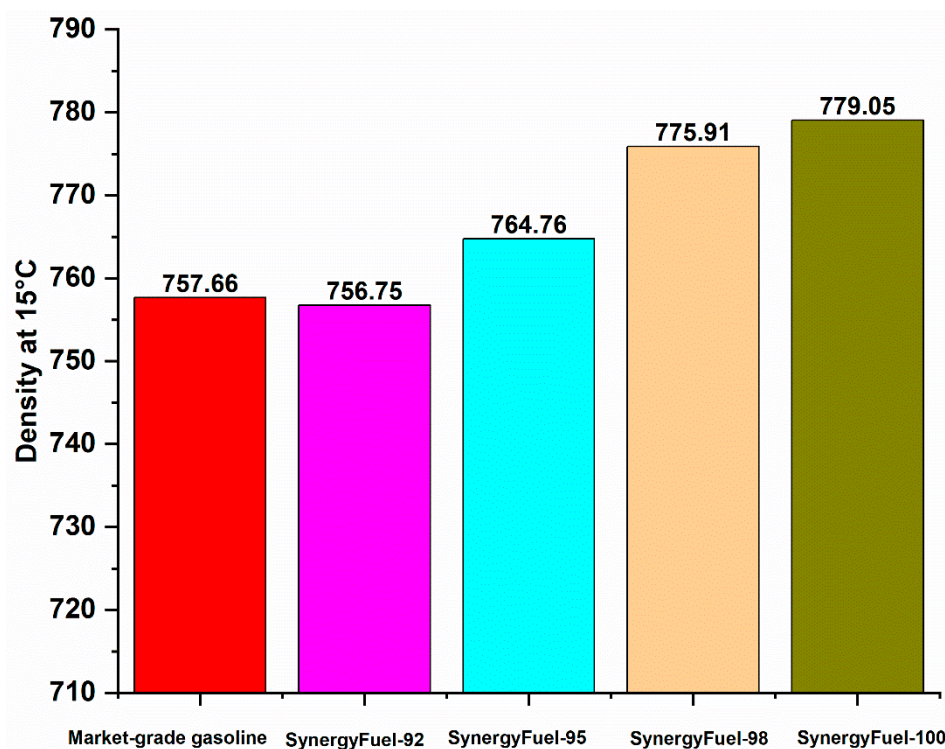


Figure 12. Gasoline fuel density for produced SynergyFuels compared to market-grade gasoline.

3.2.6. Gasoline Volatility Indexes

Equations for determining the drivability index (DI), the vapor lock index (VLI), and a vapor–liquid temperature ratio of 20 ($T_{(V/L=20)}$) are shown below:

$$VLI = 10 * VP + 7 * E70 \quad (1)$$

$$DI = 1.5(T10) + 3.0(T50) + 1.0T(90) \quad (2)$$

$$TT_{(V/L=20)} = [52.47 - 0.33(VP)] + 0.20 T10 + 0.17 T50 \quad (3)$$

where

- $T(10)$ = Temperatures (°C) at 10 % volume distilled;
- $T(50)$ = Temperatures (°C) at 50% volume distilled;
- $T(90)$ = Temperatures (°C) at 90% volume distilled;
- VP = RVP, kPa.

These factors are essential for evaluating how well gasoline performs and how useful it is in different situations. By balancing volatility and distillation qualities to meet drivability and safety standards under a variety of scenarios, these equations provide insights into how to optimize gasoline formulations for performance requirements.

The ease of starting and running a gasoline engine, particularly in cold weather, is gauged by the drivability index. Because of its significance in guaranteeing smooth engine operation during warm-up, it gives the mid-range distillation temperature ($T50$) a higher weight. Better drivability in cold conditions is usually indicated by a lower DI. The probability of a vapor lock, a situation in which excessive vaporization stops fuel from getting to the engine, is evaluated by the vapor lock index. Greater vulnerability to vapor lock, which can happen in hotter regions or with hotter engines, is indicated by higher VLI levels. A crucial threshold for appropriate fuel atomization and combustion is determined by the vapor–liquid temperature ratio of 20 parameters ($T_{(V/L=20)}$). This

parameter forecasts the fuel's performance under various circumstances by combining volatility (VP) and distillation properties.

With an emphasis on volatility characteristics, Table 6 demonstrates the gasoline volatility index calculations for several gasoline fuel types, including market-grade gasoline and a range of SynergyFuels. Key indicators, including DI, VLI, and $T_{(V/L=20)}$, describe these qualities, which are essential for comprehending fuel performance under various circumstances [62]. A fuel's cold-start and warm-up performance can be inferred from the drivability index, which is computed using the distillation temperatures T10, T50, and T90, as well as the ethanol percentage. Every fuel in the chart performs satisfactorily in cold weather since it falls within the ASTM D4814 [53]. specified range of 375 to 610 °C for DI.

Table 6. Gasoline volatility index calculations in terms of the drivability index, vapor lock index, and vapor–liquid temperature ratio of 20.

Fuel Type	RVP	T10, (°C)	T50, (°C)	T70, (°C)	T90, (°C)	DI	VLI	$T_{(V/L=20)}$, °C
Market-grade gasoline fuel	44.8	80.0	96.2	106.8	125.4	534	1195.6	55.64
SynergyFuel-92	45.5	73.9	96	105.5	117.8	516.65	1193.5	55.253
SynergyFuel-95	40.8	75.4	94.1	102.4	113.1	508.5	1124.8	56.511
SynergyFuel-98	35.4	79.0	95.9	103.7	114.2	520.4	1079.9	58.671
SynergyFuel-100	33.1	79.2	93.2	100.0	109.6	508	1031	58.975
ASTM Standard values	-	-	-	-	-	STM-D4814 (375 to 610, °C)	ASTM D4814 (800 to 1250)	ASTM-D4814 (35 to 60 °C)

A fuel's resistance to vapor lock and other hot fuel handling problems can be predicted using the vapor lock index, which is calculated using RVP and the proportion of gasoline that evaporates at 70 °C. Within the ASTM D4814 [53] of 800 to 1250, the VLI values range from 1031 to 1195.6; lower values indicate better performance in hot conditions. The $T_{(V/L=20)}$ values, which range from 55.253 °C to 58.975 °C, all lie from 35 to 60 °C, which is the ASTM D4814 [53]. This information provides details on the characteristics of fuel evaporation at high altitudes or in warm weather. A noteworthy pattern across the SynergyFuels is that greater octane ratings are associated with higher $T_{(V/L=20)}$ temperatures and lower RVP and VLI values, suggesting better hot fuel management and resistance to vapor lock.

SynergyFuel-100 demonstrated the strongest hot fuel handling qualities and resistance to vapor lock among all mentioned fuels, as seen by its lowest RVP and VLI, and highest $T_{(V/L=20)}$. Higher $T_{(V/L=20)}$ and a further decrease in RVP and VLI were seen in SynergyFuel-98, suggesting improved resistance to vapor lock. Compared to SynergyFuel-92, it demonstrated a better mix of attributes, with reduced RVP, VLI, and DI, indicating better performance in both hot and cold climates. In VLI and $T_{(V/L=20)}$, SynergyFuel-92 performed similarly to market-grade gasoline; however, it had a lower DI, suggesting an even greater cold-start performance. Market-grade gasoline fuel may be more susceptible to vapor lock than SynergyFuels, as evidenced by its greatest VLI (1195.6) and moderate $T_{(V/L=20)}$ of 55.64 °C.

Finally, the development of eco-friendly, low-carbon, high-octane biofuel gasoline has several complementary advantages that address engine performance, energy security, and environmental concerns. This novel method ensures compatibility with current automobiles and infrastructure by using renewable feedstocks to create gasoline that is chemically equivalent to petroleum-based fuels. Because carbon dioxide is captured during feedstock growth, the production process, which may include hydrotreating, biological sugar upgrading, and catalytic conversion, produces a fuel that not only lowers greenhouse gas emissions but also improves engine performance by achieving higher octane ratings.

Additionally, the domestic production of these biofuels helps to create jobs and improve energy security. By lowering capital costs and permitting gradual adoption, the integration of biofuel production with traditional petroleum-refining operations offers financial benefits. Further merits of the proposed biofuel approach involve improved air quality through the reduction in harmful pollutant exhaust emissions, the improved durability of fuel systems due to the lubricating properties of certain bio-components, and the flexibility to tailor fuel blends to meet specific performance or regulatory requirements. This integrated strategy highlights how advanced technologies can simultaneously address environmental challenges, maximize engine performance, and support economic growth, positioning it as a prospective solution for the future of renewable and sustainable transportation.

4. Conclusions

The present study aims to develop four grades of high-octane gasoline—SynergyFuel-92, SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100—by strategically blending petroleum-based components such as reformate, isomate, and DC naphtha with renewable octane enhancers like bio-methanol and bio-ethanol. Various analytical methods were employed to evaluate key fuel properties, including antiknock performance, density, oxidation stability, distillation behavior, hydrocarbon composition, Reid vapor pressure (RVP), and volatility index, to assess the overall quality and performance of the formulated gasoline blends.

The experimental results indicated that the gasoline blends made from biofuel (SynergyFuel-92, -95, -98, and 100) showed adherence to important fuel quality criteria in the USA, Europe, and China. These blends had good qualities, such as low quantities of benzene and sulfur, regulated levels of olefins and aromatics, and good distillation qualities. By fulfilling these strict regulations, SynergyFuel is positioned as a competitive and eco-friendly substitute for traditional gasoline. SynergyFuel-95, SynergyFuel-98, and SynergyFuel-100 have better knock resistance than market-grade gasoline, as shown by their higher RON, MON, and AKI values, according to the examination of anti-detonation properties. A comparable increase in density occurs when the SynergyFuel number rises. Out of all the fuels evaluated, SynergyFuel-100 has the greatest density value, indicating a possible relationship with the formulation. SynergyFuel-95, -98, and -100 have reduced RVP values, which makes them especially appropriate for usage in regions with strict evaporative emission regulations. Furthermore, the SynergyFuel blends had oxidation stability values of over 415 min, which is far longer than the 360 min minimum required by international regulations.

The results reported that SynergyFuel-100 demonstrated the strongest hot fuel handling qualities and resistance to vapor lock among all mentioned fuels, as seen by its lowest RVP, VLI, and highest $T_{(V/L=20)}$. Higher $T_{(V/L=20)}$ and a further decrease in RVP and VLI were seen in SynergyFuel-98, suggesting improved resistance to vapor lock. Compared to SynergyFuel-92, it demonstrated a better mix of attributes, with reduced RVP, VLI, and DI, indicating better performance in both hot and cold climates. In VLI and $T_{(V/L=20)}$, SynergyFuel-92 performed similarly to market-grade gasoline; however, it had a lower DI, suggesting even greater cold-start performance. Market-grade gasoline fuel may be more susceptible to vapor lock than SynergyFuels, as evidenced by its greatest VLI (1195.6) and moderate $T_{(V/L=20)}$ of 55.64 °C.

Finally, the eco-friendly, low-carbon, and high-octane biofuel gasoline production with synergistic benefits is a big step in the direction of sustainable transportation. This creative strategy focuses on using cutting-edge refining methods and renewable resources to produce a fuel that improves engine performance while lowering greenhouse gas emissions.

Moreover, it may maximize the quality and quantity of petroleum-derived fractions, like DC naphtha, reformat, and isomerate to decrease the dependence on petroleum fossil fuels.

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